

Integrated Auto Alignment and Calibration for High Resolution Capacitive Sensor System

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Abstract

Capacitive displacement sensors are very well suited for short stroke measurements with sub-nanometer or even picometer resolution. A drawback is the accurate alignment of the sensor head that is necessary for correct operation. Machining tolerances and mounting errors make that this alignment is not obvious. Time consuming manual alignment procedures or expensive and unstable alignment systems limit the use of capacitive sensors in industrial applications.

A sensor head with self aligning capability can overcome these alignment difficulties. This article presents such a concept that enables the use of high resolution capacitive sensors in industrial applications, without being dependent on strict tolerances or difficult alignment procedures. The used thermal actuation concept can also be used for on site calibration of the capacitive sensor system.

1 Introduction

Increasing requirements on accuracy and precision result in higher demands on the design and construction of high precision machines. High stiffness constructions or active positioning systems are needed to guarantee the correct position of key components subjected to dynamic disturbances. When the demanded accuracy is on the nanometer level, for example in the semiconductor industry, remaining disturbances might be higher and prevent correct operation of the machine. In this case displacements of critical components are measured and the signals are used for correction in a control loop. These are basically position measurements of static objects with a maximum stroke of only a few micrometers and sub-nanometer resolution.

Capacitive sensors are a relatively cheap solution for short range measurements with sub-nanometer or picometer resolution, but they require accurate positioning and

alignment to achieve this. In case of a parallel plate sensor, the most utilized structure, two electrodes have to be placed at a distance of around 10 micrometer with sub-micrometer error. Reducing machining and mounting tolerances to achieve this would make the total system very costly and in some cases the specified accuracy can still not be reached.

Instead of reducing the tolerances, they can be compensated by adding an external alignment mechanism to each sensor. Unfortunately, these mechanisms increase total cost and complexity of the system and manual alignment of many sensors in a complex machine is a time consuming and hence costly procedure. Even more important, the stability of the alignment mechanism must be very high in order not to increase the uncertainty of the measurement system due to instability and creep.

2 Self aligning sensor head

Problems with mounting and alignment tolerances can be solved by integrating an alignment mechanism inside the capacitive sensor head. Remote or autonomous operation allows the capacitive sensor to be aligned to its ideal operation point without any human interaction.

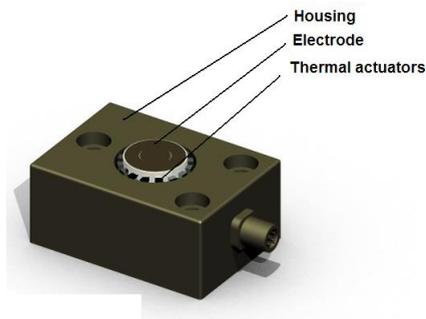


Figure 1: Design of a capacitive sensor head with integrated alignment mechanism.

Prerequisite for this solution is an alignment mechanism that is small enough to fit inside the sensor head, is cheap and ensures a stable position after the alignment procedure. Such a positioning system has been developed [1] specifically for sub micrometer initial alignment and occasional re-positioning. Compactness and simplicity make it suited for integration inside the sensor head. The used alignment system is based on thermal actuation of the clamping elements that hold the

capacitive electrode in position. Heating the elements in a special sequence enables a stepping motion of the electrode which results in a permanent displacement, even after all the elements have cooled to their initial temperature.

A demonstrator setup which shows the integration of the alignment mechanism inside a sensor head has been designed and built. Figure 1 shows the design of a self aligning sensor head. Figure 2 shows the built prototype used for experiments.

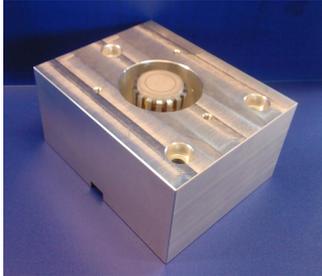


Figure 2: Prototype of the self aligning sensor head.

3 Alignment and calibration

Correct alignment of the sensor head is determined by two main geometrical parameters. These are the nominal distance d_{nom} and the angle α between the electrodes. Typical values for a sensor system with sub-nanometer resolution are a distance d_{nom} in the order of 10 micrometer and a maximum angle α in the order of 10 micro Radians. Mounting a sensor head without special measures easily results in a linear error of ten's of micrometers and angular errors up to a few mRad.

The presented self aligning sensor head reduces these errors in three stages as shown in figure 3. In the first phase the system will use the stepping motion to reduce the relatively large initial distance (up to a few 100 μm) between the electrodes, until they come into contact. In the next phase all elements are heated, causing them to expand. Although the electrodes are already in contact, further expansion does not cause any damage because of the limited friction force between clamping elements and electrode. This action makes use of the occurring slip to push the electrodes into a parallel position. The last step consists of cooling down the elements to their initial temperature. The known temperature step in combination with the previously calibrated thermal expansion of the elements makes the retraction of the electrode

well defined and both electrodes end up at a known distance and parallel within a few μRad . This has been demonstrated in prior research [2].

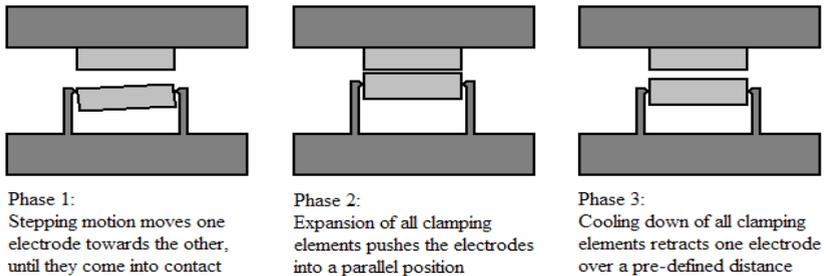


Figure 3: Schematic representation of the alignment procedure.

The very predictable behavior of the thermally actuated movement of the electrode can be used for on site calibration of the displacement measurement system. After alignment, all clamping elements are subjected to a known temperature step. The resulting displacement of the electrode is very reproducible and can be used to calibrate the measurement system.

4 Conclusions and future work

The presented concept of a capacitive sensor head with integrated self alignment and calibration system makes this type of sensors applicable in industrial applications without the need of expensive and time consuming alignment procedures. An experimental setup has been built, which will be used to verify the performance of the alignment and calibration system. The results will be used to optimize the design of the presented demonstrator

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References:

- [1] J.P.van Schieveen, J.W.Spronck and R.H.Munnig Schmidt, "Thermal stepper, positioning system for stable micro alignment", Euspen 2009, vol II pp. 110-113
- [2] S. Xia, J.P. van Schieveen, S. Nihtianov, J.W. Spronck., "Concept Evaluation of a High Performance Self-Aligning Capacitive Displacement Sensor", ICIT 2010, to be published