Customized Products Manufacturing

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Preface

People need for good, reliable and affordable products is obvious for the times we are living. There are times of crises, both political and economical so, new ways of moving forward are being searched.

One, maybe not the most important but relevant enough, is that of offering onto the market customized products, meaning those products fitted for a certain requirement expressed by customer. There are many types of manufacturing techniques for the customized products, depending on product's final use – in industry or as consumer goods.

This book is aimed to be a relevant presentation of some important aspects related to customized products manufacturing, such as:

- Product - life cycle, design, manufacturing, development;
- Customized product and customized manufacturing;
- Specification processes and configuration system;
- Rapid prototyping processes and rapid manufacturing;
- CNC machining, laser micro-machining and sub-surface engraving;
- Holography and holograms;
- Plastics forming;
- Gifts, gadgets and items manufacturing.

For all of the above mentioned, there should be evidenced the importance of computer, even if it is software or internet, in establishing the manufacturer – customer interaction and in developing new, sophisticated but, reliable and useful manufacturing technologies.

The book can be an interesting reference for students – in product design and manufacturing courses but, it can also be of interest for designers and engineers – working in industrial companies or in small workshops.

I am grateful to my family and to all the people who helped and supported me in writing this book.

February, 2011 *Mihaiela Iliescu*

Foreword

The ability to design, develop and manufacture marketable products is a major instrument for modern economic prosperity. The near collapse of the global financial organisations in recent years showed the folly of relying on the service industries (financial, insurance, etc) as the main means of generating a country's income. Moreover, with the increases in the environmental and monetary costs of transport, the need for production and supply of manufactured goods, 'locally', is becoming more and more prominent. These, with the increasing appetite of today's markets for newer and better performing products, combined with the crucial requirement for reducing the environmental costs of manufacturing, as well as the international competition pressures for lower prices, underlines the need for continual improvement and updating of education and staff development material in the area of product design and manufacture. The text that follows is one such source of knowledge, information and data.

The book begins, in chapter 1, with a good description of product life cycle, and of product design and manufacture and product development activities. The various stages of product design and realisation are shown and described, clearly. This chapter also gives a good overview of the families and types of materials available to product designers and manufacturers. In chapter 2, concepts of customised product design and manufacture are introduced in the context of the new trends in customer taste and expectations; their relationship with marketing and the effects on cost are discussed. The process of drawing specifications is covered in chapters 3 and 4. Here, a very logical and disciplined process for developing and arriving at a product specification is described, developed and discussed. The chapters cover all the aspects, including those relating to cost, thoroughly and methodically. In chapter 5, the various technologies and processes of rapid prototyping are reviewed in detail and discussed. The review is thorough and covers both historical and contemporary techniques with numerous examples of polymer based components and products. Chapter 6 covers modern CNC machining, micromachining and micro-welding. Here, aspects of sub-surface processes are also covered. The chapter includes many good examples of both metallic and polymer components. The processes of producing holograms are described in chapter 7, where both historical and new developments are reviewed and explained with typical examples. Chapter 8 is on manufacturing of polymer components, covering industrial production processes for both thermoplastics and thermosets; the common processes are reviewed and described, clearly. Also, a simulation of mould filling and temperature profiles in the injection moulding process, using a computer software, is presented. In chapters 9 and 10, examples of customised products and customised manufacturing are described and discussed, and examples of analysis of some of the operating parameters such as force and deformations during the machining operation are shown.

The book is very well illustrated with clear diagrams and photographs, and also supported with numerous references and website sources.

Dr Eng Iliescu's book is a welcomed publication in the area of modern design and manufacture and should make a very valuable addition to the reading list for students on product design, engineering and manufacturing courses, as well as a good source of support material for design and manufacturing industries.

Professor Kamran Tabeshfar, MPhil, PhD, CEng, MIMMM, FRSA
February 2011

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1. PRODUCT – DESIGN, MANUFACTURE AND DEVELOPMENT

There is a huge competition in most of modern life activities whose result is an increased customers' demand for products of more various types and with better performances. It really is a strong need for low cost, high quality and short delivery time products.

So, a new kind of manufacturer – customer relationship develops as the answer to nowadays economical situation, involving continuous narrowing of market segments fitted for new products development. This means that the manufacturers answer to special customers demands by *customized products*, also named *personalized / individualized products*.

1.1 Product – Definition and Life Cycle

Product - means any goods / objects / services that can be offered to the market for satisfying someone's need or requirement..

When there are involved commerce type activities, the products are called "merchandise" but, if manufacturing type activities are performed, then the products are bought as raw materials and are sold as final goods. Thus, there is involved the definition of a *thing* generated by work and effort.

The verb *to produce* comes from the Latin word *produce(ere)* which means the action of leading, getting forward. Since 1575, the noun "*product*" has been used when referring to anything is produced, meaning, generated / manufactured / worked out. Pragmatically thinking, a product is anything that can be sold by an enterprise or corporation to its customers.

Anyway, the common used term of *product* does refer to one element / unit, or to a group of equivalent elements, or to a reunion of goods / services, or, even, to an industrial classification of goods / services.

Certain products can be viewed as equivalent or inter-changeable for specific commerce activities reasons, evidence recording or reporting even, they do differentiate a little from the point of view characteristics, location or destination.

Many times it is rather difficult to differentiate a new product from an improved one – by small changes of an existing product. For example, if a thermal isolated window frame is considered, the change from a four isolating rooms frame to a five isolating rooms frame, can be viewed as product improvement – see figure 1.1. But, a coloured laminated PVC frame can be considered a new product, when compared to the common white PVC frame – as shown in figure 1.2.

Fig. 1.1 White PVC window frame [http://www.easteuro.ro]

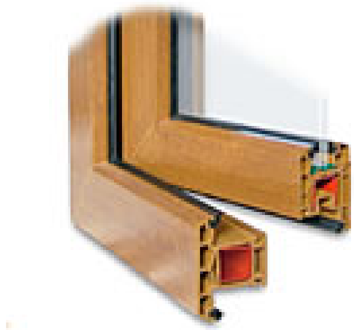


Fig. 1.2 Coloured laminated PVC window frame [http://www.easteuro.ro]

Product line is a group of products connected by their similar function or, by the fact that they are sold to the same group of customers, or by being commercialised through the same systems, or by having similar prices. May offers include product lines types that are specific to a certain organization / companies or, common for more industrial fields.

As for example, the laser crystal engraved product line is specific to the manufacturer that owns a sub-surface laser engraving machine (ST-C3 3D/2D, [http://www.sintecoptronics.com}, while the product line of cars with (1400÷1600) cm^3 cylinder capacity is common for more organizations whose activity develops in several industrial fields (auto-vehicles, machine building, etc.)

In time, there have been developed several products classification systems. One of the oldest, and still in use, is the Aspinwall system (1958), that mentions the five criteria used in grouping the products. So, there are the following ones:

- the replacement rate ⇒ meaning how often the product is bought for the second time;
- the advantages ⇒ referring to how much the profit from each product is;
- the adjustment to customers' scope ⇒ showing how flexible the customer's habit of buying the product is;
- the period of product satisfaction ⇒ evidencing how long the product does offer benefits for the user;
- the period of asking for the product ⇒ reflects how long the customers want to buy the product.

Another system is the NICP one, introduced by National Institute of Governmental Purchasing. It consists in a series of 26 digits, symbolizing the class (3 digits), the class characteristics (5 digits), the characteristics of class group (7 digits), the group specific details (11 digits).

The product classification / marking system of barcode is used for data stocking. It stores the information by printed parallel lines width (bars) and the space between them, the data being collected with special optical devices.

One system of this type is Code 128, meaning a high density alpha-numeric system, introduced in the early '80s – see figure 1.3. It consists in 106 printed characters type, each of them "hiding" certain information that can be "decoded" by a special device, called barcode reader.

Start Character	Data Digits	Check Character	Stop Character
Ì	CODE-128	O	Î

CODE-128

Fig. 1.3 Barcode - Code 128 [http://www.idautomation.com]

Product Life Cycle represents the product's sales and profit evolution in time. It does refer to product's life on the market, as reported to business / commercial costs and to sale specific elements. Thus, it means several stages, involves different professional fields and requires versatile abilities / capacities, means and processes.

Usually, it is said that there is a product life cycle if there can be make positive statements on the next four aspects:

- the product has a limited life time;
- the product's sale goes through distinct stages, each of them involving challenges, opportunities and problems to be solved by the customer;
- the profit goes up and down, for the different stages of the life cycle;
- the product requires different marketing, financial, manufacturing, sales, human resources strategies – for each of the life cycle stages.

The product life cycle develops through five stages, whose name and important characteristics are mentioned to be:

- product development ⇒ the activities sequence starting with idea generation, as consequence of market opportunity identification, and ending with manufacturing, sale and delivery of the product;
- product market introduction ⇒ there is a high cost, the sales are low, the competition with other manufacturers is poor, it is necessary to generate a request for the product, the customers must be tempted to try on the product;

- product growth ⇒ the cost is reduced, the sales and profit do have a significant increase and there is a high competition with the “new comes” on the market;
- product maturity ⇒ there is a product low cost, the sales market is very well defined and sales are on top, the competition with similar product increases, the brand differentiation and feature diversification are emphasized, the profit is getting down;
- product saturation and decline ⇒ the cost are counter productive, the sales are low, the profit is used for production/distribution efficiency rather than sales increasing.

The observation is that product life cycle goes through two “extremes”, similar to “life” and “death”. The great majority of important corporations’ successful brands have had their leader position on the market for, at least, 20 years.

Many times, the product life cycle is longer than the cycle planed by the company involved in product development, that usually considers only the product maturity stage. In fact, Dhalla & Yuspeh (1976) consider that the product life cycle does represent a market actions dependent variable and not an independent one, while the company should adjust its marketing programs according to it.

Product Life Cycle Management is the sequence of management strategies used as the product goes through its life cycle stages.

It is required, as there is always a change in product sales conditions that has to be managed through product life cycle. For example, in the product development stage, life cycle management deals with conception, design, manufacturing, while in product maturity stage, the management is focused on service type activities.

1.2 Product Design

The concept of *design* has been developed in England (in 1851) as result of complex realities in industrial production. Referring to design it is synonymous to involving the creation concept / method used in order to ensure a high functional rate for the product considered.

Synthetically, the concept of design is associated to a product associated project / drawing / sketch and includes three major elements, as follows [http://ro.wikipedia.org]:

- image – as an idea, or concept result;
  - by conscience reflection of an object, as a feeling, perception or representation;
  - as an object reproduction by optical system, or plastic representation (drawing, picture, sculpture), or words reality artistically reflection;
- function – as a role to be fulfilled;
- morphology – as structure according to function.

With design there is the attempt to correlate material abilities, technological level, internal and external economic relationships, spirituality – expressed by artistic option and creation capacity. All of the above are based on the idea that art, technique and science are not incompatible, contradictory or competing fields but, they are specific and solid with reciprocal involving and conditioning.

Product Design represents the sequence of activities that involve: idea generation, concept development, testing and manufacturing, or product implementation - the product being either a physical object or a service.

Based on the fact that the design can be considered as form of expression and the products can be viewed as exchange means that do generate profits, a higher importance is given to the design – manufacturing – marketing activities interactions. Thus, it can be considered *product design* as the generic concept of making an object whose origin lies in design (as drawings, sketches, prototypes, models) and through a design process extends to production, logistics and marketing.

Products are designed based on designer / customer / end user considerations. These are evaluated by the rates of sales and intensity of use. The higher technological progress, the “in fashion” feeling quicker changes, the more often influenced / changed criteria of choosing a product are and thus, the product life cycle is considerable reduced.

A product can turn into a desirable one when it involves improved functionality, high fabrication performances and gets cultural significance. A good designed product can be a real chance in a world of competitiveness.

In any business, the design perception has changed for better and the companies managers has accepted the fact that design investments do generate high considerable profits. A well designed product can be a real chance in a world of competitiveness.

Product designers must have the ability to correlate the past, the present and the future, as well as the possible effects of political, social and emotional environments. Also, they do have to know and use the information on technological and logistical systems, ergonomics, aesthetics, etc.

The product design specific activity has been performed since ancient times. Initially, products were manually obtained and aimed to primary functions within community. By art and crafts customization there has been developed the wish of eventual exchange and, consequently, of a profit.

At the beginning of XXth century, the product design term has been related to the idea of production – meaning the fabrication of more of same items. By the end of the XXth century (1990), product design term got complex significance, being viewed as designers activity that combines arts with social needs / requirements, within the limits set by materials obtaining and processing procedures.

An example of the evolution of a knife design is shown in figure 1.4. There can be nioticed the product evolution from mono-functionality, to multi-functionality.

[http://www.ascasonline.or]

[http://www.dkimages.com]

[http://www.worldknives.com]

[4]

Fig. 1.4 Design evolution for a knife type product

Nowadays product design is focused on how to attract, both the individual and the mass (of customers), the designers motto being [4} "keep an eye on the present, understand the past and look toward the future"

There is a tendency of designing hybrid products. A hybrid product is the one made of two, or more objects, reunited to create something new but, with visible references to the past, to the original scope. This is how, a new perspective of considering product relevance is induced and a challenge to determine the reason for that product is launched.

One example is presented in figure 1.5, for a custom doorbell. It suggests the joy of having guests, by those glasses and their shrill sound when filed with good wine, shared and toasted with dearest friends.

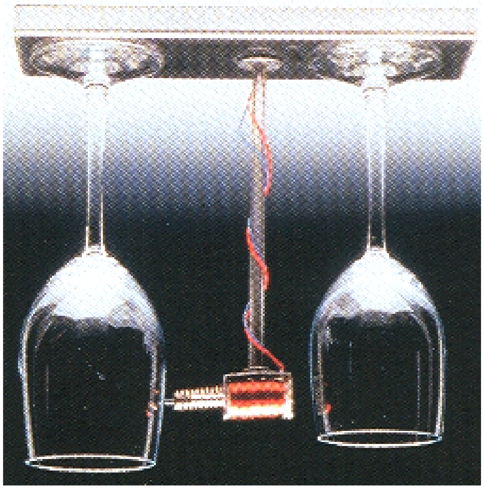


Fig. 1.5 Customized doorbell [4]

Product design involves some important aspects, mentioned next.

◘ Functionality ⇒ this is the reason why, many times, the product is made of modules and the final user is able to decide for the required configuration. So, there are generated, both ambiguity and challenge when dealing with form and function traditional norms.

◘ Functional ergonomics and hidden functionality ⇒ it is about the development of new materials and sensorial systems. It determined the appearance of complex forms and small dimensions products, so that touch feeling is associated with visual and emotional perception.

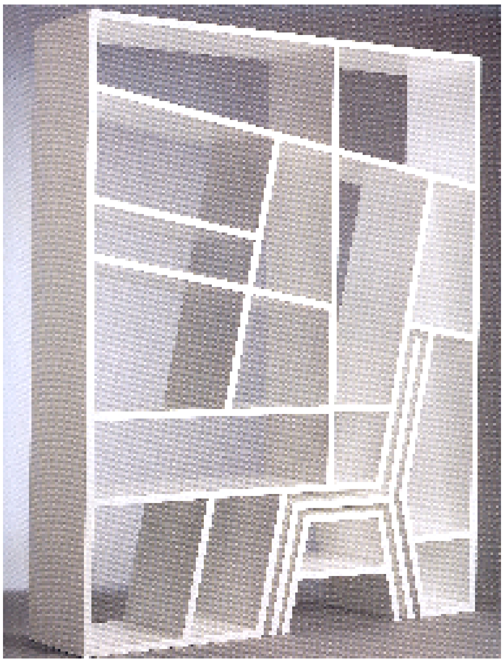
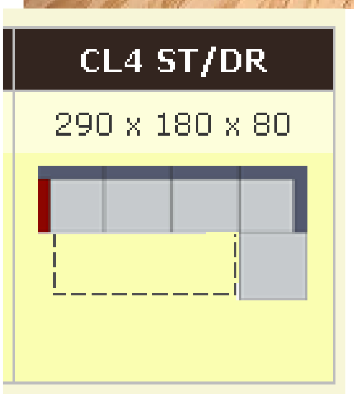


Fig. 1.6 A "chameleon" product example [4]

◘ Duality or multi-functionality ⇒ involved, specially in urban life, where there is little, expensive space and the time spent at work is competing with the free time. So, there have designed the “chameleon” products (whose function is not visible, or is changing) and the ones with added functionality – see figure 1.6 and, respectively, figure 1.7.

- household appliance [http://www.moulinex.com]



- hospitable sofa in the living room, turning into friendly bed, if required

[http://www.canapele.ro]

Fig. 1.7 Examples of added functionality products

◘ Decorations ⇒ the technological products are characterized by simplicity, the decorative ones are characterized by ornaments, while the building type products do represent a "border" of the two aspects, even sometimes they can be one of the above mentioned extremes – as shown in figure 1.8.

- electrical fireplace -
[http://www.seminee-electrice.ro]

- **indoor fountain –**
[http://www.casesigradini.ro]

- chocolate fountain -
[http://www.hotelchatter.com]

Burj Al Arab - Dubai - 60 floors and 321 m high
designed by architect Tom Wright
[http://www.casesigradini.ro]

Sagrada Familia – Barcelone
designed by architect Antoni Gaudi
[http://www.sagradafamilia.cat]

Fig. 1.8 Examples of decorations – for various products type

For a successful product design it is necessary to exist an information flow between the different departments of design, production, marketing, accounting and customer interaction. The better customer needs and requirements identified, by feed-back, the higher the benefits from the involved product.

The information flow creation model – specific to a successful product design can be noticed in figure 1.9.

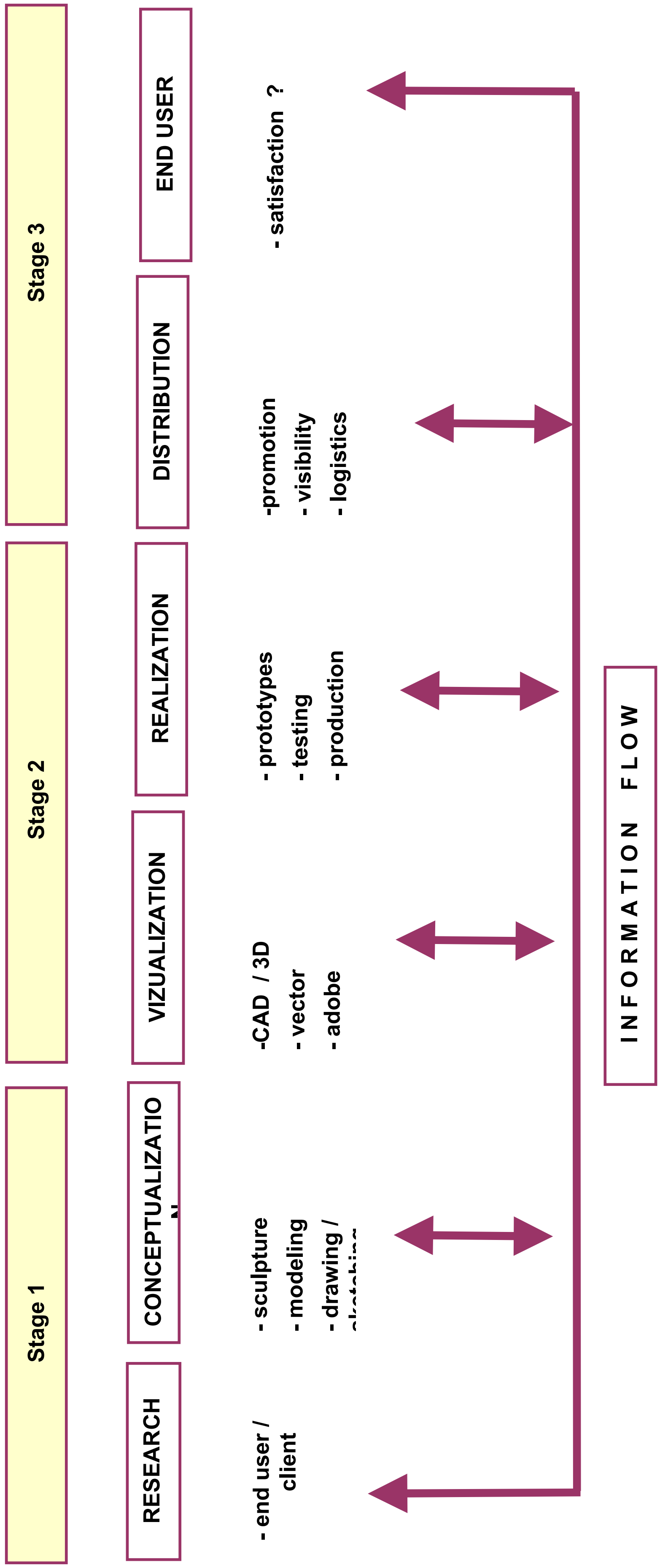


Fig. 1.9 Information flow creation model [4]

The concept of *Industrial Design* was developed in the early ’20s, as result to industrial revolution. It was then, when mechanization and improvement of production techniques have resulted in new, more specialised and performant products and, thus, the need for professional design strongly arised.

There are more similar definitions for this concept, some being mentioned next.

◘ Industrial Designers Society of America defines the industrial design as a professional service for the creation and development of concepts and specifications, thus optimizing products function, value and aspects, with mutual benefit for customer and producer.

◘ International Council of Societies of Industrial Design states that the industrial design is a creative activity whose purpose is of creating multi-functional qualities for objects, processes, services and systema, all through their life cycle – that is why the industrial design represents the major factor for technologies innovative humanization and the determinant factor for cultural and / or economical exchanges.

◘ Industrial design does represent the art applied where esthetics and utility of mass produced products can be improved for marketability and production [http://en.wikipedia.org]

Industrial desgin is focused on the technic concepts, products and processes, while an industrial desginer is the „connection” of the engineer and the artist. His role is that of creating and developing design solutions so correct and efficient solve problems dealing with: shape, how it’s used, production, marketing, brand development and sales.

The industrial desgin process can be considered a creative process that is going on correlated / succesively to many other processes, such as: users identifying, comparative product designing, model making, prototyping and testing. In order to go through all the stages from product concept to production, this process requires high 3D software and CAD programs.

While product designing process, the industrial designers establishes product’s characteristics of shape, details position, color, texture, ergonomics. Also, the designer can specify aspects regarding manufacturing process, materials selection, how the product is presented to the client when selling. That is why, the role of an industrial designer, through the product life cycle, can be stated to be that of adding value, by improving product’s utility, lowering production costs and making more attractive products.

Figure 1.10 presents an example evidencing product design evolution, with all the aspects involved by industrial design. As noticed, the product presented is an Oldsmobile car.

Fig. 1.10 Oldsmobile (USA) car design evolution [http://www.oldsmobile.com]

1.3 Product Manufacturing

Manufacturing (production) represents a sum of activites involving the use of machines, tools and work, with the goal of obtaining products to be used or sold. This term can be used when refering to a large field of activities, from the manual to the high technology specific ones, but, usually, it is associated to industrial production activities, when raw materials are transformed into final goods.

The manufacturing process is developed in all economical systems with some specific characteristics. So, in communism – there are manufactured products required by state centralized economy, while in capitalism – the products asked by customers and bringing profit are the ones being manufactured.

Depending on production volume, product’s constructive characteristics and time involved, there are four types of organizing the production system, thus generating four production types: individual (one of a kind), series (small, medium, high), mass and customized. It can be considered that, for nowadays, the predominant ones are the next:

◘ mass production ⇒ is the production of high volume, same type standardized products, usually on fabrication lines;

◘ customized production ⇒ is the production of customized products on computer aided flexible fabrication systems

The new modern fabrication technologies do include a large variety of processes required by production and product components integration, all of them correlated with engineering sciences and industrial design specific elements. For example, an industrial designer is responsible of product's shape and aspect, that depending on its material and fabrication process characteristics. This is why it is important for him / her to know about the available materials and fabrication processes, so that there is a certainty for an economic and adequate fabrication process.

Figure 1.11 evidences the main types of materials used in engineering by industrial designers.

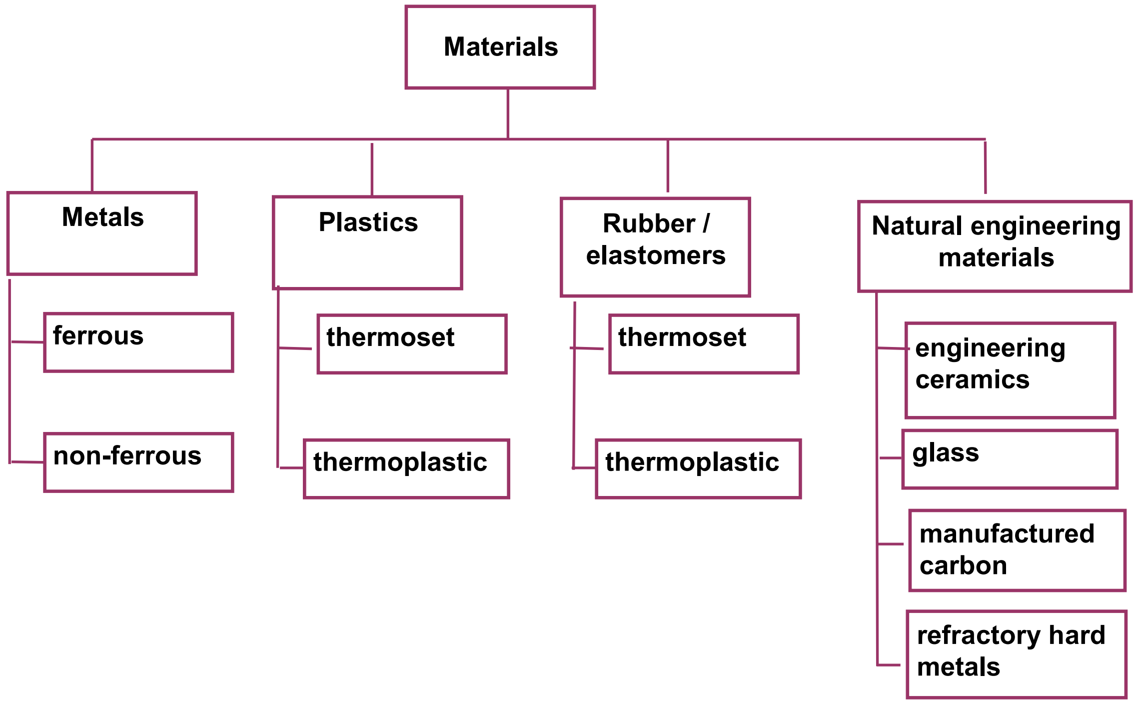


Fig. 1.11 Material types used in industrial design [3]

A classification of *metals* is shown in figure 1.12, where it can be noticed that they are:

◘ pure metals ⇒ made of same type atoms;

◘ metal alloys ⇒ made of two, or more, chemical elements, at least one being metal.

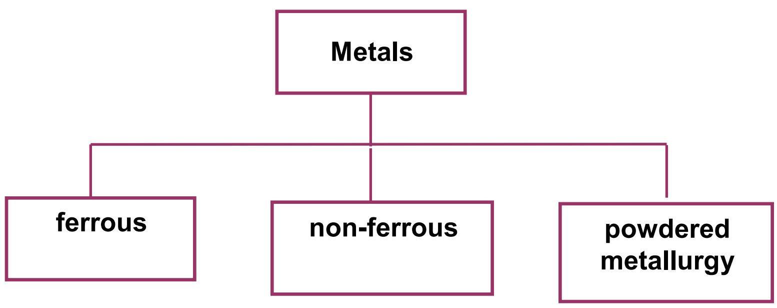


Fig. 1.12 Metals classification [3]

Plastics can be resins, or polymers, obtained by hydrogen, carbon, nitrogen, oxygen, silicon, sulphur, chlorine atoms, derived from oil.

With Greek origins, the word "polymer" describes macromolecular materials made of repeated identical structures and chemically bonded as long chains. In fact, polymerisation means monomers chemical bonding, such resulting blocks for large molecules.

Mainly, there are two types of plastics, meaning:

- thermoplastics ⇒ they soften and melt when heated and harden when cooled; can be injected, extruded, some of them are: polyesters, melamine, polyurethane, etc.;
- thermosets ⇒ they harden when heated, can be used in thermoforming, blow forming, cold forming, being cold shaped as desired and then heated so that to harden, some examples are: PVC, polyethylene, polystyrene, etc.

Rubbers or *elastomers* represent the materials that do get their initial shape after being stretched to several times their length. So, as mentioned in [3].

- rubber ⇒ is the material that quickly recovers from large deformations and retracts within one minute, to less than 1.5 times its original length, after being stretched at room temperature to twice its length and hold for one minute;
- elastomer ⇒ is a macromolecular material which at room temperature is capably of recovering substantially its shape and size, after removal of the deforming force, with no time given for full recovery.

Natural engineering materials represent the new materials formed by new combination of old/ classic materials, such as ceramics and metals, or carbon and plastics. Thus, they offer high values of tensile strength, corrosion and high temperature resistances, ensure good dimensional stability.

A classification of these materials is evidenced by figure 1.13

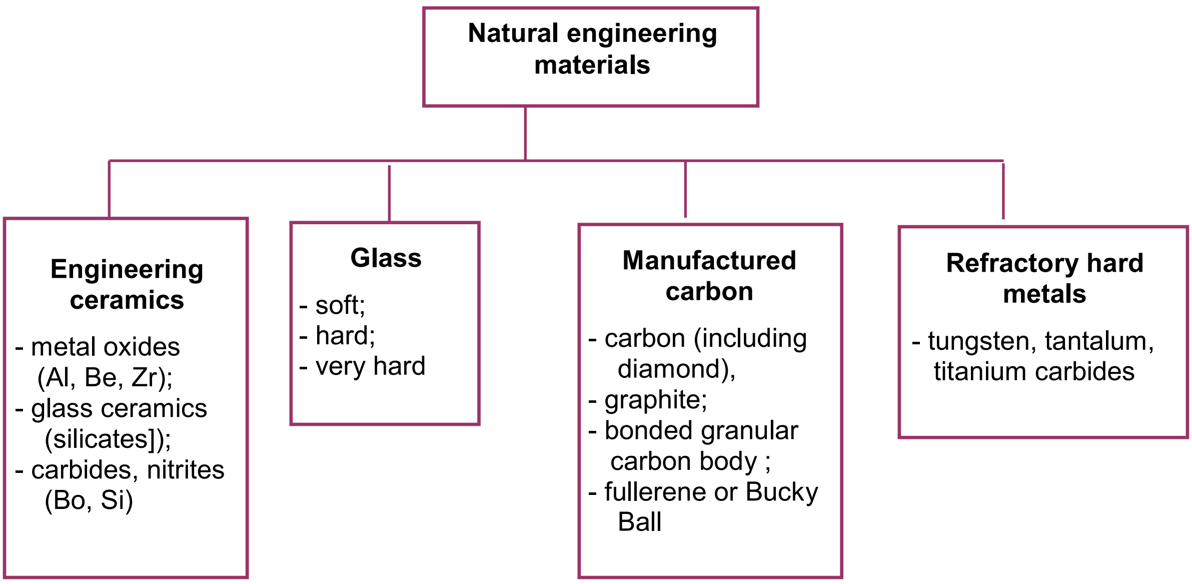


Fig. 1.13 Classification of the natural engineering materials [3]

Customized product manufacturing processes, specific to most of all the above mentioned materials types, are described further in this book - from chapter 5 up to chapter 8.

There will be presented Rapid Prototyping and Rapid Manufacturing techniques, CNC machining and micro-machining procedures, Plastics Forming technologies and aspects dealing with holography and holograms.

1.4 Product Development

Product Development represents the set of activities starting with identifying / getting the perception of a market niche and ending with production, selling and delivering of the product [5]. There is also the *New Product Development* term, used when referring to the complete process of bringing a new product or service to market [http://en.wikipedia.org].

When developing a new product, a lot of time and money are required, proportional with the number of people in the product development project team and with the period of time required by the project. In a product development process, there is involved the sequence of corporations / enterprises activities dealing with product conception, design, development and selling.

So, in a product development process, there are two parallel paths to be followed, meaning:

- idea generation, product design and detail engineering ⇒ the first path;
- market research and marketing analysis ⇒ the second path.

Some reasons for a good definition of the product development process can be the ones that follow:

- quality assurance ⇒ by correct / complete definition of the stages involved in development process and of the moments / elements to be checked out;
- coordination ⇒ by development process' role of master plan, there is an accurate coordination of all team members activities, such as mentioning the moment and the contribution required, the people to exchange information with, etc.;
- planning ⇒ by pointing out the objectives and moments when they have to be fulfilled; for each of the process development stages;
- management ⇒ by evidencing the developing activity's performances and comparing the real situation with the one required by the process, thus it is possible for the manager to identify and react when certain problems are identified;
- improving ⇒ by correct and complete documentation on the development process needs, many times there have been identified opportunities for improving the product.

There are many stages for product development, their definition and name do vary a little, according to each researchers experience and opinions

So, K.T. Ulrich and St. D. Eppinger [5] mention the six stages of product development process, as follows.

0. Planning ⇒ is the stage prior aproving the process development project and includes the presentation of development techniques and market objectives, defines the market segments involved in getting the target, the hypotheses and the existing restraints.

1. Concept development ⇒ is the stage dealing with identification of target market requirements, with generating and evaluating the alternative products concepts, when one or more concepts are chosen for further development and testing.

2. System design ⇒ is the stage when product arrchitecture is defined and the subsytems and componets are settled, thus a geometrical representation for the product is obtained and functional specifications, for each of product's subsytems, are defined.

3. Detailed design ⇒ in this stage, complete specifications of geometry, materials, tolerances for each specific componments of the product are defined, also, standard elements that must be supplied are identified.

Once this stage is over,the whole product control documentation is done, meaning drawings, operation plans for manufacturing, assembling, etc.

4. Testing and perfectioning ⇒ is the stage when making and evaluating of more product versions, by prototype manufacturing is performed. So, there are the ones that follows

- α prototype ⇒ whose material and geometry are similar to that of final product, being used to check if the product does function and satisfies the most important requirements;
- β prototype ⇒ is made of product component elements and is used for an internal, detailed analysis, so that relevant infomation on performance and reliability to be obtained. Thus, any necessary changes of product design or manufacturing technology can be done.

5. Production ⇒ first, there is the „zero sery" and further, when any necessary adjustments done, there is the series, or mass production.

As mentioned by [http://en.wikipedia.org], the new product development process stages are the ones mentioned below.

1. Idea generation (fuzzy front end) ⇒ obtained from basic research using a SWOT analysis (Strengths, Weaknesses, Opportunities & Threats), once the opportunity study being completed.

2. Idea screening ⇒ its objective is to eliminate unsound concepts prior to devoting resources to them and should answer to several questions as:
- will the customer in the target market benefit from the product?
- what is the size and growth forecasts of the market segment/target market?
- what are the industry sales and market trends the product idea is based on?
- is it technically feasible to manufacture the product?
- will the product be profitable when manufactured and delivered to the customer at the target price?

3. Concept development and testing
⇒ develop the marketing and engineering details by: solving problems as:
- investigating intellectual property issues and search patent data bases
- deciding who is the target market and who is the decision maker in the purchasing process?
- what product features must the product incorporate?
- prove feasibility through virtual computer aided rendering, and rapid prototyping
- what will it cost to produce it?

⇒ testing the concept by asking a sample of prospective customers what they think of the idea.

4. Business analysis ⇒ involving an estimation of selling price based upon competition and customer feedback, as well as a sales volume estimation, based upon market size;

5. Beta Testing and Market Testing ⇒ by producing a physical prototype, testing the product and its packaging in typical usage situations, making adjustments if necessary, etc.

An initial run of the product is produced and sold in a test market area to determine customer acceptance

6. Technical Implementation ⇒ is done by new program initiation, resource estimation, department scheduling, supplier collaboration, logistics plan, program review and monitoring, etc.

7. Commercialization (often considered post-new product development) ⇒ involves a series of activities as: launch the product, produce and place advertisements and other promotions, critical path analysis.

8. New Product Pricing ⇒ refers to the Impact of new product on the entire product portfolio or, to competition and alternative competitive technologies, or to product costs (fixed & variable), or, finally, to forecast of unit volumes, revenue, and profit

Many corporation managers do consider the new product development process as a continuous developing one, where the whole organization is involved in finding new opportunities. As the product development process requires, both engineering and marketing expertise, the team involved is a cross-functional one. This team is responsible for all the process stages, starting with idea generation and ending with commercialization.

In the industries where developed products are complex, development research is typically expensive, and product life cycles are relatively short, strategic alliances among several organizations help to spread the costs, provide access to a wider skill set, and speed the overall process.

Brief conclusion on the aspects presented in this chapter should be that:

⇒ any successful product has to satisfy someone's need or requirement and it is essential to be brought on the market with minimum work and time consumptions;

⇒ a good management of the product life cycle is always required;

⇒ an innovative design for the product can be the answer to certain new customers requirements;

⇒ the product development process is a complex one, developed in many stages and many times involves cooperation inside and outside company's departments

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2. CUSTOMIZED PRODUCT AND CUSTOMIZED MANUFACTURING

A new product is, usually developed, as a need for satisfying the medium market segment requirements. That is why there is a limitation of the rate it satisfies all clients needs and, the product is assumed to be right for all clients (one size fits all), or at least for a certain segment of the customers in the involved market.

This way of considering a new product development aspect is classic, traditional and efficient, only if the market segment it is addressed to is large enough and if the needs of involved customers are relatively homogeneous.

There will always be customers with specific needs, whom, more or less, the product won't be able to satisfy. This aspect is known in the concept development stage and it exists even, for the well defined market segments. The involved customers does represent the "dark side of the market" and will always be there, without being an exception. This is how, a high failure rate of new products could be explained (Crawford, 1979 and Cooper, 1999).

2.1 Customized Product

The global economy, characterized by high international competition, market fragmentation due to customers' discriminatory requirements and fast technological change goes through a new industrial "revolution", where production of customized products is essential.

Customized (Individualized) Product is a special product designed and manufactured to satisfy the needs and requirements of a certain customer.

Customized products have become popular on the market and do represent an opportunity of new business affairs. Their high development is based on the new customer – manufacturer relationship, which allows the manufacturer to offer a customized product to each customer, according to its specified needs / requirements (Frank & Schreier, 2002).

This does represent a hope for solving the "dark side of the market" customers problem.

In fact, the essence of customization is that it offers what the clients want, in the right time, meaning: low price, high quality, fast delivered and, specially, requirements tailored products,

The development of customized products is possible due to two major aspects, mentioned next :

◘ new internet communication methods ⇒ allowing manufacturers to quickly and efficiently analyse each customer's requirements ;

◘ new production methods ⇒ specific to customized manufacturing and enabling a significant drop of production costs.

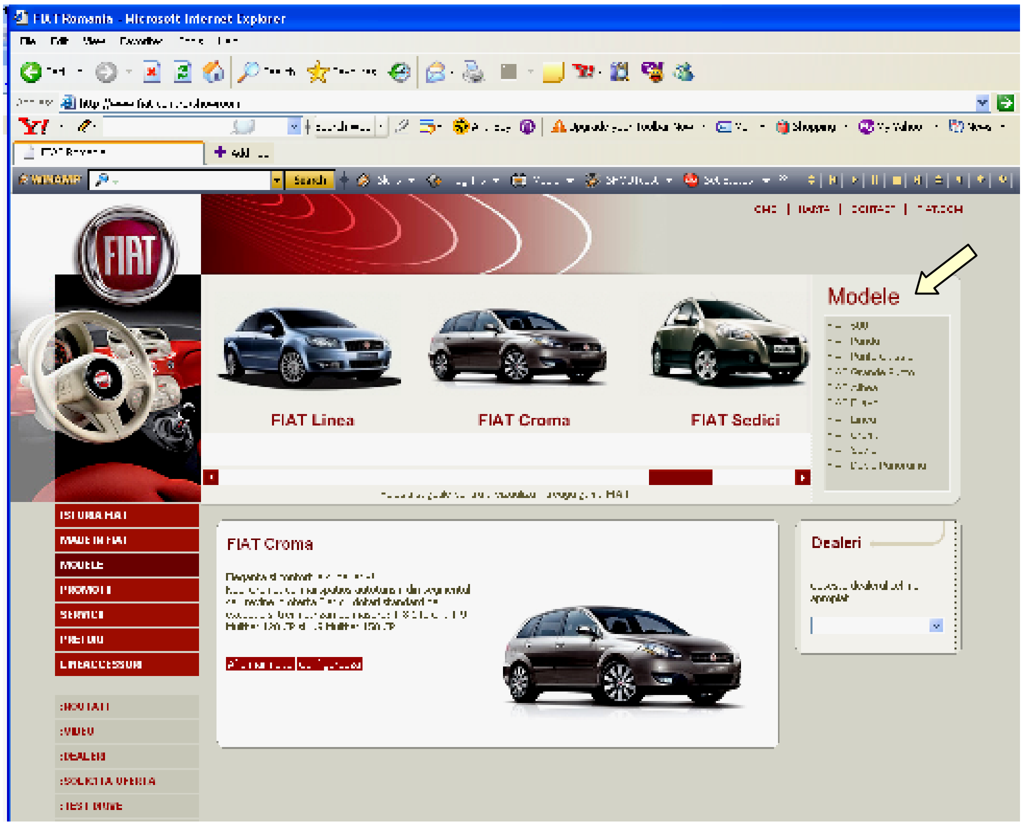
Some managers have developed a customer interaction relationship based on policies and procedures named "*customize / individualize*". This is because it has been noticed that, when developing both industrial and consumer goods, clients and, specially, end users did have a significant contribution in developing successful products / prototypes. So, there were many cases when customers did innovate the new product type or, highly contributed to its improvement / perfection.

Thus, it was noticed that the customers externalization of certain stages in product development has proved to be possible and, more of it, benefic. By specific means (internet accessed design software) customers can express their ideas, preferences and options for new products, according to certain specific needs.

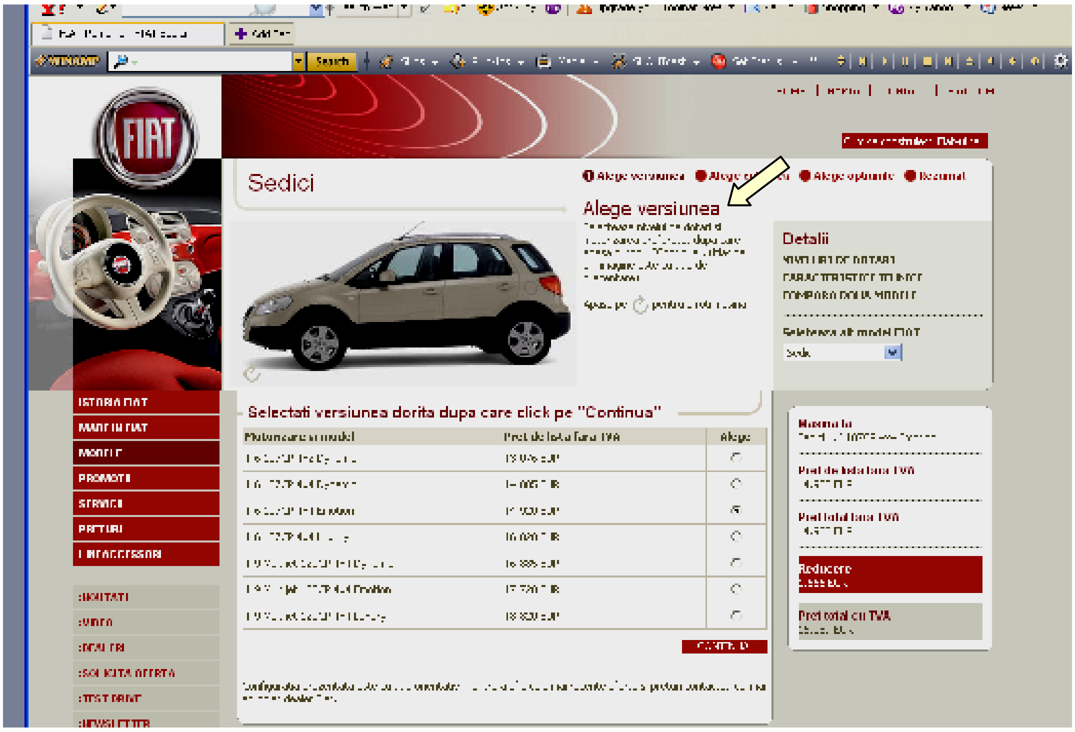
Kamali & Locker (2002) have noticed that many customers are willing to pay more, just to have a customized product, whose value can be, even, 100% higher. In fact, there are many international companies offering customized products, such as: Dell (for computers configured according to any individual need), Levi's (for jeans and jackets fitted to personal size), Adidas (for sport shoes adapted to any food loading), Fiat (for cars individual configured as model, motor, color, facilities – all just by answering some website questions).

An example of how the customer can decide the desired products configuration is shown in figure 2.1 and figure 2.2.

Summarizing, it can be considered that bringing to market of the products fulfilling certain customers specific needs it is a challenge. It has been proved that these customized products do generate enough profit as to justify production strategy changes when compared to classic, series or mass production, concepts.

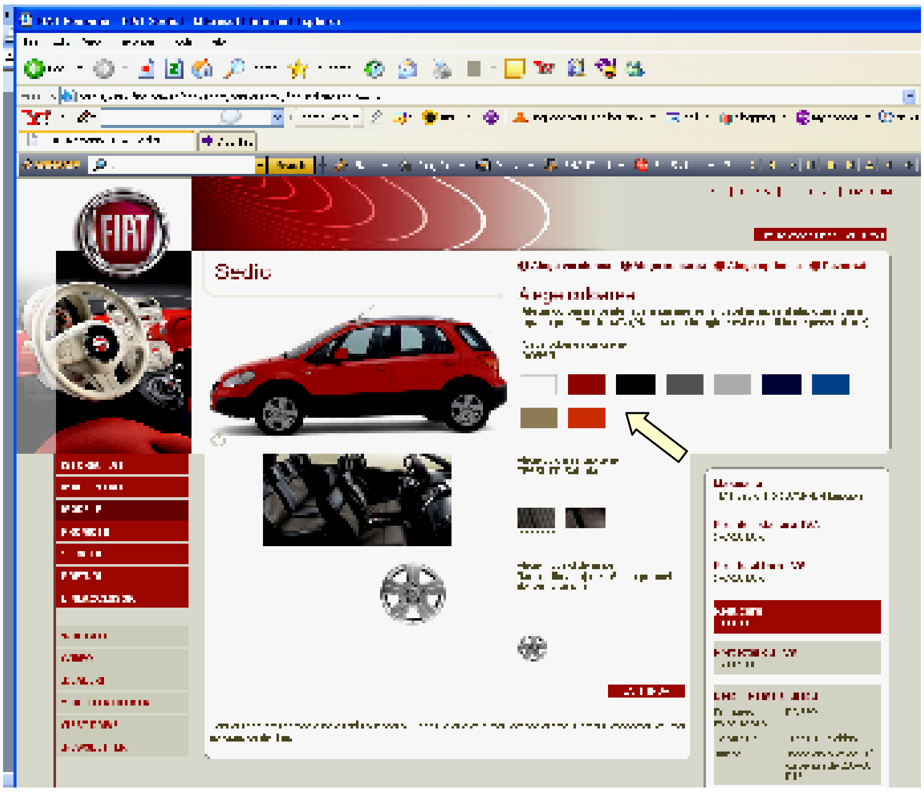


Step 1 – model's choice



Step 2 – variant's choice

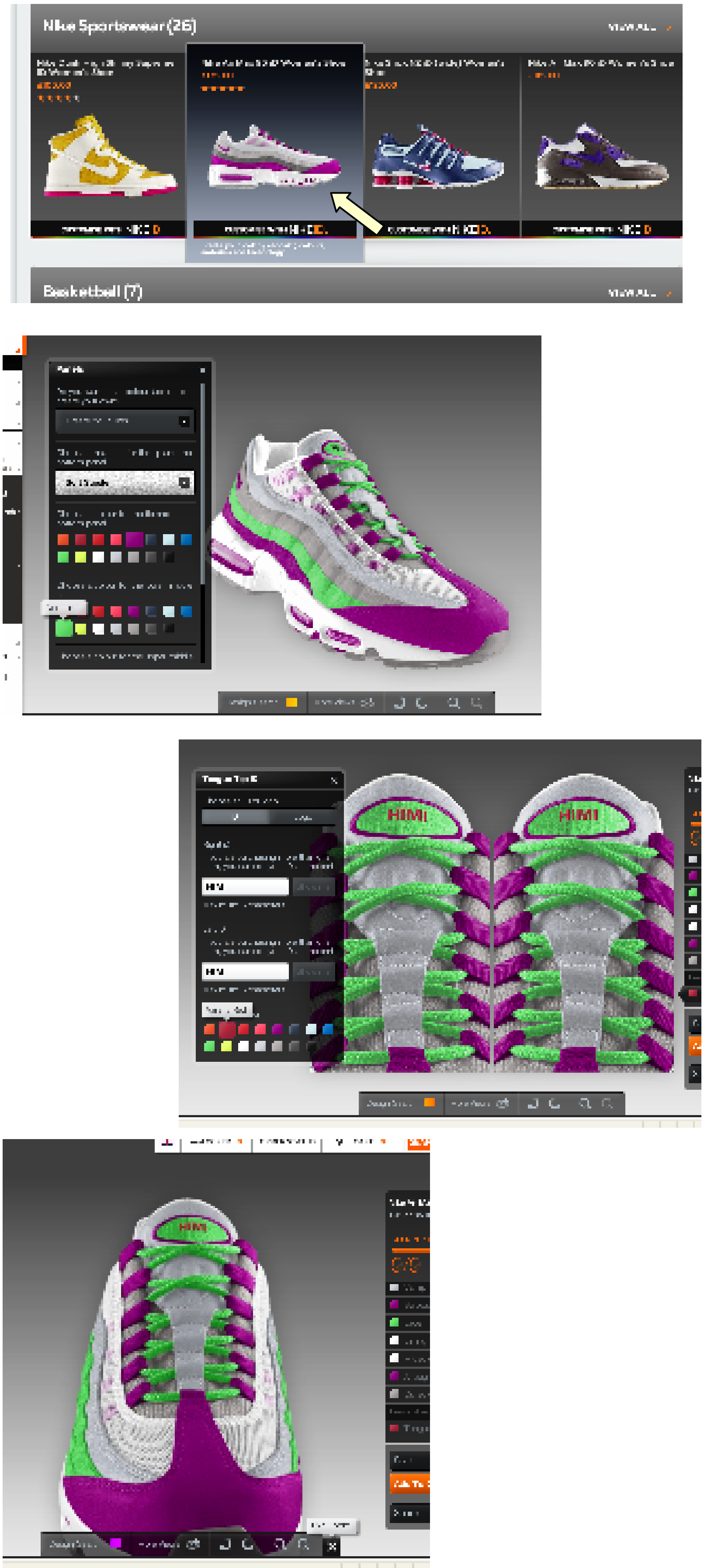
Fig. 2.1 On line ordering a customized Fiat car [http://www.fiat.ro]
- to be continued -



Step 3 –colour's and wheels' choices

Step 4 – optional facilities choice

Fig. 2.1 On line ordering a customized Fiat car [http://www.fiat.ro]



Step 1 –choose model

Step 2 –choose material and colour for panels and lace

Step 3 – write ID

Step 4 – choose size and ..order

Fig. 2.2 On line ordering a customized NIKE pair of shoes [http://store.nike.com]

2.2 Customized Manufacturing

The idea of customized products mass production was first mentioned by Alvin Toffler (1970) in his book, “Future Shock. It was further developed by Stan Davis (1987) in the ”Future Perfect” book and by Gilmore and Pine (1997) in the book “Mass Customization”.

There are more similar definitions for *mass production customized manufacturing*, or *mass customization*, some of them being presented below:

◘ Pine (1993) ⇒ production of customized products / services, highly differentiated but without an increase of costs;

◘ Han (1996) ⇒ using the flexible process and organizational structures to produce a wide variety of customized products, in the price of alternative similar mass produced products;

◘ Rich (2000) ⇒ the term used to describe manufacturers ability of making any necessary changes in the production process so that the “exit” to be that of small quantities customized products, even one of the kind;

◘ Silvers (2001) ⇒ the system where informatics technologies, flexible processes and organizational structures are used so that to deliver a large variety of objects / products that do satisfy the customer needs, with the price equaling that of mass produced similar products;

◘ Huang (2006) ⇒ the production system where a customer can order and get a special configuration product that satisfies certain needs, in a reasonable price, by choosing from many options

◘ Hvam (2008) ⇒ the production type where customized products are manufactured and delivered using mass production advantages.

The customized manufacturing system and its specific principles involve a special strategy to be undertaken. Some of its essential elements are the next ones:

- focus on a certain market segment where the customers can get their desired products and there are no cases to be turned down;
- development of manufacturing specifications involving product configuration systems;
- product range is based on modular structure, so that a customized product can be obtained by selecting, combining and, even, adapting of a standard modules set;
- the installation and post-selling service, consisting in the installation and replacement of modules.

There can be noticed the central element, the new idea of such a system, which is that of developing the product range based on modules and product configuration systems. All of these are specific to customer oriented processes that include customized product’s sale, design and manufacturing specifications development.

The systems that enable mass production of customized products are characterized by high flexibility based on continuous innovation and short production cycle. So, there can be obtained products with characteristics adapted to customer individual requirements, but whose time and money consumption are comparable to those of similar mass produced products. This type of production systems involves a strong customer – manufacturer dialogue, meaning a short answering time, allowing simulation of various solution to satisfy customers requirements.

A schematic representation of the mass customization process is shown in figure 2.3. There can be noticed the main types of interaction between customer, seller, manufacturer, supplier and distributor of the customized product.

So, the manufacturer plans and calculates the components to be supplied, the ones to be produced and the time needed to fulfill and deliver the order. If there is a stock of them, then the customer can get a price and delivery time offer, also including some details on customized product quality. But if the components must be ordered to suppliers, then, first, the manufacturer has to negotiate the price and delivery time with them and after that can make the offer to the customer.

Once all the terms settled and accepted by, both customer and suppliers, the manufacturers launches the production order. After all components have been manufactured / delivered, the next step is that of assembly them and, further, to deliver the customized product to client.

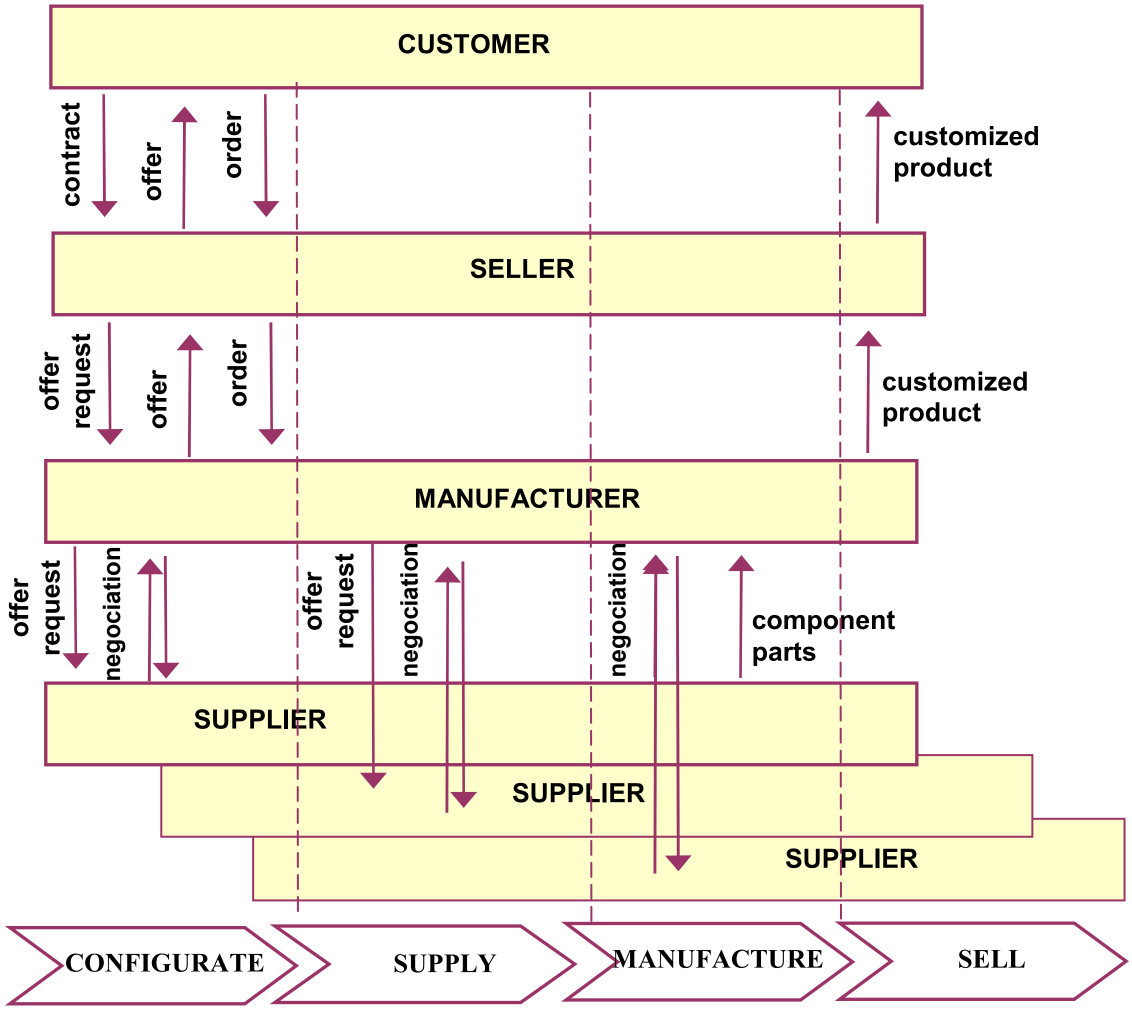


Fig. 2.3 Scheme of the mass customization process [2]

Gilmore and Pine (1997) pointed out four features of the customized manufacturing, as follows:

- collaboration - of product designers / manufacturers and customers ;
- adaptation – by modifying the standard products ;
- cosmetics – by customized packing of standard products ;
- transparency – by transforming the standard products according to a certain customer needs.

As mentioned by Feitzinger and Lee (1997), there are three organizational principles that represent the base of any customized manufacturing process and allow fulfilling customers requirements at low price. These principles are the next ones::

◘ product design as independent modules that can be fast and low cost assembled, resulting various product variants ;

◘ manufacturing processes taking place in different modules that can be conveniently moved or re-arranged, so that different distribution networks could be supported ;

◘ supplying networks that are both able to offer the basic product in accordance to customized manufacturing requirements, and to be flexible enough as to take customized orders and fast deliver the required products.

Nowadays, meaning the beginning of XXIth century, are characterized by changes in production and marketing specific activities, so that there is a change from mass production to customized products manufacturing, with the benefits of the first one.

This new approach of product manufacturing is based on the idea that a product should be obtained differently, for each customer, within the principles of mass production (Goldsmith and Freiden, 2004).

Some of the elements generating the above mentioned change in product manufacturing should be mentioned as :

- the market, as well as the customers ⇒ that do become more fragmented and specialised ;
- customers requirements ⇒ do change fast and have evolution within the frame of low cost, high quality and small quantities of customized products ;
- reduced product life cycle ⇒ determining short time for products development / manufacturing ;
- customers wish to be treated like important persons ⇒ meaning separately and individualized.

Traditionally manufacturing methods were focused on mass production, where standardizing principle was the leader and large volumes of standard objects / products were obtained at low cost. In products customized manufacturing, a better connection of company's abilities to customers needs is achieved, while the modern manufacturing systems and the high level computer aided technologies ensures advantage over any competitor, when medium, or small production volume were involved.

With mass production specific strategies, companies can make customized products as required by certain customers or market segments, with an efficiency that, at least, equals the mass production one. In fact, there has been noticed that many customers are willing to pay more for a customized product, specially if they can contribute, even a little, to its production.

In figure 2.4 there are shown the economic implications of customized manufacturing in a mass production systems. It should be noticed that there is a profit only if the production volume is low.

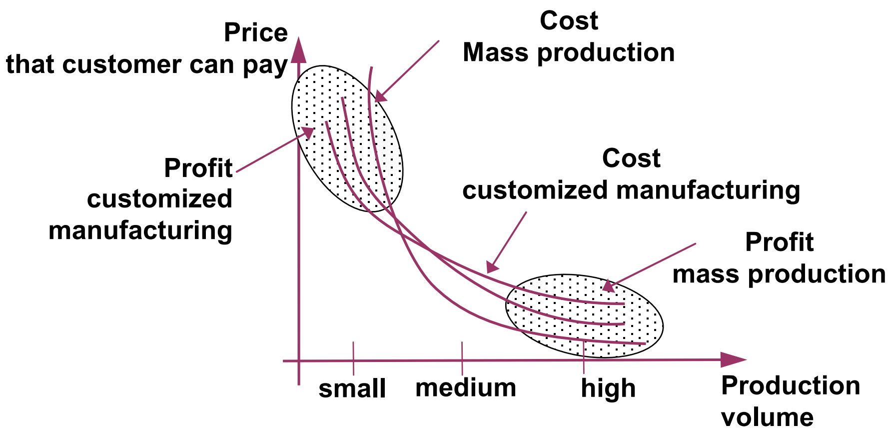


Fig. 2.4 Economic implications of mass customization [2]

2.3 Integrated Relation: Marketing – Agile manufacturing – Supply Chain Management

The conceptual changes in business and, consequently, in production involved appearance and development of *Agile Manufacturing*. This type of manufacturing is specific to customized manufacturing as mass production and it is focused on making highly individualized products, how and when the customer wants.

Agile Manufacturing concept was first introduced in USA (Iacocca Institute, 1991) and was promoted as the definition of how to win the strong competition existing nowadays in the global market. It is characterized by high flexibility potential and, as consequence, by the ability to make essential and fast changes of production volume, delivery date and product range.

The agile manufacturing system is organized so that it enables to identify and apply the best methods and means for a company to get manufacturing agility / rapidity. This is characteristic of the business "turbulent" environmental (Ian, 2001). Thus the company must be able to produce multiple and various products, to make up-dates and re-design the products with reduced life cycle and, simultaneously, to modify efficiently its production capacity.

A practical guide of how to develop and apply the agile manufacturing system, within mass customization processes, is presented by Oleson (1998). He does evidence the importance of high flexibility and agility for the companies ability of real time answering to the consumers and market specific needs. In order to integrate the agile manufacturing system and to efficiently manufacture the customized products, the companies must have a correct supply chain management.

It was in the '90s when, within big companies, it has been noticed that attention should also be given to the outside problems, meaning to the company – supplier, company – suppliers' suppliers and company – customers interactions. This determined a change in company's focusing problems from the management of internal processes to the management of the processes that are going on between companies.

The *Supply Chain Management* represents the integration of all important processes – from the final users to the initial supplier of materials, products and information – so that added value should be given to products (Lambert, 1998). It really is a competitive strategy of integrating both suppliers and users in order to improve company's flexibility and reaction ability to different requirements.

There is a strong tendency of increasing products customization and it does represent a challenge for the supply chain designers (Su, 2005). This is because, as stated before, in the companies dealing with manufacturing customized products it is a need for strong cooperation where customers, suppliers and third-party companies have their contribution to the product design and its value increasing. Many times, partners with specific skills and expertise have to be found outside the company and, thus, a virtual corporation of many companies should appear. Its target is that of solving customers requirements.

Based on these reasons, Childerhouse and Towill (2000) introduced the idea that the traditional supply chain is no longer adequate and it had to be replaced by a new model one, fitted to customized manufacturing and called *Customized Agile Supply Chain*. So, if in the '80s the existing supply chain involved long time (weeks, even months), had no transparency and synchronization problems appeared, in the 2000s, by the customized agile supply chain a short time (maximum a week) is needed for the delivery of customized products / component elements to the production company or distribution centres.

Specific for this supply chain model is the important role of automaton and internet access. These represent the basic elements for creating the platform whose role is that of registering the online orders, of costumers interaction and, the most, of ensuring real-time information for all the chain components. So, the accessibility of order and production data allows the reduction of inutile stocks and the change of both, "on stock" and "on order" manufactured products costs.

Considering all the customized manufacturing specific elements – mentioned above, there have been developed integrated strategies whose final goal is that of satisfying a certain customer's requirements, with costs similar to those of mass produced ones. These strategies are based on production and distribution flexibility, on strong partnership and synchronization of business plans that are correlated to market needs, agile manufacturing and supply chain management.

In figure 2.5, it is shown a schematic representation of the integrated strategies correlated for manufacturing / delivering of customized products. There can be noticed that, within an integrated market relation, the company identifies its customers, establishes long term cooperation relationships, and then customizes its products so that to fulfill the customized requirements.

This is why, the aspects that follow should be pointed out.

◘ Strong accent on customer – manufacturer – supplier interaction, as well as on the product type to be obtained $\Rightarrow$ customized product, determines changes in production conditions an requirements.

◘ The manufacturers must have a mass customization system $\Rightarrow$ involving informational technologies, flexible processes and organizational structures specific for the production of special configuration products that meet certain customized needs;

◘ Companies involved in customized products manufacturing must have agile manufacturing systems $\Rightarrow$ able to ensure the flexibility, agility, capacity of fast answering to market changes and customers specific requirements;

◘ The supply chain management is very important $\Rightarrow$ generating a material and information network, based on internet communication and ensuring the required flow chain from suppliers, manufacturers, distributors and sellers to the customers.

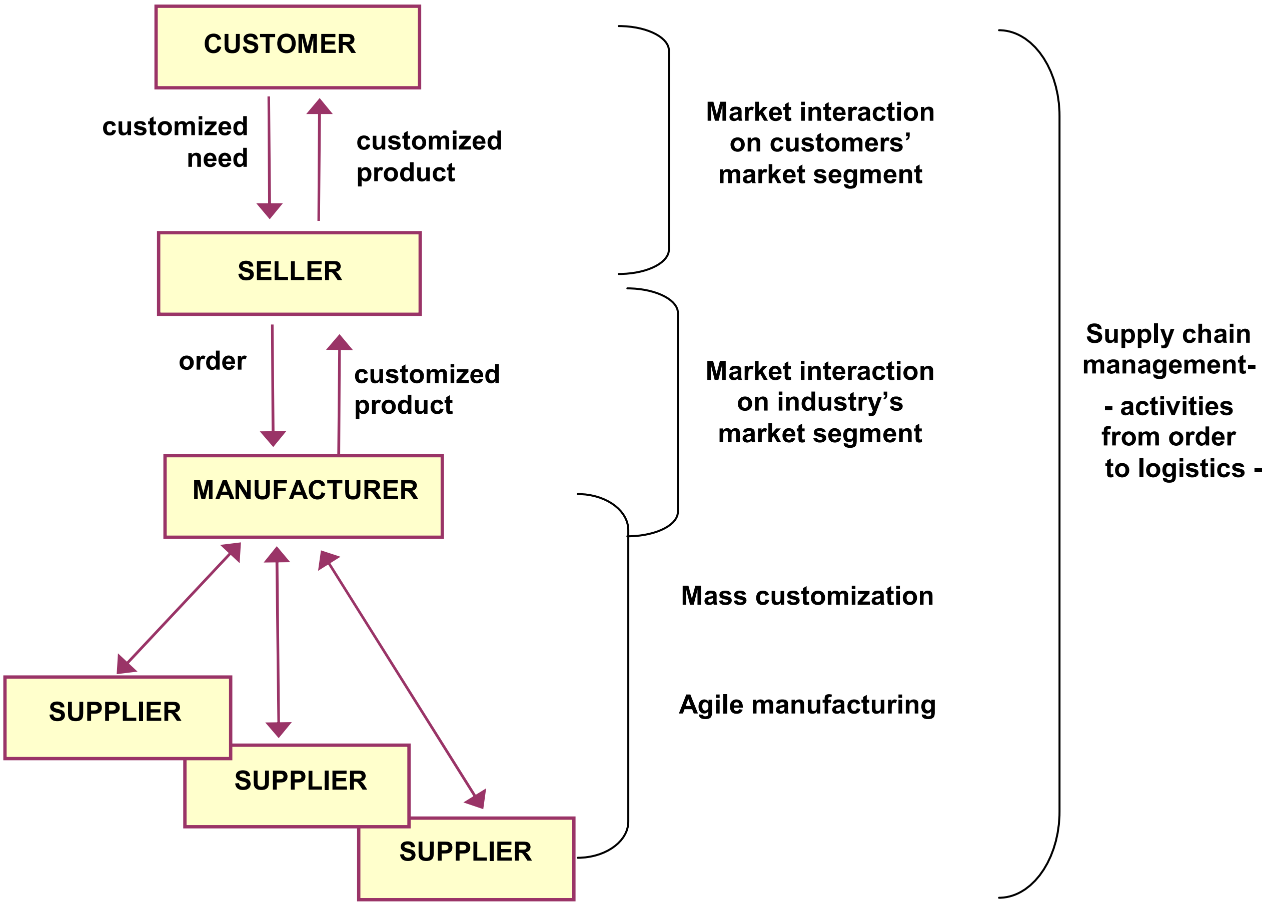


Fig. 2.5 Integrated strategies correlated for customized products manufacturing [2]

As synthesis of all the facts presented in this chapter, some fundamental characteristics of customized products and customized manufacturing can be formulated as:

⇒ nowadays customers want to be treated as individuals asking for products that satisfy their unique needs and, meanwhile, accepting to pay more, just to get them;

⇒ customized products become more popular and offer an unique potential for business;

⇒ companies must answer to the increased request for customized products and, thus, must prove the ability to change their products so that to obtain customized ones;

⇒ the strategies used by companies to change from mass production to customized manufacturing are various, but, mainly, are based on the idea of integrated relation: *marketing* (to identify customers needs) – *customized manufacturing* (to determine customized product's components) – *agile manufacturing* (to allow products fast changes and in short time) – *supply chain management* (to have correct flow with no miss - synchronization of raw materials / materials / component elements).

Further study and discussion should be on the topics of:

⇒ clarifying / detailing the roles of: informational technology;

⇒ internet communication,

⇒ customer involving product development systems;

⇒ computer aided systems of customized products manufacturing.

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3. SPECIFICATION PROCESS AND CONFIGURATION SYSTEM

One special aspect noticed when customized products are involved is that, usually, customers needs were not expressed as customized manufacturing specific terms. As it is absolutely necessary to avoid any ambiguity on the tasks these products have to fulfil, a *specification set* is used, meaning a way to configure precisely, measurable and detailed the conditions to be fulfilled by the customized product.

3.1 Specification Process – Definition and Characteristics

The *specification* term is one often used in everyday life, its significance being that of the description that, without any ambiguity, expresses and transfers the needs and / or intentions of a group of people to another group of people. For example, the instructions referring to "how to use" (a CD-player), or "how to assembly" (a bedroom furniture components), the guidance from a GPS (when reaching a certain location) do represent everyday used specifications.

Product Specifications represent the complete description of what it has to do.

When industrial products are considered, the specifications are represented by their drawings, lists of component elements, service manuals, etc.

An important accent should be on the specifications created and used for making customers offers and orders. So, the main specifications appearing in a product life cycle are evidenced by figure 3.1.

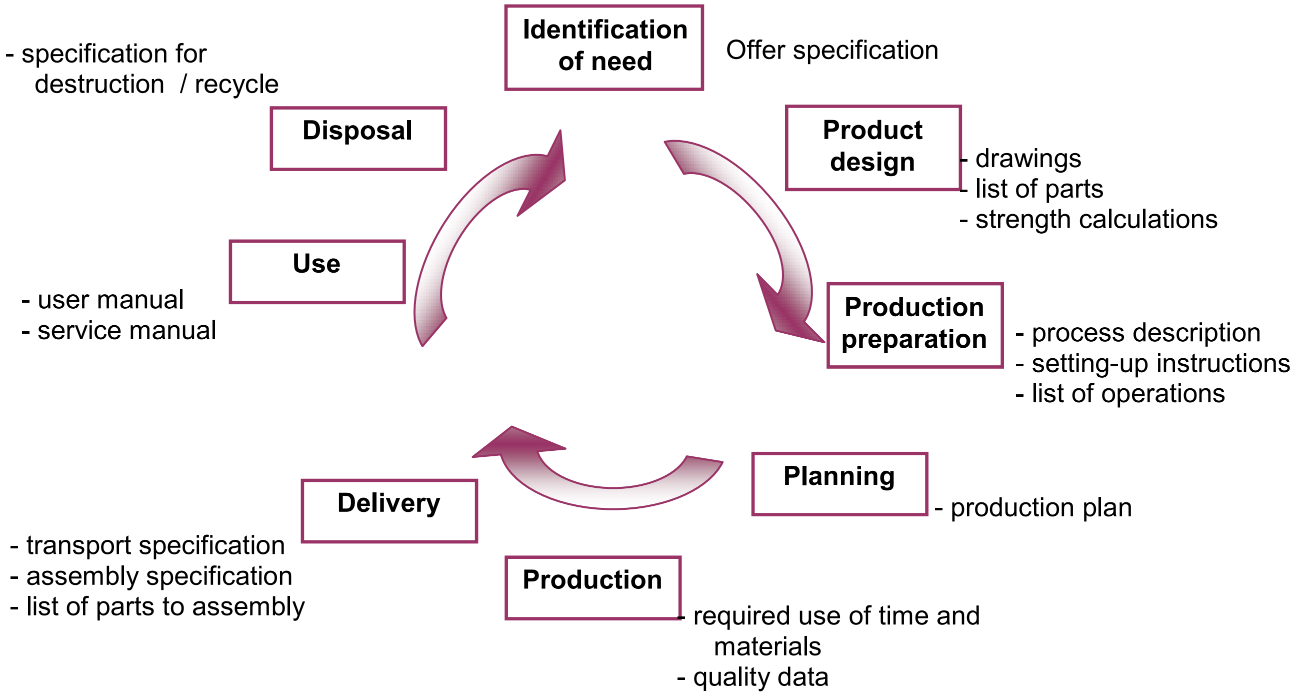

Fig. 3.1 Specifications in the course of a product's life cycle [1]

If the product is mass production manufactured, then the specifications are set in accordance to each of its development stages and are used every time the product is manufactured. But, if the product is manufactured as response to customer's requirements, then the specifications have to be configured and set for each of its offers / orders.

It is considered that any reference to a *specification processes* involves the sum of activities done in order to establish the specifications associated to customer's certain requirements.

The *specification process* can be defined as the business specific process of analysing customers needs, creating a customized product tailored to them and specifying the activities to be done in connection to supplying, manufacturing, assembling, commercialisation and servicing.

One example of a company specification process is presented in figure 3.2. It can be noticed that the making specifications activities are divided in-between company's departments. These activities are dedicated to the specification of product type, of how it has to be made, of the delivery time, etc, thus being possible the coordination of / in-between the departments within company.

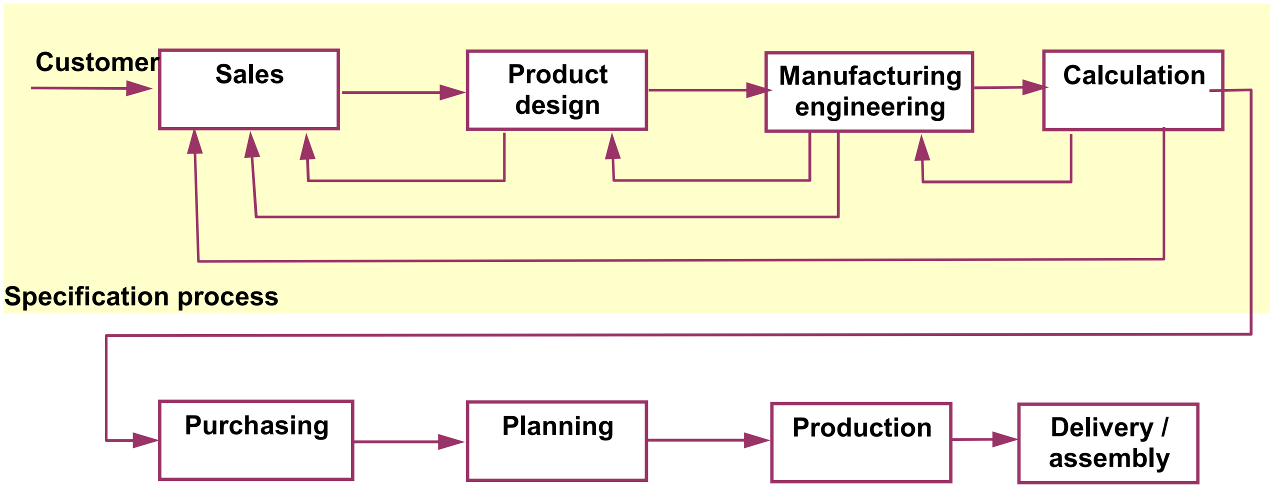

Fig. 3.2 Company's specification processes [2]

Once product's specifications determined, a *configuration system* can be built so that it could support, correlate and / or connect them all – as shown in figure 3.3.

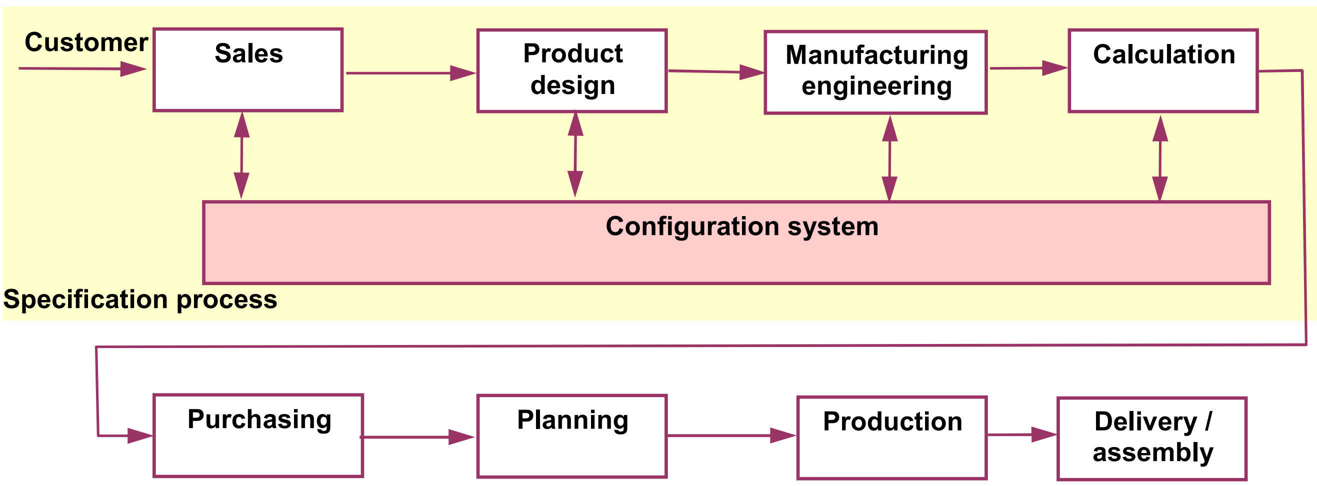

Fig. 3.3 Configuration system to support / integrate the activities in a company's specification processes [1]

People involved in design and manufacturing activities, can model the rules for product configuration and for how to work it out, can explicitly express certain constraints and conditions to be fulfilled. All of these should be further used by sales department, so that together with the customer to configure the customized product.

Basically, building a configuration system means modeling all the knowledge in an organizational unit and making them available for other organizational units. Thus, many problems of activities coordination within the company can be avoided and the way employers do their job can significantly change and improve.

As an example, the engineers and technicians who worked at making specifications for a certain product, have to maintain and develop the configuration system. This system, in its turn, sustains the development of specifications or, even, automatically generates them, starting from customer's options. In other words, these engineers and technicians do become model managers who have not only to be able configuring / dimensioning the product so that it satisfies customers requirements, but have to model their knowledge and experience in order to incorporate them into the configuration system.

The operational system specific to a company is shown in figure 3.4.

There can be noticed that the specification processes of this company do represent a part of the order chain, including activities performed as part of sales and order execution. Also, the development chain includes product range development processes and business development processes, the goal being that of obtaining the customized product. The specification processes in the order chain involve the day-to day specifications of customized products, the development of production specifications, after that being possible to plan, purchase, manufacture, assembly and deliver the customized product.

There is a strong link of the product development process to the specification processes, as the specification activity is based on the rules of developing a product new variant. This is why, at least ideally, specifications for a customized product are made by using the modules defined and developed within product development process. In fact, the development process is a creative one, with an open solution space, while the specification process does have a, relatively, closed solution space.

Some characteristics of, both, development and specification processes are comparatively presented in table 3.1.

Table 3.1

Some characteristics of development and specification processes [1]

Characteristics	Development	Specification
Degree of freedom	high	low
New modules (components)	yes	no (pre-defined)
Knowledge	generated	Utilised / taken into consideration (not generated)
Type of activities	creative	routine
Closed-world assumption	nu	yes

3.2 Mass Customization and Specification Processes

The high attention given by companies to the development of specification processes is the result of their tendency to adapt products to the specific customers needs.

In *mass customization* the big companies producing and selling mass produced products do adapt their systems so that their products fit the customers individual requirements (Forza and Salvador, 2007). This is how these products specifications become the basis for the development of manufacturing, assembly, delivery and service activities.

Another type of companies using configuration systems to interact with customers, is represented by the ones that do offer big, complex products, the "one of a kind" type, as, for example, power stations, or boiler systems. With these companies, the customer order involves a lot of work due to the need for designing each product components.

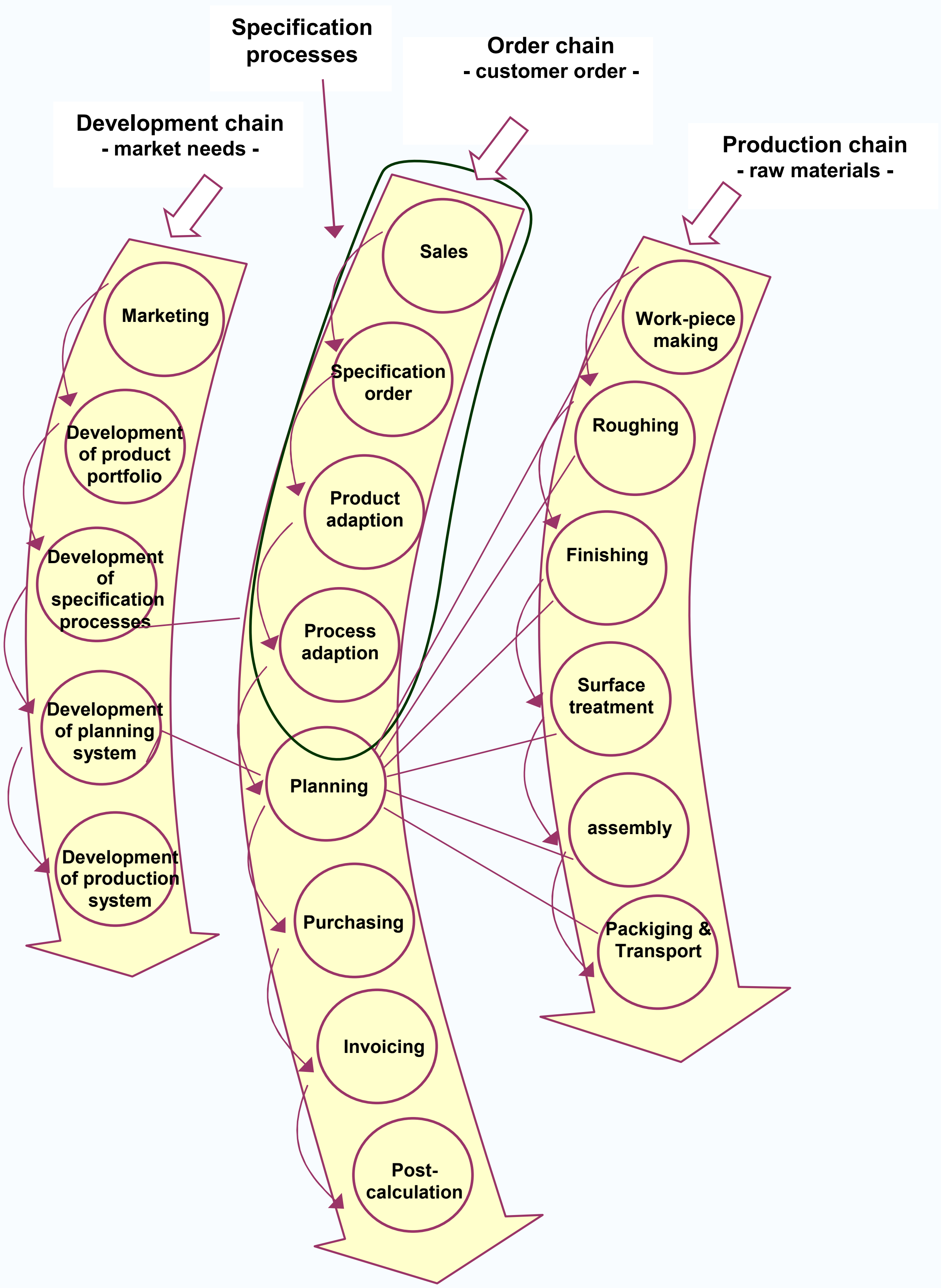

Fig. 3.4 Specification processes and their environment [1]

So, it should be distinguished between the development of a whole new product – from idea generation to delivery, and the detailed design of its components that should determine new, creative solutions to be found. These do add value / importance to the product tailored on client's needs and enable correct product specifications.

An easier and more efficient design of the customized products can be done if while the development stage, their configuration is of modular structure. Thus, they can be adapted to certain requirements only by changing modules and not by completely designing of a customized product.

The third type of companies where specification processes are very important is represented by the ones that do manufacture customized products in small series, or even as one individual. Their activity is focused on customer oriented business, meaning a thorough analyze of customer's needs and the creation of specifications that are the basis for further manufacturing, assembly and service activities.

The interdependence of company's type (mentioned above) and production type determining the specification processes can be seen in figure 3.5.

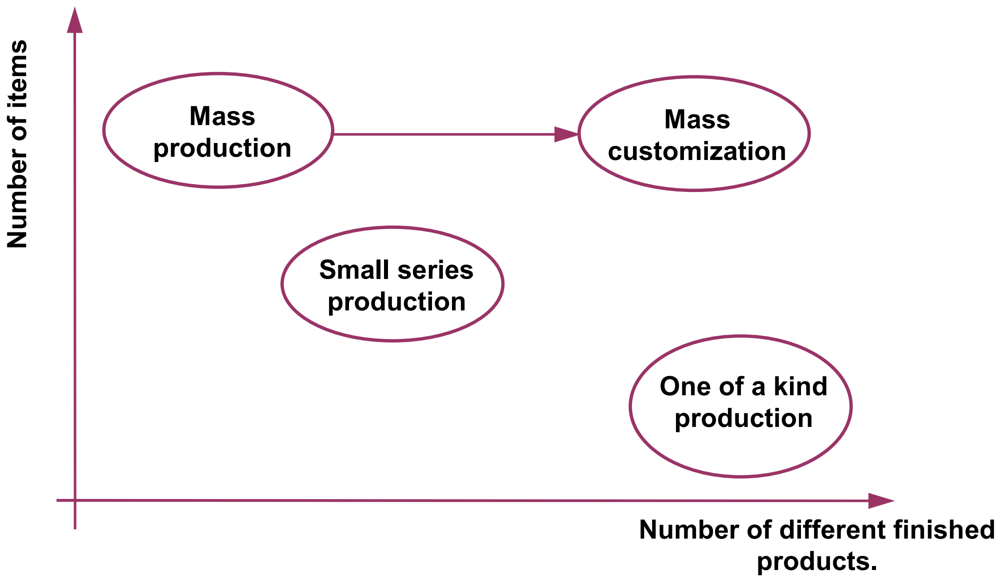

Fig. 3.5 Three main types of industrial companies – and specification processes [1]

There should be noticed the aspects that follows:

- for companies with mass production, the change toward mass customization generates new activities, meaning the development of new business processes and of new configuration systems that do enable the specification of customers needs;
- for companies were it is a small series production, or a one of a kind production, the customized products do not ask for new activities but, only for the separation of development product activities from the ones involving the design of certain parts - then it is the need of new IT support introduction so that customer interaction and expression of his / her specific requirements to be better done;
- for all three types of companies, the specification processes involve the sequence of activities leading to those specifications that are the basis for being able to sell, manufacture, use and dispose a product;

A common feature of all the above mentioned companies is that manufacturing customized products with the advantages of mass production can be done only if there is a modular configuration of the product range and if a configuration system to support customer initiated specifications processes is available. All of these are possible if there is stability over time, with a focused market strategy used by the company to choose the customer whom to sell the product to.

Depending on company type and on its initiated business process, the specification processes have specific characteristics (Hansen, 2003). So, in big industrial companies a great importance is given to the *Customer Order Decoupling Point* – that is an imaginary dividing moment between production for stock and production to order.

As shown in figure 3.6, there are three possible cases, characterized as follows:

◘ the uppermost level ⇒ specific to a production form where items are produced to be stored as finished products;

◘ the middle level ⇒ referring to the production where items are produced and components, stored and then, when required, assembled to order;

◘ the bottom level ⇒ for the production where everything is produced at order.

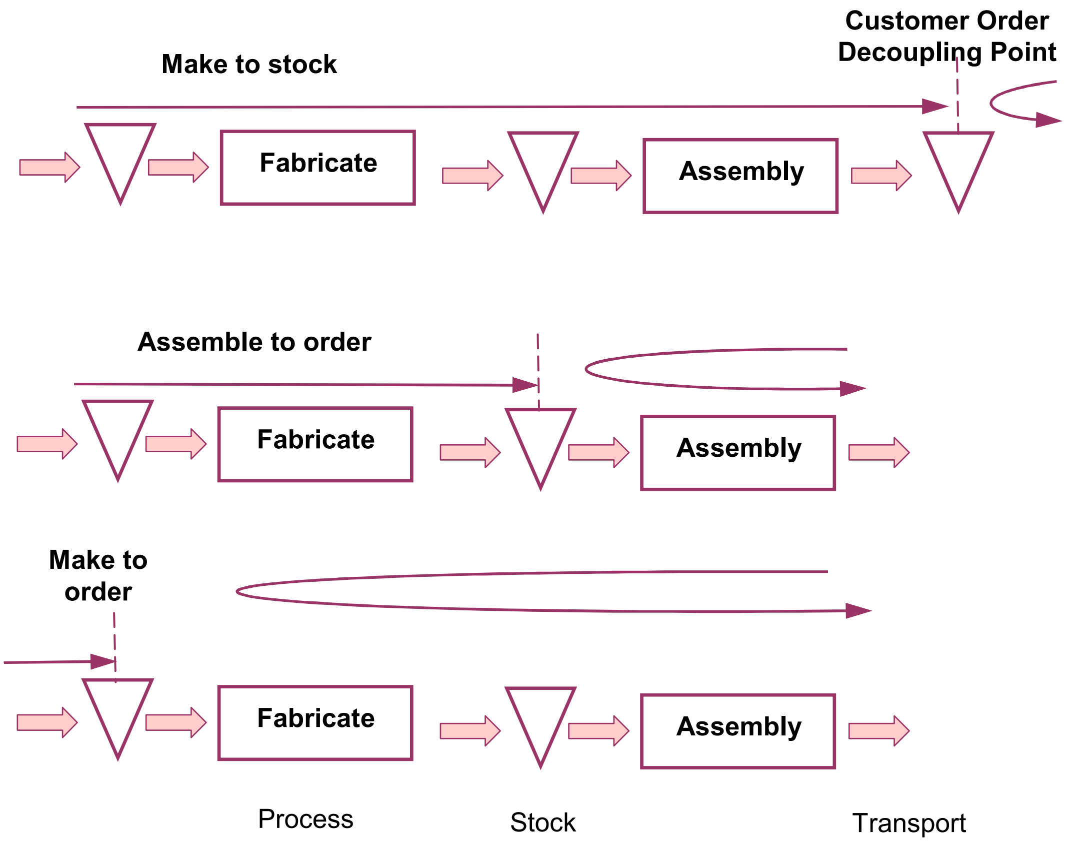

Fig. 3.6 The dividing line between stock and order based production [1]

Similarly, there can be considered a dividing line that separates the specification processes in order initiated specifications and specifications worked out without customer interaction. This is called *Customer Order Specification Decoupling Line* and it is evidenced by the diagram in figure 3.7.

Thus, referring to the dividing line, the specifications on its left side are worked out independently of the individual customers order. They result from the development process, modules, or production process and can be in the form of module description, dimensioning rules, set of instructions, etc.

On the right side of the dividing line, the specifications are worked out for individual orders. They can be offers, or drawings, or list of parts and are worked out specially for customized products orders.

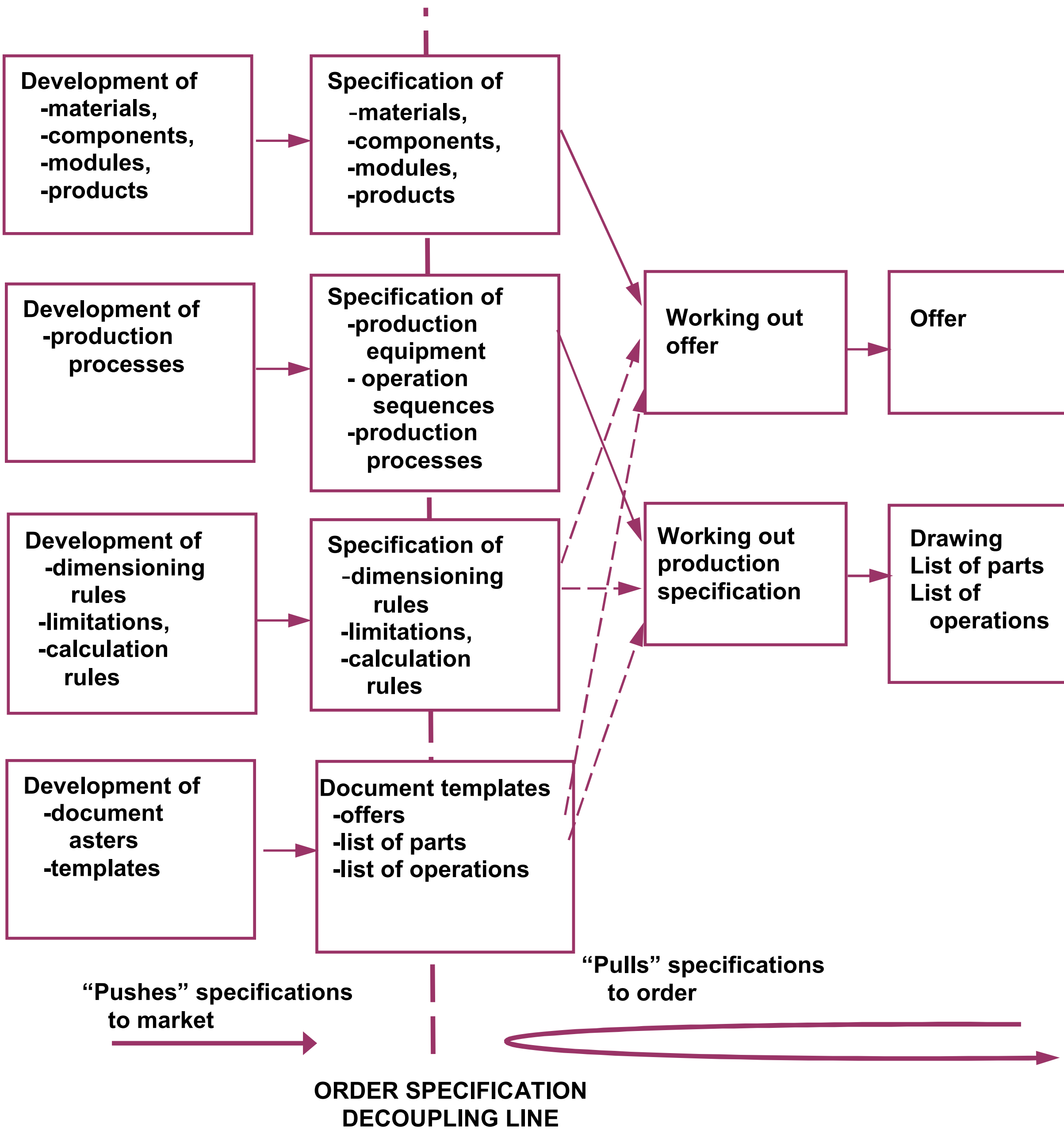

Fig. 3.7 The dividing line between product specifications types [1]

Depending on their position relative to the dividing line, there are four types of specification as mentioned below – see also figure 3.8:

◘ Engineer to order (the creative specification process) ⇒ is associated with companies supplying complex products (spray drying plants, enzyme factories) where a considerable amount of work goes into the design and specification of each individual component sub-assembly;

◘ Modify to order (the flexible specification process) ⇒ is specific to companies manufacturing customized products. They are made of pre-defined modules and assembled by using clear sets of rules of how to create a customized product.

◘ Configure to order (the dedicated specification process) ⇒ is fitted to companies where the specifications are worked out automatically by using a configuration system and the task of working them out takes place within a finite solution space.

◘ Select the product variant ⇒ is the specification process in which the customer chooses among company's standard products the one that to the greatest possible extent fulfil his / her needs. The task is that of identifying customer's needs and then finding the product that best suits them.

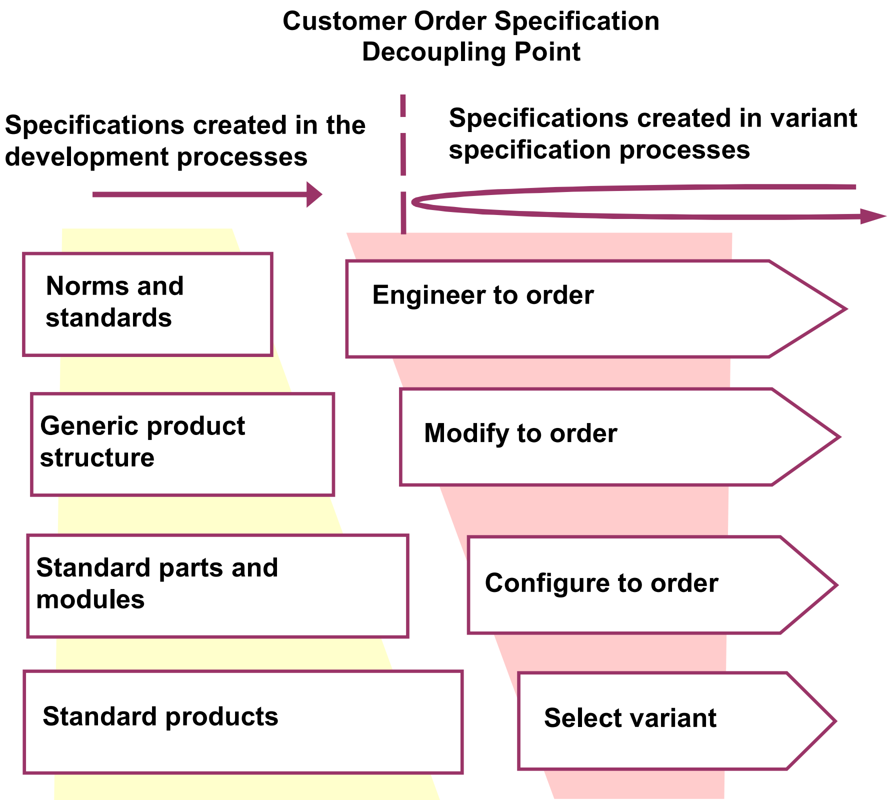

Fig. 3.8 Different types of specification processes (Hansen, 2003) [1]

3.3 Configuration System

The importance of modular configuration when customized products are involved has been mentioned many times in this chapter.

So, there is a definition of the *module* as a limited part of a product, with a well defined function and a well defined interface to the remaining parts (modules) of the product. When an individual module is considered, the interface to the other modules and their combination rules must be set and remain fixed, over a long period of time [1].

Some types of modularity (Pine, 1993, Ulrich & Tung, 1991) are presented in figure 3.9. Further comments should be on the aspects that follow:

◘ component sharing modularity ⇒ means that the same components are used for different product ranges and families;

◘ component swapping modularity ⇒ is when a new variant of family product appears, only by adding small (not very significant) components;

◘ sectional modularity ⇒ refers to the cases when the modules can be combined, in almost every way, by their interfaces;

◘ cut to fit modularity ⇒ deals with modules property of parameterization, meaning some of them can be adapted by changing dimensions;

◘ bus modularity ⇒ is the one that involves a platform development, on which components can be mounted.

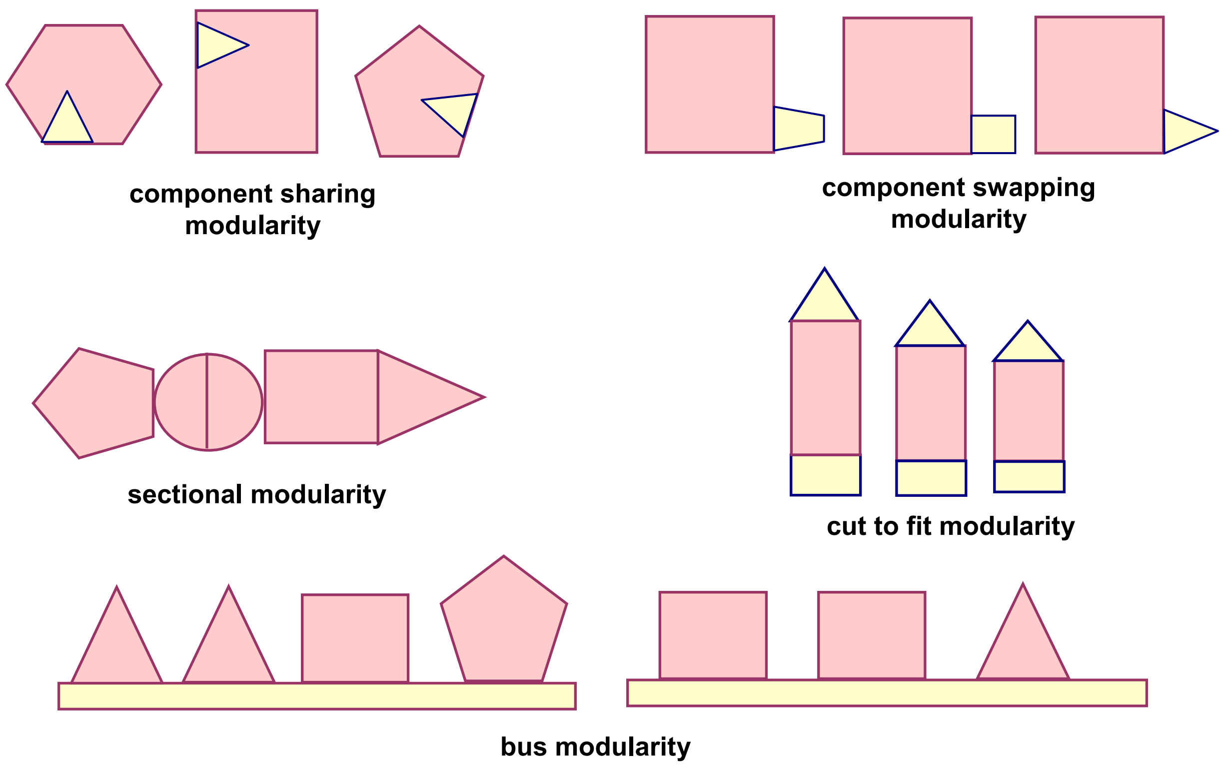

Fig. 3.9 Types of modularity (Pine, 1993, Ulrich & Tung, 1991) [1]

There should be pointed out the fact that when manufacturing customized products, the configuration of a certain product is highly correlated to its modularization. The number of variants for individual modules, as well as their possible combinations, result in a large number of possible product variants. This is why, the need for a configuration system is unquestionable

Configuration System is an IT system, mainly based on constraints programming, meaning it is an ideal system for the combination into a product of pre-defined modules, according to certain settled limitations. In another words, the *configuration system* is an expert system of combining modules individually described by a set of characteristics, according to certain constraints on assembling the involved modules.

Based on definition of the configuration idea, meaning to obtain a product from pre-defined structures (modules) according to a set of well known rules or constraints, there have been developed more definitions for the *product configuration system*, two of them being the next ones.

◘ Software systems that create, use and maintain product models that allow complete definition of all possible product options and variations with a minimum of entries (Bourke, 1998).

◘ A software that assists the person in charge of the configuration task. It is composed of a knowledge basis that stores the generic model of the product and a set of assistant tools that help the user finding the solution or selecting components (Aldanondo, 2000).

As mentioned by the first definition, the product configuration system is based on a model of company's product range. This is defined as a set of modules and rules of their combination, where the product model can be considered an abstract description of this range.

In figure 3.10 it is a schematic representation of the transformation process from the real world (the set of products and the knowledge behind them) to an IT system (a subset of the knowledge from the real world)

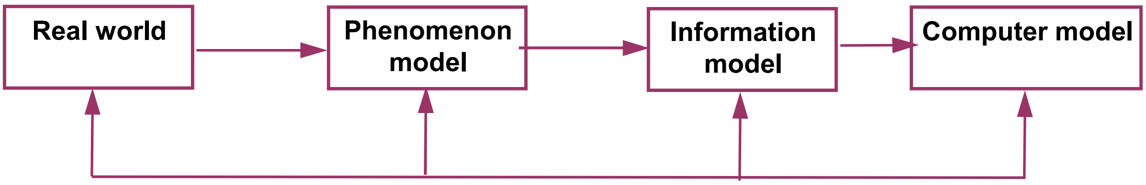

Fig. 3.10 From the real world to an IT system (Duffy, 1995) [1]

So, the first step is that of modelling the phenomenon expressing relevant aspects of the product range and having to be incorporated into the IT system. These models are formalized, then incorporated into the IT system that should further be programmed.

If the phenomenon to be modelled is the product range, then the phenomenon model is called *product model*. This term was first used at the beginning of the '70s , as reference to the development of CAD systems and, in time, has known more definitions. Two of them are the ones that follow.

◘ A product model is defined by a total set of characteristics, defining the transformation, function, organ and component structures of a machine system (Andersen, 1994)

◘ A product model is usually intended to define the various data generated through the product life cycle from specification through design to manufacture (Shaw, 1989).

It should be noticed that the product model it is not just a model of product's structural form but a model of its function, properties and interactions with the life cycle system (design, manufacture, assembly, service).

When the configuration system has to be done, knowledge on product model and its life cycle system have to be known. As example, product specifications sustained by the configuration system must consist in both characteristic data of the product model and characteristic elements of the production / installation model.

Creating a logical structure of the configuration system needs a careful selection of knowledge type on the product and its life cycle system that have to be incorporated into the configuration system. So, there has to be created the frame for product type description, specially, knowing that there are many ways of defining a product range. Some are the ones following:

◘ product structure ⇒ considering how the product is made, as well as its component elements;

◘ product functions and properties ⇒ meaning what the product can do (function) and its characteristics are (weight, surface, price);

◘ product life cycle properties ⇒ referring to the stages of identifying target market requirements, of design, manufacture, assembly, use;

◘ product family structure ⇒ thinking of the structures (modules, platform) that contribute to manufacturing customized products for the market and, meanwhile, represent standard / low complexity solutions used by the company.

Within this frame there are two levels of representing knowledge on the product, mentioned above::

◘ inferior level ⇒ that includes the description of an individual product, of its properties and life cycle;

◘ superior level ⇒ that includes the generic description of a product and its product family and offers knowledge on how a customized product can be created starting on customers requirements.

The configuration system enabling a representation of the customized product and, even a price offer, is based on the product model. This, in its turn, contains knowledge on the whole product family, meaning the product model done at a superior level.

When developing a configuration system it has to be considered the detailing rate of involved knowledge. For example, a configuration system used to work out offers does contain fewer details than a configuration system used to work out the specification required for manufacturing or assembling.

An example of how to use the configuration system for working out the offer regarding a thermo-isolated window (PVC frame and heat treated insulated glass) is evidenced by figure 3.11.

It was used internet connection to the website of Gealan Romania SRL company.

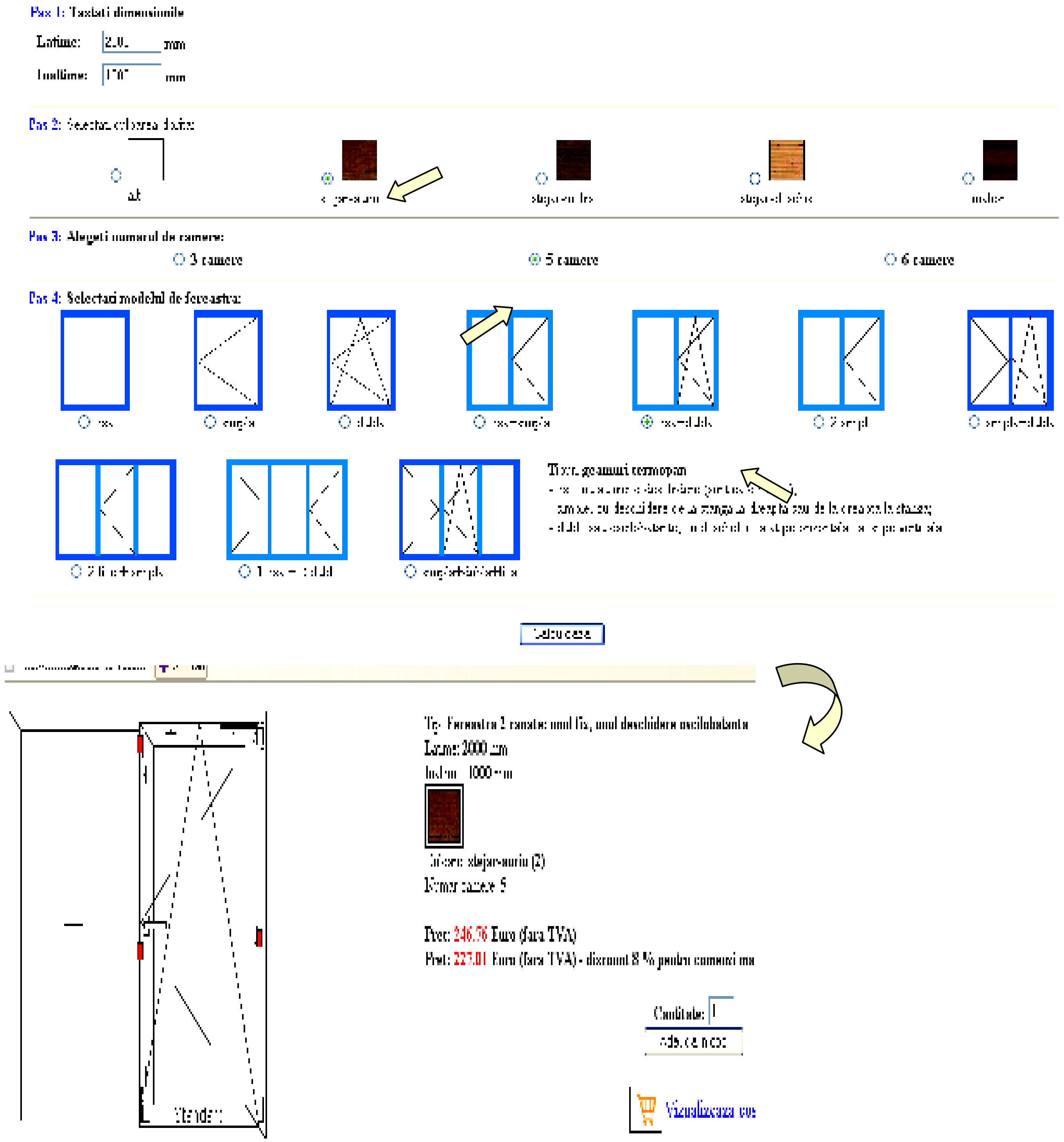

Fig. 3.12 Example of a configuration system for working out the offer – by internet website connection [http://www.gealan.ro]

In conclusion of this chapter, there should be evidenced some aspects, as:

⇒ the importance of correct and complete product specifications;

⇒ the characteristics of specification processes within mass customization;

⇒ the role of configuration system when customized products are involved.

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4. DEVELOPMENT OF SPECIFICATION PROCESSES

This chapter offers a description of how specification processes are developed within a company and how the configuration system is defined so that it should be able to support the individual specification processes.

4.1 Development of the Specification Processes

In chapter 3, there were defined two essential elements of customized products manufacturing, meaning:

◘ *product specification* ⇒ as the complete description of what the product has to do and thus, the needs and / or intentions of a group of people are transferred to another group of people;

◘ *specification process* ⇒ as the business process of: analysing customers needs, creating a customized product tailored to them and, further, of specifying the activities to be done in connection with supplying, manufacturing, assembling, commercialisation and service.

The process of *developing specification processes* is that one involving the next successive stages [1]:

- identifying and characterizing the most important specification processes;
- analyzing the requirements for the specification processes;
- designing the new specification process and defining the configuration system;
- evaluating and choosing the solution;
- working out the action plan and organizing the further work.

.

4.1.1 Identifying and characterizing the most important specification processes

The *business process* represents a structured set of activities whose result is a well defined commercial one. Further attention, in this chapter, is given to the business processes generated by certain needs for a customized product. These processes develop and deal with making specification on how the product is designed and manufactured, on which the transportation conditions should be, or on any other aspects involving assembly, use and service.

Any specification process can be described by inputs, outputs and sub-activities, all of them interacting while the process is on, as schematically shown in figure 4.1.

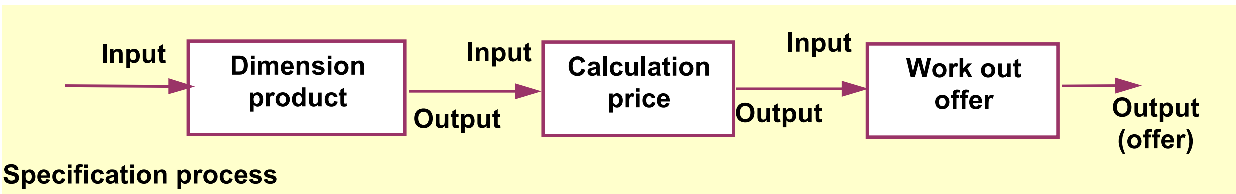

Fig. 4.1 Example of a specification process [1]

It can be noticed that within a specification process, the input (the customer requirements for the product) is transformed by the involved sub-activities into the output (the offer for the customer). Another comment should be on fact that any individual activity can be described by its input, output and activity developed, like the complete specification process it belongs to.

Usually, the activities in a specification process deal with registering the information (customers requirements), storing and checking the information, calculation, simulation, making the documents. In fact, as many times a specification process is usually identified by its output (the generated specifications), there can be mentioned the typically specification processes as the ones that follow.

◘ Working out the offer ⇒ can be done in many stages, first an approximate one and then an accurate one, worked out after the complete specification of the needs to be fulfilled by the product.

Usually, the offer contains both the specification of the product to be offered – as text, schemes, drawings, process diagrams, and the specifications received from the customer, payment and delivery conditions, product price.

That is why, working out the offer is an important part of company's activity, as its employments from sales department do spend a lot of time for this. The quality and accuracy of an offer are essential in getting the desired order.

◘ Detailing product specification after the order is received ⇒ if a complex product is involved, once the offer accepted, the product specifications have to be detailed – as drawings, list of components, calculi of certain characteristics (strength, weight, surface properties), etc.
Compared to the initial specifications (when working out the offer), these post-offer specifications are more detailed and generate the basis of further activities on planning, manufacturing, service, maintenance.

◘ Specifying the properties of product life cycle ⇒ means working out specifications on how the customized product is manufactured, assembled, transported, serviced and, even, recycled.
These specifications can be considered as a description of product interaction with the system of product life cycle. As examples there can be mentioned the operation plan (detailed describing the operations required for manufacturing), the assembly instructions and the service manual.

All activities involved in a customized product specification process can de done only by the correlated work of the employers from different company's departments (sales, product development, production). Also, their should be a good collaboration activity with customers and suppliers. Thus, there is a transfer of activities from one department to the other and, consequently, there is a transfer of responsibilities, all of these resulting in the fact that eventual errors are identified late and repaired with a lot of effort and high costs.

So, working out product specifications can be efficiently done if specialists in various fields do cooperate well. There are the product development engineers (must agree on product configuration), the production engineers (has to establish the manufacturing specifications), the sales manager (responsible for an attractive offer), etc., who have to make a good work together.

Because, as stated above there are a lot of people involved, in different places, it takes a long time to complete the specifications for a customer order (possible four weeks), even the real time needed could be very short (possible four hours).

Analysing the specification processes, from the customer point of view, there has been noticed that all the activities involved can be divided in two categories, one of *value adding* activities and the other of *non value adding* activities.

A value adding activity is that one contributing directly to obtain the product according to customer's needs and expectations, being of value to the customer. So, when considering product specifications, some value adding activities are: the analysis of customer's needs, the modelling and simulation of various customized products, the working out of product's drawings and list of components, etc.

A no value adding activity is the one that does not contribute to satisfying customer's needs and, theoretically, can be replaced without a change of product value. Examples can be considered as: checking on received specifications, selecting and correcting errors, getting further more detailed information from the customer, etc.

The reason for a large number of non value adding activities in specification process, could be the poor quality of specifications generated in the early stages of the process, the missing of correct information, the lack of process overall view, an inadequate IT system, or, even, a confused product assortment.

A fast and efficient way of differentiating the value adding from non value adding activities is that of answering the question: "Would the customer pay for this activity if it were explicitly mentioned on the bill ?".

There is always a customer when specification processes are involved. He / she can be either one of company's customers – receiving product's description, price information, delivery conditions, etc or, one of company's employers / suppliers – using specifications to organize supplying, production planning, transport, service activities.

Thus, the starting point for the development of specification processes is represented by the identification of the type of customers it should be addressed to. So, for a company's customer, the specification can be brochures, order confirmations, user instructions, etc. For the other type of customers, specifications refer to manufacturing, delivery, service and can be as:

◘ drawings and list of components worked out as result of customer order ⇒ used in manufacturing, assembly, installation or service activities;

◘ list of operations with estimated time consumption ⇒ required by production and planning departments;

- assembly instructions ⇒ to be used by everyone dealing with product's assembling;
- service manuals ⇒ dedicated to the ones ensuring company's products service.

It can be noticed that many of the subsequent processes developed within the company, or within company – customer and company – supplier interactions depend on the specifications worked out in each of the individual specification processes.

That is why a specification process must be described so that it fulfils some of the next specific objectives:

- offering an overall perspective on the most important activities;
- evidencing the activities sequence and inter-correlation;
- identifying the people having responsibility and their role in individual activities;
- defining the inputs and outputs, as well as the information flow within the process.

In addition to the above presented it is necessary to be mentioned the means used for sustaining the specification process, meaning data base, configuration systems, printed information on company's products.

Parallel to the specification process description, a short presentation and characterization of the most important problems associated to the process have to be done. For example, the existence of many cases when responsibility transfer can not be avoided, or more control activities should be involved, or miss-function in information transfer has been proved.

4.1.2 Analyzing the requirements for the specification processes

Once the most important specification processes identified, the next step in its development is that of clarifying the requirements to be mentioned. These requirements are generated either by company's environment (customers, suppliers, authorities), by company's departments functions (planning, production, assembly, service), or by other specification processes – as shown in figure 4.2

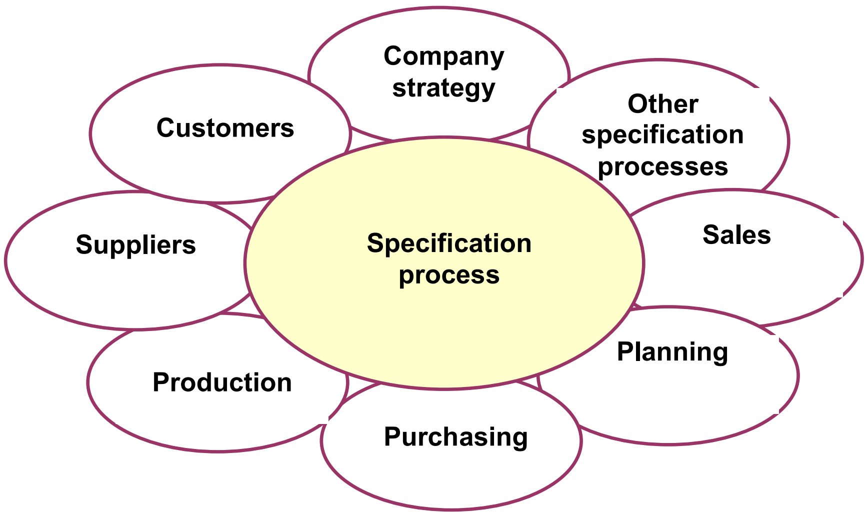

Fig. 4.2 Specification process environment [1]

So, it can be noticed that the starting point in analyzing requirements is the company's strategic plan and the commercial targets mentioned when referring to profits, product strategy, delivery capacity, etc. It is also important to clarify the requirements on company's ability to produce and offer customized products.

For specification processes identified as the most important, it is the problem of defining the targets that are critical in achieving the proposed objectives. As example, for the working out offer process, a critical target is that the difference between the price in the offer and the post-calculated one, to be less than a certain percent (5%).

There are five target types characteristic for the specification processes in a company, as mentioned next.

◘ Lead time for producing specifications ⇒ it is the time interval starting with the moment when the specification process is initiated and ending with the moment when the specification is available.
Many times, the ability to react fast to the market needs – meaning low value for the lead time, it is essential for winning an order. That is why the company must have a product configuration system to allow registration of all customers requirements on the product and, meanwhile, to generate offer and production specifications. So, the lead time can be reduced and improved quality specifications can be offered.

In fact, a high value of the lead time can suggest the existence of problems within the process, such as changes of responsibility, unclear instructions, or lacking product documentation.

◘ On time delivery for specifications ⇒ it is defined as the number of specifications out of the total number of specifications that are completed within the agreed time span.
The specifications are very important as they do represent the basis on which customers of the specification processes can do their work. For example, the production engineer can work out process specifications when drawings and list of parts are available but, production can start when all product and production specifications are available.

Any delay in finishing specifications determines delay in further processing and, that is why it is essential that they should be available at the established time.

◘ Resource consumption and frequency ⇒ the frequency of individual specification activities compared to duration of individual specification activities points out where the highest resources consumption in the specification task is and where uniform tasks are executed with high frequency.
Evidencing the way of how resources are used and the uniform consumption, high frequency activities can be done by a study on the activities involved in specification processes. This can be a frequency study that points out how much of an employer's work time is allocated to accomplish a task – defined by specification result, or specification activity.

Once determined the frequency of a certain activity and its corresponding time consumption, conclusion can be formulated on how resources are used in the specification process and on which are the high frequency constant activities.

It is table 4.1 that presents specification process activities and their correspondent time consumption, just to point out resource consumption and frequency.

Table 4.1
Time consumption and frequency of work activities in a specification process [1]

	Product element			
Activity	**Component 1 in product family A**	**Component 2 in product family B**	**Component 1 in product family C**	**etc**
Prouduce list of parts	2 hours, 200 times a year, In total 600 hours			
Produce list of operations with time		1.5 hours, 250 times a year, In total 375 hours		
Produce assembly instructions			4 hours, 30 times year, In total 120 hours	
Etc.				

◘ Quality of specifications ⇒ it can be considered from many points of view, some mentioned next.

One is that regarding their clarity and possibility to be correctly understood. It involves how the specification is transferred to the one receiving it, meaning a complete an non-ambiguous description of the customized product characteristic.

For example, if the central element of the offer is correctly understood by the customer, or if the production engineer gets a clear image on the component elements drawings that represent the basis of further product manufacturing.

It is rather difficult to appreciate quality specification this way, as it is subjective and depends on the experience and expertise of the person receiving these information.

Another aspect of specification quality is that referring to the number of errors, evaluated by the proportion of specifications containing errors.

It is considered to be an error the one that if not discovered in time, leads to manufacturing of wrong customized products.

◘ Optimizing products ⇒ both from the customers point of view and from the cost, maintenance and / or service perspective.

One factor with good influence on product optimization is the configuration system associated to it. This is because an efficient designed configuration system enables modelling and simulation of different product variants that satisfy customers needs.

So, once the optimum customized product configuration settled, the sequence of activities for its production can start.

Figure 4.3 presents an example that points out the benefits of using an adequate configuration system. So, when estimated costs for purchasing, installation and service have been considered, the allocated and realised costs were almost the same.

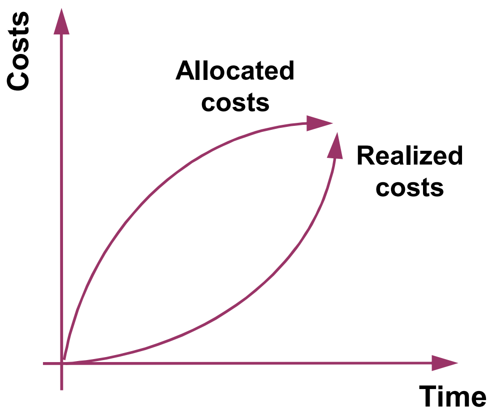

Fig. 4.3 Allocated and realized costs [1]

A thorough research on the consequences of product's use makes possible its configuration according to each of the life cycle stages. So, the customized product can be optimized from the manufacturing, materials costs, ability to be used or repaired points of view.

Many times, the targets of important specification processes must be defined according to business general strategy of the company. This targets do represent the basis of an activity if they are operational and measurable, meaning they can be quantified and formulated so that ulterior measurements and control of how they were achieved to be performed.

The specification process is considered to be of performance if the target and the existing performance are identically or, more realistically, if they are very close. In other words, a gap analysis of the specification processes should be done and thus, it would be determined were the largest gap between target and performance is.

An example of performance evaluation for specification processes in a company producing doors is shown in table 2.

Table 4.2

Targets and current performance [1]

		Target	Current performance	Gap
Delivery time	- standard doors - special doors (customized)	3 weeks 10 weeks	6-8 weeks 10 weeks or more	3-5 weeks
On time delivery	- standard doors - special doors (customized)	95 % 90 %	50 % 50 %	45 % 40 %
Quality - doors delivered with faults (%)		2 %	20 %	18 %
Turnover		10 % growth per year	stagnating	10 %
Profit rate		10 %	( ) %	(6 ÷ 10) %

4.1.3 Designing the new specification process. Defining the configuration system

Once the most important specification processes have been identified, there is the next step, that of designing the new specification processes and designing the required configuration system.

An efficient way of having new specifications is to consider relevant aspects, as:

- the targets to be achieved by the new specification process;
- the greatest opportunities for developing the specification process;
- the specification work to be done;
- the degrees of freedom and flexibility required by the specification process and the configuration system;
- the detail degree fitted for the specification process;
- the product knowledge considered in the configuration system;
- the efficient and correct customer interaction by the configuration system;
- the continuous innovation of the product and an up to date specification process.

So, there will be many ideas of how to use the configuration for producing product specification and all of them should be further summarized as scenarios for developing new specification processes.

The proposals for a new specification process can be described by explicitly defining the inputs (list of information for specifications), the outputs (list of described specifications, as: offers, list of operations with time consumption) and the information to be specifically generated for the individual order.

As for the configuration system, it is necessary to establish the specifications generated by it and who is responsible for producing them. For its correct and complete definition, there should be considered some essential elements, as:

- the purpose of implementing the system;
- the correct description of the specification process to be supported ;
- the configuration system's inputs and outputs;
- the user's interface;
- the integration with other systems;
- the system's functionality – which are the "need to have" and "nice to have" functions;
- the knowledge to be incorporated;
- the number of users.

Defining the configuration system's objective starts from defining its inputs and outputs. For example, the inputs can be described by defining the screen images for typing in product information and by defining the integration with other IT systems, or programs that might offer deliver inputs to the configuration system. It is also important to define the calculations performed by the system and how it can deliver the expected output.

An useful idea for describing the configuration system is that of modelling the product family, defining the modules to be used / changed and establishing the detailing degree to be used.

4.1.4 Evaluating and choosing the solution

The evaluation of individual scenarios for new specification process development and the implementation of its supporting configuration system are based on the commercial advantages and disadvantages evaluation.

So, the scenarios are first evaluated with respect to their contribution in achieving the targets set for the specification process.

Then, another evaluation is that of the costs incurred, meaning partly, the projects costs associated with changing the specification process and implementation of the configuration system to support it, and partly, the running coasts for operating the specification process.

Finally, there is the risk evaluation for each of the individual scenarios proposed. As a product configuration system is involved, mainly, there are three types of risks, as stated below:

- risks associated with developing ⇒ difficulty to access information on how to develop the product model, low interest of company's members towards the system, impossibility of implementing some parts of the product model in the configuration system, high volume and complexity of the system;
- risks associated with deploying and using ⇒ not good training of the configuration system's users, errors of the system as it had not been sufficiently tested, lack of motivation for the user;
- risks associated with maintenance and further development ⇒ neglect for a suitable system's documentation, the staff is not committed in maintaining and further development of the configuration system; no interest for the company in maintenance and further development

The evaluation of the greatest risk is important and, thus, all the necessary actions must be done to avoid and minimize it, before initiating the configuration system's project.

A configuration system project's risk can be reduced (Kotter, 1996) by following a systematic procedure, by using professional project management and, finally, by using principles for change management in order to handle the organisational changes which take place as result of developing and implementing a configuration system.

4.1.5 Working out the action plan and organizing further work

Once the scenario has been chosen, the plan of action for its development must be worked out. This plan contains the description of the tasks to be performed, the specification of the needed resources and the organisation of the work to be done.

Some of the tasks to be performed, in addition to the development of specification process and introduction of the configuration system, are mentioned next:

- to analyse and model the product range;
- to determine the work procedures in the specification processes;
- to define the inputs and outputs of the configuration system;
- to integrate the configuration system within other company's systems;
- to program the product configuration system and its user's interface;
- to test the configuration system;
- to train experts for developing and maintaining the system;
- to further develop the specification process and the configuration system.

For each of the above tasks there have to be mentioned the aspects involved, meaning: who does the work, what is the estimated time consumption, when does it start and when does it end. Also, the company should offer all the needed support by managing and involving the right people, by ensuring a good customers interaction, so that their needs and expectations from the configuration system could be correct evaluated.

The action plan and project management should be focused on those parts of the project where the risk of not fulfilling the targets can be anticipated. Getting to them is the answer to the question on the most difficult obstacle in the project.

If there is a first time for the company when a product configuration system is introduced, then high attention (time and money) should be given to the training on company's products configuration technology, or to the learning about organisational changes occurring when a configuration system is used.

For an efficient operation and maintenance of the specification process and the supporting configuration system, measurements of the process performances are worth be done. So, the commercial advantages would be pointed out and, more, if the targets are missed, the possibility of an early intervention so that to correct the errors is available.

4.2 Example of Specification Process Development

◘ Identifying and characterizing the most important specification processes

Let's consider company X, that produces doors for hotels, schools, and industrial buildings. The doors are produced as customers require, in many variants of different dimensions, isolation systems, locking systems, materials and colours.

Many times customers were not satisfied by the long delivery time, the high price and the existence of fabrication faults in the ordered doors. The employers in the sales department blamed their colleagues in the production department for the long delivery time, while the last ones said that people in the sales department did send them customers orders with a lot of errors. So, it was a responsibility sharing between sales and production departments and nothing could be change for improvement.

A careful analysis carried out by the company's manager and a consultant evidenced the fact that it was the problem of the business process where both customer and production process are involved. More precisely, it was a problem of the doors specification process, as it was a poor description, without a clear definition and delimitation of the product types, meaning the standard door and the special doors, whose specifications were most alike.

In order to identify the most important specifications, there were first analysed those regarding the working out of the offer and the order, as mentioned below.

⇒ When working out the order, the employers from sales department fill in data on customers address, delivery address, dimensions of the building the door is made for and customers requirements. The customers fill in data on dimensions, material, colour, windows position, accessories.

⇒ The offer has specifications on how big the building is, door's dimensions and material, isolation, price, delivery time, payment condition and, even has a sketch of the door.

⇒ Order's confirmation has both company's accept and delivery time.

⇒ In the designing department there are made some sketches of the doors with dimensions mentioned.

⇒ The list of component elements and the list of required operations are completed, as well as the estimated time consumption.

⇒ The production order has the specifications on doors components, how they are manufactured and the delivery time.

⇒ Installation instructions have information on doors dimensions, as well as those of the building it is installed to. They do also mention the sequence of steps for doors complete installation.

It could be noticed that many of the existing specifications have similar information – as example it is the production order, on one hand, and the list of component elements and required operations, on the other hand. That is why the specification process was changed, so that depending on the required door's dimensions there are worked out the lists of operations sequence, estimated time consumption, component elements, etc.

So, after receiving the order, the customer gets an offer mentioning the delivery address and time, the price, the specifications on building dimensions and door's characteristics (accessories, openers, glass), the delivery conditions and offer validity

If the offer is accepted, then the order is launched for production and the departments of product development, manufacturing, purchasing do become involved.

In conclusion, it can be stated that the long delivery time and doors poor quality were determined by deficiencies in the specification processes, the most relevant being the one that follow:

⇒ it was too much responsibility sharing within company's employers and many errors whose origin was hard to establish appeared;

⇒ there were not well defined rules for designing the door, many decisions being left for employers;

⇒ the product was not completely defined, as it was aimed to be easy customized and, many times people from the deign department had to decide things for a complete definition of the customized door;

⇒ it was not clearly distinguished the difference in the concepts of standard door and special door.

So, once analysis done and all necessary changes made, the most important specification processes resulted in:

⇒ working out the offer for standard doors;

⇒ working out manufacturing specifications for standard doors – list of components and their drawings, list of operations and estimated time consumption, installation instructions;

⇒ working out offers for special / customized door - list of components and their drawings, list of operations and estimated time consumption, installation instructions;

◘ Analyzing the requirements for the specification processes

The requirements analysis in company X, proved out the fact that there was no consensus on the targets to be reached. So, the employers in production department considered the target to be a non error and in time specification, while the people in the sales department thought that offering customers the required doors, with an attractive price and delivery time was their target.

As it was impossible to solve the problem within the company, a further step was that of interviewing the customers on their expectations from the company. The result was their wish of having the doors delivered as fast as possible and in time, while the quality and price should be similar to those of other similar companies, if possible, even lower prices.

Based on the measurements of company's performance and interviews results, the targets for the specification processes have been established to be: the lead time reduction, the delivery date (for on order and production specification) to be as agreed, the offer quality to be improved, the time for specifications work out to be reduced.

There have also been defined significant factors in the development of the specification processes, as the ones mentioned next:

⇒ establishing the product concept, meaning the estimation of a future period (5 to 10 years) when no important changes in doors construction and manufacturing are expected to be;

⇒ the ability of specification process to allow analyzing and planning, by a set of relatively simple rules on designing a certain door variant (dimensions, accessories, locking systems) and its required operations, as well as on time consumption.

◘ Designing the new specification process. Defining the configuration system

Reaching the targets in a new specification process involves organizational changes within company and how this could be done is simulated by three development process scenarios (S1, S2 and S3).

<u>S1</u> : Improvement of how the order is worked out – by specialising the personnel and a clear definition of differences between standard and special / customized door

<u>S2</u>: Development of a configuration system that, right from the very beginning (in sales department), to enable doors' dimensioning, listing of component elements, calculation of time consumption, working out the offer, presentation of installation instructions. This should be a data base containing about 500 drawings of the doors, costs of specific materials and accessories, etc.

The inputs of the configuration system are the data on door's dimension, material option, colour and are introduced by the sales department employers. The configuration system contains both a structural description of the doors, including the reference to heat waste, corrosion resistance and knowledge on how their manufacturing and installation procedures. All of these can be done by system modelling.

<u>S3</u>: Development of a more complex configuration system that enables 3D representation of doors (dimensions, component elements, etc.) and is integrated with the company's IT system – thus, being able to use its data base.

◘ Evaluating and choosing the solution

All of the three scenarios were evaluated from the commercial advantages, involved costs and assumed risks points of view. This is how, some interesting aspects have been noticed, as follows.

⇒ S1 scenario results in modest effect, while the S2 and S3 scenarios determine significant effects on the established targets, the S3 one being more spectacular and efficient.

⇒ The magnitude of costs involved includes the honorarium of company's employers, that of the consultant and the software cost, thus it results the hierarchy of scenarios as: S3 > S2 >> S1.

⇒ The risks involve both the specification processes and the development of the supporting configuration system, as well as their implementing, operation and maintenance. So, for each of the scenarios, the estimations are mentioned below.

- S1 – there is the risk that company's employments consider the project a threat, as it is aimed to make them work and produce more in the same time;
  - it is rather difficult to develop a new specification process, valid and reliable on a long shot ;
- S2 – there is the risk on the development of configuration system so that to enable doors dimensioning;
  - there is also the risk of some company's employers not willing to use the system as they think it could affect their jobs.
- S3 – there is a high risk from technical point of view, meaning: incorrect system's integration to other IT systems, low ability of working out doors 3D drawings, designing non-technological component elements that are impossible to manufacture;
  - the employment from sales and order launch departments are very reticent in using the system.

The overall conclusion is that scenario S2 was considered to be the best.

◘ Working out the action plan and organizing further work.

In order to introduce and develop the new specification process and its supporting configuration system, the gradually programming and testing of its components have been done. Also, the employers from sales and order launch departments were involved and all the necessary resources allocated.

Towards the end of project, after the specification processes and configuration system became operational, further action involved:

⇒ measuring performances when reaching the targets;

⇒ analysis of data from the development department, for up-dating the product model, as well as the configuration system;

⇒ maintenance of product model and configuration system;

⇒ establishing a continuous dialogue with the users of configuration system and its continuous adapting to present requirements.

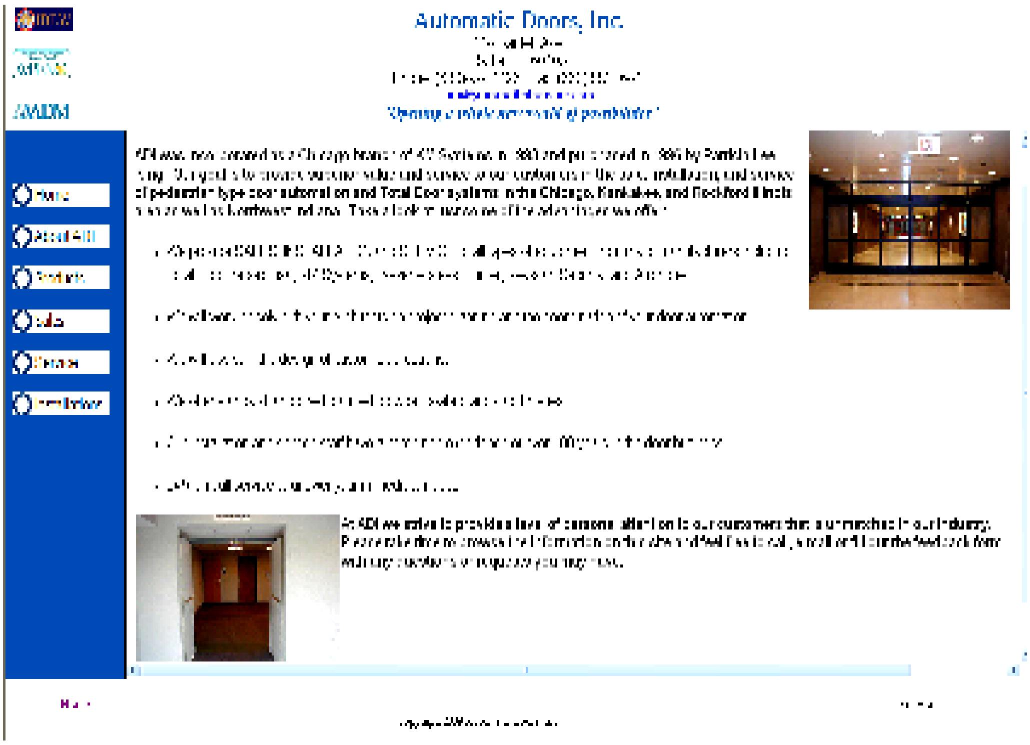

Fig. 4.4 Company's presentation [http://www.automaticdoorsinc.com]

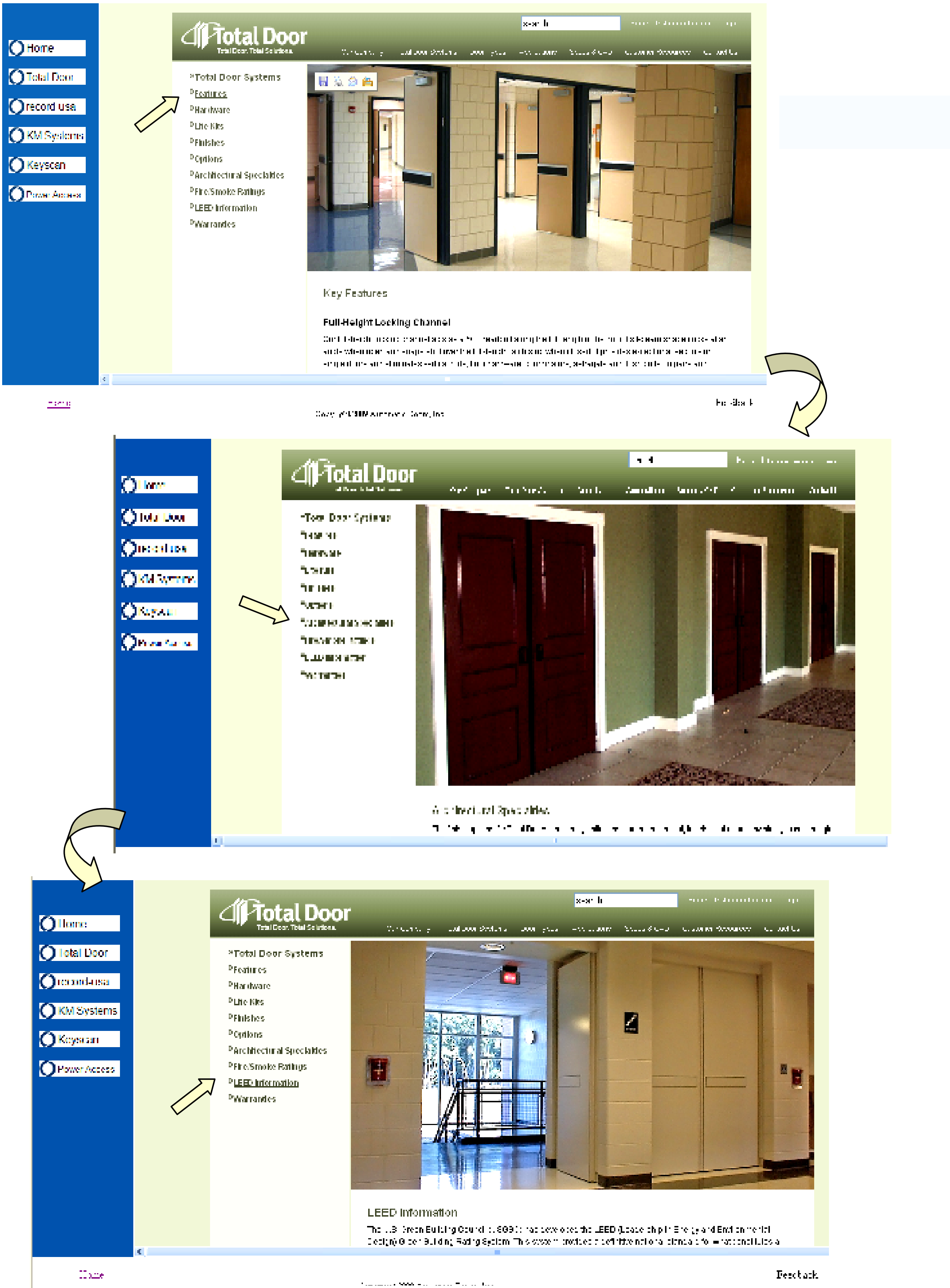

Fig. 4.5 Using the configuration system
[www.automaticdoorsinc.com]

An example of the specification process and its supporting configuration system, available on the website of Automatic Doors, Inc. is shown in figure 4.4 (general view) and figure 4.5 (how it works).

Summarizing all the above mentioned, it should be stressed on the importance of the five stages in the specification processes development. Also, measurements of the process performances are worth be done, so that an efficient operation and maintenance of the specification process and the supporting configuration system to be possible.

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5. RAPID PROTOTYPING AND RAPID MANUFACTURING

The product manufacturers do compete nowadays in bringing to market new, high performance and short time delivery products. Thus, the processes involved in development of a new product – design, manufacture, testing, market launch – have been "compressed", from the points of view of both time consumption and material resources.

It was possible to do the above mentioned, as result of manufacturing means and technologies spectacular evolution, where computer and specialized software are very important..

5.1 Prototype and Prototyping

A prototype's role in the product development process is very important and many times it is associated to product designer's activity. Along time, the term was used when referring to both the activities involved in making the prototype, as a physical object and to the product itself .

The Oxford Advanced Learner's Dictionary of Current English defines the *prototype* as "the first or original example of something that has been, or will be copied or developed – it is a model or preliminary version". Another definition of the prototype is that of "an approximation of a product (or system), or its components, in some form for a definite purpose in its implementation" [1].

As it can be noticed, the term of "prototype" refers to physical objects, as well as to abstract ones, some examples being that of the physical approximation of a product, drawings (2D / 3D), mathematical models, etc.

The general definition of a prototype contains three aspects of interest, meaning [1]:

- implementation ⇒ from the entire product (or system) to its sub-assembly and components;
- form ⇒ from a virtual prototype to a physical one;
- degree of approximation ⇒ from a rough representation to an exact replication of the product.

Further description of these aspects is presented next.

- Implementation of the prototype includes all actions taken for prototyping the whole product / system, or prototyping only one part of it, or of some product's components.

When prototyping the whole product – usually full-scale, it is possible to model most of its characteristics. This prototype is generally used, in studies / tests performed on groups of people interested in using the product. So, possible designing and functional errors could be identified and avoided in the final product.

Prototyping certain parts or components of the product is useful when there is an interest only in the design and exploitation behaviour of that part –supposed to need special attention. Many times, the sub-assemblies or component elements are tested with some kind of test rigs, or on experimental platforms.

- Form of the prototype refers to the way of how it is being implemented.

This can be virtual – as, for example, the mathematical model associated to a control system, and based on the assumed hypotheses and the knowledge existing in the field. The virtual prototype is used when a physical prototype for the product is difficult to be obtained - because of too high costs, or large product's dimensions.

Disadvantages of using a virtual prototype involve the lack of product's behaviour evaluation when some real, unexpected, not hypotheses assumed exploitation conditions do occur.

The physical prototype do represent something real, to be touched, and is generally used when products testing / experimenting must be done.

- Degree of approximation means the accuracy of representing the real product by the prototype. It can be rough or exact.

The rough representation is a good one for the early stages of product development, when an evaluation of product's dimensions and space required is needed. Many times, this rough form can differ much from the final form.

The high degree of approximation, mean an exact, full scale representation of the product and, mainly is fitted for the end stages of the product development process. For example, the pre-production prototype models every aspect of the product and can be used for the evaluation of both customers needs satisfaction and manufacturing concerns.

Schematic representation of all the aspects mentioned above is shown in figure 5.1

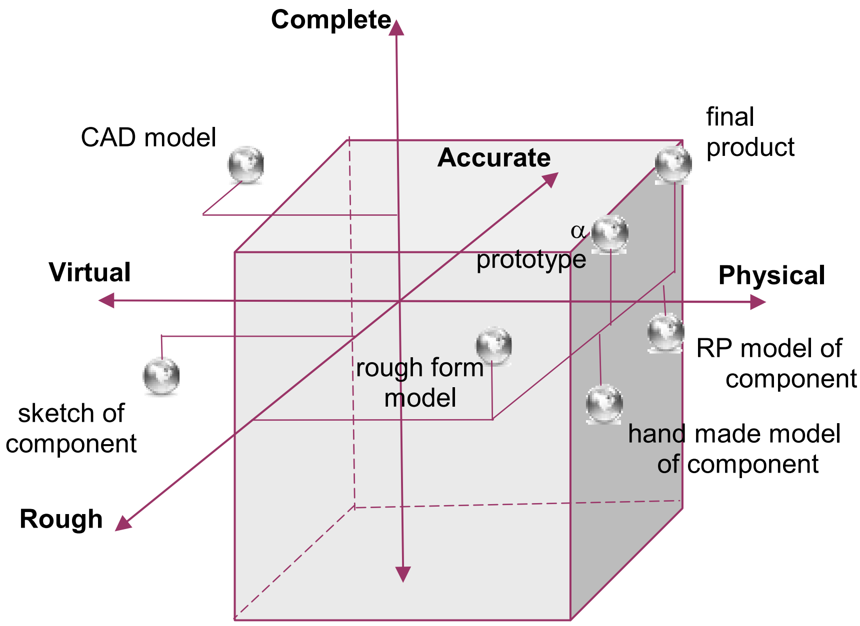


Fig. 5.1 Types of prototypes described along the three aspects of implementation, form and approximation [1]

Within the product process development, a prototype has different roles, some of them being mentioned next [1]:

- experimenting and learning ⇒ by using it in conception and designing activities,
- testing and proofing ⇒ when it is used for checking and demonstration of product development's specific ideas and concepts;
- communication and interaction ⇒ as it is mean of transmitting information and ideas communication, both in product development stages and in management activities, as well as in customers interaction;
- synthesis and integration ⇒ by materializing the whole product concept and bringing the various components and sub-assemblies together and check if they do work correctly;
- scheduling ⇒ as, usually it is used as markers for fir the end or start of different stages in the product development process – that is because, each of the prototypes may represent the completion of a certain product development stage.

In fact, may companies consider that there should be a further product development stage if the prototype for the current stage does proof the fulfilment of all product's requirements for it.

Prototyping is the process of making prototypes. It has been known from ancient times, its original meaning being that of making models.

As, the goal of a physical prototype is that of conceptualizing product design, usually it has to be obtained before production launch of the product.

Generally viewed, it is an impressive time evolution of prototyping, some of its most important moments being the one that follow [1].

- Manual prototyping ⇒ initiated when the first tools appeared and nowadays being considered the first stage in prototype development. Making a prototype, usually takes about 4 weeks, depending on how accurate it is and it does involve a lot of work.

◘ Virtual or soft prototyping ⇒ started in mid ‘70s, correlated with the apparition and development of computers, software (CAD, CAE, CAM) and computer aided manufacturing techniques. The models obtained by computer are tested, analyzed and changed as if they were physical ones.

So, the products and their prototypes become more and more complex and, accordingly to it, the time for making them is very long. This is because, despite the CNC machines that make manufacturing easy enough, the time consumption involved is really high.

The major disadvantage of virtual prototyping is that prototypes can not be tested if the conditions are different than the ones anticipated or simulated by the software used.

◘ Rapid prototyping ⇒ have been continuously developing since the ‘90s, and represents the process of obtaining solids by successive deposition of material layers. The obtained parts are very complex and the time required for prototyping is relatively low (hours).

The relationship, as well as time evolution, of geometric modelling and prototyping are evidenced by table 5.1

Table 5.1

Parallel between geometrical modelling and prototyping [1]

Geometric Modelling	Prototyping
2D Wireframe - started in mid ’60s ; - were drawn straight lines or plan sketches of the components; - ”natural" drafting technique	Manual prototyping - traditional practice for many centuries ; - prototyping as skill craft in : → traditional and manual ; → based on prototype’s material; - ”natural" prototyping technique
3D Curves and Surface modelling - started in mid ’70s ; - increasing complexity ; - representing more information on precise shape, .size and surface contour of parts.	Virtual or soft prototyping - started in mid ’70s ; - increasing complexity ; - virtual prototype can be stressed, simulated and tested with exact mechanical and other properties .
Solid modelling - started in early ’80s ; - edges, surfaces and holes are knitted together to form a cohesive whole; - computer can determine the inside of an object from the outside, can trace across the object and readily find all intersecting surfaces and edges ; - no longer ambiguous, but exact	Rapid prototyping - started in the mid ’80s ; - benefits of a hard prototype made in a short time (by CAD modelling) ; - hard prototype can be used for limited testing; - prototype can assist in the manufacturing of the products.

5.2 Rapid Prototyping – Definition and Characteristics

Depending on how materials are processed to obtain the final part, *manufacturing processes* can be divided into three major categories as follows.

◘ Subtractive processes ⇒ were the rough part’s dimensions are greater than that of the final part. While the process is on, the required shape and dimensions are obtained by removing the material – in conventional cutting processes (turning, milling, grinding, etc.) or in non-conventional processes (electro-discharge, electro-erosion, laser engraving, etc.). Many of the above mentioned processes are computer aided, meaning the machine used are CNC machines.

◘ Additive processes ⇒ where the final part’s dimensions are greater than that of material’s the process starts from. The material is handled so that successive layers are added until the whole solid final part is obtained.

Relevant processes of this kind are the rapid prototyping processes like stereolithography, selective laser sintering, 3D printing, etc.

◘ Formative processes ⇒ the rough material is deformed under mechanical pressure and / or restricting forms until the required shape and dimensions of the final part are obtained.

As example there can be mentioned pressing processes, such as die pressing, deep drawing, extrusion, etc.

The schematic representation of these processes categories is evidenced in figure 5.2.

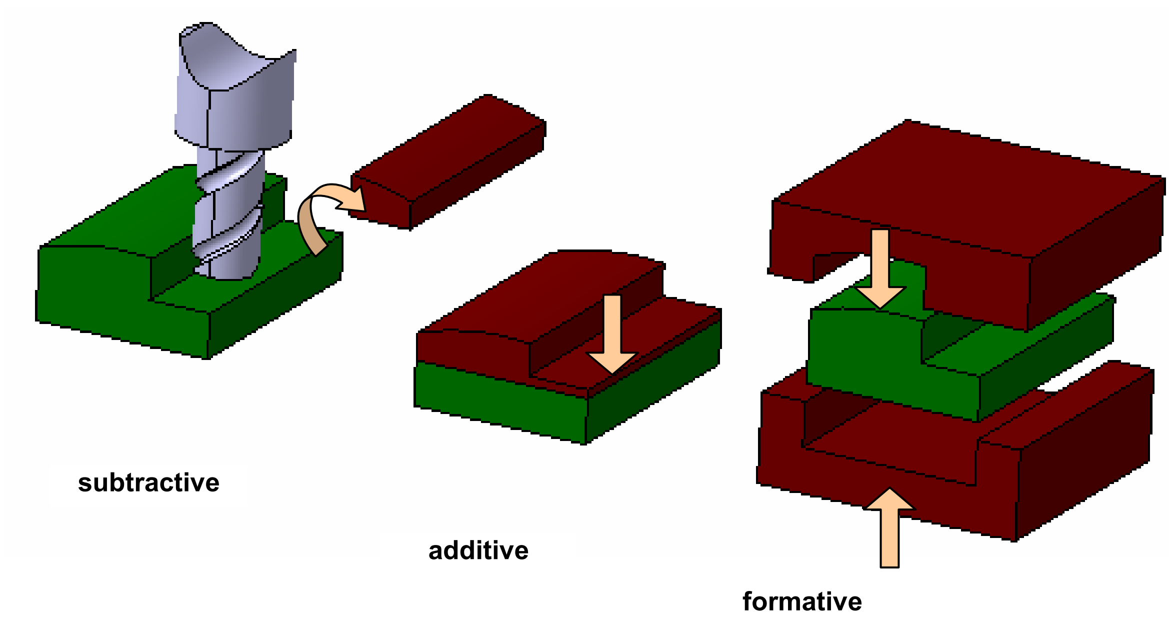


Fig. 5.2 Types of the manufacturing processes

Rapid Prototyping (RP) is the automatic construction of a physical object using solid freeform fabrication or, similarly, using additive manufacturing technology. This technique involves the sequential generation and directing of energy and / or material towards well defined spatial points, so that the solid physical object to de constructed successively layer by layer [http://en.wikipedia.org].

As it is an additive manufacturing technology, in rapid prototyping, the virtual designs are taken from CAD or animation modeling software and transformed into thin, virtual cross-sections. Each of them is successively physically generated, one after the other, until the whole model is complete. So, the virtual model and the physical one are almost identical and the process is a WYSIWYG process, meaning a What You See Is What You Get process.

There is an big difference between having the prototype obtained by rapid prototyping process (successive layer deposition) and by classical manufacturing process (successively removal of material layers) By rapid prototyping there can be obtained objects with almost any geometrical complexity, without the need for complicated systems to adjust the machines. Many times, there is not even the need to assembly the component elements as, the whole product is constructed in one “shot”.

This is how, manufacturing complex and unique products becomes an attractive and easy to manage process, done in a relatively short time.

As result of all the above mentioned aspects, there can be evidenced the main stages of rapid prototyping process, as the next ones:

◘ modeling the physical object ⇒ by CAD software, so that it results in a close volume;

◘ transforming the virtual model into a STL file ⇒ as it is the file recognized by the prototyping machine software;

◘ analyzing the file by machine software ⇒ checking if all the model’s surfaces are closed ones and then slicing it into thin cross-section that should further be:

- systematically recreated by solidifying the material (initially liquid or powder) and combined so that the 3D model to be obtained, or
- transferred onto thin layers of adhesive-coated sheet material, stacked bond and cut on top of the previous one, until the 3D model is completed.

The process chain of a rapid prototyping process is shown in figure 5.3.

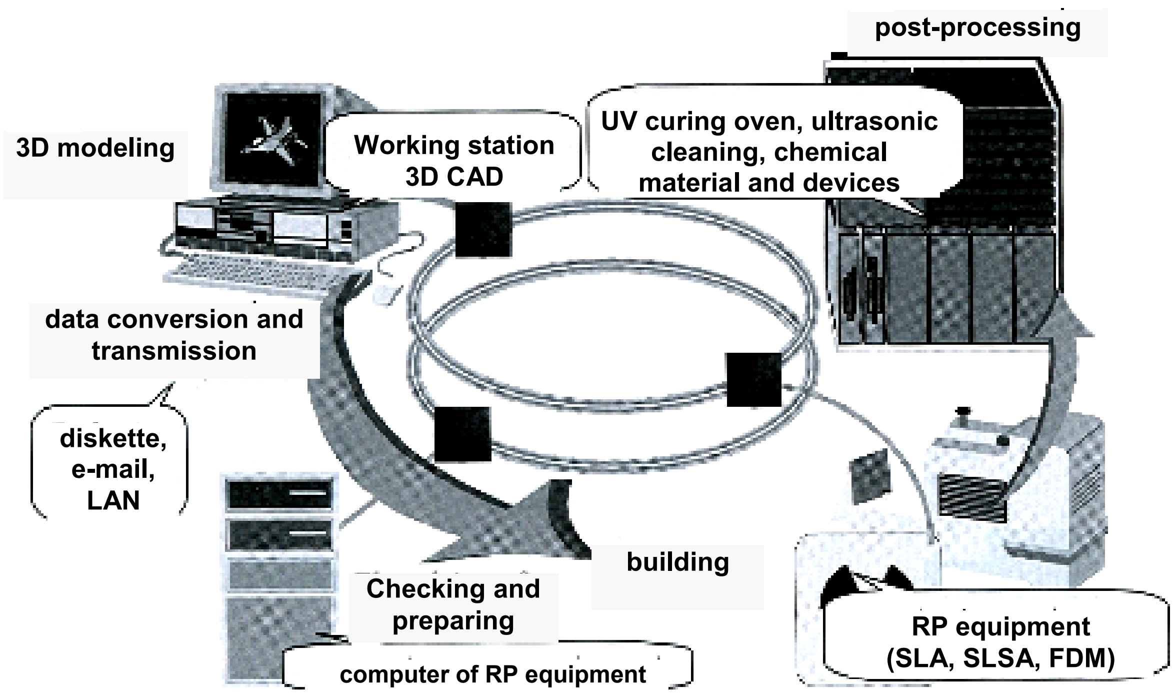


Fig. 5.3 Process chain of Rapid Prototyping process [1]

The development of a rapid prototyping process is based on four major elements, mentioned below.

◘ Entrance ⇒ means the electronic information associated to the 3D description of the physical object. It can be either a CAD model or a physical model – in this case a data acquisition system has to be used for model's reconstruction in a CAD system. This is the so called Reverse Engineering technique and requires special equipments, such as coordinate measuring machine or laser digitizer.

◘ Method ⇒ it is specific to rapid prototyping systems producers and for the most cases involves one of the following: photo curing, cutting and bonding, melting and fusing, bonding.

◘ Material ⇒ the initial state can be solid (granules, wire or laminated), liquid or powder, while some material types are: paper, nylon, was, resin, metals, ceramics.

◘ Application ⇒ there is a wide spectrum of fields for the prototyped products to be used, the well-known ones being:

- design,
- engineering, research and planning;
- tools and products manufacturing.

Mainly, there is an industrial application, such as: aerospace, automotive and biomedical products or consumer product goods.

In rapid prototyping the generated benefits are usually divided into direct benefits and indirect benefits.

It is the ability of manufacturing high complexity products, in a short time, that generates *direct benefits*. These have various impacts on company's activity, depending on prototype's role in the product development process.

Example of the benefits generated by rapid prototyping in the production stage are shown in figure 5.4, while further comments on these benefits type are stated below.

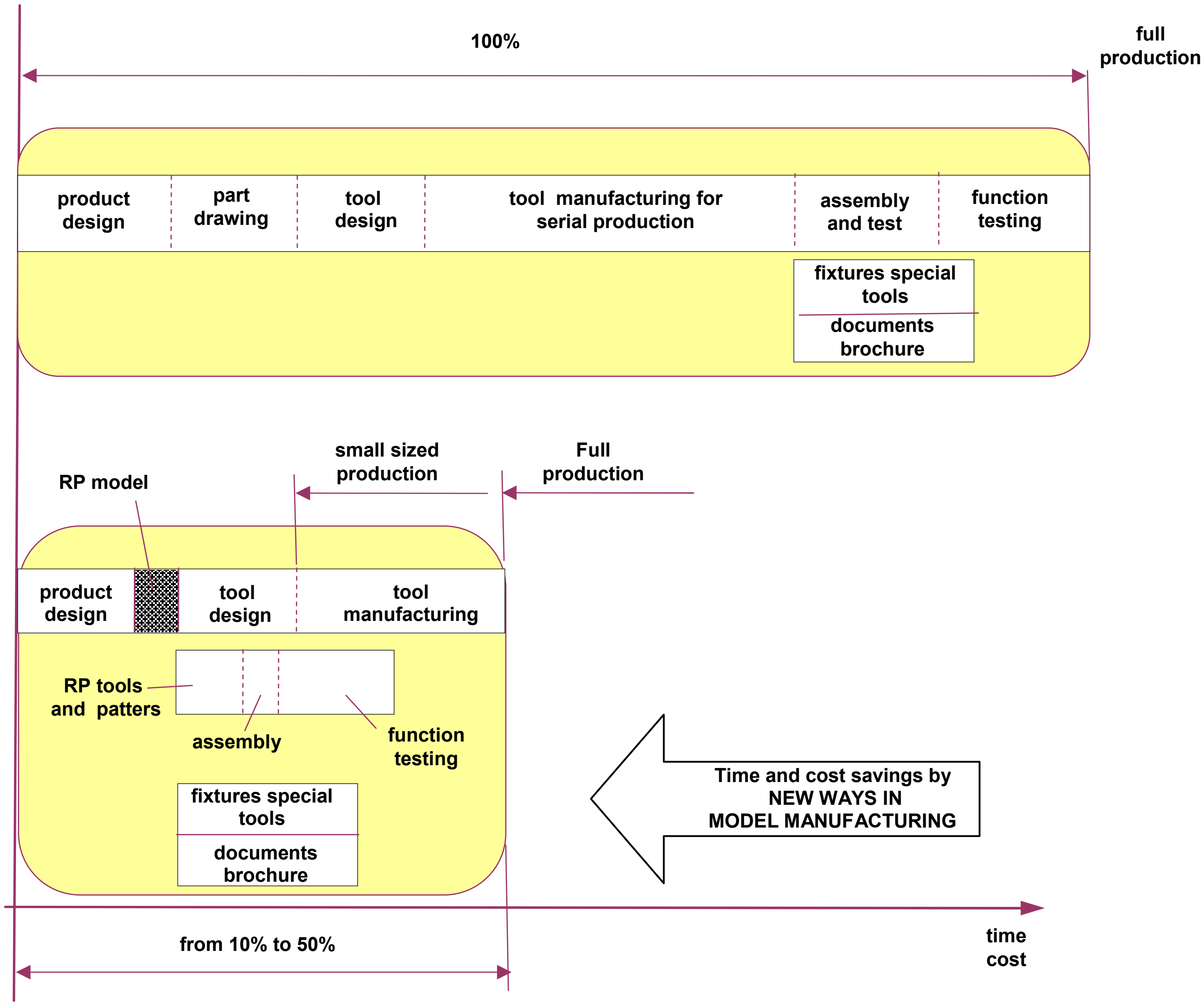


Fig. 5.4 Results of the integration of rapid prototyping technologies [1]

Product's designers can increase its complexity without a significant influence on time consumption and costs. More of it, they are allowed to optimize products shape in order to fulfil customers requirements, under low restrictions from the manufacturing process point of view.

There can also be diminished the number of product's component elements by combining their function / characteristics into one element. So, the time consumption for controlling, adjusting and assembly the components is much diminished.

Another benefit of rapid prototyping is that of eliminating many restrictions from the technological point of view, as their in no material removal or direct contact of the part with the tool. Thus, the material needed for the part can be better calculated and an optimum rate strength – weight can be achieved, with no increase in the manufacturing costs. This is why discussion on what the probability of a correct, complete and efficient manufacturing process is, can be avoided.

Engineers working on devices and tools for products manufacturing, do consider rapid prototyping as an efficient mean in reducing the time for their design, manufacturing and testing, even in obtaining more productive and reliable tools.

When production engineers use rapid prototyping they can obtain benefits by reducing the time for machine adjustments, by elimination of some tools or, by reducing as much as possible of the control and assembly time. There is less waste and, consequently, their recycling problems diminish a lot.

One effect of using rapid prototyping techniques is that of reducing the number of suppliers and of simplifying the calculi on material consumption and processing time – as they are automated performed by the RP equipment's software.

Another more prototyping benefit is that of avoiding miss-understandings of product's drawings, as well as of potential tension between designers and manufacturers. This is because the prototyping process is a WYSIWYG one.

Indirect benefits refer to those benefits generated beyond company's design and production departments.

So, there are new opportunities of reducing the time to market period and, thus the next would happen:

◘ the reduced risks for the products not to correspond to customers requirements, due to fast market changes;

◘ the more adapted product to satisfying customers needs;

◘ the good price – quality rate, as result new technologies involved;

◘ the economical market testing of new products.

By marketing, there can be made changes of production system components, as required by market, in real time and with reduced impact on the production process.

Customers can buy products that meet their needs. With rapid prototyping there is a wide variety of products to choose from and, more, the customers can contribute to the design of their customized products.

The common classification of prototyping processes is based on materials initial form. This is why, the rapid prototyping systems are the ones mentioned below.

◘ Liquid Based systems ⇒ where the material, initially in liquid state turns into solid, by a hardening process. Some of them are:

- Stereolitography Apparatus (SLA);
- Cubital's Solid Ground Curing (SGC)
- Sony's Solid Creation System (SCS)
- CMET's Solid Object Ultraviolet-Laser Printer (SOUP)
- Two Laser Beams
- Rapid Freeze

◘ Solid Based systems ⇒ includes solid state materials as: wires, rolls, laminates, granules. Examples of these systems are:

- Laminated Object Manufacturing (LOM)
- Stratasys' Fused Deposition Modeling (FDM)
- Paper Lamination Technology (PLT)
- Multi-Jet Modeling System (MJM)
- Shape Deposition Manufacturing Process (SDM)

◘ Powder Based systems ⇒ even in solid state, powders are considered separately and the systems are:

- Selective Laser Sintering (SLS)
- Z Corporation 3D Printing (3DP)
- Laser Engineered Net Shaping (LENS)
- Multiphase Jet Solidification (MJS)
- Electron Beam Melting (EBM)

Some of the prototyping technologies and their required materials are presented in table 5.2.

Table 5.2
Prototyping technologies and required materials

Prototyping technologies	Materials
Selective laser sintering (SLS)	thermoplastics, metallic powders
Fused Deposition Modeling (FDM)	thermoplastics, eutectic metals
Stereolithography (SLA)	photopolymers
Laminated Object Manufacturing (LOM)	paper
Electron Beam Melting (EBM)	Ti alloys
3D Printing (3DP)	powders

5.3 Liquid-Based Systems

The basic principle of a *liquid-based system* is that of building a "solid" in vat of photosensitive liquid organic resin (polymer) that selectively cures when exposed to a laser radiation, usually in UV wavelength range. The radiation determines the near to surface resin layers' solidification and so, a hardened layer of the part (solid) "appears". Once formed, an elevation control system lowers it, thus enabling the next layer of resin to be similarly hardened over, and the process goes on until the whole solid is built.

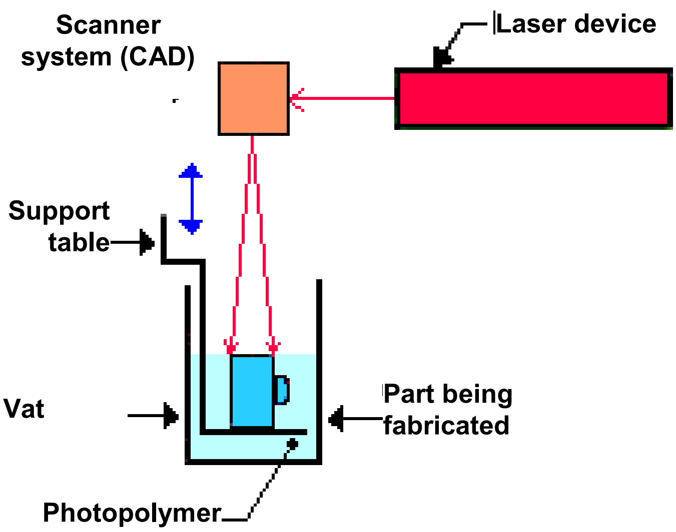
An exception to the principle above is Rapid Freeze Prototyping, which involves creating ice parts by layered freezing of water droplets.

Liquid-based additive manufacturing processes offer some advantages for prototyping, the main ones being accuracy and high definition. Also, the photo-curable resins involved have known continuous developing lately, so that the obtained parts do look like injection moulded components.

Still, there are disadvantages of the process, too, the most obvious one being low stability in time of photo-cured parts mechanical properties, specially when aging, exposed to sunlight or humidity.

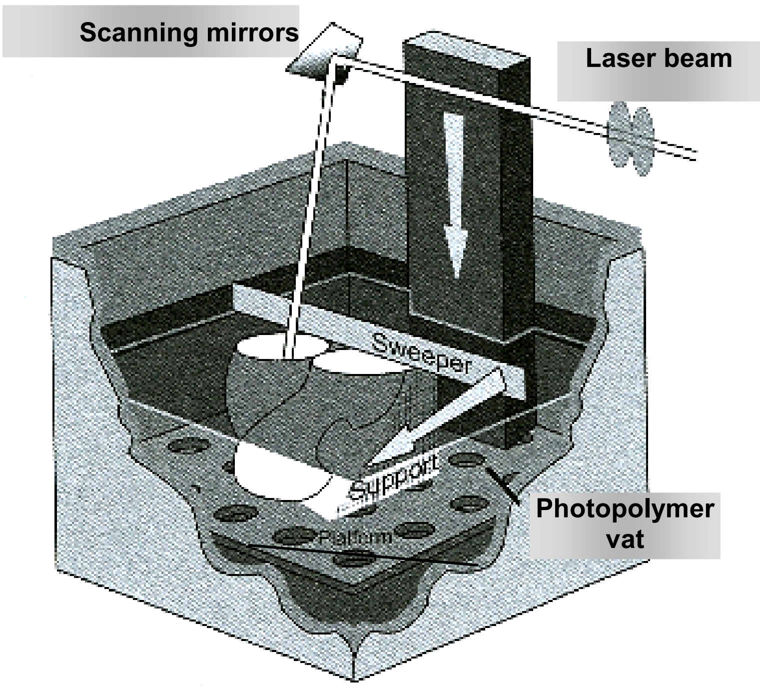
5.3.1 Stereolithography (SLA)

The *SLA system* was patented in 1986 by C. W. Hall and R.S. Freed. It uses an ultraviolet laser beam to initiate the curing process into a photo-curable resin [2].



a.
[http://www.additive3d.com]

Fig. 5.5 Schematic representation of the SLA system – to be continued



b. [2]

Fig. 5.5 Schematic representation of the SLA system

The laser beam is traced, by a CAD file data, on the surface of a vat of liquid photopolymer and so, selected zones of the resin (meaning one layer of the part to be prototyped) are cured and solidified. Then the support table is lowered (usually, by 100 µm) and another liquid resin is driven on top of the previously solidified one. The laser scans the new layer and, because of material's self-adhesive property, it bonds onto the previous one. The process continues by building the part from bottom to top, until the solid is completed.

A scheme of the SLA process is shown in figure 5.5 (a. and b.)

Some objects have overhangs or undercuts which must be supported during the fabrication process. This is done by support structures that are manually, or automatically (by machine's software) designed – see figure 5.6.

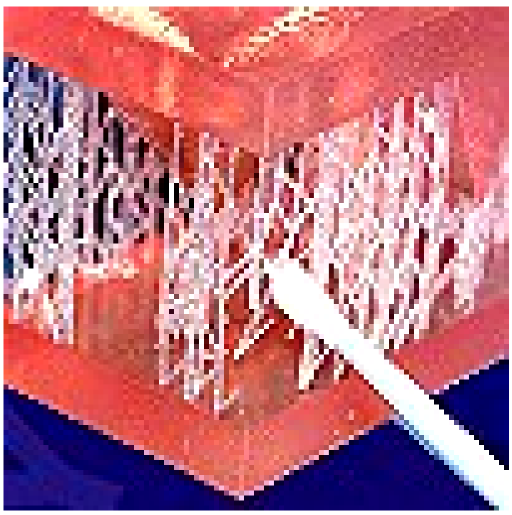


Fig. 5.6 Support structure of a SLA part [*]

Once the part built, it is removed from the machine and support platform, the excess of resin is taken away, and then the support structures removed. Post-processing in an UV / electric oven is used for curing any un-cured resin.

There is a wide range of machines, produced by 3D Systems in order to "cover" miscellaneous parts size, geometry and throughputs involved by the stereolithography process. In figure 5.7 it can be noticed a SLA Viper machine - solid imaging system to combine standard and high-resolution part building, as well as the post-processing equipment.


Fig. 5.7 3D Systems Viper machine and post-processing equipment
[http://www.3dsystems.com]

Usually, the geometric precision of the SLA parts involves tolerances in between ± (10 to 15) μm, while the high precision fabricated parts means ± (5 to 8) μm. The higher the resolution of SLA process, the better accuracy and quality of parts but, the slower and more expensive the process

As mentioned above, the materials used with the SLA process are liquid photopolymers (resins) that do solidify when exposed to electromagnetic radiation in the UV range. Some frequently used resins are: Accura 25 and Somos 9110 (resins with material properties similar to polypropylene); Accura 60 (rigid epoxy resin ideal for master patterns used in design verification models), DMX-SL 100 (material with high impact strength and resistance to breakage). A new tested one is 14-28 &, whose properties are similar to ABS.

There are many applications of stereolithography built parts, such as:

⇒ models for presentation, conceptualization and learning;

⇒ prototypes for checking and functional testing, even strain and stress analysis;

⇒ parts for prototype tooling;

⇒ patterns for sand casting, even moulding;

The SLA process is one of the most widely used prototyping processes, offering control of the design process, reasonable costs, reduced time to market for the product.

Few examples of SLA parts – with different application, are shown in figure 5.8.

[http://www.boedeker.com]

[http://www.dpt-fast.com]

Fig. 5.8 Examples of SLA built parts

5.3.2 Solid Ground Curing (SGC)

The *SGC system*, also known as *Solider Process*, was patented in Israel, by Cubital Inc. (1987) and it is considered a high-throughput production process, because of its large work space and ability to harden each layer of photosensitive resin at once.

It involves the use of several types of materials, as:

◘ liquid resin and cured resins ⇒ to create parts;

◘ water soluble wax ⇒ as support material;

◘ ionographic solid toner ⇒ to create an erasable image of part's cross-section on a glass mask (by ionographic printing technique).

The Cubital's SGC includes three main stages presented above – see also figure 5.9.

◘ *Data preparation* ⇒ when the CAD solid model of the part is completed and then its digitally generated cross-sections are transferred to the mask generator.

◘ *Mask generation* ⇒ there is an "image-wise", non-impact ionographic process, where each layer (cross-section) is produced using toner (black powder) on a glass plate (on which it adheres electrostatically to) and so, creating a photo-mask (step 1).

◘ *Model making* – it includes several steps, as:

- spreading onto the work surface of a photopolymer resin thin layer (step 2);
- placing the photo-mask close above the work-piece and aligning both, above an UV lamp (step 3);
- turning on the lamp for a few seconds and so, the part of resin layer exposed to UV light, through the photo-mask hardens (step 4) – the layered are thicker than needed, the correction being made while the milling process;
- removal of the un-solidified resin from the work-piece (step 5);
- spreading melted wax into the cavities created and then, cooling it in order to produce a whole solid layer (step 6);
- milling the layer to the smooth and precise required height (step 7);
- final curing of the work-piece, under a powerful longitudinal UV lamp (step 8);
- applying a new resin of layer onto the surface of the work-piece (step 9).

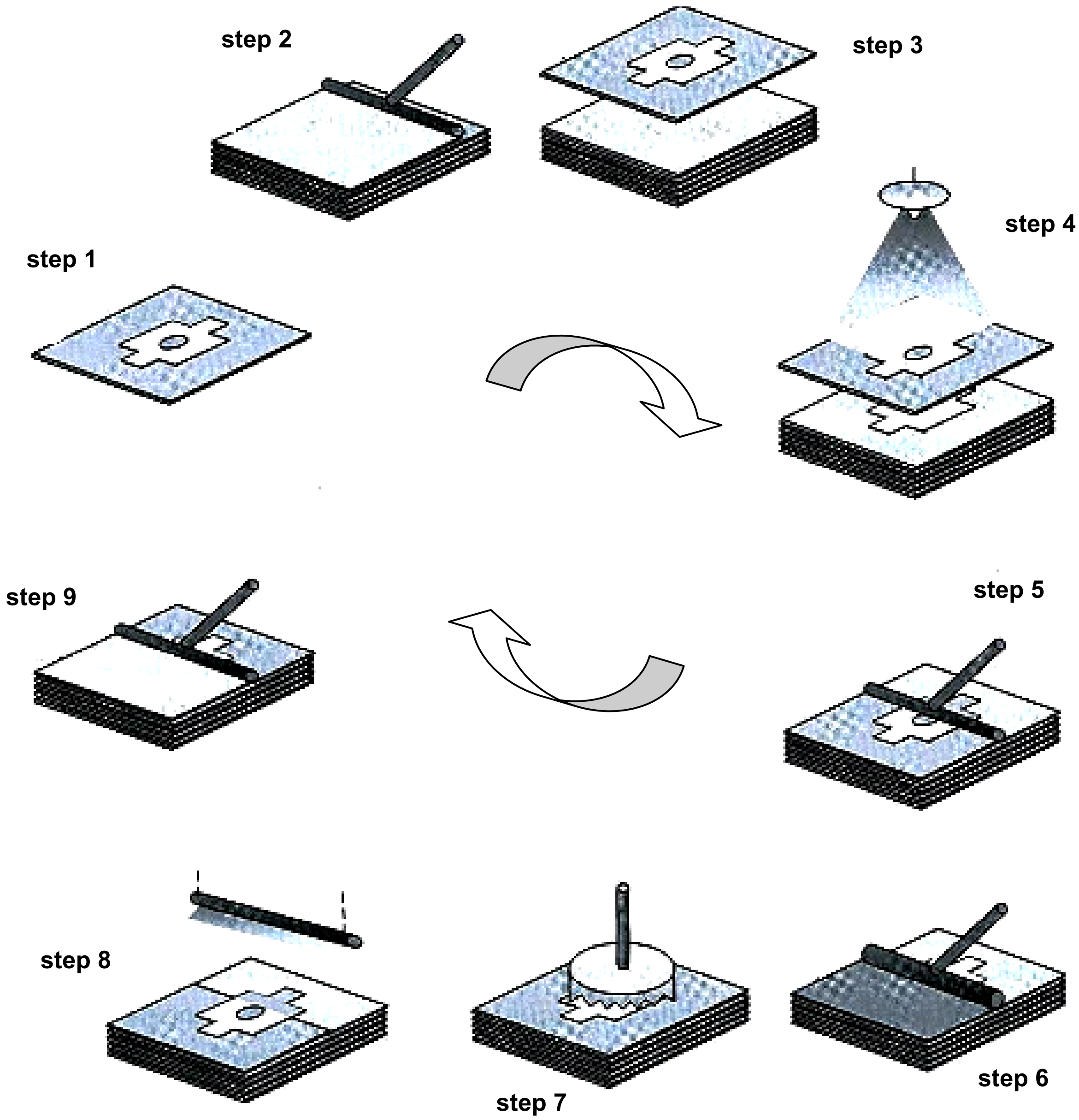


Fig. 5.9 Schematic representation of a SGC process [1]

There are advantages of Cubital's solid ground curing system, referring to:

⇒ the large size of the parts that can be fabricated (500 x 500 x 350 mm);

⇒ simultaneously curing of a whole cross section layer - compared to point by point curing in other systems;

⇒ self supporting - due to the wax that supports the whole surface of the work-piece;

⇒ accuracy – as by milling there is generated flatness for the subsequent layer;

⇒ low shrinkage and high stability of the parts – because of layer by layer curing on one hand, and because of the fact that the curing process minimizes the development of internal stresses into the structure, on the other hand.

There are, also, disadvantages of the SGC systems, dealing with:
⇒ the large physical space required;
⇒ the wax that gets stuck into the corners and crevices – sometimes, it can be noticed with the parts;
⇒ the big quantity of waste – due to the milling process;
⇒ the high level of noise – compared to other systems.

Application of the SGC system are mainly referring to:
⇒ general - in design proofing, engineering testing, market research, etc;
⇒ tooling and casting – in sand casting, tool manufacturing of plastic, etc;
⇒ mold and tooling – in silicon rubber tooling, plaster mold casting, etc.;
⇒ medical imaging – diagnostic, reconstruction planning, prosthesis design, etc.

5.3.3 Solid Object Ultraviolet Laser Printer (SOUP)

The *SOUP system* was patented by Computer Modelling and Engineering Technology (CMET) Inc. and it is based on laser lithography technology.

It has a galvanometer mirror with Z focus unit, whose scanning speed can be up to 20 m/s, while the X, Y movements of the laser light are directed by a X, Y plotter mechanism - easier to control than the galvanometer mirror system. Laser beam's diameter is very small (even, less than 0.1 mm) and, that is why, accurate small parts can be obtained.

The specific material for this system is a photo-curable epoxy resin.

The process is made of three steps, as follows:

◘ *creating the 3D model* ⇒ with a CAD system;

◘ *processing the data* with SOUP-ware ⇒ by correction of possible errors in the CAD solid model (gaps, overlaps, etc.), slicing it into cross-sections, generating the machine data;

◘ *building the model* – the laser scans the resin, solidifying it as each cross-section of the model, by subsequently lowering the elevator (part support).

Some parameters that do influence system's performance are: the galvanometric mirror's precision, the laser spot's diameter, the epoxy resin's characteristics.

A scheme of the SOUP system is shown in figure 5.10.

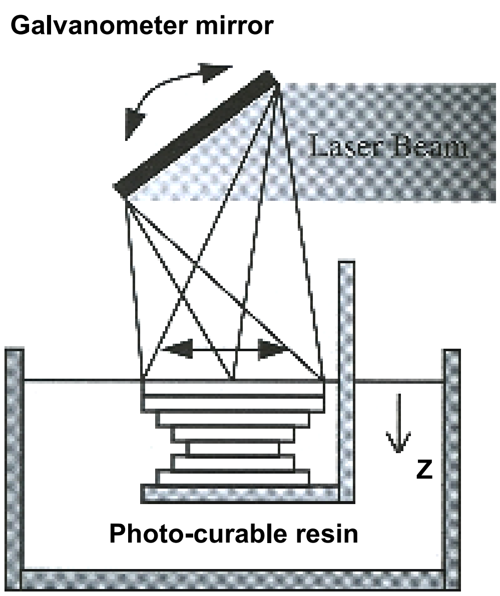


Fig. 5.10 Schematic representation of the SOUP system [1]

There are advantages involved by this system, such as: an accurate Z layer's thickness and a high scanning speed, while the disadvantages refer to:

⇒ the necessity of support structures - for overhangs and undercuts;

⇒ post processing - for removal of supports and uncured material;

⇒ post curing – for integrity of part's whole structure

Application of SOUP fbuilt parts involves obtaining of:

⇒ conceptual models for visualization and commercial presentation;

⇒ working models for simple functional tests;

⇒ medical models of human anatomy;

⇒ 3D stereolithographic copy of an existing product

5.3.4 Rapid Freeze Prototyping (RFP)

It is Dr. Ming Leu and other researchers from the University of Missouri-Rolla, who developed the *RFP system*.

It is based on the process of spraying droplets of water layer-by-layer in a freezing chamber, thus water being the base material. Still, many times, the process involves creating first a frozen "shell," or boundary, out of ice, then filling the enclosed interior with a steady stream of water that freezes.

The experimental system developed consists of three subsystems, one for *3D positioning*, the second for *material depositing* and the third for *freezing the water*. Also, there are used modeling, simulation and analysis software for fluid spreading and material solidification behavior while the ice part building process.

A schematic representation of the process can be noticed in figure 5.11.

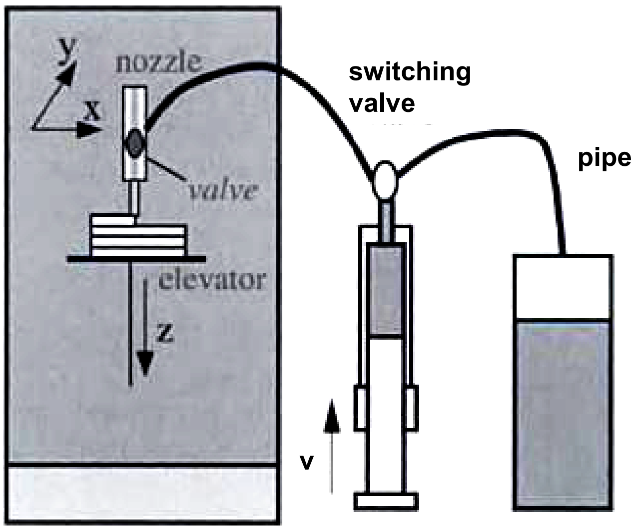


Fig. 5.11 Schematic representation of the RFP system [1]

The RFP systems are used to make ice objects and casts for complicated molds, which melt away from the object after casting. – an example is shown by figure 5.12

Advantages of Rapid Freeze Prototyping systems are evidenced by:

⇒ low costs of materials and energy consumption;

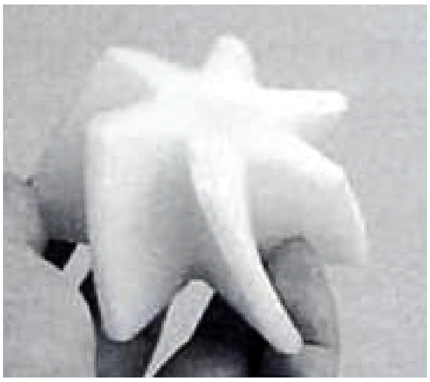
⇒ high accuracy and good surface finish;

⇒ easy removal of the part in a mold making process;

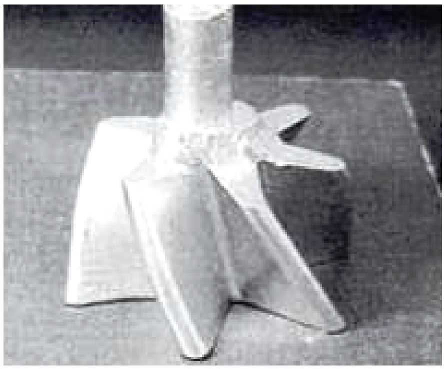
⇒ high productivity – due to water's low viscosity it is possible to create the boundary first, then filling it which considerably reduces the time involved.

a. RFP part

b. UV silicone mold



c. urethane part – made by UV silicone mold



d. metal part – made by UV silicone mold

Figure 5.12 Application of RFP system [1]

As for the disadvantages of the RFP process, there can be mentioned:

⇒ the requirement of a cold environment;

⇒ the need for additional processing – as the prototype has to be subsequently cast into a mold;

⇒ low repeatability – because of water characteristics which, relatively, are difficult to control and a part once obtained may differ from the next one to be obtained.

Fig. 5.13 Examples of RFP parts [http://isc.mst.edu]

Some possible application of the RFP parts deals with:

⇒ ability of part visualization - possible interest to the medical field, as transparent models which allow interior details are valuable in surgery;

⇒ ice sculpture fabrication – for entertainment purposes;

⇒ silicone molding – when making silicone molds in ice patterns.

There can be obtained, both transparent and colored parts – see figure 5.13.

5.4 Solid-Based Systems

A basic feature of all *solid-based systems* is that the processes involved requires solid materials, except of powder form, as medium for creating the prototypes. Some important characteristics of these systems, as well as their application are presented next.

5.4.1 Fused Deposition Modelling (FDM)

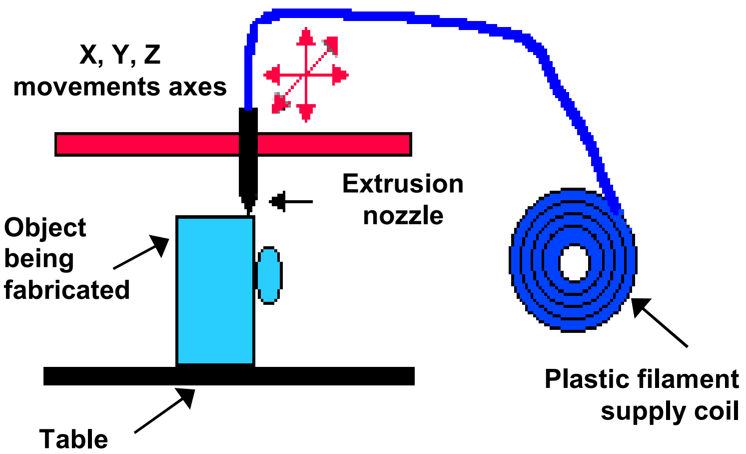
The *FDM process* was developed (1988) and patented (1992) by Scott Cramp, while the corresponding systems has been commercialised by Stratasys Inc. since 1992.

The basic principle is that of layering material by extruding it – see figure 5.14 (a., b and c.). It can be noticed that a plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn on and off the flow. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions (X and Y axes) by a numerically controlled mechanism. So, semi-liquid material is extruded through FDM head and then deposited in ultra thin layers, each at a time. As the air surrounding FDM head is maintained at a temperature below material's melting point, the extruded material hardens immediately and bonds to the layer below.

The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic.

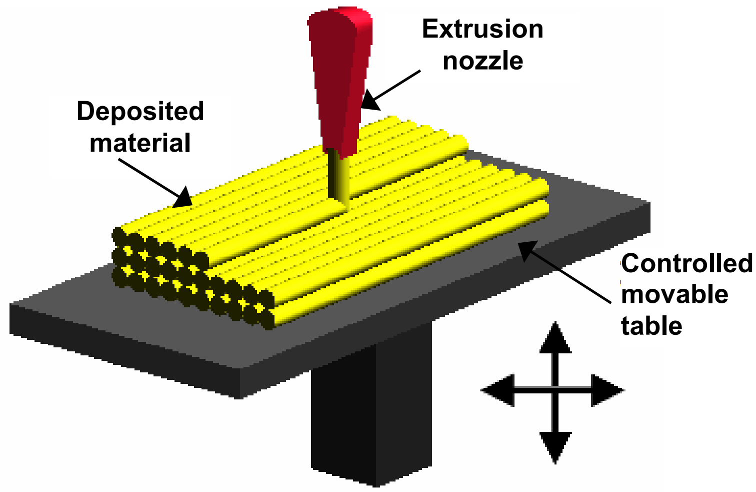
A characteristic of FDM machines is that there are two types of materials extruded (by nozzles) and deposited in each layer, one is the part's material and the other is the support material – which, once the 3D model completed, is removed manually or washed away.

There are some factors that influence Fused Deposition Modelling process performances, like: material's column strength, material's viscosity, X and Y positioning accuracy, width of the extruded "raw", etc. For example, horizontal width of the extruded material can vary, even from layer to layer, between 0.250 and 0.965 mm, while the commonly nozzle's diameter is about 0.3 mm – which, in fact, limits resolution and accuracy.

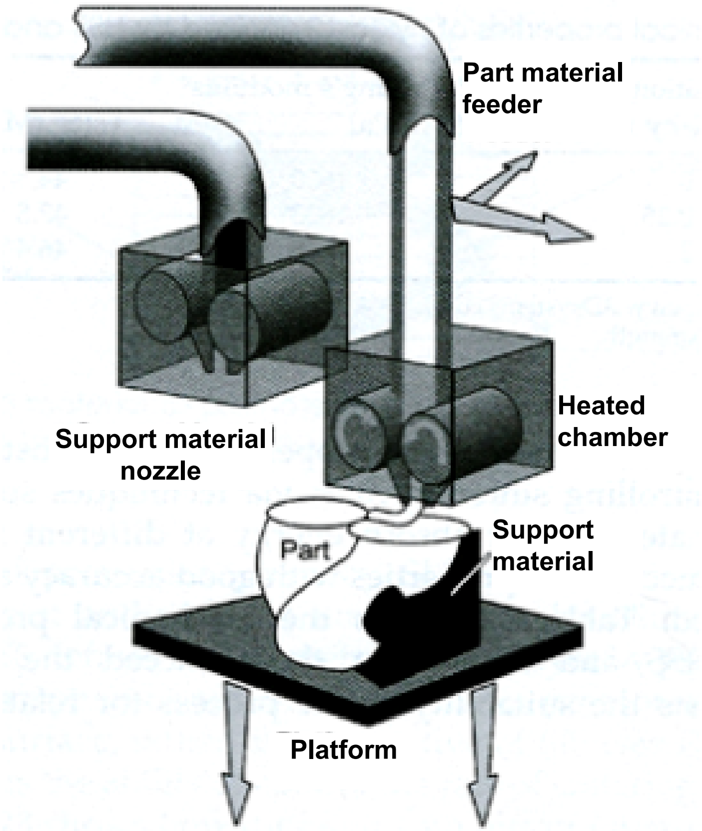


a.
[http://www.additive3d.com]

Fig. 5.14 Schematic representation of the FDM system – to be continued



b.
[http://en.wikipedia.org]



c. [2]

Fig. 5.14 Schematic representation of the FDM system

Materials available for the process are: ABS, ABSi – new material sterilized via gamma radiation and ethylene oxide [www.quickparts.com], polycarbonate (PC) and polyphenylsulfone (PES or PPS).

Advantages of Fused Deposition Modeling systems are:

⇒ ability to fabricate prototypes whose material is similar to that of their molded parts;

⇒ minimal waste, as the part is built by directly extruding semi-liquid melt onto the model;

⇒ ease of support removal, by breaking or washing away the support structure – depending on the material type (Break Away Support System or, Water Works Soluble Support System).

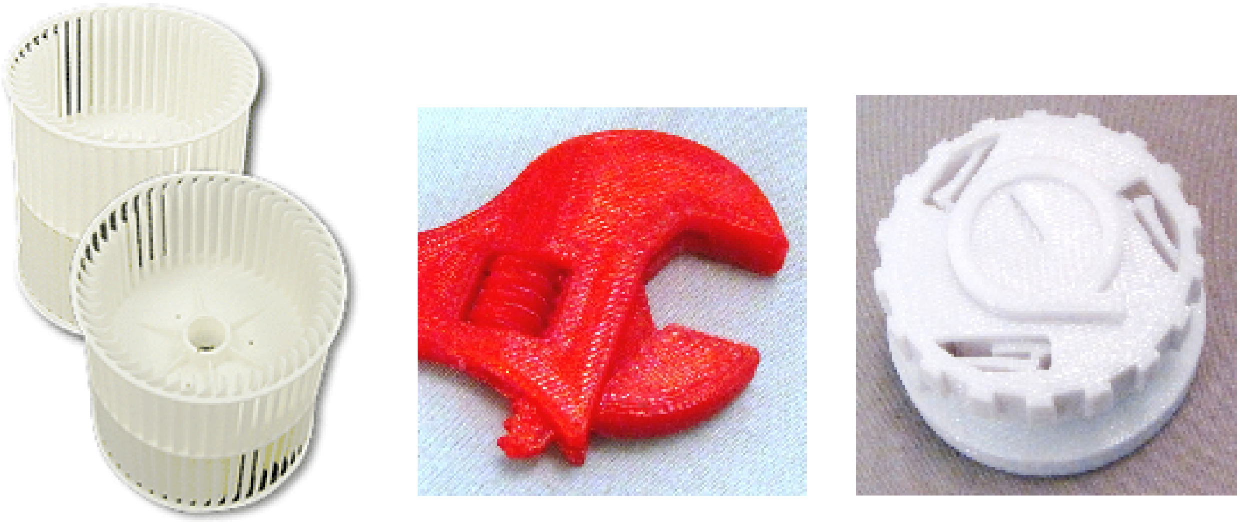
As for the disadvantages of the FDM process, there can be mentioned:

⇒ relatively low accuracy – on horizontal plane (X, Y axes) it is from ± 0.013 mm and up to 0.12 mm (for large parts), while on Z axis (vertical), it is in-between ± 0.025 and 0.125 mm;

⇒ long taking time process – as the building speed is limited by the low flow rate of extruded materials;

⇒ unpredictable shrinkage – because of the internal stresses induced when the extruded material fast cools and solidifies.

Some examples of FDM parts are presented in figure 5.15.



blowers for air flow testing **ABS wrench** **polycarbonate knob**

Fig. 5.15 Examples of FDM parts [http://www.quickparts.com]

As for the application of the FDM parts, these can be:

⇒ conceptual and presentation models;

⇒ prototypes for functional testing;

⇒ patterns for sand casting and molding.

5.4.2 Laminated Object Manufacturing (LOM)

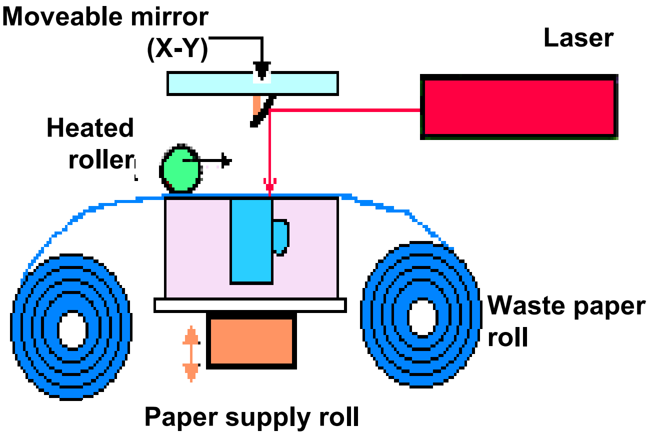
The *LOM system* has been developed by Helysis and is based on automated fabrication by sequentially laminating the 3D part's cross sections. Nowadays it is Cubic Technologies Inc. that succeeds Helysis.

The process of laminated object manufacturing involves building parts by stacking, bonding, and cutting layers of adhesive-coated sheet material on top of the previous one. A laser cuts the outline of the part into each layer. After each cut is completed, the platform lowers by a depth equal to the sheet thickness and another sheet is advanced on top of the previously deposited layers. The platform then rises slightly and the heated roller applies pressure to bond the new layer. The laser cuts the outline and the process is repeated until the part is completed. After a layer is cut, the extra material remains in place to support the part during build.

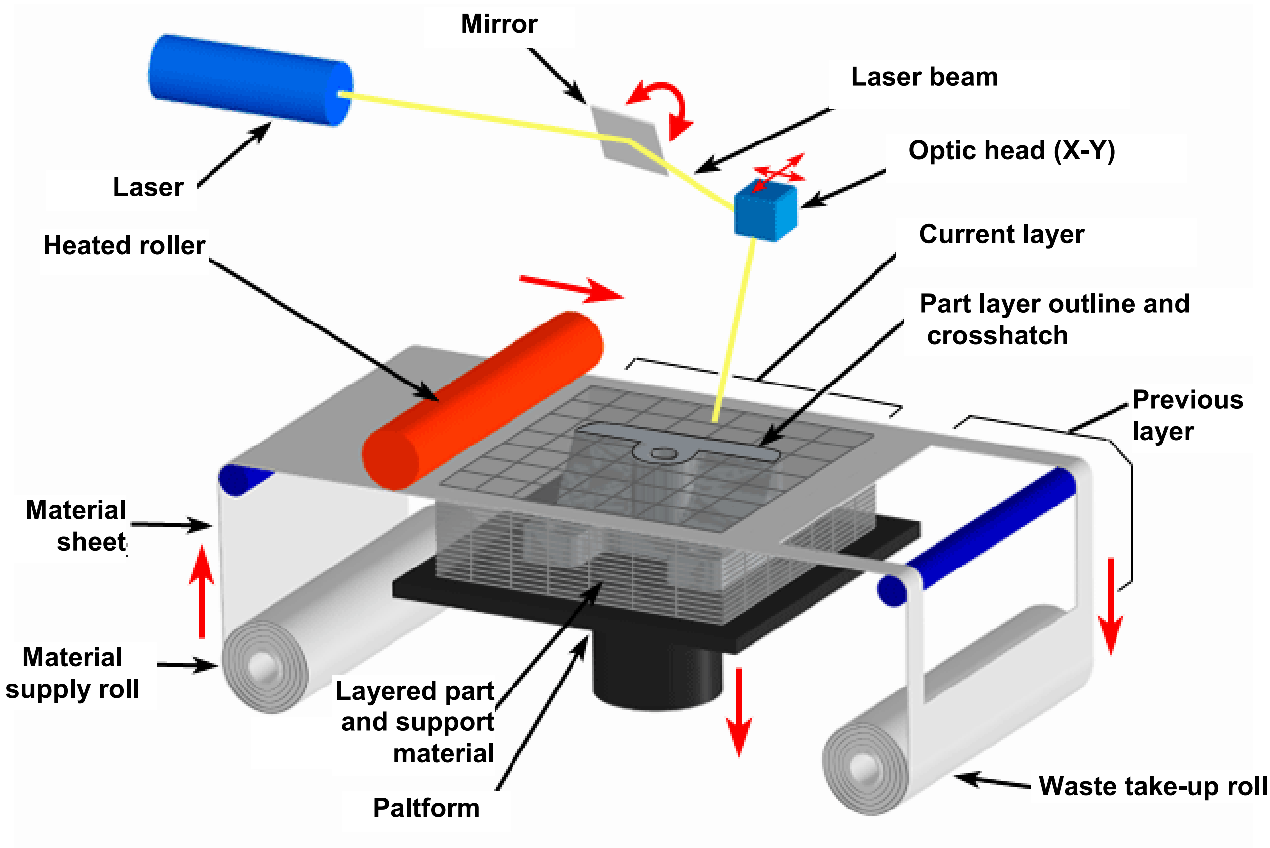
A scheme of the LOM system is shown in figure 5.16 (a. and b.)

The material sheet used has a polyethylene coating on the backside and when the LOM process starts, it is important to create a base on which the material can attach itself to. This is done by placing a special tape down onto the platform.

The laser used by the system is a CO_2 laser. Once cutting the outline of part cross-section pattern is done, the laser creates a border around the build and so, the part stays "still" as each new layer is created. When the border is cut, the laser beam is driven to create hatch marks, or cubes, that surround the pattern within the border and act as supports for the part.



a.
[http://www.additive3d.com]

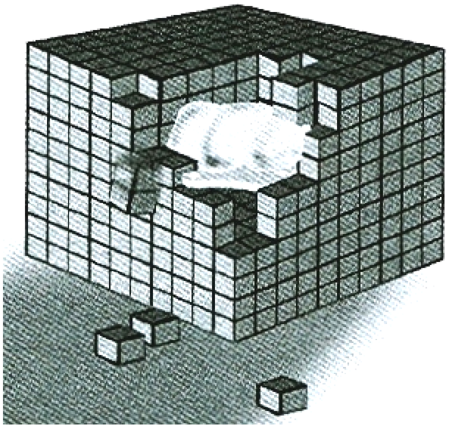


b.
[http://www.custompartnet.com]

Fig. 5.16 Schematic representation of the LOM system

The post-processing phase is important and it does involve the steps that follow::

- removing the platform from the LOM machine;
- removing the part from the platform – if necessary, by a wire "to cut", placed between the part and the platform;
- removing the border of frame of the part;
- separating the hatch marks, or cubes from the prototype – see figure 5.17.
- sanding the part and sealing it with epoxy or silicone spray – to prevent moisture absorption.



[2] [http://www.pmli.com]

Fig. 5.17 Removed part – with support cubes

Advantages of the Laminated Object Manufacturing systems can be mentioned as:

⇒ the use of a wide variety of materials - theoretically, meaning any material in sheet form: thermoplastics (PVC), paper; composites (ferrous, non-ferrous and ceramics);

⇒ short build time - as it is outlined the periphery of each cross-section;

⇒ no need for additional support structure.

Disadvantages of the LOM process are:

⇒ necessity of precise power adjustment - so that the laser beam cuts the perimeter and crosshatches of the current layer in lamination, and not to penetrate into the previously laminated ones;

⇒ not fitted to fabricate parts with thin walls, especially on Z direction - because of the fact that walls should be rigid enough to withstand post-curing operation;

⇒ integrity of parts - it is the sealing adhesive that gives strength to the LOM parts, so they can not withstand high mechanical loading.

Application of the LOM parts can be:

⇒ visualization models - as parts have the look and feel of wood;

⇒ prototypes for form, fit and function evaluation;

⇒ rapid tooling and pattern making - as wood like molds can be used for injection of wax, polyurethane, low pressure materials.

5.4.3 Paper Lamination Technology (PLT)

Paper Lamination Technology (PLT), formerly known as *Selective Adhesive and Hot Press* (SAHP), was developed by Kira Corporation Ltd.

In the PLT process, a laser printer prints a resin powder on a paper, that is successively layered, hot pressed to the previous layer and, cut by a knife as each cross section of the part to be fabricated.

A scheme of the paper Lamination System is presented in figure 5.18.

When the process is over and the part removed, it can be finished by wood-working. There should be mentioned that the part does shrink when is cooled down in the hot press unit and it does expand because of humidity in the hot press unit. So, together with cutter movement accuracy (along X and Y axes), temperature and humidity do influence fabricated object's dimensions.

The formerly SAHP process involved obtaining parts with tensile and bending strengths values about half of the wooden models, while the current PLT process enables fabricating parts with improved hardness, up to 25% better than that of the corresponding wooden model.

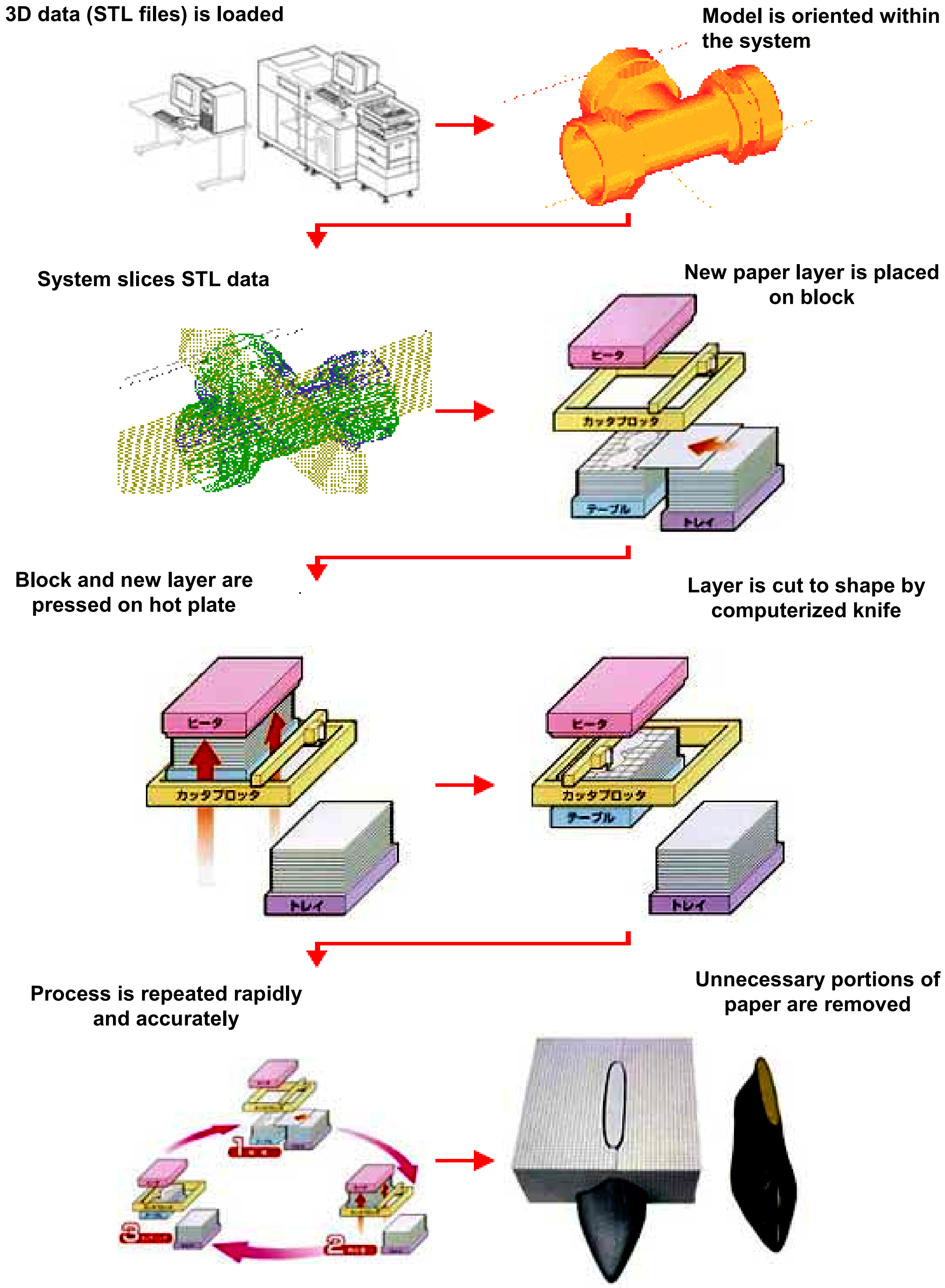


Fig. 5.18 Schematic representation of the PLT process
[http://www.impact-int.com]

Some advantages of the PLT systems consist in:

⇒ flatness of the model - due to the hot plate and pressure to bond layers;

⇒ surface smoothness – as the sheets of paper are cut by computerized knife;

⇒ no support structure required – as the part is supported by the paper out off the cut-path perimeter;

⇒ office friendly process – a safe process, with no high-power laser or hazardous materials.

Disadvantages of the Paper Lamination Process “deals' with:

⇒ slow process - as in Z direction the layer's thickness is determined by the thickness of paper;

⇒ limitation in walls; thickness – specially in Z direction, where walls are joined transversally and, possible, not strong enough for post-processing;

⇒ impossibility of fabricating internal voids models – because of the impossibility to remove waste material from within the voids.

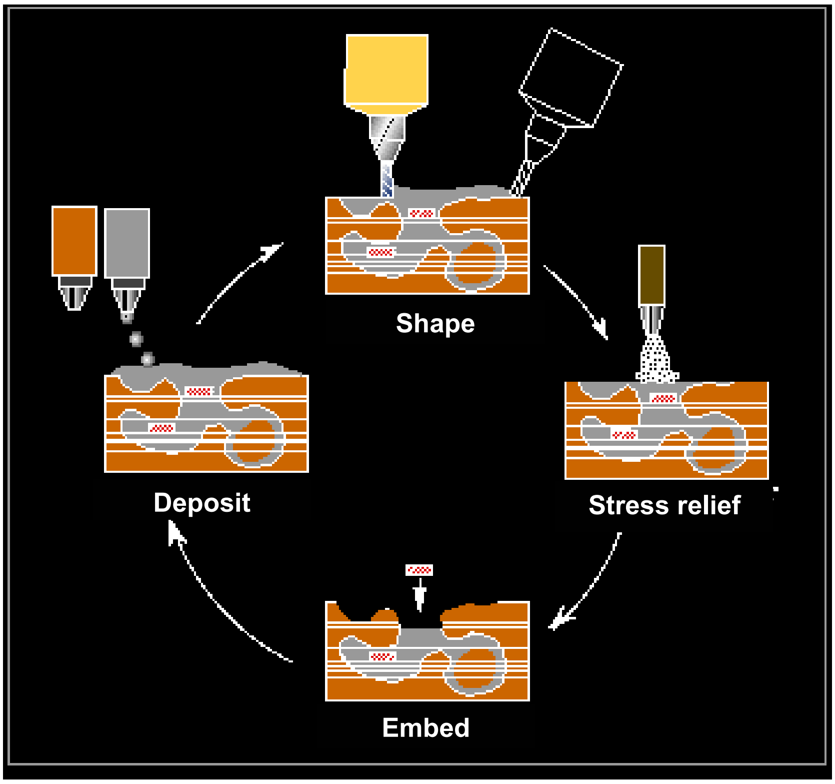
The main application of the PLT parts is in conceptual modeling and visualization.

5.4.4 Shape Deposition Manufacturing Process (SDM)

Shape Deposition Manufacturing process (SDM) was developed by Prof. Fritz Prinz and it is based on combining the additive layer manufacturing process with subtractive CNC machining process.

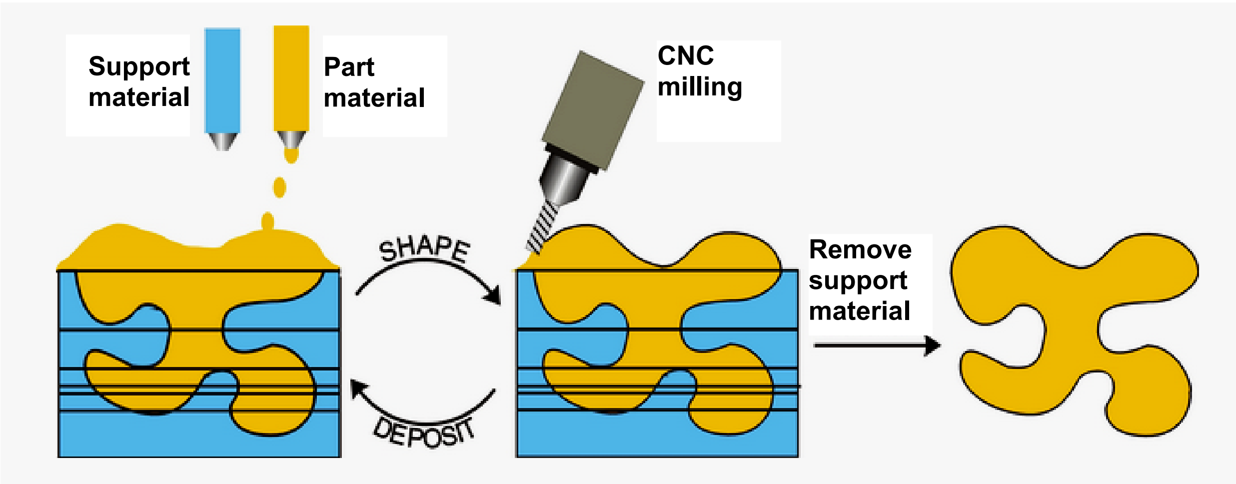
As K. Ramaswami says [5], SDM is a modifed solid freeform fabrication (SFF) process that can manufacture arbitrarily complex shaped structures directly from CAD models in an automated environment. It, also, allows the manufacture of multi-material and embedded structures that cannot be produced with the traditional manufacturing techniques. So, it combines the benefits of SFF (handling complex geometries), CNC milling (accurate and precise with good surface quality) and weld-based deposition (superior material properties).

A scheme of the process is presented in figure 5.18 (a. and b.).



a. [5]

Fig. 5.18 Schematic representation of the SDM process – to be continued



b. [http://www.cs.cmu.edu]

Fig. 5.18 Schematic representation of the SDM process

The CAD model is decomposed into simpler building block called compacts, such that undercut features need not be machined, but formed by depositing onto previously deposited and shaped segments. The compacts are deposited as near-net shape using a deposition method such as plasma or laser based deposition process. The thickness of each compact is variable, depending not only on the local part geometry, but also on deposition process constraints. Layer boundaries are strategically inserted at heights where there are transitions between undercut and non-undercut surfaces or where there are changes in material composition.

For the example presented in figure 5.18 (b.), the depositing, shaping part and support materials sequences are illustrated in Figure 5.19.

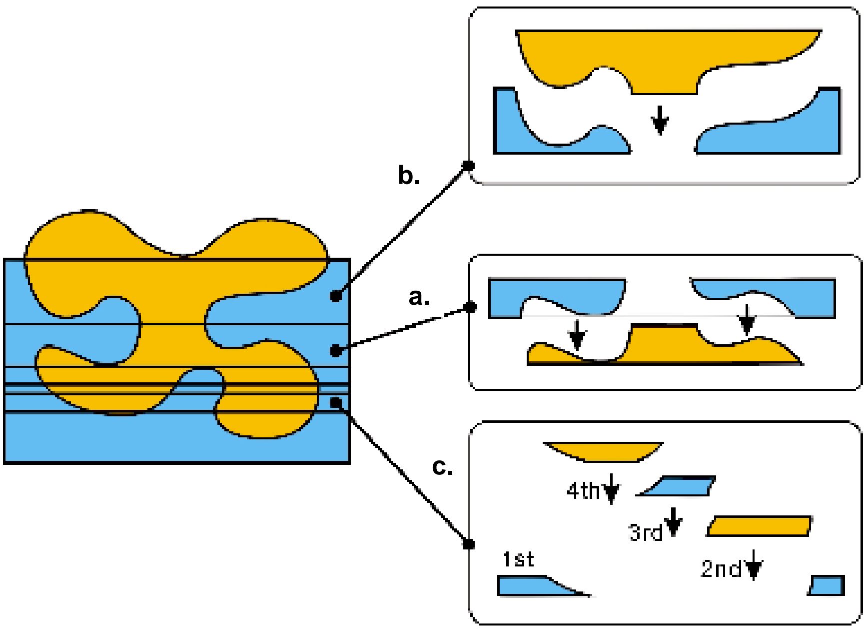


Fig. 5.19 Shape decomposition in SDM process [http://www.cs.cmu.edu]

If a material heterogeneous structure has to be obtained, or prefabricated components to be embedded within the growing shape, the SDM process is the required one. So, multi-material and functional-gradient parts can be built by depositing different materials within each layer, following the same cycle.

For the example in figure 5.18 (b.), the compact splitting strategy and sequence for depositing and shaping materials are shown below - see figure 5.20

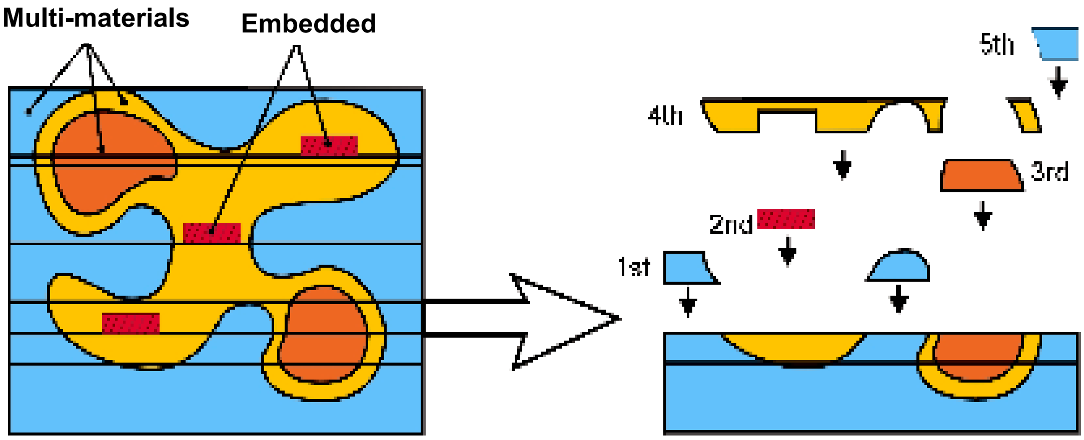


Fig. 5.20 Shape decomposition in SDM process – multi-material structure with embedded components [http://www.cs.cmu.edu]

After deposition, each layer is accurately machined to net shape using CNC milling or EDM (Electro Discharge Machining). Processes such as shot-peening are used to control the build-up of residual stresses. Sensors, electronic components, prebuilt mechanical parts or circuits can be embedded into each layer. After completing one layer, the next layer is deposited and the process is repeated till the part is completed.

In SDM, support for overhanging features is provided by the sacrifcial support material. Each layer is embedded in the support material. The CAD model of the support structure is obtained as the compliment of original CAD model. The support structure is built along with the original model and follows the SDM cycle. After the part is completed, the support material is removed either by melting or etching process.

Some advantages of the SDM systems consist in:

⇒ wide variety of materials - steel, metals, wax, ceramics, photo-curable plastics, etc.;

⇒ ability to build heterogeneous structures;

⇒ variable layer thickness – depending on part's geometry and process constraints;

⇒ building undercuts.

Disadvantages of this process do exist, some being represented by:

⇒ precise control of the automated transfer robot that moves the part from one station to the other (material deposition, material removing, cleaning, stress relieving, etc.);

⇒ thermal stress – due to high temperature while the deposition process;

⇒ large area required for the whole SDM system.

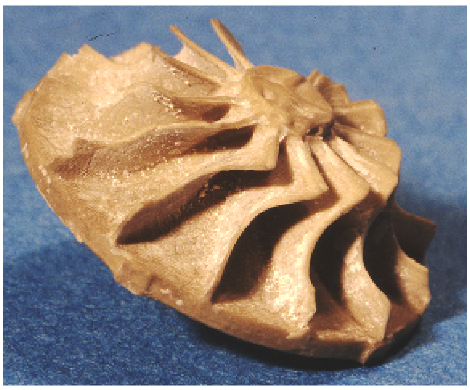


Fig. 5.21 Turbine rotor made by SDM process [http://www.cs.cmu.edu]

Some of the current application areas of the Shape Deposition Manufactured parts are

⇒ *s*hape conformable embedded electro-mechanical structures

⇒ manufacturing of custom tools - injection molds with cooling channels, tools with multi-material inserts, tools with embedded sensors

⇒ complex shaped parts made of hard-to-machine materials – for example, a turbine rotor – see figure 5.21 .

5.5 Powder-Based Systems

The common feature of *powder-based systems* is that the material used for building the part is powder, even if it involves polymers, metals or ceramics. More of it, when combining powder and additive manufacturing techniques, functionally graded materials can be obtained and, thus, versatile and high functionality parts are available.

Important characteristics of these systems and their application are evidenced below.

5.5.1 Selective Laser Sintering (SLS)

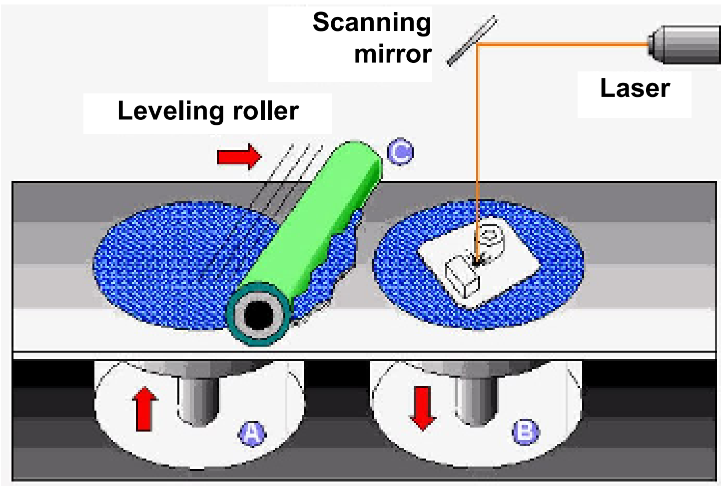
The *SLS process* was invented and patented by R. Householder (1978) but, it was dr. C. Deckard who first commercialised the selective laser sintering system, after patenting it, too, in mid-1980's.

This process consists in sintering or melting of a powdered raw material by a high power laser (CO_2) whose beam selectively fuses the surface of a powder bed by scanning cross-sections generated from a 3D digital description of the part (CAD file).

There are some phases specific to a SLS system that operates, some of the most important being mentioned next:

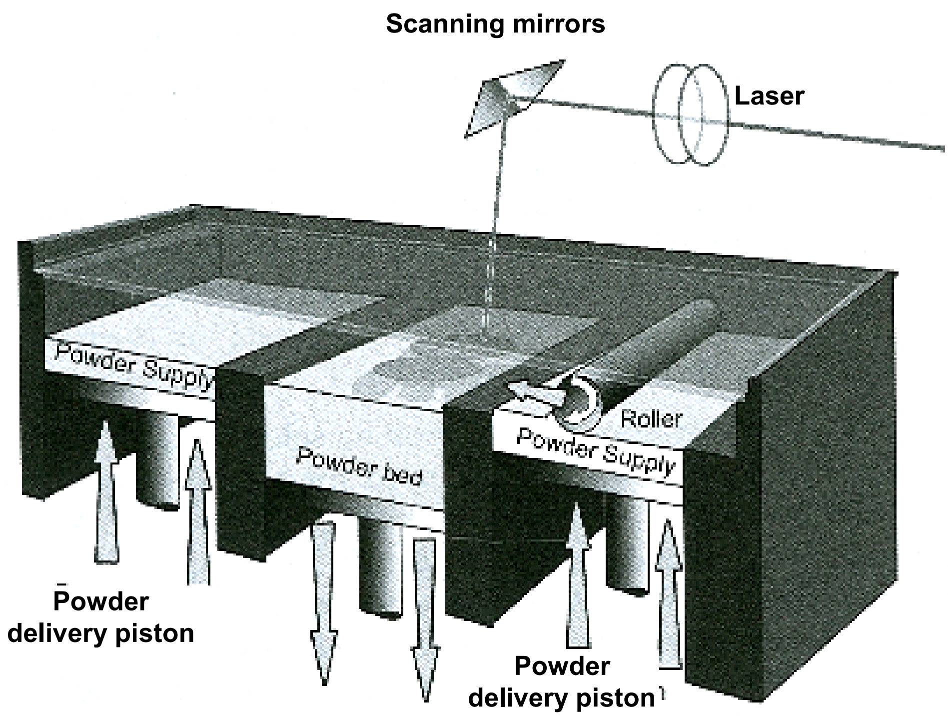
- make a deposit of heat fusible powder thin layer in the part building chamber;
- scan the bottom cross-section slice of the CAD part file by the laser beam and, thus, the powder particles are melted and fused to a solid mass;
- deposit a new layer of powder, typically of 100 μm thickness, on top of the previously scanned layer, that has already been lowered by a layer thickness;
- scan the new layer by the laser beam and, so a new cross-section is generated, while the new layer fuses on the layer below;
- the process continues until the whole 3D part is created;
- remove the part from the build chamber.

A schematic representation of the process is shown in figure 5.22 (a., b. and c.).

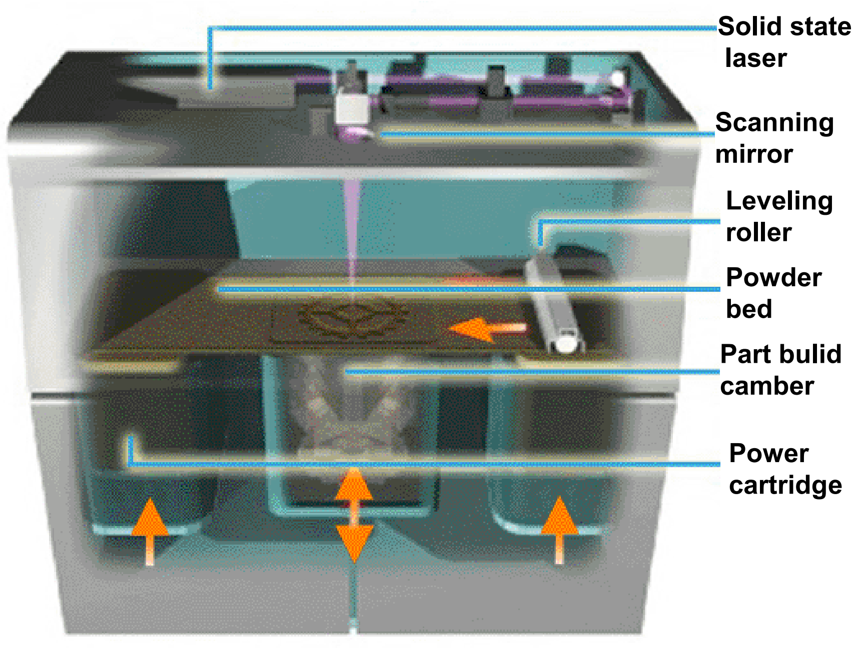


a.
[http://www. plynetics.com]

Fig. 5.22 Schematic representation of the SLS system – to be continued



b. [2]



c. [http://www.lasersintering.com]

Fig. 5.22 Schematic representation of the SLS system

While the Selective Laser Sintering process, the powder bed is heated prior to laser scanning, so that powder temperature, most of the times, is brought close to the sintering one, only a few degrees (ºC) lower. This is usually done by infrared heaters and helps reducing the laser energy required to sinter the powder.

There should be mentioned that the selective laser sintering process does not involve building support structures, as overhangs and undercuts of the part are supported by the solid powder bed.

There is a wide range of materials suited for the selective laser sintering process, meaning:

- polyamide ⇒ used to create rigid parts for functional engineering environments;
- thermoplastic elastomer ⇒ for rubber like parts;
- polycarbonate ⇒ used for casting patterns of metal prototypes or for cast tooling;
- nylon ⇒ fitted when resistance to heat and chemicals is required;
- metals ⇒ an example is polymer coated stainless steel powder infiltrated with bronze;
- ceramics ⇒ such as zircon and silica coated with phenolic binder, used to make molds.

Some advantages of the selective laser sintering process can be mentioned as:

⇒ a wide range of processing materials – thus flexibility and various functional application being offered;

⇒ nu support structures required – as the part being constructed is surrounded by not sintered powder at all times;

⇒ no post-curing required – as the sintered part is solid enough

⇒ further machining possible – if necessary.

There are, also, disadvantages of the SLS process, involving:

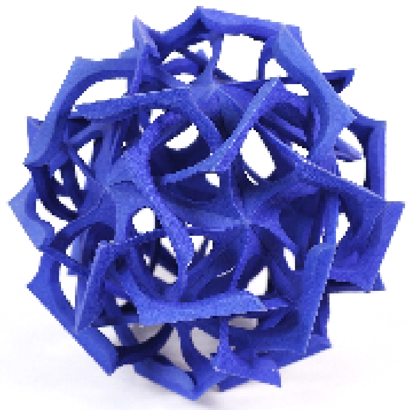
⇒ large physical size of the unit;

⇒ high power consumption;

⇒ poor surface finish – being a sintered part, it results with porous surfaces.

Examples of SLS part are presents in figure 5.23. There can be noticed the complex part structure that can be obtained deduced some of the process application.

[http://www.martello.co.uk]



[http://www.georgehart.com]

Fig. 5.23 Examples of SLS built parts

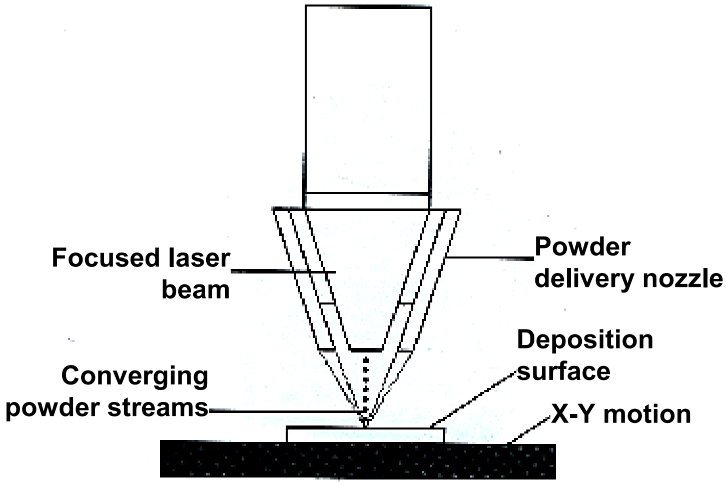
5.5.2 Laser Engineered Net Shaping (LENS)

The *LENS process* is based on blowing metal powders into a melt pool created by a high power laser beam and has been developed by Sandia National Laboratories, while the first commercial system was delivered by Optomec Inc.

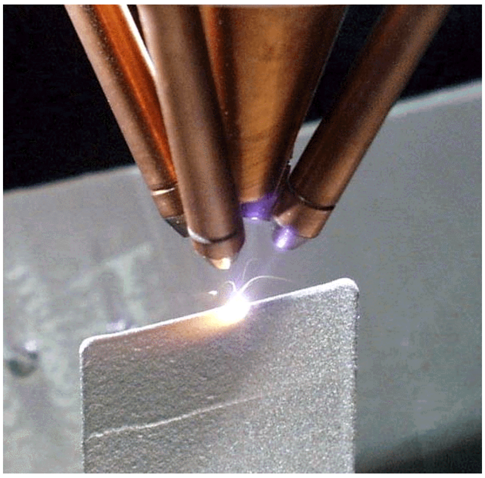
In the Lens Engineered Net Shaping process, a Nd:YAG laser is used to fuse metal powder supplied coaxially to the laser beam focus, through a 4 nozzles deposition head. By a series of lenses, the laser beam is focused to a small spot while the substrate (platform) is moved, by a motion system, in X-Y direction, as derived from a thin layer of the CAD solid model. Once a layer completed, the deposition head moves up and correlated with the laser, a new layer of the part is build.

The metal powder is directed through an argon gas, so that the melting zone to be oxygen free and good layer to layer adhesion.

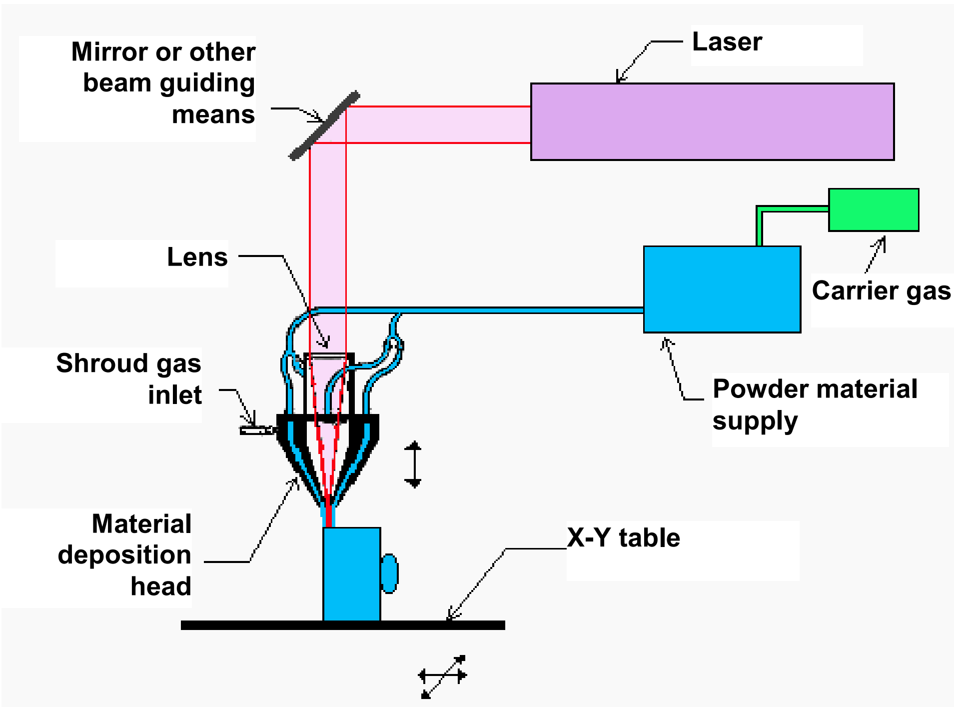
Some schemes of the LENS process and an image of how it works, can be noticed in figure 5.24 (a., b. and c.)



a. [1]



b. [6], [8]
LENS process performing a single-line build



c. [http://www.additive3d.com]

Fig. 5.24 Schematic representation of the LENS system

The LENS process involves relatively low deposition rate but, is special, as it transforms directly raw material into metal parts, without the need on any secondary operations. It also allows obtaining functionally graded materials in high melt temperatures metals, including titanium.

Some advantages of the Lens Engineered Net Shaping process can be mentioned as:

⇒ obtaining superior material properties – high density of metal parts, most with embedded structure;

⇒ ability to produce complex parts;

⇒ few post-processing operations required.

As for the disadvantages, the main ones refer to:

⇒ possibility to obtain only metal parts;

⇒ large area required for the unit and high power consumption

Application of laser engineered net shaping technology includes:

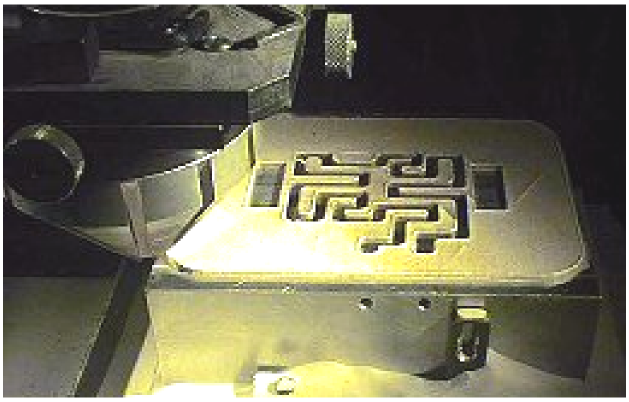
⇒ fixing and repairing broken parts – such as mold tools;

⇒ producing titanium components – for human implants

⇒ obtaining functionally graded structures

Examples of parts repaired or manufactured by LENS are shown in figure 5.25.

Repaired blisk
[http://www.optomec.com]



Injection mold [*]

Fig. 5.25 Examples of LENS built parts

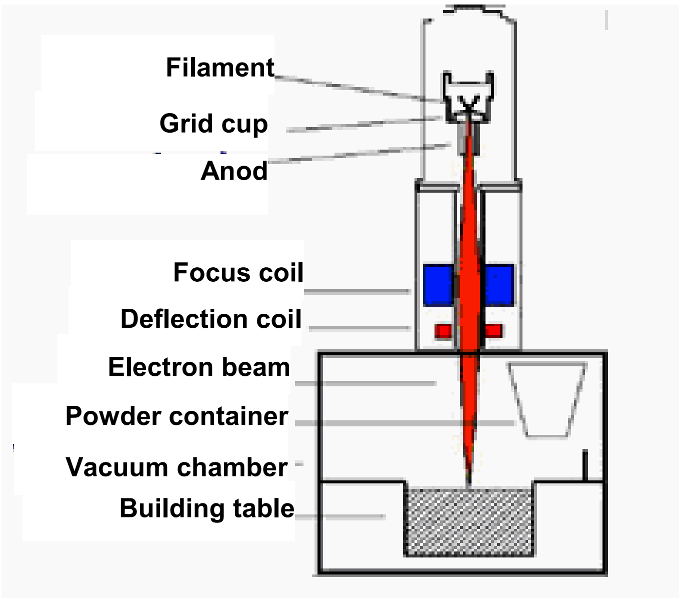
5.5.3 Electron Beam Melting (EBM)

The *Electron Beam Melting technology* was developed by Arcam AB in Sweden and first commercialised in 2001. It ensures obtaining 100 % metal parts, from metal powder, melted by the high energy of an electron beam.

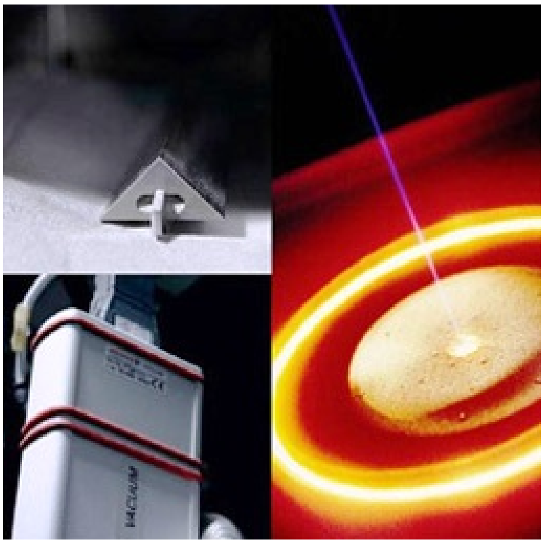
In EBM part is built layer by layer, usually of 0.1 mm thickness, in vacuum. at elevated temperature. First, a thin layer of powder is scraped onto a surface, whose vertical position can be adjusted. Then, the first cross-section geometry is created by the high speed electron beam that bombards the surface and melts the powder together, as directed by the CAD file of the part. After that, the built surface is lowered by one layer thickness and the next layer of powder is scraped on top of the previous. The procedure is repeated until the whole metal part is complete.

For each layer of powder, the electron beam first scans the powder bed to maintain a certain elevated temperature, specific for different alloys. Thereafter the electron beam melts the contours of the part and finally the bulk. The electrons speed is 0.5 to 0.8 times the speed of light, generating heat and causing local vaporization of the material.

A representation of the EBM process can be seen in figure 5.26 (a. and b.)



a.
[http://www.calraminc.com]



b.
[http://www.arcam.com]

Fig. 5.26 Representation of the EBM process

So, it can be noticed that the EBM process involves the aspects mentioned below:

◘ electron beam melting ⇒ each layer being melted to the exact geometry defined by the correspondent cross-section of part's CAD file;

◘ high energy of the electron beam ⇒ allowing high melting capacity and high productivity still, the electron beam is managed by electromagnetic coils which provides higher accuracy than optics and moving mechanical parts;

◘ vacuum system ⇒ providing a base pressure of 10^{-4} bar, or better, throughout the entire build cycle and also, a clean and predictable build environment that is important to maintain the chemical specification of the material used

◘ warming process ⇒ the electron beam, first heats the powder bed to the optimal temperature of the powder and after that melts to create the layer.

There is, also, EBM MultiBeam™ technology that utilizes the extremely fast deflection electronics in the EBM technology. So, melting at multiple locations simultaneously is possible. Carefully controlled energy input at each location leads to finer surfaces.

There are some major advantages of the Electron Beam Melting process, like:

⇒ high power developed by the electron beam and so, there can be fully melt titanium or cobalt-chrome alloys;

⇒ the obtained parts are free from residual stresses and do not suffer from distortion.

⇒ possiblity to manufacture parts with lattice and cellular structures.

Related to these, there can be summarized the benefits of EBM technolgy as:

⇒ free Form for Free – meaning design for function, integrated trabecular tructures for improved bone ingrowth, enabling mass customization

⇒ excellent material properties – referring to controlled microstructure, better than cast, compliant with applicable standards

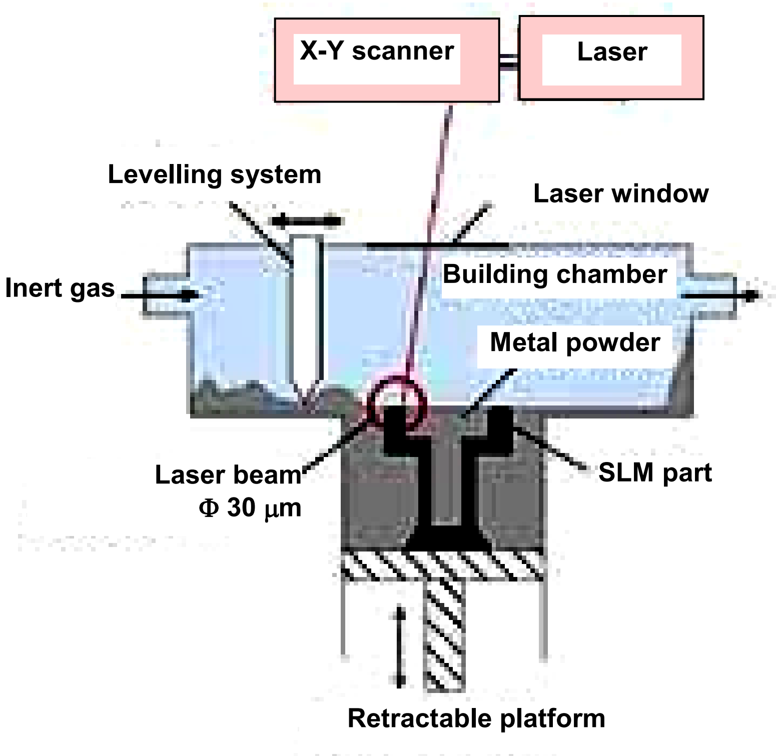
⇒ cost-efficiency – involving high productivity and material recycling

One relevant disadvantage is that the process is limited to conductive materials.

5.5.4 Selective Laser Melting (SLM)

The *Selective Laser Melting* process has been developed and is commercialized by MTT Technologies Group. SLM is an additive manufacturing process, characterised by the use of high power fiber laser to melt fine metal powders together. There are used gas atomised metallic powders, that are fully melted in a tightly controlled atmosphere. The built part is obtained layer by layer, in thickness ranging fro 20 to 100 μm.

A schematic representation of the process is shown in figure 5.27.



. 5.27 Schematic representation of the SLM process [http://www.mtt-group.com]

The Selective Laser Melting process is adequate when very small metal parts with complex structures must be obtained. Due to the fact that metallic powders are melted, not sintered, the parts are fully dense and with good feature resolution. The metallic powders suited for the process include Stainless steel, Titanium and Cobalt chrome.

There are many applications of the SLM manufactured parts, starting with medicine (orthopedics, dental), going to electronics and up to high technology engineering and aerospace.

Examples of parts – with medical or industrial application - are presented in figure 5.28.

Fig. 5.28 Examples of SLM parts [http://www.mtt-group.com]

5.5.6 Three-Dimensional Printing (3DP)

Three-Dimensional Printing process was invented and patented at the Massachusetts Institute of Technology.

It was licensed and further developed by Z Corporation whose products, related to prototypes manufacturing, are *3D printers* (that produce physical 3D models from digital data), *prototyping systems* (that build long lasting plastic prototypes, rivaling injection molded parts) and 3D scanners (that digitize 3D surfaces in real time).

The 3DP process involves shooting droplets of liquid (binder) to a solid compound (plaster or resins powder). By selectively binding of powder together a layer of the model corresponding to the cross-section of the part is formed.

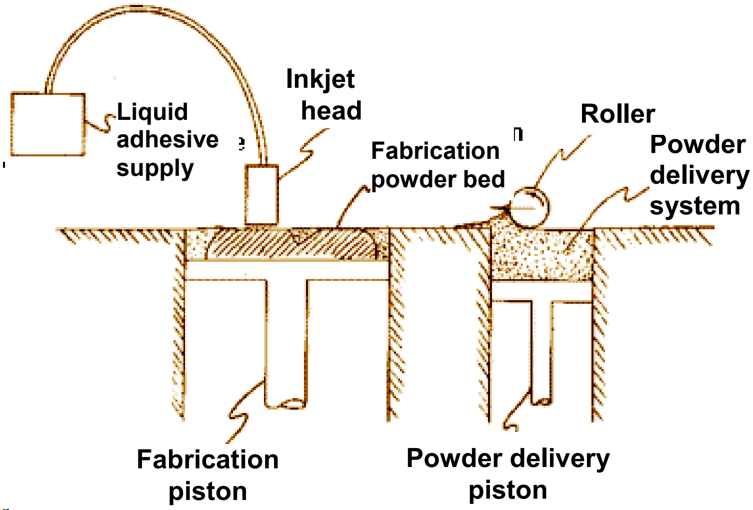
The main steps developed in the process are the following:

- the CAD file of the part to be built is cross-sectioned by machine software
- a first layer of powder is spread to cover the surface of the build piston;
- the print head shoots droplets of binder onto the powder, that is glued together were the binder is printed and, thus, the first cross-section of the part is formed;
- the build piston is lowered, a new layer of powder is spread onto its surface, droplets of binder are shoot and so, the next cross-section is formed;
- the above steps are repeated, until the whole part is built, layer by layer.

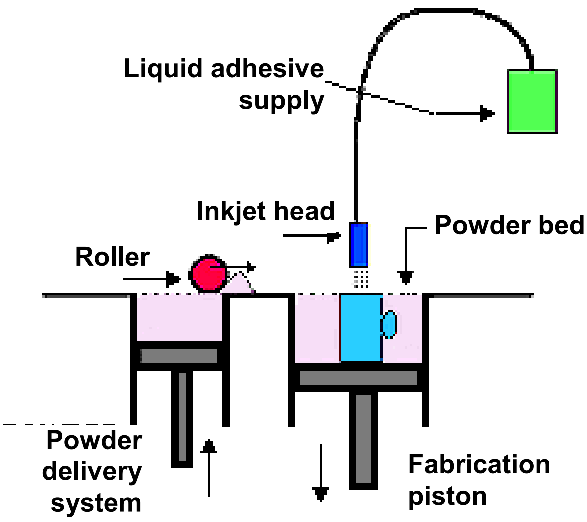
When the building process is over, the part is completely covered and surrounded by loose powder – that, in fact, acts as support for the part's structure. Extracting the prototype out of the powder bed has to be carefully done, not to cause damages of it.

A schematic representation of the process is evidenced by figure 5.29 (a, b. and c.).

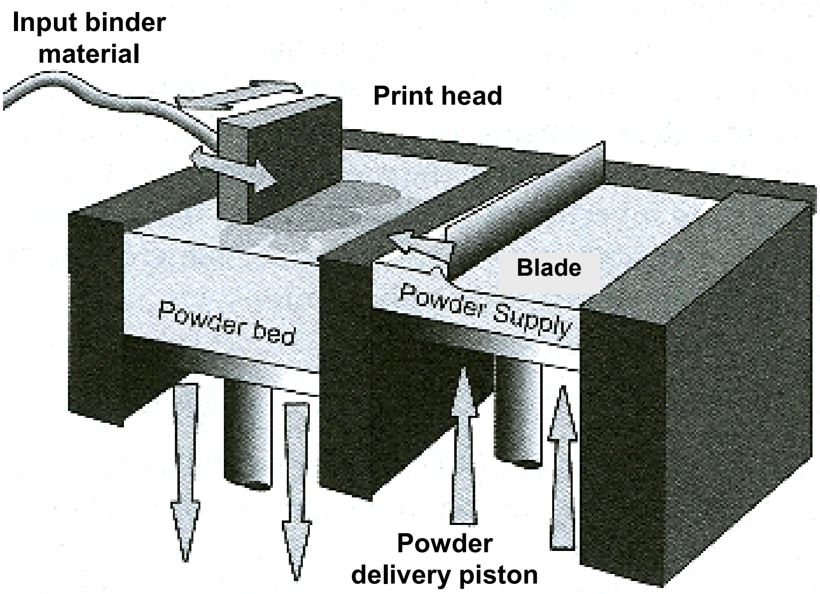
Z Printer Corporation commercializes both monochrome (ex. ZPrinter® 350) and color printers (ex. ZPrinter® 650), the three dimensional printing process being the only one that enables obtaining full color prototypes.



a. [http://www.efunda.com]



b. [http://www.additive3d.com]



c. [2]

Fig. 5.29 Schematic representation of the 3DP process

As mentioned above, Z Printer Corporation commercializes both monochrome (ex. ZPrinter® 350) and color printers (ex. ZPrinter® 650), the three dimensional printing process being the only one that enables obtaining full color prototypes.

Some other advantages of 3DP are evidenced by:

⇒ high speed – it is recognized as the fastest method of rapid prototyping;

⇒ simple to operate;

⇒ low waste rate – the not printed powder can be reused

⇒ wide application - in jewellery, footwear, architecture, design, engineering, etc.

Disadvantages of the process consist in:

⇒ limited functionality – the parts are, relatively, weak;

⇒ limited materials – only plaster-based ones;

⇒ post-processing necessary – for improving surface finish and obtaining a higher strength.

Examples of parts obtained by 3DP technology are shown in figure 5.30.

Fig. 5.30 Examples of 3DP parts [http://www. zcorp.com]

5.6 Rapid Manufacturing

Rapid Manufacturing can be considered either, a quick method of manufacturing final products or, an additive manufacturing process used in the production chain of a final product.

All the aspects presented below involve some similar definitions of *Rapid Manufacturing* (RM) as:

◘ the manufacturing process which creates physical parts directly from 3D CAD files, or data, using computer-controlled additive fabrication techniques without human intervention [www. wikipedia.org];

◘ the use of CAD based automated additive manufacturing process to construct parts that are used directly as finished products or components [2];

◘ producing finished parts for highly-specialized applications direct from 3D CAD digital input, thus dispensing with the costly and time-consuming process of tool making [www.paramountind.com].

There are Rapid Manufacturing similar used terms, like:

◘ *Direct Digital Manufacturing* ⇒ pointing to the fact that finished parts are produced directly from digital data, the 3D CAD models being able to define intricate geometries and finishes;

◘ *On-Demand Manufacturing* ⇒ thus, evidencing customer's important role in defining, almost, any king of part geometry – without restrictions from machining or tooling

RM has known a great development lately, specially because of global economy's challenges, such as fast delivering of products that do satisfy customers' requirements. With a high degree of customers' involvement – if necessary, there can be obtained parts of almost any geometrical complexity, made of metals, ceramics, powders, resins and, even functionally graded materials.

The are important aspects to be pointed out when Rapid Manufacturing is involved, some of them being the one that follows.

► Design freedom

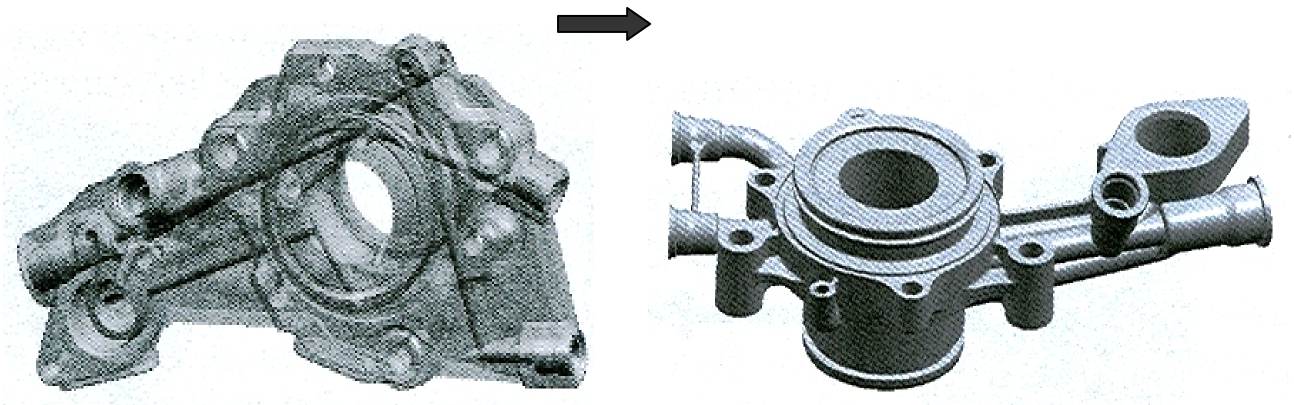
As an additive manufacturing technology, RM is characterized, at least from theoretical point of view, by the ability of obtaining parts, as complex as needed, without the need of additional tooling.

There are some important aspects of the design freedom induced by rapid manufacturing, like:

◘ designing complex parts fully optimized for their function – see figure 5.31;

◘ consolidating many components into one part, thus reducing cost, shortening manufacturing and assembling process, etc. – see figure 5.32;

◘ body fitting customization, mainly referring to some degree of customization for mass market products – see figure 5.33.



Conventional front plate **Design optimised front plate**

(manufactured by Delphi Diesel System)

Fig. 5.31 Optimizing part design [2]

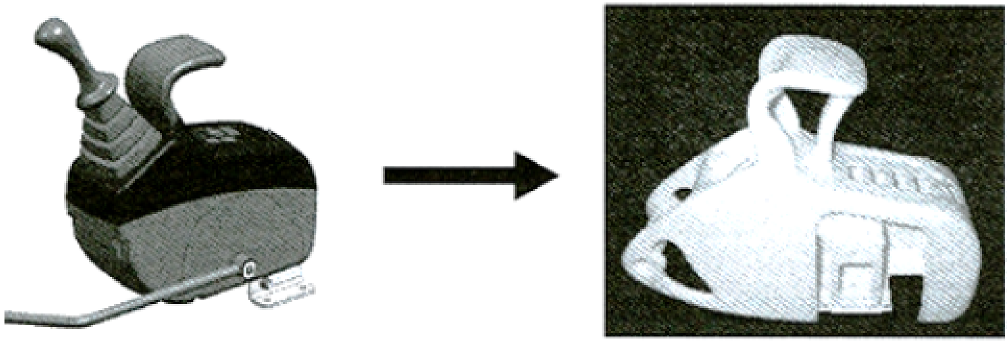
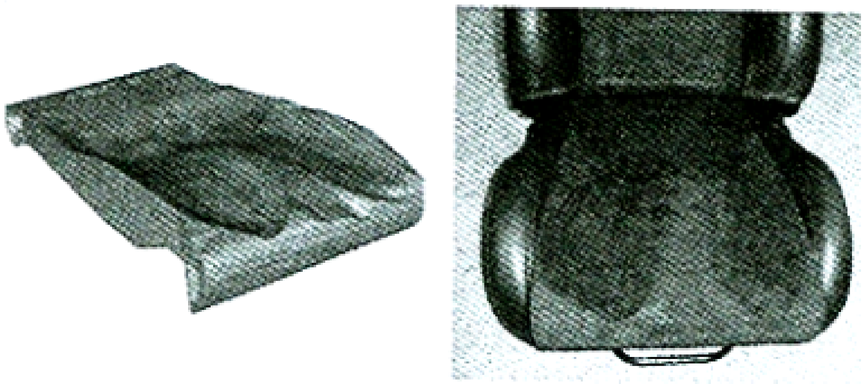


Fig. 5.32 Consolidation of components [2]



Platform **Seat**

(produced for MG SV, by MG Rover Group)

Fig. 5.33 Body fitting part design [2]

In Rapid Manufacturing, with no tool necessary, it is supposed that many of the restrictions like "Design for Manufacture and Assembly" - essential in classical manufacturing (subtractive and / or forming), are valid no more. If usually, designers develop part design with geometry restricted by the ease and possibility of manufacturing, in RM the geometry is no longer a limiting factor. So, due the ability to produce whatever geometrical complexity created in a CAD file, it can be considered the new concept of "Manufacture for Design", rather than the "Design for Manufacture" [2].

Rapid Manufacturing is different from usual manufacturing, because both manufactures and customers are involved. For manufactures, there is the possibility to obtain parts with as complicated geometry as needed, with no tooling and thus, lower costs and reduced manufacturing time is possible. More of it, mass-customization is fitted to the benefits of mass production – meaning the production of unique, one-of-a-kind designs in large quantities. For customers, there is the possibility of configuring products, according to their needs and having them built fast, with acceptable costs.

► Customer input and customization

Customer input is important to product development, as it allows obtaining products fitted to their needs. So, the inputs, meaning customers needs and requirements, may refer to:

- functionality - reliability, performance, etc.;
- ergonomic*s*– ease to use;
- environment – environment friendly, aesthetics (form, color, texture, etc.);
- emotions (feel of luxury, of unique, etc.)

Capturing customer's requirements into product design specification is good, even they come from many or few customers. This can be done, either by asking / questioning potential customers about an existing product / prototype and the new design concept. The results should be analyzed and transformed into specific requirements – product specifications.

There has been developed procedures for closer involving customers into the design process, one proposed by Khalid [7] being an iterative one, such as:

- survey ⇒ identify user needs through a questionnaire;
- focus group ⇒ measure responses to significant needs;
- design ⇒ integrate user needs within the conceptual design;
- simulation ⇒ evaluate the intend use and purchase of the product, by end users.

Customization can be considered as the process of adjusting / manufacturing a product to meet a specific customers requirements.

There are two extremes of customization, meaning:

- producing a product designed for one particular customer
- modifying of one feature of a standard product, for one / a group of customers.

From one extreme to the other, there is the modularization, where a customized product can be obtained by selecting from different options.

Rapid Manufacturing can be used in all cases of customization but, generally, it can be considered that each RM product made is an unique one. In other words, it means that manufacturing would be on a "batch size of one". So, the geometry and, even material characteristics of a part can be changed in accordance to customers needs, without an excessive price increasing.

Knowing that the main reason behind customization is adding value to the product, rapid manufacturing should best be used for customizing features that do add value. There as a value index to be calculated [2]:

$$\text{Value index} = \frac{\text{Extra price paid by customer}}{\text{Cost of customization}}$$

and to decide if, and what feature, to customize.

► Rapid Manufacturing processes

Rapid manufacturing processes are the ones, originally developed for Rapid Prototyping. The involved systems have been continuously developed so that, high accuracy and reliability to be ensured when repeatedly producing of parts There is a tendency for the future, to develop systems that process material within a layer, rather than sequentially, as it is now.

So, with RM, there are frequently used the systems initially aimed for RP, such as: Stereolitography, Fused Deposition Modeling, Laminated Object Manufacturing, Selective Laser Sintering, Electron Beam Melting, Three-Dimensional Printing, etc – see § 5.3, § 5.4 and § 5.5.

Figure 5.34 points out how Selective Laser Sintering process has been developed and gradually has substituted a widely used manufacturing procedure – injection molding.

At Northrop Grumman Corp, in 1997, there was a research program on application of several additive manufacturing technologies to the production of tools for sheet metal forming.

The tooling required is relatively expensive to produce by traditional machining, but layer manufacturing offered great savings. For the most complex dies, used in hydraulic forming and rubber pad forming, fabrication by hand machining required 96 hours whereas stereolithography (SLA) was able to produce the same shapes in 2 hours, a time saving of 98%. The dies were ready to shape metal as soon as they cured [2].

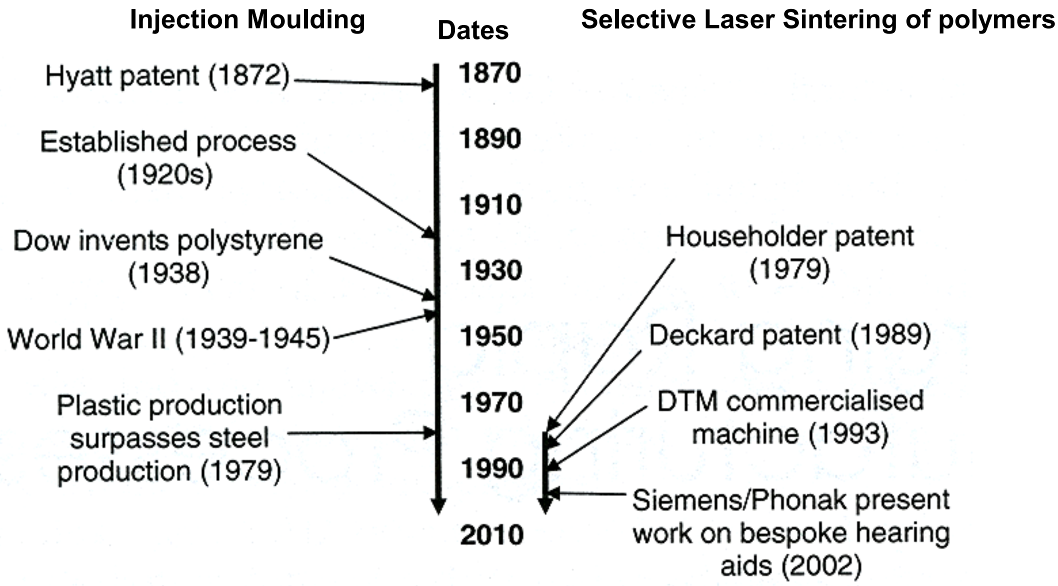


Fig. 5.34 Development of Injection Moulding and Selective Laser Sintering [2]

► Economics

There are two types of economics of the RM, one involving direct production and the other considering manufacturing systems.

The *direct production costs* are considered to be the ones associated with creating physical products from CAD files. So, there should be:

- machine costs ⇒ dictated by machine depreciation and maintenance;
- material costs ⇒ that are higher than the ones for materials machined or injection molded but, there is the benefit of little waste and high material recovery rate;
- labor costs ⇒ which depend on part's complexity and size, of process type and, consequently on further part post-processing.

Using Rapid Prototyping systems for Rapid Manufacturing, generally results in a part production cost beak down [2] of: 50÷75 % - for machine; 20÷40 % - for materials and 5÷30 % for labor.

As for *manufacturing systems economics*, there should be stressed some aspects like:

- the production of parts requires minimum operator involvement, most of the time the machine operating independently, so the majority of costs will result from machine – capital cost, energy consumption, usage, etc.;
- overheads allocation will be to the RM machine – not to labor content (as with machining and injection molding);
- business costs
  – the ability to get products to market quickly allows the company to be a leader,
  - the reduced risk in new product launches because there is no investment in tooling;
  - the ability of fast making design changes, if necessary, ease of bringing the process to market;
- reduction in stock costs – the required stocks are CAD files of the product and the raw material for machine to build it so, there is a good effect on the economics of business;
- elimination of the Work in Progress – as it is carried on the RM machine.
- reduction in logistics – as parts are built locally and, therefore, the need of suppliers may be reduced.

5.7 Rapid Prototyped and Rapid Manufactured Customized Products

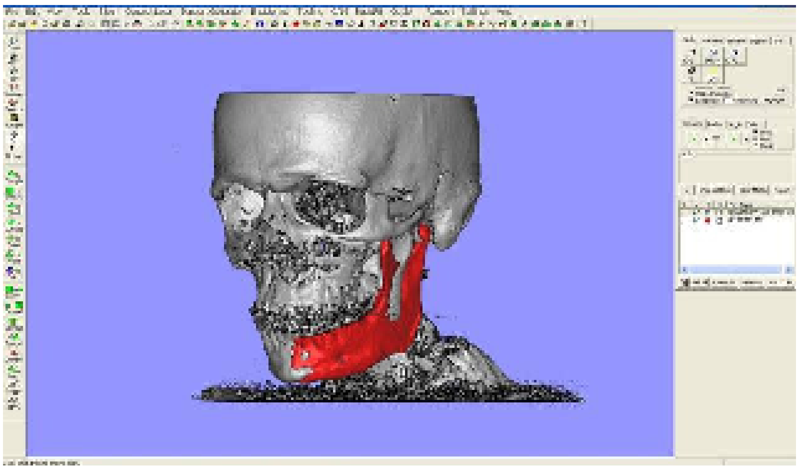
◙ **Example A**

A first example shows how RP technologies were chosen as solution of manufacturing a customized implant used in curing Hemifacial Microsomia**.**

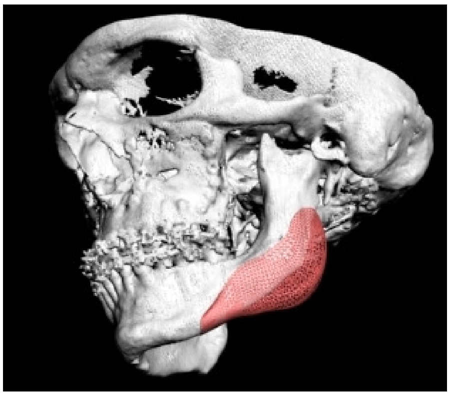
This complex and special work was done by specialists of Faculty of Mechanical Engineering in Maribor and University Clinical Centres in Slovenia, the results being presented in this chapter, courtesy of Igor Drstvenšek [9].

So, an attempt to cure a patient with hemifacial microsomia has been done. This is a severe asymmetry of facial bone and soft tissues in vertical, sagital and transverse plane combined with hearing impairment on the affected side. The goal of the work was to achieve bone symmetry as good as possible and it was decided for a *custom made titanium angular implant*. This was because the implant's material wouldn't allow for bacteria to develop, and would be light enough as the implant remains functional.

The first step was to reconmstruct the structure of patient's bones – skull. Based on traditional computer scanned images and specialised complex software, packages, the skull 3D model was obtained. The idea was to split it in two parts in the middle, mirror the right, healthy, side over the left one and obtain the 3D model of the required implant through Boolean subtraction operations - see figure 5.35 (a.). Due to the facial bone asymmetry the subtracted model could only be used as a reference for further modelling using 3D software – as evidenced by figure 5.35 (b)..



a.
Reference shape for implant design



b.
Virtual model of the implant

Fig. 5.35 Skull 3D model

After final inspection of the 3D model, it was the second step, meaning the skull model was produced out of polyamide using *Selective Laser Sintering (SLS).* Once obtained, the models (skull and implant) were checked for dimensional accuracy and analysed by surgeon – see figure 5.36.

Fig. 5.36   Alteration requirements

The CAD model of the implant was later changed as required by the surgeon who considered the muscle positions and practical demands of the surgical procedure. All details established, the implant model was sent to the *Selective Laser Melting (SLM)* machine to be produced out of Ti6Al4V ELI alloy.

The weight of the implant wais about 6 g, which is quite acceptable, but the compromise was that it had approximately 0,7 mm thin walls, since the desired 0,2 mm walls were too thin for the state of art of SLM procedure.

As conclusion, it can be stated that the presented case study points out the great potential of RP and RM technologies in medical applications, this being one of the first cases of RP implant production and implantation in Slovenia.

◙ Example B

The second example is about showing some application of *Electron Beam Melting Technology (EBM®)* courtesy of Arcam Company [http://www.arcam.com].

It is about obtaining trabecular structures for bone ingrowth in implants and about manufacturing light weight compionents used in aerospace industry.

So, by EBM technology it is possible to design the trademark trabecular structure in CAD and, thus, to optimize it for osseointegration, within the characteristics:

- pore geometry (no limitation);
- pore size (down to ~400 μm);
- porosity (up to ~85%)
- surface friction

with competitive manufacturing costs, usually, less than 2 € / cm^3 trabecular structure – see figure 5.37.

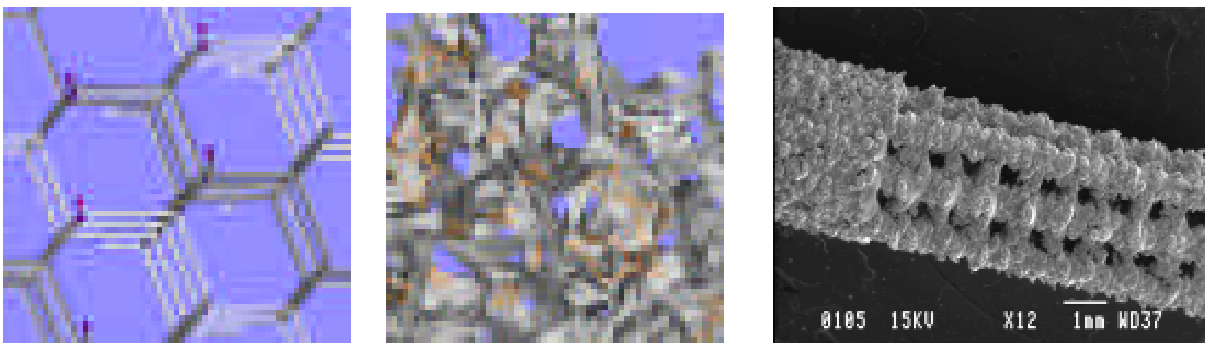


Fig. 5.37 Trabecular Structures™ - to be continued

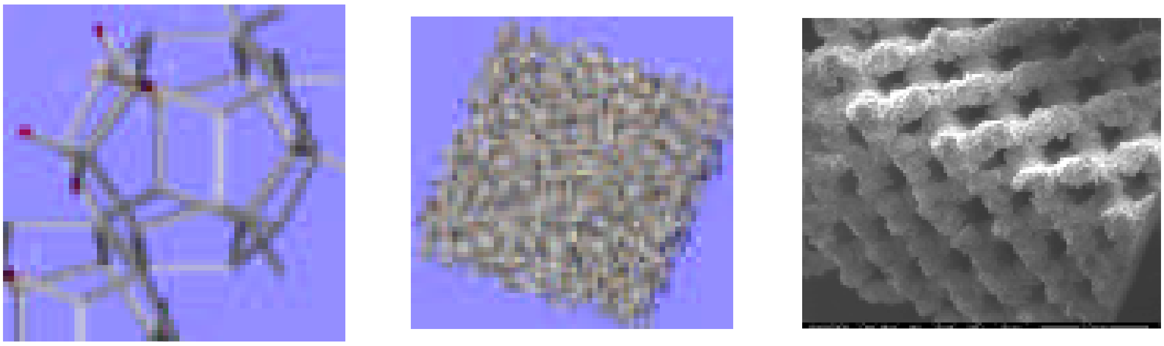


Fig. 5.37 Trabecular Structures™

The volume production of EBM-manufactured, *CE-certified orthopedic implants* is now reality and well over 10.000 orthopedic implants produced with EBM technology have been implanted.

The most important production benefits are the following ones:

⇒ single-step production of solid and porous sections with structural continuity between them;

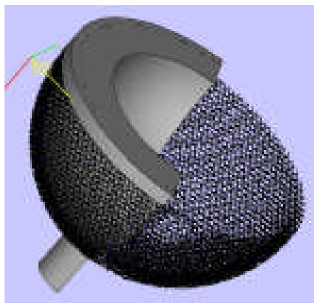
⇒ all-porous implants possible (augments, wedges, etc);

⇒ no secondary high temperature process to apply the porous structure that could cause grain growth;

⇒ high build temperature gives low residual stress, and no need for heat treatment after the build

In production there are several implant categories, as: acetabular cups, revision cups; augments; femoral stems; spine - some examples of EBM manufactured implants are shown in figure 5.38.

Acetabular cup
Lima-Lto, IT - 2007



Acetabular cup
OEM X, YY - 2010

Acetabula cups
Adler Ortho, IT – 2007
Material: Ti6Al4V

Revision cup
Delta TT™
Material: Ti Grade 2

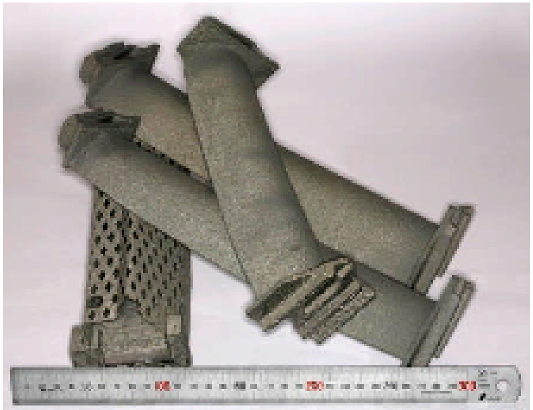
Lumbar PLF Cage
FUSE™
Material: Ti Grade 2

Fig. 5.38 Implant EBM manufactured parts

Arcam's EBM technology does represent a right solution for manufacturing *custom parts* used in *aerospace industry*.

This is either because of its charatersitics as additive manufacturing technology (constant design iterations, geometric design complexity, application of new materials) and, because of its advantages (high productivity, excellent material properties).

Some EBM manufactured parts, used in aerospace industry are shown in figure 5.39.



Turbine blades
Material: γ-TiAl
Building time: 7 hours / blade

Aerospace Prototype
Material: Ti6Al4V
Building time: 40 hours

Fig. 5.39 EBM manufactured aeospace industry parts

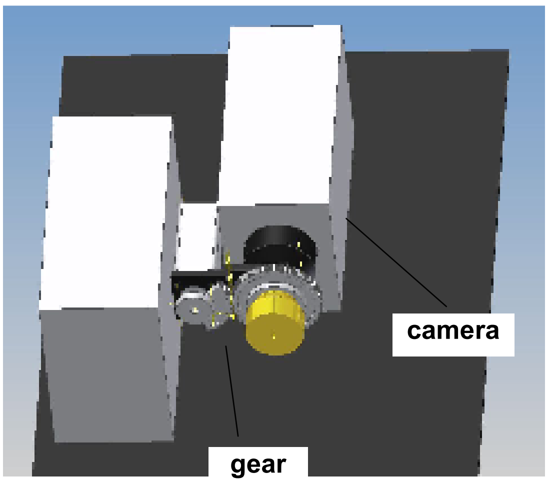
Example C

The third example is about modelling, simulation and 3D Printing in developing a customized remote control system [10]

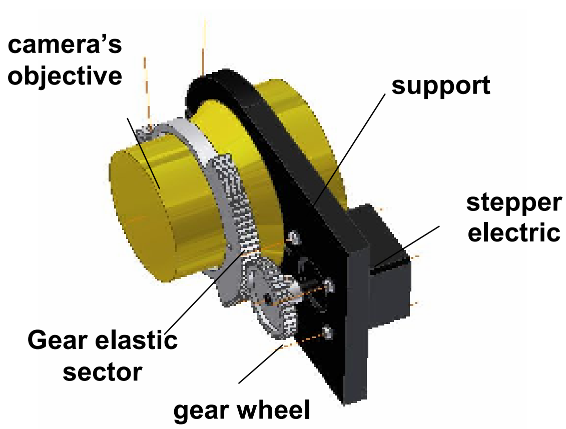
This system is used in a more complex assembly for optical measurements (ex. surface roughness, dimensions and geometric profiles) or for taking video images / pictures of special processes (ex. combustion analysis, temperature field, failures and cracks propagation).

The objective of a photo or video camera has to be remote activated, through a stepper motor, and thus, the system rotating the aperture ring has to be carefully designed and manufactured.

Its schematic representation can be seen in figure 5.40 (a. and b.)



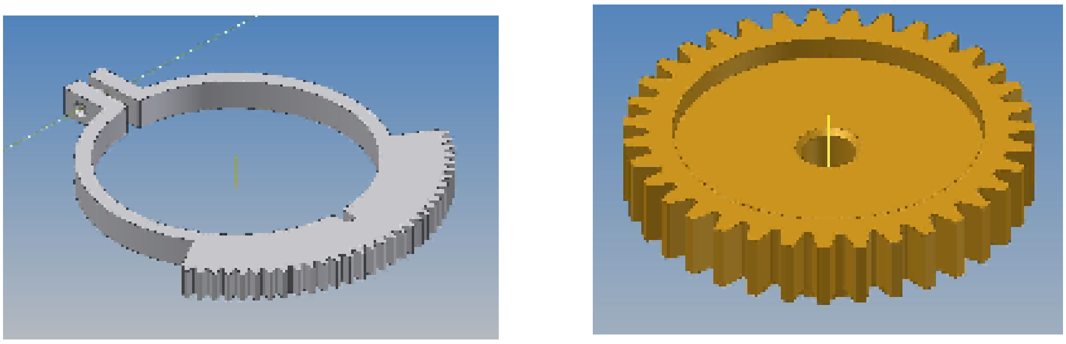
a.
assembly drawing



b.
sub-assembly drawing

Fig. 5.40 Drawing of the remote control system

Component elements whose development is presented further, refer to the gearing sub-assembly, meaning the elastic element and the wheel - see figure 5.41.



Elastic sector **Wheel**

Fig. 5.41 Gear components CAD drawings

To rotate the aperture ring with one position it is necessary to choose the number of steps and command. In micro stepping, the number of steps necessary to command the motor must be multiplied by (2/4/8).

A special software (SolidWorks) was used to model and simulate the rotational movement generated by gear component elements (figure 5.42) and to analyse the bending stresses and strains that do occur while loading (in gearing).

The tooth selection and loading for the elastic sector and wheel can be seen in figure 5.43 and, respectively, in figure 5.44. There should be mentioned that the generated meshes resulted in 28.068 nodes and 16.522 finite elements – for the elastic element, and 27.650 nodes and 15.715 finite elements – for the elastic element.

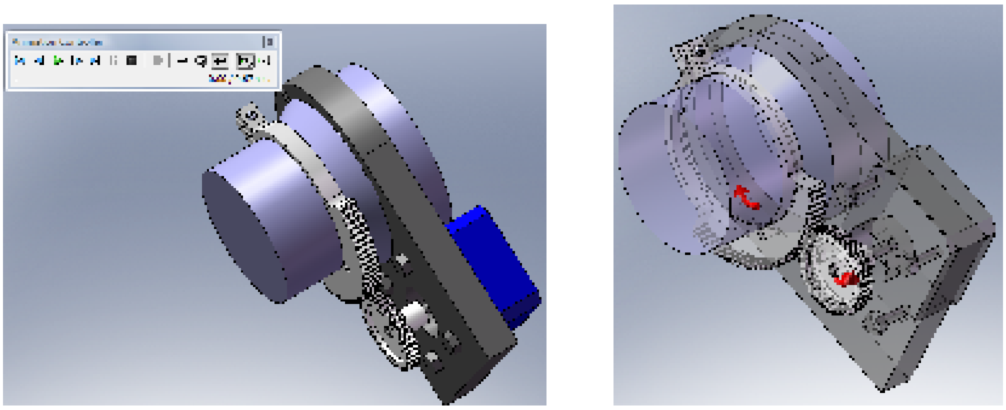


Fig. 5.42 Parts and trajectories involved in simulation

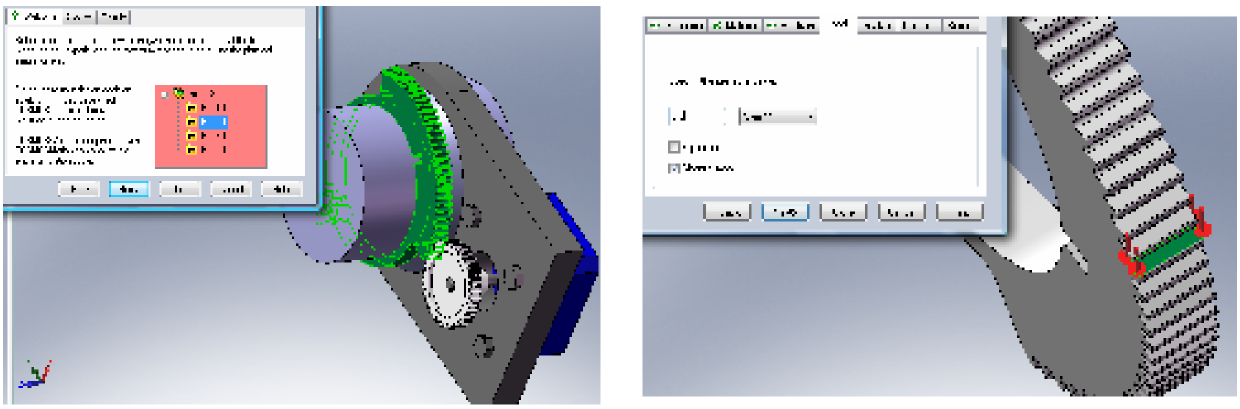


Fig. 5.43 Selection of elastic sector's tooth loading

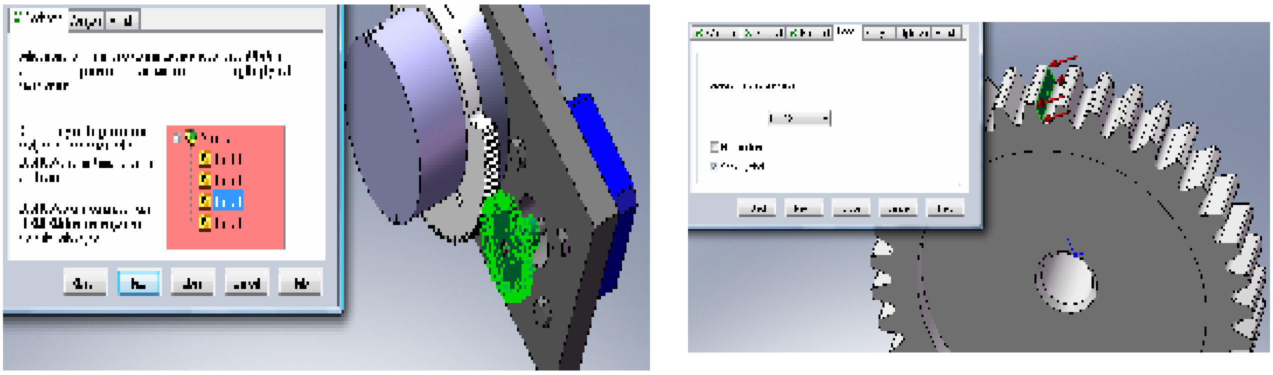
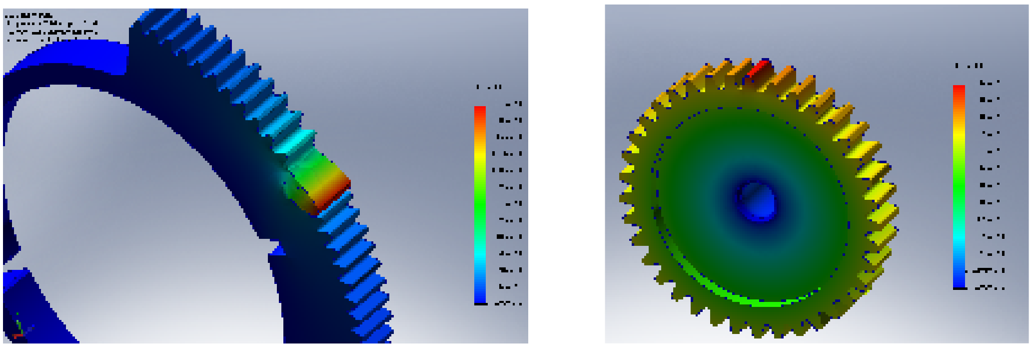


Fig. 5.44 Selection of wheel's tooth loading

Results of teeth displacements distribution are shown in figure 5.45. One can notice that there is too high displacement for the tooth, specially that of the elastic sector which is over-loaded, so re-dimensioning it is necessary.



Elastic sector **Wheel**

Fig. 5.45 Teeth displacements distribution

Once all necessary changes in component elements design being made, the next step of further developing the customized remote system was done. It that involved rapid prototyping, more specifically, *three-dimensional printing*

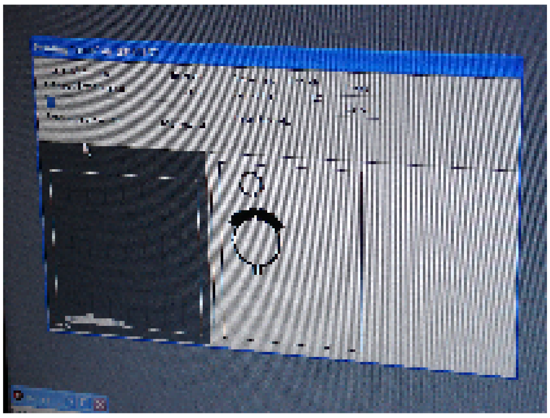
The prototypes were obtained on a ZPrinter 310 Plus machine and the materials used were:

- Zp®131 powder ⇒ material to be bond by printing;
- Zb 60 ⇒ binder solution;
- Z-Max ⇒ a high strength epoxy resin, meaning the material used for making the prototype hard enough to be handled and, if necessary, further machined.

The printing machine software enables (based on CAD parts drawings) preliminary calculi of important process parameters, such as:

- models height (15 mm);
- layer thickness (0.1016 mm);
- number of layers (147);
- estimated build time (25 minutes);
- estimated binder usage (10,6 ml);
- - total volume of models (19.47 cm^3), etc.

Images taken while the 3D printing process is on, are evidenced by figure 5.46.



Machine's computer screen

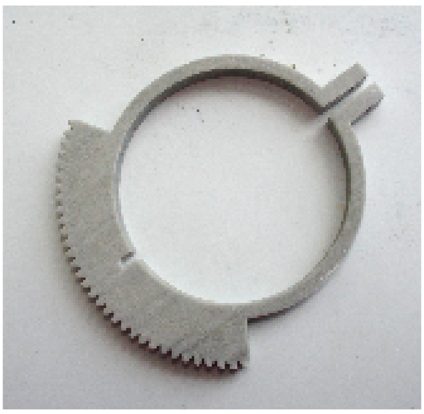
Machine's building chamber

Fig. 5.46 3D Protoyping process

Once the prototyping process over, the prototypes were carefully extracted (figure 5.47) and then, cleaned off the remaining powder. After that, they were heated into an electric oven (for complete dry) and impregnated with the resin (for hardening),

Fig. 5.47 Extraction of prototypes

The prototyped parts can be noticed in figure 5.48.



Elastic sector

Wheel

Fig. 5.48 Rapid prototyped customized parts

When all the other parts of the remote control system were prototyped, the assembly could be "put together" and checked if the component elements fitted and the system worked right.

So, it was noticed that the gearing was right, meaning the wheel and the elastic gear sector rotated the same angle and there was not too high clearance between their corresponding teeth. But, still, the elastic sector did not fit the camera's objective too well, meaning that:

◘ if the sector was tightened on the objective (to avoid slipper when rotational way changes), the objective could move no more;

◘ if the sector was large enough on the objective to allow movement when reversing the rotation, there was a free rotation of the sector (for few degrees), without the objective's rotation.

That is why, some adjustments to the inner diameter of the elastic sector had to be done.

The conclusion of the example presented is that, when developing the customized remote control system, some important changes of parts design could be made prior to manufacture, thus enabling important costs savings.

So, by *modelling and simulation* there was evidenced the need for re-dimensioning, so that the elastic sector's teeth could resist to loading in gearing. By *rapid prototyping*, the situation was much "closer" to real working condition and, thus, was proved the need for adjusting the inner cylindrical part of the elastic sector, so that to correct fit the camera's objective.

.◙ Example D

This fourth example presents the application of *3D printing rapid prototyping technology* in a laser device components fabrication [11].

The device is used in urology - for splitting kidney stones and in surgery - for fixing damaged bones. The laser involved is solid state holmium one, with a THC:YAG rod emitting at 2100 nanometer, with 20 watts power and 250÷350 microseconds pulse duration.

A schematic representation of the studied laser device is shown in figure 5.49, while a detailed representation of the components to be prototyped (connecting piece and side cap) is presented in figure 5.50.

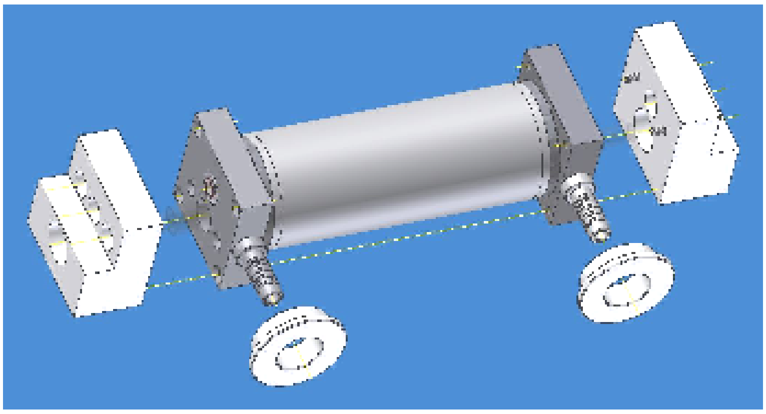


Fig. 5.49 Assembly drawing of the laser device.

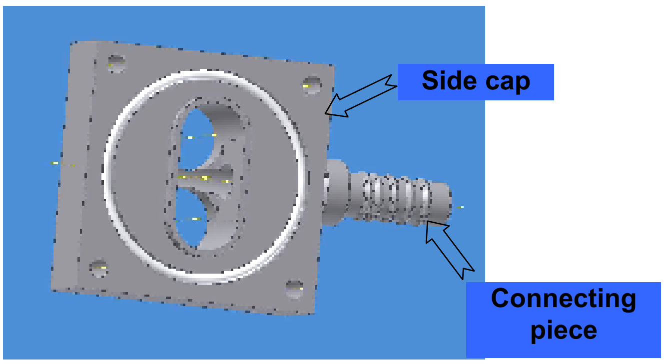
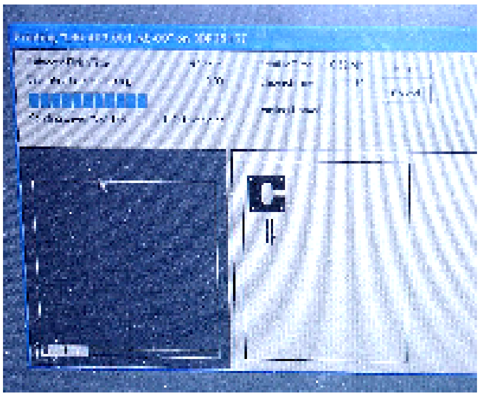


Fig. 5.50 Drawings of the parts to be prototyped

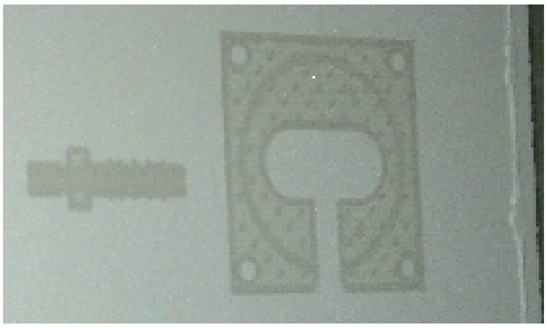
The *3D Printing system* was the following one:

- printing machine ZPrinter 310 Plus (Z Corporation);
- materials used for rapid prototyping, that are: Zp®131 *powder* (high performance composites for tough parts and very good resolution); Zb60 *binder solution* and Z-max *high strength epoxy*;
- compressed air cleaning enclosure;
- electric oven.

While prototyping, layer thickness has been set at 0.01 mm and so, the estimated building time has been indicated (by machine software) of 21 minutes. Images taken while the process is on are shown in figure 5.51.



Machine's computer screen

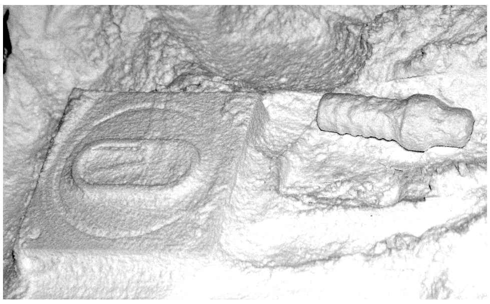


Machine's building chamber

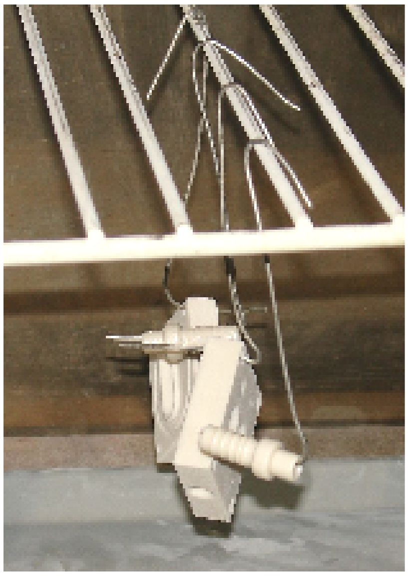
Fig. 5.51 3D Protoyping process

After the process is over and, the required waiting time has passed (so that the built powder hardens a little) the prototypes are carefully extracted and cleaned out of the remaining powder, into the special enclosure Drying into the oven and, then, impregnating by a mixture of special binder and high strength epoxy are further steps required to obtain a hard, and ready to use prototype part.

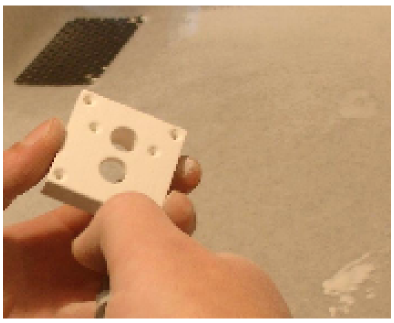
All of the above mentioned steps are evidenced by figure 5.52



Extraction of prototypes



Electric oven drying



Compressed air cleaning

Hardening by impregnation

Fig. 5.54 Further steps in 3D Prinitng – once prototypes removed from the machine building chamber

It should be mentioned that the studied parts (side cap and connecting piece) must join together by a thread assembly type. The thread could not be obtained by prototyping as, it would have been almost impossible to extract the models out of the powder without damaging the threaded part. So, the threads were obtained on a drilling machine, after hardening and drying.

The 3D printed parts are presented in figure 5.53.

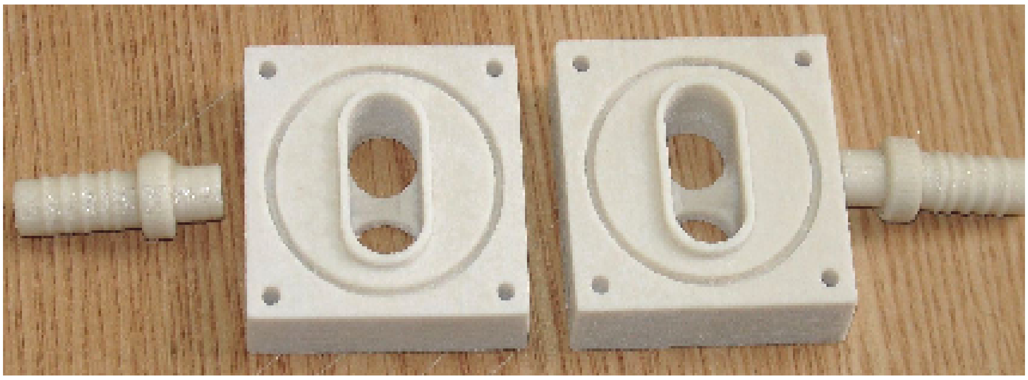


Fig. 5.53 Three-dimensional printed customized parts

All the other components of the laser device were similarly obtained by ink-jet printing rapid prototyping. When trying to fix them together, problems, dealing with parts geometry and dimensions, have been noticed.

One of them refers to the cooling fluid. Through each of side cap's main central holes there is special glass tube that isolates the laser flash and, respectively, active medium (Holmium) from the other components. Through the connecting piece there is the entrance / exit of the cooling fluid – unionized water, that maintains appropriate temperature of laser "body". While joining the prototyped parts, it was noticed that the cooling fluid could not "get" into both of the glass tubes, as they were too long and their end restricted the fluid access.

Another problem was that the shape of the parts "flushed" by the cooling water did not fit tight so, there was fluid spread away. Thus, there was evidenced the need of using special insulating elements, such as O-rings.

As conclusion of the example, it should be mentioned the fact that by 3D Printing it was possible to discover some errors in the design of component elements of an innovative laser device. So, there have been saved time (about one month) and money but, more important, there was no waste of very expensive special materials – needed for real laser device's component elements.

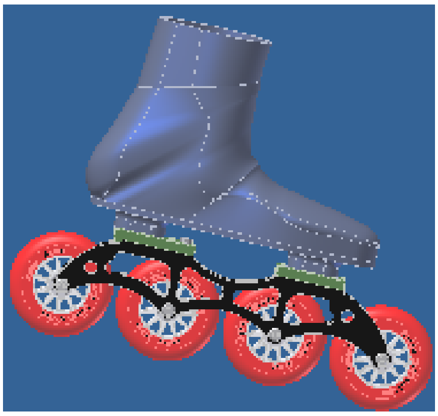
.◙ Example E

This fifth example is about an innovative system that enables roller skates and ice skates to be easily and safely in use, with minimum effort [12].

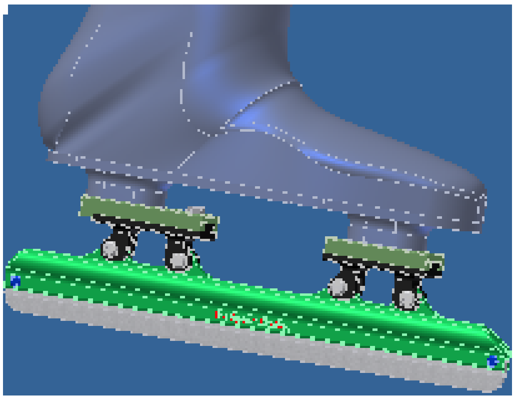
The idea of developing a system enabling to attach on the same boot, of both rollers and ice blades came after studying the existing patents and market offers in the field. There were registered many users' complaints, as:

- ◘ the high weight that reduces the speed when skating;
- ◘ the low precision of blade and rollers orientation systems;
- ◘ the difficulty of joints between the boot and the supporting system. of rollers and blades
- ◘ the long time of turning from ice skates to roller skates.

Images of the new system components, designed with Autodesk Inventor 2010 software are presented in figure 5.54.



Roller skates



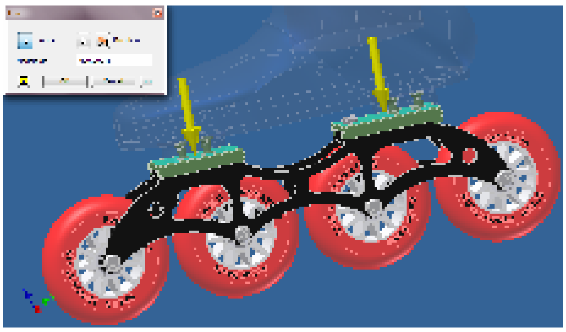
Ice skates

Fig. 5.54 3D drawing of the innovative system – available for both types of skates

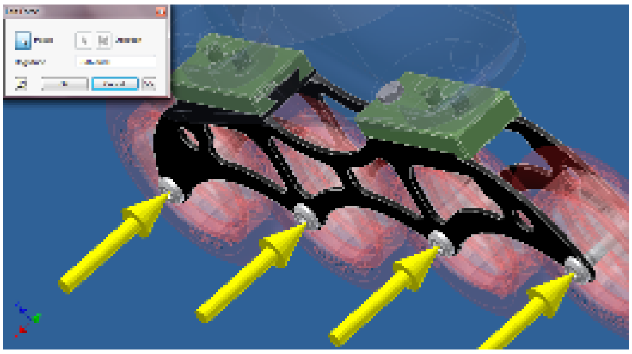
In order to complete the system's components design, simulation of different loading cases has been done under the assumptions of:

- a 80 kg weight person;
- real situations in skating, like:: *steady position*, *starting the motion*, in *motion* (rolling/sliding) and *braking*.

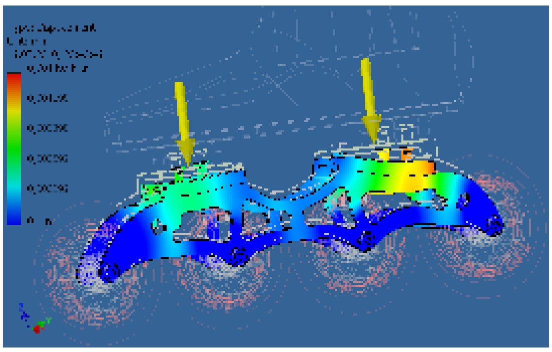
Examples of the obtained results are shown in figure 5.55 (for roller skates) and in figure 5.56 (for ice skates).



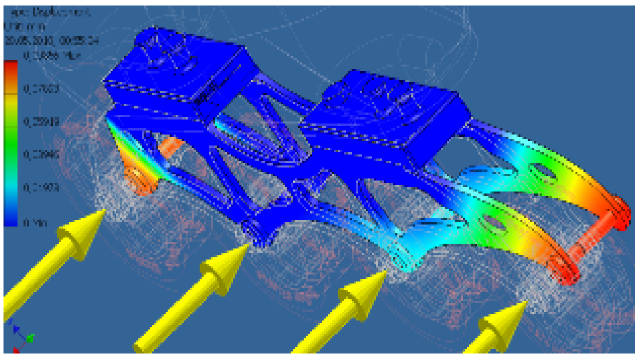
Rollers' support compression simulation



Rollers' support bending simulation

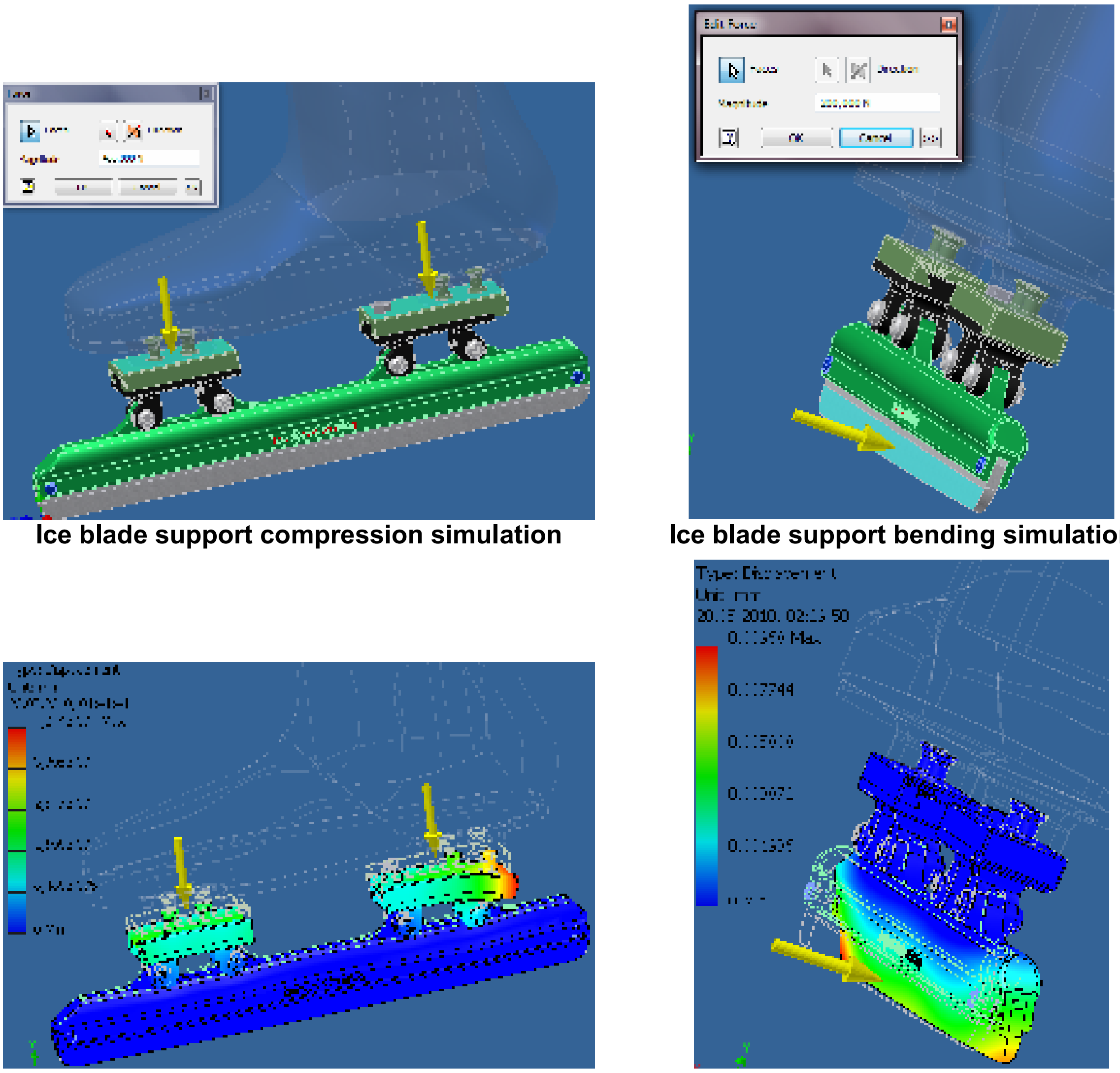


Generated strain simulation
- Steady Position -



Generated strain simulation
- Braking -

Fig. 5.55 Roller skates components in simulation



Ice blade support compression simulation **Ice blade support bending simulation**

Generated strain simulation - Steady Position - **Generated strain simulation - Braking -**

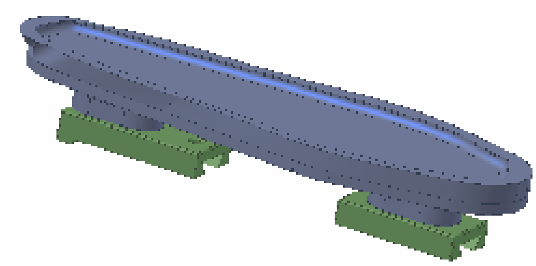
Fig. 5.56 Ice skates components in simulation

Once all important aspects of component elements behavior – resistance and deformation – being settled, further step in system's developing has been carried on. It involved *three-dimensional printing* rapid prototyping.- useful in testing real bevahour of the product, before patenting and production.

It was used a ZPrinter (Z Corporation) machine – see, also, Example C and Example D.

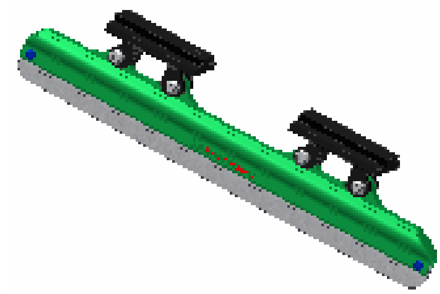
The goal of prototyping was to test how correct and efficient the proposed system was, when "transforming" the skates – from roller to ice ones. That is why, there have been prototyped the three main sub-assemblies, shown in figure 5.57. It can be noticed that, for materials economy reason (powder, binder, resin), the boot was not completely prototyped, but only its lowest part – the one that joints with rollers / ice blade support

3DP machine's software does enable a thorough analysis of part's design, before prototyping – as shown in figure 5.58. This is about discovering any potential miss-definitions of its surfaces, both interior and exterior ones, that would lead to errors in prototyping.



Boot's lower part sub-assembly

Rollers support sub-assemlby



Ice blade support sub-assemlby

Fig. 5.57 System's sub-assemblies to be prototyped

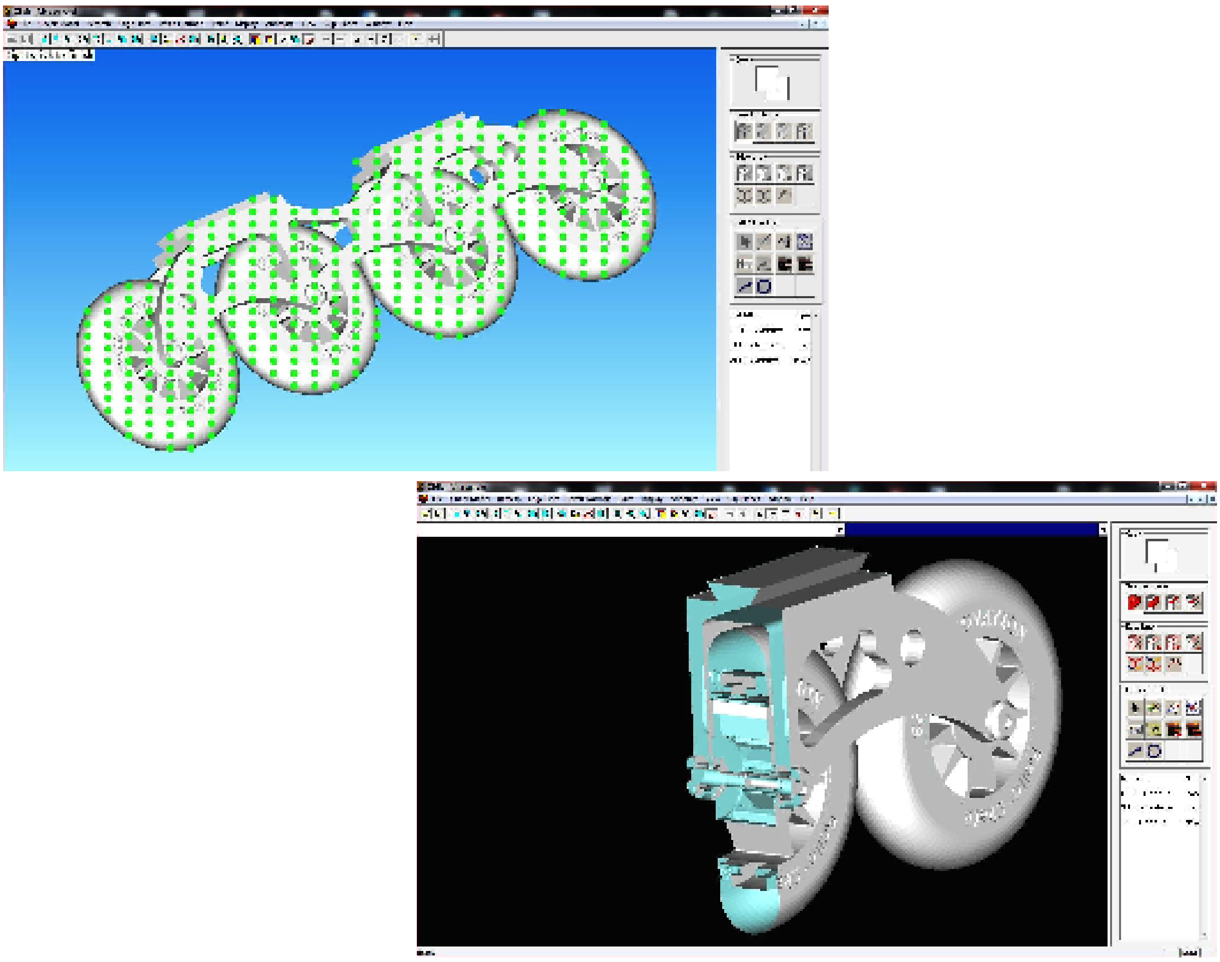


Fig. 5.58   Machine's software analysis of part design

It is also the machine's software that allows an estimation of materials consumption (powder and binder), as well as of the time required for obtaining a correct and reliable prototype – see figure 5.59.

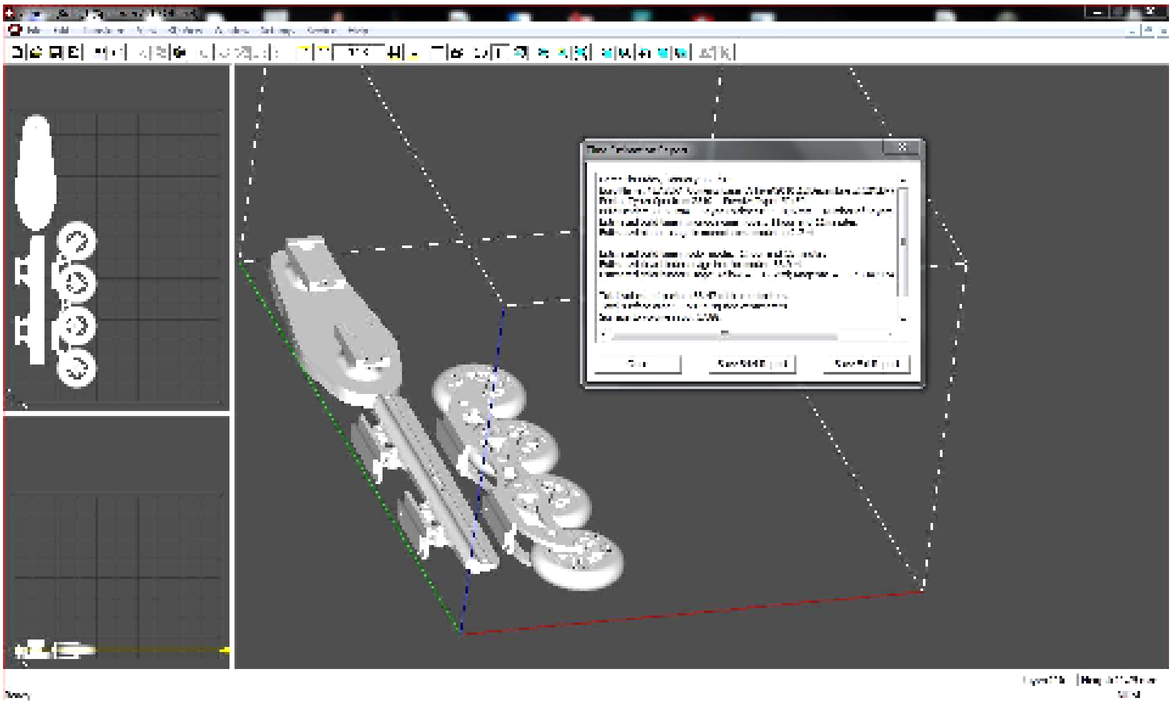


Fig. 5.59 Machine's software estimation of time and materials consumption

So, once prototypes obtained, tests were done to check on system's accuracy and efficiency. Fortunately, the lower part of the boot fitted tight to, both rollers and ice blade supports. The time for turning the roller skate into the ice skate was low enough and, without any disconfort in maneouvring

Figure 5.60 shows the 3DP prototyped components– after hardening (by the binder) and drying (inot the electric oven).

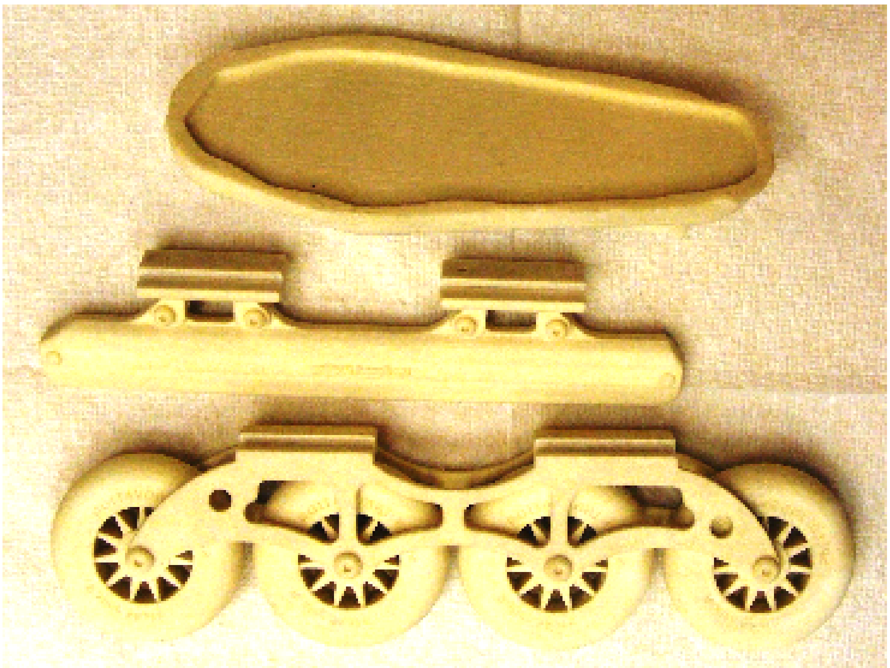
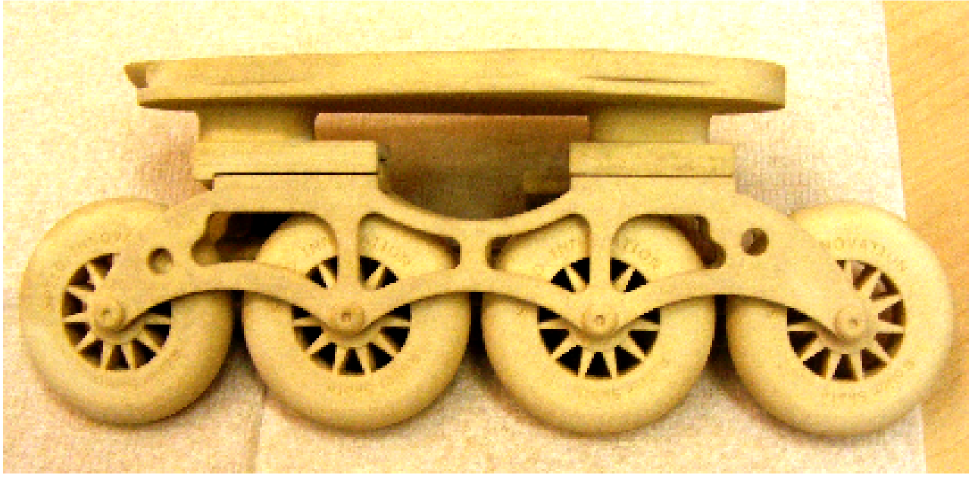


Fig. 5.60 3DP prototyped sub-assemblies - to be continued



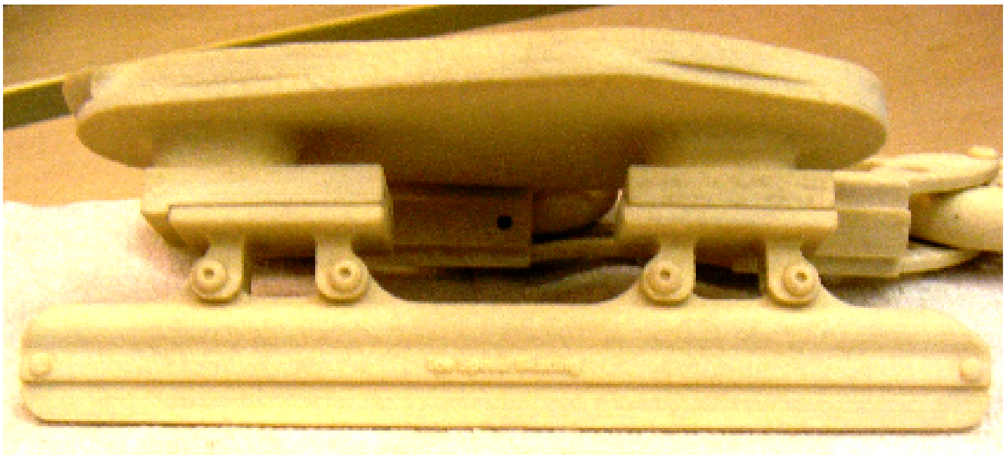


Fig. 5.60 3DP prototyped sub-assemblies - to be continued

Conclusion of all the information in this chapter should be summarized as:

⇒ prototype's role in the product development process is, with no doubts, very important;

⇒ rapid prototyping is a relatively new technique of building prototypes – its greatest advantage being that of allowing obtaining products with almost any geometrical complexity and in, relatively, good efficiency;

⇒ rapid prototyping systems do cover a large spectrum of part building processes, and involve the use of vary different materials;

⇒ rapid manufacturing is mainly based on rapid prototyping techniques, being considered a quick method of manufacturing final products;

⇒ examples shown do point out the importance and benefits of rapid prototyping and rapid manufacturing in the development of a successful product.

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http://www.cs.cmu.edu

http://www. plynetics.com

http://www.lasersintering.com

http://www.martello.co.uk

http://www.georgehart.com

http://www.optomec.com

http://www.calraminc.com

http://www.arcam.com

http://www.mtt-group.com

http://www.mtt-group.com

http://www. zcorp.com

http://www.efunda.com

6. CNC MACHINING AND MICROMACHING

6.1 General Aspects of CNC Machining

The concept of *Numerical Control* (NC) is related to John T. Parsons, and refers to the automation of machine tools that are operated by abstractly programmed commands encoded on a storage medium.

First NC machines were conceived in the '40s, by using motors to move the existing tools as to follow points fed into the system on punched tape. These early servomechanisms were improved with analog and digital computers, creating the modern *computer numerical controlled* (CNC) machine tools that have revolutionized the manufacturing processes. So, curves are as easy to cut as straight lines and complex 3-D structures are relatively easy to produce [www. wikipedia.com].

In modern CNC systems, by *computer-aided design* (CAD) and *computer-aided manufacturing* (CAM) programs, it is generated a computer file that is interpreted to extract the commands needed to operate a particular machine via a postprocessor, and then loaded into the CNC machines for production. By CNC automation it was reduced the frequency of errors and provided CNC operators with time to perform additional tasks. It also allowed for more flexibility in the way parts are held in the manufacturing process and for reducing the time required to prepare the machine to produce different components.

Since, in production, any particular component might require different machining procedures, a series of machines may be combined into one station, commonly called a *cell* - so that, progressively, the component to be "built". There are other cases when a number of different machines are used with an external controller and industrial robot systems to perform many kinds of machining operations. So, hundreds of parts can be made on weekend by a machine with no operator, each part being checked with lasers and sensors.

Examples of CNC machines and machining centers are presented in figure 6.1, while CNC manufactured parts can be seen in figure 6.2.

- highly accurate and smooth-running;
- modular built CNC machine, with CNC path control;
- good dynamics and a ideal price / performance ratio.

- designed for training and small- series production.
- suitable for milling, drilling, cutting, engraving, measuring, positioning.
- wood machining
- schools and Education
- model making
- jewelry Industry
- advertising Industry

EuroMod CNC Machine
[http://www.cnc-machines.isel.com]

Fig. 6.1 Examples of CNC machining centres – to be continued

Haas VF-5SS: 5-AXIS Vertical Machine Center
[http://www.acmanufacturing.com]

- a machining center that combines innovative design principles, unique control features and quality construction to make it simple, versatile and affordable;
- the ability to machine complex shapes, undercuts and difficult angles in a single setup reduces tooling cost and labor time.

Nakamura Tome Slant TMC-300C
[http://www.acmanufacturing.com]

-two-axis Slant Bed CNC Turning Center;
- CNC Lathe 300 mm, 15 HP wide range motor
- box type slides and rigid turret
- quick change tooling

Matsuura MC-500V PC-2S
[http://www.acmanufacturing.com]

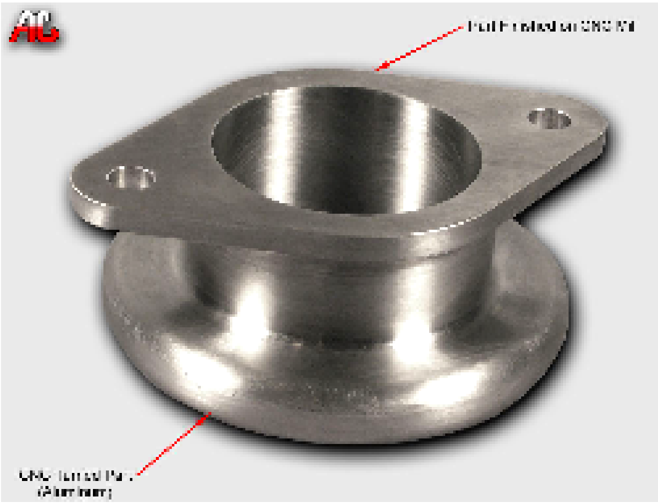
- twin pallet vertical CNC machining center with magnetic spindle installation;
- a three axes vertical mill center with magnetic spindle capable of high speed machining;
- on-line signal analysis;
- closed-loop machining system control.

Fig. 6.1 Examples of CNC machining centres – to be continued

NVX5000 SERIES – vertical machining center
[http://www.moriseiki.com]

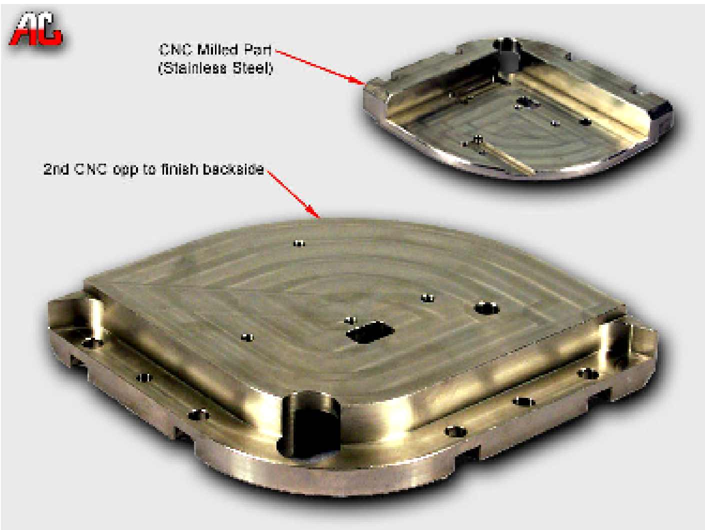
- the machine offers high machining ability and accuracy;
- is designed to reflect feedback opinions for the conventional models, achieving a high level of reliability;
- slideways that are used for all axes control residual vibration and improves dynamic rigidity.

Fig. 6.1 Examples of CNC machining centres



[http://www.acmanufacturing.com]

- aluminum part turned on our Nacamura Tome and finished on Matsuura mill.
- it is an example of an automotive performance part made for a customer whose work and hobby were to improve racing techniques.



[http://www.acmanufacturing.com]

- stainless steel part, originally started as a raw stock of steel;
- customer specification to hold flatness within 0.001" and most of the material removed in an odd shape involved two stage roughing process on both sides;
- after that this part was finished to perfection.;
- some holes had to be reamed to customer specifications at +0.0002/ -0.0000.

Fig. 6.2 Examples of CNC machined parts

6.2 CNC Machined Customized Parts

◙ Example A

The first example is about modelling and simulation of manufacturing a custom part, made of cast iron. Initially, it was machined on conventional drilling and milling machines but, the time required and the accuracy were not too good. The customer asked for a simulation on EuroMod (Isel®), so that estimation of costs and time consumption to be done and thus, to decide if it would be better to build the part by CNC machining.

The Isel-automation system available for simulation is made of four basic components, mentioned below [http://www.cnc-machines.isel.com]:

- *isy CAM2.5* software ⇒ Windows-based CAM software for 2D and 2.5D engineering and manufacturing tasks;
- *Remote* ⇒ universal control program for outputting files into the machining- processes
- *ProNC* ⇒ operating and output software for executing NCP files;
- *E*uroMod ⇒ highly accurate and smooth-running, modular built CNC machine, with CNC path control, good dynamics and a ideal price/performance ratio.

The part drawing is shown in figure 6.3 and images from simulation – of the cutting tool trajectory and machining the surfaces are presented in figure 6.4.

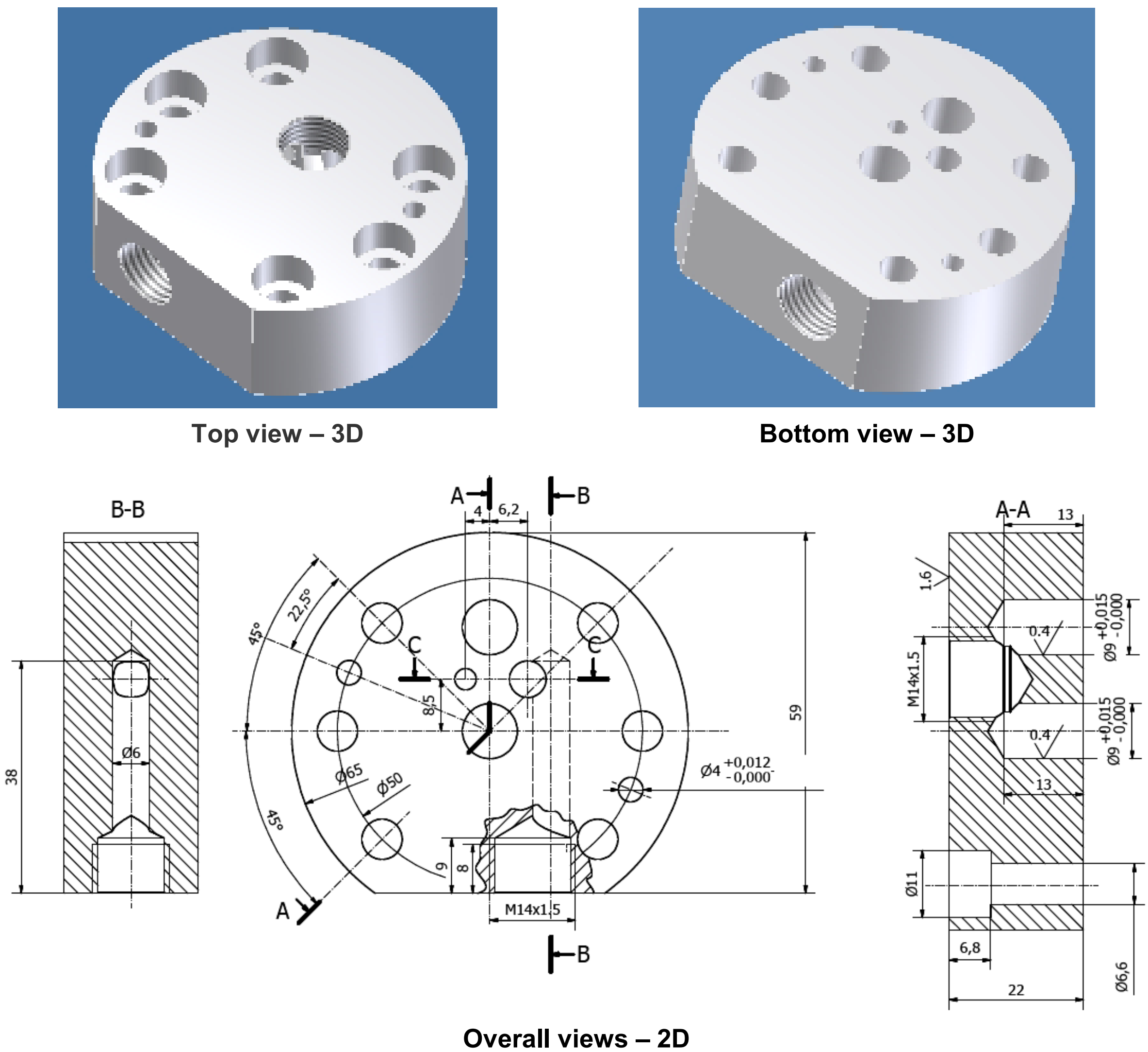
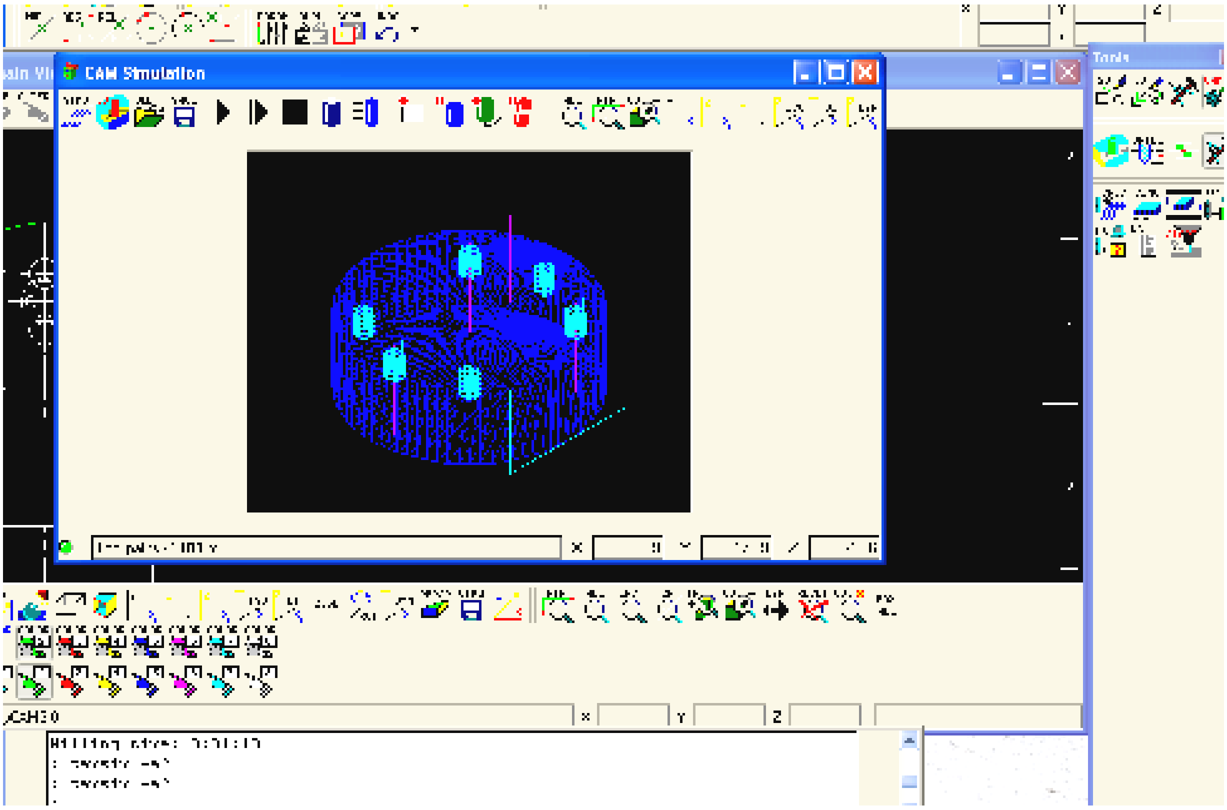
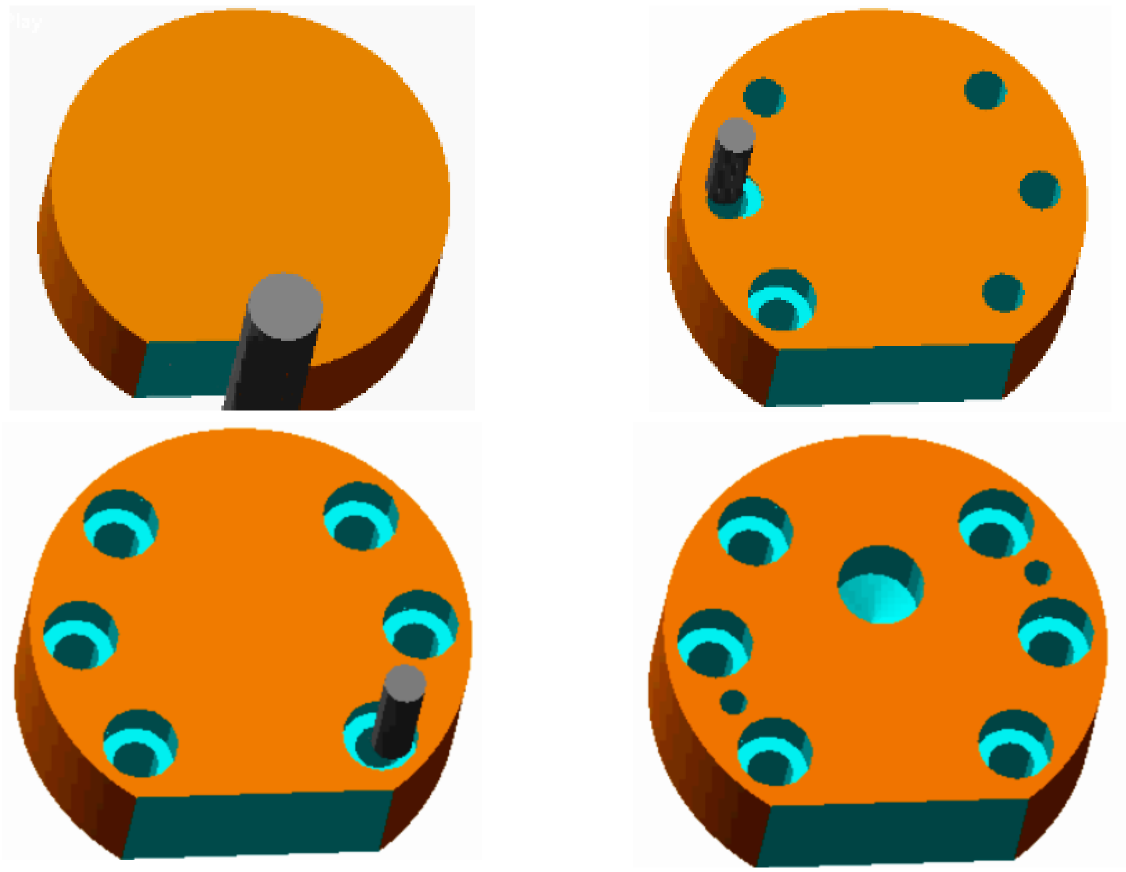


Fig. 6.3 Custom part drawing



Simulation of tools trajectories – for machining on the top side



Simulation of milling and drilling – for machining on top side

Fig. 6.4 Machining simulation images

◙ Example B

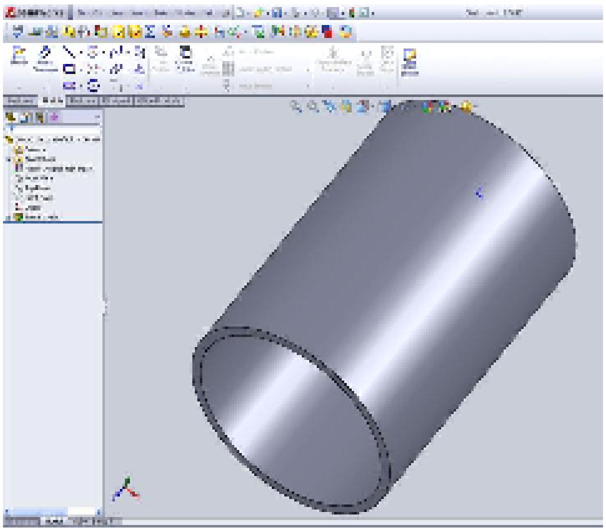
This example is about “writing” a name on a pens & pencils support - a promotional gift, offered together with notebooks, pencils, pens, etc.

It is an interesting example, that points out how milling on an exterior cylindrical surface can be done and it is presented courtesy of OPTOELCTRONICA 2001 Company [http://www.optoel.ro], The CNC system used for machining is the Isel-automation one.

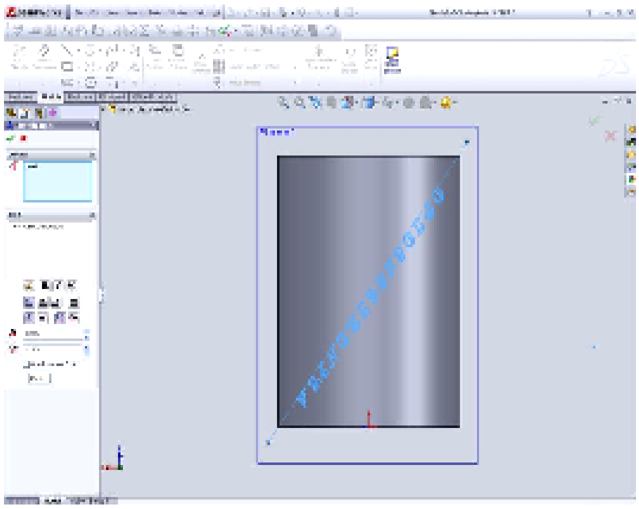
So, the first step was modelling of the word to be “written” – each letter written on a plane surface was “projected” on the cylindrical surface of the support model.

The next step was that of simulation the milling process, meaning checking cutting tool’s trajectory, once machining parameters being settled and tool’s parameters selected.

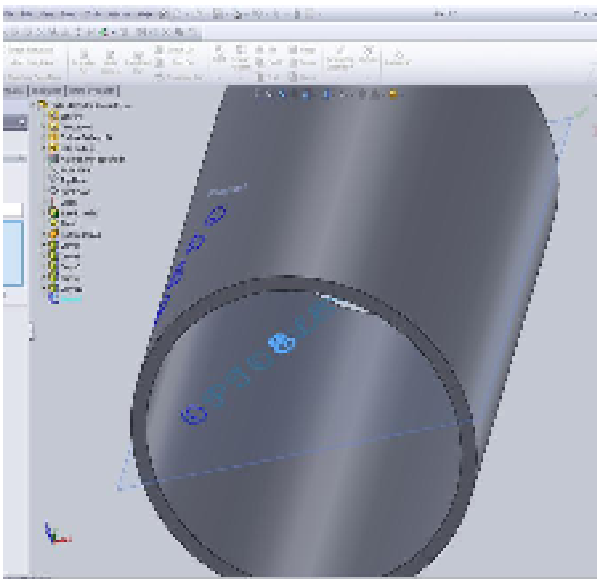
Images while part modelling and milling simulation are presented in figure 6.5.



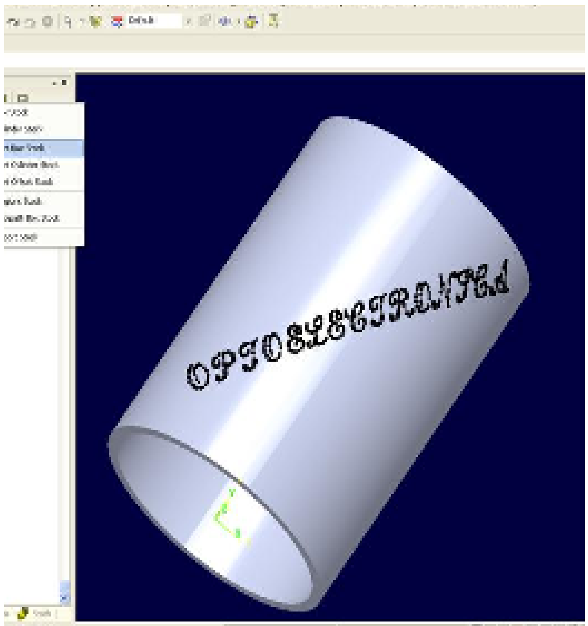
Cylindrical part model



Word written on the axial plane

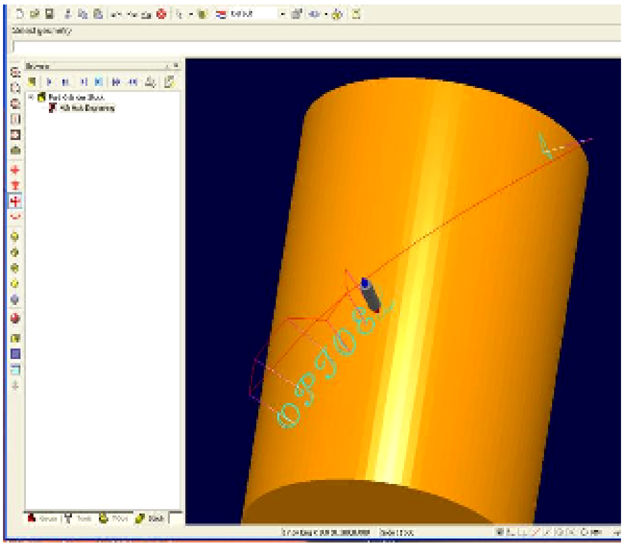


Projection of each letter on the cylindrical surface

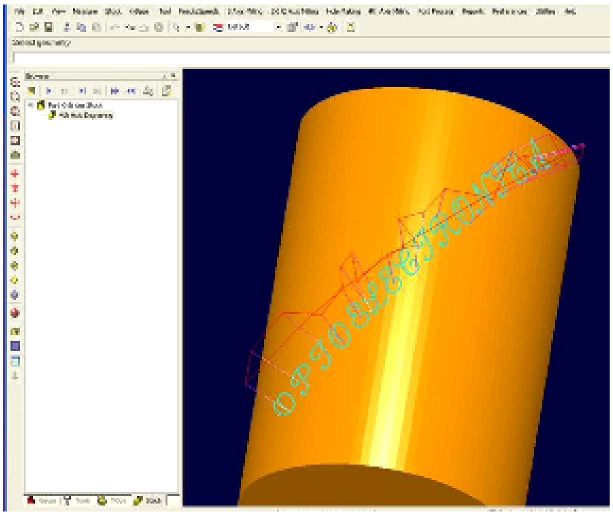


Final model of the part

Fig. 6.5 Part model and milling process simulation – to be continued



Letter milling simulation



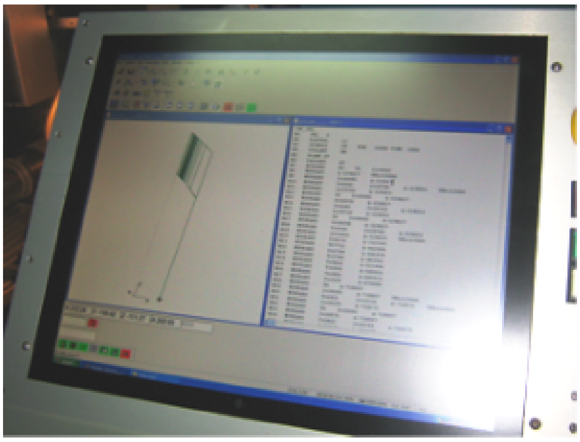
End of the word milling simulation

Fig. 6.5 Part model and milling process simulation

Once part model and milling simulation completed, any necessary correction must be done.

Then, the CNC system is prepared so that the work-piece is correctly positioned and fixed, the cutting tool is right positioned and the generated CNC program (in simulation) is well transferred, recognized and processed by the machine software. All of these accomplished, the real machining process is on and, finally, after inspection, the customized part is obtained.

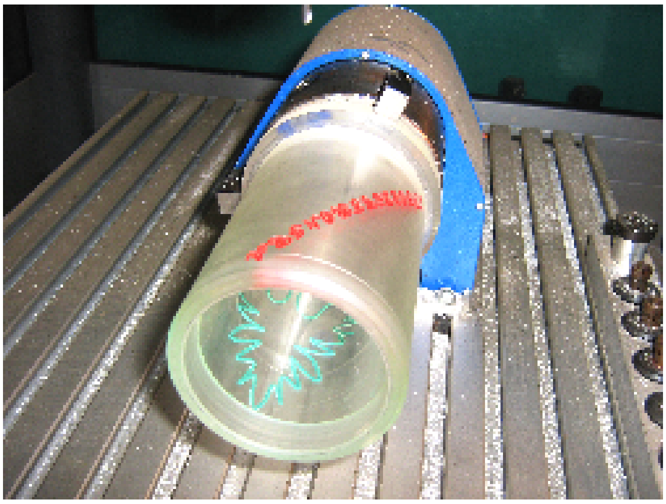
Images taken while all the above were carried on, are shown in figure 6.6.



Machine's computer screen image –
- CNC program

CNC milling

Fig. 6.6 Customized part CNC milling



Part in the end of milling process

Customized part

Fig. 6.6 Customized part CNC milling

6.3 Laser Micro-Machining

When conventional (mechanical) machining procedures (turning, milling, drilling, etc.) can no longer be used because of severe conditions related to geometrical complexity, accuracy and / or material required by new application areas of the parts involved, there are the micro-machining technologies to be applied.

One of the most efficient is *laser micro-machining*, where the laser beam does represent an universal tool that "machines" with no need of special force to fix the part and without wearing when impacting the surface to be transformed. In laser micro-machining there is no absolute request for void equipment, thermal influenced zones can be neglected and thermal deformations are very small, while the machined materials can be tough, extra-tough or, fragile ones.

Some of the most important factors that do "ask" for laser micro-machining can be mentioned as:

- part material ⇒ glass, polymers, silicon, hard stainless steel, thin films, etc;
- shape and geometrical precision of the surfaces to be obtained ⇒ holes, slots, channels, complex 2D / 3D shapes;
- high accuracy and small dimensions ⇒ from hundreds of microns up to microns..

There are also, expectations from laser micro-machining processes, referring to:

- obtaining the required features with high precision;
- good price, fast turnaround, one off to larger numbers of parts;
- new, inovative design and product ideas, customized products.

Laser micro-machining „covers" a large spectrum of machining procedures, the most relevant ones being: *laser micro-drilling, laser micro-welding, laser micro-cutting* and *laser engraving*.

Due to the complexity of factors that do influence the process and to the, relatively, short period of time it has been developed, there are very few, if any, 'standard' procedures available. This means that the result is determined as much by who is doing the work and how it is undertaken it. So, prediction of the „outcome" is of rather high uncertainty.

Materials suitted for laser micro-machinimg are of various types, depending on their industrial application. They can be polymers, metals, glasses, silicon or thin films.

Application of laser micro-machined parts is wide, fitted to new modern industrial sectors, such as:

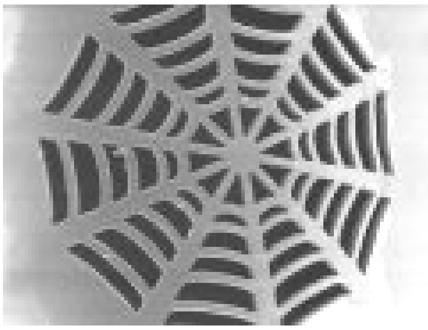
⇒ microelectronics – patterning of high resolution electronic circuits; fabrication of high quality deposition, printing and transfer masks; scribing, dicing and machining of silicon, glass, ceramics substrates;

⇒ biotechnology – obtaining high quality micro-channels in polymers; fabrication of optical structures as micro-lenses, machined in situ on chips;

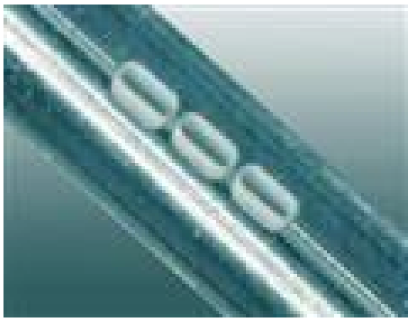
⇒ photonics – high quality machining of optical materials and semiconductors; precision machined placement structures as grooves and wells for optical devices;

⇒ precision engineering – high speed drilling of meshes in metal foils with hole size as small as 2 microns; in situ trimming of machined and pre-assembled devices without damage to adjacent parts; production of high tolerance slits and holes

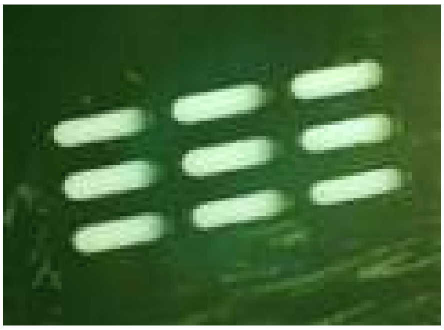
Some examples laser micro-machined parts, as well as their application, are presented in figure 6.7.



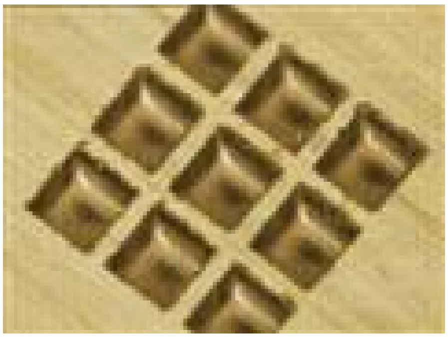
Precision cutting of 50 micron thick polyimide.



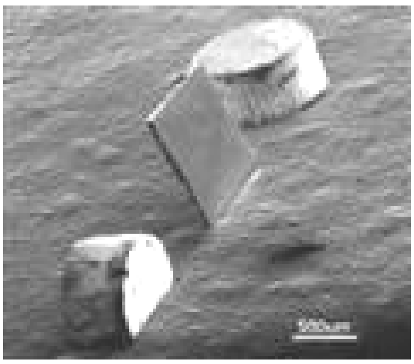
Precision cutting of slots in 1mm polymer tube.



200 micron wide slots in 200 micron thick stainless steel.



Milling of 1mm squares in brass.



Laser diced silicon wafers with 50 micron thick sample in centre

Removal of chrome from glass to produce mask.

Fig. 6.7 Laser micro-machined parts [http://www lasermicromachining.com]

◙ Example C

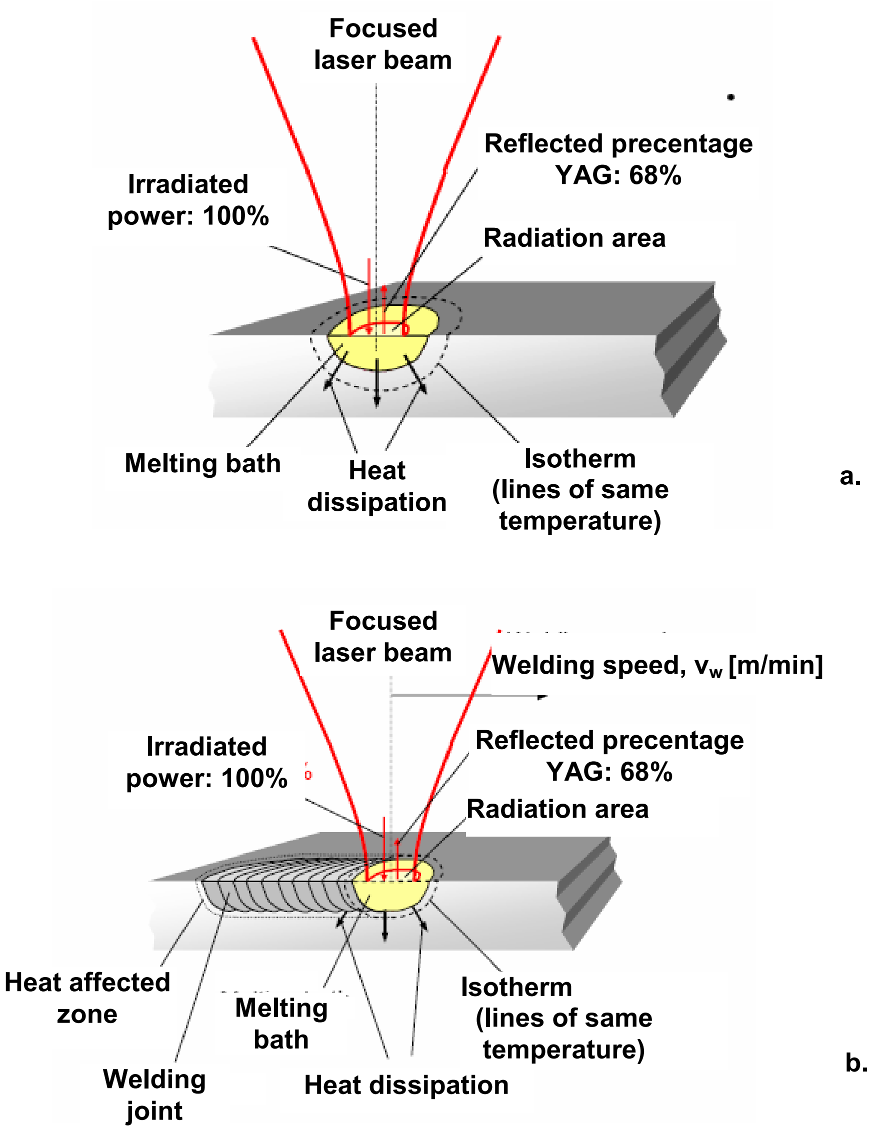
This example focuses on researches done in order to determine optimum parameters of *laser micro-welding* and *micro-drilling* processes, so that some guidelines of the adequate technologies to be state. [3], [4].

The experiments were made at OPTOELCTRONICA 2001 Company and are presented courtesy to its general manager..

It was used a Nd: YAG laser, which generates intense invisible radiations, with wavelength „close to" infrared radiations, values from 1030 nm to 1064 nm. The unit is a *TruePulse 62,* enabling flexible use of pulse energy and accurate pulse shape [http://www.us.trumf.com].

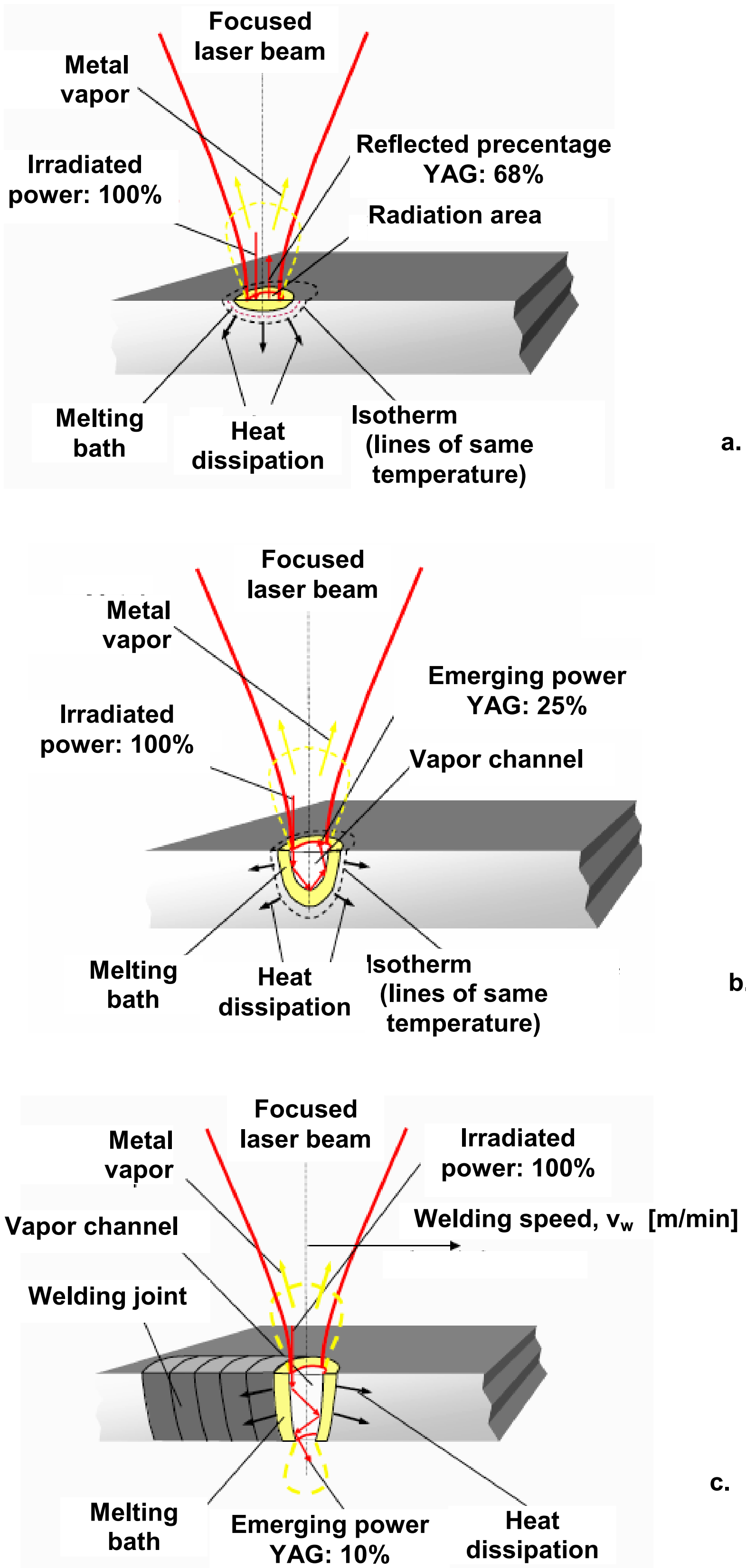
The laser head was fixed on the vertical support of an Isel system's machine. So, complex and accurate trajectories of the laser beam could be generated.

Materials used in experiments were of different type, like stainless steel, aluminium alloy and copper-zinc alloy. The micro-machining procedures studied were micro-welding and micro-drilling, theoretical development of the involved processes being shown in figure 6.8 and, respectively, figure 6.9.



A. Micro-welding by thermal conduction

Fig. 6.8 Scheme of micro-welding process development – to be continued [http://www.us.trumf.com]



B. Micro-welding by penetration

Fig. 6.8 Scheme of micro-welding process development [http://www.us.trumf.com]

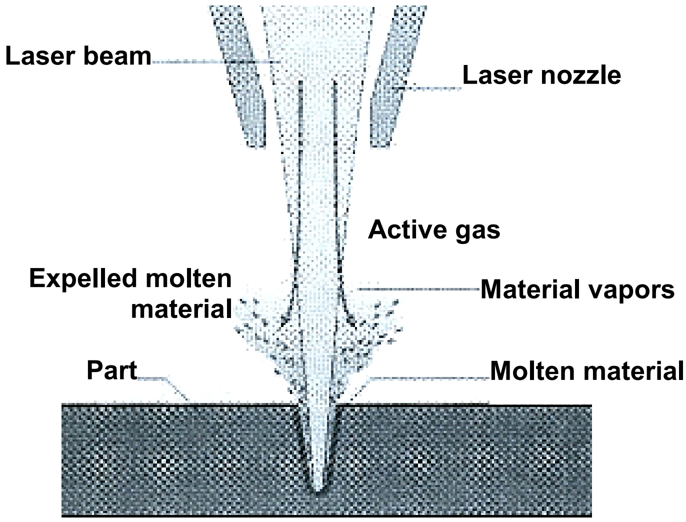


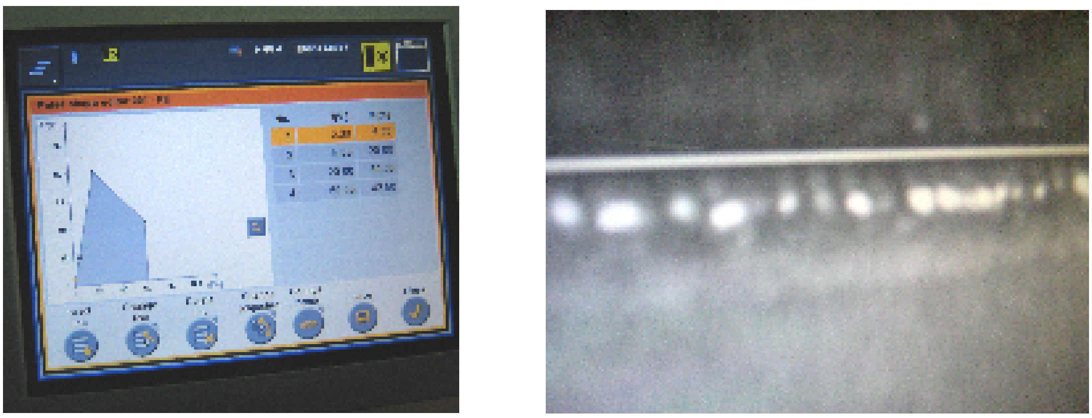
Fig. 6.9 Scheme of micro-drilling process [http://www.us.trumf.com]

Initially, laser process parameters were settled to values specified by laser unit producer.- for each material type but, because of objective reasons (different characteristics of real material compared to the ones mentioned by the producer, various material plate thickness, etc.) the obtained results were far from being good.

That is the reason why, successive changes of pulse power, shape, duration and, when necessary (welding) speed movement of the laser head were done, until experimental results – meaning micro-machined surfaces characteristics were good enough. The micro-welding was a penetration process so, high depth and very narrow welding belt could be obtained. The Nd:YAG laser was used in the CW mode (continuous wave) .

As mentioned above, many experiments were carried on – laser micro-welding and micro-drilling processes, for the established materials studied (stainless steel, aluminium alloy, copper-zinc alloy) and finally, some technological guidelines could be stated so that expected good results to be obtained.

Images taken while experimenting can be noticed in figure 6.10.

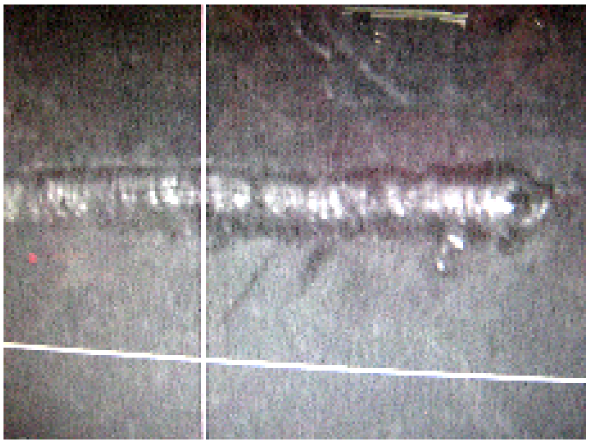


Computer screen image – laser pulse characteristics

Computer screen image – micro-machining process

Material: stainless steel; Process: micro-welding

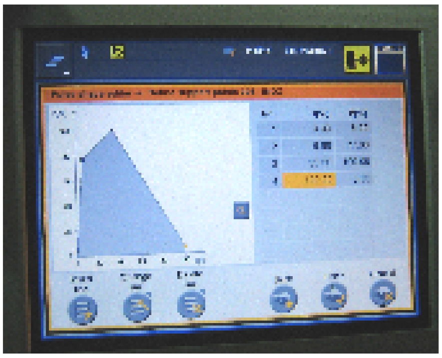
Fig. 6.10 Laser micro-machining processes – to be continued

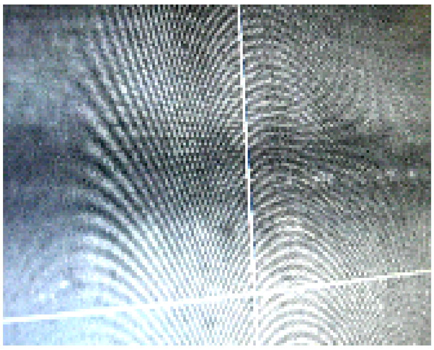


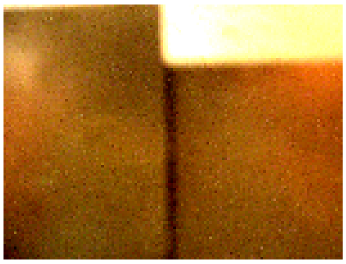
Computer screen image – process parameters

Computer screen image – micro-machining process

Material: aluminium alloy; Process: micro-welding





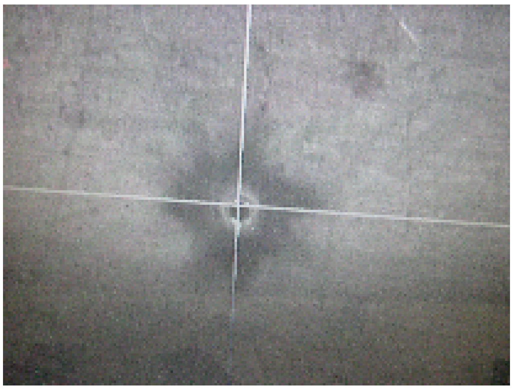


Computer screen image – laser pulse characteristics

Computer screen image – micro-machining process

Obtained part

Material: copper-zinc alloy; Process: micro-welding



Computer screen image – process parameters

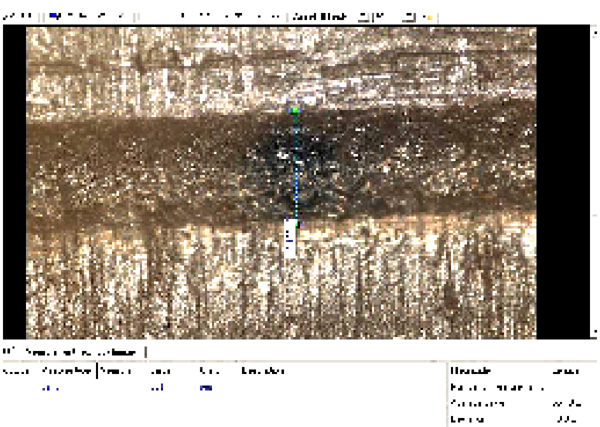
Computer screen image – micro-machining process

Material: stainless steel; Process: micro-drilling

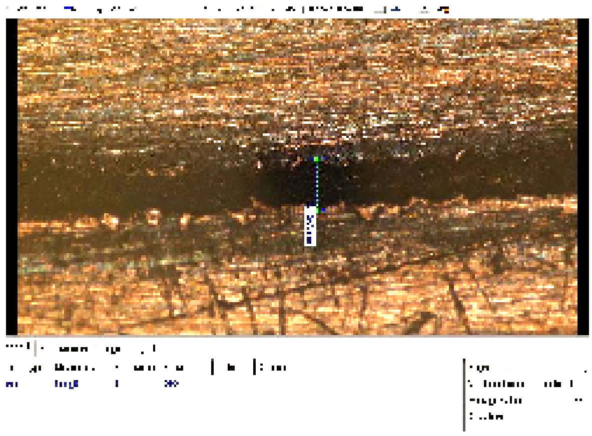
Fig. 6.10 Laser micro-machining processes

Once the micro-machining process over, the obtained parts were submitted for inspection. Some geometrical characteristics of the laser micro-machined surfaces are evidenced by figure 6.11.

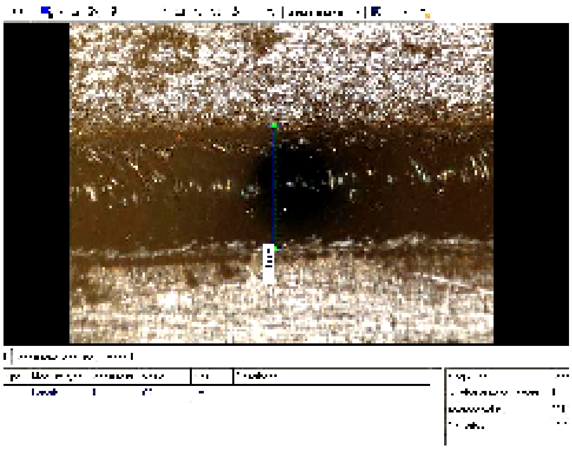
So, once the micro-machining process are were handled, customized product, such as patterning of electronic circuits, optical structures, meshes in metal foils, etc. can be accurately obtained.



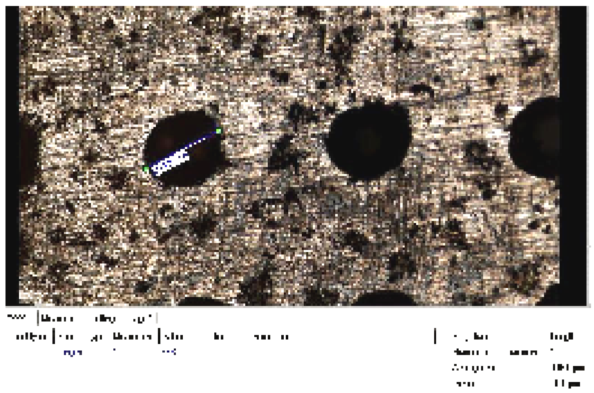
Micro-welded belt width: 651 µm
Material: aluminium alloy



Micro-welded belt width: 263 µm
Material: copper-zinc alloy



Micro-welded belt width: 831 µm
Material: stainless steel



Micro-drilled hole diameter: 446 µm
Material: stainless steel

Fig. 6.11 Geometrical characteristics of the laser micro-machined parts

◙ Example D

The example is about *laser engraving.* This (micro-)machining procedure does represent a way of customizing products, such as: part identification, company branding, circumferential marking – as shown in figure 6.12

Usually, there are two types of procedures involving the use of laser energy to obtain patterns, designs or inscriptions on the parts, meaning:

◘ *laser engraving* ⇒ laser beam penetrates the surface of the part and removes the material by melting, displacement and/or evaporation;

◘ *laser marking* ⇒ laser beam energy alters the surface permanently

As for part material, there is a wide range that can be laser engraved, the most commonly used are: aluminium, stainless steel, titanium, brass, polycarbonate, etc.

Advantages of laser marking / engraving refer to:

⇒ high accuracy and high resolution of the process – as it is computer aided and controlled;

⇒ non-contact process – as there is no contact tool-part and no stress / deformation of the part on hold ;

⇒ flexibility – as any kind of information to be displayed on computer screen can be laser engraved / marked;

⇒ good prices and environmentally friendly process.

Part Identification:
Part numbers, Serial numbers, Labels

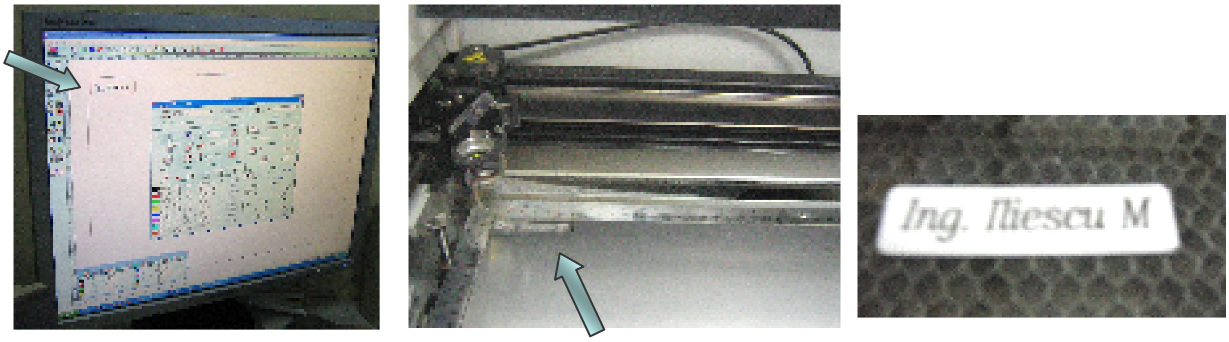
Patent number

360° circumferential marking

Fig. 6.12 Laser engraved / marked parts [http://www lasermark.com]

At OPTOELCTRONICA 2001 Company, laser engraving / marking is widely used. Examples of laser engraved customized parts are presented courtesy of OPTOELCTRONICA 2001 general manager, Dr. Teodor NECŞOIU. They do refer to on an aluminum alloy plate laser engraved is presented - figure 6.13, and to a glass cylindrical exterior surface laser engraved - figure 6.14.

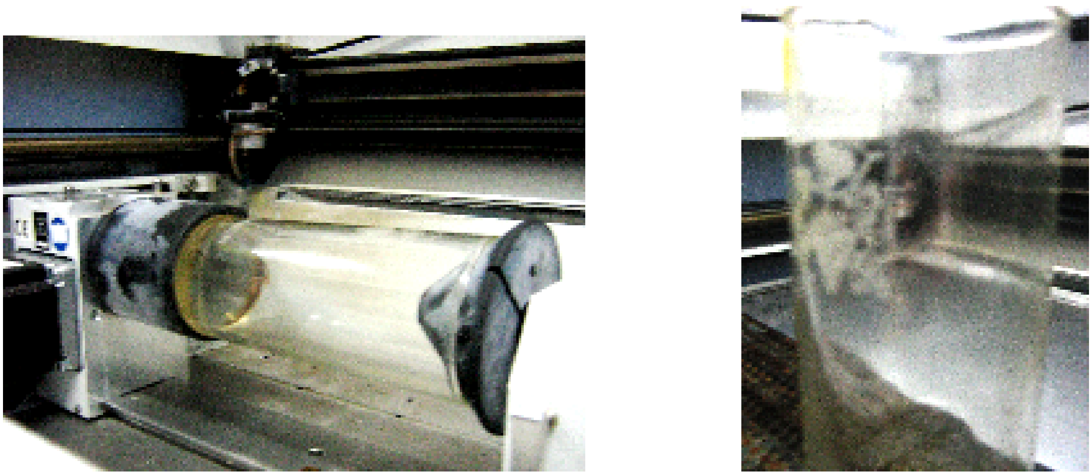
There should also be mentioned that the parts were engraved on a GRAVOGRAPH LS 100 machine [http://www.gravograph.com].



Computer screen image – setting characteristics of the text to be engraved

Machine chamber - engraved part

Fig. 6.13 Laser engraving process on flat surface



Machine chamber - engraving part

Cylindrical engraved part

Fig. 6.14 Laser engraving process on cylindrical surface

6.4 Sub-Surface Laser Engraving

Sub-Surface Laser Engraving (SSLE) is the process of engraving an image inside a solid material, below its surfaces.

The laser is a diode-pumped solid-state one, its beam being focused inside transparent materials to produce nanometer points of vaporous burst. Controlled by computer, these points can be the ones of pictures, patterns or words, so that, oridinary transparent materials can be transformed into impressive customized products.

The SSLE process has been developing since late 1990s and the machines involved combines laser technology, computer technology, integrating optics, machinery and electronics together. These machines are expensive ones, usually, ranging from small (30,000 – 60,000 USD) to large production sized tables (more than 250,000 USD) and, usually, require expensive cooling, maintenance and calibration.

One example is the ST-C5 3D/2D machine (see figure 6.15), a new laser processing equipment that adopts servo-controlling system with high precision and efficiency under the computer control. It has the features of high production efficiency and stable processing performance [http://www.sintecoptronics.com].

Fig. 6.15 ST-C5 3D/2D Laser Subsurface Engraving Machine
[http://www.sintecoptronics.com]

The laser processing technology makes the crystal and laser focus point move correspondingly. Laser focus point gasifies the crystal by optical effect, and then forms countless ordered spots, which make up an exquisite and perfect threedimensional picture. Its products can give person Crystal-clear and fine noble visual image, that's elaboration for the decoration.

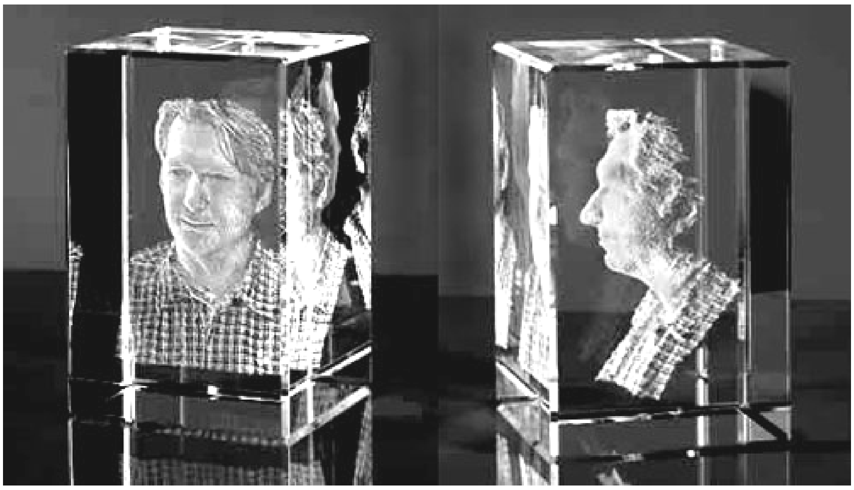
Usually, there are three steps of the process, as follows:

- step 1 $\Rightarrow$ the desired 3D picture is taken;
- step 2 $\Rightarrow$ the 3D acquisition must be processed cleaned and converted into a point cloud ready to be burned by the laser engraving machine
  $\Rightarrow$ the resulting 3D image that is to be engraved can be previewed on-screen for viewing purposes and real time adjustments made to the brightness and contrast before the etching process begins;
- step 3 $\Rightarrow$ the desired crystal block is placed in the laser-engraving system and the 3D etching begins.
  $\Rightarrow$ the laser beam penetrate the crystal to create tiny cracks in the glass so, an unique mosaic representing the scanned 3D image is obtained.

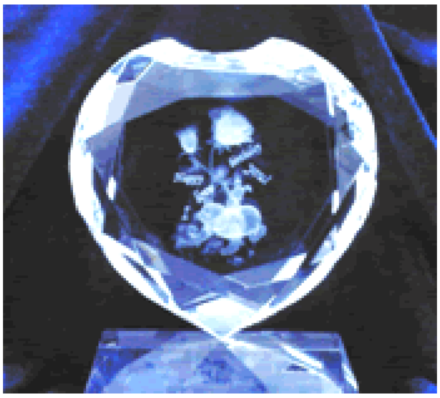
Common applications of the SSLE process are in glass decoration industry, crystal gift industry, glass gift industry, glass and Plexiglas signs industry. It can also be in secondary process industry of all kinds of bottles and other transparent materials.

Over the past 10 years, this process has become popular in jewelry and advertising business, as 3D CAD designs are drawn in glass, dot by dot. So, thanks to advances in 3D camera technology, one customer can walk into a photo crystal shop, sit for a quick 3D photo, and have its wish immortalized in a block of crystal. [http://www.inition.co.uk]

Some examples of sub-surface laser engraved customized products are presented in figure 6.16.



3D laser engraved portraits [http://www.inition.co.uk]

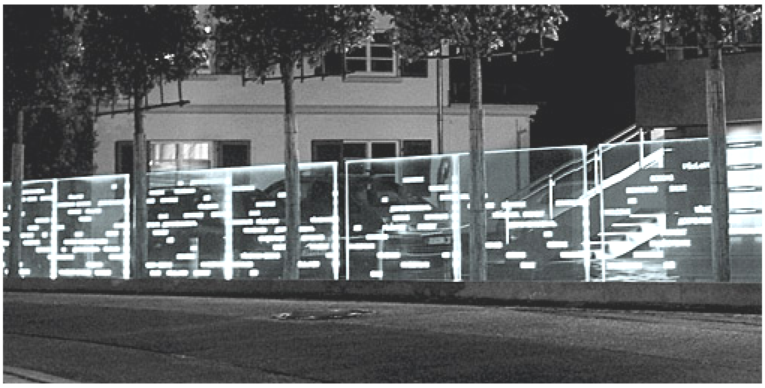


[http://www.sintecoptronics.com]

[[http://www.edge-wave.com]

Gifts – image from a hypermarket boutique in Bucharest

Fig. 6.16 Sub-surface laser engraved customized products – to be continued




3D laser engraved parts [http://www.cerion-laser.de]

Fig. 6.16 Sub-surface laser engraved customized products

A brief conclusion of all the things presented in this chapter is that a wide variety of high accuracy parts, made of different materials, with different and complex geometrical precision, can be efficiently and, many times, uniquely manufactured by CNC machining or micro-machining procedures.

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http://www.sintecoptronics.com
http://www.inition.co.uk
http://www.edge-wave.com
http://www.cerion-laser.de

7. HOLOGRAPHY AND HOLOGRAMS

7.1 Holography and Holograms

The theory of *holography* was developed in 1947 by Dennis Gabor, a Hungarian physicist and refers to the technique of recording and then, later, reconstructing the light scattered from an object, so that volumetric image in space can be obtained.

The early holograms were legible, but plagued with many imperfections because Gabor did not have the correct light source to make crisp, clear holograms Two years after the advent of the continuous wave laser (959-1960), Leith & Upatnieks (at the University of Michigan) reproduced Gabor's 1947 experiments with the laser, and launched modern holography [http://www.holo.com].

Holograms are the medium containing information, meaning the recording of interference laser light waves bounced off the object with another coherent laser beam. The word comes from the Greek words: *hólos* (whole) and *grafē* (writing) and, briefly, can be considered nothing more than a high contrast, very fine grain, black and white photographic film [http://www.holo.com].

According to IHMA (International Hologram Manufacturers Association), the word *hologram* is used to describe most of the images or optical effects which can be recorded by interference laser techniques or, physical gratings which can be revealed by the diffraction of light on the medium.

There are some "tools" required to make a hologram, a brief description being the one that follows [http://science.howstuffworks.com].

- the laser ⇒ usually a helium-neon (HeNe) one;
- the lenses ⇒ for spreading out the laser beam;
- the beam splitter ⇒ with mirrors and prisms used to split one beam of light into two beams;
- the mirrors ⇒ for directing the beams of light to the correct locations;
- the holographic films ⇒ a layer of light-sensitive compounds on a transparent surface, which can record light at a very high resolution.

The difference between *holographic* and *photographic films* is that holographic film has to be able to record very small changes in light that take place over microscopic distances. In other words, it needs to have a very fine grain**.** In some cases, holograms that use a red laser rely on emulsions that respond most strongly to red light.

As mentioned in the IHMA Glossary of Holographic Terminology, there are several types of holograms, such as the next ones.

- *Classic hologram* ⇒ a 2D or 3D image, recorded in a photosensitive medium from an object or flat artwork, by laser interference techniques and revealed by diffraction of light when the medium is illuminated.

- *Reflection hologram* ⇒ a hologram recorded in the depth of the recording medium which reflects light to achieve effect, therefore being viewed and illuminated from the same side.

The image does not show color shift when viewing at different vertical positions. This hologram type can only be reproduced optically on photosensitive material, using laser light to replicate the hologram.

Holograms on driver's license, on credit cards or, on everyday objects are reflection type.

When a holographic emulsion is developed, the surface of the emulsion collapses as the silver halide grains are reduced to pure silver. This changes the texture of the emulsion's surface. One method of mass-producing holograms is coating this surface in metal to strengthen it, then using it to stamp the interference pattern into metallic foil [http://science.howstuffworks.com].

A common laser and objects setup to produce reflection holograms is the inline setup, with the laser, the emulsion and the object, all in one line – see figure 7.1.

So, the beam from the laser starts out as the reference beam. It passes through the emulsion, bounces off the object on the other side, and returns to the emulsion as the object beam, creating an interference pattern. When white or monochrome light reflects off of its surface, the hologram is viewed. It is still a virtual image, as it is brain's interpretation of light waves that seem to be coming from a real object on the other side of the hologram.

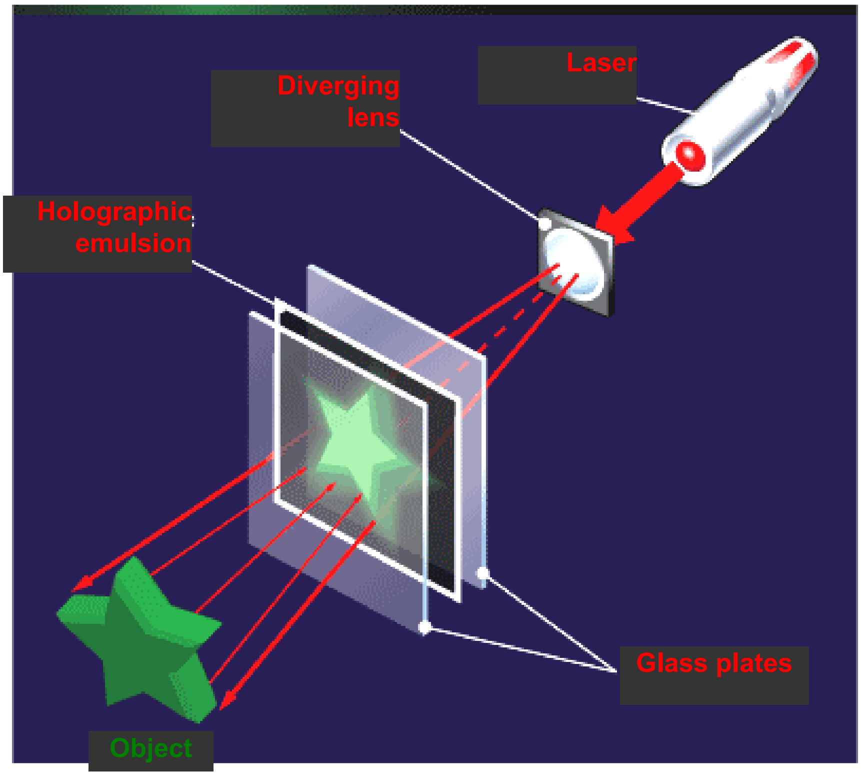


Fig. 7.1 Schematic representation of the process of making a reflection hologram
[http://www.science.howstuffworks.com]

◘ *Transmission hologram* ⇒ a hologram which transmits light to achieve its effect and which is therefore illuminated and viewed from opposite sides.

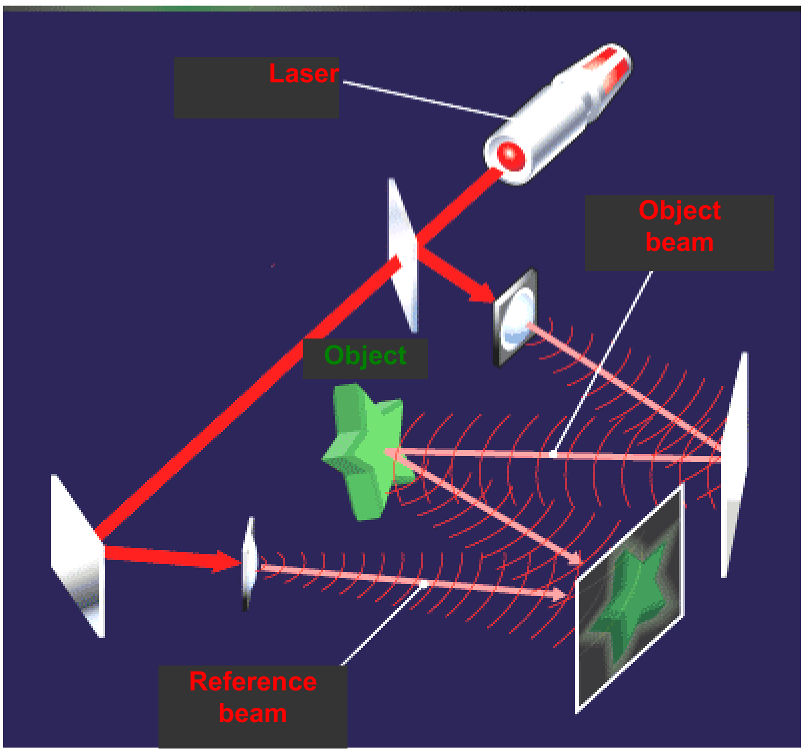


Fig. 7.2 Schematic representation of the process of making a transmission hologram
[http://www.science.howstuffworks.com]

This type of hologram can be viewed in white light or, only, in laser light, depending on the optical recording configurations. It can be reproduced optically on photosensitive material or by stamping or molding into an appropriate medium. Also, it can be metallized to create a mirror which reflects the transmitted light, so that it can be viewed by lighting on the same side as the observer.

A schematic representation of how a transmission hologram is obtained, can be seen in figure 7.2.

So the “steps” taken in order to work this hologram are the next ones:

- the laser points at the beam splitter, which divides the beam of light into two parts;
- the mirrors direct the paths of these two beams so that they hit their intended targets;
- each of the two beams passes through a diverging lens and becomes a wide swath of light rather than a narrow beam;
- one beam, the object beam, reflects off of the object and onto the photographic emulsion;
- the other beam, the reference beam, hits the emulsion without reflecting off of anything other than a mirror.

Application of holography and holograms is very wide, covering:

⇒ security and product authentication, labels and tapes 0 provided with a self adhesive backing or as hot stamping foil;

⇒ packaging - consumer goods brand protection - flexible packaging, board packaging, rigid box, pack packaging;

⇒ art and interactive graphics, gifts - for individuals or companies, to enhance brand image;

⇒ sport events - to protect event tickets, event merchandise, and also accreditation programs, etc.

Examples of holograms are shown in figure 7.3.

Security hologram – on credit card

Packaging holograms

Labels and tapes holograms

Fig. 7.3 Examples of holograms’ application [http://www.hologramsuppliers.com]

7.2 Example of Holography Research

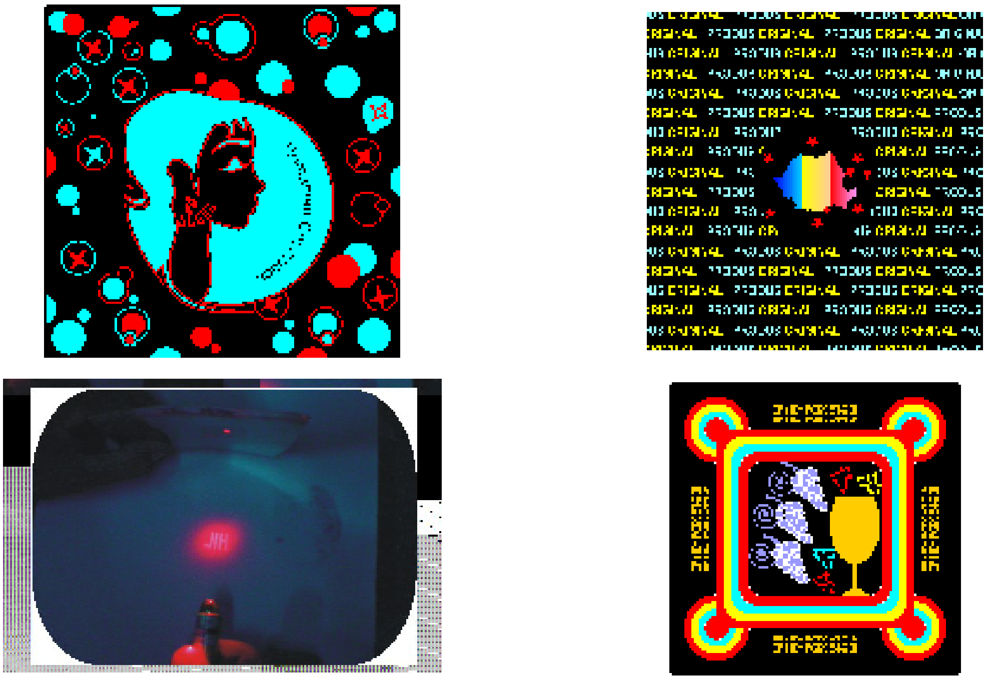
This example is presented courtesy of S.C. OPTOELECTRONICA 2001 Company [http://www.optoel.ro] that is member of International Hologram Manufacturers Association

A large variety of holograms, both 2D and 2D/3D.can be worked out here, some of them referring to:

- micro-text ⇒ invisible and available to read only with special lenses – see figure 7.4, **a**.;
- “flip-flop” image ⇒ two different images when viewed from different angles – see figure 7.4, **b**.:
- “real colour” image – see figure 7.4, **c.**

a.

b.



c.

Fig. 7.4 Examples of holograms obtained at SC OPTOELECTRONICA 2001

In order to obtain high accuracy holograms, research has been done on some of the holographic process parameters [2], knowing that:

- peak pulse power is typically required to overcome processing thresholds;
- pulse energy governs the amount of thermal energy available to effect any material processing;
- pulse duration impacts the laser beam - material interaction time.

The laser used was a pulsed fiber one, its characteristics being:

- wavelength of 1064 nm; repetition rate of (20 – 100) kHz;
- output power of 20W;
- pulse duration of (1-200) ns;
- maximum pulse energy of 1 mJ;
- water cooled.

Images taken while experimenting are presented in figure 7.5.

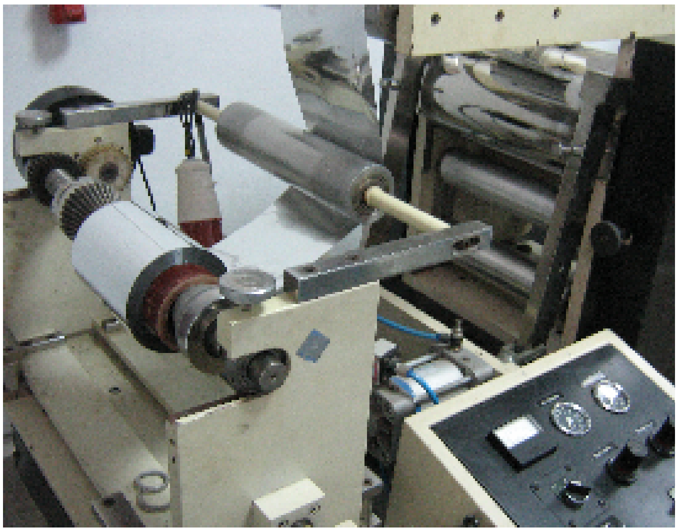
hologram design

⇒

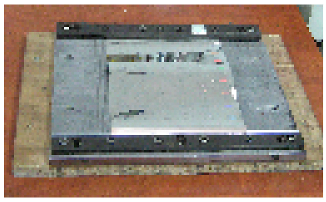
electroforming (obtaining the Production Master)

⇓

embossed foil



embossing



the shim

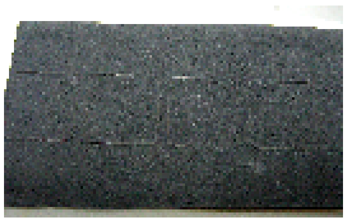
⇓

⇐

laminating

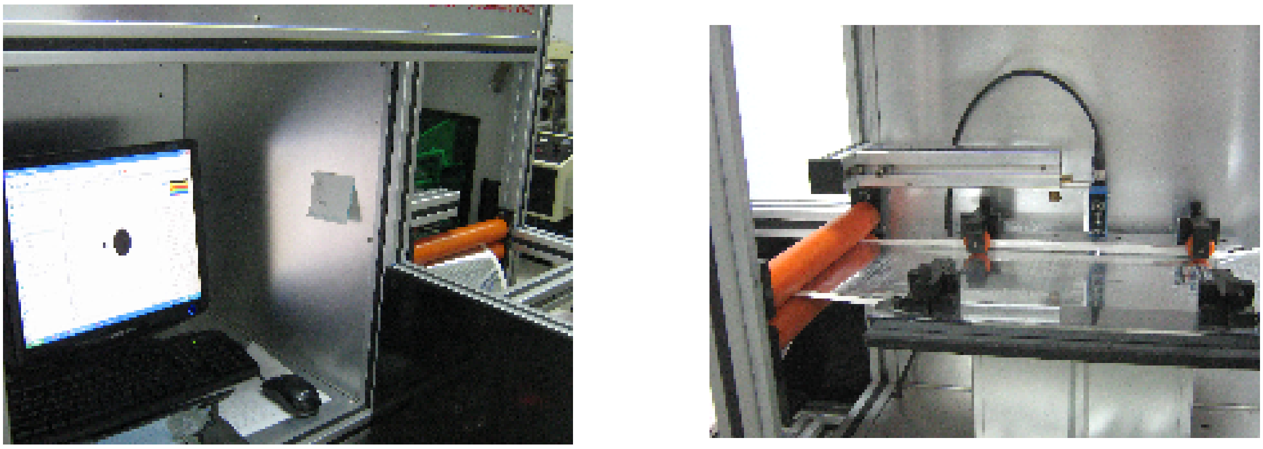
⇒

die cutting



the die

Fig. 7.5 Images taken while holograms engraving experimenting - to be continued



laser engraving

Fig. 7.5 Images taken while holograms engraving experimenting

Some of the obtained results, proving the influence of laser parameters values on the obtained holograms resolution, can be seen in figure 7.6.

speed: 800 ms	speed: 1,000 ms	speed: 500 ms
jump speed: 6,000 ms	jump speed: 6,000 ms	jump speed: 3,000 ms
frequency: 100 kHz	frequency: 100 kHz	frequency: 100 kHz
pulse duration: 1ns	pulse duration: 1ns	pulse duration: 1ns

Fig. 7.6 Examples of the obtained experimented holograms

So, it can be concluded that in order to obtain high resolution engraving results, low speed, high frequency and small pulse duration of the laser beam should be used.

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8. PLASTICS FORMING

8.1 Plastics – Definition and Characteristics

"*Plastics*" is a term coming from the Greek word "plastikos" which means capability of being shaped or moulded.

When naming "*plastics*" it is implicitly accepted the reference to materials such as resins or polymers that are built from hydrogen, carbon, oxygen, silicon, chlorine atoms, etc.

So, *plastics* involve polymers meaning large molecules composed of repeating structural units, typically connected by covalent chemical bonds. Even there are natural polymers, like rubber, asphalt, cellulose, silk, cotton and wool, still man's ability to synthetically create polymers has tremendously developed and so, various materials needs for nowadays products could be satisfied.

The synthetic plastic industry started in 1909 with the development of a phenol formaldehyde plastic (Bakelite) by Dr. L. H. Baekeland. The phenolic materials are, even today, important engineering plastics. The development of additional materials continued and the industry really began to blossom in the late 1930's. The chemistry for nylons, urethanes, and fluorocarbon plastics were developed; the production of cellulose acetate, melamine, and styrene molding compounds began; and production of commercial equipment to perform the molding and vacuum forming processes began [http://www.sdplastics.com].

As mentioned in [2], it can be considered that:

- plastic material ⇒ is an organic polymer of large molecular weight,
  ⇒ is solid in its finished state,
  ⇒ at some stage in its manufacture can be shaped by flow;
- resins and polymers ⇒ are terms often used to denote the basic polymerized material;
- plastics ⇒ encompasses compounds containing plasticizers, stabilizers, fillers and other additives;
- commodity plastics ⇒ are the materials used for packaging, low cost consumer products, toys and a wide array of throwaway products from party (knives, forks, spoons, garbage bags, etc.);
- engineering plastics ⇒ are those materials with mechanical, chemical and thermal properties suitable for use as construction materials, machine components, chemical processing components, etc.

Depending on their behavior to heat, plastics are divided in two categories as *thermoplastics* and *thermosets*.

Thermoplastic*s* do soften and melt when heated, so, they can be injection molded, extruded or foamed. More of it, thermoplastics production scraps can be reground and reused.

Thermosets are characterized by cross links, interconnections between neighboring molecules that limit chain movement. When heated, this network of polymer chains tends to degrade, rather than soften. Until recently, they could not be re-melted and reused after initial curing.

Due to their internal structure and to the processes occurring while forming, plastics have various different properties and behaviors, like:

- viscoelastic behavior ⇒ with characteristics of, both, viscous liquid and spring-like elastomer and, consequently, "offering" :
  - crip – the deformation that occurs over time when a material is subjected to constant stress, at constant temperature.
  - stress relaxation – the gradual decrease in stress at a constant strain and temperature;
- stress / strain behavior ⇒ involving the values of their most important mechanical characteristics, such as:
  - tensile properties – with five transitional points (proportional limit, elastic limit, yield point, ultimate strength point, break point) determined by standard tensile tests,
  - ultimate strength – that measures the highest stress value during the tensile test,
  - flexural properties – reflecting plastics' ability to bend or, resist bending under load,
  - impact strength – meaning part's ability to absorb and dissipate energy, varying with its shape, thickness and temperature;
- thermal behavior ⇒ evidenced by the values of
  - deflection temperature under load – used in comparing the elevated temperature performance of material, under load,

- heat sag – an important factor in the case of parts that will be painted and baked or, will be exposed to elevated temperatures.

◘ weather / UV behavior ⇒ when exposed to outdoor weather, specially to UV radiation, color and appearance can change from little to severe, while mechanical performances do reduce, as for instance, the impact resistance;

◘ chemical exposure behavior ⇒ the degree of chemical attack depends on plastic type, chemical in contact, temperature, exposure time, state of internal stresses in the part, etc.

Some of the common used plastics are:

◘ for the thermosets ⇒ melamine, polyester, alkyl, polyurethane, epoxy, etc;

◘ for thermoplastics ⇒ low-density and high-density polyethylene, polypropylene, polyvinyl chloride, expandable polystyrene, etc.

8.2 Plastics Forming Processes

There is a wide range of plastics forming processes, depending on their state while forming and, of course, of plastics' characteristics.

Some of these processes are mentioned as [2]:

◙ *liquid state forming processes* ⇒ when heated, resins become liquid or fluid as they enter the mould

⇒ thermosets are, often, in a dough like mixture when placed in the mould - few of the forming processes are: Reaction Injection Moulding, Compression Moulding, Reinforced Plastic Moulding, etc ;

⇒ thermoplastics rather become viscous and are "forced" by high pressure that cause them to behave like liquids while filling the mould cavity – few of the forming processes are: Rotational Moulding, Transfer Moulding, Injection Moulding, etc.;

◙ *plastic state forming processes* ⇒ suited for thermoplastics, some of the forming processes can be mentioned as: Thermoforming (Vacuum Forming, Pressure Forming), Blow Moulding (injection Blow Moulding, extrusion Blow Moulding), etc;

◙ *solid state forming processes* ⇒ for thermoplastics as polypropylene, polycarbonate, rigid PVC, which are sufficient ductile at room temperature, the processes being Cold Forming or Solid State Forming.

Some of the processes mentioned above are going to be further presented.

8.2.1 Reaction Injection Molding (RIM)

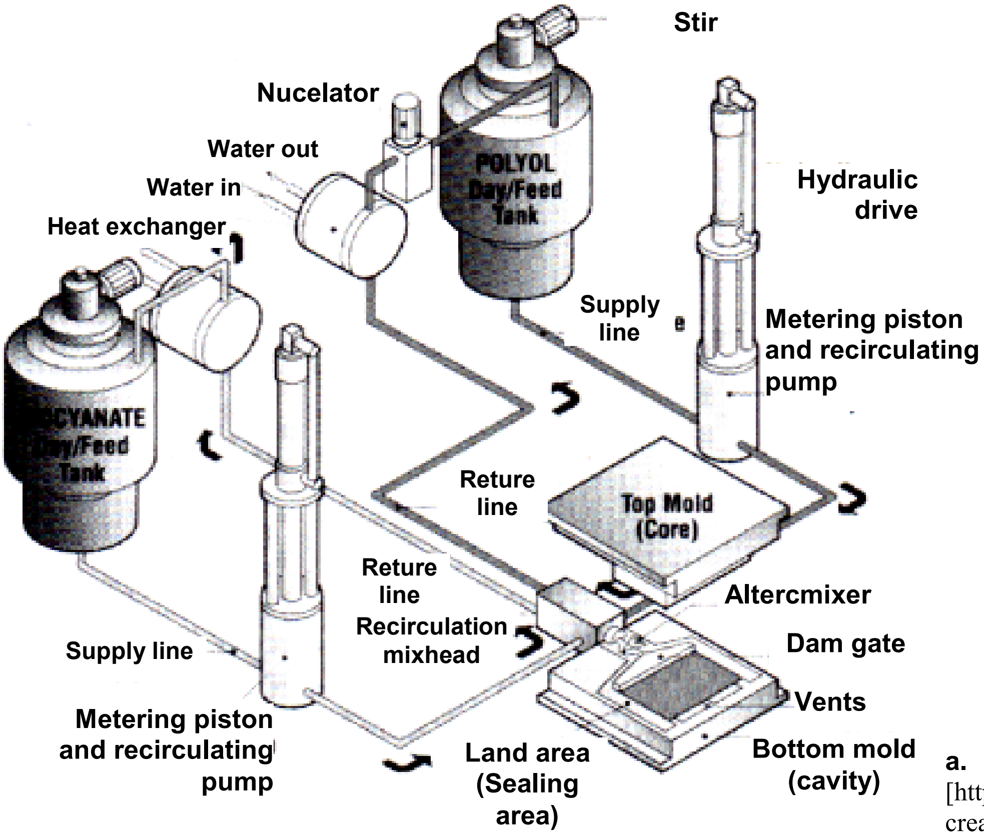
The *Reaction Injection Molding* (RIM) process is named after the chemical reaction that occurs within the tool, between the two components (the isocyanate component and the polyol resin mixture) of the plastics used, meaning thermosets, either polyurethanes or foamed polyurethanes.

A brief description of the Reaction Injection Molding process and its schematic representation are presented below – see also figure 8.1.

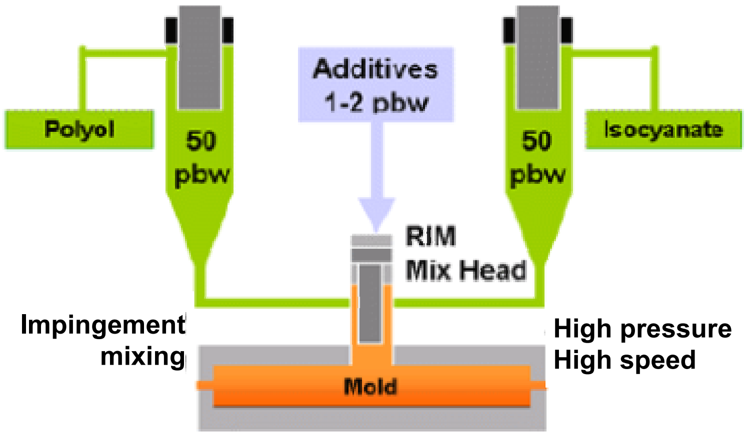
The two liquid reactants - polyisocyanate component and resin mixture - are held in separate temperature controlled feed tanks equipped with agitators. From these tanks, the polyol and isocyanate are fed through supply lines to metering units that precisely meter the reactants, as high pressure, to the mixhead. When injection begins and valves in the mixhead open, the liquid reactants enter a chamber in the mixhead at pressures between 1,500 and 3,000 psi where they are intensively mixed by high-velocity impingement. From the mix chamber, the liquid flows into the mold at approximately atmospheric pressure and undergoes an exothermic chemical reaction, forming the polyurethane polymer in the mold.

Shot and cycle times vary, depending on the part size and the polyurethane system used. An average mold for an elastomeric part may be filled in one second or less and be ready for demolding in 30- 60 seconds. Special extended geltime polyurethane RIM systems allow the processor to fill very large molds using equipment originally designed for molds with smaller volumes [http://www.creativeurethanes.com].

Reaction time is usually expressed in seconds. For extremely large parts the reaction time can be extended to allow for proper filling of the mold.



a.
[http://www.
creativeurethanes.com]



b.
[http://www.
osborneindustries com]

Fig. 8.1 Schematic representation of the RIM process

Advantages of the RIM process are mentioned to be:

⇒ low cost of the tools involved;

⇒ requires less energy to make the same product injection molded thermoplastics;

⇒ excellent choice for larger plastic parts produced in short run or low volume production quantities;

⇒ foamed polyurethanes are natural thermal and acoustic insulators;

⇒ high strength and low weight of parts which offer dimensional stability;

⇒ free design freedom for parts, due to materials' good flowing properties that enable complex geometry including: louvers, ribs, bosses;

⇒ high encapsulation ability – of a variety of inserts

Some examples of RIM customized parts are shown in figure 8.2.

machine tool for optical lenses

mammography Unit

housing component for a TV stand

Fig. 8.2 Custom RIM parts [http://www.thieme-products.com]

8.2.2 Compression Moulding

One of the oldest methods for plastics forming is *Compression Moulding*. The material to be molded is first placed in an open, heated mold cavity. After that, the mold is closed, pressure is applied to force the material get into contact with all mold areas, and heat and pressure are maintained until the molding material has cured.

So, the steps of a compression molding process are the ones that follow.

◘ Placing the preheated, pre-weighed amount of a polymer mixed with additives and fillers into the lower half of the mold ⇒ as it is preheated, .the material becomes softer and, thus, the molding cycling time shortens;

◘ Closing the mold, by moving down its upper part and thus, pressing the polymer to fill the mold cavity ⇒ the heating system of the mold cures the polymer (if it is thermoset);

◘ Opening the mold and removing the part by ejector pins ⇒ if thermosetting resin is molded, the mold may be open in hot state (as cured thermosets maintain their shape and dimensions even in hot state) but, if thermoplastic is molded, the mold and the molded part are cooled down before opening.

Schematic representations of the compression molding process is shown in figure 8.3.

Most of the times, there are thermosets materials used for compression molding, with raw form of granules, putty-like masses, or preforms

Thermoplastics can also be molded with unidirectional tapes, woven fabrics, or chopped strand.

So, common plastics used include polyester, polyamide, polyphenylene sulfide, polyetheretherketone, melamine formaldehyde, epoxies, fiber reinforced plastics, etc.

The compression molding process is suited for molding large flat or moderately curved parts, some of its advantages being:

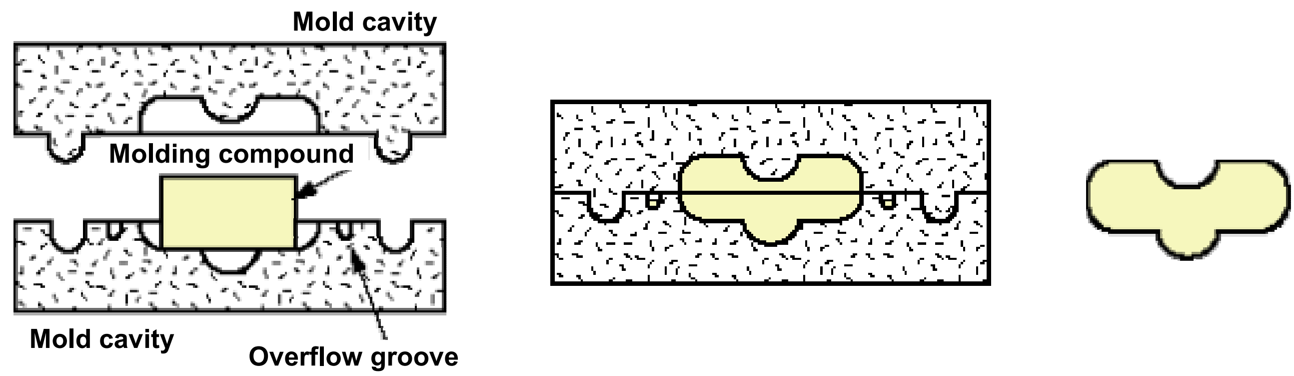
⇒ relatively low costs;

⇒ allows obtaining of intricate parts;

⇒ usually there is a good surface finish of parts;

⇒ produces fewer knit lines and less fiber-length degradation than injection molding.

One of the main process disadvantage if related to its low production speed.

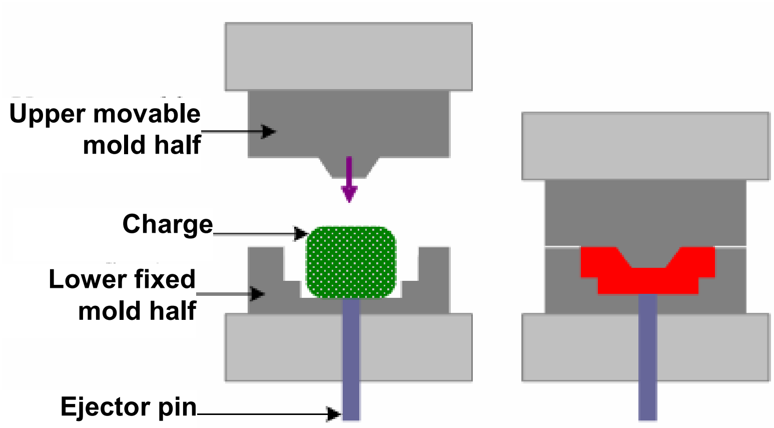


- molding compound is placed in an open, heated mold cavity

- the mold is closed and pressure is then applied to force the material to fill up the entire mold cavity.
  - excess material is channeled away by the overflow grooves.
  - the heat and pressure are maintained until the plastic material is cured.

- the final part after the mold is removed

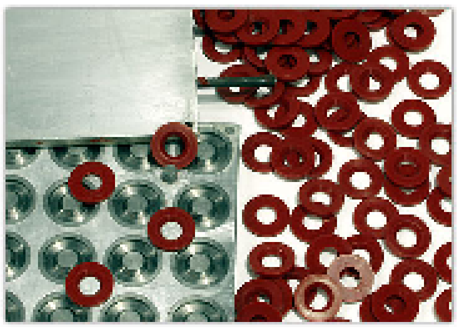
a.
[http://www.efunda.com]



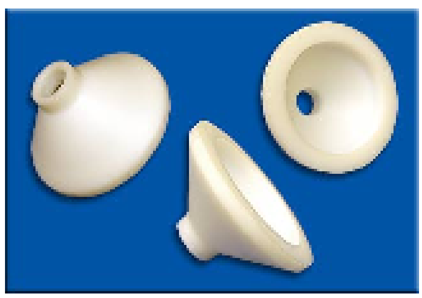
b.
[http://www.substech.com]

Fig. 8.3 Schematic representation of the Compression Moulding process

Examples of compression molded parts are presented in figure 8.4.



- seal rings, contoured castings, and parts with metal inserts



- part requiring minimal machining

[http://www.escoplastics.com]

- rubber boots before the flashes are removed.
[http://www.wikipedia.org]

Fig. 8.2 Examples of compression molded parts

8.2.3 Injection Moulding

One of the most common used plastics forming processes is *Injection Moulding*, that has been used since XIX'th century, for producing a large variety of parts, starting with household appliances, consumer electronics, power tools, and ending with medical devices or automotive dashboards.

It was n1872, when the American inventor John Wesley Hyatt and his brother Isaiah, Hyatt patented the first injection molding machine – which used a plunger to inject plastic through a heated cylinder into a mold. In 1946, American inventor James Watson Hendry built the first screw injection machine, which allowed much more precise control over the speed of injection and the quality of articles produced. This machine also allowed material to be mixed before injection, so that colored or recycled plastic could be added to virgin material and mixed thoroughly before being injected. In the 1970s, Hendry went on to develop the first gas-assisted injection molding process, which permitted the production of complex, hollow articles that cooled quickly [http://www.wikipwdia.com].

The parts can be produced from both thermoplastics, or thermosets materials, the manufacturing process involving the use of an injection molding machine, the raw plastic material, and the mold.

Any injection molding process is performed in some steps which, briefly, are stated to be the next ones [http://www aclaryn.com].

◙ The mold is bolted into the clamping section of the machine;
- the machine closes the mold, then applies a large force to "lock" the mold closed.
- inside the closed mold is a cavity that is the exact shape of the plastic part.

◙ The Injection section of the machine has a hopper to hold plastic pellets; a barrel with heater bands to liquefy the plastic pellets; a feed screw to move the pellets forward in the barrel; a check valve to force the liquid plastic into the mold, and a nozzle to seal the injection section to the mold.
- the liquefied plastic is forced into the cavity of the mold with high pressure.

◙ Once the liquid plastic has been injected into the mold, the machine goes into the cooling phase.
- the liquid plastic must cool enough to turn solid so it takes on the shape of the cavity and stays that way.
- while the cooling take place, the screw will rotate, bringing in more pellets for the next part.

◙ When the part is ready to be removed from the mold, the clamp will open, and the part will be removed from one half of the mold.
- the part will be ejected from the other half of the mold, and the machine will start a new cycle.

A more detailed description of the process is presented further [http://www.cheresources.com].

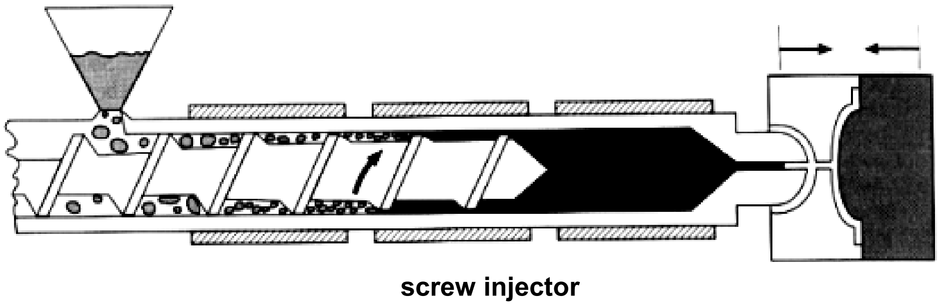
So, the resin is fed to the machine through the hopper. Colorants are usually fed to the machine directly after the hopper. The resins enter the injection barrel by gravity though the feed throat. Upon entrance into the barrel, the resin is heated to the appropriate melting temperature. The resin is injected into the mold by a reciprocating screw or a ram injector. The reciprocating screw offers the advantage of being able to inject a smaller percentage of the total shot (amount of melted resin in the barrel). The ram injector must typically inject at least 20% of the total shot while a screw injector can inject as little as 5% of the total shot. Essentially, the screw injector (see figure 8.5, a.) is better suited for producing smaller parts.

The mold is the part of the machine that receives the plastic and shapes it appropriately. The mold is cooled constantly to a temperature that allows the resin to solidify and be cool to the touch. The mold plates are held together by hydraulic or mechanical force.

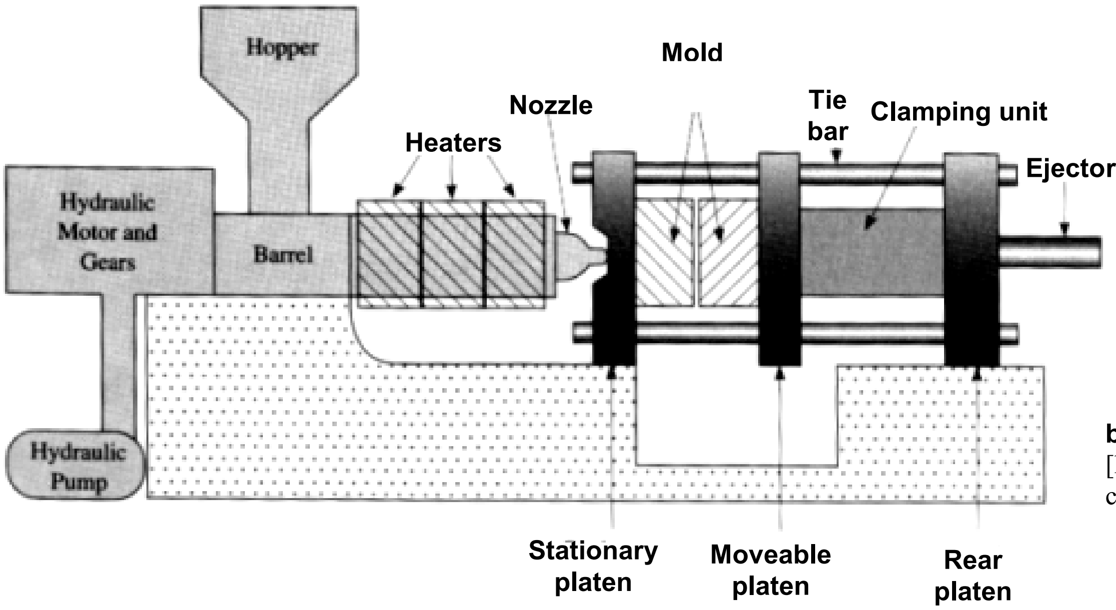
The clamping force is defined as the injection pressure multiplied by the total cavity projected area. Typically molds are over-designed depending on the resin to be used. Each resin has a calculated shrinkage value associated with.

Schematic representation of injection molding machine and, as consequence, of the process can be noticed in figure 8.5 (b. and c.)

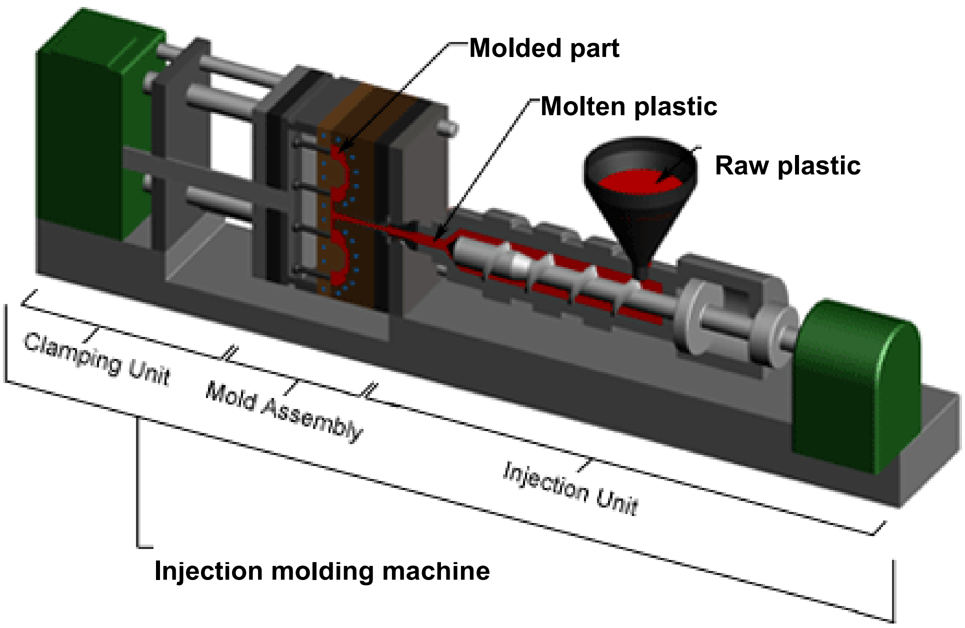
As mentioned above, thermoplastics (nylon, polyethylene, polystyrene), thermosets (epoxy, phenolic) and, even, elastomers (thermoplastic rubber) can be used in injection molding.



a.
[http://www.
cheresources.com]



b.
[http://www.
cheresources.com]



c.
[http://www.
custompartnet.com]

Fig. 8.5 Schematic representation of the Injection Moulding process

The advantages of injection molding process are:

⇒ fast process with high production rate;

⇒ ability to maintain prescribed tolerances of parts, when highly repeated;

⇒ relatively, low labor costs;

⇒ little need to finish parts after molding.

Some disadvantages refer to:

⇒ need for expensive equipment investments;

⇒ limitations in parts design due to molding process requirements.

Examples of injection molded custom parts are shown in figure 8.6

Fig. 8.6 Examples of injection molded parts [http://www.prototypingrapid.com]

8.2.4 Thermoforming – Vacuum Forming

Thermoforming is a plastic forming process, in which a sheet of thermoplastic material is heated and deformed to the desired shape in a mould.

The process, consists of two main steps, first is heating and then is forming. Heating is usually accomplished by radiant electric heaters. The heating cycle is as long as necessary to sufficiently soften the sheet and depends on the polymer, its thickness and color.

Plastic thermoforming processes can be done by one of the three below mentioned methods:

◙ *vacuum thermoforming* ⇒ when a negative pressure is used to draw the preheated sheet into a mold cavity.

◙ *pressure thermoforming* ⇒ when a positive pressure is applied for forcing the heated plastic into the mold cavity.

◙ *drape (mechanical) thermoforming* ⇒ by matching positive and negative molds that are brought together against the heated plastic sheet, forcing it to assume their shape.

As the earliest and most common thermoforming process is *vacuum forming*, its characteristics and scheme are presented further.

So, in the vacuum forming process the holes for drawing the vacuum in the mold are on the order of 0.8 mm in diameter, so their effect on the plastic surface is minor. The process, mainly consists in four steps – see figure 8.7:

- the flat thin plastic is softened by heating;
- the softened sheet is placed over a concave mold cavity;
- the vacuum draws the sheet into the cavity
- the plastic hardens on contact with the cold mold surface, then the part is removed and subsequently trimmed from the web.

The molds can be aluminum, epoxy or wooden ones but, if they are aluminum made, water-cooling or a chiller system is often used to expedite the formation process.

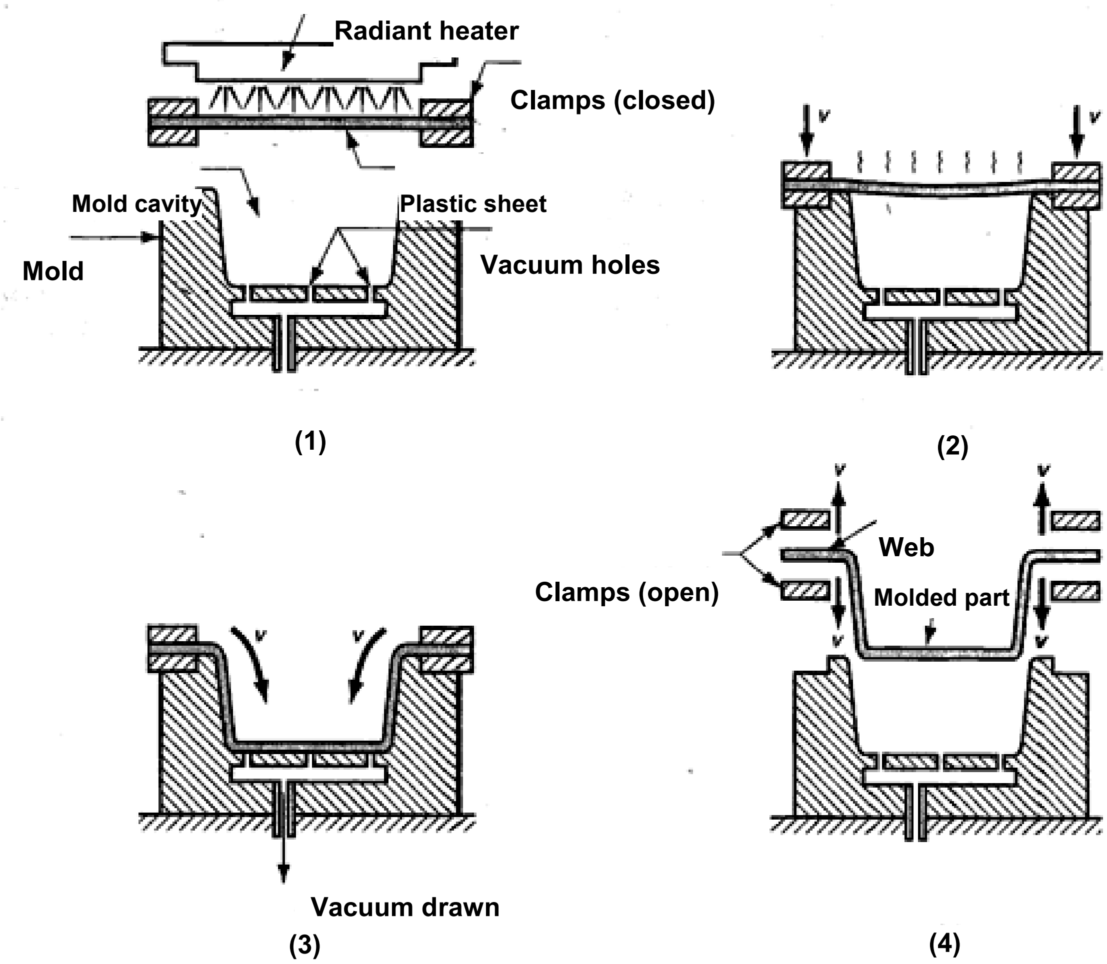


Fig. 8.7 Schematic representation of the Vacuum Forming process [http://www.sinotech.com]

Materials suitted to thermoforming are, theoretically any thermoplastic that is available as extruded sheet stock, typically examples include polystyrene, ABS, acrylics, polycarbonates..

Sheet thickness less than 1.5 mm is usually delivered to the thermoforming machine from rolls or from a sheet extruder. Sheet thicknesses greater than 3 mm is usually delivered to the forming machine by hand or an auto-feed method, already cut to final dimensions.

Advantages of the thermoforming processes can be considered the next ones:

⇒ obtaining parts with thin walls, starting even from 0.01 mm, with no internal molding stresses;

⇒ tooling costs are reasonable for large parts;

⇒ multiple parts can be made using a single multi-former.

Disadvantages of this process refer to:

⇒ the need for a secondary process to trim the sheet;

⇒ part design should be so that draft angles exist and with no undercuts;

⇒ low accuracy of the side of the part that does not contact the tool surface.

The thermoforming process is often associated with manufacturing of packaging items such as blister packs, disposable coffee cup lids but, some other important application is in manufacturing of vehicle door and dash panels, refrigerator liners, plastic pallets, etc.

Examples of vacuum thermoformed parts are shown in figure 8.8.

[http://www.thomasnet.com]

[http://www.texchem-pack.com]

Fig. 8.8 Examples of vacuum thermoformed custom parts

8.2.5 Blow Molding

Blow Molding process is the one used for manufacturing hollow, thin walled plastic parts.

The process gets its origins from the Egyptians and Babylonians times and it is, based on the blowing glass idea The first blow molding machine was produced by Enoch Ferngren and William Kopitke (in the '30s) and, so the beginning of commercial blow molding process can be considered. While the '40s, the variety of blow molded products was not so large but, starting with the '70s, the plastic containers, the pets industry has blossomed.

In blow molding, the raw material is represented by thermoplastics, such as polyethylene (low density or high density), polypropylene or polyvinyl chloride. The initial form is that of pellets or granules. First, this material is melted and transformed into a hollow tube, called *parison*. Then, the parison is clamped between mold halves and pressurized air is used to inflate and force it take the inner shape of mold cavity. After that, once the plastic has cooled and hardened, the mold opens and the part is ejected.

Depending on the method used to obtain the parison, there are three types of blow molding process, as follows

◙ *Injection Blow Molding* ⇒ the hollow parison is formed by injection molding of plastics, around a core inside the parison mold. When the parison mold opens, both the parison and core are transferred to the blow mold and securely clamped. The core then opens and allows pressurized air to inflate the parison.

A schematic representation of the process can be noticed in figure 8.8, where the stages are.

(1) - parison is injection molded around a blowing rod;
(2) - injection mold is opened and parison is transferred to a blow mold;
(3) - soft polymer is inflated to conform to a blow mold;
(4) - blow mold is opened and blown product is removed.

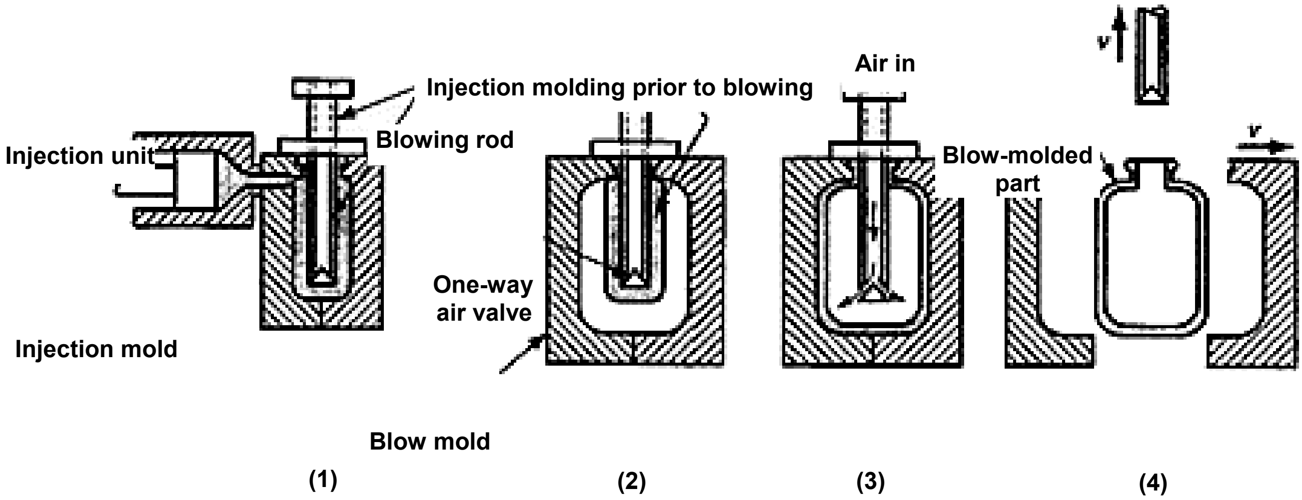


Fig. 8.8 Schematic representation of the Injection Blow Moulding process [http://www.petmachine.in]

Advantages of the process are:

⇒ low unit price;

⇒ suited for small complex parts, like those in medical applications;

⇒ allows high accuracy in neck design, weight and wall thickness.

As for disadvantages, there can be mentioned:

⇒ demand for high volume production;

⇒ limitation to simple hollow forms

◙ *Extrusion Blow Molding* ⇒ the molten plastic is extruded through a die head that forms the parison around a blow pin. Pressurized air flows through the blow pin to inflate the parison and forces it against the mold cavity to form the final shape. Finally, the excess pinched material has to be removed of the part.

The schematic representation of the process is shown in figure 8.9, where there can be noticed the main stages as:

1) extrusion of parison;

(2) parison is pinched at the top and sealed at the bottom around a metal blow pin as the two halves of the mold come together;

(3) the tube is inflated so that it takes the shape of the mold cavity;

(4) mold is opened to remove the solidified part.

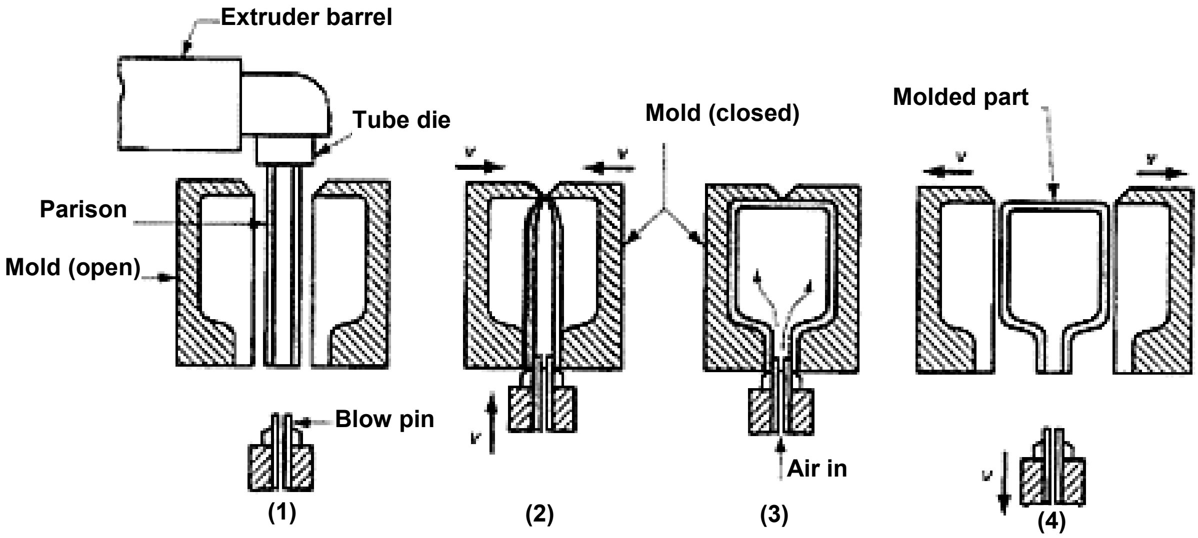
The process has many advantages, such as:

⇒ very low unit price;

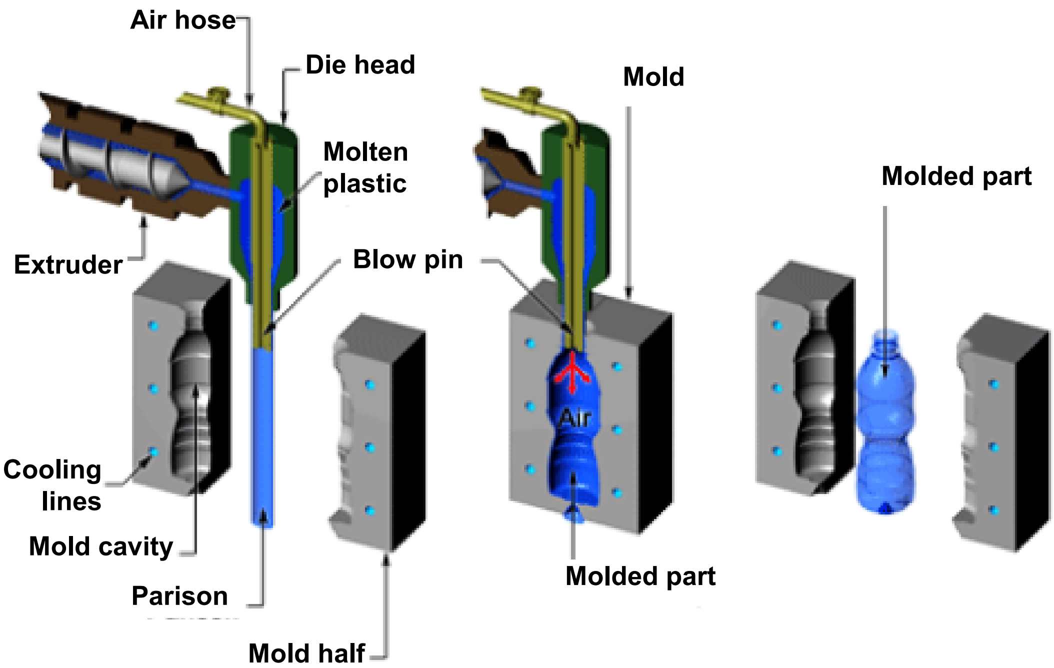
⇒ suited for production of large and complex shapes,

⇒ fast production rates.

The main disadvantage is that of demanding high production volumes.



a. [http://www.petmachine.in]



b. [http://www. custompartnet.com]

Fig. 8.9 Schematic representation of the Extrusion Blow Moulding process

◙ *Stretch Blow Molding* ⇒ the parison is obtained as in injection blow molding, usually with the necks of the bottles, including threads (the "finish") on one end.

These parisons are packaged, and fed later (after cooling) into a reheat stretch blow molding machine. They are heated (typically using infrared heaters) above their glass transition temperature, then blown using high pressure air into bottles using metal blow molds.

Usually the parison is stretched with a core rod as part of the process. This stretching provides greater strength to the plastic.

The process scheme is presented in figure 8.10, where there can be noticed the stages of.
(1) injection molding of the parison;
(2) stretching;
(3) blowing.

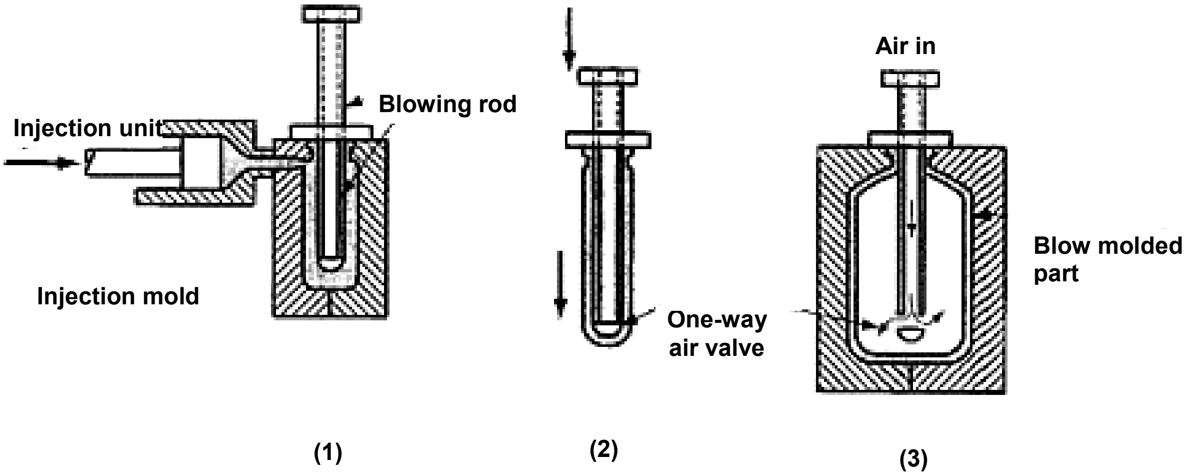


Fig. 8.10 Schematic representation of the Stretch Blow Moulding process [http://www.petmachine.in]

The process is applied when there must be obtained parts that must withstand some internal pressure or be very durable, such as soda bottles, narrow mouth water bottles, liquor bottles, peanut butter jars, etc. An image of parison and the molded part is presented in figure 8.11.

Fig. 8.11 The parison and molded part example [1]

More examples of blow molded parts, made by S.C. Sabiplast S.R.L., a Romanian company, are shown in figure 8.12.

bottles for no-pressure liquids

bottles for pressure liquids

Fig. 8.12 Examples of blow molded parts [http://www.sabiplast.ro]

8.3 Application – Injection Moulding of a Customized Part

This example is about steps taken in order to design and manufacture the injection mould for a customized part and, further to produce the part, which is a plastic glass.

It was possible to present this, courtesy of Prof..Constantin OPRAN; Head of Composites Products Laboratory; POLITEHNICA University of Bucharest, Romania [http://www.ltpc.pub.ro].

So, the custom part design, done with Delcam PowerSHAPE software, is shown in figure 8.13,

The injection mould – with its main elements "visible", is presented in figure 8.14. There should be added that the mould design was, also done with Delcam software, particularly, Delcam Toolmaker.

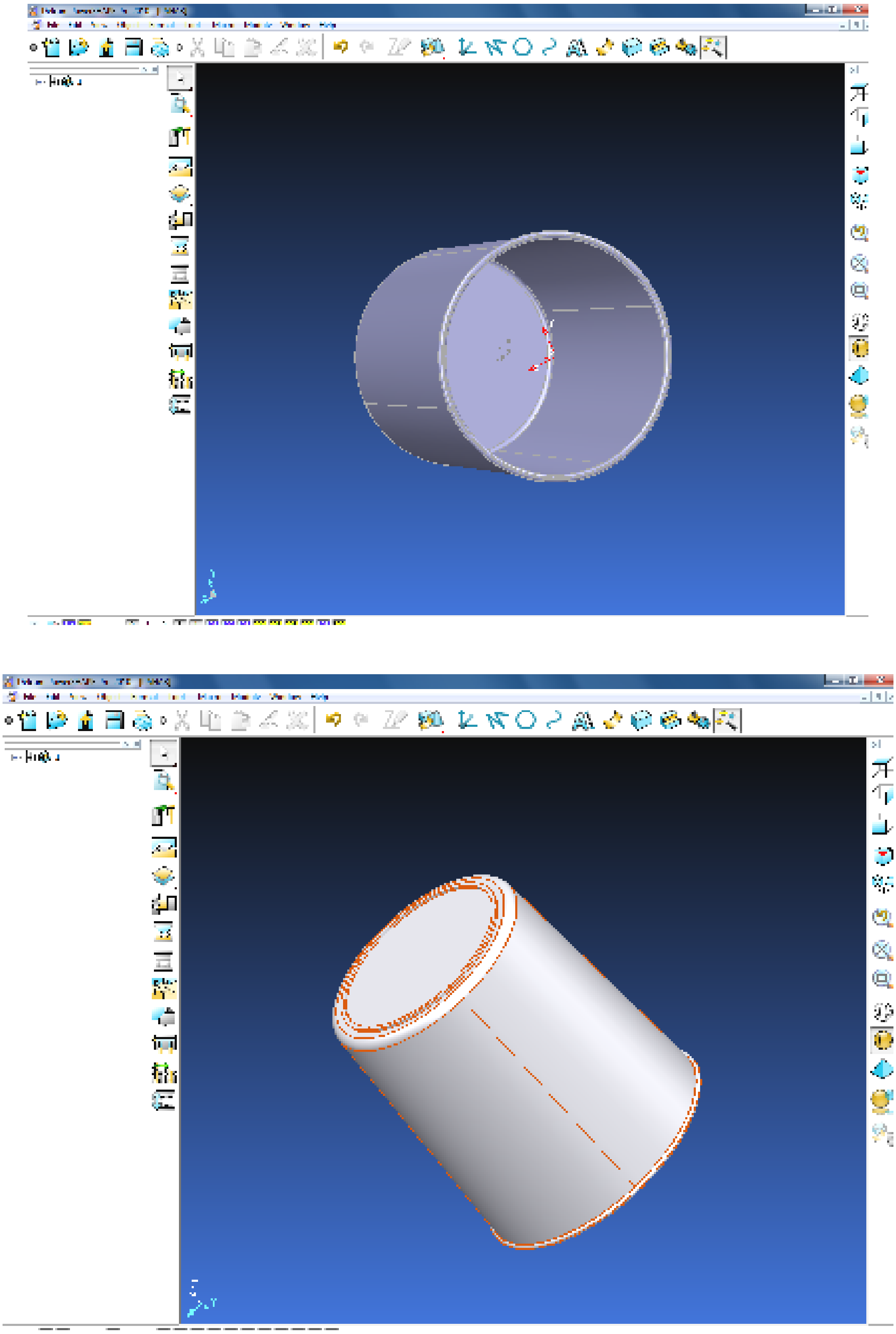


Fig. 8.13 Custom part design - plastic glass

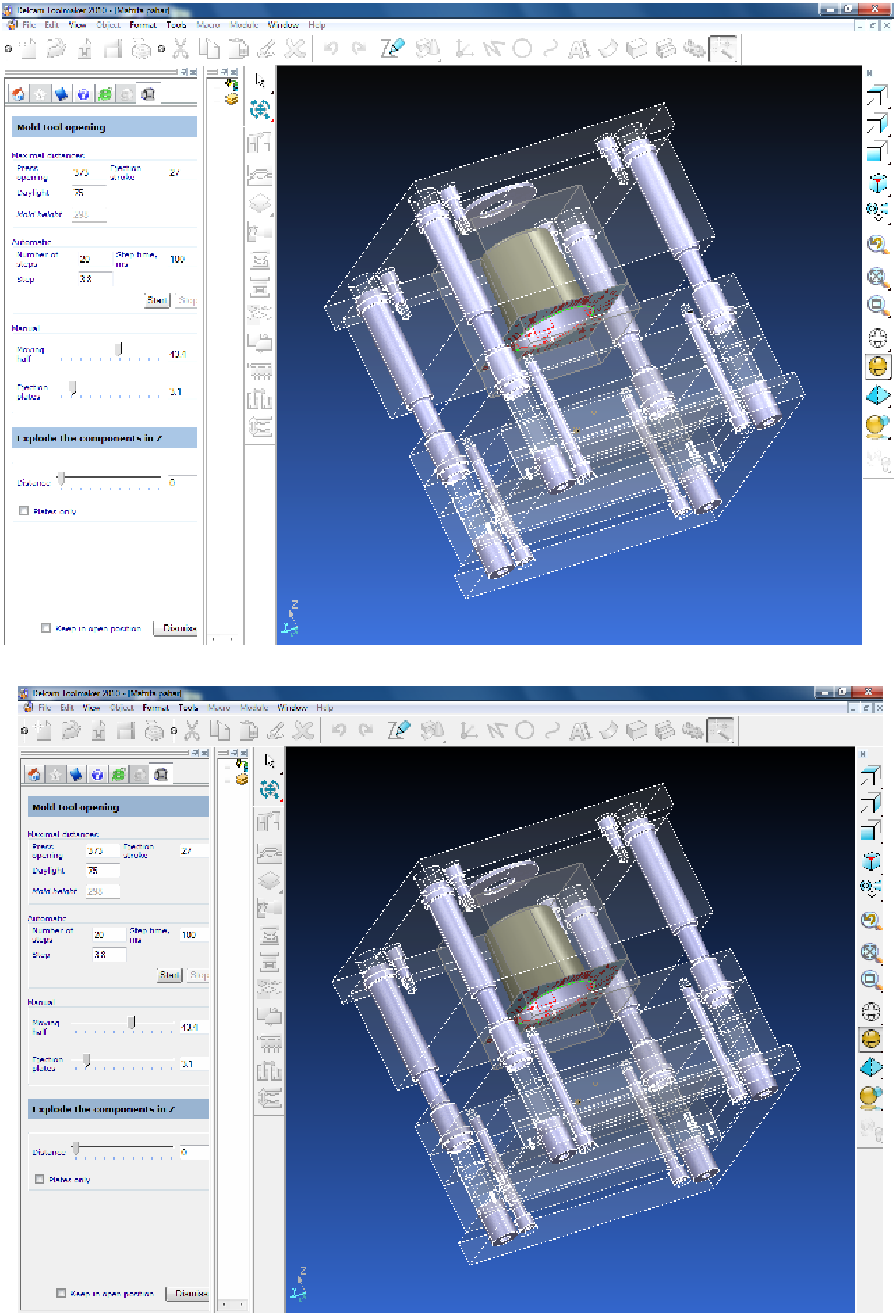
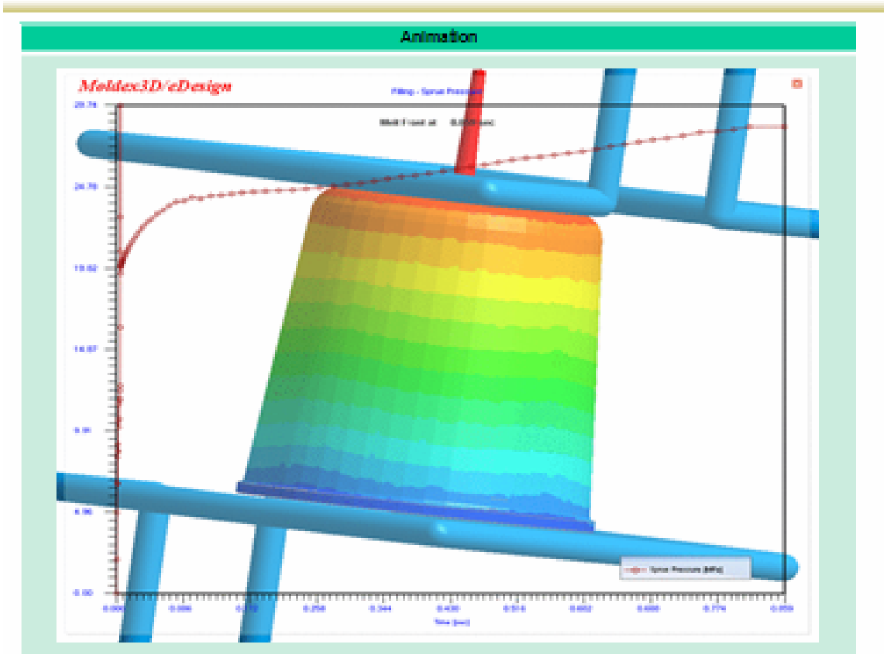


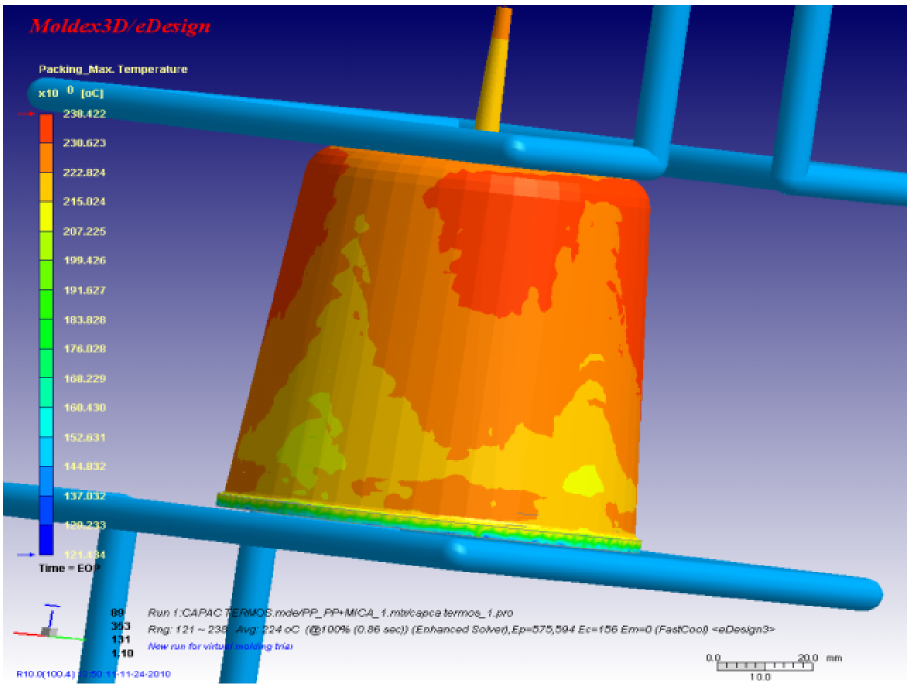
Fig. 8.14 Injection mould drawing - for the customized part considered

An important aspect of injection is that of how the molten material fills the mould cavity – meaning if there are all the cavity parts filled, with no voids or, cracks while cooling, if the material temperature while injection is fitted for the process, etc.

So, it is important, if possible, to simulate the injection process, such as: material's temperature, its filling paths and, consequently, its behaviour when injected. All of these, accomplished, prior to injection mould manufacturing are very important as, eventual errors in mould design can be detected and corrected. The software used for these, was Moldex 3D and some of the simulation results can be noticed in figure 8.15.



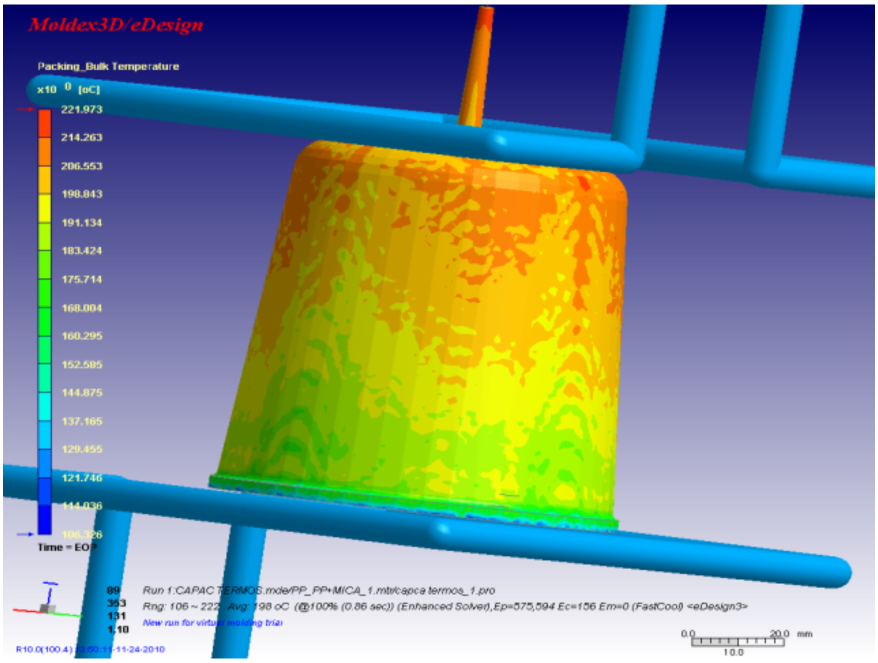
- simulation results for material's pressure while injection



- simulation results for part material's temperature while injection

Fig. 8.15 Simulation of the injection process – to be continued

Observation: the blue lines represent the cooling channels of the mould



- simulation results for bulk's temperature while injection

Fig. 8.15 Simulation of the injection process

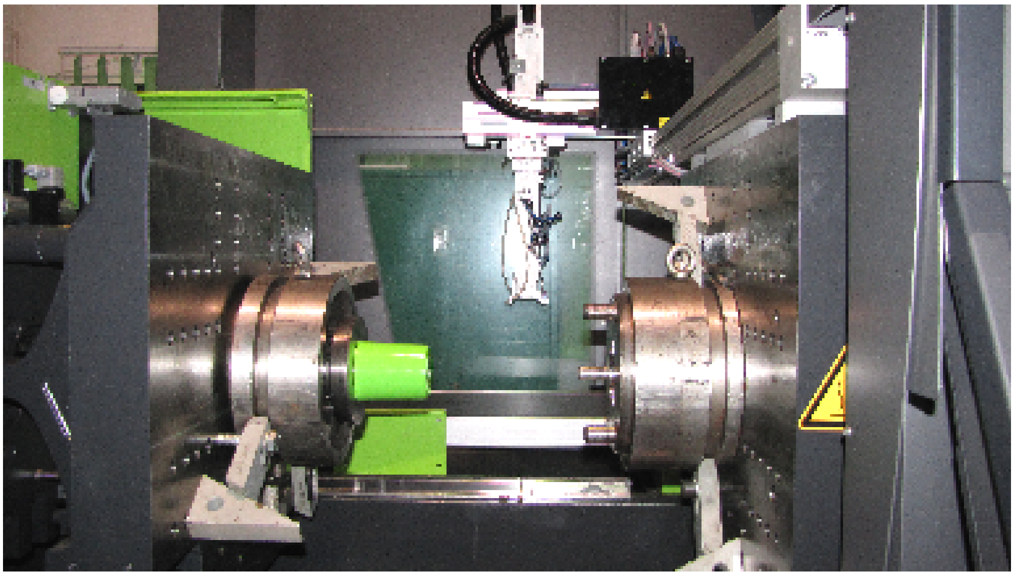
Observation: the blue lines represent the cooling channels of the mould

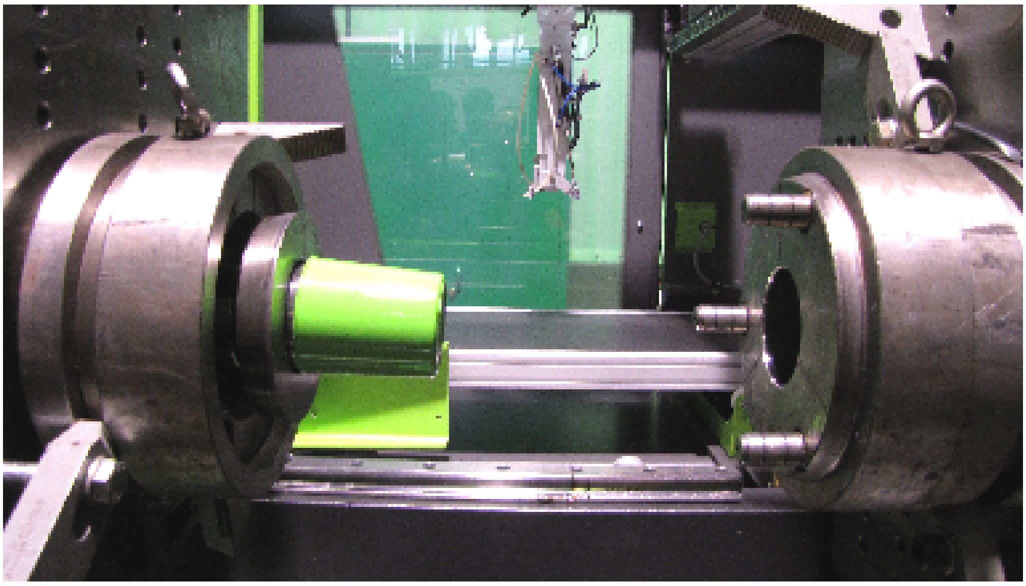
Once all the theoretical aspects of the injection process being solved, the next step was taken, meaning the injection mould manufacturing. Then, after the injection machine prepared (correctly programmed), the injection process was on.

Some relevant images – once the injection process over, are shown in figure 8.16.

- the injection machine, the mold and the molded part -

Fig. 8.16 Injection molding of the customized part – end of process





- the mold and the molded part -

- the molded part -

Fig. 8.16 Injection molding of the customized part

Summarizing all the information presented in this chapter, some conclusion can be stated, meaning:

⇒ the synthetic plastic industry started in 1909 and since then, it has been continuously developed;

⇒ there is a wide range of plastics forming processes, depending on their state while forming and, of their characteristics;

⇒ parts obtained by different plastics forming processes have application in so many fields – electronics, agriculture, automotive, households, etc.

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9. GIFTS, GADGETS AND ITEMS

There are many cases when customized products, like T-shirts, sweatshirts, hats, mugs, ornaments, candles, stickers, posters, flyers, binders, etc. have to be manufactured, in order to get gifts, gadgets, advertising or, just things to enjoy.

How all these “products” are manufactured is very interesting and involves versatile technologies, such as the “ancient” heat transfer and laminating, while the most modern ones deal with digital printing.

For example, courtesy of zazzle [http://www.zazzle.com], it can be evidenced the fact that when manufacturing customized clothes, there is used a new digital technology that chemically bonds ink to cotton molecules, resulting in brilliant colors and photographic quality. The image is soft, breathable, vibrant and durable, without that "decal" feel typically imparted by heat-transfer and screen print methods. There is no overprint around the image area, and images have a "wash fastness" equal to or better than other print methods on 100% cotton.

In figure 9.1 there can be noticed some of the custom T-shirts types available at zazzle.

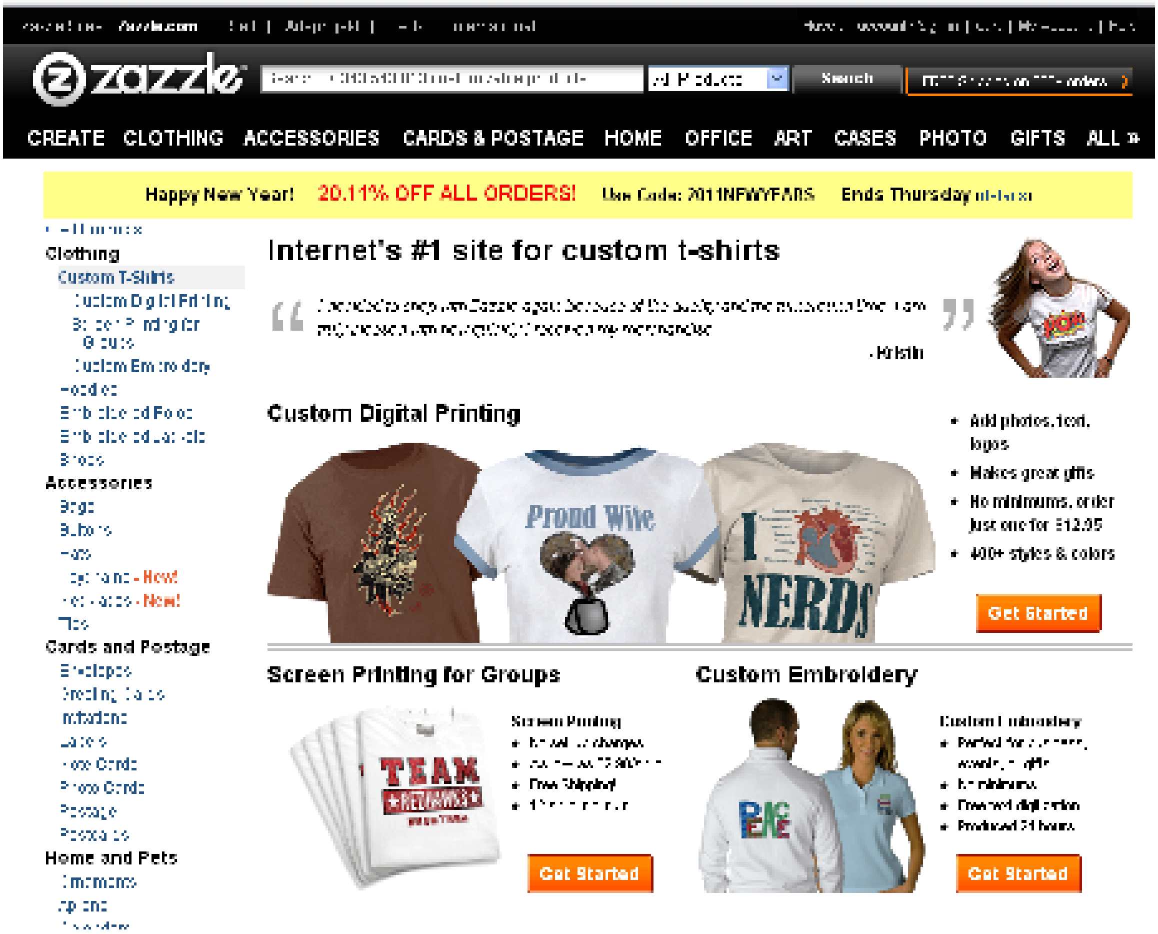

Fig. 9.1 Custom T-shirts – to be ordered on-line [http://www.zazzle.com]

Courtesy of customInk.com® [http://www.customink.com], there should be mentioned another technology used when manufacturing custom shirts, meaning that of screen printing, which involves the use of screens to transfer ink onto the shirts. The ink sinks in a bit, but sits more on top of the fabric.

They do also use digital printing, when the ink really sinks into the fabric, almost like giving the shirts a tattoo. It can be viewed as using a printer, but it is the biggest, most high-tech, expensive printer you could get.

As for caps and other hats, the customer order is fulfilled by embroidering the design on by stitching it on with thread.

Some samples of customized products (T-shirts, sweats, athletics, caps, hats, etc.) that can be worked out with customInk.com® are shown in figure 9.2

Fig. 9.2 Custom clothes – to be ordered on-line [http://www.customink.com]

Examples of how customized products are ordered on http://www.zazzle.com website are shown further. So, there is figure 9.3 presenting some of the steps followed for getting a custom tote bag and figure 9.4 pointing out how a special custom ornament can “bring your best friend wherever you are”.

Another wanted customized products – specially for companies and / or conferences, are the pencils and pens. How an on-line order can be launched so that to get a special ink pen can be noticed in figure 9.5.

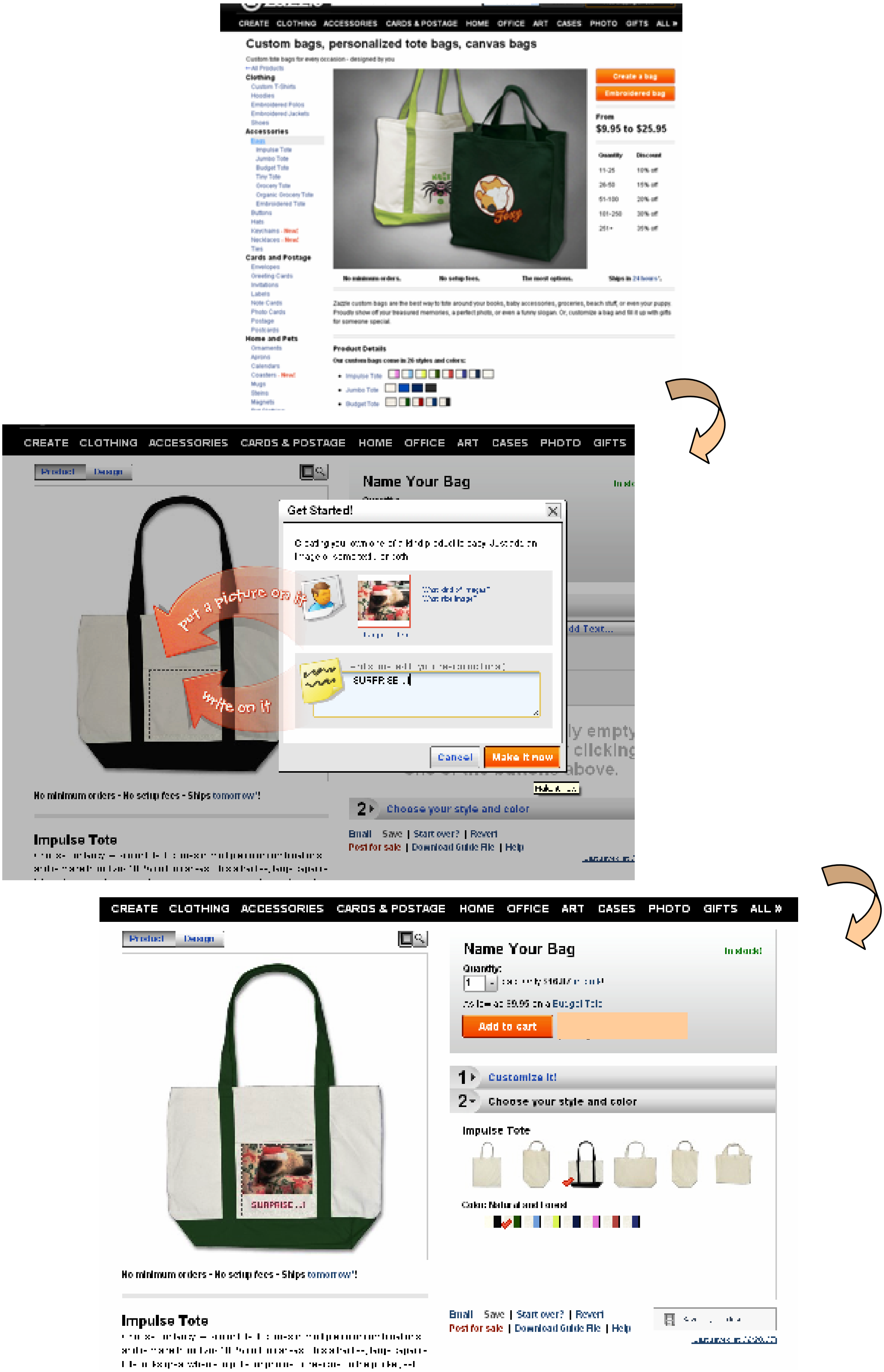

Fig. 9.3 Ordering a custom tote bag at zazzle [http://www.zazzle.com]

Fig. 9.4 Ordering a custom ornament at zazzle [http://www.zazzle.com]

Fig. 9.5 Ordering a custom ink pen at pensxpress [http://www.pensxpress.com]

Customized products, often offered as gifts or souvenirs are the one made of glass and, sometimes, of crystal. As customers desires and orders have become versatile and, rather, sophisticated, new technologies for obtaining the required products have been developed.

So, a modern one is that of digital printing (also mentioned above), with modern, high performance printers that do effectively cut both operating and indirect costs related to printing.

Figure 9.6 shows two kinds of glass printers, one for cylindrical surfaces and the other for flat surfaces, while in figure 9.7 there are presented some glass printed customized products.

UN-OT-MAS01 Glass Printer

- fashionable and smooth mould appearance.
- thousands deposited images in software
- average printing time: 45 second
- print customized image though USB
- wearable printing, durable
- personalized pictures can be edited and paint

UN-OT-MASD03 Glass Printer

- max. printing width: 1520mm and length: 2500mm
- print head: 6 colors, 256 nozzles per colors
- max. printing speed: 1200*600dpi 6m^2/h
- drier method: hot wind or hot light
- print head height: adjustment (2-200mm), suitable for different thickness

Fig. 9.6 Glass printer types [http://www.glass-printer.com]

Fig. 9.7 Customized printed glasses [http://www.glass-printer.com]

The new, trendy way of surprising someone dearest is that of offering him / her a customized candle or, more, a personalized flower.

How they can be manufactured is also related to digital printing technology. Printer examples and the gorgeous customized products obtained are evidenced in figure 9.8 – for flowers and, in figure 9.9 – for candles.

- it can paint any designs on three flowers at one time.
- present write words and edit function
- fast drying and waterproof
- curving flower holder
- openly million designs saved

UN-FL-MN102A Flower Printer

Fig. 9.8 Flower printer and custom printed flowers - to be continued
[http://www.flowersprinter.com]

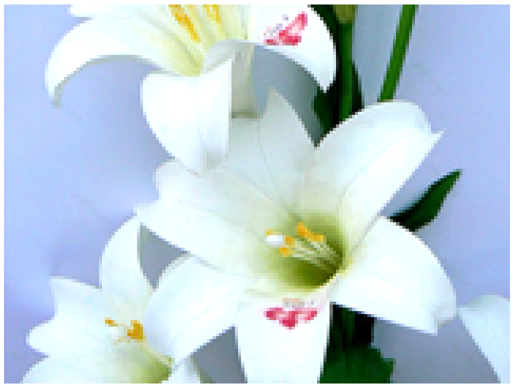

Fig. 9.8 Flower printer and custom printed flowers [http://www.flowersprinter.com]

UN-SO-MN101 Candle Printer

- it can print any designs directly on candles in different shapes: pillar, ball, conical, square;
--customers can not only choose designs from gallery, but also save their own photos, designs or words into software and then print on candles directly.
- fashionable and smooth mould appearance.
- max. printer size:140mm diameter and 210 mm length for pillar objects; 130 x 210 x 140 mm for square and pyramid

UN-SO -MD01

- max. printing size: 75mm diameter and 200mm length for pillar candles,
- input Voltage: 220V 50Hz/110V 60Hz;
- packing in wooden case: 1500x 550 x2200mm

Fig. 9.9 Candle printer and custom printed candles – to be continued
[http://www.candlesprinter.com]


Fig. 9.9 Candle printer and custom printed candles [http://www.candlesprinter.com]

Conclusion of all the aspects shown in this chapter should be that:

⇒ customized products, like T-shirts, sweatshirts, hats, etc. – are easy to order and to manufacture, specially when an internet connection is available;

⇒ special gifts like customized printed glasses, candles or, more, personalized flowers – do represent a special way of surprising someone dearest.

⇒ there are also so many other customized products (pens, chains, rings, jewelry) to be offered as promos or gifts, and that do involve interesting, new technologies of manufacturing.

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http://www.pensxpress.com

10. MANUFACTURING CUSTOMIZED PRODUCTS FOR INDUSTRY

10.1 Customized Device for Machining Force and / or Torque Measurement

When manufacturing a product, it is important to know the forces and / or torques while the process is on – even it is a cutting, or a forming one. Their values have a great influence on the geometrical precision of the machined part, technological system's rigidity and energy consumption.

Measuring manufacturing forces / torques is, usually, performed into laboratories – for experimental–theoretical research or, into production – for adaptive command of the technological system.

The manufacturing force / torque measuring devices, that do already exist, have various constructive-functional structures but, are special or specialized ones – meaning they can be used only for a single manufacturing process type. That is why, a customized product, meaning *a force and / or torque measuring device* used in machining processes (cutting and forming) had to be manufactured.

The most important component of a force measuring system is the *force measuring device*, whose relevant characteristics are: the load, the exit signal, the calibrating curve, the hysteresis, the rigidity – both static and dynamic. A correct use of such a system is possible only if it is calibrated.

The elastic element – defined by shape, dimensions, material, etc., represents the key element of the device. There are transducers bond on it should "signalize" any kind of its deformations - the studied referring to resistive ones. Usually, the elastic element is submitted to various loading types. The decoupling of its complex deformation's components is possible only if the transducers are placed in an appropriate number, section and direction.

► Product specifications

Based on the needs expressed by researchers in technical university laboratories ("POLITEHNICA" University of Bucharest, ENGINEERING and MANAGEMEMT of the TECHNOLOGICAL SYSTEMS Faculty) and engineers working in production departments, the product specification have been settled as:

- force and / or torque measurement ⇒ in manufacturing systems associated to, both cutting processes (turning, drilling, milling, grinding) and, metal forming processes (punching, bending, drawing, extrusion);
- nominal load ⇒ along each of the main axis - 10,000 N value
- nominal torque ⇒ around each of the main axis - 500 N·m value (OXYZ as the reference system)
- good signals' decoupling ⇒ regardless loading direction / measuring channel;
- limited dimensions and weight ⇒ circular, about 200 mm diameter and 80 mm height; no more then 6 kg weight

► Elastic element design

The *innovative shape of the elastic element* consists in a two sides wheel – the upper one rotated by 90° with respect to the lower one, each of them having two spokes – see figure 10.1.

► Modeling and Simulation

The program used for modeling and simulation was ANSYS [http://www.ansys.com]. It was a ten points tetrahedron element obtained for the parametric model of the elastic element, while simulation of its behavior in different loading types cases was done.

Because of the constructive and loading symmetry, the simulation was considered only for one part of the elastic element. The purpose of this modeling was to determine:

- maximum values of equivalent stresses;
- the influence between measured components;
- resistive transducers' position, so as to get maximum sensitivity and lower signal's reciprocal influence.

So, in loading with vertical F_y force (along OY axis of the reference system), the equivalent Von Misses stresses and the specific deformations, along the indicated line are presented in Figure 10.2. Similarly, the equivalent Von Misses stresses and the elastic element specific deformation's variation, when loading with M_y torque (around OY axis), are shown by Figure 10.3.

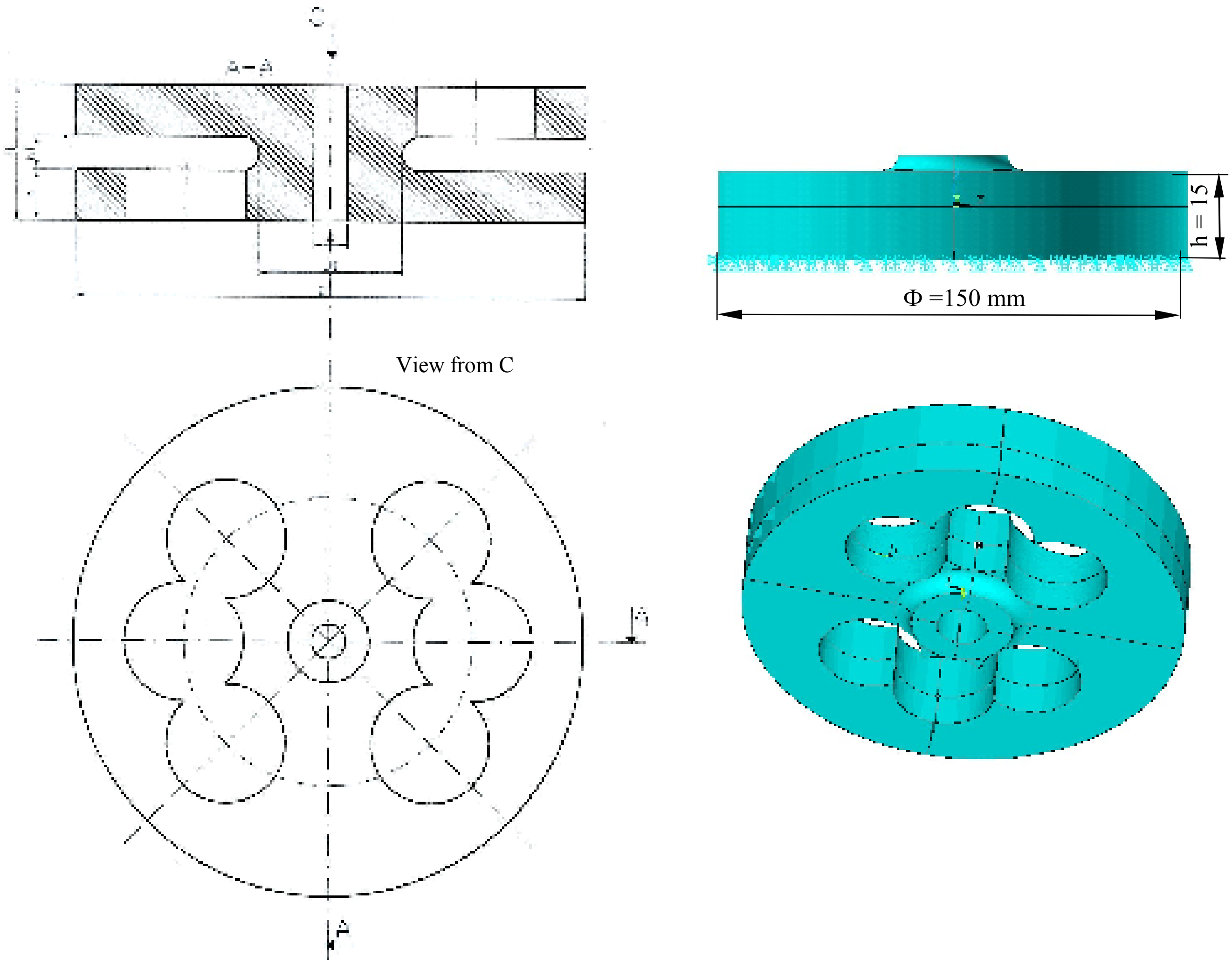
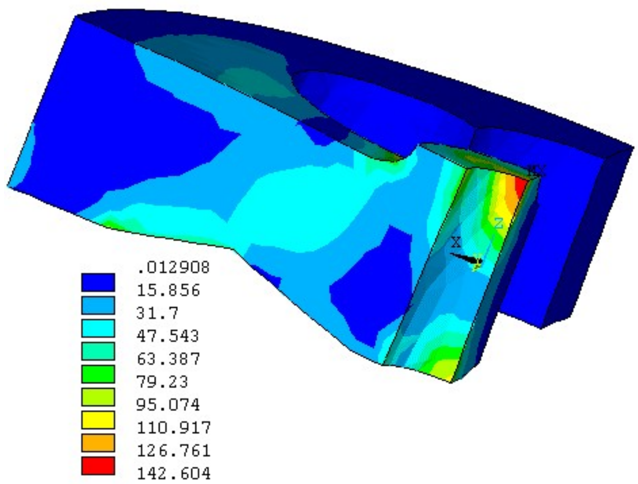
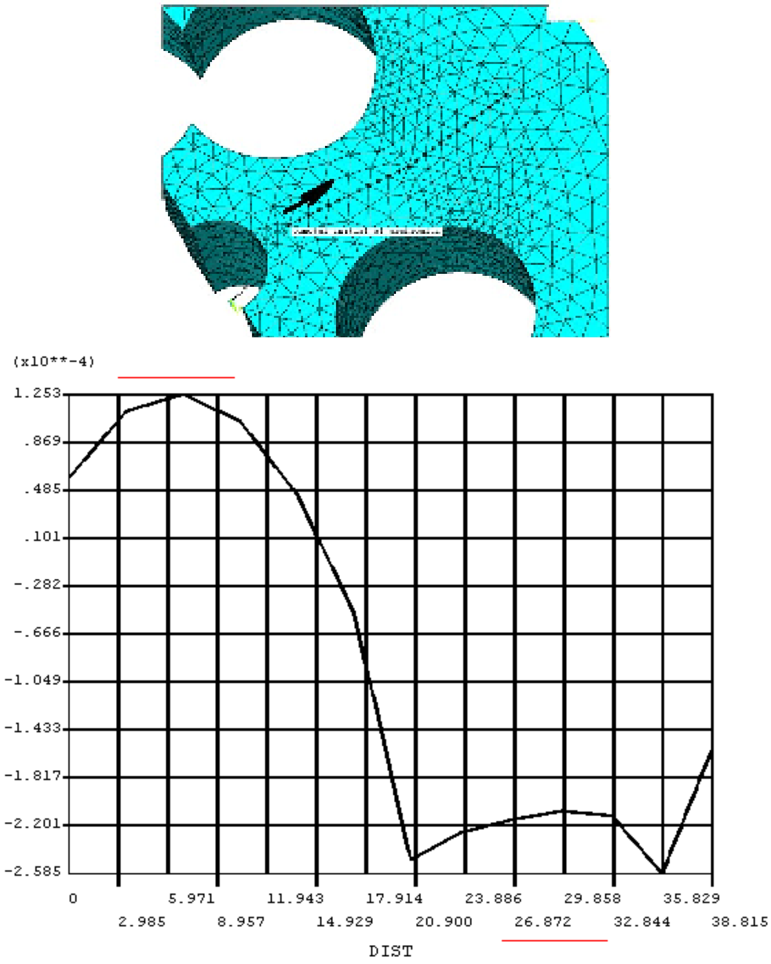


Fig. 10.1 Elastic element drawing



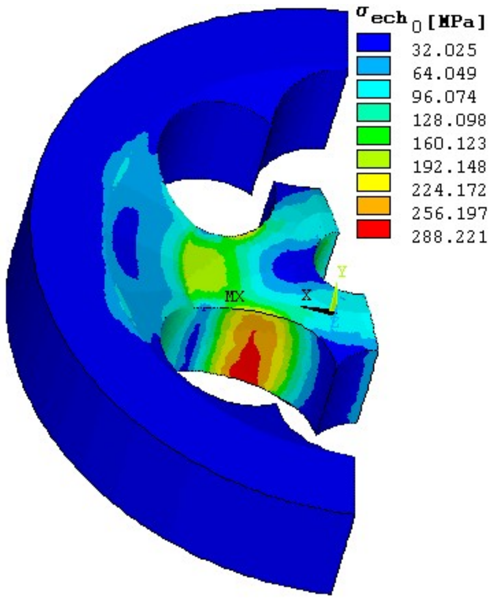
- equivalent Von Misses stresses -

Fig. 10.2   Model and simulation for F_y loading – to be continued



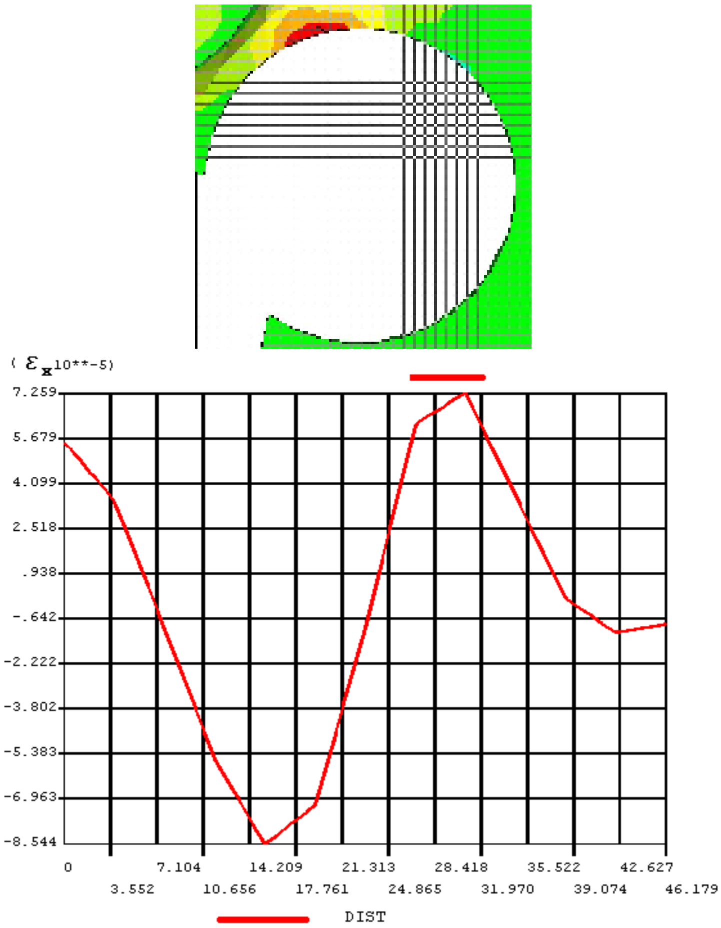
- specific deformation variation -

Fig. 10.2 Model and simulation for F_y loading



- equivalent Von Misses stresses -

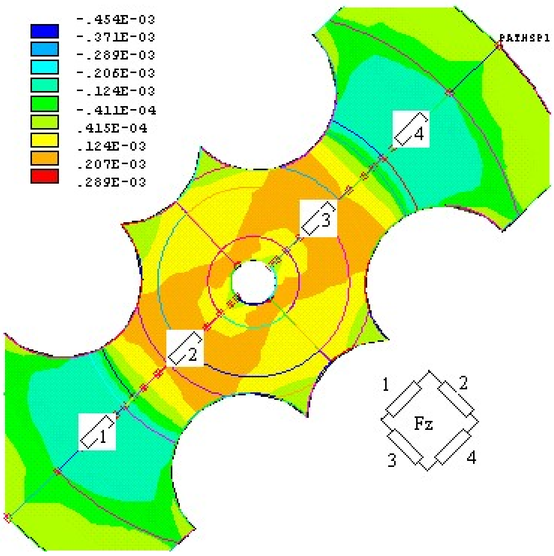
Fig. 10.3 Model and simulation for M_y loading – to be continued



- specific deformation variation -

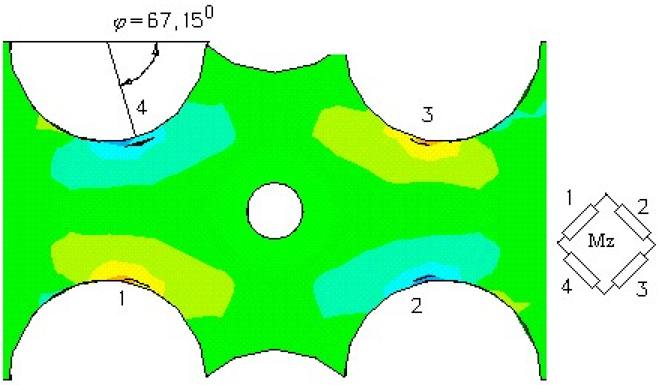
Fig. 10.3 Model and simulation for M_y loading

As result of the whole loading conditions simulation, it was possible to determine optimum position and connection of the resistive transducers used (TER). Example of transducers' Wheatstone bridge connection, for F_y and M_y loading, are presented in Figure 10.4.



- for F_y measurement -

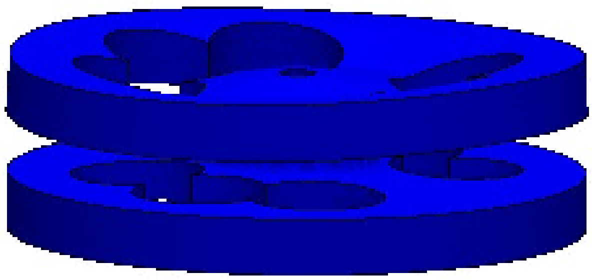
Fig. 10.4 Resistive transducers position and connection – to be continued



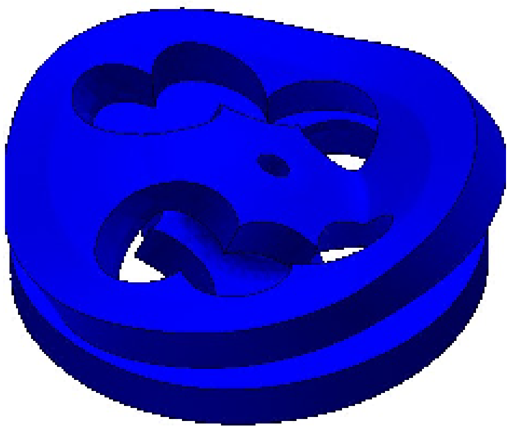
- for M_y measurement -

Fig. 10.4 Resistive transducers position and connection

A study of elastic element's rigidity, in dynamic loading, has also been done, some results are shown in Figure 10.5.



- vibration resonance frequency ν_0 = 627,5 Hz -



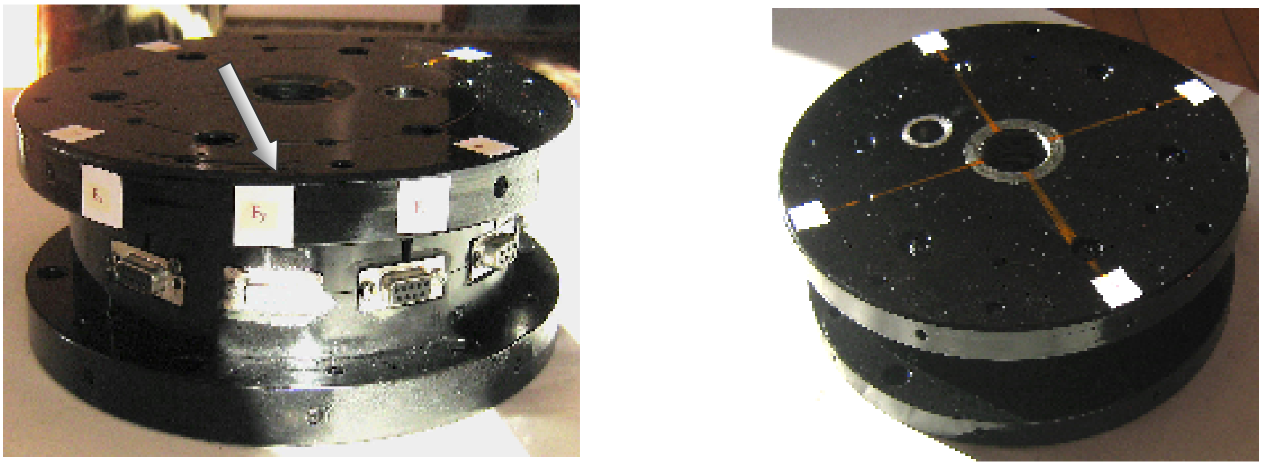
- vibration resonance frequency ν_0 = 7182,7 Hz -

Fig. 10.5 Dynamic loading simulation

As result of all the above mentioned aspects, and of more others – determining screw holes, technological system contact elements, etc - the force measuring device has been made – see figure 10.6.

Observation:

The white marks show the transducers connection for each of force / torque components measurement.



- the device -

- the device equipped for turning type processes -

- the device equipped for milling, drilling, cold forming type processes -

Fig. 10.6   The manufactured device for machining force and / or torque measurement

► Deformation and rigidity characteristics

Some elements need to be defined, so as to theoretically-experimentally determine deformation and rigidity characteristics. Thus, there are:

- loading force, F $\Rightarrow$ along each of reference system axes, called F_x, F_y and F_z;
- loading forces, F $\Rightarrow$ in XOY, YOZ and XOZ plans, called F_{xy}, F_{yz} and, respectively, F_{zx};
- angles $\Rightarrow$ between force direction and reference axis– OX, OY and OZ, φ_x, φ_y, and, respectively, φ_z;
- static resulting deformation, U $\Rightarrow$ along each of the reference system's axis, called X, Y, Z;

The loading force, F, was applied to well defined points (of the device) and, along well defined directions, while the resulting deformation, U, was measured on certain points (of the device).

The deformation characteristic was determined, as graphical dependence:

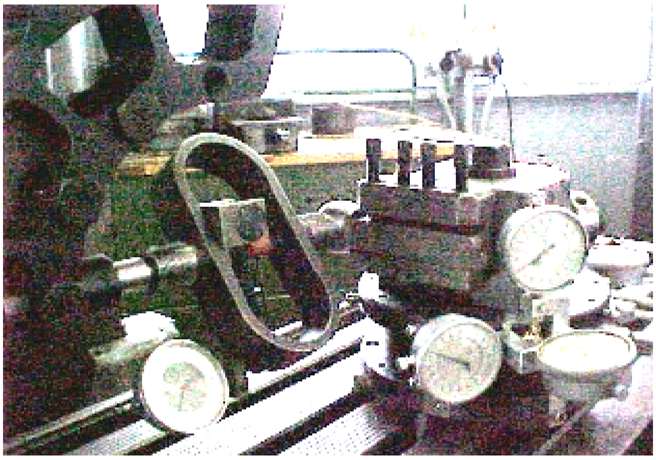
$$U = U(F) \tag{10.1}$$

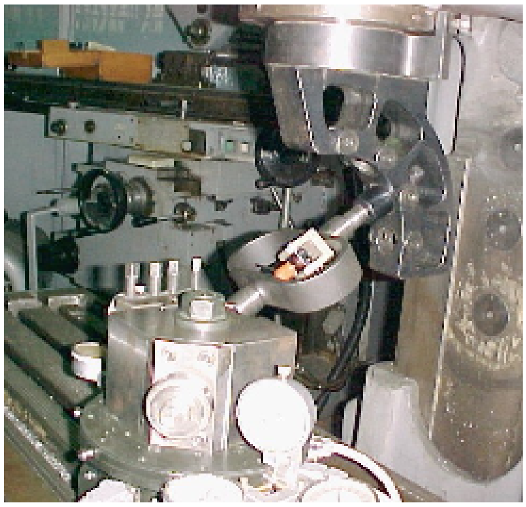
while the deformation and rigidity values, C and, respectively, K, were established by relations:

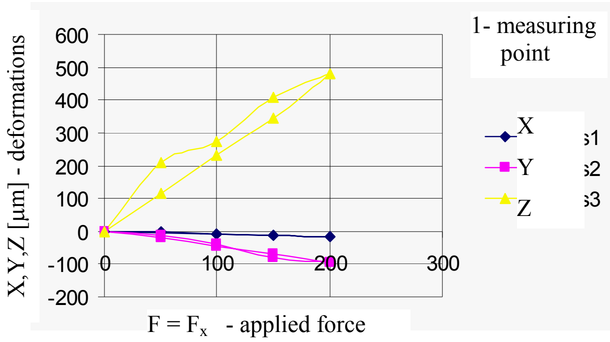
$$C = \frac{U_{max}}{F_{max}}; \quad K = \frac{F_{max}}{U_{max}} \tag{10.2}$$

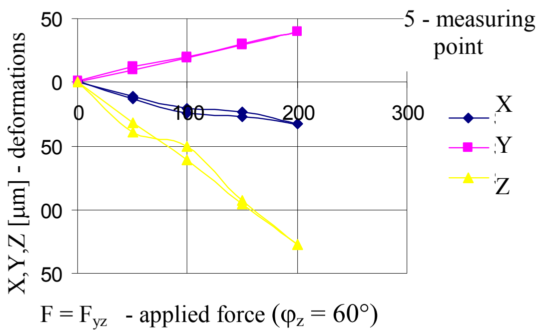
Some images, taken while determining of deformation and rigidity characteristics, are presented in figure 10.7. There are also presented the corresponding determined static deformation characteristics.

Examples of experimental results, thus obtained, are presented in Table 10.1.





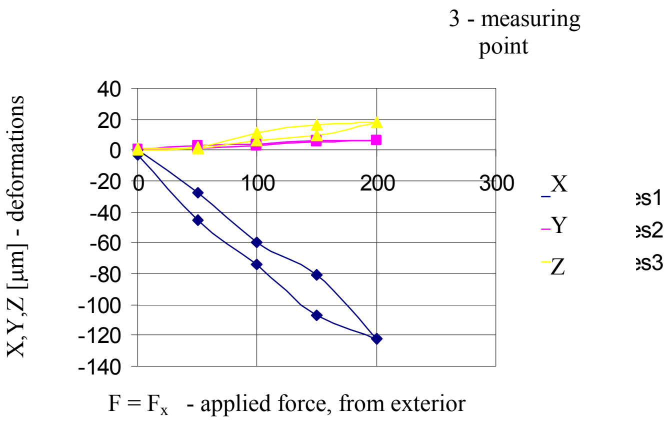




- F_x loading force -

- F_{yz} loading force (φ_z = 60°) -

– turning type processes -



- F_x - loading force, from exterior -

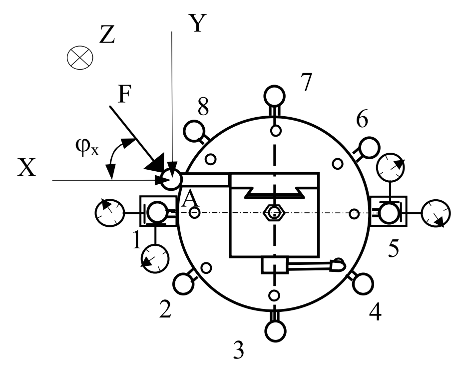
- drilling, milling, punching, bending, drawing type processes -

Fig. 10.7 Loading cases – for obtaining deformation characteristics

Table 10.1

Experimental results – for turning type process

F_x [daN]		Deformation [µm] X	Y	Z
0	l	0	0	0
	ul	*0*	*0*	*0*
50	l	0	-21	117
	ul	*-4*	*-13*	*210*
100	l	-7	-45	232
	ul	*-10*	*-40*	*275*
150	l	-13	-68	343
	ul	*-14*	*-80*	*410*
200	l	-16	-96	479
	ul	*-16*	*-96*	*479*

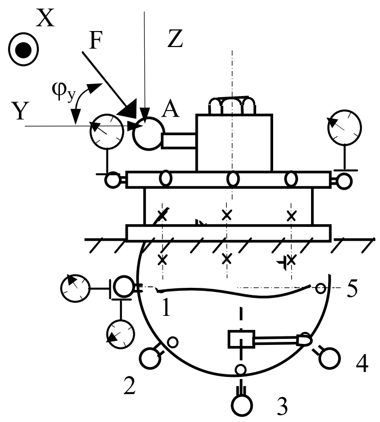


A: loading point
1: measuring point

l: loading
ul: unloading

$\varphi_x = 0°$; ($\varphi_y = 90°$)
$\varphi_z = 90° \Rightarrow F_x$

F_{yz} [daN] ($\varphi_z = 60°$)		Deformation [µm] X	Y	Z
0	l	0	0	0
	ul	*1*	*1*	*0*
50	l	-11	10	-39
	ul	*-13*	*12*	*-32*
100	l	-20	19	-50
	ul	*-24*	*20*	*-61*
150	l	-23	29	-93
	ul	*-27*	*30*	*-96*
200	l	-33	40	-127
	ul	*-33*	*40*	*-127*



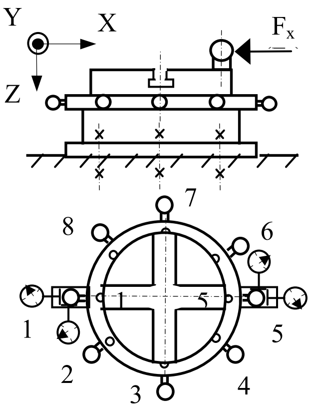
A: loading point
5: measuring point

l: loading
ul: unloading

$\varphi_x = 90°$; $\varphi_y = 30°$
($\varphi_z = 60°$) $\Rightarrow F_{yz}$

Experimental results – for drilling, milling, punching, bending, drawing type process

F [daN]		Deformation [µm] X	Y	Z
0	l	0	0	0
	ul	*-3*	*0*	*1*
50	l	-28	1	1
	ul	*-45*	*3*	*2*
100	l	-60	3	6
	ul	*-74*	*4*	*11*
150	l	-81	5	10
	ul	*-107*	*6*	*16*
200	l	-122	6	18
	ul	*-122*	*6*	*18*



A: loading point
3: measuring point

l: loading
ul: unloading

$F_x \Rightarrow$ applied from the exterior

The resulting values - see relation (10.2), of deformation and rigidity are shown in Table 10.2.

Table 10.2

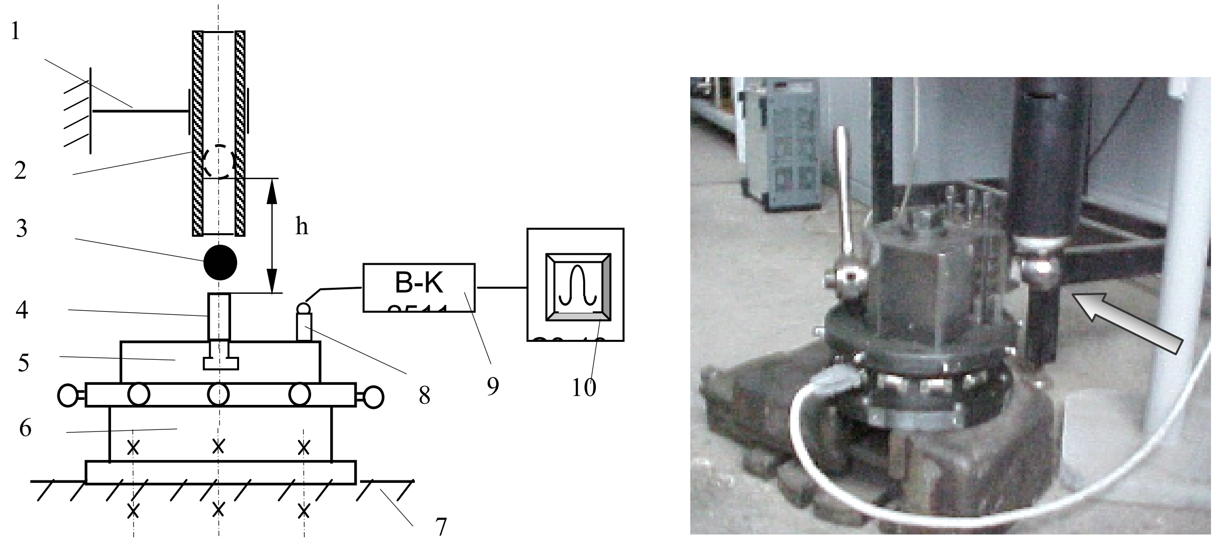
Deformation and rigidity values

F [daN]	Measuring point	Strain, C [mm/daN]			Rigidity, K [daN/mm]		
		$\frac{X_{max}}{F_{max}} \times 10^{-3}$	$\frac{Y_{max}}{F_{max}} \times 10^{-3}$	$\frac{Z_{max}}{F_{max}} \times 10^{-3}$	$\frac{X_{max}}{F_{max}} \times 10^{-3}$	$\frac{Y_{max}}{F_{max}} \times 10^{-3}$	$\frac{Z_{max}}{F_{max}} \times 10^{-3}$
F_x	1	-0.080	-0.480	2.395	-12.500	-2.084	418
F_{yz}	5	-0.165	0.200	-0.635	-6.061	5,000	-1.575
F_x - exterior	3	-0.610	0.030	0.090	-1.640	33,334	11,112

There were also carried out experiments, in order to check the accuracy of the vibration resonance frequencies, simulated with ANSYS software.

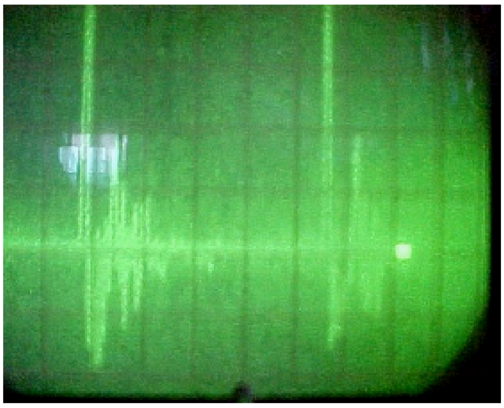
So, the device's dynamic loading was done with a spherical element, weighting *m* [kg], and falling on the device from a height, *h* [mm]. The answering resonance frequency was determined (on the oscilloscope screen) for each experiment.

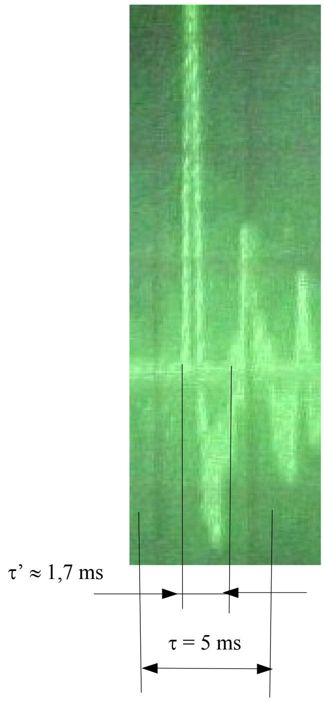
The experimental scheme is shown in Figure 10.8, while a device's vibration answering curve is evidenced by Figure 10.9.



1 – rigid support;
2- guidance cylinder;
3 – spherical element, weight *m*;
4 – additional element;
5 – addition plate;
6 – dynamometer;
7 – rigid mass;
8 – transducer;
9 –Brüel-Kjoer vibrometer;
10 – memory oscilloscope

Fig. 10.8 Dynamic rigidity experimental scheme





$$\nu' = \frac{1}{\tau'} \approx 588{,}2$$

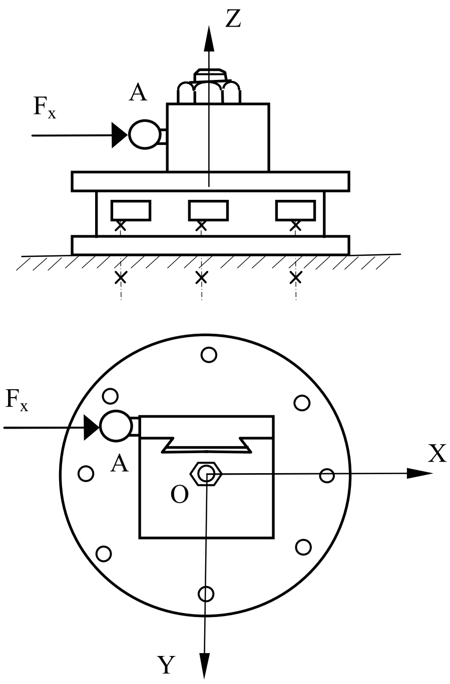
similar to the modeled one, for this case

Fig. 10.9   Vibration answering – in dynamic loading

► Calibration equations - for force measurement

Conditions like the real ones when machining had to be simulated for the device calibration. So, as the manufacturing processes conditions vary, there have been carried out lots of experiments, each being characterized by :

- loading point's position,
- direction (Ox, OY, Oz) and values of the loading force,
- device's deformations.



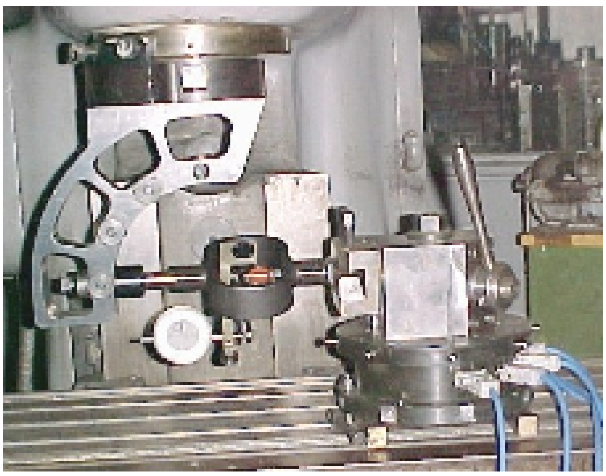


Fig. 10.10   Calibrating process - F_x force loading

Thus, under F_ρ (ρ = x, y, z) loading, there are generated the $\varepsilon_{\rho x}$, $\varepsilon_{\rho y}$, $\varepsilon_{\rho z}$ signals to the ’’C_x’’, ’’C_y’’ and, respectively, ’’C_z’’ channels of the electronic bridge.

Scheme of the calibrating experiment in F_x loading and image taken while it was on, are presented in figure 10.10.

While a certain force was applied, the corresponding deformations, along each of the reference system’s axes, have been measured. So, there were obtained linear dependence equations, such as:

$$\varepsilon_{\rho\theta} = a_{\rho\theta} \cdot F_\rho + b_{\rho\theta} \qquad (\rho, \theta = x, y, z) \tag{10.3}$$

By adding the effects,: it resulted

$$\begin{aligned} \varepsilon_x &= \varepsilon_{xx} + \varepsilon_{yx} + \varepsilon_{zx} \\ \varepsilon_x &= \varepsilon_{xx} + \varepsilon_{yx} + \varepsilon_{zx} \\ \varepsilon_x &= \varepsilon_{xx} + \varepsilon_{yx} + \varepsilon_{zx} \end{aligned} \tag{10.4}$$

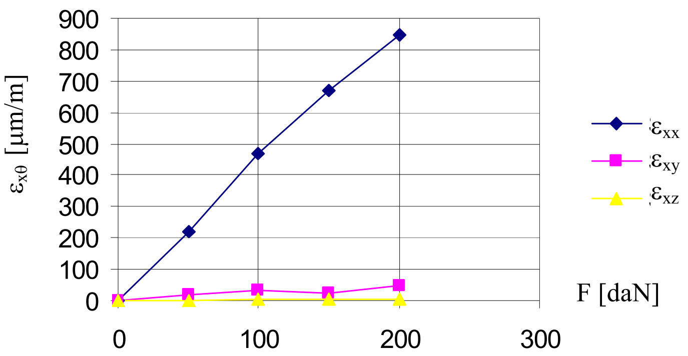
and, consequently, the calibrating equation:

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} a_{xx} & a_{yx} & a_{zx} \\ a_{xy} & a_{yy} & a_{zy} \\ a_{xz} & a_{yz} & a_{zz} \end{bmatrix}^{-1} \cdot \begin{bmatrix} \varepsilon_x - (b_{xx} + b_{yx} + b_{zx}) \\ \varepsilon_y - (b_{xy} + b_{yy} + b_{zy}) \\ \varepsilon_z - (b_{xz} + b_{yz} + b_{zz}) \end{bmatrix} \tag{10.5}$$

An example of the experimentally obtained results is presented in Table 10.3, while the corresponding calibration curves are shown in figure 10.11

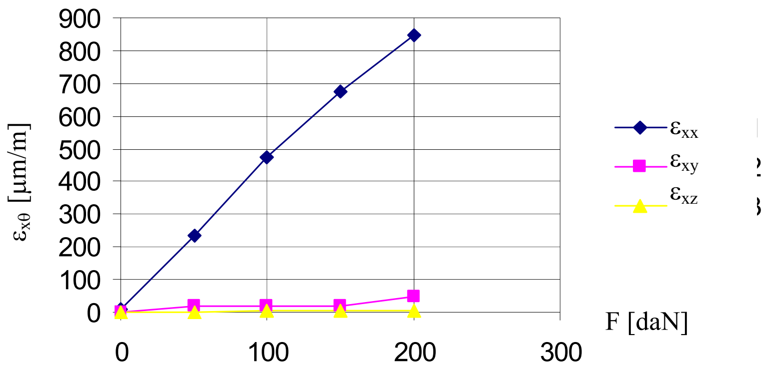
Observation:

The letter *l* is for loading and the letter *ul* is for unloading.



a.

F_x - loading



b.

F_x - unloading

Fig. 10.11 Calibration curves – for F_x loading

Table 10.3

Experimental results – for F_x loading

F [daN]		Deformation [µm] $\varepsilon_{\rho x}\ (\rho = x, y, z)$		
		F_x	F_y	F_z
0	l	0	-3	0
	ul	*4*	*-4*	*-3*
50	l	219	-9	-12
	ul	*223*	*-9*	*-13*
100	l	431	-15	-38
	ul	*435*	*-16*	*-39*
150	l	641	-21	-54
	ul	*644*	*-23*	*-56*
200	l	835	-29	-78
	ul	*835*	*-29*	*-78*

When a Hottinger electrical measurement scheme was used, the calibration equations for force were obtained as:

- for loading

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} 0{,}2402 & -0{,}0052 & -0{,}0218 \\ -0{,}0092 & 0{,}2443 & -0{,}0181 \\ -0{,}0100 & -0{,}0237 & 0{,}2361 \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_x - 6{,}200 \\ \varepsilon_y - 17{,}600 \\ \varepsilon_z + 4{,}000 \end{bmatrix} \quad [\text{daN}] \qquad (10.6)$$

- for unloading

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} 0{,}2412 & -0{,}0052 & -0{,}0214 \\ -0{,}0089 & 0{,}2399 & -0{,}0177 \\ -0{,}0097 & -0{,}0231 & 0{,}2365 \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_x - 14{,}200 \\ \varepsilon_y - 21{,}800 \\ \varepsilon_z - 2{,}200 \end{bmatrix} \quad [\text{daN}] \qquad (10.7)$$

There should be taken similar steps to determine the calibration equations for torque.

► Device exploitation

The device for measuring manufacturing forces, was tested into several technological systems – in both cutting, and metal forming manufacturing processes.

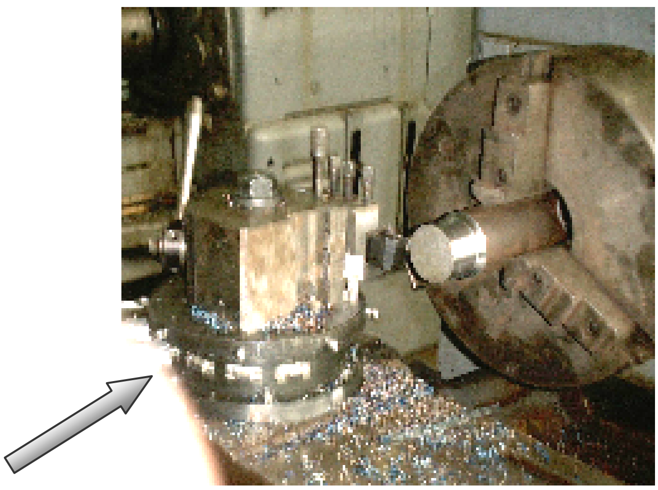


Fig. 10.12 The device used in exterior cylindrical turning of a sample

An image taken, while machining, is presented in Figure 10.12. There were experimented cylindrical samples (55 mm, diameter), made of OLC 45 and they were submitted to *exterior cylindrical turning*. The values of cutting process parameters have also been established and presented in Table 10.4.

Table 10.4

Turning process parameters

	t [mm]	s [mm/rot]	v [m/min]	n [rot/min]
TP 1	0.2	0.3	0.4	1
TP 2	0.1	0.14	0.2	0.2
TP 3	150	110	75	75
TP 4	800	600	400	400
	t – cutting depth; s – cutting feed;		v – cutting speed; n – main spindle rotational speed	

Considering the electrical measurement system's characteristics and the calibrating equation, there were obtained the values of the manufacturing force – in [daN].

For example, if the values of the cutting parameters were: cutting speed, v = 110 m/min; cutting speed, s = 0.14 mm/rot; cutting depth t = 0.3 mm then, the values of the turning force's components were determined to be: $F_x = 7.43$ daN, $F_y = 6.73$ daN, $F_z = 4.97$ daN, meaning, the global force resulted in F = 11.2 daN.

If, for the considered turning process, the turmomg force's value had been calculated with the relations presented in specific literature, then the value for the cutting force would have resulted as 12.16 daN. One can notice good concordance between experimentally and theoretically determined values.

The device has, also, been tested into a metal forming process, meaning *punching* of a part whose drawing is shown in Figure 10.13. An image, taken while the experiments were on, is presented in Figure 10.14.

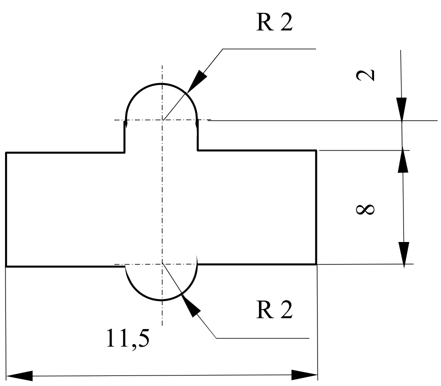


Fig. 10.13 Drawing of the punched part

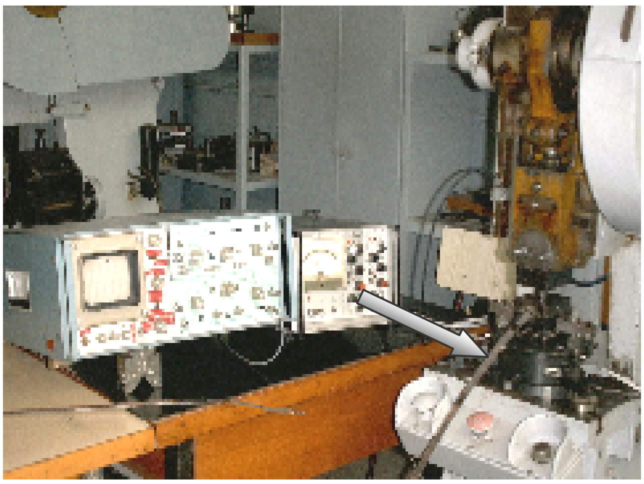


Fig. 10.14 The device used in punching of a sample

Using the device, considering the calibrating equation and force variation curve (registered on the oscilloscope screen – as shown in Figure 10.15), the obtained value for punching force was 710.2 daN.

If the punching force would have been calculated (knowing material's thickness, 0.4 mm, and shearing stress value, 30daN/mm^2), the obtained value would have resulted in 713.4 daN.

One can notice good concordance of experimentally and theoretically determined values.

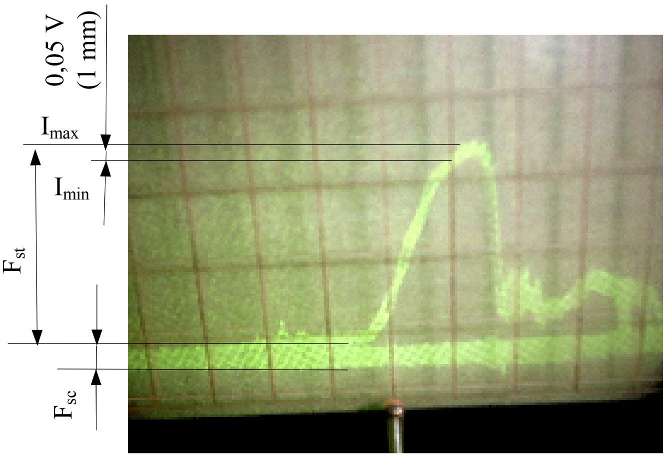


Fig. 10.15   Punching force variation curve

As conclusion of all the things presented about the custom device for force / torque measurement, there should be mentioned:

⇒ the: innovative form of the elastic element;

⇒ good deformation characteristic and high values for the static rigidity;

⇒ reliable calibrating equations;

⇒ possibility to use it in, both, cutting and metal forming processes;

⇒ opportunity of its exploitation into an automated adaptive command system

Further development of the theme should involve applications in real time control of manufacturing forces and / or torques.

10.2 Customized CNC Beveling Machine – for Marble and Granite

Marble and granite are very tough materials with lot of applications, due to their special properties. They have a nice look and a good resistance to severe (corrosive, aggressive etc.) factors, in time.

Rough form of marble and granite is that of blocks. By disk heading or milling, slabs and tiles are obtained, so that these materials are easier to handle, machine and use. That is why and how, for further application, *machining edges* is many times required.

A widely used procedure is that of polishing / beveling by a diamond based grinding wheel whose profile is identical to that of the beveled edge. Another procedure is that of kynematically determining edge profile, the grinding wheel being of a disk shape.

There are beveling machines designed and produced by famous international companies but, their major disadvantage is that of the very high price [http://www.arc-rom.ro]. These types of machines, are "huge" requiring a large space. As for the CNC aspects – software, user interface, accuracy - the data offered by producer are rather poor.

► Product specifications

So, the need for a CNC beveling machine for marble and granite edges efficiently and accurately machining, has become obvious. The specifications for this new product are mentioned below.

◘ Marble and granite slabs' dimensions of:

⇒ length – maximum 2500 mm;

⇒ width – minimum 250 mm, maximum 1000 mm;

⇒ thickness - minimum 20 mm, maximum 100 mm.

- ◘ Shape of the edges to be machined, meaning:
  - ⇒ rounded (10 to 50 mm radius),
  - ⇒ rectangle or multiple facets (0º to 180º angle) – see, figure 10.16.
- ◘ Ability to compensate the wear of diamond based grinding wheel.
- ◘ Highly automated and CNC controlled operation – with Isel® components [http://www.isel.com].

Fig. 10.16 Different shapes of marble and granite slobs' edges [http://www.arc-rom.ro]

► Modeling of beveling machine components

Machining (beveling / polishing) marble and granite slobs / tiles' edges requires diamond grinding wheels.

This process can be done with very high machining speed and, consequently, very high rotational speed, about 15,000 rev/min. Also, the feed speed is of high values and the abrasive tool's granulation should be a fine one.

Unfortunately, there is a large amount of dust that needs to be exhausted / removed because it damages the wheel and scratches the machined surface. That is why a jet of pressurized water should "come" to the machining zone.

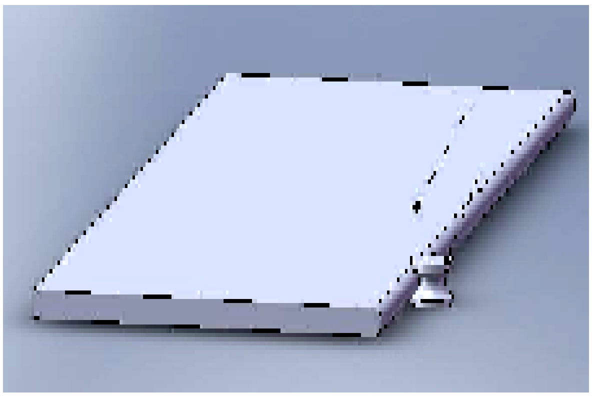
Most of the times, the beveled edge is obtained by copying the tool's profile – see figure 10.17.

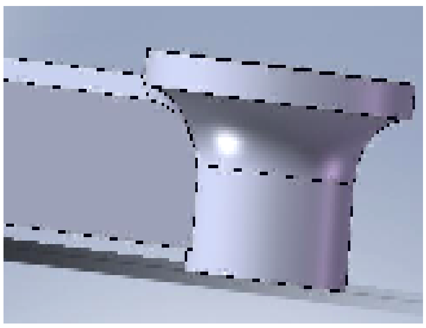
There are many disadvantages of this procedure, the most important ones being that of:

- ◘ intense wear of the abrasive tool when first gets in contact with slobs' thin edges - see figure 10.18.
- ◘ need to change the tool when the edge profile changes – during the finishing machining phases;
- ◘ many abrasive tools to be needed – with different granulation and no material's particles loaded.

All the above mentioned facts, lead to the idea of different generation procedure for the beveled edges. Thus, the edge's profile should not be copied but, kynematically generated by the same abrasive wheel – so that, at least, one piece of slob / tile to be machined.

The grinding wheel shape should be that of a disk whose machining surface is flat (plane). A schematic representation of this working principle is shown in figure 10.19.





1 – marble or granite slob

2 – abrasive tool

- detail -

Fig. 10.17 Edge beveling by profiled abrasive tool

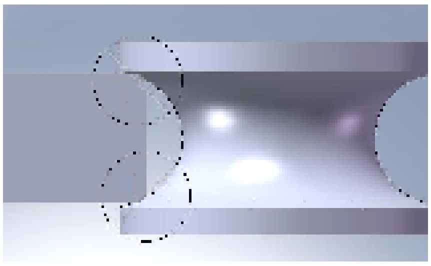


Fig. 10.18. Zones of intensive wear for the profiled abrasive tool

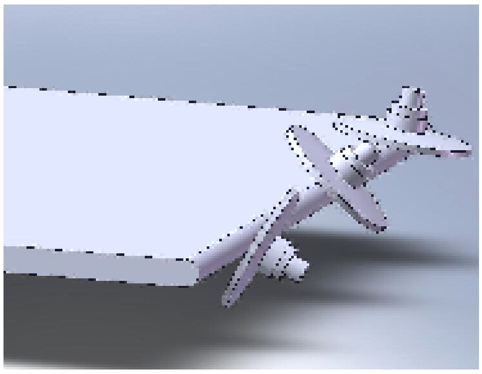


Fig. 10.19. Kynematically generation of the beveled edge

The beveling machine is a customized product and, that is why, it should be designed as module based structure, as follows.

- module of support elements;
- module of guiding and high rigidity elements;
- module of the machining head – main sub-assembly;
- module of automation and CNC elements.

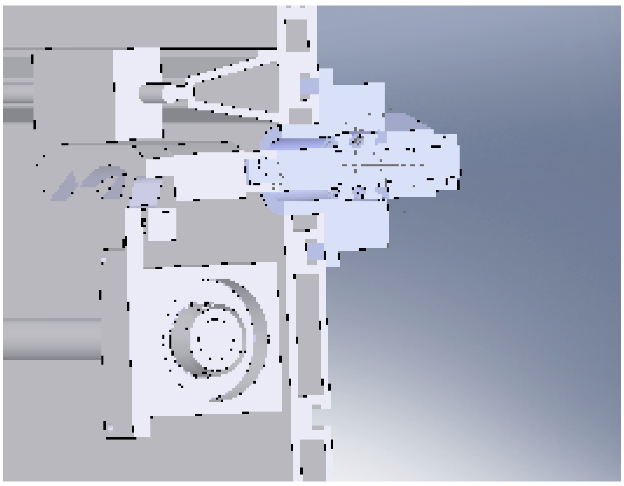
Modeling of machine's component elements has been done with SolidWorks software. Automatization and CNC commands are ensured by Isel-automation components The real component elements – meaning machine plateau, guiding profiles, rolling screws, etc – are, mainly aluminium alloys and ensure the reliability, flexibility and, most of all, rigidity needed for machining so hard materials.

The servomotors have an encoder and are produced by Isel® Corporation, too

So, based on all the above mentioned, some of beveling machine's important characteristics, are the next:

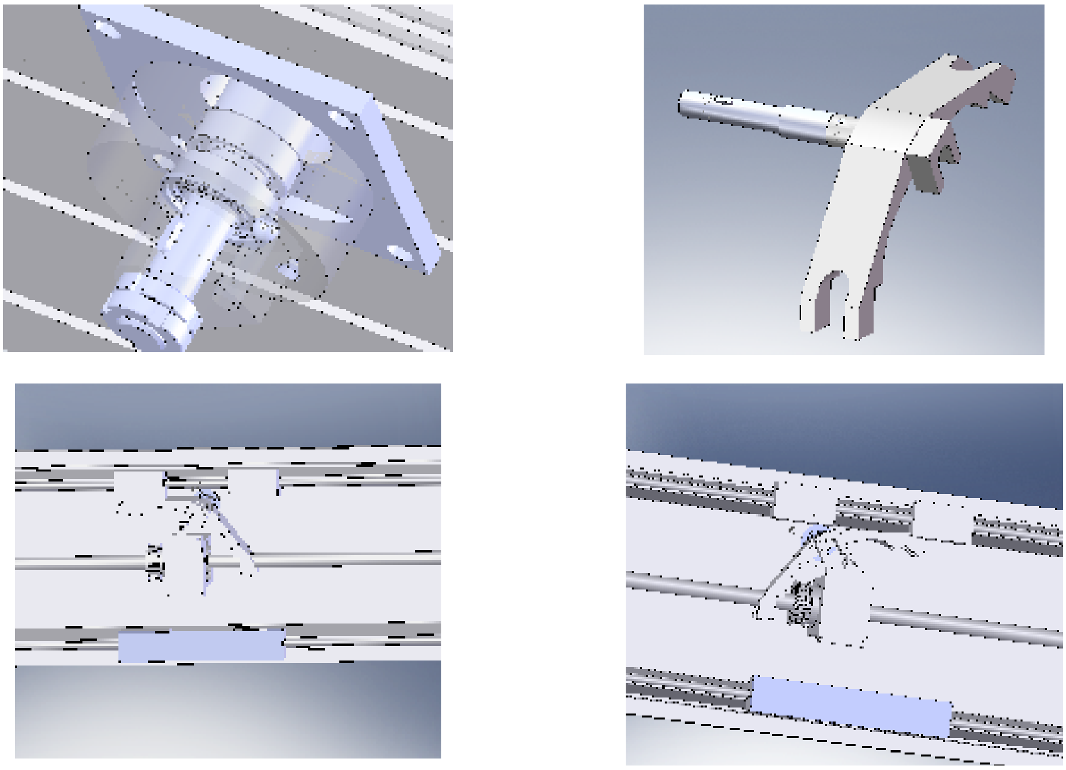
- plateau dimensions: 3,000 x 1,200 x 850 [mm];
- longitudinal axis (Y) : 3,000 x 450 with active length of 2,500 [mm];
- vertical axis (A) : 4,000 x 150 with active length of 350 [mm];
- horizontal axis (B): 350 x 150 with active length of 300 [mm];
- rotational axis (X): 180º in revolution;
- translation axis (Z): 150 x 77 with active length of 100 [mm];
- system for re-circulating and recovery of the water required by proper machining process;
- machining head – incorporating a small hydraulic turbine;
- diamond abrasive wheel – 100 mm diameter;
- five axes CNC controller, incorporated hardware

The models of main elements and modules are presented in figure 10.20.

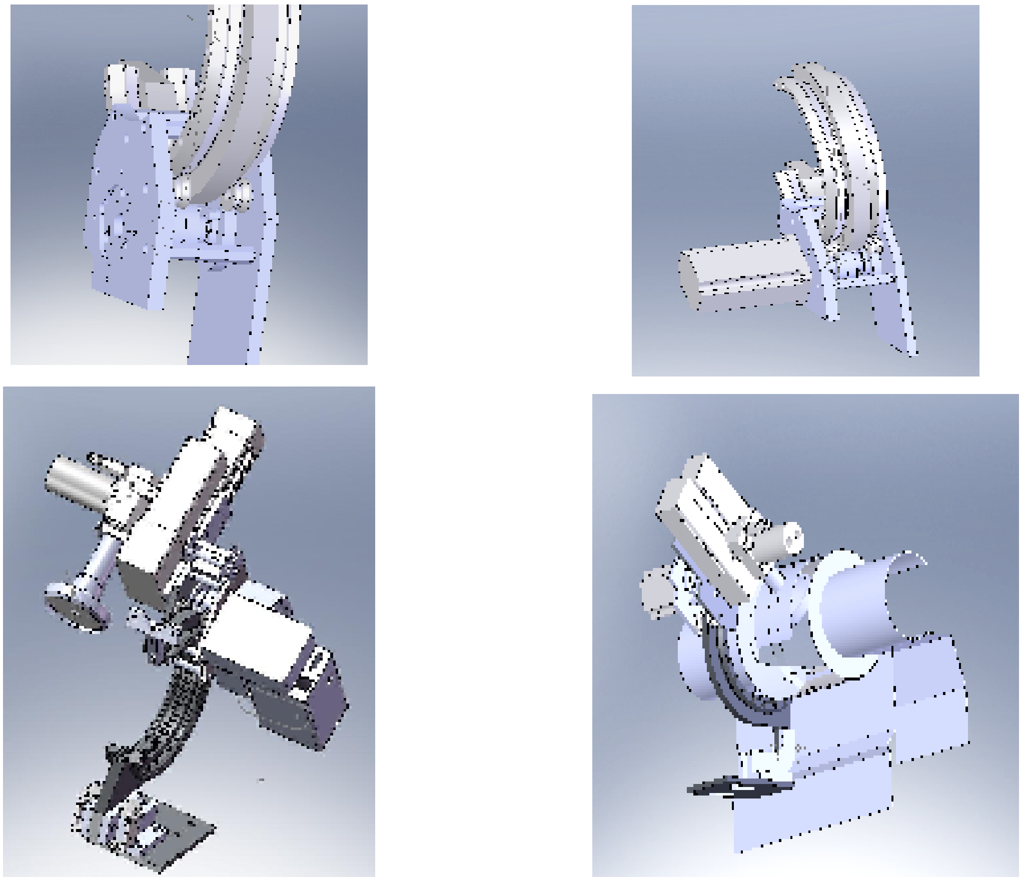


component elements for rigidity and guidance

Fig. 10.20. Models of machine components – to be continued



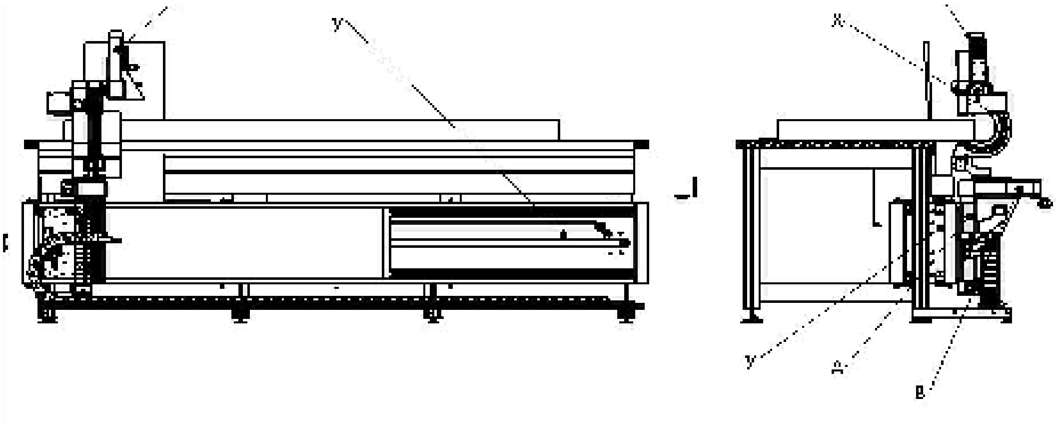
- component elements for guidance and reversing axial movement -



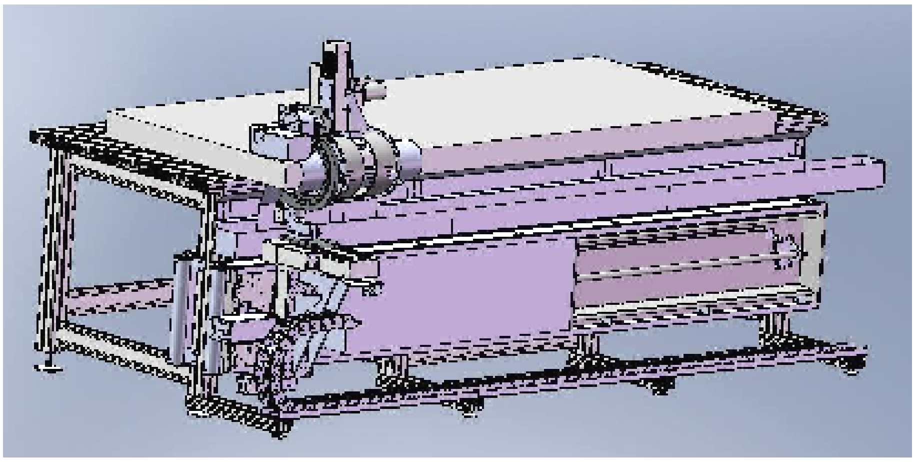
- component elements for the machining head -

Fig. 10.20. Models of machine components

So, images of the custom CNC beveling machine – both drawing and model (without computer), are shown in figure 10.21 (a. and b.).



a.



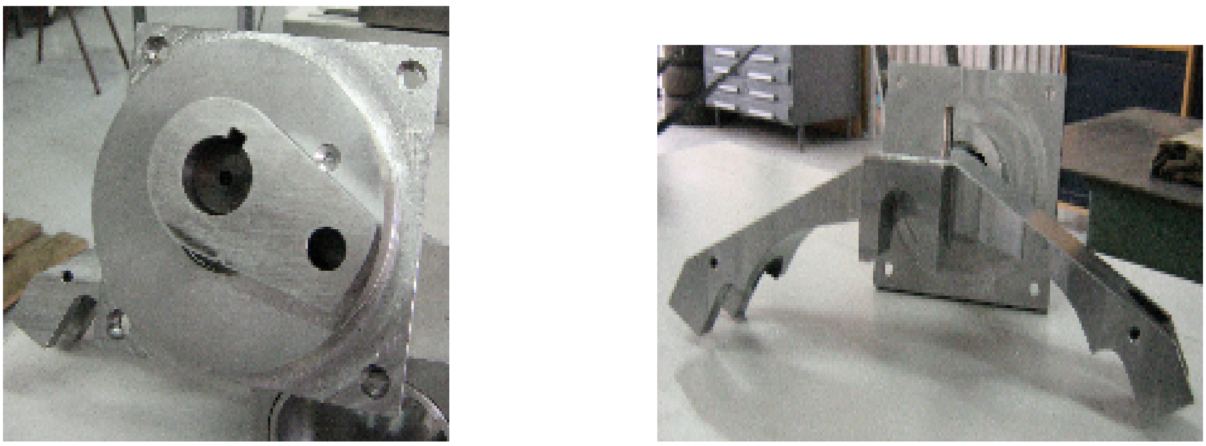
b.

Fig. 10.21 Beveling machine – drawing and model

► Manufactured beveling machine components

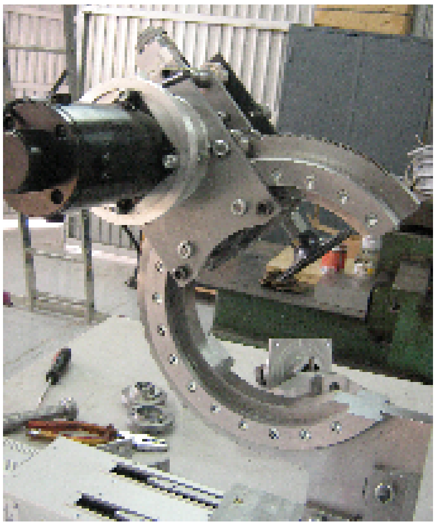
Once all component elements of the machine had been completely designed and modelled, simulation of their interaction was done – meaning .stress and strain, interference analysis. So, any possible errors in design could be corrected before production launch.

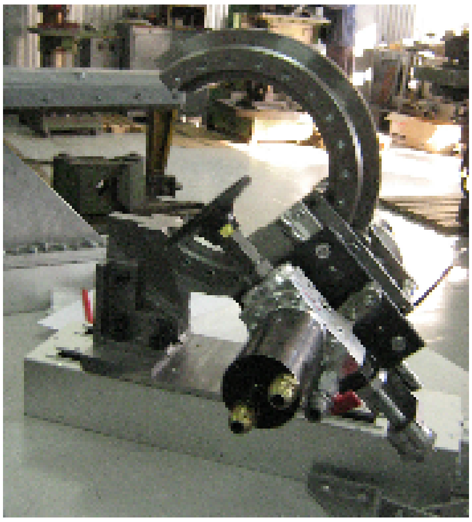
Some of machine's components, presented above as models, can be seen as real, manufacture - in figure 10.22.



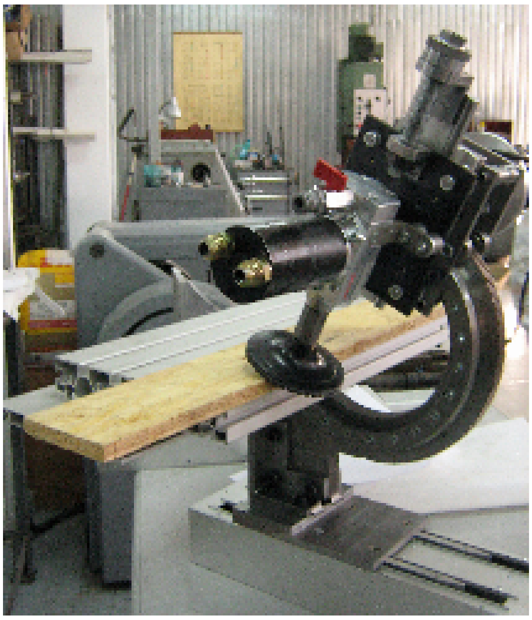
- elements for reversing the axial movement -

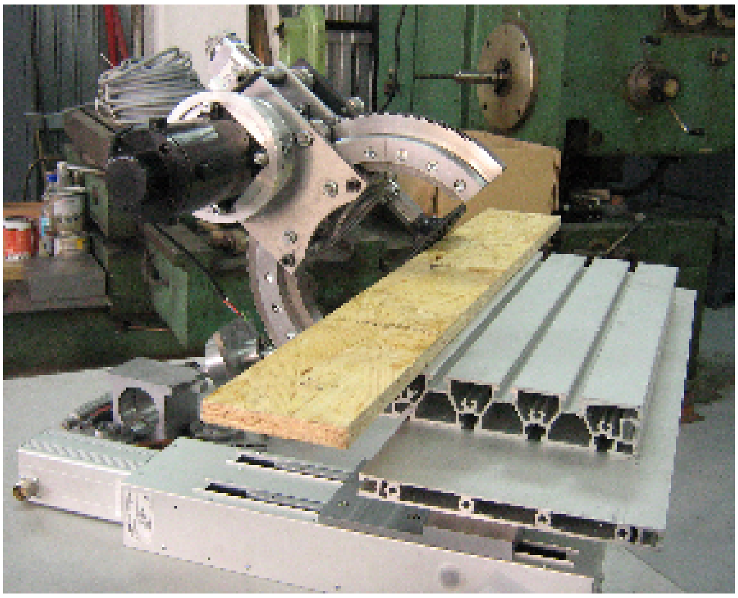
Fig. 10.21 Manufactured components of the beveling machine – to be continued





- machining head -





- beveling machine prototype -

Fig. 10.21 Manufactured components of the bevelling machine

Summarizing all the aspects mentioned in this sub-chapter, there should be the next conclusion

⇒ the worldwide producers do offer the bevelling machines for marble and granite but, at high prices that, really, do not “fit” the Romanian customers’ needs.

⇒ when the customized product is CNC bevelling machine, specifications are very important and do represent the bases for designing and manufacturing its component elements.

⇒ further research should be done in order to improve machine’s cooling system, as well as its connection and interaction with the CNC equipment.

⇒ it would be worth to consider the possibility of “extending” the machining ability for interior slob / tile’s edges.

Acknowledgment

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