CNC Micro Machine Tool: Design & Metrology Problems

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Abstract: - This paper is devoted to the problem of development of micro machine tool for microfactories. Microfactories can help to reduce the consumption of resources (energy, materials and space); and can help to increase productivity. The major problems with CNC machines tools are related with adaptive control accuracy and precision. We propose low cost CNC micro machine tool and special algorithms for purpose of measurement and adaptive control

Key-Words: - microfactory, micro machine tool, precision, measurement, low cost.

1 Introduction

At present in the world new technology direction is formed: creation of microfactories [1-8]. Micro devices are necessary for different field of production, for example, in watch industry, in automobile industry, in medical facilities, in biology investigation etc. Mechanical parts will become increasingly smaller in the future. It is possible to produce microcomponents with ordinary equipment but it is very difficult to provide high level of precision. We propose that micro mechanical equipment is to be made as a sequential generations of micro machine tools and micro assembly devices. Each next generation must have smaller sizes than previous one and must be produced by the equipment of previous generation [8].

In Japan the conception was proposed how to reduce the size of small parts production equipment to a level comparable with the size of the parts to be produced for the purpose of dramatically saving energy, space and resources throughout the production plant [1].

It is simpler to provide high precision with micro devices, than with conventional ones.

Now exists direction for manufacturing of low cost micro components of sub millimeter sizes with using modern micro electronic technology. This approach is used very widely for manufacturing micro sensors and micro actuators, but it has some limitations connected with the problems of 3-D components manufacturing. This technology makes it possible to produce flat components. So it is very difficult to make automatic assembly of micro devices, because of 2-Dimensions. Our approach has no such problems, but demands low cost micro equipment, which is absent at present. In the [8] main principles of such equipment creation are proposed.

2 The main requirements to the micro machine tools (MMT)

At first, the micro machine tools (MMT) must be sufficiently precise. This characteristic must be considered always in relation with the cost of MMT. We develop and produce the first generation of MMT. The equipments for producing components having overall sizes from some hundred microns to some millimeters must provide accuracy of some microns [1, 5].

Developed MMT, at least the machine tools of first generation, must be multifunctional. The simplest multifunctional MMT must have four or five degrees of freedom (DOF) 3-translation axis and one or two rotary axes. MMT must use the simplest types of stepping motors and the contact sensors. It's preferable not use industrial motors

and sensors for cost reasons, and because the next generation of micro equipment will demand the technology of producing of all micro equipment components using the same micro equipment.
It's important to develop and provide the simplicity of manufacturing and assembly of MMT. For this purpose all the complementary components of the machine tool must be as simple as possible. For mass parallel manufacturing process it's necessary to develop such a system of sensors and such adaptive control system, which facilitate combining of huge number of MMT in the frame of desktop micro factory, controlled by one operator.

3 State of the arts in the MMT development

Mechatronics Laboratory (CI, UNAM) had developed and tested some prototypes of first generation machine tools. The main idea was to make prototypes as simple as possible, and to use minimum of industrial components, for scaling down developed micro machine tool in future generations.

3.1 CNC Prototype

The prototype is shown in the figure 1. On the base (1) the guides (2), (4), (6), for 3 carriages (3), (5), (7) are installed by the sequential scheme, i.e. each subsequent guide is installed on the previous carriage for to provide translation movements along the axis X, Y, Z. The spindle case (10) with spindle (11) also are installed on the base. The drives for carriages and for spindle use stepping motors (8) with gearboxes (9). The spindle has clamp for to grip workpiece by turning, drill by drilling or mill by milling. Support (12) has the cutter and two parallels metal pins for measurement of turned work piece diameter. For milling and drilling special gripper for workpiece should be installed on the carriage (7). The major part of the components of the MMT is made in brass and aluminum.

3.1.1 Components

The main components of the prototype are:

1. Stepping motors. We make our stepping motors with 4 steps per revolution and they can be forced to make 8 half steps. They are used in the mode of high-speed rotation.
2. Carriage. The guides for carriage were made as the round bars. It simplifies the manufacturing, assembly and scaling down processes. For reasons of robustness we decide to include some balls from the bearings compensate errors of guide’s adjustment.

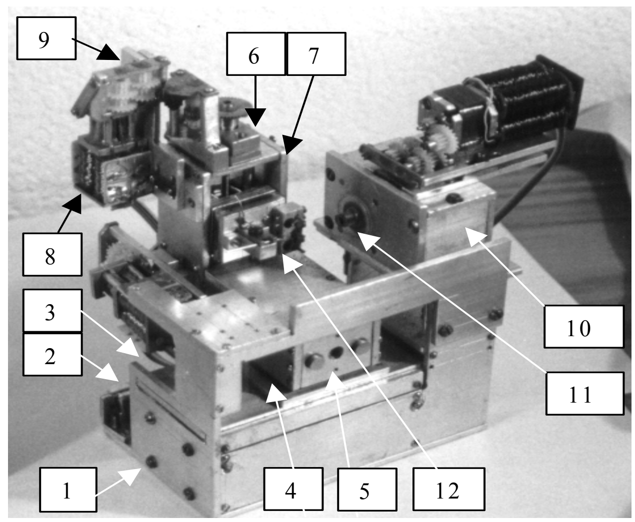

Fig. 1. CNC MMT

3. Transmission. It includes leading screws and gearboxes to reduce the speed of motors and increase the torque. All translation axes have the same configuration (gearbox, screw, stepping motor).

3.1.2 Control

The feedback from the machine tool to the personal computer was realized on the base of four contact sensors, three of them are used to determine initial position of the carriages, and one is used to determine the moment of the contact of any tool with workpiece. This contact we used for determining relative positions of different instruments needed for the whole manufacturing process, and for measurements in the manufacturing process. We use electrical contact sensor and could have the feedback only from metal workpiece. If we need to make details from plastic, we made at first the same detail from metal, and then repeated the manufacturing process with plastic workpiesces. In principle it is possible to use other types of contact sensors (for example, acoustical contact sensor) to treatment the workpieces from any materials.

The control system, acquire the signals from sensors, using the PC´s parallel port. In order to get the control of the MMT, we assigned a specific task for the A port (sends data form PC to MMT); the B port (receives data form sensors and motors); and, finally the C port (gives the control signals to the system).

3.1.3 Description

The MMT has 130×160×85mm, and is controlled by PC. The MMT has three translation axes (X, Y, and Z), and one rotational. The axis X and Z, have 20 mm of displacement, and Y-axis has 35 mm. All of them have the same configuration. The resolution is 1.87μm per step of the motor.

3.2 Test Pieces

Examples of the pieces that were manufactured with this MMT are showed in Fig. 2. Those photos are compared with a match head.

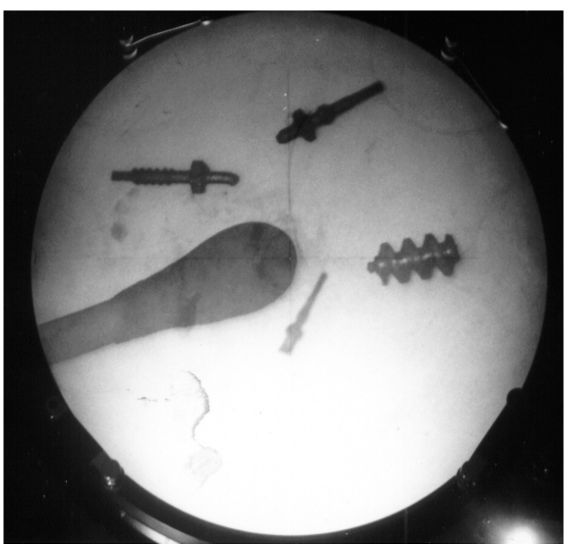

Fig. 2. Test pieces

4 Metrology process

Let us consider the problem of turning processing of ultra-thin shafts. Absolute errors of the described machine tool don't permit to machine ultra-thin shafts with necessary precision. To raise the precision of the treatment it is necessary to measure the shafts diameter during the turning process and position of the cutter relative to the shaft axis. It is desirable to set the cutter tip below the shaft axis near 10% from the diameter of processed shaft. So two tasks of measurement are appeared: measurement of the shaft diameter and definition of the cutter tip position relative to the shaft axis.

4.1 Method and algorithms

For measurement of the shaft diameter we use metallic disk, which is situated on the metallic rod (Fig.3a), and is fixed on the support.

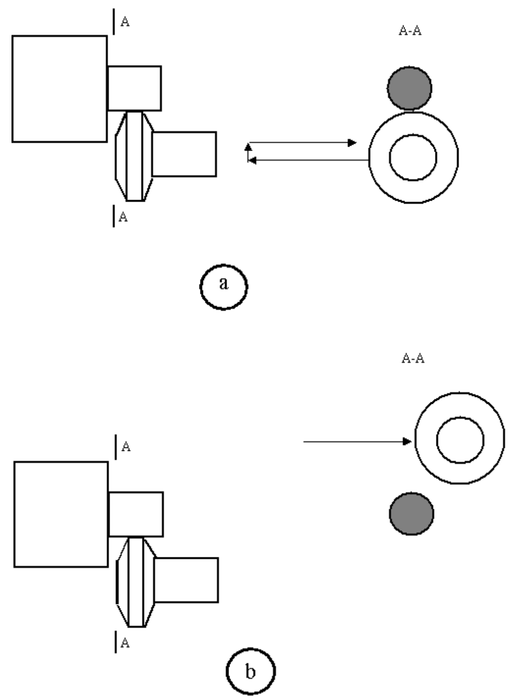

Fig.3. Measurement of the shaft diameter

For measurement the control system places the metallic disk under the measured shaft and move up (along axis Z) till electric contact with the shaft. After that the measurement procedure is organized as follows.

1. The disk moves back along axis X Moves up along axis Z with step dZ.
2. The disk moves forward and during this movement two conditions are checked. Condition A – appearance of electrical contact of disk with shaft. Condition B – the disk goes far away of the shaft axis without the electrical contact (Fig.3b).
3. Under fulfilling the condition A, the coordinates (X, Z) are recorded to the table of measurement, after that the process turns to item 1.

4. Under fulfilling the condition B, the measurement process is finished.

The table of measurement contains the coordinates of points, which must lie on the circle (Fig. 4).

As a consequence of measurement errors these points can deviate from the ideal circle (Fig. 5).

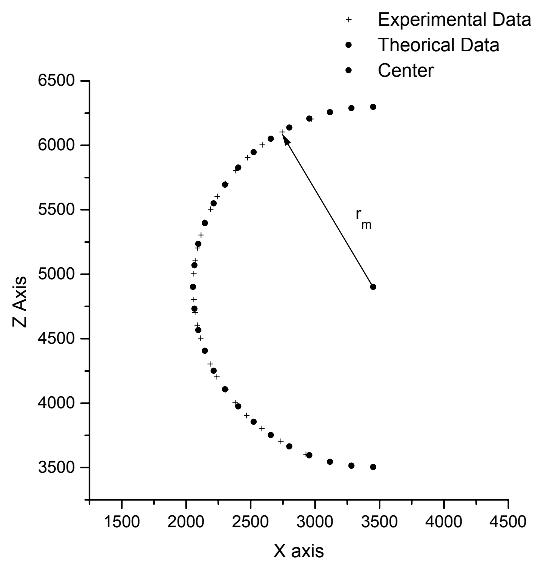

Fig. 4. Coordinates of the experimental points

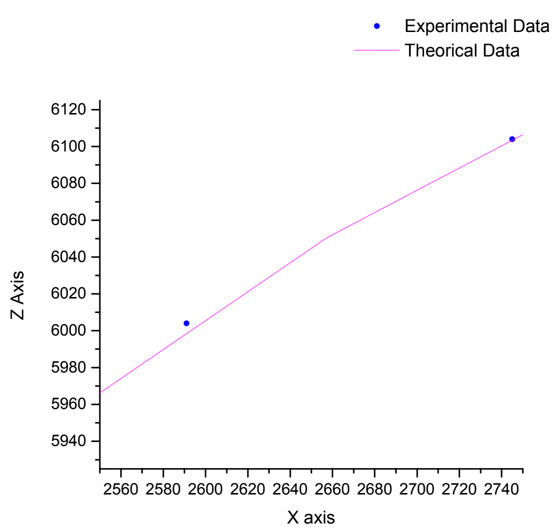

Fig. 5. Measurement errors

So it is appeared the task to build the circle which approximates all experimental points. The diameter of this circle will equal the sum of the shaft diameter and the disk diameter. To build the approximation circle we use next algorithm.

Let X_0, Z_0 – arbitrary selected point that we consider as center of approximation circle. Let us find the mean distance r_i between this point and experimental points.

$$r_i = \sqrt{(X_i - X_0)^2 + (Z_i - Z_0)^2}\,; \qquad (1)$$

$$r_m = \frac{\sum_{i=1}^{k} r_i}{k}; \qquad (2)$$

where k – the number of experimental points, X_i, Z_i – coordinates of experimental point; r_i – distance from point X_i, Z_i to point X_0, Z_0, r_m – mean distance.

$$err = \sum_{i=1}^{k} (r_i - r_m)^2. \qquad (3)$$

where err – quadratic error.

Then used the algorithm of optimum search we find such values X_0*, Y_0*, when the error err becomes minimal. Let be in this point the mean distance $r_m = r_m$*. Then the shaft diameter d_s is calculated:

$$d_s = 2 * r_m^{\ *} - d_d. \qquad (4)$$

where d_d – the diameter of measurement disk.

To define the cutter position relative to the shaft axis the similar procedure is doing with difference that experimental points are defined with contact of the cutter tip with the shaft. For measurement we use not a half but a quarter of circle, beginning with lower point and finishing with the level of the shaft axis.

4.2 Results

We have done the experiments on the micro machine tool shown in the Fig.1. The cutter, shaft and measurement disk are shown in the large scale in the Fig. 6.

The shafts of the different diameters (from 3 mm to 0.4 mm) were turned and measured by the described process. After that they were measured with micrometer having resolution 1µm. In the result the mean diameter error was 8 µm, the maximum error was 22 µm.

The positions of the cutter relative to the shaft axis were measured too. It is difficult to check these positions directly. To estimate their correctness we turned ultra thin shafts. If the cutter has no correct position it is impossible to obtain the small diameter of the shaft.

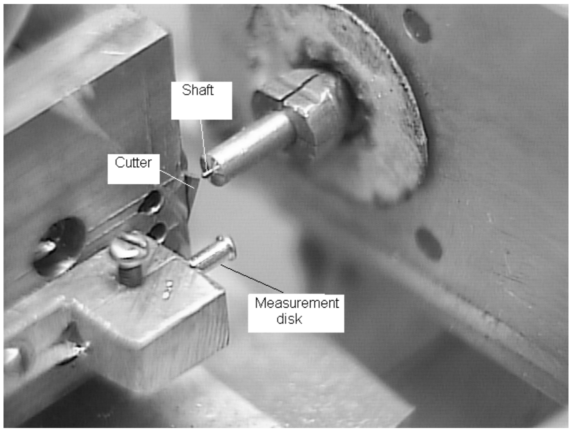

Fig. 6. Shaft, cutter and measurement disk

We have made the shafts with diameter down to 100 μm. One example of such a shaft is shown in the Fig.7. For comparison the wire having diameter 110 μm is situated near the shaft.

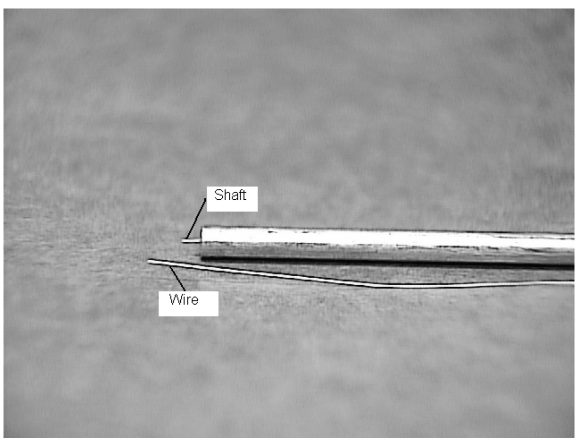

Fig.7. Shaft with wire 110 μm

5 DISCUSSION & CONCLUSIONS

For three-dimensional micro component manufacturing we use micro machine tool having overall sizes comparable with the micro components sizes. To obtain low cost micro components the cost of machine tool must be also low. For this reason we didn't use interferometers, super precise components and so on. To obtain sufficient precision of micro components we used feedback based on electrical contact of the measurement disk and cutter with treated shaft. Using this feedback we created the method of measurement the diameter of the micro shaft and the position of the cutter relative to the shaft axis. Mean error of these measurements is 8 μm.

6 Acknowledgements

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