MEASUREMENT-INDUCED WEAR OF ALUMINIUM ALLOY PARTS

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DOI: 10.17973/MMSJ.2015_12_201552

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This article presents influence of measuring probes on a dynamically measured part made from automotive aluminium alloy. Dynamic measuring (during rotation or translation) is limited not only by scanning rate of measuring sensors and processing devices, but also by physical and metrological attributes of measuring probes, which are in direct contact with the measured part. Current trend in automotive industry is to reduce weight, production costs and input materials costs, while achieving higher precision of manufactured parts. Due to these reasons, aluminium alloys with high volume of silicon are used more often than before. However, dynamic measuring of such parts presents difficulty, as the probes and measured parts interact. This interaction was the subject of the research made by Mesing Ltd. in cooperation with University of Technology Brno. The unexpected absence of adhesive wear in cases of Al_2O_3 and WC tips make them the most suitable materials for aluminium alloy measuring.

KEYWORDS
dynamic measuring, measuring probe, black diamond, Dutch diamond, measuring in automotive

1 INTRODUCTION

Basic categorization of measuring probes can be based on the principle of measurement. The shape, size, materials, manufacturing precision and other attributes depend on specified application. Therefore, to achieve the best measuring results, it is necessary to choose a suitable type of measuring device.

Four basic types of measuring devices include:

- manual/communal gauge;
- semiautomatic measuring device;
- automatic measuring device;
- CMM - Coordinate-measuring machine;
    - Manual CMM;
    - CNC CMM. [Adamczak 2008]

Each measuring probe has the same three main parts (Fig.1), regardless of its intended type of a measuring device.

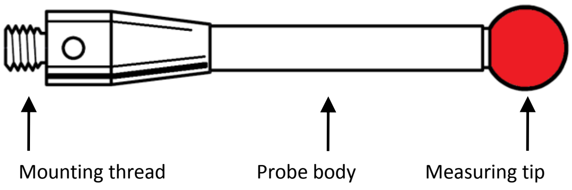


Figure 1. Description of basic measuring probe for CMM

THE IDEAL PARAMETERS OF MEASURING PROBES

A measuring probe must always have a ***mounting part***, which can be manufactured as an inner/outer thread, dovetail with locking hole, or in any other way, which allows firm and stable connection between gauge/device and measuring probe. Safe mounting and replacement of measuring tips is very important as well, and it should be available, because every tip wears off after some time. Ideally, the mounting part should be effortlessly removable, while providing a firm and stable connection with a gauge/sensor.

A ***probe body*** is the connection between the mounting part and the measuring tip. Its shape depends on the specifics of its intended use. The shape of a measured part, principle of measurement, required accuracy, available space and number of measuring probes represent crucial factors which should always be taken in consideration in the design of the body shape. During the design of a body shape, it is important not to forget about the Cosine error, and to obey the Abbe principle (if it is possible) [Kur 2013; Kur 2014]. The properties of an ideal probe body include thermal stability, compliance with Abbe principle, minimization of Cosine error, hardness, rigidity, chemical resistivity and low cost.

A ***measuring tip*** can have almost any shape, which must correspond to the measured parameter. Standard shapes of measuring tips include ball, roll and needle. It is vital to choose the correct shape for the measuring tip, because an inappropriate design of the tip makes it impossible to measure correctly. Ideal properties of a measuring tip are high hardness, precise shape, thermal stability, toughness, high surface quality, inertness to measured material, low cost and reparability.

After close examination of requirements placed upon measuring probes, it is obvious that it is not possible to meet all of them simultaneously. Therefore, it is crucial to choose the specific parameters of the probe body and measuring tip according to the specifics of the application [Adamczak 2008].

The Faculty of Mechanical Engineering of the Brno University of Technology in cooperation with MESING Ltd. have focused on mechanical wear of the measured surface caused by the probe tips made of different materials. The main aim has been to determine whether the measured surface suffers damage during the measurement. Experiments was performed on the testing device that scheme is shown in Fig.2.

2 TESTING OF INTERACTION

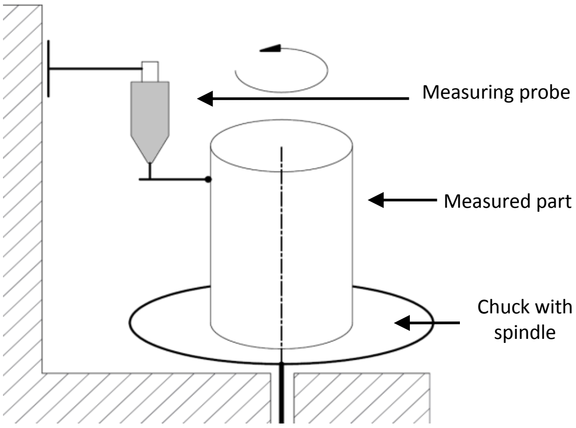


Figure 2. A scheme of a testing device

At Mesing, a simple testing device was built. It consists of a column with mounted measuring sensors. Each sensor is equipped with a probe made from different material. In the centre of the testing device, there is a very precise spindle powered by an electric motor. The last main part is a chuck connected to the spindle. Schematic representation of the testing device can be seen in the Fig. 2. Using the same type of the measuring sensor ensures that the force acting on the surface of the tested part remains the same in all cases. This force is approximately 0,6N, and it is induced by a compression spring. The tested part, obtained from an automotive costumer, was mounted in a chuck and radially adjusted to ensure constant force. The test was stopped after onethousand cycles.

The most common materials of probes used in coordinate measuring machines CMM were chosen for testing:
1) Silicon carbide - SiC;
2) Aluminium oxide - Al_2O_3;
3) Silicon nitride - Si_3N_4;
4) Zirconium oxide - ZrO_2;
5) Tungsten carbide - WC;
6) Nanocrystalline diamond;
7) Monocrystalline diamond.

Figure 3. Visible traces on the measured part

Two special probes provided by Dutch Diamonds Technologies were also evaluated. The first one is a nanocrystalline diamond probe, consisting of a ceramic core with a thin covering layer of the nanocrystalline diamond dust as shown on Fig.4.

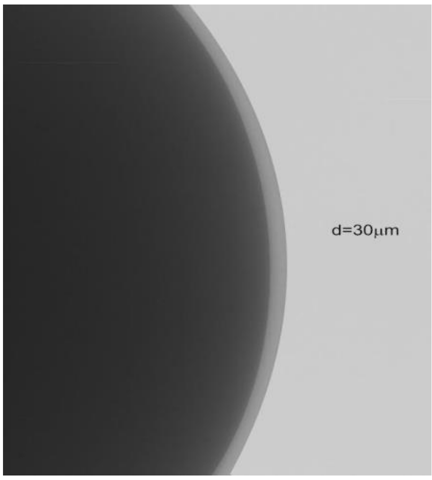


Figure 4. Thin layer of nanocrystalline diamond on ceramic core

The second probe is made of a monocrystalline diamond, which was rejected by the jewellery industry.

After the first observation of the tested part was clear, that measured surface was changed by tips of the probes. Thin visible traces were found around the whole surface in each layer where the tips of the probes were placed (see Fig. 3). A microscope with 100x magnification was used for closer examination of the surface and the first measurement of trace depth. However, this method was not precise enough. For precise analysis, a non contact (optical) surface profiler, Taylor Hobson CCI Lite, was used. The depth resolution of CCI Lite is up to 0.1nm, which makes it an ideal tool for analysis of the traces.

3 THE RESULTS WERE SUPRISING

Initially, the original surface was scanned, so it could be compared to the intact surface and surface with traces. All measurements were made using Mirau interferometer optics with 50x magnification [Whitehouse 1994]. In Fig. 5., parallel hills and dales are visible, as expected in a part machined by turning. It is also noticeable, that the distance between hills and dales is approximately the same, as are their heights and depths. Last but not least, the intact surface shows irregularly shaped defects indicating, that the material was ripped. This was likely caused by high speed turning.

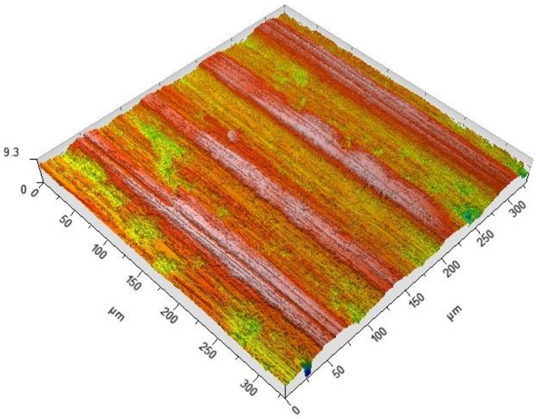


Figure 5. Original (intact) surface

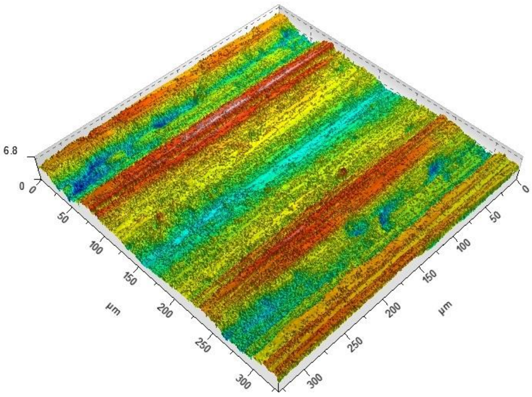


Figure 6. 3D model of the surface with trace nr. 1 (SiC)

Measurements made after the test indicate, that the visible traces were in fact abrasions of the measured surface. As shown in Fig.6., a deep dale is present in place of a hill on the original surface [ISO 25178-2:2012]. Further, the absence of defects in this dale indicates, that it was created by a very slow material removal and with a small force. To evaluate this hypothesis, the surface profile was evaluated. Longitudinal cut would have been useless, as it was necessary to see the profile in context of the surrounding intact surface to identify any present differences. Therefore, the evaluation of surface profile was performed in transverse direction as indicated by the black line on the Fig.7.

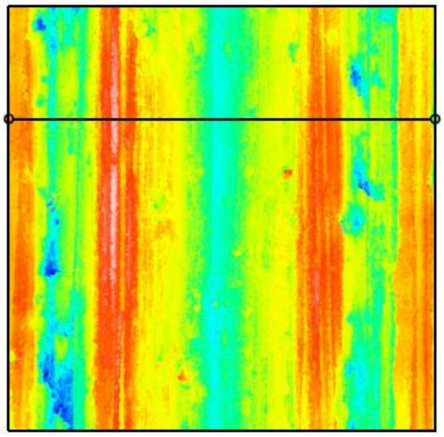


Figure 7. Transverse cut of trace nr. 1

The extracted profile is shown in Fig. 8. The valley in the middle of the profile is clearly visible and both sides of the valley present smoother texture. This is consistent with our hypothesis, that the surface of the part was reshaped by the probe tip.

The trace no. 1 was made by a silicon carbide SiC tip and that is surprising compared to the trace nr. 2. This amount of abrasion was expected with use of the Al_2O_3 tip, because of adhesive wear, when the material of the measured part is attracted and deposited on the surface of the probe tip. This phenomenon is present not only between an aluminium alloys and an Al_2O_3 tip. It appears, that the same process might be taking place between a SiC tip and alloys with a small Si content.

The third trace made by Si_3N_4 was very similar to the fourth trace made by zirconium oxide ZrO_2 (see Fig.10). It is obvious that the hill in the middle is slightly polished away, but it remains visible, as are the machining defects. However, in this case damage was not as severe as with the SiC tip. The best results, meaning the slightest damage caused by aprobe tip, was obtained from nanocrystalline and monocrystalline diamond as shown in Fig.11 and Fig. 12.

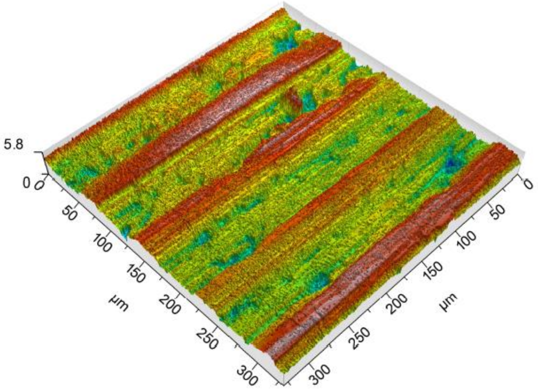


Figure 9. 3D model of the surface with trace nr. 2 (Al_2O_3)

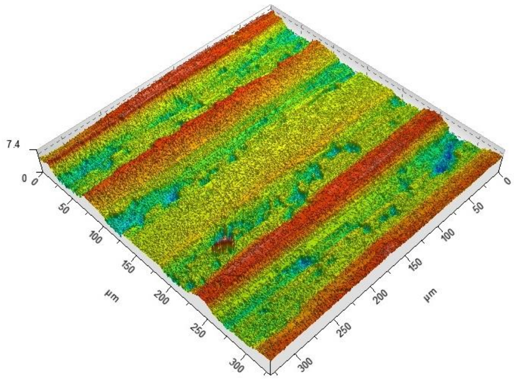


Figure 10. 3D model of the surface with trace nr. 4 (ZrO_2)

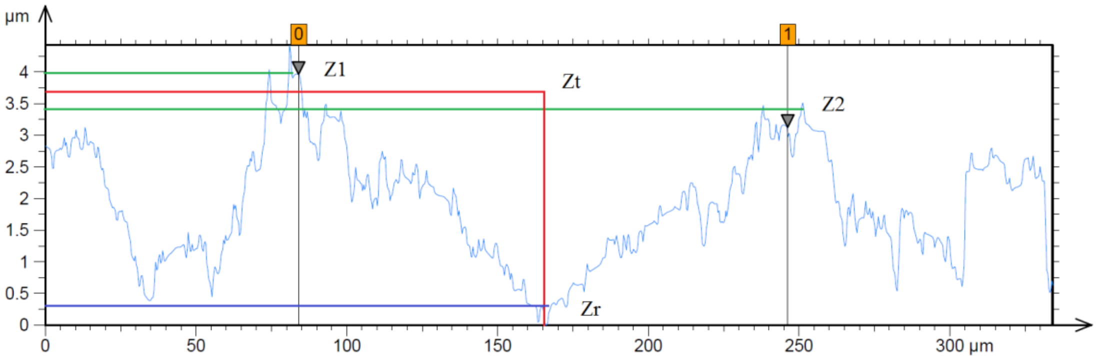
The loss of material was calculated using the equations (1) and (2). Results are shown in Tab 1.

$$Z_t = \frac{Z_1 + Z_2}{2} \tag{1}$$

$$\Delta Z = Z_t - Z_r \tag{2}$$

Results	Z_t[µm]	Z_r[µm]	ΔZ [µm]
TRACE NR. 1	3,75	0,5	3,25
TRACE NR. 2	2,43	1,38	1,05
TRACE NR. 3	2,81	0,9	1,91
TRACE NR. 4	3,12	1,7	1,42
TRACE NR. 5	2,56	0,74	1,82
TRACE NR. 6	2,70	1,25	1,45
TRACE NR. 7	1,98	1,62	0,36

Table1. Value of material loss in each trace



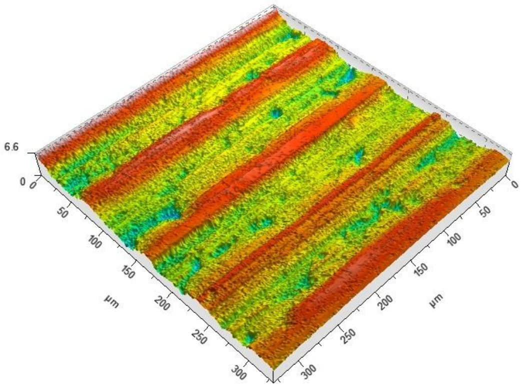


Figure 11.3D model of the surface with trace nr. 6

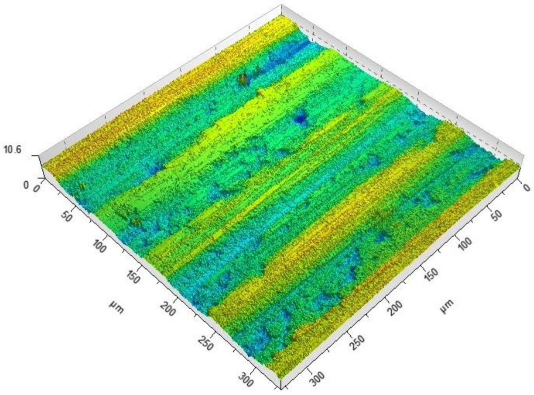


Figure 12.3D model of the surface with trace nr. 7

4 CONCLUSION

Performed experiments demonstrate that a measured part wear is a serious problem, when an unsuitable material is selected for the tip. The extent of damage of a measured part depends on the measuring force, measured material and surface roughness. Today, the most used material for CMM measuring probes include standard materials like ruby (aluminium oxide Al_2O_3), silicon nitride (Si_3N_4), zirconium oxide (ZrO_2), tungsten carbide (WC). However, it is now possible to find some unconventional measuring probe materials, such as monocrystalline diamonds, or nanocrystalline diamonds. This set of materials allows to choose a suitable tip for specific measured material.

The achieved results are very interesting and they have not yet been published. The phenomenon of adhesive wear was present under unexpected circumstances. The influence of measuring tip material on measured surface was shown and quantified.

Based on the experimental results, it can be deduced that aluminium oxide is a suitable tip material for aluminium alloy measuring. But the question remains if it is caused by a small amount of Si in the alloy content. Tungsten carbide appears to be the best tip material, as it does not cause much damage to tested surface and its cost is favourable. The smallest damage was caused by monocrystalline diamond. However, the probe is only a pre-sale sample. The cost of nanocrystalline diamond probe will be approximately 5 times more then aluminium oxide, with monocrystalline diamond being approximately 10 times more expensive. Nevertheless, it could be cost effective due to high durability of the diamond. It all depends on the price for end-users.

Wear of the measuring tip surface and the unexpectedly small adhesive wear with an Al_2O_3tip will be the subjects of further research.

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