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ENSURE SUCCESS WITH INLINE-METROLOGY

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Abstract: Inline-metrology is an important aspect in actual production concepts. The philosophy is to gain measurement data directly in the manufacturing processes and use them for an effective and fast process control and quality assurance. The goal is to increase the quality of products and the stability of processes.

Keywords: Inline-Metrology, quality assurance, process control.

1. NEW CHALLENGES FOR METROLOGY IN MODERN PRODUCTION TECHNOLOGY

The production has to meet a lot of requirements given by different sources. Short product life cycles and fast changes of product features require flexible manufacturing devices. Simultaneously the demands regarding the product quality increase. To achieve this two contrarian goals at the same time the importance of production metrology increases. Only by knowing important and relevant process parameters which have to be measured the processes can be controlled and optimized [1]. Consequently metrology is not only an element for assuring the product quality but also an economic factor and an enabler for a higher productivity.

This is illustrated in figure 1 where the added value of a production with assumed four process steps is shown in two different cases. In one case metrology is used for assuring the product quality after all four process steps. In the other case inline metrology is applied after each process step.

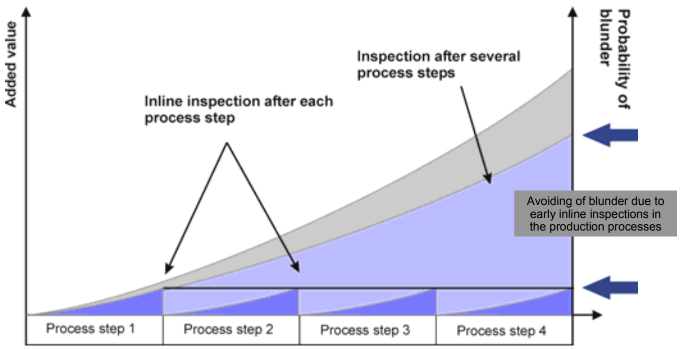

Fig. 1. Avoiding of blunder with inline-metrology

If an process error occurs in the first step this can be detected with inline-metrology immediately and blunder will be avoided by sorting out the faulty parts. In the other case the work piece will be driven through all process steps and cause not value adding work and use of resources. This simple example shows that metrology can be an economic factor when applied in an intelligent way [2].

1.1 100%-Inpection for process control and quality assurance

The philosophy of inline metrology is to gain measurement data in the work cycle and use them for instant process control and for quality assurance. With this approach changes in the production processes can be detected very fast. With immediate reactions the processes can be stabilized and the product quality increased. In opposite to the offline-metrology, which works under an ideal environment, from a metrological point of view, the inline-metrology has to work in a very rough environment caused by the surrounding manufacturing processes. Even though the inline measurements have to be full filled with a sufficient measurement uncertainty related to the given tolerances.

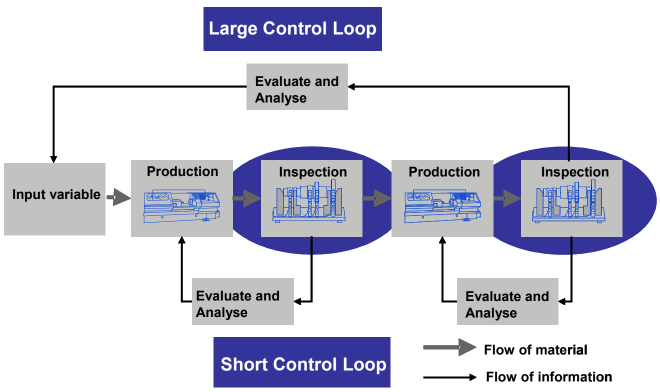

Fig. 2. Large and short process control loops

The big benefit of inline-metrology is the possibility to establish short process control loops in the production line (Fig. 2). With short control loops a direct process control is possible by collecting and evaluating measurement data close to a process step. The measurement data can for example be used for a SPC (Statistical Process Control) to stabilize the processes in a very early state of a production start. Therefore the ramp-up time of a new production start can be decreased dramatically. The consequence is that with the use of inline-metrology earnings of production start much earlier.

1.2. Strategic integration into the production planning

The described benefits can only be achieved if besides a necessary improvement of the measurement hardware the inline-metrology concept is already integrated in an early stage of production planning and layout. This includes concepts for an intelligent way of analyzing and storing the measurement data as well as a comprehensive software and interface solution to connect the metrology to the production with its CAM solutions.

2. BEST PRACTICES OF INLINE-METROLOGY

The following examples will demonstrate the productive role of metrology. These examples are chosen for underlining the general statements developed so far and for showing that the constructive contributions of metrology in production processes are worth to be taken into consideration independently from the manufacturing technologies.

2.1. Adjustment of metrology for use in the production line

If metrology is used directly in the production line it has to be considered that different precautions are necessary to avoid influences of the environment to the measurement. This can be done in a lot of different ways depending on the measurement principle. For simple sensors like strain gages this is usually not very difficult. But also automated and complex measurement devices like CMMs can be used for inline-metrology. In this case much more sophisticated adjustments have to be done [3]. This includes the hardware (Fig. 3) as well as improvements to the software and the user interface as the typical user changes from the metrology specialist to the normal worker.

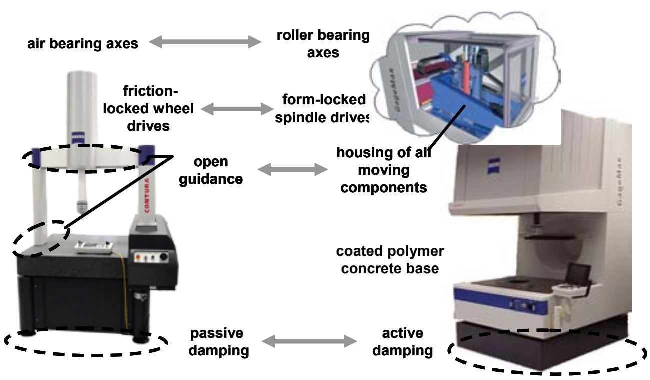

Fig. 3. Comparison of a standard CMM with an inline CMM

The changes to the hardware basically protect the CMM from the environmental influences like high temperature, dust and vibrations. This is done by housing sensitive parts of the device like the axes. It prevents mainly dust and dirt but also reduces the influence of temperature changes to the CMM. Especially to lower the temperature influence different materials like ceramics are used for the inline CMM which are much less sensitive to temperature changes.

To avoid influences from surrounding vibrations an active damping system can be used. Additionally the probing system matters as scanning probes are much less influenced than conventional touch probes because of their filter characteristics [4].

2.2. Real-time in-process measurement

The CMM is an example for an automated and very flexible inline-metrology system. The measurement is usually accomplished after a working step or during an interrupted working process. If the Inline measuring technique is used for direct process control on the processing machine and during the work, it is called in-process measurement.

An astonishing example is the in-process measurement of a polishing process for optical surfaces. A measuring procedure, determining the quality of an optical surface during the work, was for the first time realized by iTIRM (intensity detecting Totally Internal Reflection Microscopy) developed by *Fisba Optics*. It permits the indirect determination of quality relevant parameters for characterization of the glass surface.

Glass surfaces disperse light even if they are in a good polishing condition minimal by Sub Surface Damages and micro roughness such as microcracks and scratches. If the surface in total reflection is illuminated, then the light is dispersed due to these surface irregularities from the material and the intensity is reduced to approx. 1:1.000.000.

The measuring procedure detects the change of signal due to this dispersion and correlates the measured intensity with a measure for the polishing degree of the surface (Fig. 4). The condition of the surface is determined over roughness differences in the sub nanometer range. The described correlation of the dispersion to the surface quality results from a parametric allocation and an experience-dependent process knowledge.

With the measuring procedure it can be determined without an interruption of the working process whether the desired surface quality is already reached or not. Thus the polishing process can be stopped immediately. At this stage a longer polishing duration wouldn't improve the surface quality substantially, so that the polishing duration can be reduced by approx. 12 % and usage of material and tools can be saved (Fig. 4, bottom).

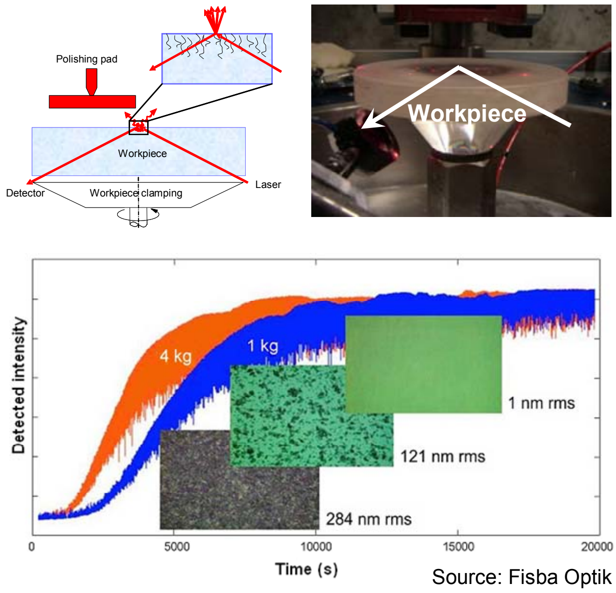

Figure 4: Working principle and correlation between the stage of polishing and detected intensity

With this in-process measurement a lot of time consuming off-line measurements can be saved. Simultaneously the process can be optimized and the product quality can be increased.

2.3. Improvement of a bearing manufacturing

The following example shows in an apparent way how an intelligent way of applying metrology inline can directly both improve the product quality, and deliver an obvious benefit to the productive output. It demonstrates that metrology is not only used for observing the product quality but gains additional information about the process itself.

The automotive industry nowadays is characterized by increasing demands for quality requirements concerning the product. The dimensional accuracy attained a high level due to the fact that in the last decade some technical specifications demand tolerances to be tightened by one magnitude. Consequently production and inspecting facilities to be adjusted too. In this context an illustrative application for this is the measurement of bearing sets of crankshaft bearings. This is a very challenging application as the tolerances to be measured in large lot size are about a tenth of a micrometer. The gauge and profile of bearing seats for crankshaft bearings have to be measured contactless in order to classify them depending on their actual size. This measurement task has to be performed directly in the production line due to the fact that a 100% inspection is required, as the measurement result is needed for the following manufacture process. Therefore the information gained by the metrology is an essential input for the production, and a powerful data source for the quality inspection as well.

The size of every bearing set is measured inline. First, a decision is made as to whether the dimensional characteristics conform to tolerance requirements. Then all bearings that meet the tolerance requirements are being sorted into ten classes (Fig. 5).

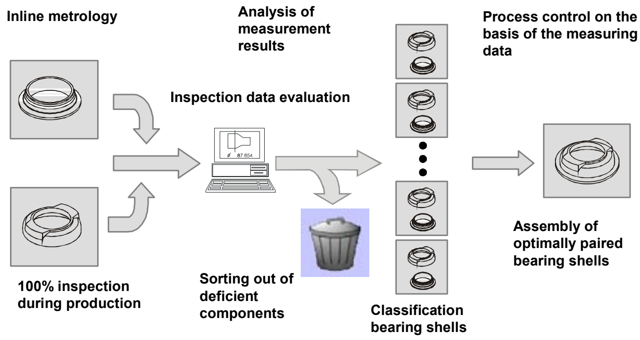

Figure 5: Using measurement results for process control

That means the metrology is not only assuring the production process in testing conform or not conform but also gaining additional information about the process and the manufactured bearing sets. In the following process step this information is used to improve the quality of the mounted crankshafts by combining the half-bearings which fit optimal to each other depending on their tolerance class.

Technically this application may be realized by using a linear capacitive sensor system. The components slide in a rounded chamber through the measuring plane that consists of two opposite sensors with exactly aligned measuring axis. The electrodes are adapted to the bearing (Fig. 6). For automatic calibration of the linearity a reference part is inserted in the measurement device and fixed at the designated measuring position.

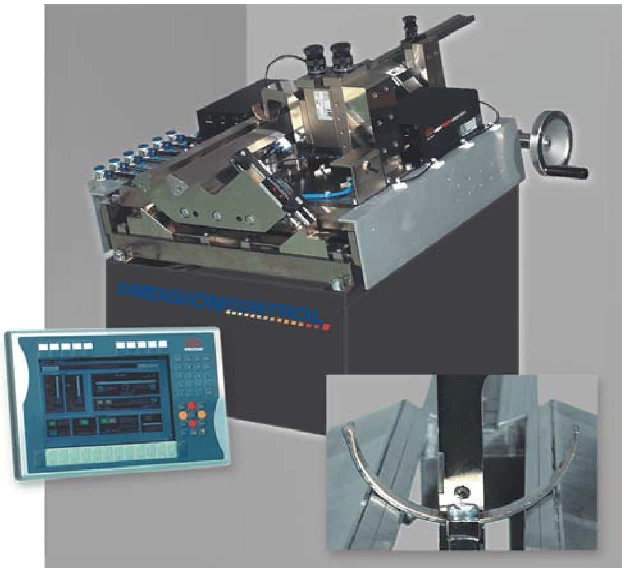

Figure 6: Measurement system with a detailed view of the air slide (Source: Micro-Epsilon)

The part inside the measuring chamber is pneumatically moved towards the sensor axis and thus performs an automatic self–linearization. The system can measure dimensional changes of the bearings up to 100 µm with repeatability higher than 0.2 µm and a sampling rate of 10 kHz.

In this example the applied metrology fulfils three functions:

1. Parts that do not fulfill the required specifications are rejected and excluded from further processing.
2. The information from the inline metrology is fed back to the production process. An established control loop reduces the long term stability requirements of the production. The benefit can be estimated by the potential costs of an alternative manufacturing process that fulfils the long term stability requirements.
3. Parts that are within the specification are sorted into classes. The selection by pairs is the only technical possibility to achieve the desired quality, since the established manufacturing process has been optimized up to its physical limits. Consequently the metrology is an enabling technology. Its benefit can be calculated directly from the product value.

This system illustrates a very obvious example for Productive Metrology, where the gained information is used in its best possible way.

2.4. Metrological aided process chains

Forming and dish tools are subject to high wear, which is retarded preventively over wear-protection layers. To be able to apply wear-protection layers several operations are necessary such as tool preparation, manual and/or partly automated deposition-welding as well as numerical control programming for the roughing and finishing with the milling machine. This is usually very time consuming. As a result the tools and machines cannot be used for a long time and therefore high costs of the tool repair occur.

Beyond that, the machining results can in particular exhibit strong differences in their quality from manual deposition-welding. At the Fraunhofer IPT a new concept, an automated repair manufacturing cell (OptoRep) was developed. It covers the entire process chain for the repair of the tools, with measuring the worn tool, target actual data alignment with the surface data of the brought in tool and the numerical control data generation for the laser powder coating as well as for the milling's treatment on a machine. The total concept is supposed to save time of at least 20% in its last stage of development in comparison to the conventional repair process of depth tools.

The measuring technique is a substantial component of the process chain. It delivers the necessary process and product information for realizing the automated repair process. The system-dependent characteristics of the optical data acquisition affect them favorably. Both the planar and above all the fast digitization and the flexible possibilities of integration qualify optical sensors. The quantitative collection of the tool topography takes place in "OptoRep" with a scanning triangulation sensor, which was integrated directly into the spindle of a 5-axes milling machine (Fig. 7).

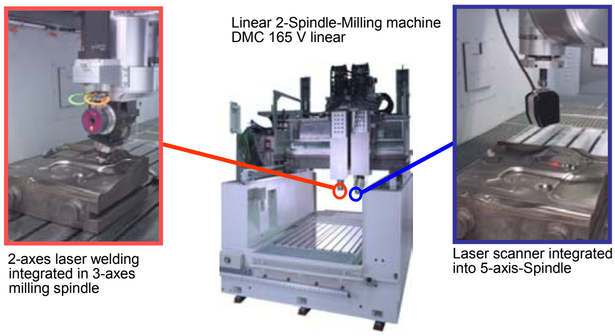

Figure 7: Automated repair manufacturing cell "OptoRep"

With this laser measuring system it is additionally possible to program CAD-based measuring strategies directly in the CAM-system. The goal is to detect worn parts at the tools with the measurement system and to measure the topology of new tools. Thus both sub ranges and the entire surface topography can be evaluated. The acquired data form the basis for the following process steps. This can be a comparison of nominal and actual values with the original CAD data of the tools, in addition, a reverse engineering process, which leads back the digitized surface into a mathematical CAD surface.

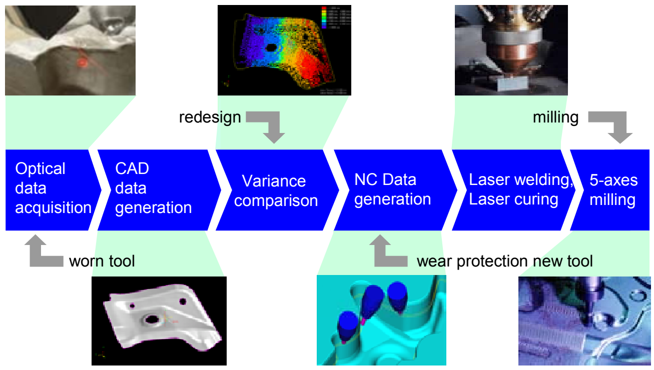

Figure 8: Process chain of "OptoRep"

With the gained model NC data can be generated in order to repair the tool by laser welding or laser curing (Fig. 8). The whole process chain is completely automated with standardized interfaces between the components. In comparison to a manual repair procedure a lot of time can be saved and therefore the whole process is much more efficient and profitable.

2.5. Automated door assembly

In the modern production technology robots are used for increasing the productivity by automating processes. This can by done very good for processes where exactly the same movements have to be repeated a lot of times. A typical example is a pick-and-place task. In this cases the reproducibility of the robot-positioning is the limiting factor. The absolute accuracy and the flexibility are not so important. For complex processes like the assembling of instable work pieces the use of robots is instead usually difficult. In this case an intelligent measurement system can give a solution.

The automated door assembly is an application which was hardly automated until today, as the positioning of the door towards the car body could not be acquired and evaluated enough. A robot-supported mounting system with optical sensors and BestFit evaluation makes this automation now possible.

The modular developed BestFit concept is based on a sensitive robot, which measures the position of the door relative to the car body with optical sensors and determines an add-gap-optimizing positioning (Fig. 9). In this way an optimal accuracy can be reached for every assembled car. Thus the manufacturing tolerances up to 0.2 mm can be meet optimally. The procedure is flexible and can be used for the assembly of different car-body parts and also with changing motor vehicle types.

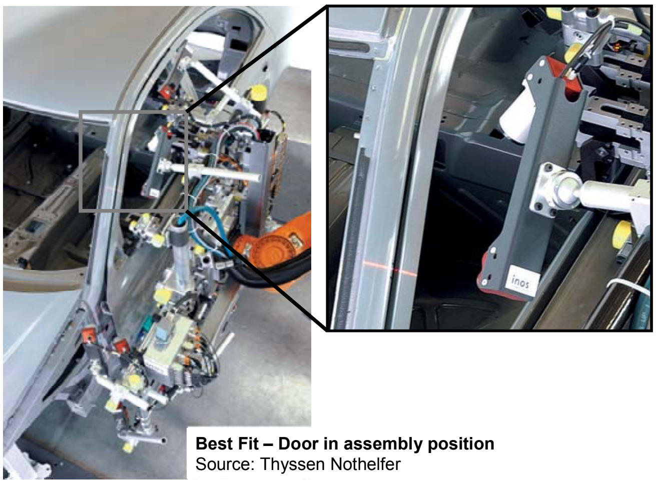

Figure 9: Automated door assembly with robot guided inline metrology

The BestFit process procedure exists of several single steps, which end with a closed quality control:

- Robot moves the door to the car body into reproaching position
- Sensors at the robot gripper determine gaps and distances between car-body and door
- The robot is readjusted on the basis of the determined values to the Best Fit position
- The door will be moved into the installation position
- The reached position is controlled by the sensors
- Door is installed in the determined position in the car body
- After the installation the obtained accuracy is measured (100% quality control)

This innovative system can be extended to other applications in the car-body assembly (engine hood, tail cover) and also for applications in the final assembly (e.g. panel installation). Substantial cost advantages arise as a result of the simplified, space-saving mechanical structure of the overall system particularly in case of planning of production line and less in the case of the re-equipment. Thus the steel structure for stationary sensor engineering can be avoided. The positioning of the car body can be done roughly as the assembling of the door is completed after the BestFit-Step of the door and the car-body. Therefore the costs of the ground clamping technology are reduced significant, since the car body can be positioned "inaccurately". An absolute defined point of reference over the car body is not necessary with this system anymore.

3. The future of the production metrology

The examples given above show solutions where metrology enables the production to be much more efficient and productive. Today these solutions are adapted to the given tasks and challenges of the production. Therefore they are highly specialized and especially optimized for a given problem. The future of the metrology will be in developing highly sophisticated solutions. But this metrology has to be much more generalized and adaptable for changing tasks.

The future of the production metrology will also be connected very close to production technology itself. As for the production the same general problem exists.

3.1 Production technology polylemma

The production technology today can be characterized within two dilemmas. The first one is the fact that production is either scale or scope orientated (Fig. 10). In a scale orientated production the goal is to achieve the highest benefit by a high scale. In other words the goal is to increase productivity just by increasing the overall output of products.

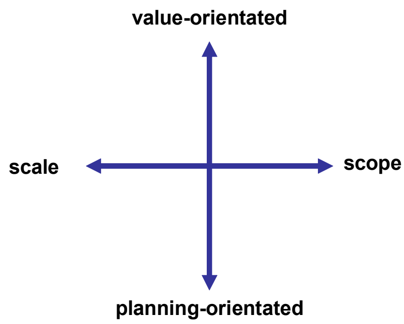

Figure 10: Polylemma of production

Scope oriented productions try to maximize the added value of the single product by manufacturing much more sophisticated products. The other extremes of productions today are the planning-oriented and the value-stream-orientated approaches. Planning-orientated production can be characterized by the use of sophisticated, investment-intensive planning systems and production systems. In opposite to this, simple and robust value-stream-oriented process chains are used. This is usually the case in low-wage countries. In future the production technology has to find solutions to solve this polylemma.

3.2. Consequences for the metrology

These tendencies will also have an impact on the metrology. The development and description of models for the integration of modular measurement on demand concepts will allow easy plug & play integration of predefined metrology objects into the line of assembly. This will generate a flexibility for assembly systems which leads to an adaptive assembly according to demand, component properties and capacities. One major research will be modular measurement on demand methodologies. Therefore augmented measurement concepts have to developed, which expand the idea of augmented reality.

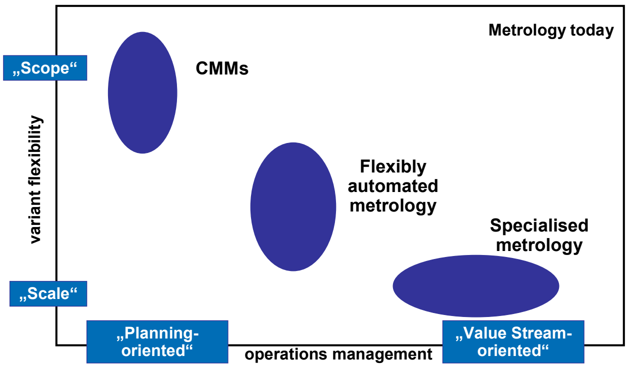

Figure 11: Metrology in the production today

Nowadays measurement technologies cover specific fields of production metrology. Metrology is either scope or scale-orientated and planning- or value-orientated (Fig. 11).

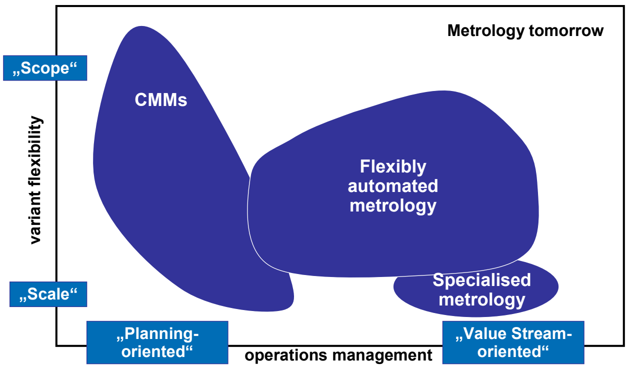

Figure 12: Using measurement results for process control

In future the metrology has to be more flexible and modular so that the measurement technologies can cover a bigger variety of applications (Fig. 12). The metrology cannot be the bottle-neck of the production for dissolving the dilemma between planning-orientation, value-stream-orientation, scale and scope. To achieve these goals different activities have to be done. The hardware and software of measurement systems have to be developed further on. But also new education concepts have to be established that the knowledge about the economic role of metrology is spread into other areas of the production. Overall metrology can play a key role in modern production concepts and be an enabler for an economic growth. This concerns single companies as well as the producing industry over all.

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