

# Novel 3D analogue probe with a small sphere and low measurement force

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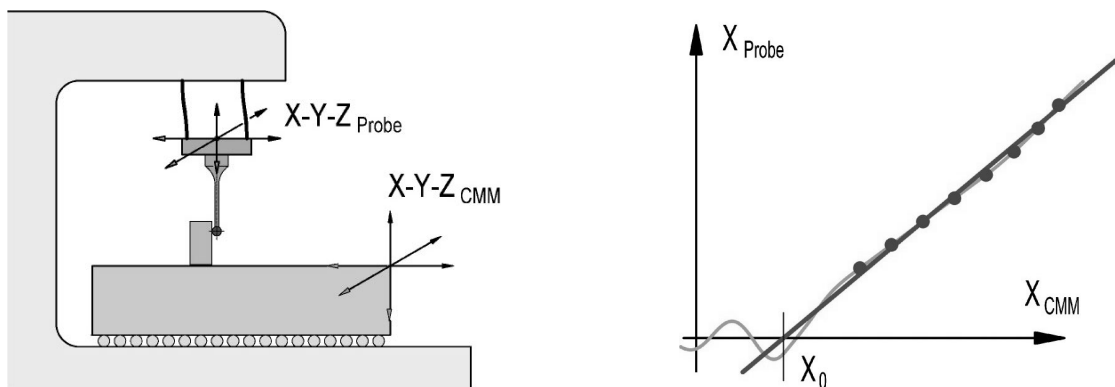
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## Abstract

A new 3D touch probe for coordinate measuring machines (CMM) with exchangeable probes with spheres in the diameter range of 0.1 mm to 0.3 mm and probing forces below 0.5 mN was developed. The device is based on parallel kinematics with flexure hinges and is manufactured out of a single piece of aluminium. All rotational movements of the probing sphere are blocked. The remaining possible translational motion is separated into its xyz-components, which are each measured by an inductive sensor. All axes have the same orientation with respect to gravity. The stiffness is isotropic with a value of only 20 mN/mm, while the effective moving mass is about 7 g. First experiments with the 3D touch probe were performed on a linear measuring machine equipped with a laser interferometer. The standard deviation of repeated measurements, e.g. the difference between left and right probing on a 5 mm gauge block, was in the order of 5 nm.

## Introduction

In the last years CMMs have become versatile and widespread metrology tools. Today's CMMs can efficiently perform very complex measurement tasks. However, with the ongoing miniaturisation in the mechanical and optical production there is a new demand for highly accurate geometrical measurements on small parts. New instruments should have low uncertainties and probe the objects with very small spheres using very low contact forces. Up to now, the limiting factor for the application of CMMs on small parts was mainly the probe head and therefore new developments are needed [1, 2].



**Figure 1:** Measuring principle of a CMM (left) and probing data used to determine the force free contact point of the probing sphere (right).

The point of contact between the probing sphere and the sample surface should be obtained by measuring probe deflections at several CMM positions. This allows extrapolation to zero deflection where also the contact force is zero (Fig. 1 right). In the context of a Swiss TOP NANO 21 research project the EPFL, the industrial partner MECARTEX and METAS developed a new 3D touch probe for measurements on small objects.

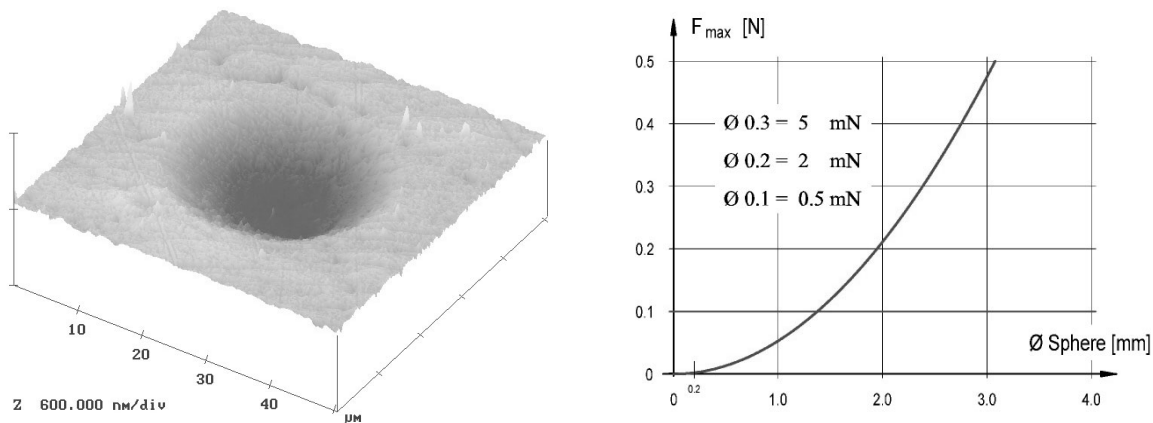
### Probing force and surface damage

The relatively large probing forces of conventional probe systems may damage the surface of the work piece and thus falsify the measurement result. Figure 2 shows on the left an atomic force microscope image of such a plastic surface deformation on an aluminium test piece. It was probed with a conventional 3D touch probe with a sphere of 0.6 mm diameter resulting in an indent with 330 nm depth.

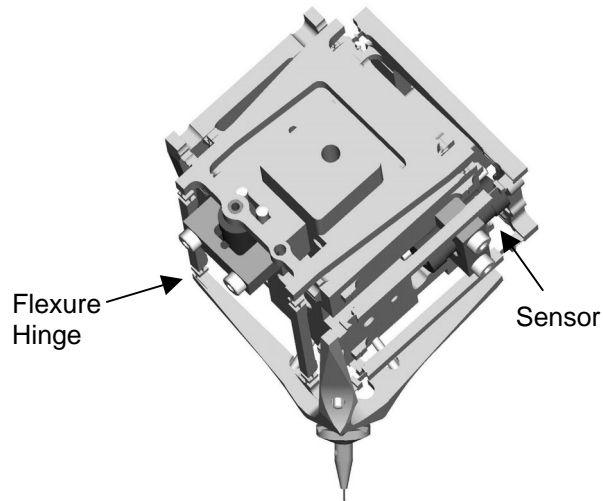
If a probe sphere with a diameter in the order of 0.1 mm is to be used without leaving any permanent surface indentation, the force needs to be about 100 times smaller than with today's commercial probe systems (Fig. 2 right). This means the stiffness of the probing system has to be very small e.g. 20 mN/mm to allow still some probe deflection at these low forces (typ. 20  $\mu$ m). The situation is even more critical with respect to dynamic forces that act when the sphere hits the surface upon first contact. Therefore the effective moving mass needs also to be as small as possible to allow reasonable approach speeds.

### Construction

Based on parallelograms and flexure hinges a new kinematic structure was designed for the probe head. This structure leaves the probing sphere exactly three degrees of freedom. The rotational movements are blocked and the translational motion is separated in its xyz-components, which are each measured by an inductive sensor (Fig 3). All axes have the same orientation with respect to gravity and provide the same probing force in all directions. The main part of the structure is manufactured out of a single piece of aluminium using electro discharge machining. Therefore the most critical part does not need to be assembled. The flexure hinges have a thickness of only 60  $\mu$ m resulting in a stiffness of 20 mN/mm. The effective moving mass is 7 g. Due to the low stiffness, the deformation caused by gravity needs to be compensated. For this purpose



**Figure 2:** Plastic deformation on an aluminium surface after probing with a conventional probe (left) and maximal admissible probing forces for various sphere diameters at 1000 MPa contact pressure (right) [3].



**Figure 3:** Kinematic structure of the 3D touch probe.

an adjustable system with permanent magnets was developed.

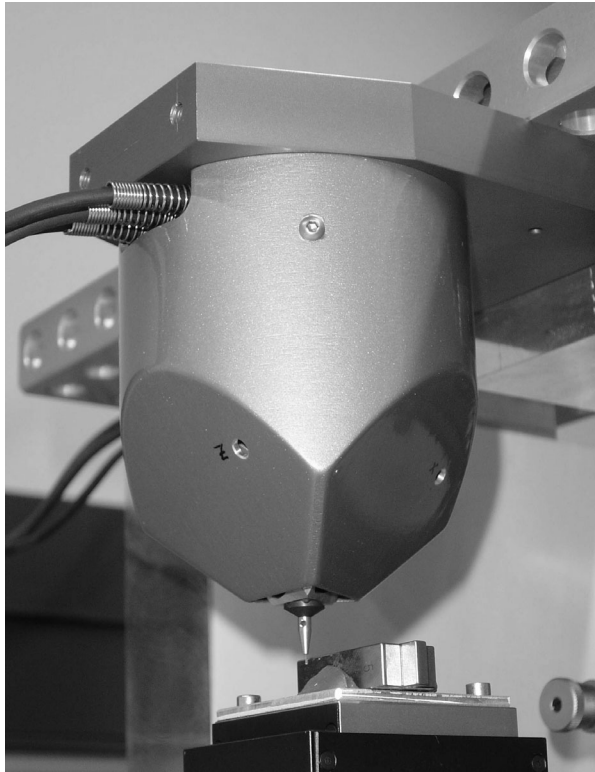
The measurement range is  $\pm 0.2$  mm while the mechanical limits allow a range of  $\pm 0.5$  mm. The probing element is magnetically attached to the head and positioned by means of three balls in three grooves (Fig. 4 left). The magnetic holding of the probing element allows an easy replacement and acts also as a mechanical fuse. Therefore the handling of this highly sensitive device remains quite easy.

A small moving mass is important to keep the dynamic contact forces low while maintaining reasonable approach speeds. Model calculations showed that the effective mass (7 g) of the probe is still too high. A small additional mechanical filter element was developed to reduce the effect of dynamic forces. Its stiffness is almost equal in all directions and roughly 100 times higher than that of the probe head but it has a very low effective mass (Fig. 4 right). Typical approach velocity is thus 1 mm/s.



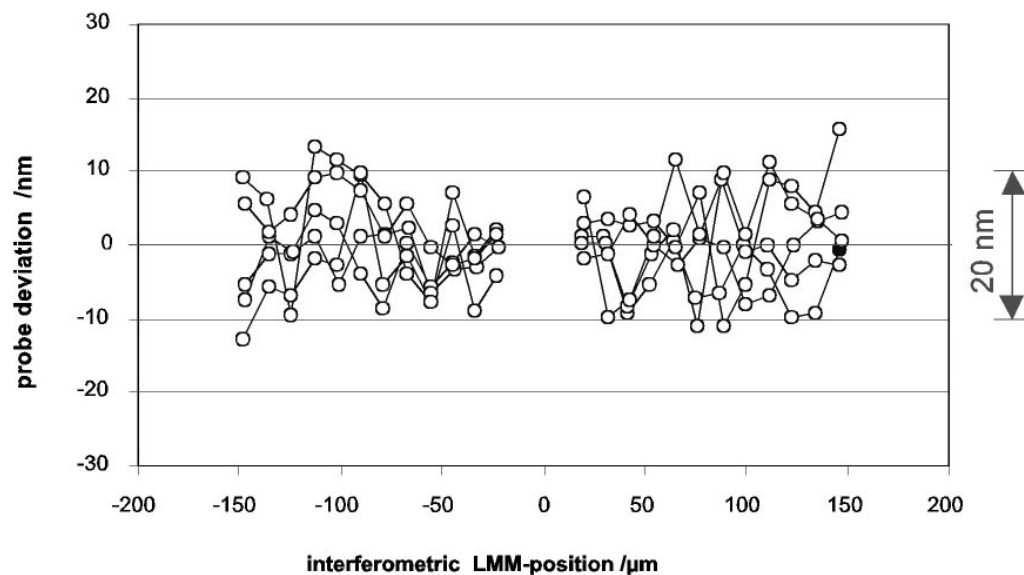
**Figure 4:** Magnetic holding of the probing element (left) and mechanical filter (right).

## Experimental Results



**Figure 5:** Experimental arrangement for the probe test on the LMM.

The full performance of the new probe can only be measured on a CMM with equal or better performance than the probe itself. However, at the moment we have no such ultra precision CMM available. Therefore the first experiments with the new 3D touch probe were performed on a linear measuring machine (LMM) equipped with a laser interferometer (Fig 5). In this way only probings in a horizontal plane could be made. However, due to the special orientation of the probe coordinate system all 3 sensors of the probe head were involved in these test measurements. The test consisted of probing a known 5 mm gauge block on the left and right side. The difference between the two points minus the gauge block length is the probe constant, which is essentially the sphere diameter. The repeatability of the probe constant is an important parameter for a 3D touch probe. In our experiments the standard deviation of 5 such measurements was always in the order of 5 nm. This value even includes



**Figure 6:** Deviation from linearity of 5 touch probe measurements for the left and right side of the gauge block.

interferometer noise and machine instability like vibration and drift. Also for large probe deflections up to 150  $\mu\text{m}$  the linearity of the probe signal remains very good (Fig. 6).

## **Conclusions**

A new 3D touch probe for CMMs with exchangeable probes and low probing forces was developed and a patent has been filed. The innovative design is based on a parallel kinematics with flexure hinges. First test measurements were very successful. With probing forces smaller than 0.5 mN the repeatability was in the order of 5 nm.

For the full characterisation of the probe needs a CMM with comparable performance. We plan therefore to incorporate the probe head into a new ultra precision CMM [4] at METAS. The goal is to offer calibration and measurement services for small parts up to a size of about 50 mm in the near future.

## **References**

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