"A Study on Abrasive Flow Machining Technique"

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INTRODUCTION

Manufacturing machine components having complex geometric shapes and profiles made up of smart materials requiring nanometer range surface finish and dimensional accuracy has led to the development of newer finish-machining techniques. It has been reported that final finishing operations constitute the most essential, sensitive, labour intensive and time consuming operations which consume almost 10-15 percent of the total manufacturing costs. Abrasive flow machining (AFM) is a novel non-traditional machining process developed as a method to debug, polish and radius surfaces and edges by flowing an abrasive laden media over otherwise difficult to machine areas and surfaces. In AFM, a semi-solid medium consisting of a polymer-based carrier and abrasives in typical proportions is extruded through or past the surface to be machined. The visco-elastic medium acts as a deformable grinding tool whenever and wherever it is subjected to restriction. The medium is flexible enough to mould itself to virtually any complex shape or contour, and it has the ability to abrade hard and tough materials. A high degree of surface finish and close tolerances can be achieved on a wide range of components by AFM.

Potential applications of the process are the finishing of critical aircraft hydraulic and fuel system components and accessory parts, such as fuel spray nozzles, fuel control bodies and bearing components which are otherwise tedious to machine. The process has potential ability of achieving high production rates in the processing of fuel injection systems, hydraulic transmissions, steering and braking systems, splines and gears, pumps, valves and fittings, textile machinery, hardware industry, etc.

The vast potential applications and capabilities of the AFM process attracts the attention of machinists and makes it imperative upon researchers to overcome the major limitation of low volumetric material removal rate of this process – a limitation shared by almost all NTM processes. Although AFM is primarily a surface finishing technique yet material removal plays a major role in providing the final surface finish to the component finish-machined by AFM. The study of AFM process mechanism indicates that with increase in material removal the finished surface texture improves and this rapid surface finishing is accomplished as a result of material removal from the high peaks present on the work-piece surface. Therefore, improvement in surface roughness and material removal are generally considered as output responses indicating performance/quality characteristics.

The present research initiative identifies the limitations and gaps through exhaustive review of published literature on AFM technique with the intent to explore the possibilities for improving the efficiency and capabilities of the process/technique. The following observations have been made:

1. Conflicting opinion of researchers regarding the effect of certain process parameters on quality characteristics.

2. Consistent and sufficient theory about the process mechanism remains yet to be established.

3. Little information reported in the direction of optimization of process parameters based on diverse performance characteristics.

Although certain good research initiatives have been reported in the direction of controlling the process parameters and analytical modeling for suggesting the process mechanisms but several key issues remain unexplored and the process can still be considered to be in its nascent stage.

The present research initiative identifies the major concern areas for improving the efficiency and capability of the process and enhancing the output performance characteristics in finish-machining of multiple holes in pin cylinder lock bodies by AFM. Live industrial components widely used in the hardware industry have been used as work-pieces with the perspective of studying the feasibility of integration of this charismatic technique with small scale industries thereby making it relevant, economic and viable for wide spread applications. The major emphasis of the current research initiative is on optimization of process parameters for enhanced/improved quality characteristics. The importance of visco-elastic medium which acts as a deformable grinding tool and its composition is also highlighted.

Parametric optimization is crucial to obtain the optimal setting of AFM process parameters which would yield better performance of the process by enhancement of quality characteristics. Extensive experimental work is therefore needed to study the effect of various operating parameters, having stochastic nature, and to obtain optimal settings of process parameters which yield better quality characteristics in AFM.

The media used has a strong effect on the performance of AFM although it is difficult to study its properties due to the non-Newtonian and heterogeneous nature. The setting of proportions of the constituents in AFM media for a particular application largely depends upon the practical knowledge of the technicians involved in the process. Systematic and scientific study for optimal setting of media constituents also seems to be an interesting and demanding area of research, which needs to be explored for better performance characteristics in AFM.

The concept of 'parameter design' introduced by Taguchi has emerged as the key element to obtain optimal parameters for achieving high quality standards. This calls for the need to apply Taguchi technique to the performance optimization of the AFM process so as to fully realise its potential advantages.

OBJECTIVES OF THE STUDY

The objectives of the present research are as follows:

1. To study a versatile uni-directional AFM set-up, which facilitates provision for variable process parameters in finish- machining of multiple holes in pin-cylinder lock bodies.

2. To study visco-elastic medium and selection of its composition which yields enhanced quality characteristics.

3. To study parametric optimization of AFM process parameters in finish-machining of multiple holes for improved quality characteristics.

REVIEW OF RELATED LITERATURE

Abrasive flow machining (AFM), also known as extrude honing, is a method of smoothing and polishing internal surfaces and producing controlled radii. A one-way or two-way flow of an abrasive media is extruded through a work-piece, smoothing and finishing rough surfaces. One-way systems flow the media through the work-piece, then it exits from the part. In two-way flow, two vertically opposed cylinders flow the abrasive media back and forth.

The most time consuming and labor intensive segment of the manufacturing process in today's industry is the final finishing of complex and precision components. This consumes as much as 5 – 15% expenditure of the overall manufacturing process. The manufacture of precision parts emphasizes final finish machining operations, which may account for as much as 15% of the total manufacturing costs. Abrasive flow machining (AFM) has the potential to provide high precision and economical means of finishing parts. Inaccessible areas and complex internal passages can be finished economically and productively. To finish an external surface, additional tooling is generally required to ensure that the flow gap between the external surface and the tooling is sufficiently tight for adequate abrasive action. AFM has been likened to a semi-solid flowing file and perhaps its greatest advantage lies in its ability to finish complex internal passages or areas that are inaccessible to more traditional methods such as mechanical honing.

Basuray (2012) proposed a model to estimate the unreformed chip thickness at the onset of chip formation.

Bowden(2010) proposed a simple analysis of axial force composed of shearing and ploughing forces. They also analysed radial force on the single abrasive grain and the real area of contact between abrasive grain and work-piece surface for the case of metal to metal sliding.

Brecker (2011) proposed a model for the minimum depth of indentation and minimum load on a grain required for chip formation. These theories can be applied to AFM process considering that in AFM grain-work piece interaction is taking place in any one or combination of the possible modes i.e. chipping, rubbing and ploughing.

Chen and Rowe (2012) applied this theory for the analysis and simulation of a grinding process. In the abrasive flow machining process, the normal force applied to such a spherical grain will cause it to penetrate the work-piece surface.

Gorana(2009) conducted Scratching experiments to simulate and acquire the knowledge about the action of abrasive grains during the AFM process.

Khrushchov and Bavichov (2009) identified two processes taking place when abrasive grains made contact with the wearing surface:

(1) The formation of plastically impressed grooves

which do not involve material removal;

(2) The separation of material particles in the form of micro-chips.

Whether chip formation takes place, or rubbing, or both depends upon the shape of indenting particle. In particular, spherical indentors have been found to show a change over from rubbing to at least partial chip formation when the indentation strain (defined as the depth of indentation divided by the diameter of the indentor) exceeds a certain value. The machining action during AFM compares to a grinding operation as medium uniformly removes material from the work-piece surface.

Morochkin (2010) proposed three different regimes of grain work-piece interactions i.e., chip regime, plastic regime, elastic regime.

Ravi Shankar (2011) suggested that the chip size in AFM is far smaller (μ-chips) than the ones obtained during machining with tools having well-defined cutting edges. Micro to Nano level removal of material in AFM process allows production of better surface finish, closer tolerances and more intricate surface features.

Shaw (2011) proposed a theory of microchip formation for fine finish grinding assuming spherical abrasive grain.

EXPERIMENTAL DESIGN AND ANALYSIS

Conducting experiments and drawing correct inferences from experimental observations are two most important prerequisites of any scientific study aimed at product or process development. Clarity of objectives and proper planning of experiments is very crucial for assimilating accurate and meaningful conclusions from the experimental results. Design of experiment is a very powerful tool for accomplishing these objectives. Adopting robust design of experiments adds value and reliability to the experimental results besides certain other advantages, like cost cutting by reducing the number of experimental runs and trials; and determination and reduction of experimental errors. It is therefore imperative upon researchers to properly plan and conduct experiments to obtain adequate relevant data which facilitates interpreting maximum knowledge from the experimental data thereby developing better insight of the process or subject. The most widely used experimental approaches are briefly discussed as under,

(1) Trial-and-Error/One-Factor at-a-Time Approach:

Performing a series of experiments arbitrarily or by varying one factor at-a-time approach wherein each experiment gives some understanding of the basic phenomena and the effect of individual parameters. This approach usually requires very large number of experiments, is labour intensive and time consuming and may be expensive, and at times does not depict the correct behaviour of the process parameters, and does not give the interaction effect of parameters.

(2) Full Factorial Experiments:

A well planned set of experiments, in which all parameters of interest are varied over a specified range, is a much better approach to obtain systematic data. Mathematically, such a complete set of experiments ought to give desired results. Usually the number of experiments and resources (materials and time) required are prohibitively large. The analysis is at times tedious and thus effects of various parameters on the observed data may not be readily apparent. In many cases, particularly those in which some optimization is required, the method does not directly point to the BEST settings of parameters.

(3) TAGUCHI Method

Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

EXPERIMENTAL SETUP

The present work is an attempt to experimentally investigate the AFM performance measures in finish-machining of multiple holes in pin cylinder lock bodies made up of Brass and Zinc materials. Live hardware industrial components have been used as work-piece surfaces bearing multiple holes for finish-machining by AFM technique and the process output responses have been measured. Material removal, MR and surface roughness, Ra value are taken as performance measures indicating the output responses. Taguchi’s robust parameter design approach has been applied for planning of experimental conditions, to perform and analyse the experimental results. The experiments are performed on the simplified uni-directional table top AFM setup developed by the authors. The machined surface roughness is measured using tally surf portable tester and for material removal measurement, an electronic weight balance having accuracy up to 10^{-4}gm has been used.

DEVELOPMENT OF AFM SETUP

The objective of developing the present setup is to provide a simplified, efficient yet economical equipment for unidirectional abrasive flow machining for finish-machining, deburring, radiussing, polishing and grinding of intricate and otherwise difficult to reach surface profiles, internal bores and cavities in machine components. The emphasis is on integration of the said technique with present-day small scale industries to completely exploit the vast potential use and applications of the process. And with this perspective, attention is given to detail at the design stage of the setup to provide rapid, facile and consistent finish-machining by AFM process thereby making fullest use of the vast potential applications of the process.

Fig. 1 shows a pictorial view of the table-top setup for an AFM process, designed and fabricated by the author. The setup is mounted on the work table with the help of steady rests. The configuration is a one-way AFM setup which comprises of media cylinders, piston, end and mid support plates, work-piece holder with clamp and guiding fixtures, and nozzle to match work-piece profile. The work pieces comprising pin cylinder lock bodies having multiple holes and made up of Brass and Zinc are placed in the work holder for finish-machining by AFM. The setup works as described below.

The forward translational motion of the piston inside the extrusion cylinder pressurizes the abrasive laden visco-elastic media in the cylinder in a forward direction and extrudes it through or past the work-piece surface. As a result, the abrasive laden media abrades the work-piece surface mounted in the work hold

The forward direction of the piston is reversed after completing the stroke and the media is refilled in the extrusion cylinder from the media collector during the reverse stroke. This combination of one forward and reverse stroke completes one cycle of the AFM process. The work-pieces are machined for a predetermined number of cycles, as specified in the experimental conditions. After the machining is over, the work-pieces are taken out from the setup and cleansed with acetone before any measurement is taken.

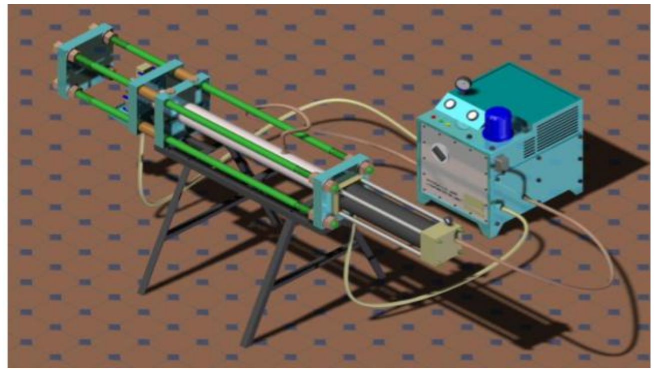
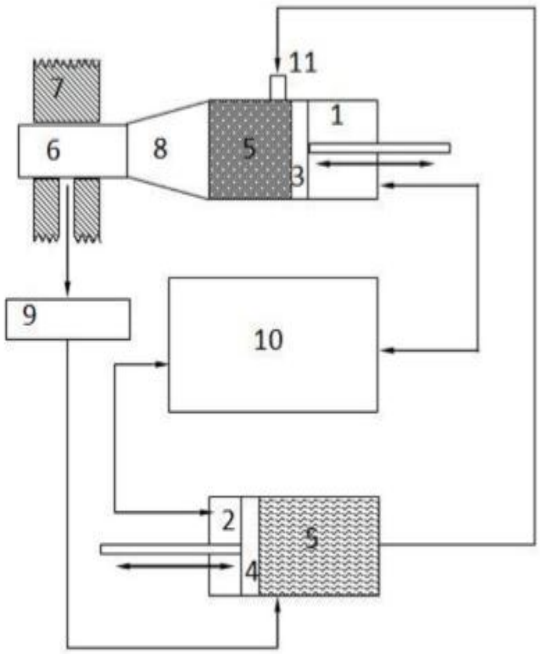


Figure 1 : Pictorial view of the AFM Set-Up

An abrasive flow machining and polishing setup having reciprocating piston inside an extrusion medium cylinder adapted to receive and extrude a visco-elastic abrasive dispersion uni-directionally through or past the internal surfaces of a work-piece has been developed by the author for the purpose of present study.

Fig. 2 shows the schematic diagram of the setup. A nozzle to match work-piece profile with the aid of fixture directs the flow of abrasive laden visco-elastic media from the extrusion cylinder into the internal passage of the work-piece surface. The visco-elastic abrasive dispersion finishes the work-piece surface as it extrudes from across the internal passage and drops into the collector which is set to gravimetrically collect the out-flowing media.

The visco-elastic media is recycled from the media collector back into the extrusion medium cylinder which is provided with an access port to receive the return flow of the visco elastic abrasive dispersion. The intermittent withdrawal of the piston from its extruding position within the said extrusion cylinder facilitates the return flow of the visco-elastic abrasive dispersion through the open port and into the extrusion cylinder. The reduced pressure created in the extrusion cylinder as the piston is withdrawn also assists the return flow of the medium which is forced from the collector into the extrusion cylinder thereby accelerating the refilling process.



EXPERIMENTAL METHODOLOGY

Drawing valid and objective conclusions from an experimental investigation requires conducting experimentation in accordance with proper planning and design of experiments. In performing a designed experiment, the input variables are varied and the corresponding changes in the output variables are observed. The input variables are called factors and the output variables are called response. Factors may be either qualitative such as type of material, color of sample etc. or quantitative in nature. Each factor can take several values during the experiment wherein each such value of a factor is referred to as a level. A trial or run is a certain combination of input factor levels whose effect on the output is of interest. It is essential to incorporate statistical data analysis methods in the experimental design in order to draw sound and reliable conclusions from the experiment. Firm conclusions cannot be drawn from an experimental study unless proper planning, careful study and due diligence is observed in the selection of input variable factors, their chosen levels and proper recording of all the possible output responses.

SELECTION OF AFM PROCESS PARAMETRIC SPACE

The parameters can be classified on the basis of three major elements of the process, as mentioned below,

1. Machine Parameters: Extrusion pressure, media flow rate, media flow volume, number of cycles.

2. Medium Parameters: Abrasive Size, Abrasive Type, Abrasive Concentration, Additives/Oil Concentration, Temperature and Viscosity of the medium.

3. Work-piece Parameters: Work-piece Material, Passage Geometry, Reduction ratio, Initial surface roughness.

4. Extrusion Pressure: It is the pressure developed inside the extrusion cylinder or media cylinder with which the media extrudes through or past the work-piece surface thereby causing finish-machining by the abrasive action of the abrasive laden viscoelastic medium which acts as a flowing tool in this process. The pilot experiments suggested enhanced output responses, in both the performance measures viz. material removal and change in surface roughness, with increase in the extrusion pressure and these results also support the findings of Williams and Rajurkar and Walia who have reported that extrusion pressure significantly affects both surface roughness and the material removal. The level of extrusion pressure has been selected in between 10 – 30 bar on the basis of the results obtained from the preliminary experiments and the limitations imposed by our experimental setup.

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