

# MICROMACHINE TOOL: MEASUREMENT AND CONTROL

A. Caballero-Ruiz, L. Ruiz-Huerta, E. Kussul, T. Baidyk, G. Velasco

Laboratory of Mechatronics, CCADET, UNAM(Center of Applied Sciences and Technological Development, National Autonomous University of Mexico). Circuito Exterior s/n, Cd. Universitaria, Coyoacán, 04510, A.P. 70-186 México, D.F.

Tel. (+52) 5622-8602 to 07 ext 115 E-mail. albcaru@servidor.unam.mx

## 1. INTRODUCTION

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.

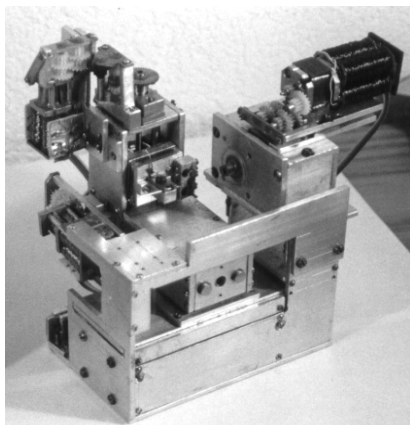
The micromachine tools (MMT) must be sufficiently precise. This characteristic must be considered always in relation with the cost of MMT. We develop and produce the first generation of MMT. The equipments for producing components having overall sizes from some hundred microns to some millimeters must provide accuracy of some microns [1, 2].

Beside to development of MMT raises the need of generate the technology that allow us to learn its behavior for development systems to minimize error and increase the precision of these. At this moment, those needed technologies are too specific and expensive. In the past we worked in the characterization of micromachine tools by indirect method [3], the results obtained with this method permitted us to know the behavior of this MMT, but these results are not offer us sufficiently information about the specific geometrical errors to development correction methods.

In this work we propose low cost special algorithms to determine geometrical errors on each guide way of a the MMT by two balls; and the adaptive control to reduce these errors in the MMT is proposed.

## 2. STATE OF THE ARTS IN THE MMT DEVELOPMENT

Mechatronics Laboratory (CCADET, 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]. One of these prototypes is shown in the figure 1.



*Figure 1. CNC prototype.*

This prototype 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 displacement, and Y-axis has 35 mm. All of them have the same configuration. The resolution is 1.87μm per step of the motor.

## 2. CONVENTIONAL METHODS TO EVALUATE CNC's.

There are many methods to detect and correct errors in CNC's, some of these are developed to apply single dimension tests, such as interferometers and graduated standard; and multi-dimensional tests, such as the Double Ball Bars and the Lattice Grid Plate [4]. The results obtained with these methods are employed to design electronic systems and software to compensate the errors.

All of these methods to evaluate conventional CNC's are difficult to put in practice within micromachine world where the overall sizes of a micromachinetool is less than 20x20x20 cm.

## 3. METROLOGY PROCESS TO EVALUATE MMT's

To determine the real characteristics of micromachine tool, we proposed a method based on to employ two balls: one ball (B1) is fixed in a point within the workspace of the MMT, another ball (B2) is fixed on the tool support. In the figure 2, the balls are shown.

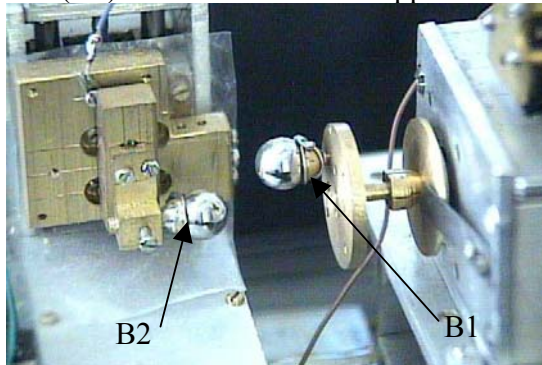


Figure 2. Placement of the balls in the MMT. (The balls have a diameter of 9.11 mm with deviations less than 0.5 μm.)

With the help of the ball B1 is possible to measure many positions of the ball B2, the measures are made by electric contact. The measurements are divided in three groups: each one, contains one axis constant. The first measurements group will have the "X" axis in a constant position and the ball B1 will move in the "Y", "Z" axes to make the measures; the second group will have "Y" axis position constant; and the third will have "Z" axis position constant. By a computer program, the process of measurements is made automatically as follows (we only explain the procedure to the first group of measures, all the procedure are similar, only changes the movement axes) :

- 1) At first the MMT goes to its home position.
- 2) The ball B2 moves to a position under B1, then B2 moves forward along "Y" axis until makes electric contact with de ball B1. The measure is recorded in a text file.
- 3) B2 moves back along "Y" axis a distance dY (with this distance we assure to eliminate the error generates by the backlash). It moves up dZ.
- 4) B2 moves forward again along "Y" axis until makes electric contact with de ball B1 and the programs records the measure.
- 5) This steps are repeated along the "Z" axis (see figure 3).

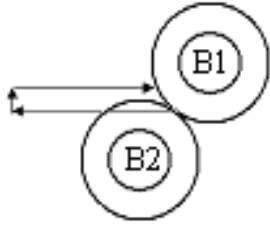


Figure 3. Measurement of B2.

The files with the measurements are read by algorithm based in genetic algorithms, this algorithm finds the center of the associated sphere with the experimental measurements by an error equation,

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

where  $err$  is the quadratic error;  $r_i$  is the distance between an arbitrary selected point  $X_0, Y_0, Z_0$  (that we consider as a center of the approximation sphere) and the experimental points  $X_i, Y_i, Z_i$  (see equation 2); and  $r_m$  is the real distance between ball centers.

$$r_i = \sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2 + (Z_i - Z_0)^2}; \quad (2)$$

The algorithm searches the values  $X_0, Y_0$  and  $Z_0$  where the equation of error began to be minimal, then this point is the theoretical center of B1. In the figure 4 and 5 some results are presented.

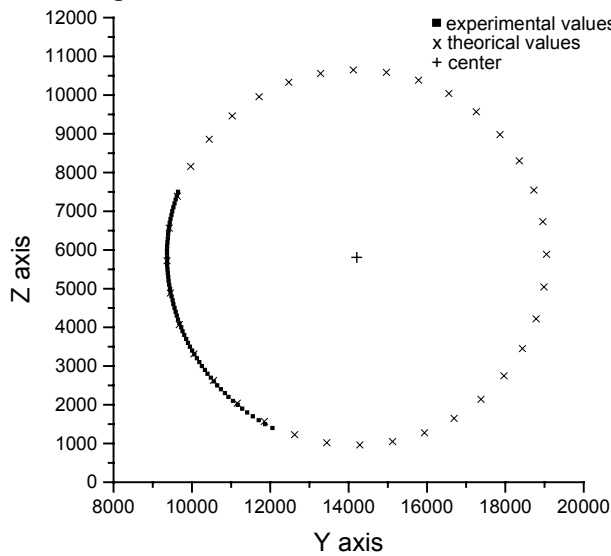


Figure 4. Coordinates of the experimental points<sup>1</sup>

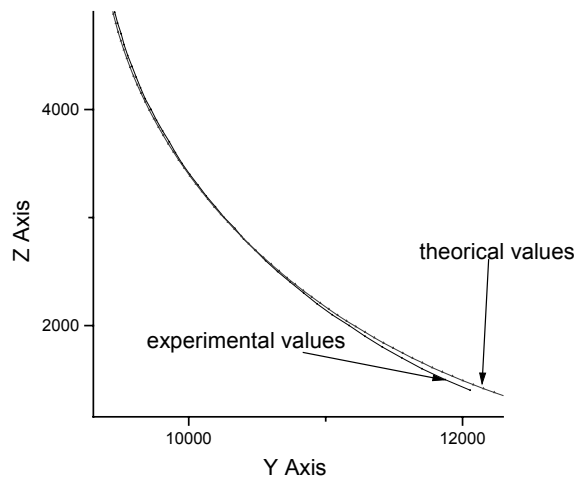


Figure 5. Measurement errors

In the figure 5 is possible to see the difference between the experimental values and the theoretical values. This difference represents the error in the MMT. The sources of errors in the machine tools can be associated with the mechanical parts and its characteristics[5]. In the case of MMT,

<sup>1</sup> All the measures are in steps of motor, each step is equal to 1.88 $\mu$ m

the errors sources are associated with: the non squareness between all the axes; the non straightness of each axis; the rotation of axis; the not linear behavior of leadscrew, etc. Many error sources can be represented by mathematical functions. A general decomposition of the errors in the MMT is shown bellow,

$$\delta_x = f_1(x) + y \cos \alpha_{xy} + z \cos \alpha_{xz} \quad (3)$$

$$\delta_y = f_2(y) + x \cos \alpha_{yx} + z \cos \alpha_{yz} \quad (4)$$

$$\delta_z = f_3(z) + x \cos \alpha_{zx} + y \cos \alpha_{zy} \quad (5)$$

$$\alpha_{xy} = \varphi_1(x, y) \quad (6)$$

$$\alpha_{xz} = \varphi_2(x, z) \quad (7)$$

$$\alpha_{yz} = \varphi_2(y, z) \quad (8)$$

Where  $\delta$  represents the error associate to each axis,  $f$  is the function error of leadscrew, and  $\varphi$  is the function error of straightness, rotation and squareness.

An other algorithm introduces the error equations into the experimental measures to compensate the error found in the previous algorithm.. The errors equations employed in this algorithm are presented below,

$$\delta_x = C_1 + C_2x + C_3x^2 + y \cos\left(\frac{\pi}{2} + \alpha_1\right) + z \cos\left(\frac{\pi}{2} + \alpha_2\right) \quad (9)$$

$$\delta_y = C_4 + C_5y + C_6y^2 + x \cos\left(\frac{\pi}{2} + \alpha_1\right) + z \cos\left(\frac{\pi}{2} + \alpha_3\right) \quad (10)$$

$$\delta_z = C_7 + C_8z + C_9z^2 + x \cos\left(\frac{\pi}{2} + \alpha_2\right) + y \cos\left(\frac{\pi}{2} + \alpha_3\right) \quad (11)$$

Where the constants  $C_1, C_4, C_7$  represent some errors produced by parts of MMT such as gear boxes, home position, randomly errors, etc.; the constants  $C_2, C_5, C_8, C_3, C_6, C_9$  represent some errors related with the leadscrews and the non straightness of each axis; finally, the constants  $\alpha_1, \alpha_2, \alpha_3$  represent the deviation angle between all axes.

At first it's proposed random values for the constants of the error equations. Then, the experimental values are compensated with the values  $\delta_x, \delta_y$  and  $\delta_z$ , then the algorithm creates a new file with the experimental values compensated.

The compensated values are introduced in an algorithm to find the new center employing the equation (1). This algorithm changes the constants according the genetic principles, searches and finds the optimum values to the constants of error equations.

The figures presented bellow show the results obtained whit the compensation algorithm.

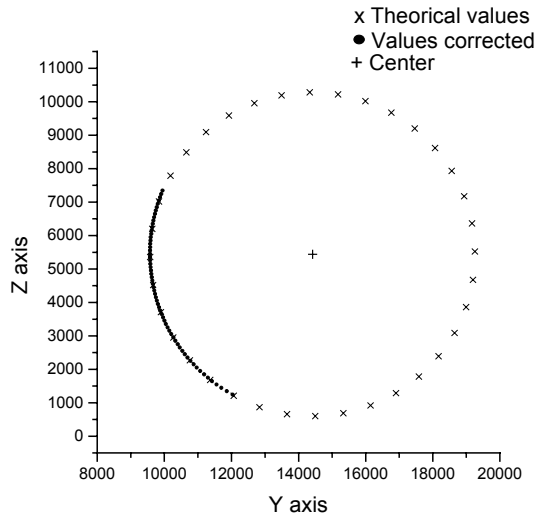


Figure 6. Coordinates of the compensated points

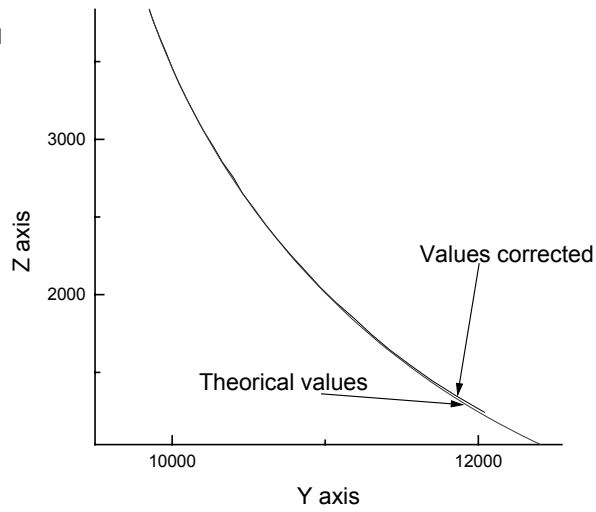


Figure 7. Measurement of compensated errors

### 3.1 Results

The algorithm have demonstrated to be stable, in some experiments developed the algorithm can reduce the errors six times the initial errors. In the figures presented up, at the beginning the software found the center with an error maximum of 158 steps (282  $\mu\text{m}$ ) after the compensation, the error maximum decrease till 32 steps (57  $\mu\text{m}$ ). The values of the constants are shown bellow,

$$C_1=14.76, C_4=0, C_7=10.26, C_2=0.0013, C_5=0.00066, C_8=0.0012, C_3= -1.20 \times 10^{-7}, C_6= -8.29 \times 10^{-8}, C_9= -1.8 \times 10^{-7}, \alpha_1=0.013, \alpha_2=0.006, \alpha_3=0.051$$

### 4. CONTROL

The information generated with the help of the previously algorithms will help us to reconstruct the work space of the MMT and find the associated errors to each point of this space. It is difficult to sample all the work space of the MMT. To cover all the work space we propose to develop a software based in neural networks to generate an adaptive control. At this time we are working on this algorithm.

### CONCLUSIONS

An method to find and compensate errors in a MMT was presented, the results obtained at this moment are satisfactory, but it is necessary to make more researches about the error equations to reduce the error even more and increase de accuracy in the MMT's. This method represents an alternative low cost method to assess not only MMT's. The obtained results will help us to increase the actual accuracy of MMT ( $\pm 18 \mu\text{m}$ ).

### ACKNOWLEDGEMENTS

This work was supported by CONACyT 339944-U.

## REFERENCES

- [1] Ishikawa Yu., Kitahara T. Present and Future of Micromechatronics. 1997 International Symposium on Micromechatronics and Human Science, pp.13-20.
- [2] Kussul E., Ruiz L., Caballero A., Kasatkina I., Baydyk T. CNC Machine Tools for Low Cost Micro Devices Manufacturing. The First International Conference on Mechatronics and Robotics; St.-Petesburg, Russia; 2000, Vol.1, pp.98-103
- [3] A. Caballero-Ruiz, FIRST GENERATION MICROMACHINE TOOL CHARACTERIZATION, ASPE's (American Society for Precision Engineering), 16th Annual Meeting , Criytal City, Virginia, Washintong DC, USA.
- [4]Machine Tool inspection by Rick Glos, Heidenhan corporation ([www.heidehain.com/INSPECTN.HTM](http://www.heidehain.com/INSPECTN.HTM))
- [5] Kussul E., Rachkovski D., Baidyk T. and Talayev S.. Micromechanical Engineering: a Basis for the Low Cost Manufacturing of Mechanical Microdevices Using Microequipment, J. Micromech. Microeng., 1996, 6, pp. 410-425.
- [6] G.H.J. Florussen, F.L.M. Delbressine, M.J.G. van de Molengraft, P.H.J. Schellekens. Assessing geometrical errors of multi-axis machine by three-dimensional length measurement. Journal of measurement, Elsevier edited, 2001