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A Novel Sensor for Dimensional Measurement Combining Laser, Image Processing, Focus Variation and Tactile-Optical Probing

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Abstract:

A new sensor will be presented, being capable to realize optical and tactile 3D measurements on workpieces by combining several measuring principles in one sensor head.

An image processing sensor enables lateral measurements of edges and margins of objects. To determine the objects surface shape, a laser distance sensor and alternatively a focus variation sensor, both operating thru the same telecentric optic, are used for vertical measurements. A third measuring method is realized by detachably mounting a flexible fiber including a tiny probing sphere in front of the optic to enable tactile probing (Figure 2a).

As the deflection of the probing sphere has to be transmitted to a detection circuit via the stylus, all conventional tactile touch probes suffer from the limitations to the stylus diameter. Bending of the stylus does not have to be considered by using image processing for the direct determination of the probing spheres deflection. Existing commercially available fiber probe sensors are using this advantage for the lateral deflection with image processing (Figure 2b). The vertical position of the probing element is defined by the vertical position of the coordinate measuring machine that is used for the probing process as the stylus element is vertically stiffen. Probing spheres are available down to 20 µm in diameter.

A new approach for the vertical deflection determination uses a laser distance sensor operating on the upper fiber end (Figure 4c). Lateral and vertical measurement are now combined to determine the three dimensional deflection of the fiber resulting from object contact. Image processing and distance sensing are provided by the same optical system applied above the fiber (Figure 4a). The vertical deflection of the fiber is enabled by a flexible stylus fixation that additionally ensures isotropic probing forces.

The new assembly will be presented as well as the current state of development. The target parameter for 1D probing error is below 0.15 µm using unidirectional probing. The specification for the 3D probing error is below 0.25 µm. It will be shown, how these values have been reached using special correction and calibration methods.

Introduction

Coordinate measuring technology requires high precision measurements on smaller and smaller features, even distributed along larger workpieces. Increasingly, emphasis falls on objects with high aspect ratios, from the spray holes of injection nozzles to the features on micro gears.

Existing optical sensors, designed for high accuracy measurements of features at the surface and edges of parts, prove unsatisfactory when measuring features within deep holes or on steep surfaces. Due to this, a viable approach is the use of tactile measuring. The governing principles for conventional tactile measuring require the use of relatively thick shafts, stiff enough to transmit the probing force to the detection circuits, leading to dimensional and other restrictions.

Tactile-optical sensors provide the only reasonable response, offering both very small sphere diameters and low probing forces. Until recently they have shown limited 3D capabilities.

The new tactile-optical sensor gains from strengths inherent to the individual optical sensors of which it makes use. This provides a practical solution for most measuring applications, especially in multisensor coordinate measuring machines.

Optical sensors

The advantages of optical sensors are well known, allowing for high measuring speed, excellent lateral resolution and non-contact measuring with high accuracy [1].

Image processing sensor can be used to fast capture edges and scan contours for form tolerances using both transmitted and reflected light. The ability to quickly capture an enormous number of points makes them the ideal choice for many applications.

To measure surface topography distance sensors are used. In its basic form these are single point sensors, also capable to measure entire surfaces by scanning. Autofocus sensors using contrast evaluation are suitable for diffuse reflecting surfaces. To scan partially reflective and steep surfaces quickly, the Foucault sensor uses a special triangulation approach, integrated into the beam path of an image processing sensor.

Area distance sensors measure many points in a single cycle based on different principles. The use of a more sophisticated procedure, the focus variation based 3D Patch concept, uses many focus points measured throughout a single cycle. This is done by dividing the image into many individual segments within a grid pattern. For each grid section the surface distance is calculated individually, allowing for the formation of a surface patch for the scanned section.

Tactile-optical sensors

The tactile measuring principle in certain executions has an advantage over the conventional optical approach, through increased 3D capability [2]. In the case of conventional tactile micro-probes, operating on the electro-mechanical principle, significant probing force must be transmitted to a detection circuit via the stylus. The practical implication of this is a limited minimum size for the stylus. Thus the probing spheres size is limited to a minimum greater than 100 µm in diameter. The longest shafts for such probes, able to transmit the contact force, are only several millimeters in length and have a significant risk of breaking. Additionally sensitive features such as optical surfaces will be damaged and easily deformed parts cannot be measured accurately due to the relatively high probing force.

For example steep surfaces and long small holes seen in injector nozzles and similar applications therefore, require an entirely different approach to measuring. To date, the most successful is the Werth Fiber Probe (ref. Fig. 1) [1]. Through the use of an image processing sensor, the lateral deflection of a small probing sphere is measured (ref. Fig. 2). Since the stylus must only support the probing sphere, not transmit the probing force, spheres as small as 20 µm in diameter are possible, and may be supported on styli as long as 150 mm. Since significant lateral stiffness is not required, the contact force of the probe is minimal, measured in micro-Newtons. The ability to measure with virtually non-contact also allows for the accurate measurement of flexible and sensitive parts. Furthermore this low contact force is a source of surprising probe resilience. The Werth Fiber Probe sees frequent application in demanding environments, including the shop floor. Since actual measuring with the tactical-optical systems is done through the image processing sensor straight above the probe, actual deflection of the probe is easily seen by the operator, making the process more intuitive.

Several different fiber geometries can be stored simultaneously on a single machine, an automated measuring CNC program can then switch or remove fibers without the need of assistance from an operator.

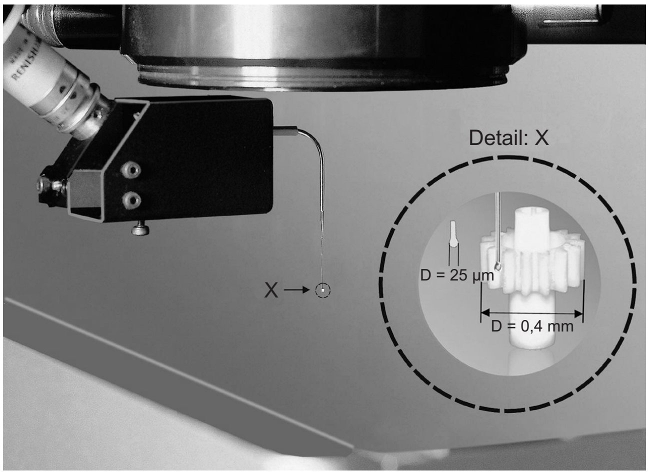

Fig. 1: Werth Fiber Probe used for measurement of the smallest structures. Probing sphere diameters down to 20 µm are available.

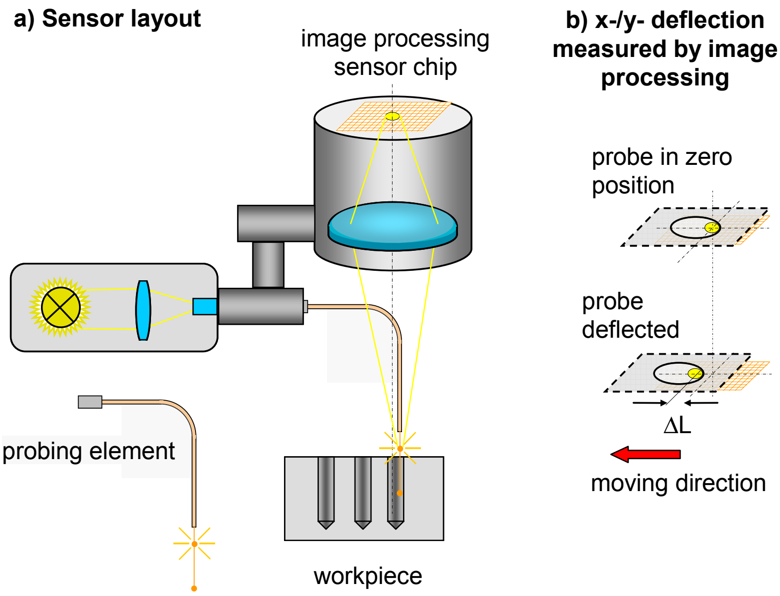

Fig. 2: Fiber Probe: The sensor layout a) shows an optical system including an image processing sensor that is arranged above a tiny probing element. The lateral deflection of the probing element or a small sphere aligned to the probing element is measured by image processing b).

While capable of measuring 3D geometries, in the basic version of the Fiber Probe lateral deflection is directly measured by image processing while the vertical position is defined by the coordinate measuring machine. This allows for the accurate measurement of surfaces down to nearly 45 ° inclination.

Measurement of the vertical deflection is achieved through several different techniques. The use of a fast distance sensor is the most recent and accurate approach (ref. Fig. 3).

Fig. 3: The new 3D Fiber Probe with stylus, probing sphere and spring leaf suspension

In addition to the image processing sensor that is used to detect the lateral deflection, the distance sensor is integrated into the same optical beam path. This enables very fast scanning and high accuracy. The use of a thin spring leaf suspension for the stylus mounting enables nearly isotropic probing force. Placing the leaf suspension well above the probing sphere, and therefore outside the focal plane, renders it nearly invisible (ref. Fig. 4).

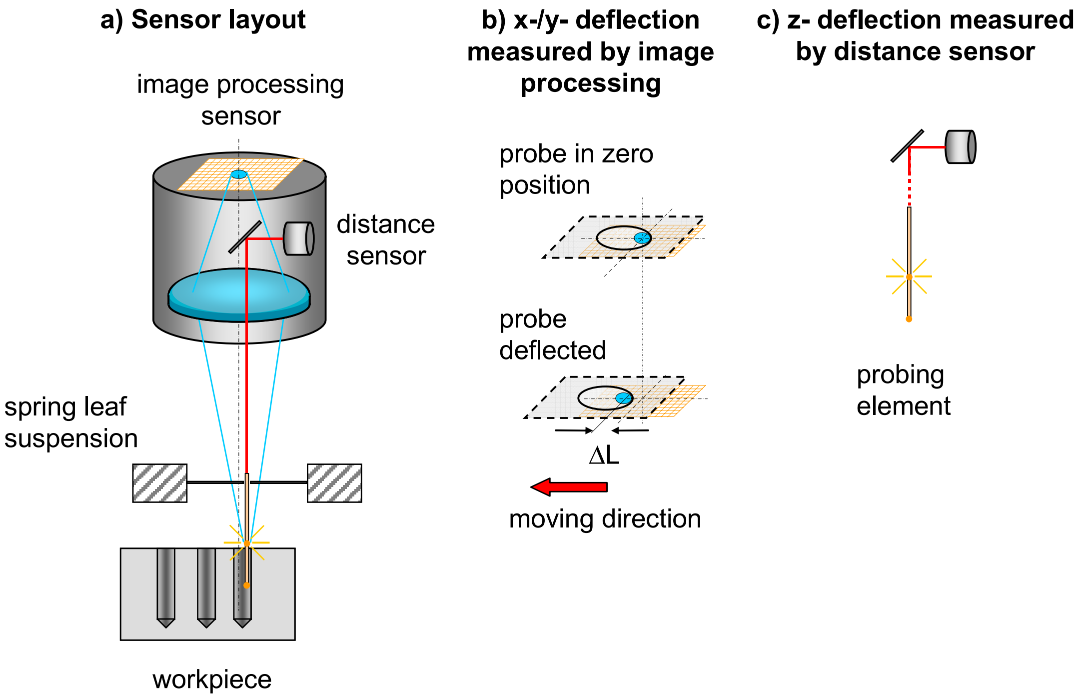

Fig. 4: Werth 3D Fiber Probe for high precision three dimensional measurements of micro features: Measuring the lateral deflection of the probing sphere by image processing b) and the vertical deflection by a distance sensor c), combined within one optical system a).

Although designed to be vertically stiff, these fibers can be manufactured with very small diameters enabling probing sphere diameters down to 20 µm. At present, distance sensing is achieved through the integration of the Werth Laser probe into the image processing sensor via specialized optics. Two separate focal planes for the lateral image processing and the distance sensing are used. This results in a sensor that combines micro spheres and negligible contact force, with highly accurate and fast 3D scanning comparable even to conventional 3D scanning probes.

When operating with an accuracy in the sub-micron range, the form deviation of the sphere plays a significant roll. Consequently probing spheres are individually calibrated to account for errors resulting from these deviations using a highly accurate calibration sphere. The calculated corrections are dependent on the local 3D vector at the point of contact. A probing error below 0.25 µm is achieved by using this probe with an ultra accurate coordinate measuring machine (ref. Fig. 5). This allows measuring of micro structures with tolerances smaller than 3 µm, such as high precision lenses, micro form dies and micro injection molds for optical or other plastic parts. Use of an automatic probe changer allows for flexible measurements with different probe configurations.

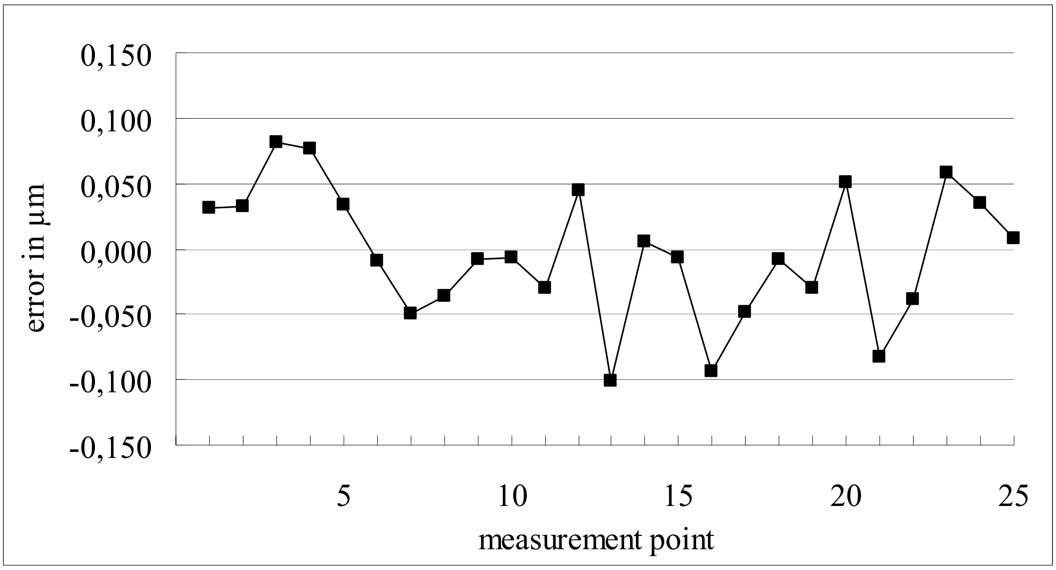

Fig. 5: Probing error of the new 3D Fiber Probe operated with a VideoCheck® coordinate measuring machine (measured on a 10 mm calibration sphere)

Summary

The highly integrated sensor, presented here, combines 3D tactile probing capability with isotropic probing forces in the micro-Newton range and probing sphere diameters down to 20 µm with conventional image processing and distance measurements.
Fully tactile 3D capability with a probing error of 0.25 µm is achieved while overcoming limitations to the probing sphere size known from conventional tactile sensors.
The automatic probe changer allows for the implementation of different sensor configurations. This enables measuring with different probe tips as well as the direct operation of the optical image processing, autofocus (including focus variation principle 3D-Patch) and laser distance sensors in a single CNC program.
Combining the Werth coordinate measuring machines with this sensor offers the greatest flexibility and precision when measuring the smallest features even on large workpieces.

References

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[2] A. Weckenmann, T. Estler, G. Peggs, D. McMurtry: Probing Systems in Dimensional Metrology, CIRP Annals – Manufacturing Technology, Volume 53, Issue 2, 2004, Pages 657-684