Good Practice Guide Deliverable D6

“Measuring the complete geometric map of rolls containing the form and microstructure using fast microprobes”.

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EMRP project Microprobes

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Summary

This Good Practice Guide (GPG) was developed during the course of the EMPIR project MicroProbes “Multifunctional ultrafast microprobes for on - the - machine measurements”. Within this project a new type of roughness sensors was developed and tested.

Long slender piezoresistive silicon microprobes are a new type of sensors for measurement of surface roughness. Their advantage is the ability to measure at higher speeds of up to 15 mm/s, which is much faster than with conventional stylus probes. The drawbacks are their small measurement range and that they break easily when deflected by more than the allowed range of 1 mm. The integration of a microprobe into an existing roll measurement device is presented together with the measurement results. The results are promising, indicating that measurements using a microprobe can give useful data on the grinding process.

This good practice guide describes the required hardware and steps for the geometric measurement of rolls.

1. Introduction

Surface roughness is an important feature for surfaces in contact, for example when mechanical components are in sliding or rolling contact. A poor surface roughness, in combination with load, speed and lubrication properties, can result in increased friction and wear. Surface roughness is also important in industries where the product is formed on rolls and is thus often measured in several of these industries [[1]]. Most often, this is done using an inductive probe that measures a profile at speeds typically ranging from 0.5 mm/s to 1 mm/s [2]. In laboratory instruments, a translator linear guide creates a straight reference. In portable instruments, a skid close to the probe generates a reference as the skid slides across the highest peaks of the surface. Although this arrangement is far from ideal, most industrial roughness measurements are done with these affordable portable instruments.

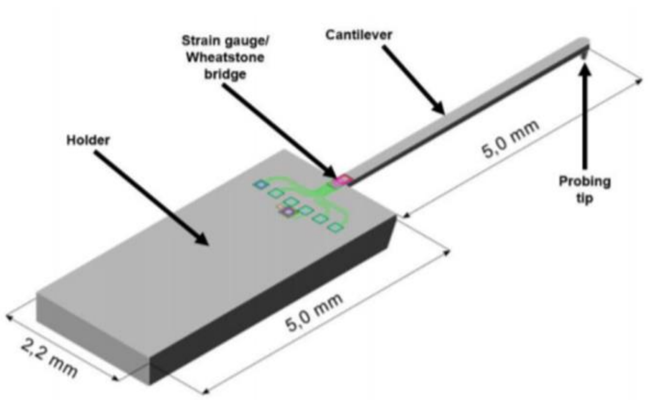
Piezoresistive silicon microprobes have recently been developed for the fast measurement of surface roughness [3][4]. There are different probe sizes for different purposes, but generally the cantilever is a few millimetres long and several tenths of millimetres wide. The microprobes are manufactured using silicon planar processing. The sensing signal is obtained from piezoresistive strain gauges integrated into the cantilever near to the clamping point. The microprobes can be used in instruments measuring surface texture, coordinate measuring machines and gear measuring machines [5] . Compared to traditional inductive surface-texture measurement probes, they have the advantage of providing roughness measurements at speeds of up to 15 mm/s . Another advantage is their relatively low price compared to optical instruments for roughness measurements. The measurement range is about 200 µm, which is sufficient for the measurement of surface texture in the manufacturing industry. A disadvantage is potential breakage of the probe when the deflection surpasses its range of 1 mm [6]. Novel microprobe designs have improved wear resistance by using diamond tips or hard coatings for the tip.

Rolls, large-scale cylindrical rotors in the paper and steel industry, are reground at regular intervals and dimensional measurements are performed throughout the machining process [7]. Deviations from the required diameter, form and texture affect the quality of the end product [8]. Therefore, roundness and cylindricity are measured during the grinding process but not the texture. For the past two decades both were measured using a piece of equipment called a roll measuring device. An example of this equipment and its measurement uncertainty is described elsewhere [9]. In the rolling process the topography of the roll surface is reproduced on the end product. In some cases, the human eye can detect stripes on the roll surface of just a few micrometres deviation or even less. Surface roughness also plays an important role in the designed functionality of some rolls. For example, if the rolls are too smooth, the paper web can stick to them; if the friction is too low, the ability of the roll to transport the paper web suffers. Therefore, the possibility to measure form and roughness of the roll would provide useful feedback for the grinding process.

2. Description of the microprobe configuration

Regular commercially available microprobes made of single crystal silicon are described in this guide. The microprobes were produced by CiS Forschungsinstitut für Mikrosensorik GmbH. Their vital dimensions are the cantilever length of 5.0 mm and the shape and size of the tip; further structural dimensions are shown in Figure 1. The microprobe tip has an eight-sided pyramid shape with a height of 100 µm. The radius of the microprobe tip is less than 2 µm with new sensors. The spring constant for the cantilever is 8.45 N/m.

When the cantilever is bent during measurement, the strain concentrates close to its connected base; four piezoresistive strain gauges are located there in a Wheatstone bridge configuration to enable measurement of the bending of the cantilever and displacement of the probe tip.



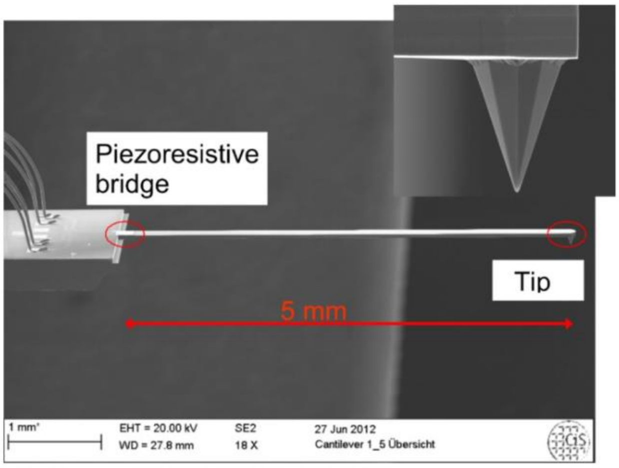


Figure 1. Illustration of a silicon microprobe.

In order to get the best possible signal-to-noise ratio, a preamplifier for the Wheatstone bridge signal is needed as close to the probe as possible. In this study, a preamplifier electronics printed circuit board (PCB) design from Technische Universität Braunschweig [10] was redesigned for this purpose. It includes a low noise voltage regulator for the Wheatstone bridge supply and an instrumentation amplifier for the bridge output voltage. The dimensions of the PCB were adjusted to a width of 50 mm and a length of 25 mm, which is better suited to the equipment intended for the industrial measurements. The bridge voltage was increased from 1 V to 3 V. The amplification gain was decreased to 61 to compensate for the voltage increase, reducing the noise amplification.

Frequency properties of the selected microprobe have been studied in earlier research [10] and the resonant frequency is calculated to be 2.8 kHz. Contact resonant frequency is much higher and slightly dependent on sample material, 9.6 to 16 kHz, and 14.1 to 14.3 kHz. Using measurement speeds up to 10 mm/s wavelengths down to 1 µm can be detected.

3. Verification

The characteristics of microprobe sensor can be verified by measuring a traceably calibrated surface roughness standard. The comparison of primary profiles measured with the stylus instrument and microprobe can be compared. For parameters Ra, Rz and Rsm the deviations from calibrated values of roughness standards should be less than 8%.

A typical uncertainty in the calibration of a roughness standard at the National Standards Laboratories and accredited laboratories is 4–5 %. When roughness standards are used in workshops for calibration of a measurement instrument, the uncertainty level is up to 8% [2].

4. Microprobe sensor set-up for roll measurements

Roll grinding machines have for several decades been equipped with measuring devices (Figure 2) to measure the geometrical form of rolls. For testing purposes for this guide, a microprobe was used to measure the local surface roughness profile of a roll from a paper machine. The measured roll was under overhaul and partially ground. The roll had a diameter of roughly 1 m, a length of roughly 8 m and was positioned in a grinding station with turning gear. The profile is measured parallel to the longitudinal axis of the roll.

Figure 2. Roll measuring device for measuring the roundness and shape of a roll.

Due to fragility of the microprobes, a sliding skid is used in the tests to protect the microprobe from too high deflections. The skid also works as a reference or datum for the measured profile. The roll is cylindrical, and the skid has shape of a plane giving a cylinder/plane contact. The sliding skid is sufficient for measuring roughness and acceptable for measuring waviness to within a few millimetres. The integration of the microprobe into the roll measuring device is described in detail in the thesis [11].

A microprobe holder was designed specifically for this study to enable mechanical installation of the microprobe on a roll measuring device. The microprobe is mounted on one of the measuring probes of the existing roll geometry device as shown in Figure 3. This allows the diameter variation or alignment errors of the roll to be ignored during roughness measurements, as the measuring probe moves radially relative to the roll. Also, the motion axes of the grinding machine can be used to perform roughness measurements. The microprobe was placed in contact with the roll on an axis moving radially relative to the roll. Measurements were performed on an axis moving parallel to the longitudinal axis of the roll. The measuring process was carried out in the same sequence each time: first make contact, then start the movement along the longitudinal axis of the roll.

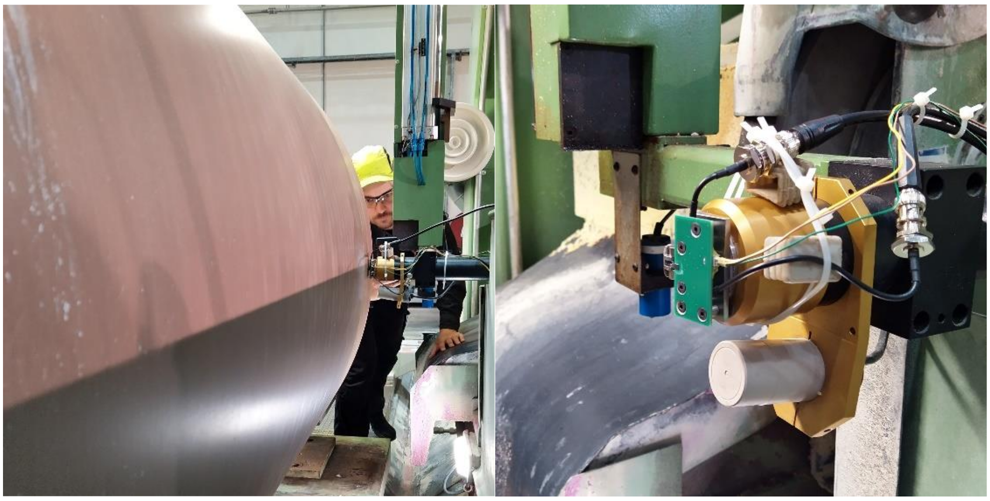


Figure 3. Paper roll with microprobe in the background (left picture). The roll measuring device in the picture (right picture) is of a different (older) type to the one illustrated in Figure 5 and 6 and as described in the text, but the head is similar.

Figure 4 shows a possible schematic integration of the microprobe into a grinding machine, including future improvements for a commercial version. The microprobe is mounted on a part of the roundness measuring instrument called the S4 arm.

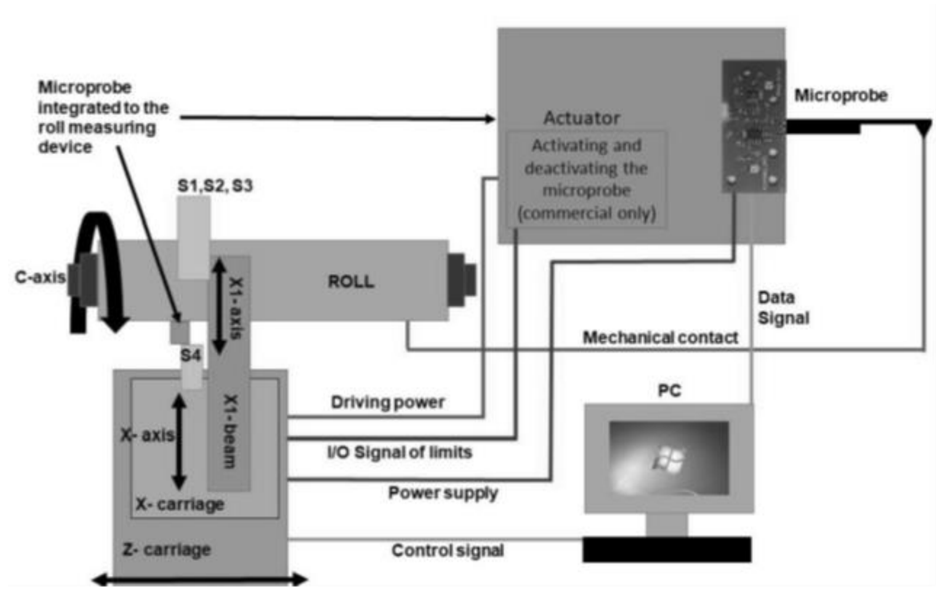


Figure 4. Schematic representation of microprobe integration into a roll measuring device. The microprobe is mounted on a measuring probe (S4) and is in mechanical contact with the roll. Power is supplied from the grinding machine and the data is processed with and stored on a PC.

Figure 5 shows the S4 arm and the microprobe with the prototype holder, which replaces the original measuring head of the arm. The kinematics is based on four bar linkage containing a spring which push the microprobe with skid into contact with the roll. With this mechanism the orientation of the probe does not change when moved into contact. The four pivot points of the arm allow filtering out of the diameter variation of the roll and are indicated in red in Figure 5.

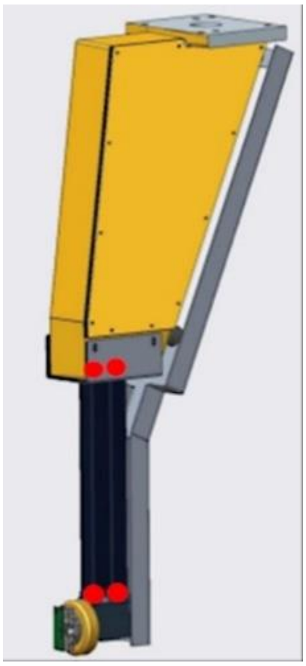


Figure 5. CAD design of microprobe integration in a roll measuring instrument.

Figure 6 shows the mounted microprobe and the prototype holder design on the left and an exploded view of the holder assembly on the right. The assembly consists of five individual parts and a nut, which belongs to the original S4 design. The parts are named in Figure 6. When the microprobe is mounted, there is a 12-degree angle between the roll surface and the microprobe.

With the microprobe integration used in this study, the diameter range of the rolls that can be measured is from 300 mm to 2000 mm. Measuring length is not limited by the integration method. However, the tip durability of the microprobe is limited, and the size of the grinding machine determines the longitudinal travel along the roll.

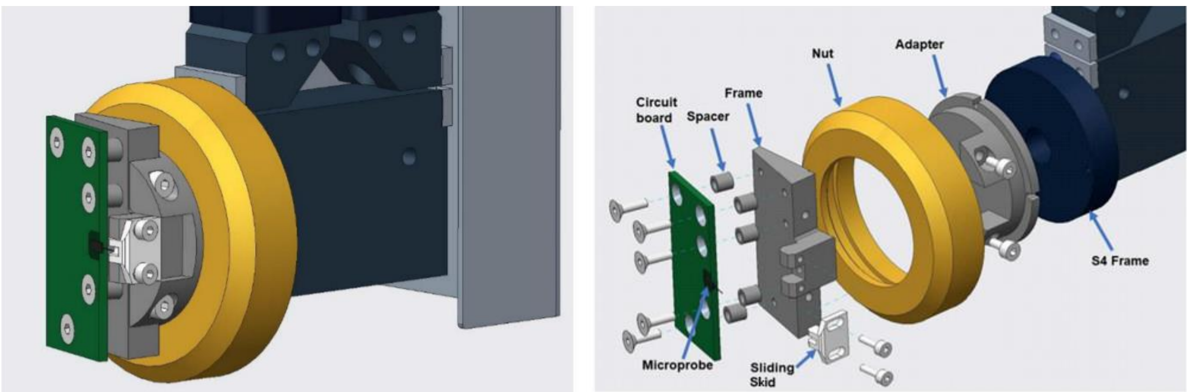


Figure 6. CAD design (left) and exploded view (right) of microprobe integration in a roll measuring instrument.

5. Making measurements

Rolls used in paper machines are large and roughness measurements are meaningful with sample spacing of about one micron or less. Therefore, it would not be economical to measure a roughness profile consisting of 10^6 points and length 10 m. Although this would be possible and, in some cases, meaningful this guide recommends measuring profiles of length 10 mm. With this length the overlapping of grinding can be detected. From these profiles' roughness parameters Ra, Rz and Rsm defined in ISO 4287 can be calculated.Click or tap here to enter text.

To inspect the complete roughness geometry map of the roll it is suggested to measure 10 mm long profiles at 10 different locations in the axial direction of the roll. If the complete roughness map of the roll is required, the roll should be rotated by for example one degree and the profile measurements would be repeated. However, normally, an angular step of 90 degrees can be used.

In some cases, the grinding wheel can produce a helical marking on the roll. These markings are called lead lines. In most of the cases they are visible, but sometimes they cannot be seen, but still leave a marking on the produced paper. To be able to measure them, a measurement length of 100 mm is recommended in different locations.

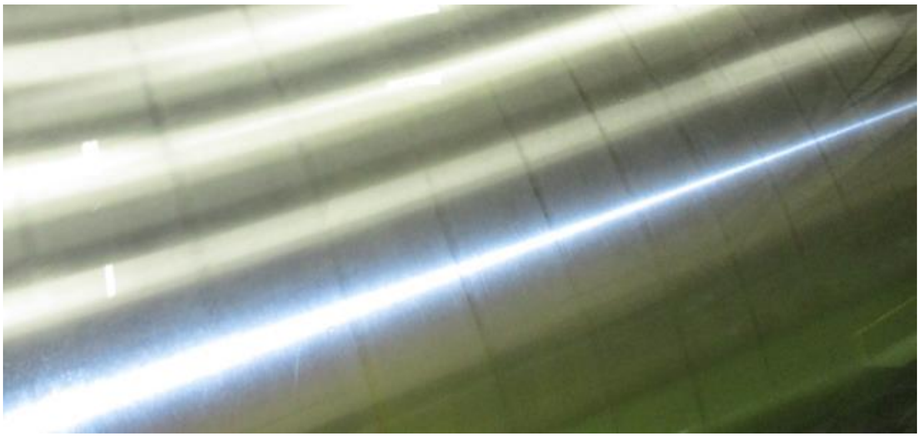


Figure 7. Visible lead lines on a roll surface.

Two examples of measured profiles at a roll of a paper machine are shown in Figure 8. They include a measurement over a lead line.

As the microprobe is equipped with a sliding skid (see Figure 6), it has limitations regarding measurements of waviness. However, for the purpose of feedback for the grinding process it might be useful to perform a waviness analysis. In Figure 9, short wavelengths are filtered out using a cut-off wavelength of 0.8 mm. This cut-off wavelength is small compared to the dimensions of the sliding skid. Now three large, repeated valleys are visible in the profiles, which tell us that there is a small mismatch between the dimensions of the grinding wheel and the pitch control of its movement. This is an additional example of useful data provided by microprobe measurements.

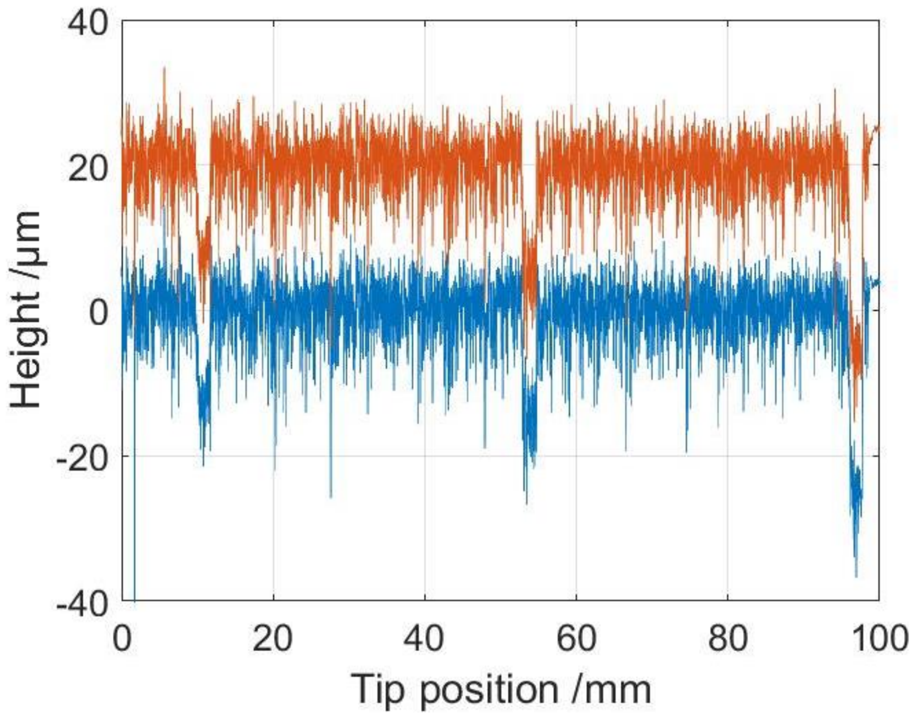


Figure 8. Two consecutive measured profiles of a roll measured at 1.67 mm/s and 100 kHz sampling rate. One profile is shifted by an offset of 20 µm.

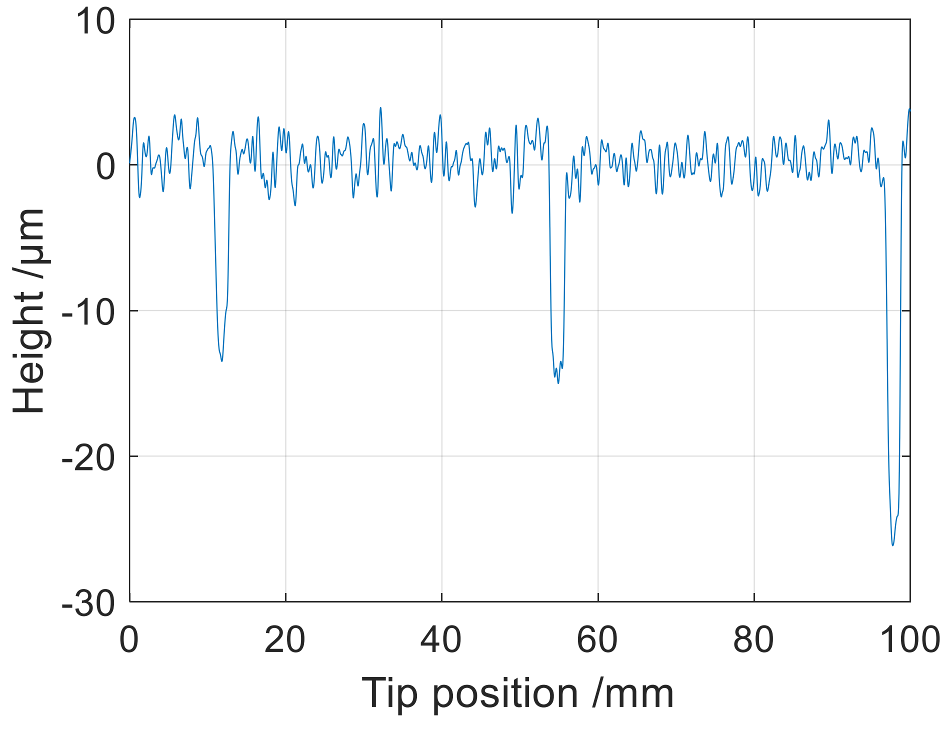


Figure 9. Waviness profile with Gaussian filter and 0.8 mm cut off. Three valleys with depths over 10 µm are visible.

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