

# Automatic Honing Stone Feeding Mechanism to Compensate Tool Wear

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**Abstract**— To obtain uniform surface endurance strength at inner and outer race of bearing, honing as super finishing process normally employed. While doing so, wearing of honing tool takes place as there is friction involve between honing tool and bearing surfaces. Though this wear of tool is insignificant after honing one component, the cumulative tool wear during mass production is considerable. This relatively large wear will result in degradation of surface finish of component being honed. As there is mass production the tools wear needs to be compensated by automatic feeding the honing tool against work piece. In this research work, a mechanism based on ball screw actuator and stepper motor has designed and installed to automate the existing manual feeding. Implementation of this system resulted in optimization in human errors caused by operator as well as productivity also.

**Keywords:** Surface Finish, Tool Wear Compensation, Ball Screw Actuator, Stepper Motor.

## I. INTRODUCTION

Honing is an abrasive machining process that machines a precision surface on a metal work piece by scrubbing an abrasive stone against it along a controlled path. The honing stones are held against the work piece with controlled light pressure. It is desired that the honing stones should not leave the work surface. Honing is primarily used to improve the geometric form of a surface, but may also improve surface texture. The surface finish has a vital influence on most important functional properties such as wear resistance, fatigue strength, corrosion resistance and power losses due to friction. It is a finishing operation employed not only to produce high finish, but also to correct out-of-roundness, taper, and axial distortion in work pieces. It is employed very frequently for finishing of bores, but there are numerous external surfaces which are honed to obtain required properties. Some examples are gear teeth, valve seating, races of ball and roller bearings [1].



Figure 1: Existing Manual Honing Machine

The existing honing mechanism is as shown in fig.1. Honing stone, after honing about 350-400 rings wears approximately by 2mm. also manual stone feeding leads to human errors and increase in idle time (1hr/shift). There is possibility that operator might feed the stone more/less than 2mm. If the feeding is less than 2mm the stone will not hone the surface. On the other hand, if feeding is more than 2mm, excessive pressure may produce marking on surface to be honed. To overcome the difficulty of honing tool wear, compensation of honing stone wear during the honing operation has given thought process towards R & D work. Real time measurement of wear was done by Henry Brunskill, P.Harper and Roger Lewis [2] in 2015 using a method called ultrasonic. Ultrasonic reflectometry is commonly used in the fields of non-destructive testing (NDT) for crack detection, wall thickness monitoring and medical imaging. A sound wave is emitted through the material using a piezoelectric transducer. This wave form travels through the host medium at a constant speed and is either partially or fully reflected at an interface.

The reflected wave is picked up by the same sensor; the signal is then amplified and digitized. If the speed that sound travels through a host medium is known as well as the time this takes, the thickness of the material can be established using the speed, distance and time relationship. Work has concluded that the ultrasonic method is too inaccurate to measure wear due to the errors caused by temperature, vibration and the experimental arrangement. Tool wear monitoring was done by Mohammad Malekiana, Simon S. Park, Martin B.G. Jun. [3] monitoring of tool wear is critical to avoid excessive wear and maintain tolerances and surface finish. The mechanical removal of materials using miniature tools, known as micro-mechanical milling processes, has unique advantages in creating miniature 3D components using a variety of engineering materials, when compared with photolithographic processes. Since the diameter of miniature tools is very small, excessive forces and vibrations significantly affect the overall quality of the part. In order to improve the part quality and longevity of tools, the monitoring of micro-milling processes is imperative. This paper examines factors affecting tool wear and a tool wear monitoring method using various sensors, such as accelerometers, force and acoustic emission sensors in micro-milling. The signals are fused through the neuro-fuzzy method, which then determines whether the tool is in good shape or is worn. The tool wear monitoring can be done by various sensors such as accelerometers (Kistler 8778A500), AE (Physical Acoustics Nano30). The sensor was fused through neuro fuzzy algorithm. Due to negative rake angle of tool fluctuations are created and cutting forces affect the tool wear. Tool wear and increase in nose radius will cause increase vibration and finally result in poor quality. The tungsten carbide tools were studied by using various sensors and tool conditions was deduced. The results of neuro fuzzy algorithms alerts the operator to change the tool. The lighting system may affect the accuracy of the edge radii measured by vision system. S.K. Choudhury, P. Srinivas [4] in their research paper titled 'Tool wear prediction in turning' developed a reliable tool wear model as a function of cutting velocity, feed, depth of cut, variation of normal load with respect to flank wear, wear coefficient, hardness of the cutting tool and the index of diffusion coefficient. Some important factors like the index of diffusion, wear coefficient, rate of increase of normal load with respect to flank wear and the hardness of tool, influencing the flank wear have been used as input parameters to develop the mathematical model. The developed mathematical model was used to relate the wear to the input parameters for a turning operation.

The input parameters were established based on the design of experiment technique. These tool wear values were compared with the experimental flank wear values and the correlation coefficient between them was found to be 0.988 which shows the stability of the model. It was shown experimentally and empirically that the cutting velocity and index of diffusion coefficient has the most significant effect on the flank wear followed by the feed and depth of cut. Results showed that this flank wear model is reliable and could be used effectively for tool wear prediction. Guoqing Zhanga, Suet Toa, Gaobo Xiao [5] in their research paper titled 'Novel tool wear monitoring method in ultra-precision raster milling using cutting chips. Monitoring tool wear was firstly conducted in UPRM by using cutting chips. In UPRM, tool wear patterns are different at different tool wear stage, e.g. fracture wear usually occurs at the early tool wear stage, smooth wear normally happens at the steady wear stage. The difference of tool wear patterns leads to the difference of cutting chip morphology, which makes the measurement mechanism of tool wear using cutting chips also different. The Author has mainly focused on fracture tool wear characteristics and machined surface quality measurement by using cutting chips. Based on the geometric characteristics and mathematical model of cutting chips, a novel on-line tool wear monitoring method in UPRM is pro-posed. Through this method, both the tool wear characteristics and machined surface quality can be predicted without the need to stop the cutting process. This method has the advantages of both direct and indirect tool wear monitoring methods and is a promising tool wear monitoring method for intermittent cutting processes. During the cutting process, the fracture wear of the diamond tool is directly imprinted on the cutting chip surface as a group of 'ridges'. Through inspection of the locations, cross-sectional shape of these ridges by a 3D scanning electron microscope, the virtual cutting edge of the diamond tool under fracture wear is built up. A mathematical model was established to predict the virtual cutting edge with two geometric elements: semi-circle and isosceles triangle used to approximate the cross-sectional shape of ridges. Since the theoretical prediction of cutting edge profile concurs with the inspected one, the proposed tool wear monitoring method is found to be effective. In column projection the area increases as the quality of the machined surface deteriorates. This helps in prediction of tool breakage even before it happens. Main objective behind this Research work was to find an alternate mechanism/method for honing tool wear compensation which would be efficient, cost effective and as simple as possible in operation.

Tool condition monitoring was done by A.A. Kassim, M.A. Mannan and Zhu Mian using texture analysis. Pre-processing of surface texture images was done to overcome non-uniform illumination, incorrect depth of focus and image noise. Further analysis was done by column projection and connectivity oriented fast Hough transform. CCD camera was used to capture images after certain interval until the tool was worn out completely. Results showed that column projection method was best suited for uniform texture and fast Hough transform was able to handle non-uniform textures. Both the methods were able to predict the condition of tool satisfactorily. In column projection the area increases as the quality of the machined surface deteriorates. This helps in prediction of tool breakage even before it happens. In connectivity oriented fast Hough transform, it is observed that the distribution of the extracted parameter changes significantly as tool wear increases. Thus total fitting error co-relates with flank wear. Column projection analysis and connectivity oriented fast Hough transform methods extract texture features and help in prediction of tool wear. Column method works well when the texture are highly regular. Connectivity oriented fast Hough transform is able to extract line segments of a variety of lengths and orientations. D.M. D'Addona and R. Teti [7] presented an excellent work on image data processing for tool wear prediction. They used neural network to produce a mapping from image data input. Tests were carried out for different cutting speeds, feed rates and depth of cut. The NN was designed using MATLAB. The authors concluded that experimentally found crater wear and the output of NN were in agreement with each other. The mean error was found to be equal to 0.049mm with highest error of 0.101mm. In the manufacturing systems, one of the most important issues is to estimate the rest of cutting tool life under a given cutting conditions as accurately as possible. In order to monitor the tool wear development during machining processes, the interface chosen between the working procedure and the computer was a digital image of the cutting tool detected by an optical sensor (video camera). Images, however, are not homogeneous: contrast, definition, size and position of the tool vary from one detected image to another and they depend on the particular condition in which they were captured by an optical sensor. Each image was resized to 100×100 pixels. Some images were made black and white. Two images training sets were used for grey images and black and white images. Cutting tool image processing, detection during turning tests is proposed. Images with standard size and pixel density were produced by elaborating tool image files.

Back propagating neural networks were utilized to produce a mapping from input vectors to output values. The back propagating neural network were utilized to produce a mapping from input vectors to output values. To overcome the reliability issues of hard turning (alternative for grinding), C. Scheffer, H. Kartz, P.S. Heyns and F. Klocke [8] developed pattern recognition fuzzy logic and NN. Indirect measurements were taken by a tool holder dynamometer. To increase accuracy, high sampling rate and to reduce noise low-pass filter was used. Self-organizing map (SOM) analysis was used to analyze the data. Comparison of obtained results with actual wear was done by calculating necessary parameters using toolmakers microscope. An AI approach was also used by combining static and dynamic NN. The measurement values of flank wear area and model estimated values were plotted v/s time of cut. Same was done for volume of crater wear. From SOM analysis it was concluded that surface roughness did not degrade linearly with tool wear. Instead it seemed to reach a maximum value during medium wear conditions and then decreased again. Results showed that rms error of the prediction was 5% despite the noisy nature of the training and testing data. An important conclusion was that the identification and isolation of disturbances on experimental data are essential during hard turning. Effect of disturbance could be removed from the data with appropriate signal processing methods. AI can be utilized for the tool wear prediction. This was done by combination of static and dynamic neural networks. Tool condition monitoring [9] is important to ensure proper machining. It reduces downtime and increases production rate. With proper implementation of tool condition monitoring system, cutting speeds can be increased by 10-50%. In this method machining process data is recorded, filtered and processed using CCD or CMOS cameras. Using Design of Experiments and Artificial Intelligence techniques, data optimization is carried out and feed to the machine controller. The major advantage of this method is that it is non-contact in nature and imparts minimum external errors in the system. E. Aligiri, S.H. Yeo, P.C. Tan [10] in their research paper titled 'A new tool wear compensation method based on real-time estimation of material removal volume in micro-EDM' proposed a new tool wear compensation method which is based on real time estimation of material removal volume in micro EDM. The real-time wear compensation estimates wear length by sensing the accumulated duration of effective (normal) discharges and relating it to the electrode wear volume.

Then, depending on the relative magnitudes of anticipated wear and real-time wear, the smaller of the two wear values is used for compensation. Instead of predicting and monitoring the tool wear for wear compensation, real-time estimation of material removal volume from the work piece is performed in order to accurately monitor the progress of the machined depth. In this method, the targeted material removal rate is compared with the predicted real time value of material removal value. The compensation length was calculated by the difference between both the values ( $V_{\text{target}} - V_{\text{MR}}$ ). The machining process is terminated only when  $V_{\text{target}} = V_{\text{MR}}$ . Experimental results shows that this method improves the depth error by 3%, 6%, and 12% for depth setting of 300, 600, and 900 micro m, respectively as compared with the normal machining method. Experimental results also show that this method improves the depth error by 7%, 1%, and 2% for the same depth setting as compared with the uniform wear method. By using the developed method, better accuracy of micro-holes can be produced as compared to other methods. As a result this method is more reliable than the uniform wear method. P. Bleys, J.P. Kruth, B. Lauwers, A. Zryd, R. Delpretti, C. Tricarico [11] in their research paper entitled 'Real-time Tool Wear Compensation in Milling EDM' proposed a new method of wear compensation. Electrical discharge milling or milling EDM can be defined as contouring EDM with a rotating cylindrical tool electrode. Tubular electrodes are used that allows dielectric flushing through the electrode, ensuring improved machining conditions and sufficient cooling of the electrode. Tool wear is compensated in one direction by continuously moving the tool downward. Milling EDM enables machining of complex cavities with simple cylindrical or tubular electrodes. To assure an acceptable machining accuracy, milling EDM requires compensation of the tool electrode wear. Existing wear compensation methods are mostly based on off-line prediction of tool wear. This paper discusses a new wear compensation method, incorporating real-time wear sensing based on discharge pulse evaluation. Tool wear is continuously evaluated during machining, and the actual wear compensation is adapted on the basis of this real-time wear evaluation. On-line estimation of tool wear is used for combining anticipated compensation with real time compensation. It gives good result in the region where the work piece material is absent. However, a small over-estimation in online wear sensing results in continuously increasing machining depth, rapidly yielding a very large geometrical error. This method largely reduces the problems occurred in both anticipated and mere real-time compensation.

This method enables milling EDM without the need to provide an accurate model of the blank geometry. Feasibility of wear compensation in micro EDM was done by G. Bissacco, H.N. Hansen, G. Tristo and J. Valentincic [12]. In micro EDM the electrode wear compensation is mainly based upon volumetric wear ratio and real time wear sensing or combined wear sensing. The real time wear compensation is based on discharge counting and discharge population characterization. The machining occurs by means of trains of discharge. Material removal per discharge (MRD) and a tool wear unit per discharge (TWD) is obtained on the basis of trains of discharge. Effective TWC can be implemented by counting the discharges and compensating on the basis of average wear per discharge. From the experiment it is evaluated that the TWC can be obtained by counting the discharge and multiplying it with number of TWD. There may be some errors while estimating the TWD. During validation it is proved that by performing periodic measurements of the tool length the errors can be minimized. Sensing and compensation of tool wear in milling EDM was initially done by P. Bleys, J.P. Kruth, B. Lauwers [13] using real time wear sensing. The wear compensation methods includes viz. the offline or anticipated wear compensation method and online or real time wear compensation the offline method necessities an accurate solid model of blank geometry. This has been overcome in by using online sensing. The online sensing mainly uses discharge pulse evaluation method. In this method a basic tool wear function is proposed and relation between worn volume and normal discharges is analytically studied and wearing sensing is expressed in terms of constant  $k_c$ . This wear sensing method is not perfect and may give some overestimation or error which may lead to increase in the removal of workpiece. To overcome this combined wear compensation is used. In this the sensed wear and predicted wear is compared. If the sensed wear length is smaller than the predicted wear length (prediction for a standard prismatic blank), the sensed wear length is applied for tool wear correction. If the sensed wear length is larger than the predicted value, the originally predicted value is applied. Experiments performed on a machine part with a grooved slot and the compensation methods were compared and concluded that by using combine wear compensation correct machining depth is obtained. Yih-Fang Chang and Zhi-Hao [14] Chiu in their research paper titled 'Electrode wear-compensation of electric discharge scanning process using a robust gap-control' have given a robust gap control method to compensate for electrode wear in an electric discharge scanning (ED-Scanning) process.

The wear length is a function of the wear ratio of the electrode, the power parameters, and the shape of the contour and the length of the path. Many parameters that govern the actual scanning process must be set. Inaccurate parameters will affect the accuracy of compensation and the shape of the machined hole. Wear of the bottom of the electrode reduces the depth of removal of a layer; hence, the aim of tool compensation is to maintain the depth of removal of one layer and accurately determine the size of the next layer. In this study, a gap-control method, such as conventional die-sinking electric discharge machining, is used to compensate for the wear of the electrode. However, designing the controller is difficult because of the non-linear and time-varying characteristics of the feedback device. A functional analysis is employed to analyse the robustness of the system. The most robust gap-control system is designed by the proposed procedure. As the electrode moves horizontally, the robust gap-control of the electrode can maintain the depth of removal of a layer. During scanning, the depth of removal is determined only by the discharge power and the tool diameter. The wear can be automatically compensated for without applying a wear function as. An actual hole with an exact conical shape can be machined by using computerized numerically controlled (CNC) drilling EDM to confirm the application of the method of compensation. A proportional controller for a gap-control system with maximal robustness is designed and robustly analyzed to override the non-linear and time-varying feedback. The bottom of the electrode is always above the eroding surface; hence, discharge occurs beneath the electrode. However, the depth of removal along the horizontal contour will vary as the bottom of the electrode is worn. The position of the electrode in the vertical direction should be regulated to compensate for the wear, in order to maintain the depth of removal. The position controller moves the electrode downward to maintain the position of the bottom of the electrode. The wear-compensation algorithm involves a complex function of the current position and factors such as the wear ratio, the parameters that govern the power, the diameter of the tool and shape of the contour. This study proposes an improved wear-compensation algorithm by using robust gap control in the direction of the main axis. G. Bissaco, G. Tristo, H.N. Hansen and J. Valentincic [15] investigated the reliability of electrode wear compensation based on discharge counting in micro EDM milling. As the accuracy of this type of manufacturing method is highly dependent upon the proper gap between electrode and surface of material (workpiece), wear compensation should be highly reliable. In micro EDM considerable variation of discharge duration and discharge energy is observed.

Material removal occurs by means of trains of discharge with identical distribution as that of the entire population. Real time material removal can be estimated by counting the discharge and multiplying it by the average MRD of the population. Accuracy of MRD determination and MRD stability over time is critical for the compensation accuracy. Sarix SX-200 micro EDM milling machine equipment with a laser scan micrometer for optical measurement of electrode profile was used. Tungsten Carbide cylindrical rods with diameter of 300  $\mu\text{m}$  were used as tool electrodes. Workpiece material was martensitic stainless steel. Discharge counting was done for current signal by means of a current probe developed in house. Removed material volumes were validated by means of confocal microscopy in dedicated experiments. The method used was discharge population and material removed per discharge. The results indicated that after certain depth of machining the decreasing trend of MRD stabilized. It was concluded that the stabilized values of MRD could be used for wear compensation. Jian-Zhong Li, Lu Xiao, Hui Wang, Hui-Lan Ya and Zu-Yuan Yu [15] proposed a tool wear compensation technique based on scanned area in 3D micro EDM. The proposed BSA technique was compared with uniform wear method and combination of linear compensation with uniform wear method. The results showed that material removal rate ( $\mu\text{m}^3/\text{s}$ ) for BSA was more than uniform wear method and combination of linear compensation for layer thickness less than 1  $\mu\text{m}$ . Tool wear rate of BSA was least among all three methods for all tested layer thickness. This shows that BSA is also a useful method for predicting tool wear. Dirk Bahre, Christina Schmitt, Uwe Moos [16] in their research paper entitled "Analysis of the Differences between Force Control and Feed Control Strategies during the Honing of Bores" developed a newer approach, called force-controlled honing, that uses a closed loop control. The traditional form of honing is an open loop control called feed-controlled honing. In the case of force-controlled honing the forces occurring during the process are measured and kept constant through a regulation of the feeding movement. This constant process force helps to reach a more stable honing process regarding the quality parameters, the material removal and the wear of the honing stone. A force-controlled approach can help to increase the process stability, the quality of the honed work pieces and the tool life. It also helps to reduce the running-in period of the process and makes it possible to hone in small lot sizes. The paper explains the differences between the two control types and shows the advantages of the force controlled approach.

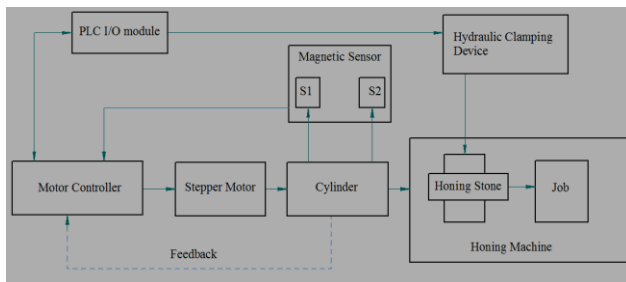
A transducer generates ultrasonic waves which propagates until it reaches the interface between the propagation medium and the sample. The wave is partially reflected at the interface and partially transmitted into the sample. The waves reflected at the interface travel back to the transducer, then the impedance of a sample is determined by measuring the amplitude of the wave reflected from the propagation medium/sample interface. From the reflected wave, it is possible to determine some properties of the sample that is desired to characterize [18].

- PA: Positioning to absolute position.
- FSL: Force Control –stroke limit active.
- PRA: Positioning relative to actual position.
- PRN: Positioning relative to nominal position.

To hold the actuator in proper position, we have designed and manufacture a support structure for combined weight of the actuator and stepper motor 1000 N the design was not done on the basis of strength. But an analysis of the whole assembly was carried out to check for the maximum stress occurring in the structure.

## II. DESIGN OF EXPERIMENTAL MODEL

Standard dimensions of the honing tool has used. for this ball screw driver of required stroke length to be approximately 50mm. From the standard catalogue we have selected ball screw. From specifications of electric cylinder maximum drive torque is found to be 1Nm. This criterion is considered while selection of stepper motor for ball screws actuator. Based on this maximum torque limit, stepper motor from standards has selected.

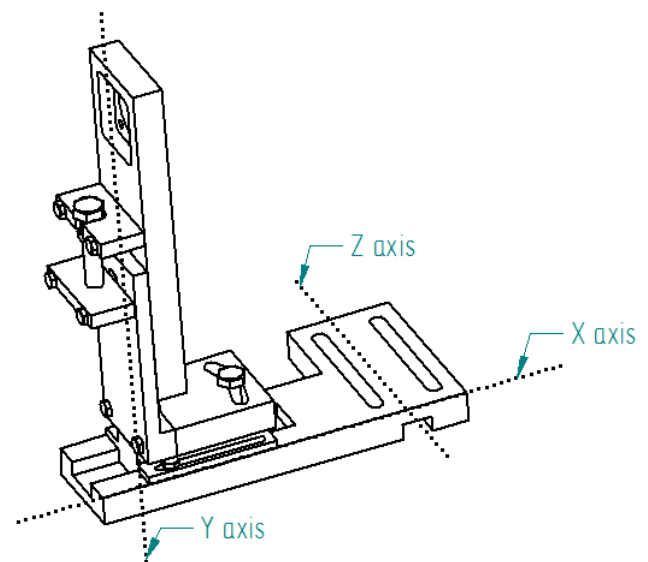


**Figure 2: Block Diagram of Honing Machine Stone Feeding Mechanism.**

Above block diagram is programmed using motor controller by inputting following record table values. The same record table has used to validate the experiment after assembling all the components.

**Table 1:  
Record Table for Stepper Motor Validation.**

Sr. No.	Type	Target	Start Condition	Velocity (mm/s)	Acceleration/Deceleration (m/s <sup>2</sup> )
1	PA	100.00 mm	Delay	200.00	3.000
2	FSL	09.0%	Ignore	80.00	5.000
3	PRA	0.10 mm	Delay	10.80	5.200
4	PRN	9.00 mm	Ignore	20.00	9.200
5	PA	9.00 mm	Ignore	200.00	9.200



**Figure 3: Support Structure Axis**

## III. RESULT AND DISCUSSION

Stepper motor was programmed using software. Following data has shows the record table created using software. After successfully running the program, we have measured the Surface Roughness parameters on inner and outer bearing races of two samples. The results show optimization in surface roughness parameters of about 25% and observed no marks on face and outer diameter which was present in manual system. As ideal time has absent in automated system, the increase in production rate per shift was 9%.

**Table 2:**  
**Record Table for Stepper Motor Validation.**

No.	Type	Target	Start Condition	Velocity (mm/s)	Acceleration/Deceleration (m/s <sup>2</sup> )
1	PA	100.00 mm	Delay	200.00	3.000
2	FSL	09.0%	Ignore	80.00	5.000
3	PRA	0.10 mm	Delay	10.80	5.200
4	PRN	9.00 mm	Ignore	20.00	9.200
5	PA	9.00 mm	Ignore	200.00	9.200

#### IV. CONCLUSION

From this it can be understood that the average surface finish of races of bearing rings improved significantly i.e. by 25%. This improvement was observed due the uniform feeding of honing stone and hence minimizing the feeding error caused by operator as discussed before. Increased in production rate by 10% is due to the fact that earlier the machine experienced a large downtime when the operator feed the tool manually. But due to the new electric actuator mechanism this downtime was significantly reduced. also total downtime of honing machine per shift was reduced by 45%. The current quality control used is of offline type and a sample from a batch is selected at random to check its finish and quality. But in future a fully online system can be implemented to check the quality of product and a feedback can be provided to the PLC. This will further improve the quality and reduce the amount of rejections per batch.

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