CHAPTER I

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 [1,2,3]. Abrasive flow machining (AFM) is a novel non-traditional machining process developed as a method to debur, 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.
4. Little effort directed towards improving the overall efficiency and capability of the process with emphasis on quality characteristics.
5. There is no information on efforts directed towards integration of this charismatic technique with present day small scale industries making it relevant, feasible, economic and viable for widespread applications.

Although certain good research initiatives have been reported in the direction of controlling the process parameters and analytical modelling 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 widespread 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 heterogenous 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.

To sum up, the objectives of the present research initiative are detailed as under:

1. Development of simple yet versatile uni-directional table top AFM set-up, which facilitates provision for variable process parameters in finish-machining of multiple holes in pin-cylinder lock bodies.
2. Development of SMART visco-elastic medium and Selection of its composition which yields enhanced quality characteristics.
3. Parametric optimization of AFM process parameters in finish-machining of multiple holes for improved quality characteristics.
5. Prediction of optimal values of quality characteristics at optimal setting of process parameters.
6. Modelling of the process to understand the relationship of quality characteristics with process parameters.

The present research initiative has been conducted in a phased manner towards accomplishment of objectives and the different phases have been described as under:

**Phase -I**

- Development of simple yet versatile AFM set-up, which has been designed and indigenously fabricated by the author keeping major design criteria into consideration and providing the provision for variation in process parameters

- Having developed and installed the AFM Set-Up, the next crucial step of our study was selection of SMART visco-elastic medium which acts as a deformable grinding tool and its composition for obtaining enhanced quality characteristics and improved efficiency and process capabilities. SMART visco-elastic medium from amongst various media alternatives has been selected by application of TOPSIS with AHP which is one of the widely used multi-attribute decision making methodology
Phase –II

Identification of all the possible AFM process parameters that may be influencing the capability and efficiency of the process and investigating the behavior of these process parameters by conducting preliminary experiments, using one factor at a time approach

Investigation of the workable range and the levels of the AFM process parameters based on the results obtained from the pilot experiments and limitations imposed by our set-up

Identification of the output response which truly reflected the performance measures of the AFM process - Material Removal (MR) and Change in Surface Roughness ($\Delta$Ra) have been selected as the quality characteristics as performance indicators

Identification of viable live industrial components which could be used as work-pieces in the present study, with the perspective of studying the feasibility of integration of this charismatic technique with present day small scale industries

Phase –III

TAGUCHI’s robust parameter design approach has been adopted for the present study and experiments are performed in accordance with $L_{27}$ Orthogonal Array (OA) which had been selected taking into consideration the number of selected parameters, their levels, and possible interactions of interest

Having performed the experiments in accordance with Taguchi’s fixed frame $L_{27}$ OA and recorded all the experimental observations on the selected quality characteristics viz. material removal (MR) and Change in Surface Roughness ($\Delta$Ra), the first step was to check the consistency of the experimental observations obtained on our developed setup by Monte Carlo Simulation.

Statistical analysis of our experimental design to investigate the effects of AFM process parameters viz. extrusion pressure, abrasive concentration, abrasive mesh size, number of cycles and oil concentration on quality characteristics viz. material removal and change in surface roughness

Optimization of AFM process parameters for enhanced quality characteristics of machined parts:

- Prediction of optimal setting of AFM process parameters
- Prediction of optimal values of quality characteristics
- Prediction of 95% confidence interval of quality characteristics for confirmation experiments and population
Experimental verification of quality characteristics at optimal setting of parameters obtained from Taguchi analysis

**Phase –IV**

- Multi-characteristic optimization of process parameters by Taguchi’s Utility concept - a multi-objective technique
- Determination of optimal values and 95% confidence interval of quality characteristics for optimal set of process parameters obtained by Utility
- Experimental verification of quality characteristics at optimal setting of parameters obtained by Utility
- Comparison of single characteristic optimization results with multi-characteristic optimization

**Phase –V**

- Validation of significant effects and percentage contribution of process parameter results obtained from Taguchi analysis for abrasive flow finishing of multiple holes by Analytical Hierarchy Process applied for criticality determination of AFM process parameters
- Validation of multi-characteristic optimization results obtained from Taguchi's utility concept by grey relational grades analysis
- Determination of optimal setting of AFM process parameters for enhanced quality characteristics obtained by Grey Relational Grades Analysis
- Experimental verification of quality characteristics at optimal setting of parameters obtained by Grey Relational Grades Analysis
- Development of mathematical models and response surfaces of quality characteristics viz. material removal and change in surface roughness using regression analysis and response surface methodology