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Constant Work Gap Perpetuation in Ball End Magnetorheological Finishing Process

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Abstract

Ball End Magneto-rheological Finishing (BEMRF) is an advanced finishing method employed for super finishing of flat, curved, intricate as well as complex 3D surfaces up to nano level. The level of surface finish achieved in BEMRF process is governed by machining and fluid parameters. One of the main contributors towards super finishing by BEMRF process is the machining parameter viz. working gap. Research work from the literature shows the contribution of working gap towards percent reduction in surface roughness (Ra) is immense. A constant working gap ensures uniform surface finish throughout the surface; however there are many cases wherein the gap between the tool tip and workpiece varies over the surface due to the surface being tapered or the linear positioner having a tilt error. This research work primarily focuses on maintaining a constant working gap for finishing of flat surfaces in BEMRF process. A confocal sensor is used to scan the flat surface prior to the finishing process in order to find out tilt or taper in the surface if any. The tilt error or taper in the surface is calculated and fed to the z axis motion of the tool tip so that the tip moves up or down as and when required to keep the distance between the tool tip and the workpiece constant. Experiments were conducted and results show a considerable difference between surface finish achieved while finishing with error and finishing with perpetuated working gap.

Keywords: Working gap, Nanofinishing, non contact measurement, confocal sensor.

1. INTRODUCTION

Finishing processes have been of great importance towards the final appearance and performance of a product. Many products require very precise finish on them which is hard to achieve using traditional finishing processes [1]. To produce such precise finish up to nano level on products advanced finishing processes [2] are used. Ball end magnetorheological finishing (BEMRF) process [3] is one such process which is capable of finishing products to such precise levels. In this process the machining parameters viz. Spindle speed [4], current [5] and working gap [6] are employed which governs the level of surface roughness reduction, the effect of these parameters on percentage reduction in surface roughness can be found from literature. The effect of spindle speed is given by [7], effect of current is given by [8] and effect of working gap is given by [9]. The effect of working gap is the most prominent as established by [10].

Since the working gap is the most important machining parameter in BEMRF process, the need for keeping the working gap constant becomes necessary as a varying working gap will result in varying finish over a surface. This research work first discusses the cases where there is a possibility of varying working gap; it further emphasizes the need for keeping the working gap constant through initial experiments. Once the need for a constant working gap is realized then a method is proposed to counter the variations in working gap. A confocal sensor is used to initially scan the workpiece and find out any tilt errors in the workpiece, the inputs from confocal sensor are then used to adjust the working gap accordingly so that the desired working gap can be perpetuated throughout the process. The present work is applicable to flat surfaces for nano finishing through BEMRF process. Finally it is shown experimentally that the roughness results achieved in BEMRF of flat surfaces vary and improved roughness results are achieved when finishing is done through perpetuated working gap as compared to BERMF done without work gap perpetuation.

2. WORKING GAP AND NEED TO KEEP IT CONSTANT

In BEMRF process the tool tip is kept at a small distance from the work surface. This gap called the working gap is filled with the Magnetorheological polishing fluid, which gets stiffened in a hemispherical ball shape under the influence of magnetic field. A typical range of the working gap is 0.6 mm to 1.5 mm [11]. Fig.1 shows the working gap schematically in BEMRF process. Since the variation in working gap varies the roughness results achieved in BEMRF process it is needed to keep this working gap constant.

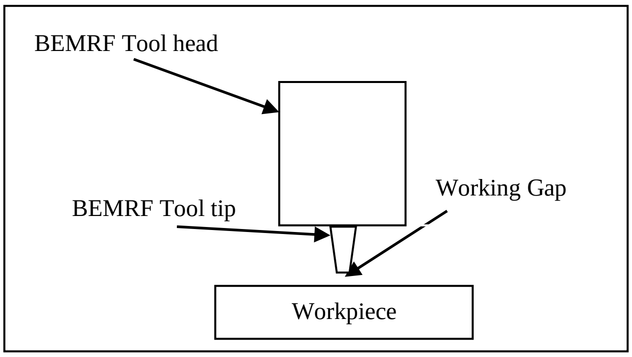

Fig. 1: BEMRF tool and working gap

However due to some errors in workpiece surface or linear positioners in the machine tool this working gap may vary within a workpiece. Fig. 2 shows one such case where a tilt in the surface of the workpiece may lead to an increase in working gap (Fig. 2a) as the error grows (Fig. 2b). Initial experiments were conducted on workpieces without error in order to establish the need for constant working gap. Workpieces are then specially tilted using angular vice in order to depict the tilt error as shown in Fig. 2c which may be present due to linear positioner error or surface tapered error. Experiments then were carried out on tilt error workpieces.

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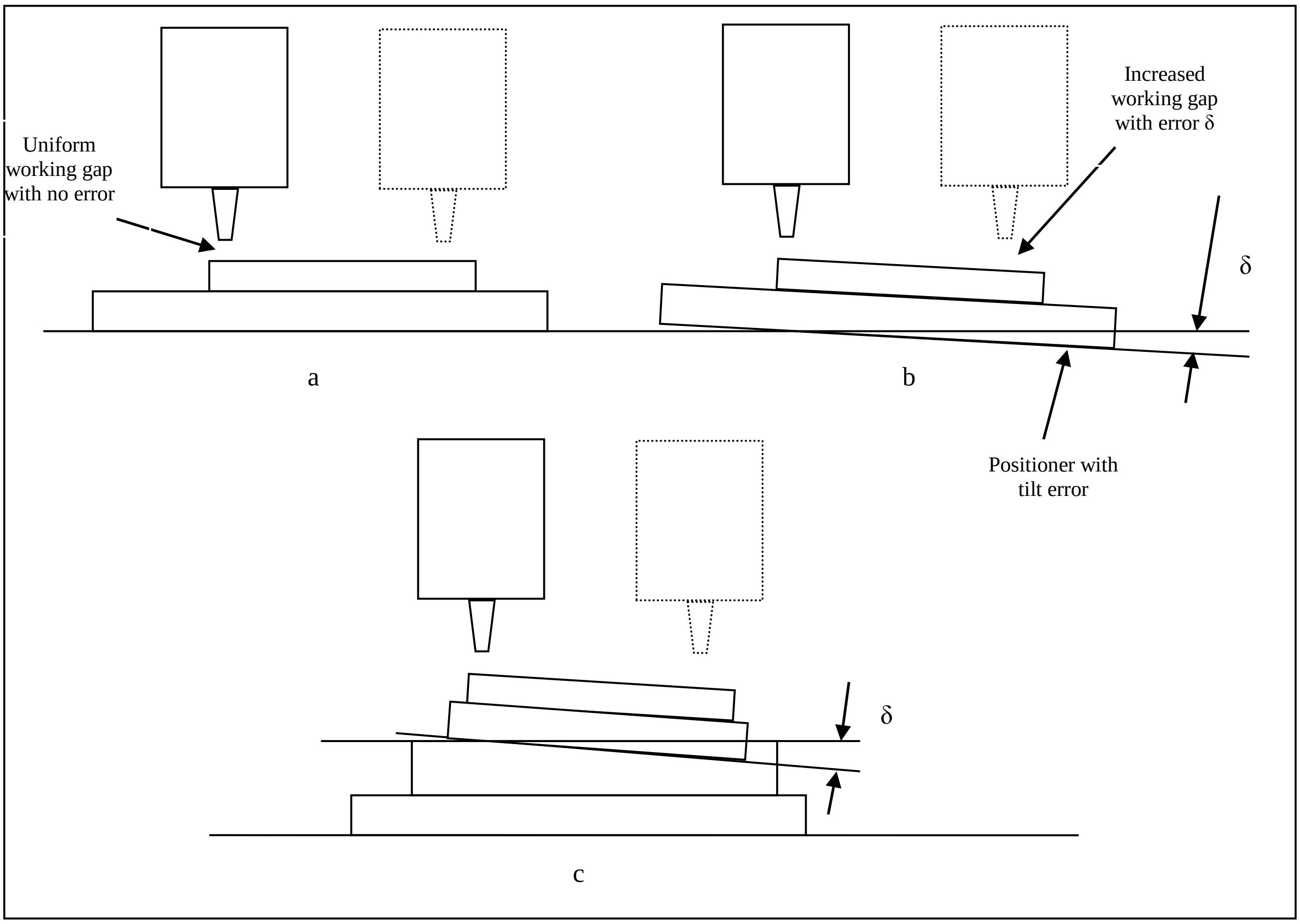

Fig. 2: (a) Uniform working gap with flat surfaces without error, (b) Tilted workpiece having error δ and (c) Angular vice used to simulate tilt error.

Fig.3 shows results achieved in BEMRF process for percentage reduction in surface roughness (Ra value) when finishing is done on a flat surface without error and when finishing is done on a surface with tilt error i.e. with working gap increasing as the error increases. Results show considerable difference in both cases when finishing is done on flat surface without any tilt and when finishing is done on tilted workpieces.

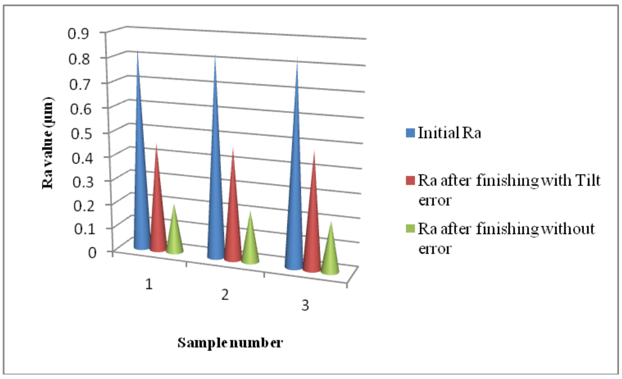

Fig. 3: Roughness (Ra) values for three samples finished with and without error

3. CONSTANT WORKING GAP PERPETUATION USING CONFOCAL SENSOR

Working gap perpetuation i.e. keeping the working gap constant is the target that has been achieved in this research work. A chromatic confocal sensor [12] (specifications given in table 1) has been used to scan the surface of the workpiece to be finished by BEMRF process.

Table 1
Confocal sensor specifications

Fiber core dia	50 µm
Light spot dia	6 µm
Probe diameter	27 mm
Probe length	154 mm
Range	300 µm
Resolution (Z)	10 nm
Working distance	6 mm

The confocal sensor gives height data of the peaks and valleys on the surface. The surface if without an error gives no shift in gives an inclined plot in z direction denoting the tilt or tapered error in the surface. A trend line is drawn on the plot provided by confocal sensor as shown in Fig. 5; this gives actual measure of the error (δ). Using the confocal data the constant change in z direction is observed and the same is provided to the BEMRF process controller to compensate for the excessive working gap. The BEMRF tool has a small tool tip and working area is also small accordingly, thus the error is primarily effective only in the direction of feed. The confocal sensor scans the workpiece for any possible tilt errors in the direction in which finishing is to be carried out. Therefore error may be in any direction the work gap perpetuation is carried out equally effectively in whichever direction feed is to be given to the workpiece for the finishing process. Fig. 6 shows a schematic of the control of working gap perpetuation process. The surface is first scanned by confocal sensor and the data is captured by confocal

the z direction as shown in Fig. 4 and the surface with tilt error

controller which provides the processed data to BEMRF controller. The BEMRF controller gets the data and accordingly controls the Z axis servo drive (controlling the z axis servomotor) according to the error on the workpiece during BEMRF process. The controlled z axis motion keeps the working gap between the tool tip and the workpiece surface always constant. The scan time for carrying out error measurements by confocal sensor is dependent on the measuring range and feed rate of the workpiece during measurement. For a workpiece having dimensions 50mm X 50mm of the cross sectional area, a single scan of 50 mm length can be covered in 5 seconds at a feed rate of 10mm/sec. This time can be varied according to the need for the number of values required to measure the tilt error or Ra value of a surface.

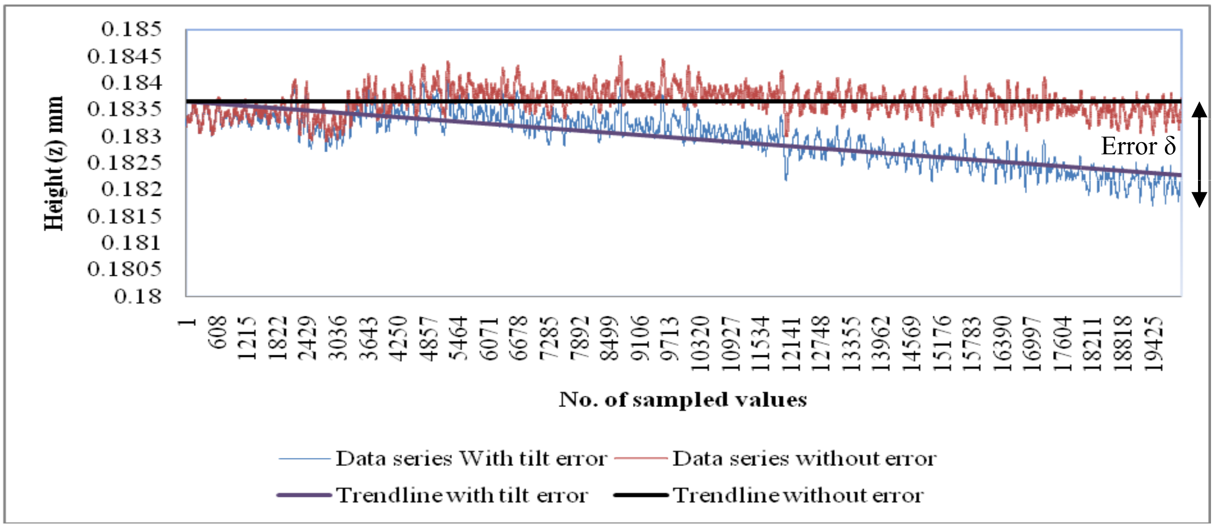

Fig. 4: Height data scanned by confocal sensor with and without tilt error

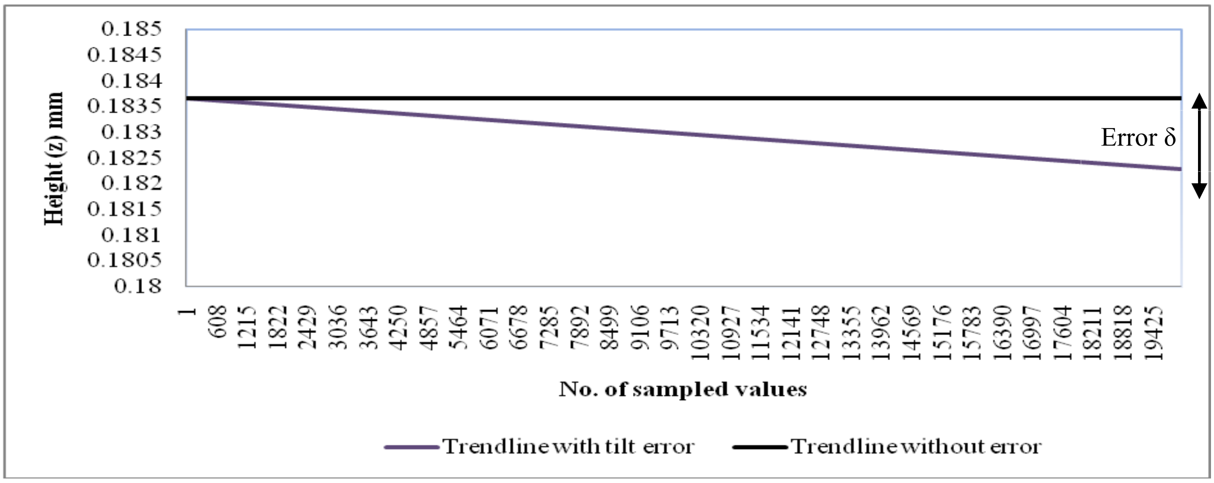

Fig. 5: Trend line of data with and without tilt error showing the tilt error

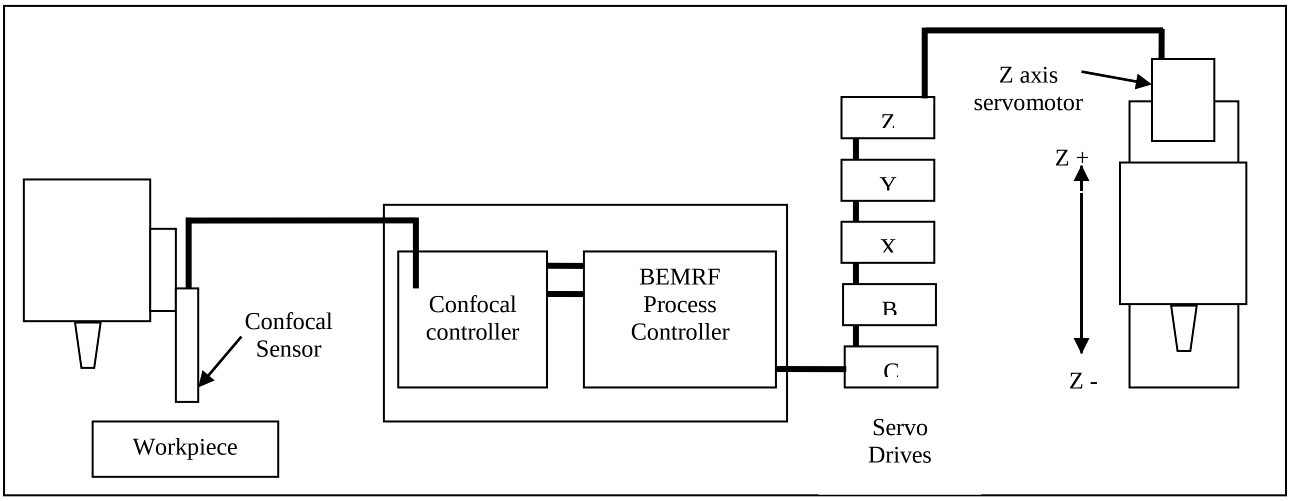

Fig. 6: Control of working gap perpetuation process

4. RESULTS AND DISCUSSION

Once the chromatic confocal sensor scans the surface and the error is evaluated the controller compensates for the error and adjusts the z height of the tool tip in process. Experiments were carried out on EN31 steel sample having flat surface. The first set of experiments was conducted on workpiece surfaces without tilt error. Then the workpieces with tilt error (tilt error depicted using angular vice as shown in Fig. 2b) were first scanned using confocal sensor and the error data was fed to the BEMRF process controller. The finishing process was then carried out on the workpieces with tilt error; the finishing results achieved with the working gap perpetuation were in close proximity with the results achieved on workpieces without error as shown in Fig. 7. As can be seen in fig. 7 the Ra reduced from initial value of 0.831 µm to 0.207 µm in case of workpiece without tilt error whereas with tilt error the Ra value is reduced from 0.831 µm to 0.454 µm. However with perpetuated working gap the error reduces from 0.831 µm to 0.220 µm despite having tilt error.

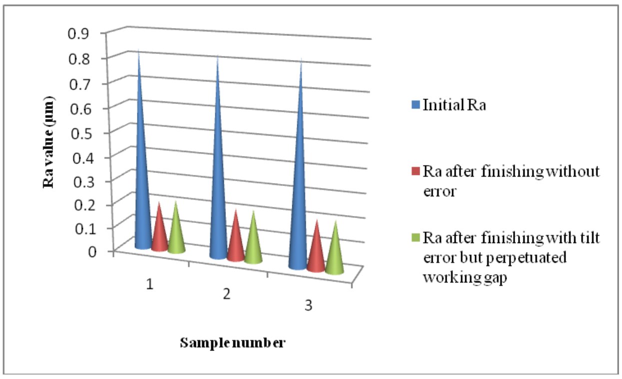

Fig. 7: Roughness (Ra) values for three samples finished with error, without error and with perpetuated working gap.

Table 2 shows the comparison of Ra values of the surfaces finished in all cases.

Table 2
Ra values for finished workpiece in all cases

S. No.	Initial Ra	Ra without tilt error	Ra with tilt error	Ra with tilt error and perpetuated working gap
1	0.831µm	0.207 µm	0.454 µm	0.220 µm
2	0.831µm	0.213 µm	0.465 µm	0.217 µm
3	0.831µm	0.209 µm	0.483 µm	0.214 µm

5. CONCLUSION

The presented research work has discussed about the need for constant working gap in BEMRF process. A confocal sensor is used to scan the workpiece to be finished, and error in the workpiece is found using the data from confocal sensor. The confocal data is then fed to the BEMRF process controller which compensates for the excessive working gap if any and controls the position of the tool tip against the workpiece keeping a constant working gap during the BEMRF process. The experimental results achieved provides a clear difference between roughness results achieved when working gap perpetuation is not in effect and the results achieved when working gap is perpetuated.

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