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Evaluation of 2D and 3D Surface Roughness Parameters by MATLAB Algorithm in Ball End Magnetorheological Finishing Machine

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Abstract

Evaluation of Surface Roughness is a crucial requirement in analyzing components life and performances. In analyzing Surface finish, Ra, Rz and Rq are the most widely used parameters in terms of 2D roughness and Sa,Sz and Sq with respect to 3D parameters. Assessment of Surface roughness involves various contact and noncontact methods. This work deals with a new surface inspection strategy applying a newly developed MATLAB algorithm for the BEMRF process. Conventionally the finished workpiece is unloaded for inspection thus generating a loss of production time and hindering the automation of the process. This work attempts to minimize the loss of time in frequent inspection of the finished workpiece by using a laser confocal chromatic sensor which is an integral part of the BEMRF setup. The laser confocal sensor measures the data points (i.e. heights of the surface asperities) of the surface there by aiding in surface finish evaluation. The Surface data points are analyzed by the proposed MATLAB algorithms. The MATLAB algorithms evaluated the data points, taking the data points as input and generated 2D parameters (Ra, Rz, Rq) and 3D parameters (Sa, Sq, Sz) as outputs. The results were compared with that of the standard methods of roughness measurement and were found to be marginally superior over them.

Keywords: Surface Roughness, BEMRF, MATLAB, Confocal sensor.

1. INTRODUCTION

Surface roughness forms an important index in establishing the quality and functionality of components manufactured by various manufacturing processes. The roughness of components depends on the surface topography which characterizes the components. Despite the need for quality inspection and importance of surface micro topography the task of insitu or in process measurement of surfaces have not been developed adequately. [1]

Conventional method of surface roughness measurement makes use of stylus and skid based measurement systems. In the stylus based methods the stylus probe is traversed over the surface and its movement is then traced by a transducer to analyses the surface characteristics. This system suffers major drawbacks due to its geometric limitations, sensitivity of the stylus tip and due to the effect of the skid. For soft materials, the tip can generate scratches and in characterizing harder materials the tip can get damaged. The other major limitation of this measurement system is the size of the tool tip. For the asperities smaller and narrower, it will be difficult for the stylus to penetrate them and hence measurement will be prone to errors. [2,3]

Thus, non-contact measurement techniques have become the need of the hour especially in the domain of micro and nanomachining. There are various non-contact measurement techniques like optical interferometry, confocal scanning microscopy and image processing measurement system.[4]

There are various surface texture parameters to quantify the characteristics of a surface such as 2D parameters, 3D parameters, Motif parameters, bearing curve parameters, etc. Conventionally 2D profile parameters are used for surface characterization. The 2D parameters generally used are Ra, Rq, Rz, Rp, Rv. These parameters are defined by ISO 4287 standards. [4].

The conventional 2-D surface parameters cannot give detailed information about the real surface topography of whole component. [5]. While the 2D parameters are acquired by the profile locus the 3D parameters are obtained by the areal surface which gives a detailed information about the surface with less degree of errors. [6] Also the statistical information gained from the 3D parameters have better robustness and reliability compared to the 2D parameters. [7] The various 3D parameters generally used for surface evaluation are Sa, Sq, Sz, Sv,Sp etc. [8].

In this work, a new measurement strategy for the BEMRF machine is developed. BEMRF is a magnetorheological finishing process capable of finishing a wide variety of materials to achieve surface finish in the nanometer range. [9]. In the BEMRF machining setup developed at IIT Delhi, the workpiece after finishing is cleaned by an automatic cleaning system and is made ready for inspection. [10] The traditional method is to unload the finished workpiece and then it is taken for external inspection. This method of a surface inspection is unfavorable for the complete automation of the BEMRF process. Hence a surface inspection system was needed to be integrated to the machine setup to prevent the frequent external inspection procedure. A laser confocal chromatic sensor was incorporated with the machining setup for the surface inspection.[14]

In the laser confocal chromatic sensor, a multilens optical system focusses the polychromatic white light onto the target surface. The arrangement of the lenses made the white light to disperse into a monochromatic light by controlled chromatic aberration. A specific distance to the target is assigned to each wavelength and only the wavelength corresponding to the target

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is adopted for the measurement. The light reflected from this point is imaged by an optical arrangement onto a light sensitive sensor element, on which the associated spectral color is detected and evaluated. Several distance points are accordingly evaluated for multi-peak measurements. [11] The evaluation is collected in form of data points which are stored in .csv format.

In this work, the surface data points (i.e. heights of the surface asperities) were generated by the Laser confocal sensor incorporated in the BEMRF machine setup at IIT Delhi. The data points are then analyzed by newly developed MATLAB algorithms which calculate the 2D and 3D parameters. The parameters calculated by the MATLAB programs were compared with standard values for validation and were found to be highly accurate. The algorithms developed can be utilized for surface roughness characterisation replacing the need for using any proprietary software. Hence a considerable reduction in the post processing time for surface evaluation can be achieved by use of this strategy.

2. EVALUATION FROM COORDINATE DATA

In this work experimentation was carried out differently for 2D and 3D surface roughness characterization. The experimental setup involved a confocal chromatic sensor which is integrated in the BEMRF machine. The confocal sensor is of MICRO EPSILON make (IFD 2451) [11]. The confocal sensor is a part of the BEMRF tool setup shown in Figure 1. The tool with the confocal sensor was held stationary in the Z slide while the workpiece was moved by moving the X and Y slides to scan the surface.

2.1. EXPERIMENTATION FOR 2D PARAMETERS

For measurement of 2D surface roughness parameters a standard specimen of TAYLOR HOBSON was evaluated by the confocal sensor (shown in Figure 2).

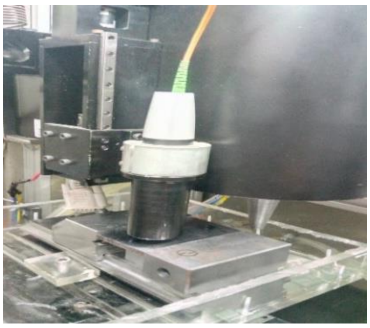

Fig.1 Laser Confocal Chromatic Sensor integrated with the BEMRF setup [14]

The confocal chromatic sensor shown in figure 1 was used for measurement of the sample surface. The workpiece was traversed in X and Y direction by controlling the X and Y linear slides. The chromatic sensor is held in the Z slide as shown in figure 1. The workpiece was traversed a distance of 4 mm in X direction at a speed of 24 mm/min for 2D measurements. The confocal sensor then acquired the data points (i.e. height of the surface asperities). The data acquisition rate was kept at 10kHz. The data points were then evaluated by the MATLAB program for calculating the 2D surface roughness parameters

2.2 EXPERIMENATATION FOR 3D PARAMETERS

Finishing experiments were carried out on mild steel samples using a five axis BEMRF machine. The MRPF used comprised of 20% CIP of CS grade, 20% SIC (#800) abrasives and 60% viscous media of paraffin and grease. [13] The tool rotation speed of 200 rpm with a working gap of 1mm at 2,3,4 A current for 10 mins was used in the experiments.

The confocal sensor was kept stationary and the workpiece was moved at 60 mm/min for 4mm in x axis with an increment for 0.01 mm in y axis when the sensor finishes 4 mm in X axis. Thus, a 4 mm × 1mm area was scanned. The data acquisition rate was kept at 0.1 kHz. The data was stored in .csv format by the data acquisition module. The data points were then evaluated by MATLAB program for calculating the 3D surface roughness parameters.

2.3 MATLAB PROGRAM FOR 2D AND 3D SURFACE ROUGHNESS CHARACTERIZATION

In order to evaluate the 2D and 3D surface roughness parameters of the work surface, an algorithm was developed in MATLAB 2016b software. The flowchart of the program shown in Fig.2

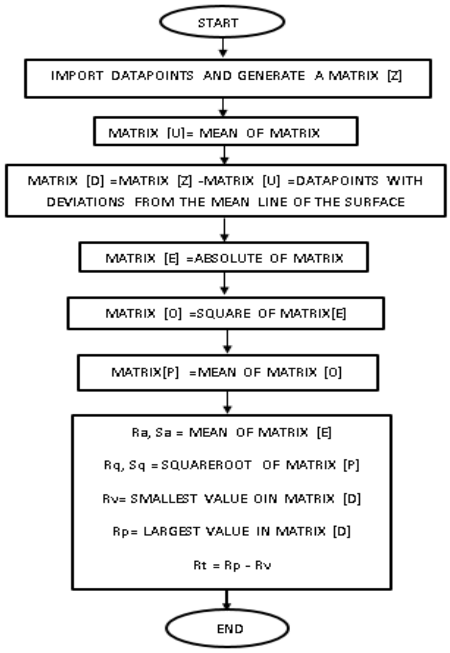

Fig. 2 Flowchart of the MATLAB algorithm

3 RESULTS AND DISCUSSIONS

The results of the surface roughness evaluation for 2D and 3D parameters are detailed in the following sections.

3.1. CHARACTERISATION OF 2D SURFACE ROUGHNESS

The results of the evaluation of the surface properties of the Taylor Hobson sample is given in table 1.

Table 1 Results of evaluation of Taylor Hobson sample

Calibrated Ra, µm (Taylor Hobson)	Calculated Ra, µm (MATLAB Program)	ERROR %
0.88	0.85	3.52

Figure 3 shows the surface plot of the Taylor Hobson sample

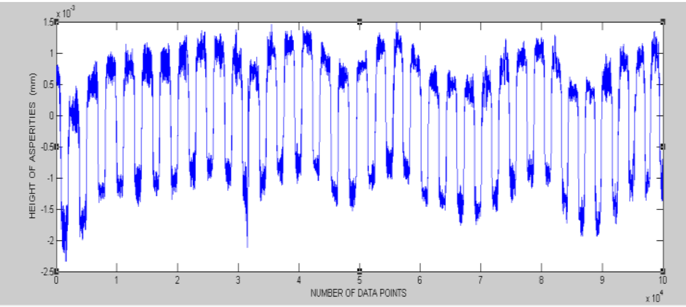

Figure 3 Surface plot of Taylor Hobson Sample

The results shown in table 1 demonstrate that the surface roughness calculated by the MATLAB algorithm is highly accurate.

3.2. FOR 3D SURFACE ROUGHNESS CHARACTERISATION

In order to evaluate the 3D surface roughness parameters, the data points were analyzed by MOUNTAIN MAPS software (Trial version). The software is an ISO certified software and it follows the ISO 4287 standards for 2D surface roughness calculation. [12] The results of the Mountain Maps software were compared for the Taylor Hobson standard sample in order to verify the accuracy of the software software.

Figure 4 shows Analysis of Surface by Mountain Maps Software

The results shown in Table 2 reveal that the Mountain Maps software gives superior results in close proximity with that of Taylor Hobson standard Sample. Hence the results of the MATLAB Algorithm were compared with this software for accuracy investigation and validation.

The results of finishing experiments carried out in BEMRF machine at various magnetising currents are given in Figures 5,6,7,8,9,10.

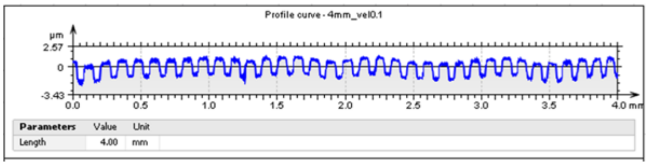

Figure 4 MOUNTAIN MAPS surface plot of surface asperities

Table 2. Results of 2D Surface Roughness Characterization by Mountain Maps Software

MOUNTAIN MAPS 2D CHARACTERISATION
Ra = 0.852µm
Rq= 0.901µm
Rp= 1.30µm
Rv=1.72µm
Rt=3.59µm

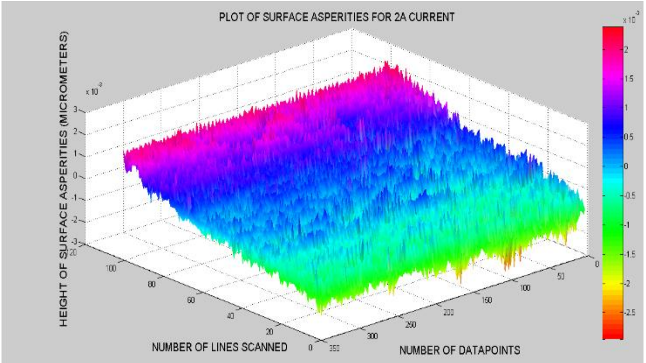

Figure 5 MATLAB plot of surface asperities for finishing at 2 A current.

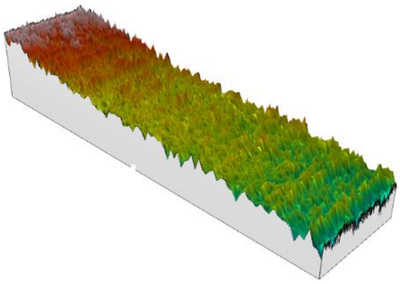

Figure 6 MOUNTAIN MAPS SOFTWARE plot of surface asperities for finishing at 2A current.

Table 3 Comparison of Results by Mountain Maps and MATLAB Software (2A Current)

FINISHING AT 2A CURRENT	
MATLAB 3D CHARACTERIZATION	MOUNTAIN MAPS 3D CHARACTERISATION
Sa = 0.655µm	Sa = 0.656µm
Sq= 0.8103µm	Sq= 0.810µm
Sp= 2.37µm	Sp= 2.38µm
Sv=2.94µm	Sv=2.95µm
St=5.32µm	St=5.33µm

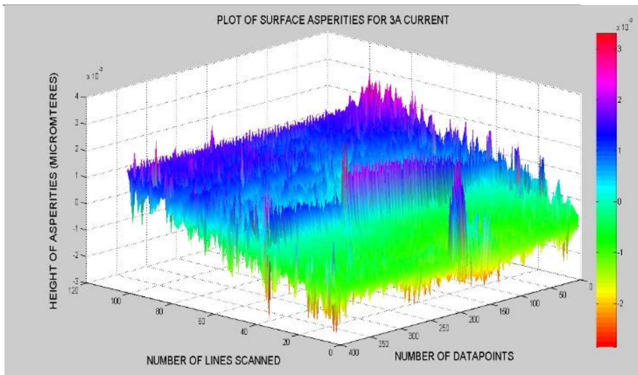

Figure 7 MATLAB plot of surface asperities for finishing at 3 A current.

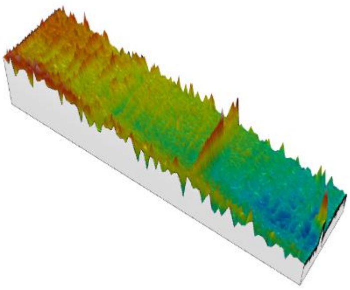

Figure 8 MOUNTAIN MAPS SOFTWARE plot of surface asperities for finishing at 3 A current.

Table 4 Comparison of Results by Mountain Maps and MATLAB Software (3A Current)

FINISHING AT 3A CURRENT	
MATLAB 3D CHARACTERIZATION	MOUNTAIN MAPS 3D CHARACTERISATION
Sa = 0.732µm	Sa = 0.733µm
Sq= 0.881µm	Sq= 0.881µm
Sp= 3.29µm	Sp= 3.30µm
Sv=2.85µm	Sv=2.85µm
St=6.14µm	St=6.15µm

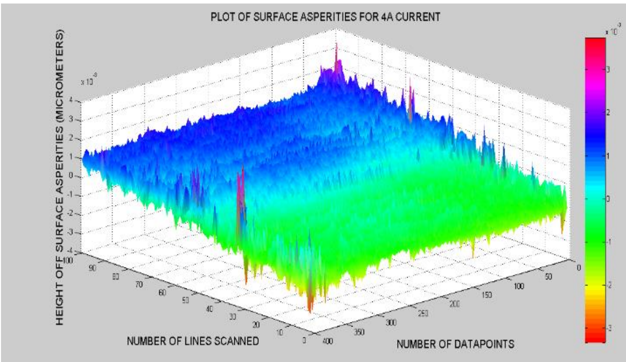

Figure 9 MATLAB plot of surface asperities for finishing at 4 A current.

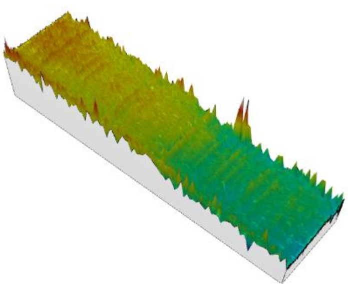

Figure 10 MOUNTAIN MAPS SOFTWARE plot of surface asperities for finishing at 4 A current.

Table 5 Comparison of Results by Mountain Maps and MATLAB Software (4A Current)

FINISHING AT 4A CURRENT	
MATLAB 3D CHARACTERIZATION	MOUNTAIN MAPS 3D CHARACTERISATION
Sa = 0.718µm	Sa = 0.718µm
Sq= 0.815µm	Sq= 0.815µm
Sp= 3.73µm	Sp= 3.73µm
Sv=3.33µm	Sv=3.34µm
St=7.06µm	St=7.07µm

Figure 6 Comparison of Mountain Maps and MATLAB Algorithm for finishing current 2 A

The results shown in the Tables 3, 4 and 5 reveals that the algorithm developed in this work calculates the surface roughness with high accuracy.

4. CONCLUSIONS

This paper reports a work related to development of a real-time roughness measurement system developed using a confocal chromatic sensor integrated with the BEMRF machine measuring the surface roughness parameters. The measurement system evaluates the surface roughness parameters of the workpieces without a need for unloading the workpieces. The MATLAB program developed for calculating the 2D and 3D surface roughness parameters from the data points generated by the confocal sensor were found to be highly accurate. Thus, the post processing time involved in the inspection of the finished workpieces has been reduced considerably.

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