Signal Processing's Importance in Manufacturing of a Special Device

MIHAIELA ILIESCU¹, BRINDUŞ COMĂNESCU², EMIL NUŢU¹ ¹Manufacturing Department; "POLITEHNICA" University of Bucharest Splaiul Independenței no. 313 Street ²S.C. Optoelectronica-2001 S.A. Atomistilor no. 409 Street, Magurele, ROMANIA <u>iomi@clicknet.ro; www.pub.ro; brindus@optoel.ro; www.optoel.ro</u>

Abstract: - Lot of the parts manufactured for various required purposes involve machining processes, such as turning, drilling or, cold pressing processes, such as stamping, drawing, extruding, etc. When these processes are involved, special attention should be given to their specific force values and, as consequence, to devices used in measuring force's values. The most important element of a force measuring device is represented by elastic element and, further, by the transducers "fitted" to it. Appropriate transducers signal processing is essential when device's characteristics have to de specified and, more, to be tested and applied into real manufacturing conditions.

Key-Words: - elastic element, resistive transducer, device, process force, calibrating, data acquisition.

1 Introduction

Challenges of nowadays society result in the need of manufacturing parts made of various materials, with more or less, complicated geometrical features and requiring high quality characteristics. There are many manufacturing methods, as injection molding, electro-erosion, machining, the last mentioned one involving both cutting (turning, milling, drilling, etc.) and/or cold pressing (punching, bending, extrusion, etc.).

Machining force's values are worth to be determined because of their influence to: surfaces geometrical precision, technological system's rigidity and reducing energy consumption [4], [7].

There are two main modalities of knowing force's value one, being based on *analytical* (theoretical or, theoretical-experimental) *models* of machining forces and, the other, involving *special* force measuring *devices*.

As for the analytical models, specific literature presents mathematical or graphical relationships, all of them considering the influence of different factors, with or without interactions, as well as their variation range values. Choosing the model that provides values closer to real ones represents a matter that requires thorough study and good working experience

As for using special force measuring devices, it is usually performed [3], [4] into laboratories – for experimental–theoretical research or, into production – for choosing appropriate manufacturing technological system components or, for adaptive command of the technological system. For all these above mentioned situations, the special devices enable each force component value to be determined, as well as machining force's direction. That is important because, there are many influencing factors, such as material's inclusions or voids, cutting tools characteristics, machining parameters' values, etc. all resulting in random direction machining forces [3].

Relevant characteristics of a force measuring device are stated [1] to be: loading force, exit signal, calibrating curve and/or equation, hysteresis curve, static/dynamic rigidity.

The most important part of a machining forces measuring device is represented by its *elastic element* and the *transducers* fitted on it. The elastic element is defined by shape, dimensions, material, sensitivity and. the fitted transducers (the study refers to resistive ones) do "signalize" any kind of its deformation. 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.

Specific literature presents mathematical relations for determining specific deformation and elastic constant values of various elastic elements type, usually with relative simple shape configuration – see table 1.

There are also presented, some schemes of fitting transducers (resistive ones) on the elastic elements, so as to get maximum sensitivity – see table 2 [1].

Characteristics of various elastic elements type				
Loading Type	Scheme	Specific Deformation	Elastic Constant	
Bending		$\varepsilon_1 = \frac{6Pl}{Ebh^2}$ $\varepsilon_2 = -\upsilon\varepsilon_1$	$k = \frac{Ebh^3}{4L^3}$	
Bending		$\varepsilon_1 = \pm \frac{3P(2a-1)}{2Ebh^2}$ $\varepsilon_2 = -\upsilon\varepsilon_1$	$k = \frac{2Ebh^3}{L^3}$	
Tensile		$\varepsilon_{1} = \frac{P}{2Eae} \left[1 - \frac{3R}{e} \left(1 - \frac{2}{\pi} \right) \right]$ $\varepsilon_{2} = \frac{P}{2Eae} \left[1 + \frac{3R}{e} \left(1 - \frac{2}{\pi} \right) \right]$	$k = \frac{Eae^3}{12\left(\frac{\pi}{4} - \frac{2}{\pi}\right)R^3}$	
Bending		$\varepsilon_1 = \pm \frac{3P(2a - L)}{2Ebh^2}$ $\varepsilon_2 = -\upsilon\varepsilon_1$	$k = \frac{Ebh^3}{L^3}$	

Table I [1]

Table 2 [1]

Loading Type	Scheme	Specific Deformation	
Tensile / Compression		$\varepsilon_1 = \frac{\Delta l}{l_0} = \frac{N}{EA}$ $\varepsilon_2 = \frac{\Delta D}{D} = -v\varepsilon_1$	
Bending		$\varepsilon_1 = \frac{6Px}{Ebh^2}$ $\varepsilon_2 = -v\varepsilon_1$	
Twisting	145° M. K.	$\varepsilon_{45^0} = \frac{8M_t D}{\pi G (D^4 - d^4)}$ where: $G = \frac{E}{2(1 + \nu)}$	

The most important disadvantage of the studied already existing machining forces measuring devices is that they are special or, specialized one – meaning can be used only for one machining procedure or, for more, if similarly.

Thus, it has been considered right to design and manufacture a device to be used in measuring both cutting processes' forces and cold pressing processes' forces. The innovative form of the elastic element, has already been patented, the whole device being designed and manufactured [5], [6]. High importance was given to appropriate signal processing and, when tested into real machining processes, very good results were obtained

2 Objective and Research Directions

The objective of this paper is to point out of how important *data acquisition* and *signal processing* are in determining optimum elastic element's design, transducers' position and calibrating equations when designing and manufacturing a special device – for measuring machining forces.

Research directions, considered and "taken" were the following:

- determining elastic element's shape;

- simulating elastic element's behavior in various loading conditions;

- establishing optimum position of resistive transducers;

- manufacturing the device;
- calibrating the device;
- testing the device into real machining processes.

3 Designing the Elastic Element

Special device's destination is that of enabling measuring forces in manufacturing systems associated to, both cutting (turning, drilling, milling, grinding) and, metal forming processes (punching, bending, drawing, extrusion).

Thus, the shape of its elastic element has been conceived so as to make possible multiple loading types, according to each of real machining processes considered [2], [5].

When designing elastic element's shape and dimensions, initial loading conditions were stated So, nominal forces along each of the main axes, with values up to 10,000 N, and nominal torques, around each of the main direction with values up to 500 N·m, have been considered (the reference system was OXYZ).

Overall dimensions of the elastic element, should be about $\Phi 150 \times 50$ (mm).



Fig. 1 Elastic element's shape

Elastic element's innovative shape is similar to two wheels mounted together, each having two spokes and the upper one rotated by 90° with respect to the lower one – see figure 1. It can be noticed that elastic element's shape is not very simple and impossible to be completely approximated by structures like plate, rod etc.

As the real loading conditions are complex and have to be modeled exactly, there has been used ANSYS software. Thus, appropriate distribution of Von Misses equivalent stresses and of deformation, as well as resistive transducers' position and reciprocal signals' influence were determined and visualized. A ten points tetrahedron element has been studied and all the mentioned loading cases have been modeled. So, for each of the considered loading situations – force horizontal components ($F_x = F_z = 10,000$ N), force vertical component ($F_y=10,000$ N), torque on horizontal axes ($M_x = M_z = 500$ N · m) and torque on vertical axis ($M_y = 500$ N · m) - equivalent stresses and strains distribution fields were obtained.

Because of elastic element's axial-symmetry, it was studied only half, even a quarter of its structure – when loading with force or, torque.

An example of the obtained simulation results for equivalent von Misses stresses in shown in figure 2 [**a.** - when horizontal force loading F_x (F_z). and **b.** – when vertical force loading (F_y)].



Fig. 2 Equivalent von Misses stresses distribution



Fig. 3 Specific deformation distribution - F_x loading

Once stresses distribution established, it is possible to emphasize the strain distribution fields. An example for F_x loading is presented in fig. 3, where it can be noticed the maximum deformation values of elastic element.

As result of ANSYS simulation, there has been established resistive transducers (Hottinger type) position, right into the points and along directions where specific deformation have maximum values. Their connection is a complete Wheatstone bridge one and the transducers are connected so that both force's and torque's components values can be measured. Transducers position, for measuring F_y vertical force is shown in fig. 4, while transducers connection scheme, is presented in figure 5.



Fig. 5 Transducers position for Fy component



a. - upper part of the elastic element

b. - lower part of the elastic element

Fig. 5 Resistive transducers' position and connection

Finally, once all components of the machining forces measuring device have been designed, its prototype has been obtained – see figure 6.



Fig. 6 Machining forces measuring device

There have also been designed and manufactured two additional elements "required' for fitting the device to machine tools' components – one of axial type, for connection to lathe, in turning, and the other is round plate type (see fig. 7) – for connection to milling, drilling machine, mechanical press, etc.



Fig. 7 Special device "equipped" for machining

4 Calibrating the Device

There were carried out tests that resulted in very good behavior of the device from rigidity point of view, in both, static and dynamic loadings. [2], [6].

So, it has been considered right to use it, into real machining processes but, before that, calibrating equations had to be determined.

Because of the various types of machining forces to be measured and, because of the fact that calibration should be done in conditions similar to real ones, there were considered multiple loading cases. Each case is defined by loading point, loading force direction, loading force values.

A schematic representation of the experimental stand is shown in figure 8.



- 1- fixed rigid element;
- 2 special support [G14] for loading with forces along each of OX, OY and OZ axes and/or 30°; 60° oriented;
- 3 loading device;
- 4 coupling element;
- 5 reference mechanical dynamometer;
- 6 additional element;

7 – support;

- 8 device to be calibrated;
- 9-rigid support;
- 10 resistive transducers coupling;
- 11 connection cables;
- 12 electronic tension bridge (N 2300; Hottinger)



Experimental results

Table 3

Basic principle of calibration is that under each force loading, F_{ρ} ($\rho = x, y, z$) there are generated deformations of the elastic element, which are "translated" into $\epsilon_{\rho x}$, $\epsilon_{\rho y}$, $\epsilon_{\rho z}$ signals at electronic bridge channels, " C_x ", " C_y " and " C_z ". There were considered, both loading and un-loading, with values from 0 to 200 daN.

Dependence of $\varepsilon_{\rho i}$ signals on loading force, F_i (i representing reference system axis) can be modeled by relation:

$$\begin{aligned} \varepsilon_{xx} &= f(F_x), \quad \varepsilon_{xy} = f(F_x), \quad \varepsilon_{xz} = f(F_x) \\ \varepsilon_{yx} &= f(F_y), \quad \varepsilon_{yy} = f(F_y), \quad \varepsilon_{yz} = f(F_y) \\ \varepsilon_{zx} &= f(F_z), \quad \varepsilon_{zy} = f(F_z), \quad \varepsilon_{zz} = f(F_z) \end{aligned}$$
(1)

The experiments scheme when F_z force loading is presented in figure 9, and an image taken while experimenting is shown in figure 10.



Fig. 9 Scheme of calibration experiments



Fig. 10 Calibrating when F_z loading

Fz		Deformation [µm]			
[daN]			Ι	II	m
0	l		-3	-3	-3
	ul		-4	-4	-4
50	l		-8	-10	-9
	ul		-9	-9	-9
100	l	XZ	-16	-14	-15
	ul	ŵ	-14	-18	-16
150	l		-20	-22	-21
	ul		-22	-24	-23
200	l		-28	-30	-29
200	ul		-28	-30	-29
0	l		2	4	3
0	ul		3	5	4
50	l		13	15	14
50	ul		14	16	15
100	l	Ezy	39	39	39
100	ul		39	41	40
150	l		65	67	66
150	ul		66	68	67
200	l		80	84	82
200	ul		80	84	82
0	l	ϵ_{zz}	-4	-6	-5
0	ul		-6	-8	-7
50	l		-226	-228	-227
50	ul		-230	-230	-230
100	l		-446	-444	-445
100	ul		-448	-436	-442
150	l		-654	-650	-652
	ul		-694	-698	-696
200	l		-826	-824	-825
	ul		-826	-824	-825

Examples of results obtained while experimenting with F_z force – loading (*l*) and unloading (*ul*) - are presented in Table 3

Using a specialized software, CurveExpert, there was determined the regression type curve fitting experimentally obtained data. So, linear regression models resulted in:

$$\varepsilon_{\rho\theta} = a_{\rho\theta} \cdot F_{\rho} + b_{\rho\theta}, \quad \rho = x, y, z, \quad \theta = x, y, z \quad (2)$$

Coefficients $(a_{\rho\theta} \text{ and } b_{\rho\theta})$ values determined are shown in table 4, while an image of regression curves, when F_z loading, is presented in figure 11.

			Table 4		
$\varepsilon_{\rho\theta} = a_{\rho\theta} \cdot F_{\rho} + b_{\rho\theta}$					
	$\rho = x, y, z, \theta = x, y, z$				
F_{ρ}	$\epsilon_{ ho \theta}$	0	h		
[daN]	[µm/m]	$a_{ ho heta}$	$D_{\rho\theta}$		
	ϵ_{xx}	4.274	13.200		
F _x	ε _{xy}	0.202	5.200		
	ε _{xz}	0.034	-0.400		
	ε _{zx}	0.396	3.000		
Fy	ε _{zy}	0.370	1.600		
	ε _{zz}	4.456	6.800		
	ε _{yx}	0	0		
Fz	ε _{yy}	4.148	3.400		
	ε _{yz}	0.300	5.400		
Obtained values are for loading with, 0; 50; 100; 150 and 200 daN					

$$\begin{array}{c} \begin{array}{c} 900 \\ 700 \\ 700 \\ 500 \\ 400 \\ 300 \\ 200 \\ 100 \\ 0 \end{array} \end{array} \begin{array}{c} \varepsilon_{zx} \\ \varepsilon_{zz} \\ \varepsilon_{zy} \\ F_{z} - loading \end{array}$$



Fig. 11 Calibrating curves – for F_z experiments

Loading with spatial force is equivalent to simultaneously F_x , F_y and F_z loading thus, generating to electronic bridge channel, the ε_{θ} $(\theta = x, y, z)$ signals.

By adding the effects, resulted in

$$\varepsilon_{x} = \varepsilon_{xx} + \varepsilon_{yx} + \varepsilon_{zx}$$

$$\varepsilon_{x} = \varepsilon_{xx} + \varepsilon_{yx} + \varepsilon_{zx}$$

$$\varepsilon_{x} = \varepsilon_{xx} + \varepsilon_{yx} + \varepsilon_{zx}$$
(3)

and, consequently, the calibrating equation was:

$$\begin{bmatrix} F_{x} \\ F_{y} \\ F_{z} \end{bmatrix} = \begin{bmatrix} a_{xx} & a_{yx} & a_{zx} \\ a_{xy} & a_{yy} & a_{zy} \\ a_{xz} & a_{yz} & a_{zz} \end{bmatrix}^{-1} \cdot \begin{bmatrix} \varepsilon_{x} - (b_{xx} + b_{yx} + b_{zx}) \\ \varepsilon_{y} - (b_{xy} + b_{yy} + b_{zy}) \\ \varepsilon_{z} - (b_{xz} + b_{yz} + b_{zz}) \end{bmatrix}$$
(3)

As result of all steps carried on, the equation systems is as follows:

- for loading

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} 0.2402 & -0.0052 & -0.021\overline{8} \\ -0.0100 & -0.0237 & 0.2361 \\ -0.0092 & 0.2443 & -0.0181 \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_x - 6.200 \\ \varepsilon_y + 4.000 \\ \varepsilon_z - 17.600 \end{bmatrix} (7)$$

- for unloading

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} 0.2412 & -0.0052 & -0.0214 \\ -0.0097 & -0.0231 & 0.2365 \\ -0.0089 & 0.2399 & -0.0177 \end{bmatrix} \begin{bmatrix} \varepsilon_x - 14.00 \\ \varepsilon_y - 2.200 \\ \varepsilon_z - 21.800 \end{bmatrix}$$
(8)

and, more explicitly, when solving, it turns into:

- for loading (9)

$$F_{x} = 0.2402 \epsilon_{x} - 0.0052 \epsilon_{y} - 0.0218 \epsilon_{z} - 1.1264$$

$$F_{y} = -0.0100 \epsilon_{x} - 0.0237 \epsilon_{y} + 0.2365 \epsilon_{z} - 4.1882$$

$$F_{z} = -0.0092 \epsilon_{x} + 0.2443 \epsilon_{y} - 0.0181 \epsilon_{z} + 1.3528$$

$$F_x = 0,2402 \varepsilon_x - 0,0218 \varepsilon_y - 0,0052 \varepsilon_z - 2.9017$$

$$F_y = -0,0100 \varepsilon_x + 0,2361 \varepsilon_y - 0,0237 \varepsilon_z - 4.9691$$

$$F_z = -0,0092 \varepsilon_x - 0,0181 \varepsilon_y + 0,2443 \varepsilon_z - 0.0174$$

Once calibrating equations determined, there were performed tests of using the device into real machining processes, such as turning and stamping. The measured values of forces components were compared with the calculated values - given by specific mathematical relations [2]. It could be noticed good concordance of the considered values.

5 Signal Processing while Machining

One experienced process was that of turning, meaning exterior cylindrical turning. The samples were made of OLC 45 steel, with 55 mm diameter. The values of cutting process parameters are presented in Table 4 while, an image of the process is shown by figure 12.

For a more accurate measuring, a computer aided data acquisition system, LabVIEW, was used The sampling rate of 1,000 measures/second, for 5 second, resulted in 5,000 successively measured values, at an interval of 1milisecond.

				Table 4
Turning	Machining parameters			
process	t	f	v	n
	[mm]	[mm/rot]	[m/min]	[rot/min]
TP 1	0.20	0.10	150	800
TP 2	0.30	0.14	110	600
TP 3	0.40	0.20	75	400
TP 4	1.00	0.20	75	400
	t – cutting depth; f – cutting feed;		v – cutting n – main s rotation	; speed; pindle nal speed



Fig. 12 Turning process



Fig. 13 Graphs of turning force's components



Fig. 14 Structure of LabVIEW program

Curves of each force's components, as appeared on a computer screen can be noticed in figure 13.

The medium values for the large amount of measured data are automatically calculated with a specific LabVIEW program – whose schematic structure is presented in Figure 14.

For example, if the values of the cutting parameters were the ones corresponding to turning process TP2 (see Table 4) then, the values of the turning force's components resulted: $F_x = 7.43$ daN, $F_y = 6.73$ daN, $F_z = 4.97$ daN, meaning, a global force of F = 11.2 daN. If, the machining force's value had been calculated with relations indicated by specific literature, the resulting value would have been F = 12.16 daN.

The second experienced process was a metal forming process, meaning stamping. An image, taken while the tests were on, is shown in figure 15, while force variation curve is evidenced by figure 16.

If the punching force had been calculated (knowing material's thickness, 0.4 mm, and shearing stress value, 30daN/mm²), the obtained value would have resulted in 713.4 daN.



Fig. 15 Stamping process



Fig. 16 Stamping force variation curve

When processing device's signals, as well as the calibrating equation and force variation curve, the obtained value of stamping force was 710.2 daN.

6 Conclusion

Designing and manufacturing a device for measuring forces, in various machining processes has proven to be adequate. The most important element, of it, is represented by elastic element, whose geometrical characteristics (shape, dimensions) are innovative and patented ones.

There has been used simulation, with ANSYS program, for testing elastic element's behavior and, thus, determining the resistive transducer's position, as to get maximum sensitivity and lowest signal's reciprocal influence.

Signal processing and data acquisition are very important in determining device's calibrating equations. Also, processing transducers signals, while a turning or a stamping process was on, resulted in good concordance of measured values and the ones obtained by laborious mathematical calculi.

Further research should be developed, so as to integrate the forces measuring device into an automated system of adapted control. It should be an efficient and easy way of setting machining process parameters values, as to get optima characteristics of machined surfaces.

References:

- [1] Constantinescu I. N., ş.a., "*Măsurarea mărimilor mecanice cu ajutorul tensometriei*", Editura Tehnică, București, 1989.
- [2] Iliescu M., Gheorghe M., "Computer Aided Design Innovative Design for Measuring Manufacturing Forces", 9th WSEAS International Conference on Automation and Information, pag. 79-84, ISSN 1790-5117, Bucharest, Romania, June, 2008
- [3] Medel J De Jessus, Hernandez G., Guevare P., *Real Time Flexible Manufacturing System*, Proceedings of 10th WSEAS on Automatic Control, Modeling & Simulation pag. 286, ISSN 1790-5117, Istanbul, 2008.
- Chatelain [4] Roy R., J-F. at al., Programming of a Machining Procedure for Adaptive Spiral Cutting Trajectories, Proceedings of 10th WSEAS on Automatic Modelling Control, & Simulation pag. 127, ISSN 1790-5117, Istanbul, 2008
- [5] Turdeanu E., Iliescu M., Găvan M, "Machinig Forces measuring device", License Patent, no. 121790/30.04.2008
- [6] Turdeanu, E., *Contribuții le dezvoltarea captoarelor de măsurare a forțelor de prelucrare*, Teză de doctorat, București, 2004.
- [7] Ussama Javed Rai, Abbas Dehghni, Design & Development of an Automated (Robotic) Snapping, Banding k Sorting System. 8^{th} Proceedings of WSEAS on Signal Processing, Robotics and Automation, pag. 309-314, ISSN 1790-5117, Cambridge, 2009