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USER REQUIREMENTS IN OPTICAL AREAL SURFACE MEASUREMENTS ON THE DEVELOPMENT OF AN ASSISTANCE SYSTEM

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Abstract: Optical procedures for surface metrology enable an improved inspection of product properties based on plane-oriented parameters. Yet, users in industry still meet many difficulties concerning the application of the new procedures. Thus, in the cooperative project OptAssyst an assistance system is developed to support the performance of surface measurement tasks with optical procedures. To define required support by the system, a user needs analysis has been conducted and typical problems of practical application have been identified.

Keywords: Optical surface metrology, Assistance system, Advanced vocational training, User needs analysis.

1. INTRODUCTION

Precise knowledge about the geometrical properties of manufactured goods enables an efficient and sustainable manufacturing. Thus, manufacturing metrology is an important contributor to more resource-saving technology and green development of engineering. Besides the inspection of fitting-related features based on measurements of length and geometrical tolerances, information about surface properties become increasingly important – especially when regarding friction or wetting behaviour of functional surfaces. It considerably influences the durability of a material as well as the degree of efficiency of moving parts and thus the need for energy during the application of the inspected product.

Conventionally, surface properties are judged based on a single, linear profile detected by tactile methods. But the rapidly developing optical methods now also allow time efficient evaluation of plane parameters, enabling to gather more information about the inspected piece and the performance of measurements that hitherto were impossible due to the required time for the measurement or the danger of damaging the surface by the stylus. A typical example for such a surface measurement task, that can only be performed optically, are thermally highly stressed cylinder walls in internal combustion engines: the efficiency and hence gas consumption with resulting CO2 emissions as well as oil consumption of a combustion engine depends strongly on the properties of the specifically designed surface of the cylinder bore. For the assessment and evaluation of such a micro-structured surface, the conventional two-dimensional profile method is no suitable option. Rather, for a meaningful assessment it is required to capture the three-dimensional surface. Similarly high demands also can be found in many other applications where special requirements exist regarding surface properties, such as in the production of joint prostheses in medicine or roller bearings, which are used in all kinds of machines as well as in many everyday devices and by their friction coefficient directly influence need for energy. Thus, a reproducible performance of surface inspections is directly related to environmental impact of many products.

For the performance of surface inspection, the operator requires profound knowledge about the underlying measurement method and a considerate approach to planning, implementation and evaluation of the measurement enabling optimal decisions adapted to the demands of the specific task at hand, e.g. regarding the setting of device parameters or the determination of required operations for data evaluation. The definition of the measurement and evaluation strategy can significantly influence the obtained measurement result. As in industrial application the gathered data is typically used for production control, ill-conceived results bring forth faulty decisions that ultimately lead to the production of sub-standard products. Thus, it is necessary to support the metrologist during the execution of optical surface measurements in order to facilitate reproducible and traceable results.

2. OUTLINE OF PROJECT OPTASSYST

The metrologist often needs a deep understanding of the principles used by the applied optical sensors and the evaluation procedure for gathered data, to set parameters adapted to the task at hand and to be able to interpret the measurement results correctly. Thus, the employee should be adequately trained for the job. Yet, for difficult tasks, this may take a lot of time and thus cause problems for the company, if an employee is away from work for a long time. Also, in optical metrology knowledge and guidelines for best practices are evolving fast. Thus, knowledge gathered by a training measure, e.g. provided by the manufacturer of the measuring machine, is likely to be incomplete soon, or even obsolete.

As an amendment to conventional training, a work-place integrated assistance system can be used. It shall provide the necessary support to define an appropriate measurement and evaluation strategy, covering especially the configuration of adequate parameters for the performance of function-oriented, reproducible measurements. To this aim, the project OptAssyst was established to develop an assistance system to support the performance of optical areal surface measurements [1].

To effectively and sustainably assure the correct conduction of measurement, it is necessary to combine both components, i.e. measures of active and passive support. Thus, on the on hand, immediate assistance should be offered during the actual performance of measurement task to avoid errors, i.e. deviation of existing standards, and facilitate an efficient workflow and a well-reasoned measurement strategy. On the other hand a sufficient basic qualification of the metrologists has to be provided, to enable the user to fully understand advice given by the system and thus apply it correctly to their tasks. Also, they have to be able to detect circumstances where exceptions are recommendable. Otherwise, a purely active system providing immediate help without supporting fundamental understanding, leads to "dependency" of the user on the provided support, which may result in faulty, over-generalized actions. Thus, by a holistic approach in the set-up of the assistance system, including active and passive support, the reproducibility of measurement results can be improved on short term as well as on long term, even in an area with continuous, rapid development, such as optical metrology.

3. DESIGN OF A SUPPORT FACILITY FOR OPTICAL SURFACE METROLOGY

Until now, in product and process development as well as in quality control during production, mainly tactile devices are used to measure workpiece geometry. In applications with micro- or nano-structured surfaces, these measuring systems are not suitable, because of the morphological filtering effect of mechanical probing as well as because of the abundant measuring time. Especially the inspection of geometric structures with high aspect ratios, which occur on components in micro system technology, or of surfaces where a plane-oriented assessment is required, is very difficult with tactile methods. Thus, the use of optical methods is increasing, e.g. based on white-light-interferometry or confocal microscopes, enabling a vertical resolution of only few nanometers.

In other fields of metrology, various solutions are explored to support the performance of complex measuring tasks, aiming to minimize operator influence on measurement results and improve the reproducibility and repeatability of the measurement results.

A classical approach is the creation of training and continuing education courses to teach basic knowledge required for the planning of measurements and the definition of a suitable measurement strategy (e.g. [2-5]), in addition to training offered by the manufacturers focusing on how to operate and program the measuring instruments. But, since the training generally is separated from the execution of the actual measurement, the participants have to apply the newly learned principles to their specific measurement tasks on their own later on. This demand may cause problems, when complex constraints have to be considered. In addition, the imparted knowledge may become obsolete quickly due to the rapid evolution of measurement technologies. As a result, despite the formation of metrologists erroneous decisions may occur e.g. if standards change or measurement practices and recommendations are transferred to another principle without a thorough and critical review. For optical surface metrology - in contrast to more mature and well consolidated fields, such as tactile coordinate metrology - thus there are no comprehensive, standardized training programs. So far, only small training units focused on specific topics are available which enable at least the introduction of users to new technologies in application. Still, for the specific and very high demands of optical surface metrology, the training of an operator without further support cannot be considered as an adequate solution to assure reproducible measurement results.

As opposed to the qualification of employees, by which they shall be enabled to perform complex measurement tasks, more and more active assistance solutions are implemented. They are designed to simplify the proper performance of the measurement task, thereby reducing the demands on skills of the employees. Most of the so far presented solutions attempt to minimize the influence of the operator by a high degree of automation of the measuring process and by a rigid guiding throughout the whole task. As a fundamental development paradigm, the greatest possible reduction of operator action and decisions is considered, aiming towards fully automated, computerized planning, implementation and evaluation of measurement. For this, it is intended to model the entire system of measurement (measurement process, influences from the environment, etc.) and then optimize it based on established criteria (e.g. [6-9]). This approach allows for designing the execution of the measurement by understandable and reproducible analyzes, e.g. setting of instrument parameters, which in conventional measurements usually is planned by the operator based on empirical knowledge. This enables a more efficient planning and execution of measurements, since time-consuming and not always successful attempts to find the best solution can be eliminated. The operator then performs the measurement in line with the recommendations determined by the assistance solution. Thus, the training time required for the applied instruments and the necessary qualification of the staff is reduced, which make up a significant cost factor in industrial application.

But as a sincere drawback, the creation of such a model of the measurement system is time-consuming and complex. Due to the rapid development of instruments and sensors in optical surface metrology, it may well happen, that measurement solutions already are used in industrial practice, but no corresponding offer of comprehensive support could be developed. If the operator has been supported by an active assistance system on previous measurement tasks, it was not possible to collect experience in the design of complex measurements in general. Thus, the initial operator qualification is very low considering the high requirements and there is no knowledge to be transferred to the new task. As an additional aspect, it has to be considered, that if an employee does not understand the recommendations of an assistance system, it is very likely, that the proposed solution will not be implemented optimally or even will be deliberately ignored [10].

In order to combine the specific advantages of a sound basic education with the direct support of an assistance offer, for the topic of form measurement a workplace-integrated assistance system developed with additional information elements has been developed [11]. The operator is assisted in the systematic processing of the measurement task as well as in the definition of relevant criteria for measurement strategy in conformity with standards and best practice recommendations. However, with the developed methodology no support is possible for decisions with very complex parameter constraints, which are not supported by common definitions, standards and guidelines.

Following, none of the already established approaches can be directly used to provide a suitable assistance system for optical surface metrology, as it has to provide an effective solution to support the metrologist with the planning, implementation and evaluation of measurements implementing procedures with very little recommendations established in standards or guidelines and steady development. Rather, an integrated assistance system has to be developed that includes different elements of the analyzed approaches in a suitable combination. Thereby, support for the operator can be provided that combines direct assistance for complex measurement tasks and general guidance by information as a base for the independent, verifiable solution of new problems.

4. ANALYSIS OF REQUIRED CONTENT

The planning, implementation and evaluation of measurements using optical methods often is a big challenge for the user. While in the area of tactile measurement already well-established standards and extensive experience, knowledge and guiding principles as a base for the implementation of measurement tasks are available and thus reproducible and traceable measurement results can be obtained, these basic conditions are not met in the field of optical surface metrology. In particular, it is problematic that currently there is no complete set of standards for plane-oriented specification of surface properties available. The leaves of ISO 25178 "Geometrical Product Specifications (GPS) - Surface texture: Areal", in which the various parameters associated with specification operators, proposed inspection methods and requirements on the utilized measuring instruments etc. should be described, are mostly still in draft form or have not yet been released at all.

Accordingly, the user has to take many decisions in own responsibility during the execution of such measurements. Various resulting problems have been identified from the experiences of typical users from industry joining the project and the results of research partners working actively on the definition of suitable measurement strategies. The identified aspects were structured into four categories according to the underlying working process.

Interpretation of specifications in drawings and definition of measurement strategy

Even by optical instruments which enable a plane-oriented data acquisition, mainly line-based characteristics are determined, amended by those areal parameters that represent a direct transfer of established 2D-characteristics on a plane-oriented analysis. Considering on contrast specifically defined areal characteristics, there still are significant information deficiencies and, accordingly, reservations towards their application. As so far a regulation in standards is still missing for the description of surface property specifications, it is often unclear which specification operators are assigned to the given areal characteristics. This is an especially serious problem since – on contrast to 2D-characteristics – there often are no default regulations for properties needed to define the measurement strategy.

As a result of these problems and lack of information in the interpretation of the technical specifications, ambiguities exist for the determination of the measurement strategy. As an example among other requirements, for the planning of the measurement an appropriate measurement field and a sufficiently high number of detected measurement points have to be chosen. Currently, however, it is still arguable, which variables have to be considered and what requirements can be derived from them.

Preparation and implementation of the measurement

It is reported to be difficult to plan in advance the set-up of the measurement layout and the measurement device. Following, difficulties appear also regarding the comprehensive documentation of settings applied during the performance of a measurement, impeding the reproducibility of gained results. This concerns particularly the determination of an appropriate positioning (distance and angle) of the measuring object relative to the lense and the choice of settings for the applied lighting. These parameters are often chosen according to personal discretion based on judgment of the recorded image. The underlying criteria as well as the ultimately selected setting cannot always be described explicitly, thus making it difficult to repeat the measurement and limiting the reproducibility of the results.

Evaluation and interpretation of data

Regarding the evaluation of gathered measuring data, firstly there are difficulties in adopting appropriate parameters for the evaluation, e.g. for selecting the operational characteristic or the filter type. Here again, many uncertainties are caused by the fact that so far there are no recommendations and default values in standards available. Additionally, it is even unclear which regulations are given at all in standards and which parameter settings would be appropriate. Yet, by applying different filter characteristics, significantly different results can be generated out of the same set of measurement data. Furthermore, differences also occur in the evaluation of a measurement data set by different software due to varying design of the established algorithms.

Secondly, when interpreting the results, there also occur problems, especially regarding the comparability with conventionally tactile gathered results. In addition, currently there is a lack of experience and empirical knowledge that would enable a plausibility check of the obtained results. In particular, the graphical representation of the calculated object surface could be used to identify and subsequently correct possible weaknesses in the definition of the measurement strategy as well as the implementation and evaluation of the measurement, if typical patterns are known that might hint towards an improper alignment or positioning, the influence of vibrations, too low density of measurement points and similar problems.

This unsatisfactory situation results in a limited usability of areal optical surface measurements, as they are often not used for conformity inspection testing compared to given specifications, but only self-referentially, i.e. not as traceable information about geometrical properties, but merely as an indicator to ensure stable properties.

Acceptance test and calibration of instruments

For this aspect of the measurement task, there is a lack of information about available artifacts for calibration and inspection of measuring devices and about their respectively envisioned use. In addition, the aforementioned points are especially relevant for the implementation of measurements as part of calibration activities, as errors, insufficient documentation and reproducibility of the applied measurement procedure also affect measurements conducted later on. Yet, it has to be considered as particularly problematic, that the capability and properties of measuring instruments are often described differently by different manufacturers, and there are significant differences between the respective procedures for these parameters.

Overall, there have been identified quite a number of problems currently existing in the industrial application of new optical and plane-oriented procedures for surface inspection. Based on this analysis, an efficient workflow for the execution of a measurement task has been described and the necessary content and activities of the assistance system have been identified.

5. SUMMARY AND CONCLUSION

Regarding the current state, as results there are now on a collection of typical influence factors on the results of areal optical measurements as well as a systematic description of problems arising during the planning, implementation and evaluation of the measurements. Also, relevant constraints of the later application of the intended system in industrial practice have been described. From the combination of these three dimensions of requirements on a suitable support by the assistance system, a workflow for the measurement task together with desired actions by the assistance system has been derived. This concept for a prototypical system was presented to industry partners and has been accepted as a suitable basis for further development. Based on this abstract description of the intended assistance system, a prototype will be developed, implementing support for the most crucial problems. Then, the validity of the assistance system can be evaluated by checking its effect on the reproducibility of measurements.

Thus, the currently existing problems during the performance of measurement tasks in optical surface metrology in industrial application can be reduced, supporting on long term the spreading of this method in order to facilitate precise knowledge and the subsequent optimization of highly-stressed surfaces.

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