euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

Electromagnetic interference and capacitive distance measurements on machine tools

Sebastian Böhl[1], Matthias Meier[1], Konrad Wegener[1]

[1] *Institute of Machine Tools and Manufacturing (IWF), ETH Zurich, Leonhardstrasse 21, 8092 Zurich, Switzerland*
boehl@iwf.mavt.ethz.ch

Abstract
An experimental analysis of electromagnetic interference (EMI) on distance measurements using capacitive transducers for spindle measurements in the working space of a machine tool is described. The experimental setup is based on capped transducers arranged in different grounding configurations. Resulting changes in signal noise due to different operating modes of the machine tool are evaluated. In addition, the influence of different sliding brushes on signal noise is analysed and reported. The analysed configurations show highly different sensitivities to machine tool circuit induced disturbances and operation modes of the machine tool depending on grounding and connection configurations. Important factors to gain robustness against electromagnetic disturbances are guarding the reference ground of the measurement device by galvanic decoupling of the measurement setup from machine tool parts and ensuring unambiguous ground connections. In case of moving targets, it is beneficial to close the measuring circuit between target and measurement device via sliding brushes that ensure almost constant contact conditions. Based on the results and analyses a setup configuration is proposed that reduces influence of electromagnetic disturbances and limits noise on a machine tool to RMS noise < 1 mV (12 nm) in case of standard measurement device configuration without optimisation for resolution and for a measuring range of 250 µm.

Key Words: Electromagnetic interference, capacitive transducer, grounding, noise, sliding brush, machine tool, environmental disturbance, spindle measurement

1. Introduction

Capacitive transducers can be used for testing geometric accuracy of spindles. In order to meet the increasing demand for higher spindle accuracy, a suitable measurement uncertainty is essential. Electromagnetic disturbances degrade the performance of the electrical measurement device, which results in distorted and noisy signals. Possible coupling mechanisms between disturbing source and susceptible system are conductive, capacitive, inductive and radiative coupling [1]. Sources for disturbances can be unwanted current flows due to multiple groundings [2]. Noise can be generated in the evaluation electronics, induced by environmental influences or excited by components in the measuring circuit e.g. sliding contacts [2-6]. In this article cap-tests (cf. [7]) are used to estimate the influence of electromagnetic disturbances on capacitive distance measurements in a machine tool environment. The experimental setup is described. Selected grounding as well as connection configurations and component influences are analysed and disturbing sources are located. The goal of this article is to specify practical measures to avoid electromagnetic disturbances on capacitive distance measurements on machine tools and thus to achieve RMS noise values under shop floor conditions similar to those achieved under measurement room conditions. The article focuses on the measurement device application rather than on measurement device design and calibration aspects. Therefore, the measurement device including calibration is taken as given.

2. Test setup

A schematic principle for a capacitive transducer is shown in Figure 1. The measuring circuit consists of a driver, a transducer and a target. It will be called closed, when the target path can be closed by an electrical connection between nodes T and R (Figure 1). Thus the target is connected to reference ground.

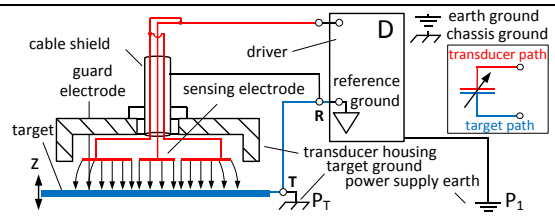

Figure 1 Schematic of capacitive transducer

The measurement device under test is typically used for geometric spindle measurements consisting of capacitive transducers, corresponding drivers and a data acquisition unit. The output voltage is ±10 V, which results in a measuring range of 250 µm for a sensitivity of 80 mV/µm.

Experiments are carried out in a measurement room (IWF) and on the PRAEZOPLAN milling machine (MT) located at IWF.

The measurement device is powered and earthed via the building's electrical supply network and a line filter is used.

To analyse the effects of different connection and grounding configurations, a special test setup is designed and used (Figure 2). The setup allows capping each capacitive transducer, setting different electrical path configurations for the target paths and testing different brushes in linear motion. Test setup components and MT table can be coupled and decoupled to or from each other individually via cable using a patch panel.

Two different brushes are tested: a carbon fibre brush and a braided nickel-plated copper drag contact (Figure 2). To simulate disturbing influences by sliding contacts, a rail/brush contact is implemented in the target path. The rail surface is ground (Rz 0.24 µm, Ra 0.05 µm). Relative motion between brush and rail is generated via the Y-axis of the milling machine with a feed rate of 500 mm/min.

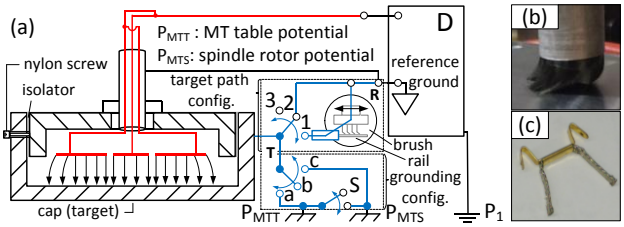

Figure 2 (a) Schematic of test setup on machine tool. Shown configuration and switch settings represent a classical cap-test. Tested brushes: **(b)** Carbon fibre brush, **(c)** braided nickel-plated copper drag contact.

By a constitutive experimental design and comparison of results of each level (e.g. influence of MT operation mode: MT OFF, MT ON, MT ON plus NC ON), disturbance sources can be separated from each other and can be localised.

3. Results

In the following, EMI phenomena are presented and measures are proposed, which are found to be fundamental for disturbance avoidance in case of capacitive distance measurement. First, the influence of grounding and measuring circuit condition (open/close) are discussed. Second, the influence of different environments is described. Third, the influence of a sliding contact in the target path is analysed.

The disturbing influence of the MT in operation mode NC ON is significant, when the target is galvanically coupled to the MT table (Figure 2: nodes T-a, S open), although the measuring circuit is closed (nodes T-2). The coupling leads to a highly distorted and noisy signal with RMS noise higher 80 mV (1 µm). It is suspected, that parasitic currents in the electrical system of the MT, which are imposed on the test setup, evoke the signal distortion. In addition, the table target coupling produces a ground loop resulting in voltage fluctuations, which cause signal noise. Galvanic decoupling of the target from the MT table (nodes T-b) reduces RMS noise from more than 80 mV (1 µm) to 0.6 mV (7.3 nm). The measuring circuit remains closed (nodes T-2). Additionally, amplitudes of harmonic components are significantly reduced. Especially, the 50 Hz component is eliminated. Benefits of the decoupling are the definition of a unique ground for the measuring circuit and the prevention of earth ground loops. Electrical isolation of the test setup against machine tool influence is the basis for low noise capacitive distance measurements. Changing the measuring circuit condition from closed to open (nodes T-2 to T-3) and holding the target decoupled from the MT table (nodes T-b), lead to an increase in signal noise of ΔRMS = 2.3 mV (28.4 nm) [closed circuit: RMS noise 0.6 mV (7.3 nm), open circuit: RMS noise 2.9 mV (35.7 nm)].

Adopting both discussed disturbance rejection measures, the capped capacitive transducer is now tested in order to estimate noise behaviour in different environments including different MT operating modes in nominal standstill of machine axis and measurement room environment (Figure 3). Changing the environment from the measurement room to the machine tool working space (MT OFF) has little influence on RMS noise ΔRMS ≈ 0.0 mV (0.024 mV, 0.3 nm). The connection configuration (nodes T-2 and T-b) proofs to be robust against changes in the working mode of the machine tool (MT OFF to MT NC ON). The change of RMS noise is negligible (0.008 mV, 0.1 nm).

A sliding contact in the target path (T-R via nodes T-1) can have a significant influence on signal noise (Figure 3). In case of the tested braided drag contact a mean RMS noise of 0.7 mV (8.7 nm) is achieved. All ten RMS noise values remain in the range of 0.016 mV ≈ 0.0 mV (0.2 nm). Given that the fibres are oriented in the same direction and that the brush is pulled, the carbon fibre brush leads to a mean RMS noise of 1.6 mV ± 0.1 mV (19.5 nm ± 1.7 nm). For the resistance, measured between nodes T and R in standstill, a value of 10 Ω in case of the carbon fibre brush is determined, whereas the braided drag contact leads to a much smaller resistance (<< 1 Ω). On the one hand the difference in RMS noise is caused by the high specific resistance of the carbon fibres, which is approximately three orders of magnitude higher than the one of the nickel-plated copper braiding. The higher stiffness of the braided drag contact, on the other hand, allows imposing higher contact forces than the carbon fibre brush, which leads to lower contact resistance and benefits low noise contacts [5]. Furthermore, the braided drag contact shows a higher capability to gain repeatable contact conditions than the carbon fibre brush due to its higher stability in shape, which results in a smaller range over ten test cycles.

Taking into account repeatability of the measurement setup, variation over ten measuring cycles, different contact forces and the quantisation error of the analog-to-digital converter a measurement uncertainty for RMS noise of U(k=2) = 0.192 mV ≈ 0.2 mV (2.4 nm) is estimated.

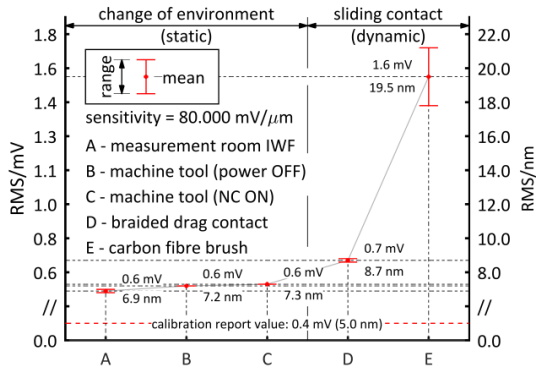

Figure 3 RMS noise of a capped sensor in closed measuring circuit configuration, under different environmental conditions and for two sliding contacts. Each case is tested 10 times.

4. Conclusions

In the case of the tested milling machine, high robustness against electromagnetic disturbances for capacitive distance measurements can be gained by galvanic decoupling of the measurement setup from the MT table and by defining a unique ground. Guaranteeing a closed measuring circuit under all conditions is substantial for low noise signals. Under discussed conditions and in case of a sliding contact, a best case RMS noise of 0.7 mV ± 0.2 mV (8.7 nm ± 2.4 nm), (k=2) for capacitive distance measurements can be achieved.

Acknowledgements: We wish to thank Dr. Wolfgang Knapp and Karl Ruhm for fruitful discussions and valuable comments.

References

[1] Weber A 2005 *EMV in der Praxis* Heidelberg Hüthig p 211
[2] Baxter L K 1997 *Capacitive sensors: design and applications* New York IEEE Press p 302
[3] Goedbloed J J 1992 *Electromagnetic compatibility* New York Prentice Hall p 381
[4] Braunovic M, Myshkin N K, Konchits V V 2007 *Electrical contacts – Fundamentals, applications and technology* Boca Raton CRC Press p 645
[5] Spayth F and East S 1953 *Sliding contacts – A review of the literature* Electrical Engineering 72 10 pp 912-17
[6] Taniguchi M, Inoue T and Mano K 1985 *The Frequency spectrum of electrical sliding contact noise and its waveform model* IEEE Trans. Components, Hybrids, Manuf. Technol. 8 3 pp 366-71
[7] ISO 230-3:2007 (E) *Test code for machine tools - Part 3: Determination of thermal effects* pp 33-34