CONTACTLESS MEASUREMENT AND EVALUATION MACHINED SURFACE ROUGHNESS USING LASER PROFILOMETRY

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Abstract

This article provides a detailed description of the system for automated control of surface roughness parameters and selected characteristics by laser profilometry. It detailed describes the software, hardware and other parts of the device for measuring the surface roughness of the components. Further it describes the behavior of these individual parts functioning as a whole, and ways to measure samples using the means of contactless measurement of object profile along the defined profile cross-sectiona by the technology of optical profilometry. The article also describes the innovative solution to the measurement of problem types of surfaces such as polished surfaces, where it is partly prevented the use of specific or non-traditional methods of polished surface modification. For measurement and evaluation of measurement data, it was found that the device for measuring the roughness, basically intended for the operation of the Department of the production process, meets our specifications in the field of software and hardware and is ready for further use.

INTRODUCTION

The importance of treatment quality of machined surfaces is growing and requires greater demands. This is due to the fact , that the surface quality has a major impact on the functionality of the entire device. Especially in the contact surfaces, the quality of roughness is crucial factor. It also has a significant impact on the life and reliability of operation of technical equipment. So it's good to monitor surface roughness functional areas and evaluate the measured parameters. Roughness arises as a result of the use of instruments and related parameters (micro-geometrical shape and size of roughness). Another reason for the roughness formation on the surface is making adjustments of the surface [1].

Roughness is seen as part of geometric deviations with a relatively small distance of irregularities. Material defects caused by accidental damage or material defects (pores, cracks), are to the surface roughness not included [2].

The surface quality of parts is one of the conditions for their proper function, and significantly influences the component life. Roughness represents the amount of inequality from the ideal shape and arises as a result of [4]:

- Used instruments and related parameters (micro geometric shape and size of the irregularities)
- applied surface treatment (physical and mechanical condition) [5].

In the engineering industry material tends to be intensively stressed during the manufacturing process . During machining, parts of removed material thermally and tension stressed. Machining takes place in primary, secondary and tertiary deformations. Due process in the tertiary area, on a work piece, just beneath the surface, hardness, tension and possibly structure can be changed. State of the work piece after the final finishing of components affects the properties of the final product. In dynamically stressed components such changes have a key influence on the properties of their reliability and durability [6].

The goal of the research and development in this area will be a tested system, mainly applicable for the measurement of roughness, which should be open for the possibility of further processing according to the specific conditions of use, especially in the software field. The system will be useful in research, development, training and education, and certainly also in the business environment.

MATERIALS AND METHODS

At the Department of operation of manufacturing processes, we have developed an experimental device for non-contact measurement and evaluation of surface roughness of components. It works based on laser profilometer (LPM - Laser Profilers). The experimental laboratory laser profilometer is shown in Fig. 1 and is designed for measurement and evaluation makrogeometry and microgeometry characteristics surface of components.

Fig. 1 Laboratory of laser profilometry

The laser profilometer (Fig. 1) consists of basic and supplementary parts. The basic part is the mechanical part (with a support aluminum structure which carries power components as shown in Figure 1. Complementary parts include divider picture calibrated with a prescribed roughness socket power strip with surge protection, battery backup power supply with overvoltage protection, external USB drive for data storage

Optical system forms part of the AVT Marlin camera 131 B and 23 FM 50 SP Tamron 50 mm with a visible area of 22 mm x 7 mm. Automated shift portion in the Y axis is realized by means of stepping motors Stan 8 MT 160-300 in each axis, a length up to 300 mm. The system allows you to measure samples of up to 8 kilogram in the precision setting position of 2.5 micrometer to move. Taking each step consists of 8 microns. Resolution of the sensor is 0.02 mm / Pixel.

Using an experimental system can be measured and evaluated parameters of waviness and roughness of the samples according to EN ISO 4287 and ISO 16610-21: 2011 (Rq, Rv, Rz, Ra, Rp, Wp, Wv WZ, Wa, Wq). The results of the evaluation parameters of the profile or profiles measured in the form of raw data can be exported in .csv format that is suitable for further processing experiments in readily available spreadsheet programs [3].

Transparent image processing and evaluation of experimental data facilitates video splitter Matrox TripleHead 2 Go Digital-Edition. It is a device for the distribution of one graphical output of the computer to three independent display output (in combination with the use of further graphics output, and selecting the enlarged working area can be obtained from four independent images) such that each monitor is different from the desktop or the application, while graphics performance of computer is not reduced [3].

The principle of measurement using LPM

The system uses laser profilometry based on triangulation principle. When this using this principle, laser line is projected on measured surface at an angle , which is then captured using a digital camera placed perpendicular to the scanned surface (Fig. 2) [3].

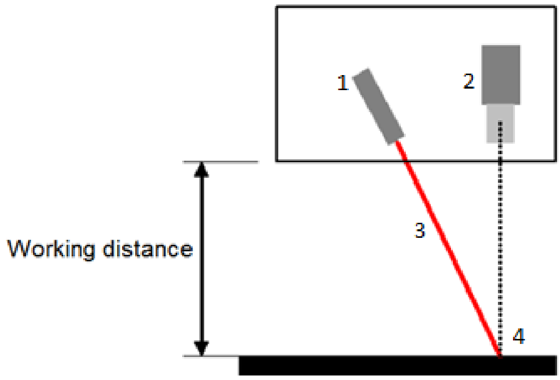

Fig. 1 Schemes to measure the LPM (LPMView User guide, 2015). (1-laser light source, 2-CCD camera, 3-laser light on the surface, 4-measured surface)

Measurement metodology using LPM

Important steps prior to measurement: (LPMView User guide, 2015).

1. Set the engine to the starting position (axis X, Y)
2. Sharpen CCD camera. Turn on the laser and start a live camera mode. Using a micrometer feed sample set so that the laser line is in the camera image. The camera is out of focus when the laser line is visible along the length of a camera view and is located in the lower part.
3. Set ShutterTime the camera. Length of the exposure period is important to the scanning, but in terms of obtaining a higher quality signal to the measurement profile. Due to the variety of scanned materials and surfaces can be re-experiment by changing the exposure time and confronting quality profile by using the tool live profile. The ideal profile would be the least noisy (still without fluctuations in value), the ideal laser line, the live image from the camera should be as continuous as well as the closest possible.

Methodology for measuring by laser profilemeter LPM consists of three steps:

• RAW image capture: Measured object is placed between the camera and light source. In terms of measurement it is the best solution to use black and white digital camera. The camera lens reflected through the illuminated object image on light-sensitive sensor that is placed in the camera. The sensor contains a certain amount of light sensitive units (pixels). Each pixel captures the brightness separately, with the intensity of light carries information about light transmission measurement object but also the background.

The light intensity at that pixel is then processed by electronic means, according to the camera type into the 8-bit form. This represents 256 levels of brightness. The result is an image consisting of a set of pixels, the color which is between 0 and 256 of gray levels, according to the light intensity at that pixel.

- Binarization of the image: In a further process the captured images is processed in software. Selecting the threshold level of intensity and that all the pixels that are less intensity level is assigned the color black and the other pixels white. In principle, it is the separation of the measured object from the background, allowing to achieve the maximum resolution of the measured object and the background.
- Calibration measurement: The result of image binarization is a set of black and white pixels representing the image of the measured object and backgrounds. We therefore assess what amount of pixels represent different geometric parameters of measured object. When placed an object whose geometric parameters we know between the camera and the light source, we can assign to each parameter the number of pixels. In this way we define the dimensions measured in pixel units, and we can measure the geometric parameters of objects with unknown parameters. It is necessary that measured objects are placed at the same distance from the camera to keep within the measurement plane.

Software equipment

Base programs:

- Operating System Microsoft Windows 7,
- MS Office (for data export to Excel).

Utilities:

- LPMView - used for communication with the laser profilemeter,
- AVT SmartView - camera preview and creating graphicall documentation,
- Test feed - management and testing XY displacement,
- Microsoft Excel - graphical processing of exported data.

Conditions for carrying out the experiment

Measured material was the precision reference specimen. It was manufactured by Mitutoyo company in Japan and is designed for calibration and evaluation of the measurement accuracy of the device for measuring surface roughness.

tab.1 Reference speciemen

Country of manufacture	Japan
Manufacturer	Mitutoyo
Ra	2.94 microns
Rmax(Ry)	9.3 microns

Fig. 2 Precision reference specimen

Software for observation of samples

Observation of the sample was used software LPM view (Figs 4 - 6). To view the image of the field captured by the camera of profimeter, AVT SmartView program is used (Fig. 4), which allows in combination with running shift shoot the video appearance of the surface of the measured component. For effective imaging samples LPM system is also equipped with an integrated light. Light consists of four white LED lights. Illumination of the sample with a laser beam or LED light is selected on the measuring head of the system.

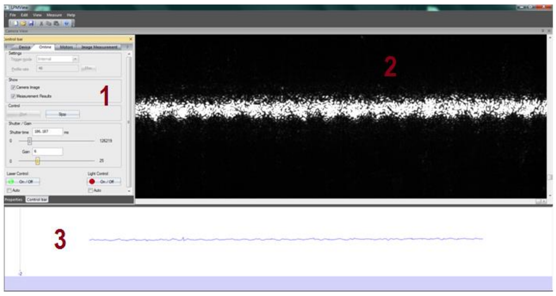

Fig. 3 Software LPM View (1-box setup and run a profilometer evaluation, 2-window real image of the scanned camera, 3-captured data, where the curve shows the real conversion)

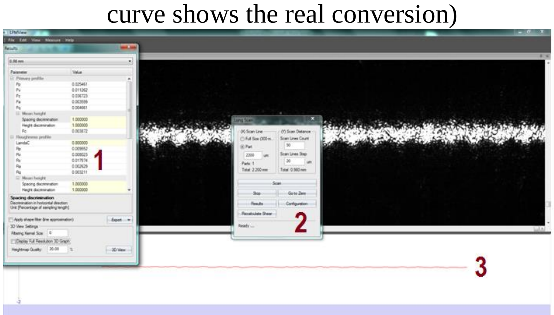

Fig. 5 Software LPM View (1- dialog with roughness parameters waviness profile, 2- long scan dialog, 3- where the curve shows graph using slope)

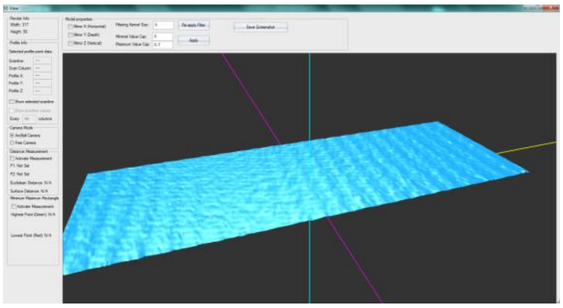

Fig. 6 3D image of the measured object

At position 2 (Fig. 4) there is a measurement of the profile window with a preview sample with visible laser line. The preview window is suitable for the construction of the image sensed as a result of setting the image brightness less adapted to high intensity laser beam.

At position 3 (Figs 3, 4) it shows the current measured profile. Stacking a series of profiles of the measured system LPM allows a 3D model of the measured object, which is shown in (Fig. 6). The model is also possible to stack the export profile in specialized programs working with spatial graphs such as MS Excel or Origin Microcal.

MEASURED VALUES

In the present experimental part of this study, it is performed the practical measurement using precision reference specimen in order to test the measurement accuracy of developed device by comparison of measured data with the standard. By evaluating the surface roughness, Ra parameter was observed - mean arithmetic deviation of the profile. Surface roughness was measured in a 53-step with the step size of 0.02 mm. The best mode with the cleanest preview in the dialog box for the sample was Gain 6 mode and Shutter time 186.2ms. From the measured values the arithmetic mean of the resulting roughness was calculated. The values for the roughness of the precision reference specimen are shown in Table. 2.

tab.2 Measurement data

Step(mm)	0	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16
Roughness(µm)	3.194	3.194	3.064	2.912	2.912	3.023	3.023	2.869	2.865
Step(mm)	0.18	0.2	0.22	0.24	0.26	0.28	0.3	0.32	0.34
Roughness(µm)	2.865	3.198	2.694	2.694	2.712	2.712	2.861	2.927	2.927
Step(mm)	0.36	0.38	0.4	0.42	0.44	0.46	0.48	0.5	0.52
Roughness(µm)	2.845	2.845	2.736	2.784	2.684	3.031	3.031	3.203	2.822
Step(mm)	0.54	0.56	0.58	0.6	0.62	0.64	0.66	0.68	0.7
Roughness(µm)	2.822	3.045	3.045	2.701	2.875	2.875	3.105	2.604	2.604
Step(mm)	0.72	0.74	0.76	0.78	0.8	0.82	0.84	0.86	0.88
Roughness(µm)	2.987	2.987	3.037	2.703	2.703	2.822	2.822	2.736	2.849
Step(mm)	0.9	0.92	0.94	0.96	0.98				
Roughness(µm)	2.849	2.963	2.963	2.972	2.729				

Roughness precision reference specimen: Ra = 2.94 µm

Average measurement data: $\overline{Ra} = 2.89$ µm

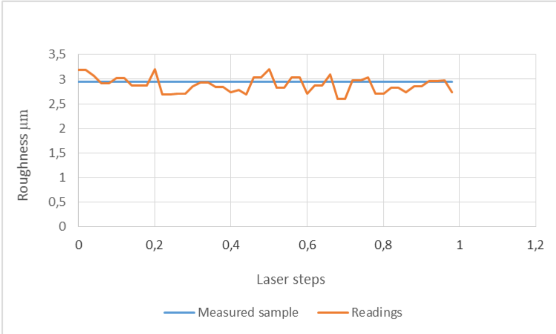

Fig. 7 Graph of the measured value

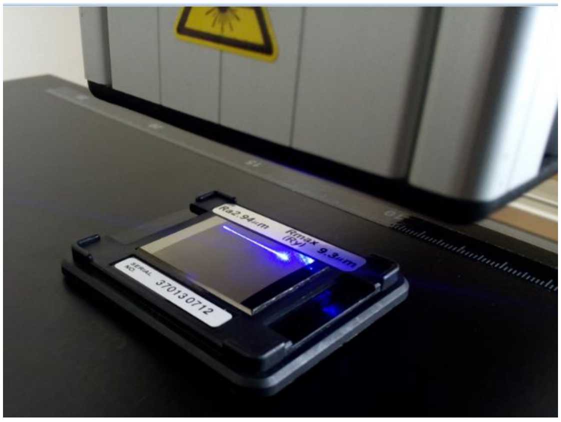

Fig. 8 Blue laser measurement

RESULTS AND DISCUSSION

The goal of this study was to evaluate the measured of sample surface using a laser profilometer, which was constructed of components available on the market at the Department of manufacturing processes. The sample was produced with a surface roughness with a value of 2.94 microns. The sample surface is glossy which caused a slight interference reflections. It had a slight effect on the measured data. Due to glossiness, during the measurements operating mode of the profilometer had to be set to Gain 6, in which there was the cleanest camera preview of the samples without any significant noise.

The graph shows the dependence of the measured surface roughness on the surface roughness of the precision reference specimen. Figure. 7 illustrates measured values for the arithmetic mean deviation Ra. As can be seen, by comparing the average of measured values and the value of the precision reference specimen, we found a difference of 0.05 microns. This difference was due to the fact that the measured surface was shiny and there was a refraction of laser light coming on the sample surface and its subsequent reflection to the CCD camera. The proposal for the research is a series of experimental measurements of different types of surfaces. The result will define the system settings, due to the application of the second measurement surface.

Ján Šustek and Adrián Banský in their study „Assessment of surface roughness using laser profilometry" stated that laser profilometry is an optical contactless measurement method for the evaluation of the profile parameters of surface roughness. The optical method also allows to measure the geometric parameters of objects that are difficult to measure using standard measurement methods. This method is much faster, more accurate and reliable solution especially compared to manual measurement systems.

According to the specifications of the standard ISO 4287 and STN EN ISO 11562 software LPMView in cooperation with a laser profilometer allows to perform a comprehensive assessment of the machined surface. As we found out in this practical measurements, also our laser profilometer allows comprehensively evaluate the measured surface. However, it is necessary to define the use of the operating mode Gain by different types of surfaces which will be the subject of further research and development [7].

The design of our roughness tester comprises of a supported aluminum construction which carries device actuators. The main part has a profilometric head consisting of a CCD camera and a laser diode with the light source. Complementary part of the assembly is a set of shifts, which allow movement in the XY plane.

Non-contact system for measuring the roughness at the Department of operation of manufacturing process is not able to measure all the objects and parts, but is merely an extension and improvement of methods for measuring the roughness of machined surfaces. The advantage of the proposed system is mainly the speed of measurement and processing of the measured values, further advantage is favorable price. Disadvantage is the geometry of the measured surface, which must be satisfactory, and that is, the shape of the measured object may not be very curved or oval.

CONCLUSIONS

Surface roughness is a characteristics that affects the durability and reliability of components, energy loss, wear resistance, tribological properties, etc. In terms of machining technology of machine parts, surface roughness is one of the standard criteria for assessing their quality. Surface roughness significantly influences the course of physical and chemical phenomena in the operation parts, friction, sealing efficiency, operational reliability, durability and economy of devices [9]

By the non-contact roughness measurement system at the Department of operation of production processes we are able to measure a wide range of soft and hard surfaces, which is a major advantage of the device. Also, the measurement is limited by the size and weight on the sample. Therefore, as part of research and development system for the contactless measurement and evaluation of surface roughness are trying the topic of surface roughness measurement to expand and improve this facility.

At the first step when improving our devices, we were based on the disadvantage to measure multilayer and glossy surfaces. When measuring glossy surfaces, a large amount of laser light incident on a surface components was reflected back to the CCD camera. The camera lens reflected through the illuminated object image on a photosensitive element which contains a certain amount of photosensitive units, which can not handle such a light. Simply, the camera sensor is undesirably illuminating by laser light reflected from the surface of the measured component. Therefore, to improve roughness meter, instead of the original red laser we used a blue laser Powerline Blue (Fig.8) with a wavelength of 445nm, which falls under the category of precision lasers. Their main advantage is the use of special optics. This lens provides uniform light intensity distribution along the length of the line compared to the previous type of laser. The aim of the experimental part of the test was correct measurement of the assembled device and comparison of measured data with the standard. However, this method of measuring surface roughness is merely extending and improving the methods for measuring roughness.

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