ONE DIMENSIONAL KINETIC MODEL OF CMM PASSIVE SCANNING PROBES

Grzegorz Krajewski, Adam Woźniak

Abstract:

Scanning probes, also known as measuring probes, are one of the most used solution for coordinate measuring machines (CMM), because of ability to collect large amount of measuring points as well as fast measurements. Fast measurement and accuracy of measuring system have recently determined two critical parameters which decide about effectiveness of the machine. Dynamic is the most significant factor limiting accuracy of measurement. Majority of research into scanning CMM does not separate the performance of the probing system from the other error sources of the machines, so a real error influenced by the probing system is not deeply determined. This paper presents the scanning probe model regardless the machine links. Determined model makes possible to better understand the probing process with higher speeds and optimize the measuring process. Finally (future work), optimization algorithms will be proposed and applied to the probing system and the result will be improved accuracy.

Keywords: *scanning probes, CMM, dynamics, model.*

1. Introduction

Modern manufacturing process, especially in aerospace and automotive industries, requires more sophisticated measuring devices. Verification process became inessential part in modern production, so the accurate measurement, high number of data collection and measuring velocity plays important role and cannot be achieved simultaneously at the satisfactory level. Dynamics became the dominant source of potential measurement error.

Scanning probes are commonly used in CMM machines. The main asset of this solution is a great number of data to be collected which influences on the final accuracy of measurement. Another advantages of this inspection is possibility to measure in continuous way number of points when the machine is moving.

One of the significant limitations of scanning speed determines the dynamic effects of the whole measuring system [1]-[3]. The Probe itself, machine, controller, calibration process, must be inter-related, as well as the measurement techniques have to be designed to ensure the better performance of the measurement.

This article focuses mainly on the scanning probes and their influence on accuracy of the measurement. It is crucial to recognize kinetics properties of scanning probes. Well known method of research, based on shape artifacts [4]-[6], demands advanced and complicated equipment [7]-[16]. International standards also provide some recommendations [17]-[19] concerning this type of measurements. Regardless of the scanning properties of measurement it is very important to create a theoretical model of scanning probe with mathematically calculated parameters of scanning.

This model allows optimizing the mechanical properties of probes as well as measuring algorithms, which finally leads to improved accuracy with high dynamics of measurements.

Scanning probes consist of three perpendicularly mounted guideways which are parallel to machine axes to perform the axis movement of stylus tip. Each guideway is incorporated with length measuring system with range up to a few millimeters and a typical resolution of 0.1 um. In fact, small range of scanning probes is compensated by machine movements for achieving continuous contact between stylus tip and material.

There are two types of scanning probes on the market, assive and active ones. A passive probe is based on simple measurement of tip displacement, while machine is moving. Contact force is controlled and evaluated using three (one axes each) parallel electronic springs which give an electrical signal proportionally to the acting force. Active sensors represent a different approach to measurement. Active scanning sensors use a motorized mechanism that is able to control the stylus movement and modulate the contact force with the component.

2. Kinetic model of scanning passive probes

Scanning probe itself can be easily modeled using the mechanical components. A model consist of mass which represent mass M of (stylus, stylus carrier, transducers, guide ways, springs). Probing system also can be described by stiffness K1 of probe mechanism and stiffness of stylus, and damping C1. Taking these factors into consideration we can easily evaluated simple probe model (Fig.1).

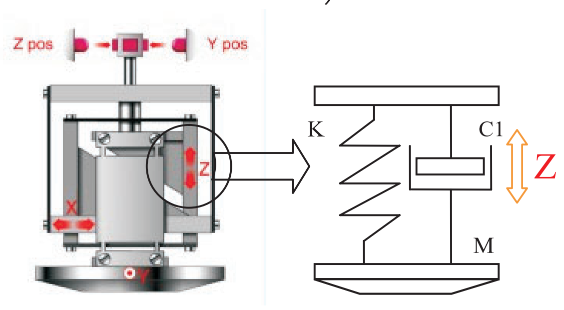
a) *b)*

Fig. 1. CMM passive scanning probe: a) picture [20], b) one dimensional mechanical model.

As the first part of simulation model one dimensional probe has been evaluated. It means that model cover only one degree of freedom probe which theoretically can measure with only one direction.

It takes into consideration only probe mechanics regardless effect of stylus stiffness and stylus mass. Proposed model can be described using a mathematic formula as the second order differential equation:

$$M\frac{d^2x}{dt}+C1\frac{dx}{dt}+x(t)K1=0 \qquad (1)$$

where:

t - time,

$x(t)$ - probe response,

$\frac{d^2x}{dt}$ - second derivative of $x(t)$,

$\frac{dx}{dt}$ - first derivative $x(t)$, $\frac{k1}{M}=\omega^2$ free undamped frequency, and $\frac{C1}{2M}=\zeta$ damped frequency.

The equation (1) has the following solution:

$$x(t)=A*e^{-\zeta t}\sin(\omega_0 t+\psi) \qquad (2)$$

Initial value considerations, $x(t)=P$ and $x'(t)=0$, parameters A i ψ can be expressed [21]:

$$A=\sqrt{P+\left(\frac{\zeta*P}{\sqrt{-\omega^2+\zeta^2}}\right)^2} \qquad (3)$$

$$tg\psi=\frac{P*\sqrt{-\omega^2+\zeta^2}}{\zeta*P} \qquad (4)$$

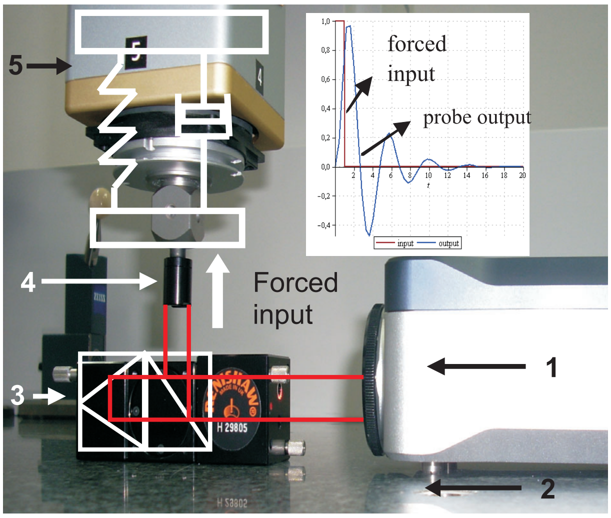

Fig. 2. Measurement of mechanical parameters of the scanning probes: 1 - laser head, 2 - machine table, 3 - stationary optics , 4 - retroleflector, 5 - scanning probe.

For the experimental evaluation of unknown parameters A, M, $K1$, $C1$, ψ, ω special measuring stand based on laser interferometer was prepared and described in Fig. 2. A small retroreflector with known mass 1 was attached to the probe carrier (styli were removed). Laser head 3 and stationary optics 2 were located on machine table 4. This configuration allowed measuring the free vibration of scanning probes. The initial values of measurement where executed using external forces. Unknown parameters where evaluated on the basis of free vibration characteristics of probe mechanism using "additional mass methods" [21]. The evaluated parameters allow for determining the dynamic properties such as stiffness of probing system, damping and masses. These parameters state the dynamic properties of the probing system, which have influence on accuracy of measurement especially with increased scanning speed.

3. Experiments

This type of measurement evaluated for two types of scanning probes: Vast XXT manufactured by Zeiss, and SP600 manufactured by Renishaw. Vast XXT is described as passive probes with maximum permissible error of scanning MPE_{Tij} = 2.7 μm, according ISO standards. SP600 is also typically passive probes with accuracy MPE_{Tij} = 3.4 μm.

Determined parameters of model can be easily adapted to a mathematical formula. The solution of equation 1 gives "real" probe response for different forcing functions. The result of VAST XXT and SP600 output performance simulations for forcing function "sin(πt)(1-Heaviside(t-1)) were presented in the Figures 3 and 4.

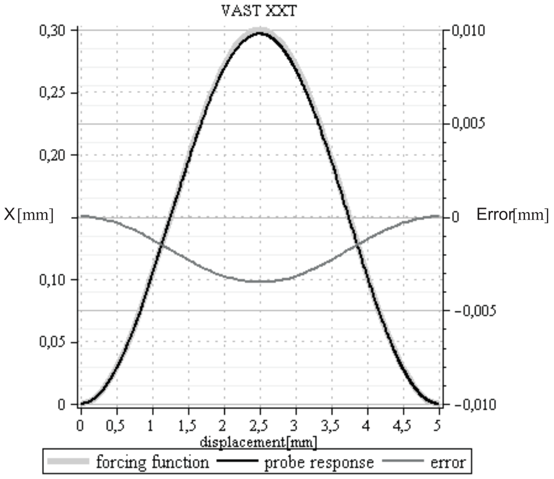

Fig. 3. Simulation of forcing response for VAST XXT probe.

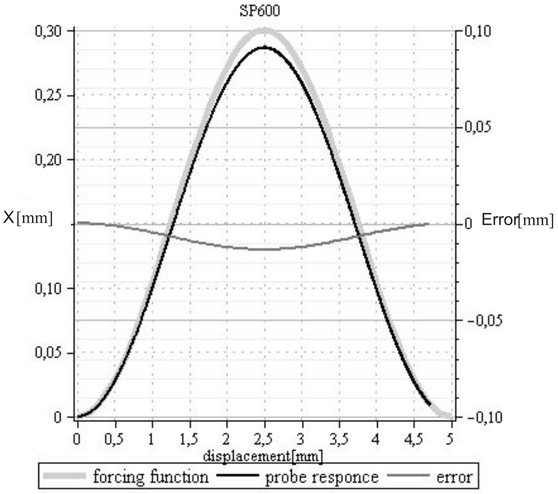

Fig. 4. Simulation of forcing response for SP600 probe.

An excitation function applied to the proposed model, which represents the measuring surface (sinus), only gives symmetric errors which are proportional to the maximum of excitation function. Proposed model applied to the evaluated probes show that error is bigger than Maximum Permissible Error MPETij specified by manufacturers of probe. For VAST XXT MPE_{Tij} specified in datasheet equal 2.7 µm but obtained by the model is closely 3.4 µm. Bigger difference between obtained results and MPE_{Tij} represents SP600 probe. For SP600 maximum permissible error describing accuracy of probe according ISO 10360-4 standards equals 3.4 µm. Simulations show that error equals 12 um, which is over than expected.

4. Conclusions

Proposed kinetic model and simulation represent only mechanical properties of probe transducers which can be valuable for probe designers and manufacturers. Deep knowledge about scanning probes principles is inessential, so the prospective model should provide information about wider group of measuring surface especially with the high speed curvature performed for high speed scanning. It is necessarily to develop model for future simulation of additional dynamic effect as stylus bending, friction between stylus tip and surface, micro- and macro geometry of measured surface. Improved model allows to compensate dynamic effects of scanning probes operation.

ACKNOWLEDGMENTS

Research co-funded as a research project of the Ministry of Science and Higher Education of Poland. A. Woźniak is a beneficiary of the Homing program awarded by the Foundation for Polish Science.

AUTHORS

Grzegorz Krajewski*, Adam Woźniak - Division of Metrology and Quality Engineering, Institute of Metrology and Biomedical Engineering, Faculty of Mechatronics, Warsaw University of Technology, 02-525 Warsaw, ul. Św. A. Boboli 8, Poland. E-mail: gkrajewski@gazeta.pl.
* Corresponding author

References

[1] Bosch J.A., *Coordinate Measuring Machines and Systems*, Marcel Dekker, Inc. New York, Hong Kong, 1995.

[2] Butler C., “An investigation into the performance of probes on coordinate measuring machines”, *Industrial Metrology*, vol. 2, no. 1, 1991 s. 59-70.

[3] Ratajczyk E., *Współrzędnościowa technika pomiarowa*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2005. (in Polish)

[4] Morse E.P., *Artifact selection and its role in scanning probes evaluation*, The UNC of Carolina at Charlotte, USA, 2002.

[5] Weekers W.G., Schellekens P.H.J., “Compensation for dynamic errors of coordinate measuring machines”, *Measurement*, vol. 20 ,1997, p. 197-209.

[6] Woźniak A., Mayer R., “Micro-shape master artifact for testing the dynamic performance of CMM scanning probes”. In: 8th *International Scientific Conference Coordinate Measuring Technique*, Bielsko-Biała, Poland, April 2008, pp. 107-112.

[7] Liang R., Jusko O., Lüdicke F., and Neugebauer M., “A novel piezo vibration platform for probe dynamic performance calibration”, *Measurement Science and Technology*, vol. 12, 2001, pp. 1-6.

[8] Bendeli A., Duruz J., Thwaite E.G., “A surface simulator for the precise calibration of surface roughness measuring equipment”, *Metrologia*, vol. 10, 1974, pp. 137-43.

[9] Woźniak A., „Metody badania dokładności sond skaningowych WMP”. In: *VII Szkoła-Konferencja „Metrologia wspomagana komputerowo”*, Waplewo, May 2005, *Papers* vol. 3, pp. 151-156. (in Polish)

[10] Woźniak A., “New method for testing the dynamic performance of CMM scanning probes”, *IEEE Transactions on Instrumentation and Measurement*, vol. 56, no. 6, 2007, pp. 2767-2774.

[11] Woźniak A., “Application of piezotranslator for the dynamic testing of scanning probes in coordinate measuring machines”, *Mecatronica (Societea Romania de Mechatronica)*, no.1, 2004, pp. 93-95.

[12] Woźniak A., Dobosz M., “Methods of testing of static inaccuracy of the CMM scanning probe”, *Metrology and Measurement Systems*, vol. X, no. 2, 2003, pp. 191-203.

[13] Woźniak A., “An investigation into the dynamic performance of CMM scanning probes”, *Elektronika*, no. 8-9, 2004, pp. 256-258.

[14] Woźniak A., “Application of piezotranslator for the dynamic testing of scanning probes in CMM”. In: *The 7th International Conference on Mechatronics and Precision Engineering*, Bucharest, Romania, 27th-29th May 2004 , pp. 245-246.

[15] Woźniak A., “Preliminary dynamic error characteristics of CMM scanning probe”. In: *2nd Int. Conf. on Global Research and Education Inter-Academia*, Warsaw, Poland, September 2003, vol. 1, pp. 201-204.

[16] Woźniak A., Dobosz M., Ratajczyk E., “Testing the inaccuracy of CMM scanning probe”. In: *International Symposium on Metrology and Quality Control*, Cairo, Egypt, 24th-27th Sept. 2001, pp. 57-63.

[17] PN-EN ISO 10360-4: 2002. Specyfikacja geometrii wyrobów (GPS). Badania odbiorcze i okresowe współrzędnościowych maszyn pomiarowych (CMM). Part 4: CMM stosowane w trybie pomiaru skaningowego. (in Polish)

[18] VDI/VDE 2617 1989. Accuracy of Coordinate Measuring Machines. Part 3. Dusseldorf.

[19] ANSI/ASME B89.1.12M 1990. Methods for Performance Evaluation of Coordinate Measuring Machines, American Society for Mechanical Engineering New York.

[20] Renishaw, *General Catalogue 2009*.

[21] Arczewski K., Pietrucha J., Szuster J.T., *Drgania układów fizycznych*, Oficyna wydawnicza Politechniki Warszawskiej: Warsaw, 2008. (in Polish)