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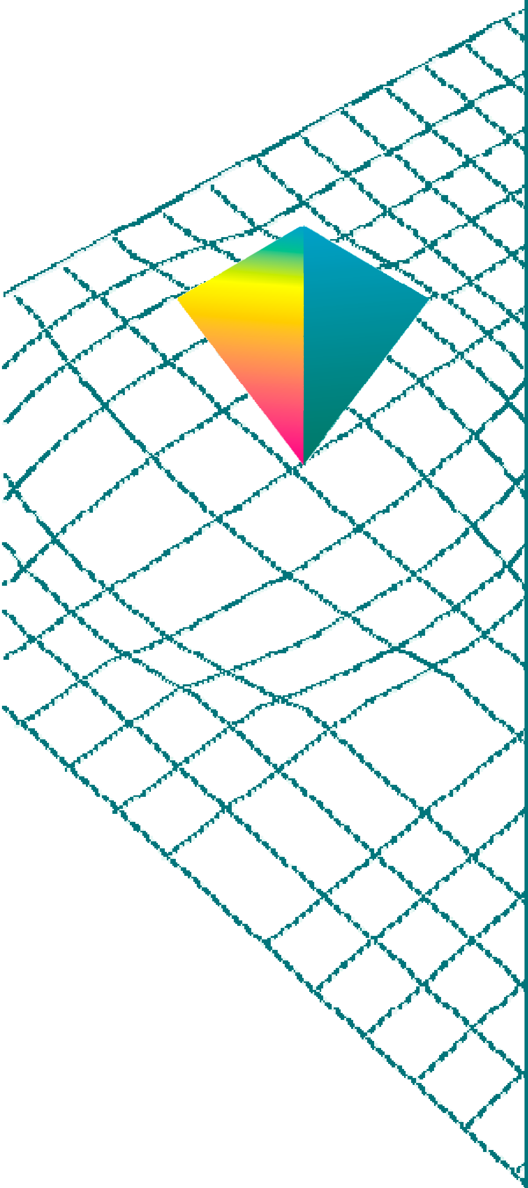

50. Internationales Wissenschaftliches Kolloquium

September, 19-23, 2005

Maschinenbau von Makro bis Nano / Mechanical Engineering from Macro to Nano

Proceedings

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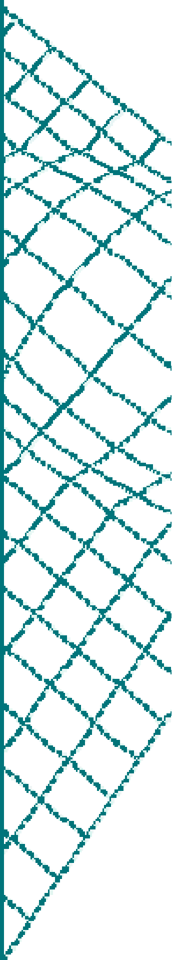

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50. Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
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1. A. Weckenmann / 2. J. Hoffmann

Micro and Nano Coordinate Measuring Technique

ABSTRACT

Miniaturized CMMs are appropriate for flexible measurements of form and dimensions of micro sized parts. In general they are set up out of the basic components: guiding and motion systems, metrology frame, probing system and software. This paper wants to show the current scientific and technological approaches for these most important components and will point out design objectives and the most promising existent implementations. While for length measuring systems only laser interferometers are used, there is a variety of different philosophies and solutions for all other mentioned devices.

APPLICATION OF MINIATURIZED COORDINATE MEASURING MACHINES

Micro sized parts with tolerances in the sub micrometer area and a real three dimensional structure gain in importance, e.g. miniaturized sensors in the automotive area (acceleration, tire air pressure, intake air flow rate), mechanical components of mobile phones and micro drives and gears (figure 1). For flexible conformance testing of their geometric features, coordinate measuring machines with a resolution in the nanometer order and measurement uncertainty of a few ten nanometers are appropriate according to Bernt´s "golden rule" of metrology (measurement uncertainty should be about 10% of the tolerance to be checked).

To achieve that accuracy, first order errors have to be avoided by applying the Abbé-principle. First order errors derive from a shift (so called Abbé-offset) between the length to be measured and and the scale used for measurement. When the scale is aligned with the length to be measured, the Abbé-offset and thus first order errors are zero. For a cartesian three coordinate measuring system this means that the probing point always has to be in the point of intersection of the three length measuring axis. This is only possible with a fixed probing point with respect to the length measuring systems, so either the specimen has to be moved for measurement, or the scales have to move together with the probing system.

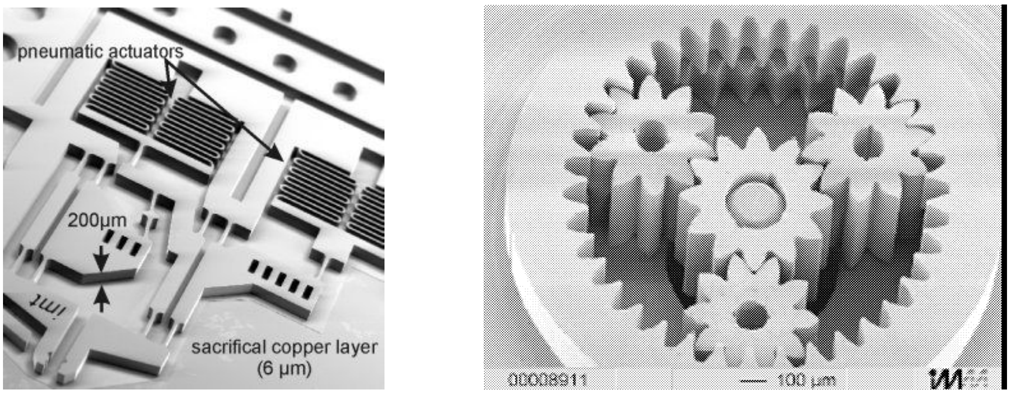

figure 1: micro gripper (left, source: imt, hannover) and micro gear (right, source: imm Mainz)

MACHINE COMPONENTS

In general micro and nano coordinate measuring machines feature the same kinds of components as large CMMs, but the technical realization has to take into account lots more influencing effects. In opposite to large CMMs the **machine base** for nano metrology equipment is usually split into a **metrology frame** and a base for the **motion and guiding systems**. For getting information about the work piece surface, at least one **probing system** is needed. To get information about work piece and probing system relative position **length measuring systems** setting up a coordinate system are used. Last but not least **software** forms the interface between **machine controller** and operator.

MACHINE BASE AND METROLOGY FRAME

Achieving nanometer resolution and accuracies of a few tens of nanometers is only possible with a very rigid and thermally stable structure carrying all high accuracy measurement systems of the nano coordinate measuring machine (NCMM) and ensuring a constant geometric relalationship between them. Usually these metrology frames are mechanically and thermally isolated from the motion and guiding systems to keep the load and thus strains small and to abandon vibrations and thermal influences resulting from the drives. Materials of choice for the metrology frame are Zerodur, a glass-ceramic compound developed by the German company Schott featuring virtually zero thermal expansion at 20°C and Invar, an iron and nickel based alloy with very low thermal expansion developed by C. E. Guillaume 1912. Adding cobalt further reduces the CTE ('Super Invar'), table 1. While Zerodur is better in linear thermal expansion Invar has the advantage of faster soaking out temperature gradients because of its better thermal conductivity. Zerodur is used in the SIOS NMM-1 [1] (figure 2), Invar in the IBS ISARA [2].

property	Zerodur	Invar (Super Invar)
CTE @ 20°C	0 ± 0,02 * 10^{-6} K^{-1} (class 0)	1,7-2,0 * 10^{-6} K^{-1} (0,3* 10^{-6} K^{-1})
thermal conductivity	1,46 W/(m*K)	13 W/(m*K)
density	2,53 g/cm³	8 g/cm³
Young´s modulus	90,3 GPa	140-150 GPa

table 1: properties of Zerodur and Invar

Measuring systems to be connected with by the metrology frame are typically three laser interferometers in Abbé-arrangement (measuring beams are intersecting in one point) and additionally several angle sensors [3]. This enables Abbé-offset free position measurements and the possibility of compensating second order errors. For low range applications also capacitance sensors are used, for MCMMs of larger travel and slightly reduced demands on accuracy and traceability scale based length measuring systems are employed.

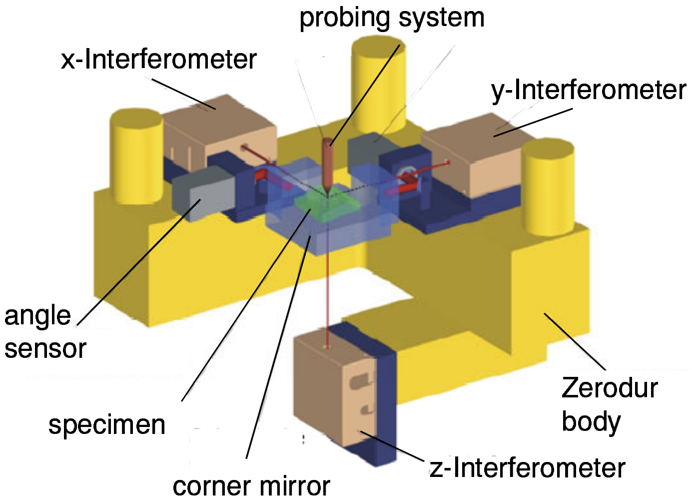

figure 2: metrology frame of the SIOS NMM-1 (source: SIOS GmbH)

MOTION AND GUIDING SYSTEMS

For the use in high precision positioning equipment, three different approaches for implementing the guiding systems are common. Air bearings commonly used in macro scale coordinate metrology have been adopted e.g. by Ruijl [2] for his Ultra Precision CMM and have the advantage of beeing frictionless and thus avoiding stick-slip motions and redcucing the required driving power. On the other hand air bearings show a certain clearance depending on the actual air pressure and load and emit exhaust air that might affect the machine performance. Another approach is to use flexure hinges and levers to compose transversal movements out of clearance free rotations, e.g. at the kinematic system of the PTB Veritekt [4], figure 4.

Advantages of these guiding systems are very high reproducibility and low friction, disadvantageous for a CMM is the highly restricted travel and the comparatively large size of these kinematics. The third possibilty is employed at the SIOS NMM-1 machine [1] and that is to use high precision roller bearings in combination with an advanced non-linear position and motion control system. Small movements of a roller bearing do not involve balls to roll but to distort and to slide leading to a complex relationship between driving force and travel that has to be taken into account and compensated for by the motion control.

There are also different approaches for implementing the driving systems depending on the required travel and acceleration. For very short travel (< 100 μm) mainly monolithic and stacked piezo actuators are used. Resolutions down to sub-nanometer level, high acceleration, low power consumption and the absence of internal relative movements make them the first choice for low range applications. On the other hand it is not possible to perform larger movements with a compact piezo element and there is a necessity for closed loop control because of large non-linearity and hysteresis effects. Larger travel is mostly performed by Lorentz actuators [1], [2] but it is also possible to build high resolution friction drives based on piezo actuators.

PROBING SYSTEM

The probing system is the interface between specimen and CMM and especially challenging for miniaturization. Nowadays there are several products available working with various principles, from small conventional systems to experimental assemblies based on e.g. optical levitation of the miniaturized probing sphere [5]. One of the basic problems in reducing the size of conventional probing systems is the necessity of probing force transport via the stylus demanding for a stiff stylus. This is in conflict with minimizing the diameter of the probing sphere, that has always to be bigger, than the stem of the stylus. Complementary there are optical and scanning probe microscopy based probing systems that can be integrated into NCMMs for special purposes, surface analysis, material analysis and navigation. Commercially available probing systems for micro coordinate measuring machines are up to now the 2D Werth FiberProbe, 3D microprobes developed by Technical University of Eindhoven TU/E and the National Physics Laboratory of the UK NPL, as well as a 3D silicon microprobe developed by PTB and Technical University of Braunschweig [4], figure 3.

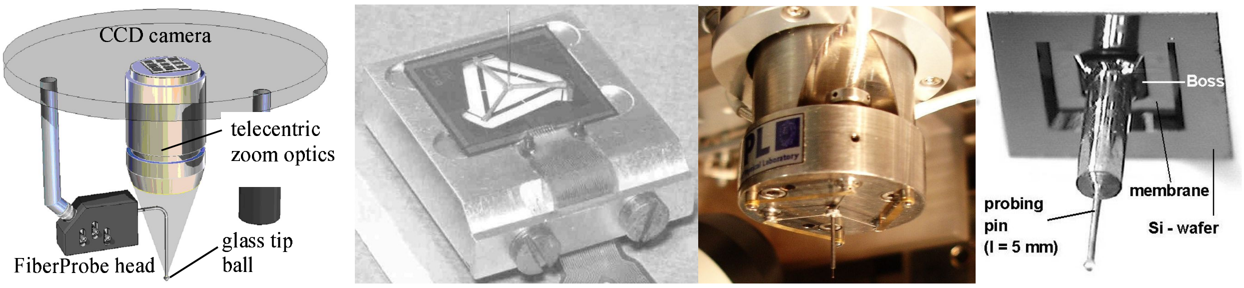

figure 3: the first commercial micro probing systems (from left to right: Werth FiberProbe; TU/E microprobe, source Schellekens; NPL microprobe; PTB microprobe, source PTB)

SOFTWARE

Today's nano coordinate measuring systems are still far from being turn-key products what is also reflected in the software. Software offering the functional range and user friendliness of modern conventional CMM software with graphical user interface and modules for operating and controlling the machine as well as for date processing and evaluation would be desirable but the small number of developers of NCMMs, additionally split into a number of research institutes, do not have the man power for developing tailor made high level software specific for their machines. Status quo is to provide low level control software to operate the machine, e.g. a script language or a small set of fundamental commands. METAS has implemented an interface to use commercial CMM software with the prototype of the IBS ISARA NCMM and Zeiss is offering its micro CMM F25 together with the sophisticated CMM software CALYPSO.

Realized Nanomeasuring Machines

Today existing micro and nano coordinate measuring machines can be subdivided according to their measuring range and resolution into metrological scanning probe microscopes MSPM, nanometer resolution coordinate measuring machines NCMM and micro coordinate measuring machines MCMM. MSPMs are characterized by a very small measuring volume of typically <100 µm in x and y axis and 10-20 µm in z-direction. Resolution reaches usually sub nanometer level. Commonly the kinematics are based on flexure hinges and the drives are implemented with piezo elements. To improve the metrological behaviour, closed loop controll is mandatory and often realized with capacitance sensors or, in high-end applications, laser interferometry. Exemplary for that category of instruments is the Veritekt C of the German NMI PTB in Braunschweig (figure 4). It is based on the commercial Zeiss AFM Veritekt (offered no more), amended by three SIOS laser interferometers. It is used for step height and pitch standard calibration for scanning probe microscopy and profilometry.

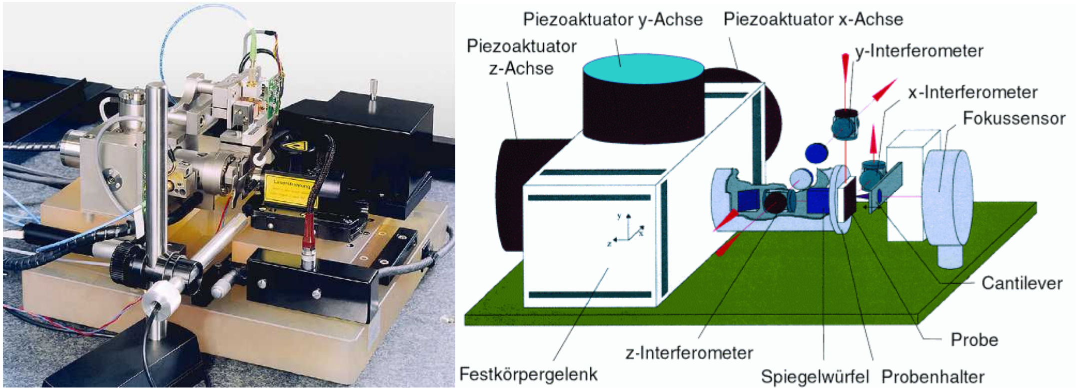

figure 4: Metrological SPM PTB Veritekt C [4]

For the second category there are already two commercial products available, the IBS ISARA (Netherlands) and the SIOS NMM-1 (Germany), figure 5. Both have a very similar basic set-up in order to avoid Abbé-errors. The moving specimen carrier is composed out of three perpendicular mirrors acting as retroreflectors of three laser interferometers. The probing system is fixed rigidly to the metrology frame, which is also carrying the interferometers. The SIOS machine has a measuring range of 25 × 25 ×5 mm^3 and a resolution of 0,1 nm [3], the volumetric positioning uncertainty is claimed to be about 10 nm. The ISARA has a range of 100 ×100 ×40 mm^3 and a resolution of 1,6 nm. Claimed volumetric positioning uncertainty is 30 nm [2].

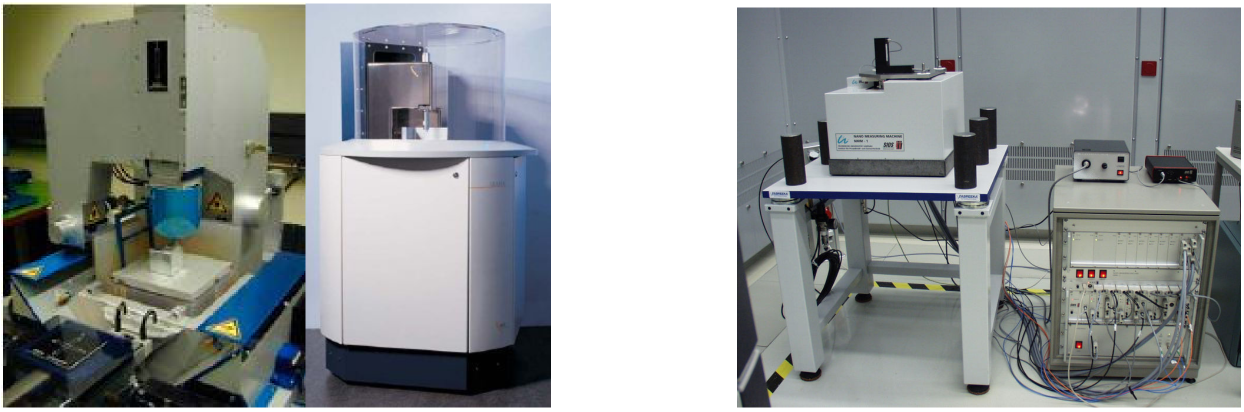

figure 5: Nano CMMs IBS ISARA (left, source: METAS, IBS) and SIOS NMM-1

An example for the third category is the PTB MME, a commercial Werth CMM modified with improved air bearings and a three axis laser interferometer system to achieve a volumetric positioning uncertainty of about 100 nm in a measuring range of 25 × 40 × 25 mm^3. It is equipped with two probing systems, the fiber probe (developed by PTB) and a 3D silicon microprobe (developed by TU Braunschweig) [5].

The first commercial micro CMM is the Zeiss F25 based on a design by Vermeulen (figure 6, [6]). Its set-up is quite different compared to all other introduced systems. The scales of that machine are mounted onto intermediate bodies between machine base and ram and are moving together with the probing system in order to minimize Abbé-errors. This machine is specified with a volumetric measurement uncertainty of 250 nm in a volume of 100 × 100 × 100 mm^3 and also uses the 3D silicon microprobe from TU Braunschweig.

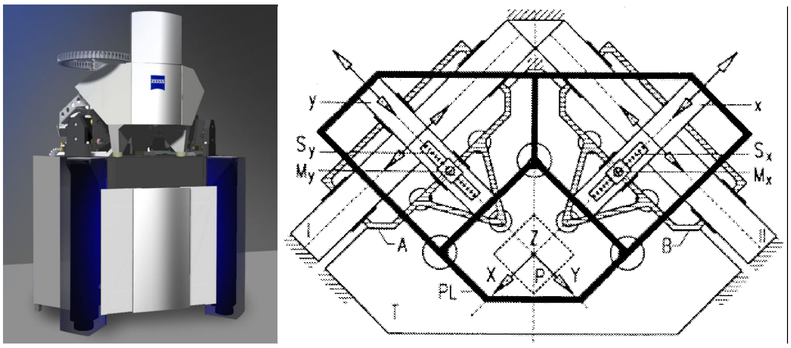

figure 6: Commercial micro CMM Zeiss F25 and its principal set-up [6]

Literatur- bzw. Quellenhinweise:

[1] Jäger, G., Manske, E., Hausotte, T., Büchner, H.-J.: Nanomessmaschine zur abbefehlerfreien Koordinatenmessung. Technisches Messen 7-8/2000, p. 319-323.

[2] Ruijl, T.: Ultra Precision Coordinate Measuring Machine. Eindhoven, 2001. ISBN 90-6464287-7.

[3] Jäger, G., Grünwald, R., Manske, E., Hausotte, T., Füßl, R.: A Nanopositioning and Nanomeasuring Machine Operation - Measured Results. Nanotechnology and Precision Engineering, Volume 2 6/2004, p. 81-84.

[4] Schulz, D.: Rasterkraftmikroskope vom Typ Veritekt. PTB, Braunschweig, 2005. http://www.ptb.de/de/org/5/51/515/rm/rm31_d.htm

[5] Weckenmann, A., Peggs, G., Estler, T., McMurtry, D.: Probing Systems in Dimensional Metrology. Annals of the CIRP 53/2, Krakow, 2004.

[6] Vermeulen, M.M.P.A., Rosielle, P.C.J.N., Schellekens, P.H.J.: Design of a high-precision 3D-coordinate measuring machine, Annals of the CIRP, 47 (1), 1998.

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