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TRACEABLE IN-PROCESS DIMENSIONAL MEASUREMENT – European Metrology Research Programme, project No. IND62

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Abstract: *Manufacturing of precision complex parts includes using machine tools that have an on-board metrology system for in process quality control purposes. Developments in the industry show that there is a need for higher accuracy and the measurements must be traceable. To satisfy these requirements the measurement uncertainties have to be reduced to a few micrometers within a meter cube. Objective of the project is to develop standards and procedures to verify traceability of the measurements made by in-process metrology tools. The project will serve as an input to further developments in coordinate metrology and has a direct impact on industry as well. The main beneficials are mechanical engineering and industry, process engineering and production technologies and the automotive industry.*

Key words: traceability, machine tools, calibration, thermal influences

1. INTRODUCTION

The foundation of effective manufacturing is minimization of scrapping, process time and production resources. In the industry of manufacturing high precision parts one of the tools to be effective, is to use in-process metrology. The philosophy is to make measurements alongside to milling, grinding, turning and other treatments. To do so, machines are often equipped with dimensional measurement tools like tactile probes or optical scanners. Using it will lead to reduction of production costs and increase in efficiency. The prerequisite of abovementioned aspects is to have traceable measurements at satisfying uncertainty level. Reliable dimensional measurements on metal cutting machine tools have a huge economic impact, especially at the last phase of manufacturing. The metrological methods and material standards developed for measuring instruments need to be further developed to suit in-process measurements.

2. NEEDS OF INDUSTRY

There is a strong need for fabricated parts to be inspected quickly and with high accuracy (for conformance testing to specified tolerances) on machine tools directly on the manufacturing floor, i.e., while the machined part is still clamped on the machine. To satisfy future production requirements, the measurement uncertainties have to be reduced to a few micrometers within a meter cube.[[1]]

3. RESEARCH AREAS

The project involves many stakeholders with different expectations. Therefore it is very important to prioritize the areas of in-process metrology. A survey has been conducted and the results have been implemented in selection of research areas [[1]].

Measurement errors on machine tools result from different sources and they can be influenced by various shop floor conditions. In order to detect measurement errors on machine tools, to evaluate them and then to correct them, one demands suitable written and material standards and procedures. These have to take into account environmental conditions of the manufacturing floor and need to be compliant with existing standards. As up to 75 % of the overall geometrical errors of machined workpieces can be induced by the effects of temperature [2], these material standards must be thermally and geometrically stable.

In frames of the project highly accurate multipurpose material standards will be designed and manufactured. These will be robust against environmental influences and high mechanical stress. They will be used for mapping of volumetric and task-specific measurement errors of machine tools.

For simulating in-situ varying manufacturing and machine tool environmental conditions a suitable portable shop floor environmental chamber will be designed and manufactured.

To determine geometric measurement errors after workpiece machining, under the influence of varying environmental conditions, procedures will be developed. Measurement performance and the task specific measurement uncertainty will be assessed using multipurpose material standards and workpiece replica measurement standards.

4. MEASUREMENT SETUP

As there are different manufacturing setups, there are also different measurement setups.

4.1 On board measurement tools of working machines

Some of the multi-axis turning and milling benches have additionally to the cutting tools also a measuring head that makes the cutting machine into a CMM-like measurement machine. There can be several different measurement heads but the positioning measurements are done using mostly scales or encoders. So the coordinates of measured points are calculated from readings of machine scales/encoders and information from measuring head. Scales can be influenced by temperature fluctuations, high levels of mechanical vibration and dust or particles from cutting process. The temperature related uncertainties are minimized mostly on two ways- either using a thermo-invariant material for scales or by maintaining and monitoring the environment and using the data for compensation calculations. Additional temperature-related effect is possible bending of measurement head and/or machine guideways due to temperature gradients in machine volume. For vibration control mostly air bearings are used. For protecting the scales from dust different encasings are constructed and/or the apparatus is equipped with pressurized air nozzles for cleaning the scale.[3]

4.2 Sensors

Sensors that are connected to the positioning devices can be classified either to contact or non-contact sensors.

Contact sensors have mostly single or multi stylus setups using a glass, ceramic or metallic contact surfaces with different sizes and shapes depending on measurement requirements. The sensing part can be capacitive sensor, inductive sensor, gauge with a thermoinvariant scale, linear variable differential transformer or strain gauges.

Capacitive sensors are affected by thermal expansion and change of dielectric constant. Thermal expansion is dependent on ambient temperature and dielectric constant is dependent on air humidity.

As capacitive sensor, the inductive sensor is also affected by temperature changes. Additionally accuracy is dependent on fluctuation of supply voltage and proximity of other metal objects.

Linear variable differential transformer (LVDT) is reported to be a reliable sensor setup with only one significant uncertainty source from fluctuating supply voltage. The supply voltage fluctuations are mostly caused by temperature fluctuations.

Gauges with thermoinvariant scales are affected mostly by systematic effects. The ambient temperature and temperature fluctuations during measurement are only minor issues compared to i.e. orthogonal measuring setup.

Probes using strain gauges are working on a principle in which resistance of the gauge lattice changes as the lattice is being deformed. The resistance is measured at terminals. This kind of sensor is affected by temperature as the lattice is expanding (or shrinking) due to thermal expansion effect. There are several techniques to compensate it making the sensors invariant compared to the accuracy of the sensor carrying system. [4]

The non-contact sensors are mostly using optical measurement principles, but there are some other principles as well. Optical sensor principles are mainly laser triangulation, laser scanner, photogrammetry, fringe projection, moiré projection and laser speckle that are used in the abovementioned positioning systems.

Laser scanners are affected by temperature, atmosphere and interfering radiation. The scanners are functioning correctly only in a certain temperature range. It should be noted, that the temperature in the laser scanner can differ significantly from the surrounding environment due to self-heating. As the measurement is done by propagation of speed of light, the result is affected by the change of the speed due to atmospheric pressure change, dust particles and humidity. Laser scanners are operating in a certain frequency range and if the surrounding radiation like sunlight or lightning is significantly stronger than the measuring signal the measurement result can be affected. [5]

Structured light based measurements, like fringe projection, moiré projection and laser speckle are mostly influenced by similar environmental conditions. The result is dependent on temperature, humidity and other influences that change the speed of light in environment. [6, 7]

The material of the object, its surface roughness and finishing affect significantly the optical measurements. Also tactile sensors are affected by surface texture but the effect is small and can be estimated.

5. THERMAL INFLUENCES

Temperature is one of the most important environmental conditions in dimensional measurements and is therefore mostly to be investigated. Temperature affects directly the workpiece and also measurement equipment.

It is important to understand the background and sources of thermal influences. In general thermal influences on machine tools can be classified in six basic groups as shown in the Diagram 1.

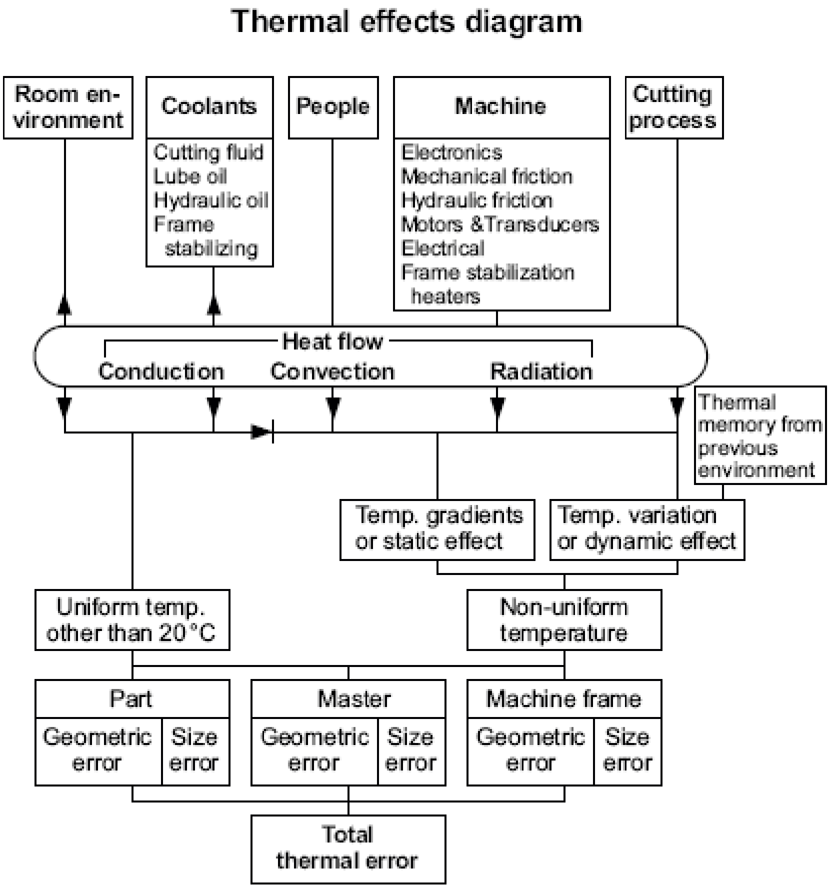

Diagram 1 Thermal effects diagram [8]

Such effects are:

- heat generated from the process,
- heat generated by the machine,
- heat exchange due to mitigating devices (cooling and heating),
- heat exchange with the environment, or
- thermal memory from any previous environment (inertia).

All these effects cause thermo-mechanical deformations and as a result inaccuracies on the machine tool and on the manufactured workpiece.

6. STATUS

The project is ongoing and the results will be available during 2015. Until now most of the work has been done in the field of researching industry and stakeholders needs. Relevant written standards regarding in-process measurements have been researched including existing standards of dimensional measurement and those under development.

The influence of temperature as well other environmental conditions have been researched for contribution to measurement errors and accuracies.

The climate chambers specification is being designed at the moment to facilitate research of different shop floor conditions influence on measurement errors and uncertainties.

The results and status of the project is available on the official project website at http://www.ptb.de/emrp/tim.html .

7. IMPACT AND BENEFICIALS

Direct beneficiaries of this project are manufacturing industries, machine tool manufacturers, machine tool end-users and standardization bodies that will exploit new standards, procedures and good practice guides. This includes a guide for evaluating the influence of harsh environmental conditions on measurement results, handbook for all the manufactured standards, guideline specifying the measurement and calibration tasks and much more.

This project will provide traceable and reliable procedures for improvement of machine tool measurement performance. It will help to overcome the obstacles related to the need for more accurate and traceable measurements. It is important to provide much needed understanding of the influences of shop floor conditions on the quality of machined parts.

In order to ensure the adoption of the results of this project, several workshops will be held, good practice guides will be published and participants will discuss the topic in different seminars and conferences. During the project developed material standards are tested in industry and the experience from these tests will be used for the handbooks and practice guides. As many of the project partners are active in standard committees, workgroups and technical committees, the outcomes will be raised for adoption in the corresponding instance.

The outcome of this JRP will not only provide technological benefits to European industries but it will also facilitate strong economic and social development. Machine tool and manufacturing industries are strong cornerstones of the European economy. In a similar manner the ability of the industries to remain competitive is crucial for maintaining living and social standards in European member states.

8. ACKNOWLEDGEMENT

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