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Low cost contactless measuring system for high precision measuring of quasi-static machine tools disturbances

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Abstract
Measurement of machine tools errors is an issue that has been addressed in many different ways by the industry: laser interferometers, contact probes (by scales, LVDT or even dial gauges), encoder grids, and among others, the largely used non-contact inductive probes or very accurate capacitive sensors. All of them have an application field well defined and known by machine tool builders and companies working in the testing and calibrations of machines. In the case of high precision non-contact probes, inductive and capacitive are the most used for machine tools' characterization, mainly for thermal and geometrical disturbances; quasi-static errors in any case. When high precision results are looking for, very fine inductive or even capacitive ones are used, with finest performance in the second case. Resolution, repeatability, linearity and therefore the accuracy of those sensors is closely linked to the final cost of measurement device. In this work, it has been tested a very low cost measurement device combined with machine's own linear scales, and all that managed by an external controller that optimizes the accuracy by a self-positioning algorithm. The low cost inductive sensors (repeatable but with a poorly linearized signal) are tested against different targets, where the main aim has been to determine whether their repeatability is good enough for studied machine errors. The study has been carried out by an algorithm implemented in MATLAB run by an external PC and connected by Ethernet to a CNC machine. Such system controls the axis of the machine, with sensors signals as feedback, and once they have converged below 0.5 µm, the linear scales value is recorded. The repeatability of developed system measuring spheres centre is below +/-1µm, good enough for the calibration of machines in the working volume.

Keywords: Low cost contactless sensor, machine tool, precision measurement, error compensation.

1. Introduction

The continuous increase of requirements in the parts to be machined or manufactured, pushes machine tool builders to improve the precision of their machines and in some cases to implement geometrical errors compensation solutions [1]. The measurement of machine's geometry has been addressed through different ways [2]. In this project a cost efficient solution is presented, bears in internal signals of the own machine (linear scales value), and therefore, feasible to be a solution for machines builders, who could have full access to PLC and CNC signals. The main aim of the work has been the validation of low cost inductive sensors, that will be part of a measurement chain where the own internal signals of the machine are considered. With a solution based on internal signals and low cost external sensors, the machine tools could integrate a very cost efficient device and solution for geometrical self-calibration [3].

2. Experimental set-up

The study has been carried out on a micromilling machine [4], with a positioning precision in each axis below 1 µm, measured and tested by laser interferometry. On the other hand, capactitive sensors from Lion Precision CPL290 with C23-C probes [5] are used in the range of 250µm to have a comparison of inductive probes behaviour with the state-of-the-art in contactless high precision sensors. The low cost sensors considered for the project are basically end-of-stroke sensors, in fact are supplied for this purpose but with the option of analogic output. It has been noted a quite good repeatability in their response, that will analysed in next sections. The main specs of the sensor are 1mm range, +/-100 µm linearity error and below 5 µm repeatability error, with a price around 185€ per channel. With those sensors and using a micromilling machine to ensure reliable movements, different materials, geometrical shapes and finally a calibration artefact based on spheres have been measured.

3. Inductive low cost sensors analysis

The main aim of this experiment has been to analyse how is affected the response of output signal with different targets material and geometrical shapes. All that compared with the well-established high precision capacitive sensors. The materials used on that experiment have been the following: Carbon steel F1140, Martensitic stainless steel AISI 420, Aluminium 7025 and Nickel alloy Invar; in all cases measurements against plane surface were conducted.

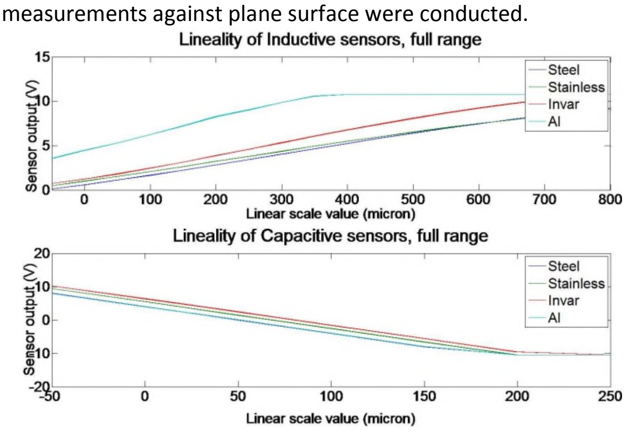

Figure 1. Inductive and capacitive sensors response in full range.

How it can be noted in Figure 1, the linearity of inductive sensors is worse than capacitive ones, and in both cases the response of the sensors are strongly dependent on materials. On the other hand, the shape of the target is analysed, with two different targets: cylinder shape of three diameters (50,25,10mm) and one sphere, diameter 20mm. This last sphere is used for calibration artefact.

4. Measurement of sphere centre

Once the sensibility of the sensor is determined, and known its poor linearity, a strategy for spheres centre measurement is implemented. It is carried out by a combination of a self-centring algorithm programmed in MATLAB and a PC/PLC communication mode with the machine control, all that to adjust the final position of the system. This way, the linearity of the sensor is not a limitation of the system anymore, and only its repeatability is an issue. There have been completed fifty repetitions of the test, where the centre of the sphere is determined by the three axis of the machine. Several iterations of self-centring algorithm are required to achieve convergence condition, below 0.5 µm error in the inductive sensors, and then the value of the linear scales is recorded. The following Figure 2 gives the results of the experiment, with error dispersion within +/-1 µm in fifty tests.

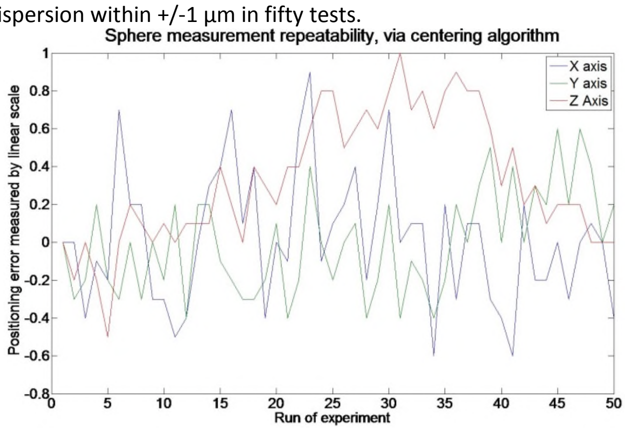

Figure 2. Measured values of spheres centre fifty test.

4. Measurement of calibration artefact

Finally, an artefact used for the calibration of volume geometry in the micromilling machine has been measured. The artefact is composed by five spheres clamped on a stable steel structure. All the tests are carried out in constant temperature and humidity conditions, into the ultraprecision laboratory of IK4-IDEKO, so that the variations due to ambient could be neglected. In this case, the process of determining the centre of each spheres is repeated ten times, so that fifty different tests are conducted. Figure 3 shows the set-up of the experiments in the micromilling machine.

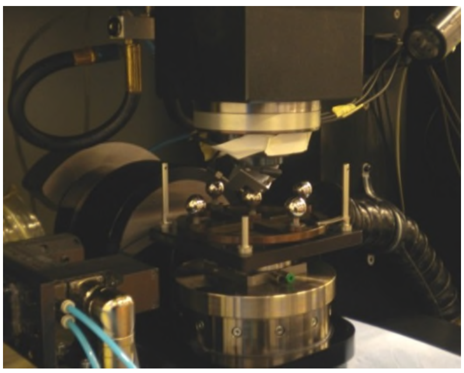

Figure 3. Set-up of measurements with calibration artefact.

The repeatability of the process to measure the spheres' centre of the artefact is evaluated during the experiment. Figure 4 gives the measured errors of the system for each axis (X,Y,Z) in the positioning of the sphere's centre.

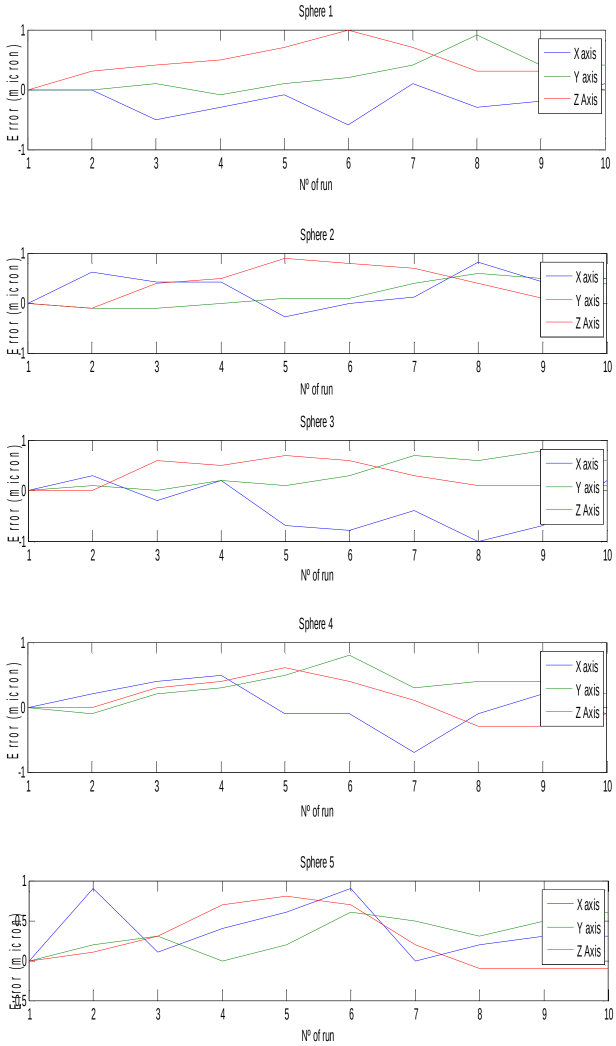

Figure 4. Positioning error in 5 spheres of calibration artefact

5. Conclusions

It has been demonstrated with the combined use of the internal data of CNC together a measurement device based on very low cost inductive sensors (end stroke switches), managed with an algorithm that looks for given geometries (spheres in this case), it is able to measure and therefore calibrate the volume geometry of machine tools. This cost efficient system for machines calibration based on artefacts could be easily implemented by machine tool builders as a self-calibration function.

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