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TOLERANCES FOR MICROTECHNOLOGIES

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Abstract: Microsystems are miniaturised technical components in dimensions of mm, which consist of mechanical and electronic or optic functions and functional elements. Microsystems are used as sensors and actuators in different applications for automobiles, medical techniques or peripheral computer equipment. They are manufactured in series or small series. Sensors, actuators and many technical microproducts require components with small dimensional form and surface tolerances in the µm range. If one includes the physical processes, precision starts to reach nano levels. The tolerances of microsystems are defined as functional tolerances. This paper deals with requirements for tolerancing systems for miniaturised components and functional elements. The different criteria and systems as well as basics for possible standards are elaborated. It is even a contribution to the discussion about the necessity of new tolerancing systems, questions of calibration and the usage of measuring systems to detect deviations in microgeometry, physical characterisation and integration of measurement in industrial manufacturing systems.

Keywords: Microtechnology, Measurement, Tolerances

1 INTRODUCTION

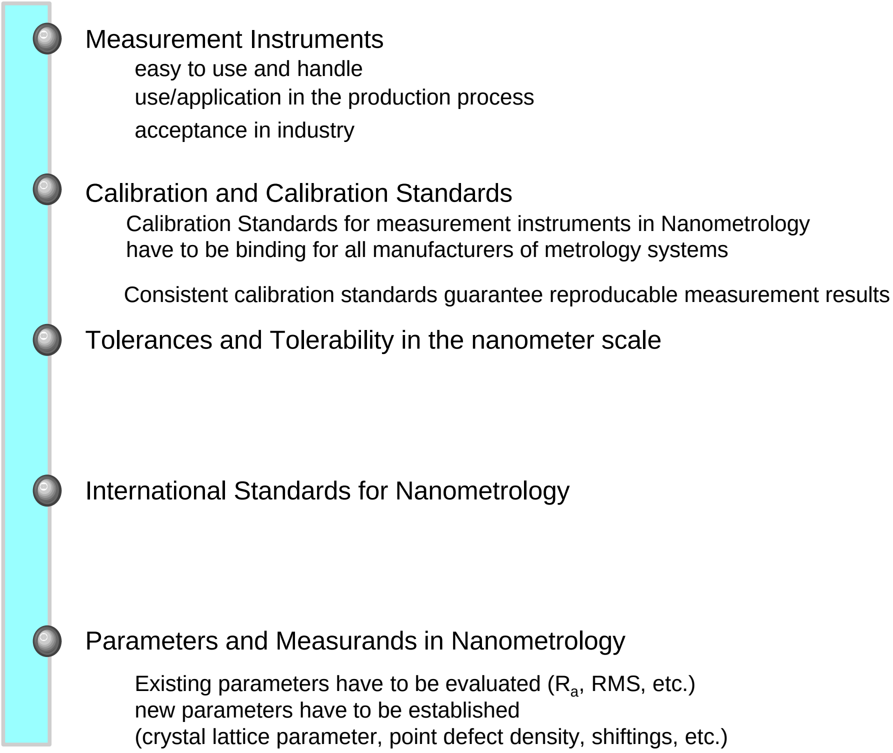
Microtechnologies are of high importance for the future development of products with internal technical intelligence. Many investigations regarding future technologies like the delphi studies see the breakthrough of this technologies in the next century. There are of course a lot of successful developments and applications, which give this technology a future perspective as a key-technology.

To produce microtechnical products economically, an industrial production technology and metrology is required. The most important feature of which is the reliability and capability under extreme precision constraints. Just the miniaturisation needs integrated engineering and design for increasing the reliability and process capability in view of technical limits and functionality. The well known tolerancing systems for geometrical criteria and the border zones are not efficient to increase the process capability.

2 STATE OF THE ART AND REQUIREMENTS

The advance in to the realm of miniaturisation of forms, form elements and function elements in the components increases manufacturing costs as well as reject rates. It is not just geometric quality criteria that are extremely relevant for future products, physical ones, e.g. properties of the border zones, are as well. Work towards industrialising microsystem engineering has attracted a great deal of interest in this respect. With the miniaturisation of forms, form elements and function elements, the effect of disturbances and deviations in parameters from the ideal settings increases. Control of the processes requires miniaturisation of the analysis and design of the process right down to molecular and atomic levels.

Tolerance-systems, which are mainly based on geometrical systems are not more suitable to define and characterise the different functional requirements of miniaturised components, form and functional elements. They have to be modified or added by new systems, which enable manufacturers to handle the deviations of processes and influencing measurement technologies.



- Measurement Instruments
  easy to use and handle
  use/application in the production process
  acceptance in industry
- Calibration and Calibration Standards
  Calibration Standards for measurement instruments in Nanometrology
  have to be binding for all manufacturers of metrology systems
  Consistent calibration standards guarantee reproducable measurement results
- Tolerances and Tolerability in the nanometer scale
- International Standards for Nanometrology
- Parameters and Measurands in Nanometrology
  Existing parameters have to be evaluated (R_a, RMS, etc.)
  new parameters have to be established
  (crystal lattice parameter, point defect density, shiftings, etc.)

Figure 1. Requirements for Tolerancing Systems in Micro and Nanotechnology

The dramatic improvement of ultraprecise manufacturing machines and the invention of new production techniques like LIGA (X-ray lithographic and galvanic processing) and Focused Ion Beam Technology has made the production of form- and functional elements with micro- and nanometer size possible and economically reasonable. In metrology, a further development of Scanning Probe Techniques such as Atomic Force Microscopy, Magnetic Force Microscopy and related techniques has helped to establish the so called Research-oriented Nanometrology in research institutes and meanwhile in industry (especially semiconductor industry) too [1].

Although both manufacturing technology and measurement instrumentation fulfil most of today´s demands in Micro- and Nanotechnology, international measurement standards in Nanometrology are still missing. These standards, including the calibration of microscopes, the toleration of form and functional elements in the nanometer scale, new parameters and measurands for nanometrology and guidelines for reproduceable and comparable measurement results are vital for the acceptance of an industrial Micro- and Nanometrology in industry.

3 STEPS TOWARDS INDUSTRIAL MICRO- AND METROLOGY

The functionality and performance of a workpiece or a mechanical micro- or nanosystem is closely connected to the indicated tolerances. If they are too narrow, the costs of manufacturing will raise although there is no improvement in performance. If the tolerances are too wide, the functionality of the manufactured parts can not be ensured. This leads to a toleration by personal experience and practical knowledge instead of applying scientifically ensured results and standards defined by international standards organisations. Furthermore it is still not clear which form- and functional elements in Microtechnology are to be tolerated. Form and function of microparts differ from conventional parts used in mechanical systems. So the principles and strategies for tolerating form and functional elements have to be adapted to the required performance, the production processes in Microtechnology and the available measurement instrumentation.

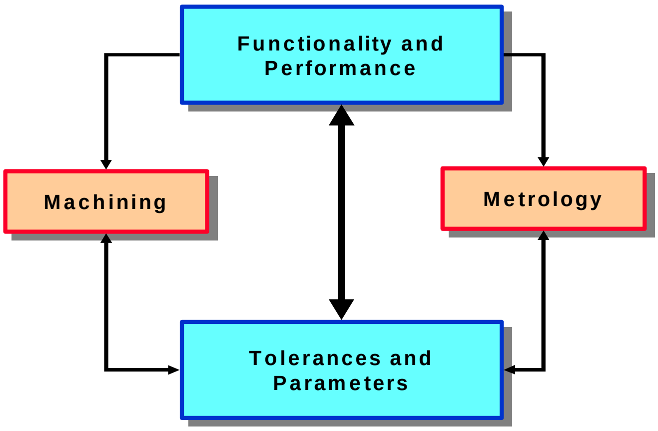


Figure 2. Tolerancing on base of functional aspects

Manufacturing on atomic scale is only possible, when physical, chemical and material-dependent properties of the workpieces are taken into consideration. This means that new parameters and measurands like crystal lattice, point defect density, shifting are getting important, whereas the significance of roughness parameters like RMS and R_a decreases [2,3,4]. For the revision of todays standards and the specification of new standards, those parameters have to be taken in account.

To avoid a “parameter rash” in Nanometrology [5], a meaningful classification of the available and measurable parameters is necessary. A suggestion is made in [6], where parameters are classified in three groups by means of geometric, functional and machining properties. Only the parameters relevant for the performance of the functional element or system are measured, applying a measurement strategy that ensures a minimum of parameters and measurands.

New parameters (crystal lattice, point defect density, shifting) must be taken into account
Revision of existing parameters and measurands concerning their use in Nanometrology
Classification of parameters in geometric, functional and machining properties
Definition of measurement strategies to reduce the measured parameters to a minimum and to ensure, that the measured parameters correlate with the functionality of the workpiece
Assessment of form- and functional elements only by quantitative parameters, not by a vision driven inspection of the surface

4 INTERNATIONAL MEASUREMENT STANDARDS

Several international standards which refer to roughness, waviness and toleration are more than ten, partly even twenty years old. In the last ten (resp. twenty) years new and improved technologies of ultraprecise manufacturing enabled today´s industry to produce workpieces of inconceivable sizes and forms. Surface roughness is reaching atomic dimensions and can be measured by sophisticated microscopes like Atomic Force Microscopy. Although the machining and the metrology is able to handle atomic dimensions, rules and standards for those dimensions are not in sight.

A feasible approach to new international measurement standards for roughness and toleration on the nanometer scale would be the adaptation and transfer of the GPS (**G**eometric **P**roduct **S**pecification) to Nanometrology. The GPS committee was established in 1993 with the aim to create a “masterplan” which subsumes all existing geometric standards. In this masterplan there are the 18 most important geometric parameters listed, each of them with the appropriate standards [7]. Similar to this approach in conventional geometric metrology, a masterplan for the most important geometric parameters in Nanometrology could be designed and then serve as the basis for the definition of new international measurement standards.

- **Measurement instrumentation** designed for the production process will improve the process stability and lead to a better quality of the miniaturized workpieces.

- **Calibration standards** for Nanometrology will help to insure reliable, comparable and reproduceable measurement results.

- **Parameters and measurands** will be adapted to the measurement tasks in Nanotechnology and fixed in international standards.

- **New standards for tolerating** micro- and nanoscale form- and functional elements will help to reduce production costs in an early stage.

Figure 3. Procedures to develop new tolerancing systems for micro and nanotechnologies

There is a great potential for Industrial Micro- and Nanometrology to reduce production costs in micro- and nanofabrication, to raise the quality of form and functional elements with micro- and nanometer dimensions and to improve the process stability in the production process significantly. These advantages can be reached by realizing the five points mentioned above. Parts of them are in progress (calibration standards from the PTB will be obtainable soon), but most of the mentioned problems and handicaps still have to be solved. When industry, manufacturers of measurement instruments, research institutes and national standards organisations will closely cooperate, there is a good chance that Industrial Nanometrology will be the metrology for a future production on atomic scale.

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