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TACTILE-OPTICAL MICROPROBES APPLIED TO DIMENSIONAL MEASUREMENT AND EVALUATION OF MICROFEATURES

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Abstract: The miniaturization of parts and components and the growing demand for more accurate measurements have led to ongoing development in the field of dimensional metrology. The development of new sensors mounted on coordinate measuring machines, has enabled metrologists to handle dimensional engineering challenges. Probing systems that combine mechanical and optical principles and provide three-dimensional information about micro-scale features in micro- and meso-scale components are outlined in this paper. Real application cases are reported and their practical issues discussed under a metrology view.

Keywords: Microprecision Dimensional Metrology, Multisensor Coordinate Metrology, Tactile-Optical Probes.

1. INTRODUCTION

Scientific and industrial metrology developments need to be closely related to ongoing trends in production processes and their products. Factors such as the increasing demand for more efficient, economical and robust mechanical parts have led to commensurate progress in product dimensional engineering. Particularly, it has been observed the growing trend towards miniaturization of parts, components and their geometries and more accurate measurement [1]. Coordinate metrology as a multipurpose and an efficient measurement technology has been widely used in the industrial sector, and thus deserved considerable efforts to extend its capabilities to new engineering needs impelled by the market.

Classical probing systems attached to most coordinate measuring machines find two major problems when micro-geometries need to be evaluated. The first is related to the size of the stylus tip, technically limited to several tenths of a millimeter. That makes impracticable measuring internal geometries with sub-millimeter size. The other constrain is linked to the contact force applied to collect the measuring point, which may damage the part surface during probing or even when clamping the part to avoid physical movements.

The use of optical techniques in coordinate metrology, based upon high-resolution CCD camera integrated to an image processing unit, has shown productive to inspect 2-D features. Several metrology equipment suppliers provide coordinate metrology equipment that use optical methods to sample the workpiece surface. The specific advantages over classical probing systems are the reduced measuring time of the points of concern, although the evaluation time might be even greater, and the contactless attribute, which makes possible inspecting materials easily deflected and distorted by physical contacting.

However, optical measuring sensors could not be the right choice for complete dimensional characterization of holes, tapers, and other inner geometries. Spray holes of injection nozzles, spark plugs holes and micro-turbine holes are some examples of parts that require different approaches to measuring their characteristics and evaluating functional parameters (e.g., bore surface cylindricity, perpendicularity of a bore axis related to a datum frame). The combination of optical and tactile measuring principles in a single sensor has been observed in recent developments, the so-called tactile-optical measuring probe [2,3]. Tactile-optical probes have been made available for some years on commercial multisensor coordinate measuring machines.

Significant efforts have been undertaken by the Institute for Technological Research of the State of São Paulo - IPT to redefine their capabilities in dimensional metrology. For this reason, innovative measurement technologies of high intrinsic value have been gradually introduced and offered to the market. Microprecision dimensional metrology is a field that has received considerable investment in an attempt to provide appropriate metrology solutions to already-known market demands and even to nowadays unknown demands.

Just to name a few applications cases to be covered by the new laboratory, one can mention the measurement and evaluation of features in: (a) micro-gears and micro-threads found in mechanical parts, and medical and dental devices; (b) orthopedic and dental implants; (c) stents; (d) cutting tools; (e) electromechanical micro-systems; (f) delicate parts such as contact lenses and woven fabrics.

In this paper, the first measurements performed on multisensor coordinate measuring machines outfitted with the tactile-optical sensor for 3-D measurements and tactile-optical sensor for contour and roughness evaluations. Real application cases are outlined, some of them that could be evaluated even by classical measuring methods, which could enable comparing the methods and results.

As a whole, the macro expectation of this work is to establish the potential applications of that new branch of the laboratorial and industrial metrology, i.e., microprecision dimensional metrology. In fact, microprobes mounted on high accuracy multisensor coordinate measuring machines could be potentially used to many other situations than those that driven the development of tactile-optical probes.

2. TOPICS OF CONCERN

Measurement of micro-features on parts and components from a few millimeters to the micrometric range (micro-parts) or even of macroscopic devices with sub-micrometric uncertainties requires new measuring techniques on accurate coordinate measuring machines, conceptually similar over the years, but with progresses in their mechanical stiffness and thermal stability over time.

The 3-D tactile-optical measuring sensor, the so-called fiber probe, illustrated in Fig. 1, is based on a tiny glass contact tip down to 0.02 mm diameter on the end of an optical fiber. The ball is illuminated through the fiber and the probe tip contacting is checked by a CCD camera. The actual measurement of the position of the stylus ball is carried out by an image processing sensor integrated to the system. The deflection of the shaft is therefore not included in the measurement result [4]. Since there is no need for stiffness, the fiber can be made very thin, and the contact force is therefore only in the micronewton range.

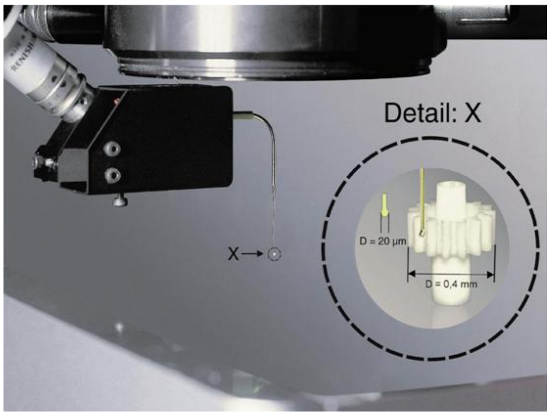

Fig. 1. Tactile-optical sensing system - the so-called fiber probe - for measuring small parts and features [Courtesy: Werth Messtechnik GmbH]

The tactile-optical sensor for contour measurement shown in Fig. 2 combines a contact tip with a laser distance sensor. The measuring sensor detects the contact probe deflection in compliance with the comparator principle. The integration of the tactile-optical contour sensor on a multisensor coordinate measuring machine allows fully automatic contour measurement in a large volume and in the workpiece coordinate system. The sensor is capable of measuring surface contour and roughness in any direction on a plane or even on curve surfaces

Although acceptance and reverification tests for classical coordinate measuring machines are specified in ISO 10360, VDI/VDE 2617 and ASME B89.4, it is not trivial extending the methods to multisensor coordinate measuring machines for micro-features. Special parameters which describe the measuring sensor behavior, such as the measuring force and the force-induced deformation, cannot be extracted from well-known methods. Reference measuring standards have been conceived and patented [5], which enable determining metrological attributes of the measurement system under particular conditions.

Workpiece measurements, even in a reference metrology laboratory, would involve the interaction of the measuring equipment with many other influence quantities, especially those attributed to the object under scrutiny. The material, shape and key features of the workpiece, for example, may result in operational and metrological issues that need to be considered when defining and confirming the measurement process.

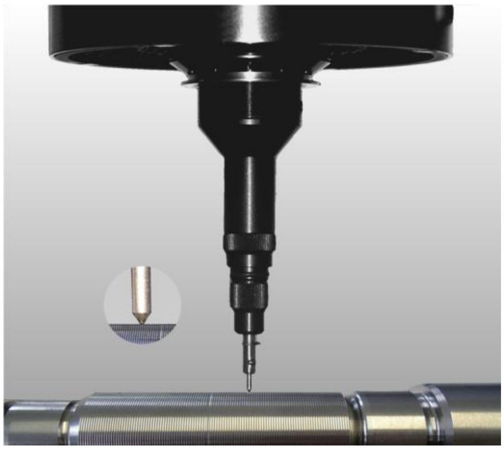

Fig. 2. Tactile-optical probe for measuring roughness and contour on general purpose parts [Courtesy: Werth Messtechnik GmbH]

The studies proposed in this paper are restricted to the operational and metrological evaluation of the 3-D tactile-optical measuring probe and the tactile-optical sensor for measuring contour and roughness by contacting or not the part. Both sensors are mounted on multisensor coordinate measuring machines capable of inspecting small linear sizes with uncertainties down to 0.25 μm.

3. PRELIMINARY RESULTS

The 3-D tactile-optical measuring sensor could operate in two modes. If the glass fiber supplies light to the probing tip, measurement can be performed in the self-illuminating mode, which is indicated for measuring blind elements. It is also possible to use the sensor in the transmitted-light mode, which uses the optical system of the coordinate measuring machine and ensures illuminating the part from the bottom.

The fiber probe applies a negligible measuring force. For this reason, the fiber probe can measure especially contact-sensitive workpieces made of rubber and plastic in point-to-point measuring mode and scanning mode. When measuring aluminum and some plastic parts in the horizontal direction, adhesive forces may be observed between workpiece surface and probing element. Some tests have revealed that measurements performed in the vertical direction are less sensitive to the effect of intermolecular attraction between components. The measuring sensor also contains a vibrating system to attenuate the adhesion effect.

Let the use of a contact tip of 0.05 mm diameter, the measurement of tiny gears with 0.12 mm module and 2 mm nominal diameter has been made possible. The measuring sensor, however, cannot measure very deep holes. In spite of the nominal length of the glass fiber wire is of about 40 mm, the effective measuring distance from the top of the surface is restricted to a few millimeters.

The tactile-optical sensor for measuring contour and roughness allows the evaluation of linear, angular and circular features in contours, as well as the roughness evaluation in circular sections or free-form sections. The working principle is similar to that observed in articulated measuring arms, with a counter-balancing mechanism at one end for adjusting the measuring force.

The linear tactile-optical sensor, due to the constructive characteristics, does not enable evaluating bores and tapers; on the other hand, the laser-based roughness measurement with a tiny contact tip on curve surfaces is a substantial advance in comparison with bench-top roughness measuring instruments (they cannot measure curve surfaces).

4. DISCUSSION AND CONCLUSION

Metrology needs directly related to component and part miniaturization, have been partially answered by developing new measuring sensors. Improvements in machine hardware and software have been also relevant to achieve a suitable metrology solution. Regarding the matter of this work, the tactile-optical sensors have shown essential elements which make possible continuous development and improvement of microprecision dimensional engineering.

The very small sizes of the sensors and their features of concern, i.e., negligible contact force and scanning mode capability, combined with multisensor coordinate measuring machines, allows direct measurements of micro- and meso-scale structures with uncertainties down to a few tenths of micrometer.

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