XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

MEASUREMENT OF ROUGHNESS USING IMAGE PROCESSING

J. Ondra
Department of Mechanical Technology
Military Academy Brno, 612 00 Brno, Czech Republic

Abstract: A surface roughness measurement technique, based on an optical method using a computer vision system, was investigated for applicability to in-process monitoring of surface quality. The developed vision system uses a CCD camera for scanning gray-scale images from an area of the machined workpiece. This images were analysed with digital image processing system. Some new optical roughness parameters were derived from the images based on their histograms and optical objects of machined surface. New parameters were plotted against the corresponding average roughness values (Ra) determined using a stylus method. The resulting curves were researched to determine which optical parameters are optimal for use in the surface monitoring system. As most useful were a number of dark objects of the image and coefficient of variation of the histogram of inspected surface.
Keywords: Surface roughness, CCD camera, monitoring system

1 INTRODUCTION

The present increase in automation level of machinery production is leading to continuous rise of demands for knowledge of machining process nature and characters. This trend is - to a certain extent - complicated by complexity of physical, chemical and other processes existing in the course of machining or by a great number of characteristics influencing the cutting process. Machine operators in standard production accomplish a range of monitoring, deciding and control actions (tracing of tool working conditions, checking on tool condition, etc.). These actions are carried out during interruptions of machining cycles or in conjunction with checking the workpiece for quality. But man's reaction capabilities and his speed of operation are often not sufficient to control the machining process reliably even in this conventional production. This fact can have severe economical and quality consequences especially when expensive and complex workpieces such as those made of special and heavily machinable materials are being machined. Therefore in the modern machinery production these actions are still more often provided by means of tracing and monitoring systems capable to be aimed at cutting process monitoring, at monitoring the workpiece or at monitoring the machine or the cutting tool.

The monitoring systems must trace the machining process as the control and also the metrological aspects are concerned to prevent possible damages that could arise due to a machine or tool crash or due to out-of-quality production. The sensors read various items of information from the manufacturing process, they form parts of information system of the technological site in question and transfer the information flow for further processing. That means they serve as connecting links between the technological process of machining itself and the machine control system. But the standard conventional methods of surface measuring are not capable to provide objective scanning without contacting the surface being measured and do not allow to provide checking in the real-time, too. We can therefore just imagine with much difficulty the usage of classic profilometers (even the portable ones) as facilities for on-line or off-line checking on workpieces within the automated production directly. The main disadvantages of optical methods for evaluating the surface microgeometry consist in dependence of those methods upon optical features and dimensions of workpieces. The advancement in optoelectronics now allows quick and contactless measuring of surface roughness. As the currently used surface roughness characteristics are proposed predominatingly for stylus method assessment it is necessary to bind the information obtained by means of optical methods with the existing system of surface roughness assessment. The effectiveness of machinery production can therefore be significantly supported by advancements of modern systems for checking and inspection those systems being based on digital processing and evaluation of images scanned by means of cameras. The systems for image digital processing in linking with the computerized evaluation can identify reliably a great deal of imperfections and defects of produced workpieces. The application area of those systems consists in

- checking for the surface quality
- checking for appearance and completeness of products
- checking for adherence of product dimensions
- identification of products
- determining the correct position of workpiece

The above-mentioned circumstances have formed the base of suggestion for solving a research project. The aim of the latter should be the selection and investigation of modern technical and technological principles to enable tracing, monitoring and assessment of machining process including quality characteristics of surface on machined workpieces. The project has been directed to the area of special materials (steels) machining with usage of the most often used machining methods.

Suitable ways for tracing the machining passes and for the surface roughness assessment should be verified during machining the reference (etalon) and special steels in order to extend and improve the procedures for tracing and monitoring the cutting process including the contactless assessment of workpiece surface.

2 EXPERIMENTAL RESEARCH WORK

The steels 13 240 (Mn-Si) and 15 230 (Cr-Mn-Si-Mo) were selected as the experimental steels and the steel 12 050 (C45) was selected as the reference material for comparison of the results. The steel 12 050.1 was in the state after normalizing, the steels 13 240 and 15 230 were used for testing in two states of heat treatment:

- in the state after **soft-annealing** (the material condition corresponding with the state after delivery from the manufacturer and used in some cases for drilling of deep holes) and
- in the state **after heat treatment to strength** corresponding with the strength used for finalproduction.

Table 1. Mechanical properties of tested steels

Steel	Hardness [HV]	Breaking strength R_m [MPa]
12 050.1	186 a 188	630 a 640
13 240.3	175 a 181	600 a 620
13 240.7	312 a 317	960 a 980
15 230.3	144 a 147	520 a 540
15 230.7	358 a 368	1120 a 1150

Scanning of machined surfaces was carried out on specimens machined by turning, drilling and grinding. A monochrome CCD camera 752x582 dots with the lateral control panel was used for assessment of the machined morphology. The camera was attached to the type BPH20 grinding machine by means of a specially prepared stand, the latter enabling the camera's vertical movement above the machine table with the workpiece clamped. The precise focusing was carried out using an objective after rough focusing by camera's repositioning. The adjustment of the camera (including objective) was invariable for all of the specimens being ground so that the width of the scanned viewing field was 1.25 mm of the workpiece surface. This setting enabled to scan an image corresponding to the measured length of surface roughness. The camera was interconnected to a digitizing card by means of a cable. Monitoring of the machined surface itself was carried out in the SlowScan mode by means of an image analyzer which could restrain any random disturbing effects during image scanning. The surface images were scanned after stopping the feed in one dead center of the grinder table. The surface images scanned were stored using the DIG format and prepared for further processing. The double-monitor arrangement of the digitizing card allowed on-line surface tracing on one monitor (including the precise adjustment of the specimen position for scanning) while the digital image analysis itself was carried out on the other monitor. The surfaces turned using the type SUI40 lathe were scanned after stopping the machine and evaluated in a manner similar to that for the ground specimens. The morphology of holes drilled using the type VO32 drilling machine was scanned by means of a boroscope after cleaning the holes. The boroscope was attached to the camera by means of an adapter. The scanning took place in the depth close to the bottom of individual holes and the image analyzer was used again under the same conditions as with grinding and turning. The SlowScan control can be used for static image scanning only. The slow scanning makes it possible to get images of a very high quality even under very adverse conditions for image scanning such as under extremely low lighting with scanning be means of a TV camera or under low contrast of the image scanned. The high quality is achieved thanks to an integrated video input during the time of taking several shots. The surface images were displayed in gray-scale hues so that the white colour was corresponding to the value of pixel „255“ while the black one - to the value of pixel „0“. The slow scanning was preferred during solving the task and the reason was the higher precision of the image obtained which allowed the first-rate assessments and conclusions. The system can be operated even in the classic video mode during machining thus making possible scanning of images directly from the video signal in the TV form. Signals from several cameras placed within the technological process can be transferred to the digitizing video-adapter inputs. After loading the input one of the monitors can display the actual image conducted to the input in question. It is possible to „freeze“ the input image from the technological process which in turn makes it possible to find a suitable moment for reading-in an image in the case of moving images. After reading the image into the computer main store the image changes into a working image displayed or processed on the second monitor. The system makes possible even quick scanning of several images in success from one video input and their storing into a storage medium.

Various methods of processing and filtration of surface images obtained were also tested with solving the task and with verification of the system. Various variants of linear, non-linear and adaptive filters were tested as accessories serving for noise suppression, image definition increase, highlighting of object and structure boundaries. The best result were achieved with images of ground, turned and drilled surfaces when non-linear filtration procedures were used, especially with equalization of the image histogram. This procedure enabled emphasizing of structures within the image and improve recognition of minor details of a low-contrast image. The system makes use of variably large pixel ambient for calculating the cumulative histogram, the ambient size being loaded with procedure activation. The selection of a small ambient leads to remarkable emphasizing of image fine structure. On the other hand, the image global contrast can be deteriorated. The optimum image then can be find somewhere between the two extremes mentioned. As the investigated machined surface images are concerned, the selection of an ambient of 27x27 pixels revealed optimum and this ambient was also used for further processing. A special sub-routine was used to suppress noise within the image (this noise being represented by objects mostly one pixel in size) or for selective removal of small objects up to the size of 32 pixels. After accomplishment of this image editing the real assessment of surface images was carried out this assessment consisting in determining the number of objects within the image, always for one of the selected and defined pseudocolours. The processing resulted in an object rate histogram dependent on the object area and portioned into 128 classes, in a histogram of object cumulative rate in dependence on the object area and in the total number of objects within the image in question. Another characteristics of the surface image were obtained through evaluating the type and parameters of an image histogram the latter originating from absolute and relative rates of pixel values. The numbers of objects for the selected gray levels are titled in the graphs as B1 (the pixel values 0 up to 127, dark objects) and B2 (the pixel values 128 up to 255, light objects). As the turned specimens are concerned, the influence of wear was traced always within the framework of one machined material.

3 RESULTS AND CONCLUSIONS

The accomplished experiments have confirmed the presumptions about possibilities to exploit the technology of image digital processing for in-process monitoring of the surface state or roughness, as the case may be. The experimental monitoring system allowed to distinguish various characteristics which influence the optical appearance of surface. The visual evaluation of an image allowed to find remarkable differences in surface morphology of the individual steels, investigated these differences resulting from the grade and heat treatment of special steels in question or from wear of a drill or a turning tool (Figs. 1, 2), respectively.

The initial uniformly scored surface gets gradually more rough and contains small „islands“ of sticked-on and additionally deformed material. The numerical characteristics of roughness are growing subsequently due to this phenomenon and are in correlation with the number of objects identified on the specimen surface, especially from the view of the surface trend [1]. In practice and with all the steels investigated, the wear of cutting tool deteriorates the roughness of the machined surface and, at the same time, diminishes the number of objects identified on the surface (coefficient of correlation being -0,841 to -0.981).

The surface objects are being „cast“ into bulks due to the tool wear and the optical reflectance is increasing (Table 2).

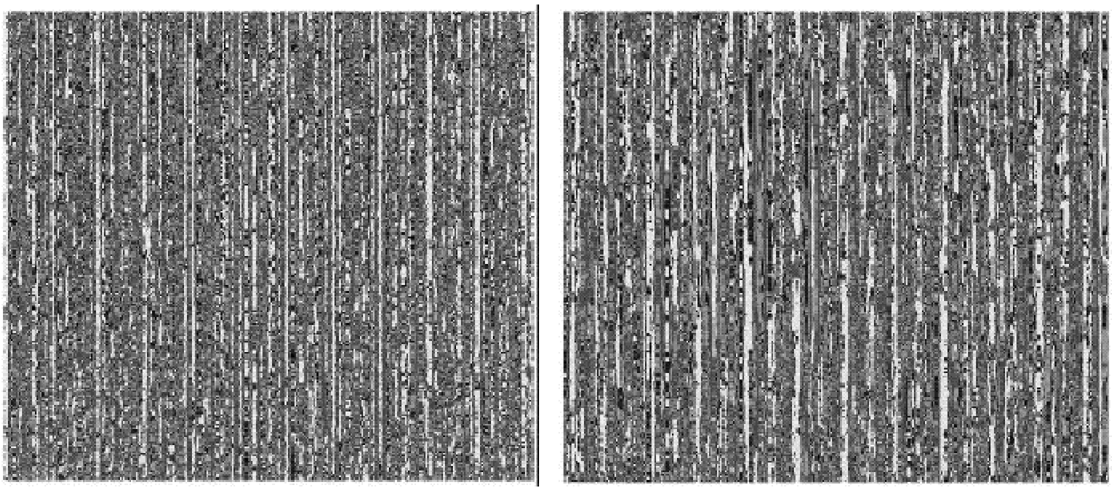

Figure 1. Turned steel 13240.3 surface morphology (sharp and worn-out tool)

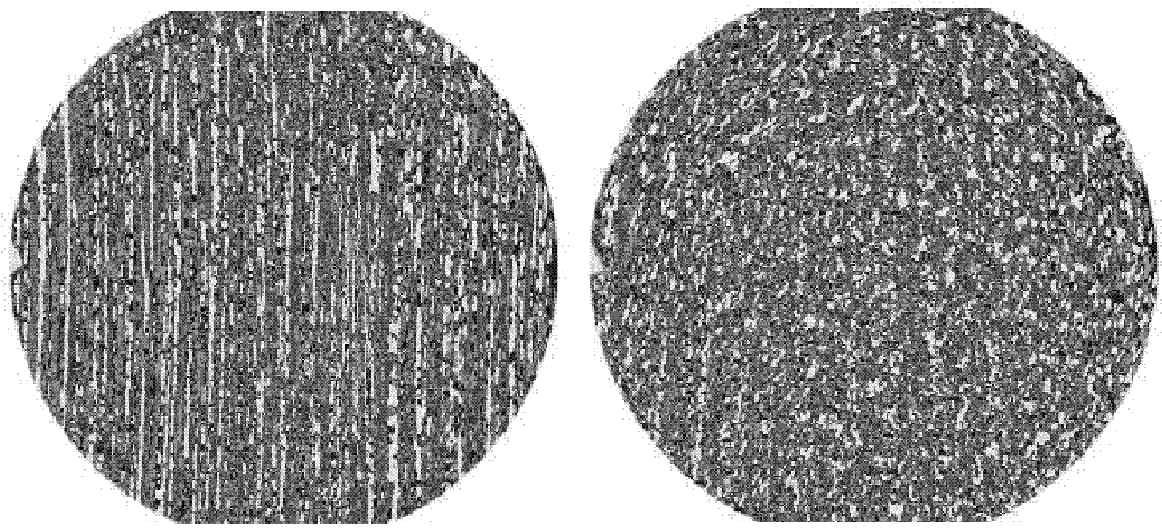

Figure 2. Drilled steel 15230.3 surface morphology (sharp and worn-out tool)

Table 2. Histogram characteristics of surface images

Material	Average value	Scattering	Mode/relative rate
12050.1 sharp tool	94.5	1965.2	66/2.50%
12050.1 worn tool	114.1	3515.4	70/1.49%
13240.3 sharp tool	98.9	2366.6	62/2.09%
13240.3 worn tool	115.7	3697.6	64/1.41%
15230.3 sharp tool	106.6	2901.9	64/1.91%
15230.3 worn tool	114.0	3364.0	68/1.48%

Concerning the specimens after grinding, the influence of grinding conditions upon the surface characteristics were tested using type A99 25drilling and turning (Figs. 3, 4) were found between the roughness Ra and the number of identified objects especially for heat-treated-to-strength steels, except for one combination of cutting conditions. The image histograms of turning proved the tendency towards increasing the average values and scattering with increased wear of tool and this was also confirmed by graphic illustration of surface profiles passing through the selected line of image.

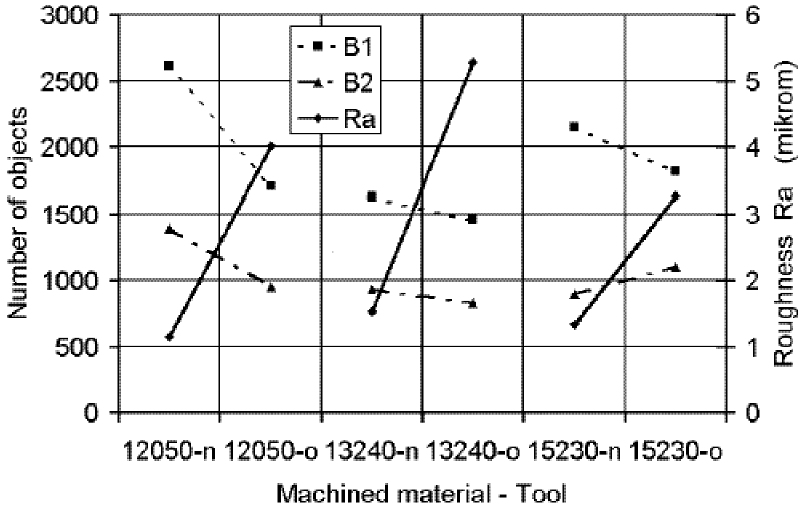

Figure 3. Influence of tool wear upon number of objects in turning (n-new tool, o-worn tool)

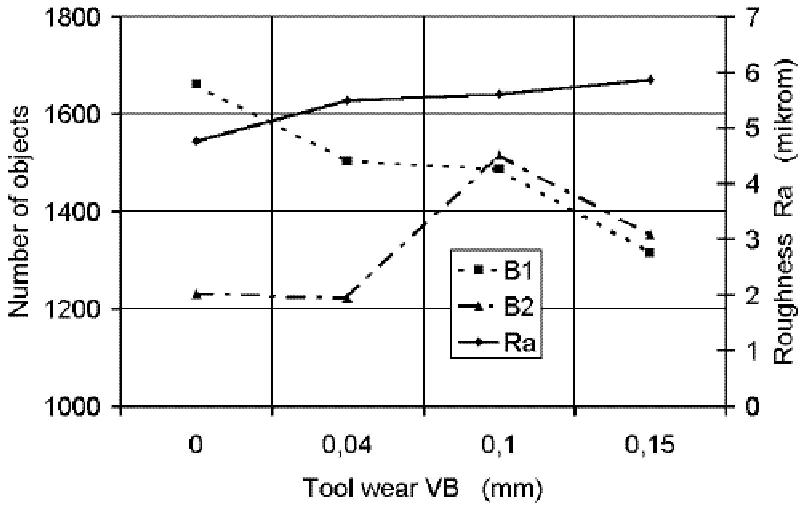

Figure 4. Influence of tool wear upon number of objects in drilling

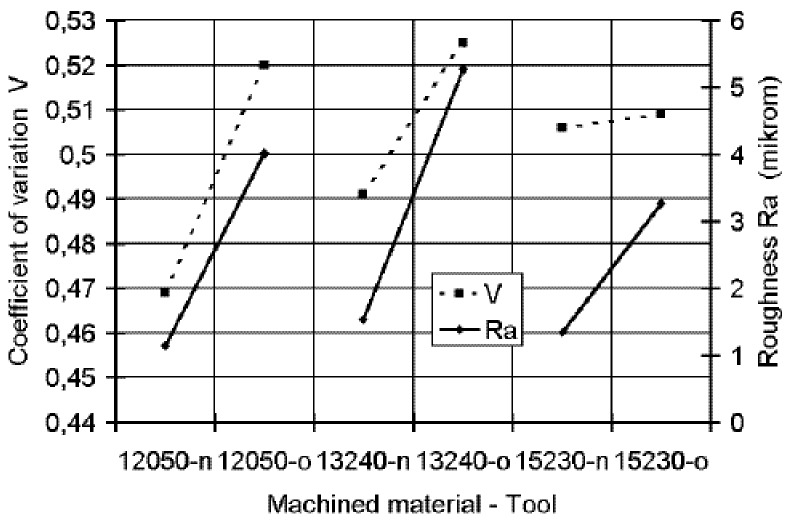

Figure 5. Roughness Ra and coefficient V dependence upon tool wear (turning)

Figs. 5 and 6 shows the roughness Ra dependence upon the value of coefficient of variation belonging to the normal distribution of image histogram (V = s/m). The parameter V proved also a very good correlation with the roughness Ra as well as the number of dark objects and therefore they can be used with the roughness monitoring in a wide manner. The accomplished experiments form a good starting position for further investigation how to apply the methods of image digital analysis for surface assessment during machining. The monitoring system used is suitable for off-line scanning of surfaces and even for on-line scanning with grinding and face milling. Nevertheless, in-depth verification of correlations between the optical and conventional surface roughness parameters will be necessary.

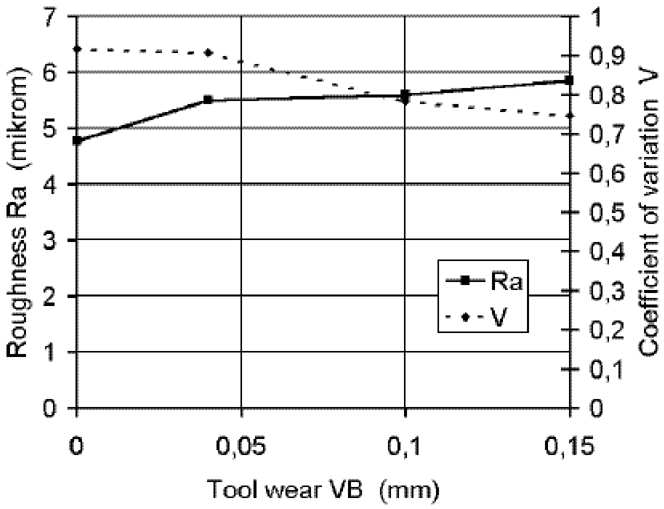

Figure 6. Roughness Ra and coefficient V dependence upon tool wear (drilling)

REFERENCES

[1] J. Ondra, Machined Surface Monitoring (Czech), in: *Proceedings of the 5 th Professional Seminar "Materials and Technologies in Special Armament Production" (Brno, 6. May 1999),* Military Academy Brno, Czech Republic 1999, p.39-46.

AUTHOR: Ass. Prof. Dr. J. ONDRA, Department of Mechanical Technology, K203, Military Academy Brno, Kounicova 65, 612 00 Brno, Czech Republic, Phone +42 05 4118 2433, Fax +42 05 4118 5367, E-mail: josef.ondra@vabo.czal