CERTIFICATE

Delhi Technological University

Department of Mechanical Engineering

Delhi-110042

This is to certify that the thesis entitled **'STUDY OF ROTATIONAL ABRASIVE FLOW MACHINING'** done by **Jitendra Kumar Singh** (Roll Number 2K12/PIE/29) on partial fulfilment for the award of degree of Master of Technology in Production Engineering at **Delhi Technological University**, is an authentic work carried out by him under my guidance. The matter embodied in this thesis has not been submitted earlier for the award of any degree or diploma to the best of my knowledge and belief.

Dr. R S Walia
Associate Professor
Department of Mechanical Engineering

Dr. Qasim Murtaza
Associate Professor
Department of Mechanical Engineering

ABSTRACT

Over recent years a significant amount of research has been going on to develop a process which can machine component with higher MRR and surface finish (Ra value). There are significant applications of finishing processes of internal straight or contoured holes in industries. For this purpose there are several researches going on in the field of Abrasive Flow Machining (AFM). In the extension of AFM process we have Rotational Abrasive Flow Machining (RAFM). There are huge complexity in the existing RAFM processes. So there are a lot of improvements can be done in the existing system.

In this report the study and synthesis of the new design and development of RAFM is discussed. In this study an attempt is made to compare the Conventional AFM with RAFM. Also we have discussed the magnetic effect of a motor core on the process. For this study the Styrene Butadiene Rubber as media and Silicon Carbide (SiC)+ Ferric Oxide(Fe_2O_3) as abrasive to determine end results.

DEDICATIONS

This project work is dedicated to my parents; who have made me capable of growing forward in my life. Also I dedicate this work to Shambhu my elder brother who has been a greatsource of moral support, strength, motivation and inspiration.

ACKNOWLEDGMENT

I am greatly indebted to my mentor **Dr. R S Walia** and **Dr. Qasim Murtaza** for his patience, concern, invaluable guidance and also encouragement throughout the undertaking of this research. I wish to express my gratitude to the Mechanical Engineering Department faculty members and many others whose support was great for the success of this work and their continued support with the resources and technical knowledge without which this work could not have been possible.
I am very thankful to **Mr. Sachin Dhul,** PhD scholar Mechanical Engineering Department, Delhi Technological University, for his valuable support and exceedingly helpful nature.

Jitendra Kumar Singh
2K12/PRD/29

CONTENTS

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

Technology is emerging and advancing day by day with the demand for highly accurate, precise and highly efficient machining process for advanced industries from critical aerospace and medical components to mass production automobile parts. This process has capability of finishing even the most areas which are not accessible, processing multiple, slots or edges , holes in one operation[1]. The development of materials having higher strength, hardness, toughness and other desire properties. This also needs to develop the advanced cutting tools material which can ease the process and economical without compromising productivity.

The application of advanced abrasive finishing technique are increasing as to get the highly accurate and highly efficient machining of complex shaped 3D components with nano level surface finish.

Abrasive finishing can be employed to finish most mechanical parts with shape limitations. Initial surface roughness of 0.25µm R_a can be improved easily to 0.05 µm within a few minutes. In addition AFM process many attractive advantages, such as self sharpening, self adoptability, controllability and finishing tool requires neither compensation nor dressing.

There are various abrasive particles like Al2O3, SiC, CBN, Diamond powder etc. are available which is being used for abrasive finishing process. To increase the MR and surface roughness, the abrasive are made magnetic in nature with ferromagnetic material by various techniques like sintering, mechanical mixing using ball mill etc.

1.1 Non-traditional manufacturing processes

Since beginning of the life on earth, people have evolved energy sources and tools to power these tools to meet the requirements for making the life easier. In the early stage of human beings, tools were made of stone for fabrication of products. When tools were invented, desirable metals and more sophisticated articles would be produced. Earlier products were made from durable and consequently, unmachinable materials. In an effort to meet the fabrication challenges created by these materials, tools have now developed to include materials such as steel alloy, carbide, ceramics and diamond. A similar evolution has taken place with the methods used to power our tools. Initially, tools were powered by muscles; either human or animal. However as the powers of water, wind, steam and electricity were harnessed, human beings were able to further extend manufacturing capabilities with new machines, accuracy and faster machining rates. The traditional manufacturing processes in use today for material removal basically based on electric motors and hard tool materials to perform tasks such as drilling, boaring, milling and broaching. Conventional forming operations are performed with the energy from pneumatics, hydraulics, electric motors and gravity. Likewise, material joining is conventionally achieved with thermal energy sources such as burning gases and electric arcs. In contrast, non-traditional manufacturing processes harness energy sources considered unconventional by yesterday's standards. Material removal could be achieved with electro-chemical reaction, plasmas and high velocity jets of liquids and abrasives particles. Materials those were in the past have been extremely difficult to form, are now formed with explosives and the shock waves from strong electric sparks and magnetic fields. Material-joining capabilities have been expanded with the use of high-frequency sound waves and beams of electrons and coherent light. During the last 50 years, over more than 20 different non-traditional manufacturing processes have been invented and successfully implemented into production. The non-conventional manufacturing processes are not affected by toughness or brittleness, hardness of material and can produce any intricate shape on any work piece material by suitable control over the various physical parameters of the processes. The non-traditional manufacturing processes may be classified on the basis of type of energy namely, electrical, chemical, mechanical, thermal or magnetic, apply to the work piece directly and have the desired shape transformation or material removal from the work surface by using different scientific mechanism. Thus, these non-conventional processes can be classified into various groups according to the basic requirements which are as follows:

(i) Type of energy required, namely electrical, mechanical, chemical etc.

(ii) Basic mechanism involved in the processes, like ionic dissolution, erosion, Vaporization etc.

(iii) Source of immediate energy required for material removal, namely, hydrostatic Pressure, high voltage, high current density, ionized material, etc.

(iv) Medium for transfer of those energies, like high velocity particles and electrolyte, Electron, hot gases, etc. On the basis of above requirements.

Various types are as follows:

1.1.1 Ultrasonic Machining Ultrasonic Machining is a non-traditional process, in which abrasives contained in slurry are driven against the work by a tool oscillating at low amplitude (25-100 µm) and high frequency (15-30 KHz). The process was first developed in 1950s and was originally used for finishing EDM surfaces. The basic process is that a ductile and tough tool is pushed against the work with a constant force.

A stream of abrasive slurry passes between the tool and the work (gap is 25-40 µm) to provide abrasives and carry away chips. The majority of the cutting action comes from an ultrasonic (cyclic) force applied. The basic components to the cutting action are believed to be, brittle fracture caused by impact of abrasive grains due to the tool vibration; cavitations induced erosion; chemical erosion caused by slurry.

1.1.2 Jet Machining In jet machining, high-velocity stream of water (Water Jet Cutting) or water mixed with abrasive materials (Abrasive Water Jet Cutting) is directed to the work piece to cut the material. If a mixture of gas and abrasive particles is used, process is termed as Abrasive Jet Machining and is used not to cut the work but for finishing operations like cleaning, polishing, deburring.

1.1.3 Water Jet Cutting Water Jet Cutting (WJC) uses a fine, high-pressure, high velocity (faster than speed of sound) stream of water directed at the work surface to cause slotting of the material: Water is the most common fluid used, but additives such as oil products and viscous glycerol are added when they can be dissolved in water to improve the fluid characteristics. The fluid is pressurized at 150-1000 MPa to produce jet velocities of 550-1400 m/s. The fluid flow rate is typically from 0.5 to 2.5 l/min. The jet has a well behaved central region surrounded by a fine mist.

1.1.4 Abrasive Water Jet Cutting (AWJC) In Abrasive Water Jet Cutting, a narrow, water jet is mixed with abrasive particles is impacted with very high pressures resulting in high velocities that cut through all materials. The presence of abrasive particles in the water jet reduces cutting forces and enables cutting of thick and hard materials (steel plates over 80-mm thick can be cut). The stream velocity is up to 90 m/s, about 2.5 times the speed of sound Abrasive Water Jet Cutting process was developed in 1960s to cut materials that cannot stand high temperatures for stress distortion or metallurgical reasons such as wood and composites, and materials which were difficult-to-cut traditionally. e.g. glass, stones, ceramics and titanium alloys. The common types of abrasive materials used are quartz sand, silicon carbide, and corundum (Al2O3), at grit sizes ranging between 60 and 120.

1.1.5 Abrasive Jet Machining (AJM) In Abrasive Jet Machining, fine abrasive particles (typically ~0.025mm) are accelerated in a gas stream (commonly air) towards the work piece surface. As the particles impact the work piece surface, they cause small fractures, and the gas stream carries both the abrasive particles and the fractured (wear) particles away. The jet velocity is in the range of 150-300 m/s and pressure is from two to ten times atmospheric pressure. The preferred abrasive materials involve aluminium oxide (corundum) and silicon carbide at small grit sizes. The grains should have sharp edges and should not be reused as the sharp edges are worn down and smaller particles can clog nozzle. Abrasive Jet Machining is used for debarring, etching, and cleaning of hard and brittle metals, alloys, and non-metallic materials (e.g. silicon, glass, ceramics and germanium).

1.1.6 Electric Discharge Machining: this is one of the most widely used non-traditional processes. A formed electrode tool produces the shape of the finished work surface. The sparks occur across a small gap between tool and work surface. The machining must take place with dielectric fluid, which makes a path for each discharge as the fluid becomes ionized in the gap. The fluid, quite often kerosene-based oil is also used to flush the debris. The arc discharges are generated by a pulsating direct-current power supply connected to the work and the tool. Electrode materials are high temperature, but easy to machine, thus allowing easy manufacture of intricate shapes. Typical electrode materials include graphite, copper and tungsten. The process is based on melting temperature, not hardness, so very hard materials can be machined this way.

1.1.7 Wire Electric Discharge Machining: Wire Electric Discharge Machining (Wire EDM) is a special form of EDM that uses a small diameter wire as the electrode to cut narrow kerfs in the work. The work piece is fed continuously and slowly past the wire in order to achieve the desired cutting path. Numerical control is used to control the work-part motions during cutting. As it cuts, the wire is continuously advanced between a supply spool and a take-up spool to present a fresh electrode of constant diameter to the work. This helps to maintain a constant kerfs width during cutting. Wire EDM must be carried out with dielectric fluid. This is applied by nozzles directed at the tool-work interface as in the figure, or the work part is submerged in a dielectric bath. Wire diameters range from 0.08 to 0.30 mm, depending on required kerfs width. Materials used for the wire include copper, brass, tungsten, and molybdenum. Dielectric fluids include demonized water or oil. As in electric discharge machining, an overcut in the range from 0.02 to 0.05 mm exists in wire EDM that makes the kerfs larger than the wire diameter.

1.1.8 Laser beam machining (LBM) Laser beam machining (LBM) uses the light energy from a laser to remove material by vaporization and ablation. The types of lasers used in LBM are basically the carbon dioxide (CO2) gas lasers. Lasers produce collimated monochromatic light with constant wavelength. In LBM all of the light rays are parallel, which allows the light not to diffuse like normal light. The light produced through the laser has significantly less power than a normal white light, but it would be highly focused, thus delivering a significantly higher light intensity and respectively temperature in a very localized area. Lasers are being used for a variety of industrial applications like heat treatment, welding, and measurement, as well as a number of cutting operations such as drilling, slitting, slot cutting, and marking operations. Drilling micro-diameter holes is possible, down to 25 µm. For larger holes, the laser is controlled to cut the outline of the hole. The range of work materials that can be machined by Laser Beam is virtually unlimited including metals with high hardness and strength, ceramics, soft metals, glass, plastics, rubber, wood and wood. LBM can be used for 2-Dimensional or 3-Dimensional workspace. The LBM machines typically have a laser mounted, and the laser beam is directed to the end of the arm using mirrors. Mirrors are often cooled (water is common) because of high laser powers.

1.1.9 Electron beam machining (EBM) Electron beam machining (EBM) is one of several industrial processes that use electron beams. Electron beam machining uses a high-velocity stream of electrons focused on the work piece surface to remove material by melting and vaporization an electron beam gun generates a continuous stream of electrons that are focused through an electromagnetic lens on the work piece surface. The electrons are accelerated with voltages of approx. 150,000 V to create velocities over 200000 km/sec. The lens is capable of reducing the area of the beam to a diameter as small as 25 micron. On impinging the surface, the K.E of the electrons is converted into thermal energy of extremely high density, which vaporizes the material in a much localized area. EBM must be carried out in a vacuum chamber to eliminate collision of the electrons with gas molecules. Electron beam machining is used for a variety of high-precision cutting applications on any known material. Applications include drilling of extremely small diameter holes, down to 50 µm diameters, drilling of holes with very high depth-to-dia ratios, more than 100:1, and cutting of slots that are only about 25 µm wide. Besides machining, heat treatment and welding are other significant applications of the technology. The process is generally limited to very thin parts in the range from 0.2 to 6 mm thick. Other limitations of EBM are the need to perform the process in a vacuum which required the high energy and the expensive equipment.

1.2 Basic principle of AFM

In abrasive flow machining, the abrasive fluid flows through the work piece, effectively performing erosion. Abrasive particles in slurry contact raised features on the surface of the work piece and flush them. The fluid is forced through the work piece by a Hydraulic ram where it acts as a flexible file, molding itself precisely to the shape of the work piece surface. The highest amount of material removal occurs in areas where the flow of the fluid is restricted; according to Bernoulli's principle, the speed and pressure of the fluid increase in these areas, facilitating a higher MMR. The pressure exerted by the fluid on all contacting surfaces also results in a very uniform finish. AFM may be performed once, as a one-way flow process, or repeatedly as a two-way flow process (double acting). In the two-way flow process, a reservoir of medium exists at either end of the work piece, and the medium flows back and forth through the work piece from reservoir to reservoir.

Classification of abrasive flow machine

AFM machines are classified into two categories according to the direction of flow of abrasive media i.e. one way AFM and two way AFM.

1.2.1 One way AFM process

In one way [2] AFM process the media is extruded inside the work piece only in one direction. For this purpose the setup has a hydraulically actuated reciprocating piston and an extrusion medium chamber adapted to receive and extrude medium unidirectional across the internal surface of the work piece having internal passage formed therein. Piston direct the media through the internal passage of the work piece while a medium collector collects the media as it is extruded out through the work piece. The extrusion media chamber is provided with an access port to periodically receive medium from the collector into extrusion medium chamber. The hydraulically actuated piston intermittently withdraws from its extruding position to open the extrusion media chamber access port to collect the medium in the extrusion media chamber. When the extrusion medium chamber is charged with the working media, the operation is resumed.

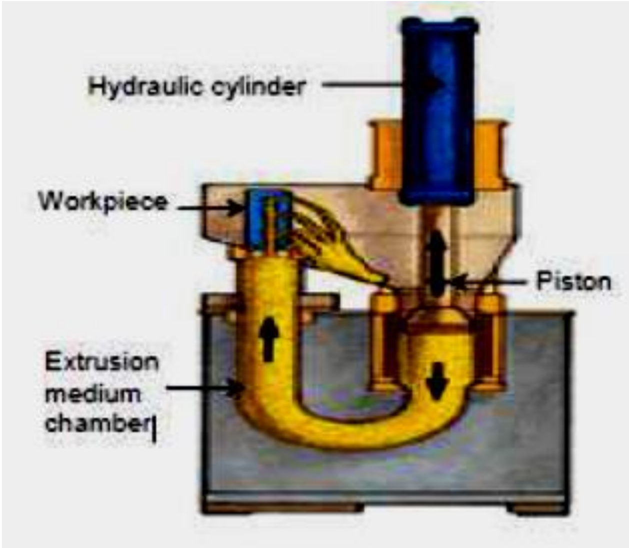

Figure 11. Schematic of One –way AFM[3]

1.2.2. Two-way AFM process

Two ways AFM machine [4] has two hydraulic cylinders and two medium cylinders. The media is extruded, hydraulically or mechanically, from the filled chamber to the empty chamber via the restricted passageway through or past the work piece surface mounted in fixture to be abraded (Figure 2). Typically, the medium is extruded back and forth between the chambers for the predetermined fixed number of cycles. Counter bores, recessed areas and even inaccessible cavities can be finished by using restrictors or mandrels to direct the medium flow along the surfaces to be finished.

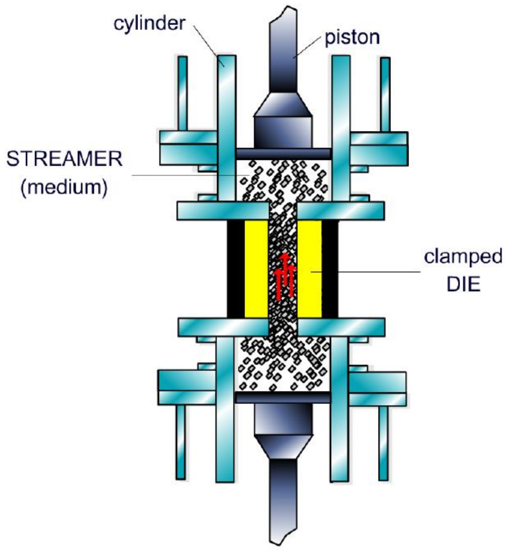

Figure 12.Schematic of two way AFM[5]

1.2.3 Orbital AFM

In this process good surface finishing is obtained by producing low-amplitude oscillations of the work piece [6].The tool consists a layer of abrasive-laden elastic plastic medium (i.e. same as used in two way abrasive flow finishing), and has a higher viscosity and more elastic in nature.

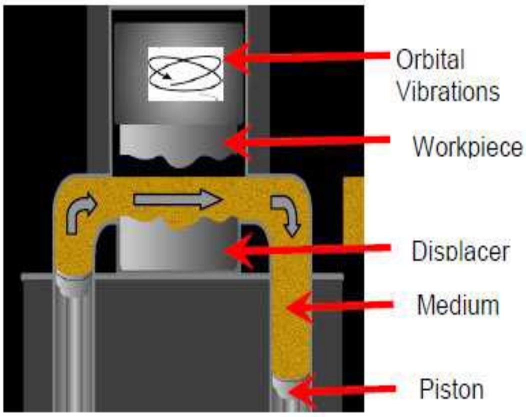

Figure 13.Operational set up of Orbital AFM [6]

1.2.4 Helical AFM

In this kind of abrasive flow machining, the abrasive medium is made to flow in helical pathway as shown. To attain such fluid flow, a typical helical drill-bit is engaged which is held along the axis of the hollow cylindrical work-piece. The abrasives loaded media is extruded through the recess between the drill-bit and the inner surface of the hollow cylindrical work-piece. After the completion of one stroke, the process is reversed and the combination of these forward and backward strokes constitutes a cycle. During the upward and download stokes, initially drill-bit rotates. It is then either lifts or moves downward, and then arbitrarily orients itself in a stable position for the rest of the stroke with the help of upper and lower locking pins. As the medium passes through the cavity in-between the stationary drill-bit and work-piece, it follows a combination of directional flows. Consequently, it is found to increase the proportion of active abrasive grains.

As the abrasives loaded media extrudes through the helical passage, the internal cylindrical surface of the work-piece is finished by the abrasion process. Due to its helical flow, machining forces incorporate a combination of axial, radial and centrifugal components. This helps in significantly improving surface roughness of the work-piece and allows for thorough intermixing of media. Furthermore, helical AFM enhances polishing effectiveness by increasing the abrasive surface area and radial shear forces.

A-Cheng Wang et al [6] have demonstrated how the use of four helices passageway significantly increases the surface roughness uniformity in helical abrasive flow machining. Brar B S et al [7] have shown the use of stationary drill-bit in Helical AFM in increasing the material removal by a factor of 2.66 over the basic AFM process, along with a maximum percentage improvement in surface roughness of 74.69%.

1.3 Parts of abrasive flow machining

Abrasive flow machining required some elements to perform the process. The various elements are fixture or tooling, the machine, and abrasive laden media. The abrasive media determines what kinds of abrasion occur, the fixture determines exact location of abrasion, and machine decides the extent of abrasion as the abrasive particles are responsible for direct abrasion action on the surface and fixture is responsible for holding the work piece against the abrasive particles. Pressure, type of drill bit decides the force by which abrasive particles strike the surface.

1.3.1 Fixture

Steel, urethanes, aluminum, nylon, Teflon are the material can be used to make fixture. Aluminum and nylon are easily machinable lightweight materials so they are perfect for fixture material. Steel is rarely used and used only for its strength and durability.

Fixture design is often a very important factor in achieving the desired effects from the AFM process as the design of fixture depends on the shape of work piece. In this project the work piece is cylindrical so a proper design of fixture is used which can hold a cylindrical work piece. Basic functions of fixture [7] include:

- Holding the work piece in proper position between the media cylinders.
- Directing media flow to and from the areas of the part to be worked on, during the process cycle.
- Protecting edges or surfaces from abrasion due to media flow by acting as a mechanical mask.
- Providing a restriction in the media flow path to control the media action in selected areas.
- Containing the media and completing the closed-loop system required for multiple machine cycle operation without loss of media.

If AFM is used to process external edges or surfaces, the tooling contains the part in the flow passage, restricting the flow between the exterior of the part and the interior of the fixture. Any number of parallel restrictions can be processed simultaneously with uniforms results. To maximize productivity, fixture can be designed for batch production processing of many parts simultaneously if their configuration and size permit.

Figure 14. Nylon Fixtures used in AFM setup

1.3.2 Abrasive media

This technique uses a non-Newtonian liquid polymer containing abrasive particles of Al_2O_3, SiC, boron carbide or diamond as the grinding medium and additives [8]. The viscosity and the concentration of the abrasives can be varied Most widely used carrier is a high viscosity fluid. The base materials has enough degree of cohesion and tenacity to drag the abrasive grains along with it through various passages/regions. AL_2O_3 and SiC are most suitable abrasives for many applications but Cubic boron nitride (CBN) and diamond are specifically used for special applications. Abrasive particles to base material ratio can be varying from 2 to 12.Abrasive are available in different mesh sizes. The abrasive have limited life. AS a thumb rule, when the media has machined an amount equal to 10% of its weight, it must be discarded. Machined parts should be properly cleaned before use, by acetone. The additives are used to enhance the base carrier to get the desired flowability and rheological characteristic of the media. Hydrocarbon gels are commonly used lubricants in the media. All additives are carefully blended in predetermined qualities to obtain consistent formulation.

1.3.3 Machine setup

All AFM machines regardless of size are positive displacement hydraulic systems, where work piece is clamped between two vertically opposed media cylinder. By repeatedly extruding media from one cylinder to the other, an abrasive action is produced whenever the media enters and passes through restrictive passage as it travels through or across the work piece.AFM machine controls two crucial parameters for determining the amount of abrasion, the extrusion pressure and the media flow rate. Standard units operate within 10 bar to 200 bar pressure range with flow rates up to 400 liters/minute. The systems are essentially provided with controls on hydraulic system pressure, clamping-unclamping of tooling or fixtures, volume flow rate of abrasive media, and advance and retract of media pistons. Programmable microprocessor control unit can be used to monitor and control additional process parameters at the machine, such as media temperature, media temperature, media viscosity, abrasive wear, and flow speed. Several accessories such as part cleaning stations, automatic flow timers, cycle counters, pressure and temperature compensated flow control valves, automatic media lubricant replenishment, and media heat exchangers units may also be integrated to the conventional AFM systems for production applications.

Figure 15.Vertical double acting AFM machine setup

1.4 AFM applications

(A) INTERNAL EDGE CONTROL

The Abrasive Flow Machining (AFM) process provides a controlled and repeatable method for burr removal and surface finish enhancement at hole intersection(s) and difficult to reach surfaces. Irregular shapes, holes and intersecting surfaces can be deburred or even polished with precision and predictable results in places that are impossible to reach by virtually any other method.AFM removes the burrs and enhances the adjacent surfaces by flowing the selected abrasive material on the target surface/edge and is typically limited ONLY by hole size coupled with the particulate size of the chosen abrasive.

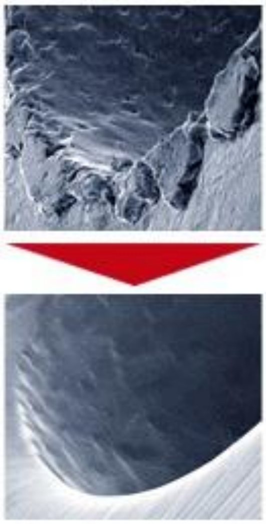

Figure 16.Internal Edge finished component [9]

(B) MOLDS AND DIES

- Metal forming
- Glass forming
- Plastic applications

Critical, forming surfaces may be enhanced as much as (X10) on many applications. EDM's surfaces (all types), milled surfaces and ground surfaces can be consistently and uniformly polished to a very low Ra to further enhance speed and overall quality and production efficiency while maintaining critical tolerances.

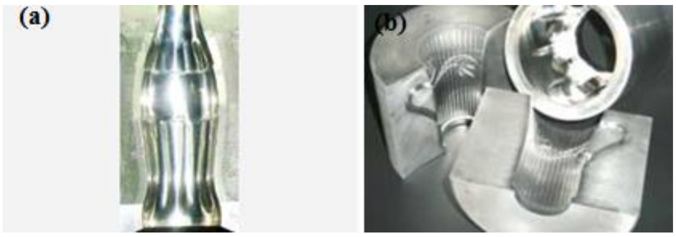

Figure 17.New glass moulds (dies and moulds)[9]

(C) AERONAUTICAL COMPONENET MANUFACTURING

- Increased fatigue strength
- Higher performance and efficiency

Abrasive Flow Machining will precisely remove the "recast layers" of material resulting from the thermal characteristics of laser and EDM cutting techniques in many high-strength applications. Improved surface integrity with enhanced eddy current readings results in more reliable components. Accurate and repeatable edge control, regardless of configuration, typically equates to less flow resistance and enhanced cycle fatigue strength

Figure 18. Critical aircraft hydraulic and fuel system components [9]

(D) ULTRA CLEAN

- Food processing
- Semiconductor (front-end) equipment
- Pharmaceutical manufacturers
- Ultra-clean or high purity devices

Polishing surfaces to mirror-like requirements minimizes the amount of microscopic and/or inaccessible areas that enable contamination or entrapment. Ultra-smooth surface finishes greatly diminish the areas of concern for surface absorption, foreign particulate, chemical contaminants and bacteria. The AFM process minimizes "flow-retardation" due to machining and/or dies and mould "microgrooves."

AFM allows for extreme fine finishes on intricate geometry and difficult-to-reach surface configurations often found in prosthetic applications and in a broad range of materials.

(E) INTERNAL COMBUSTION ENGINE

- Diesel engines
- Automotive

A high-pressure fuel injection system's life cycle can be extended through Abrasive Flow Machining by reducing surface cracks and more uniform surface finishes in critical areas of fatigue failure. Reduction of resistance in fuel and exhaust passages enhances performance and efficiency while maintaining critical tolerance parameters. Smoother intake passages allow for effective mixing of air/gas, higher efficiency and a more powerful engine.

Figure 19.Automotive components [9]

CHAPTER 2

LITERATURE REVIEW AND PROBLEM FORMULATION

Technology is emerging and advancing day by day with the demand for highly accurate, precise and highly efficient machining process for advanced industries from aerospace and medical components to mass production automobile parts. This process has capability of finishing even the most areas which are not accessible, processing multiple, slots or edges, holes in one operation [1]. A lot of work has been done to study the effects of important AFM process parameters. Some the work has been reported as under:

2.1.1.Extrusion Pressure

It is found that cutting is faster at an increased extrusion pressure, with all other parameters remaining constant. A part of total pressure is lost within the media due to its internal resistance to flow and rest is imparted to abrasion particles contacting the work piece surface [2]. Jain and Jain [3] reported that at higher pressure improvement in material removal stabilize due to localized rolling of abrasion particles

2.1.2 Number of Process Cycles

It has been reported in a number of studies that abrasion is more pronounced in some initial cycles after which improvement in the surface finish stabilize or reduce in some cases.

2.1.3 Media Flow Volume

If media flow volume is increased than material removal increases.

2.1.4 Media Viscosity

Williams and Rajurkar [4], and Williams et. al. [2] have reported that viscosity of the media is one of the significant parameters of the AFM process.

2.1.5 Media Temperature

From the experimental results reported by Weller [5], it can be interpreted that an increase in temperature during processing results in faster cutting of the material, under otherwise constant cutting conditions.

2.2 Latest developments in RAFM

Ravishankar et al [6], (2009), in the paper entitled, 'Experimental investigations into rotating workpiece abrasive flow finishing', improved the performance of AFF process by providing rotary motion to the workpiece. Preliminary experimental comparative study was done on AFF and R-AFF processes to compare their process performance in terms change in *R*a and material removal.

Then complete experimental study on R-AFF was conducted using central composite rotatable design and the responses were plotted using response surface methodology. The workpiece materials used in the present study were Al alloy, Al alloy and Al alloy/SiC (15%) metal composites (MMCs). The study showed that rotational speed of workpiece had larger effect on output responses. Indigenously developed semi solid abrasive laden medium was used. The experiments showed that R-AFF had a very promising future for the industries in terms of higher finishing.

An indigenously developed and hydraulically powered R-AFF experimental set-up is designed and fabricated as shown in Fig. 1. Depth of penetration of abrasive particles in the workpiece depends on pressure, abrasive medium viscosity and grain size. The penetration of abrasive particles into the work surface depends on the radial force acting on them, and the axial force removes the material in the form of micro chips as discussed later [7-8]. The rheological properties of the abrasive laden medium determine the pattern of the abrasive action. Abrasion is high where medium velocity is high [9]. An increase in pressure and medium viscosity increase material removal rate while surface roughness decreases. In any finishing operation, better surface can be achieved if the active abrasive grain moves in random motion.

Fig.1 R-AFF Experimental set-up [6]

This set-up has been designed keeping in view the mechanism of the process and basic functional requirements of different types of parts. The R-AFF set-up consists of specially designed rotary tooling, variable frequency drive and high torque motor, speed reduction gear box, external geared tooling work fixture, hydraulic drive and supporting frame.

Three workpieces are fixed in the central boss of a removable cylindrical rotary tooling fixture. The medium is filled tightly in the lower cylinder. The tooling is designed in such a way that the system is medium leak proof for the specified extrusion pressure range. The desired extrusion pressure is set using hydraulic power pack and the desired work rotary speed is obtained using VFD. Medium reciprocates due to piston motion and workpiece rotates due to external rotary set-up, Fig. 2(a). The resultant interaction path of abrasives on the workpiece surface is approximately helical, Fig. 2(b).

To enhance productivity of the process and to impart random motion to an active abrasive grain, several modifications in AFF process was tried. To enhance the performance of AFF, magnetic field was applied to the AFF process [10-11]. Some researchers planted spiral fluted screw [14] and drill bit [15] to guide the medium flowing path to improve the finishing efficiency. Al alloy/ SiC metal matrix composites have many times replaced conventional materials in various industrial and other engineering applications such as aerospace, automotive, and other industries. Al alloy/SiC composite has better mechanical and physical properties namely improved wear properties, higher modulus of elasticity and strength to weight ratio than Al alloy.

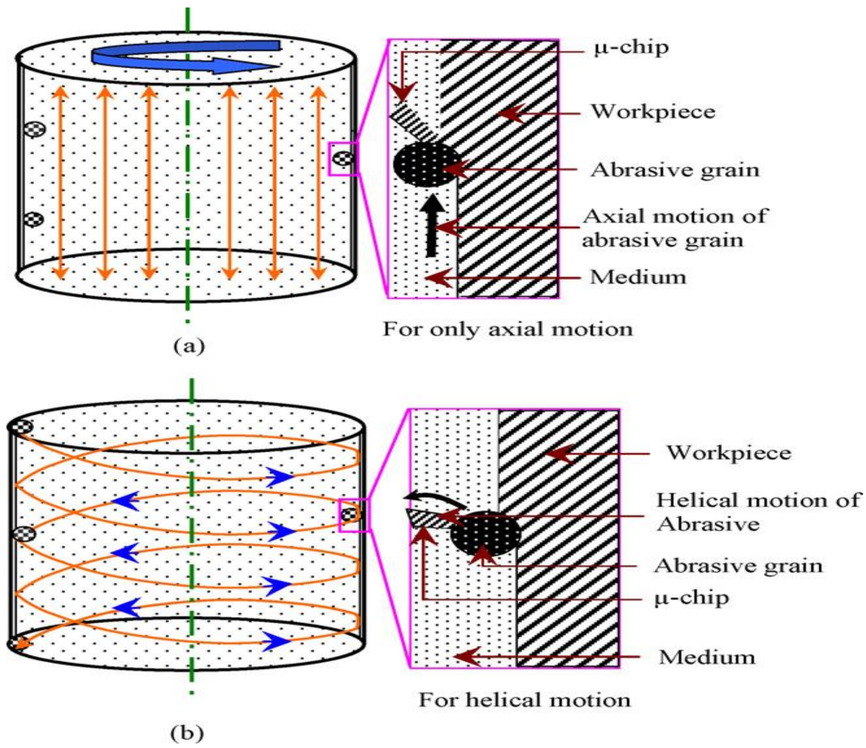

Fig. 2. Abrasive medium motions, (a) two motions of R-AFF (b) approximately helical finishing path on the work piece surface [6]

Comparison of AFF and R-AFF processes:

Experiments are conducted to study the effects of input parameters (wt% of processing oil (10%), extrusion pressure (6.25MPa), total cycles (550) and work speed (RPM) (0, 2, 4, 6, 8, 10)) on the process performance of AFF and R AFF in terms of roughness and MR. Ra and MR an higher in R-AFF process as compared to AFF process (Fig. 3) because in AFF process the medium reciprocates to and fro so the abrasives finish the surface peaks that come in shortest path of its flow. So, the number of surface peaks that come in contact with an active abrasive grain is low.

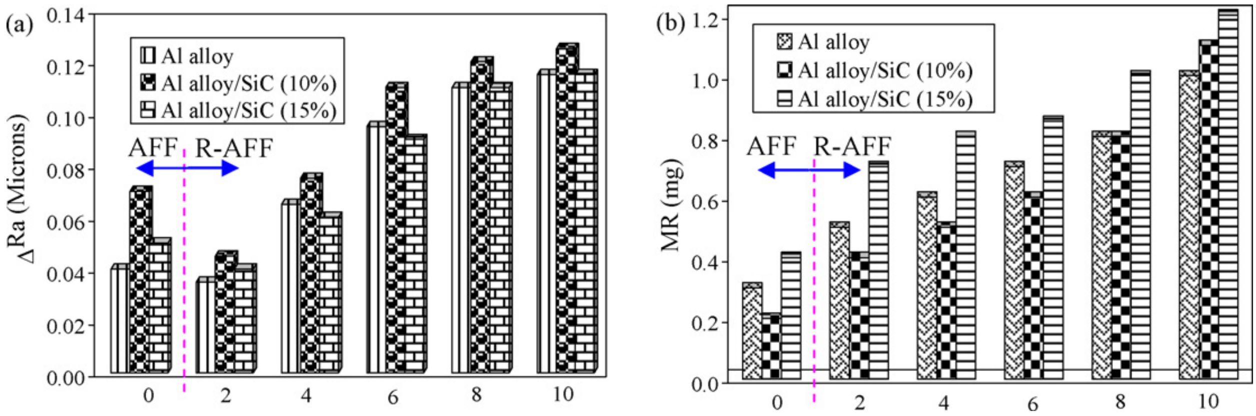

Fig.3 Comparison of (a) _Ra and (b) MR (at *N*= 550, *P* = 6.25MPa, *M*= 10%) in AFF and R-AFF [6]

R.S.Walia, H.S.Shan et al [13], (2007), in the paper 'Determining dynamically active abrasive particles in the media used in centrifugal force assisted abrasive flow machining process', demonstrated that the process is capable of providing excellent surface finishes on a wide range of simple and intricate components. Low material removal rate was one major limitation of the process, because during machining not all the abrasive particles participate in removing material from the work piece. Limited efforts had been directed towards improving the efficiency of the process so as to achieve higher material removal rates. An effort has been made towards the performance improvement of this process by applying centrifugal force on the abrasive media with the use of a rotating centrifugal force generating rod introduced in the work piece passage. The modified process is known as centrifugal force assisted abrasive flow machining (CFAAFM). The paper presented a mathematical model developed to calculate the number of dynamics active abrasive particles participating in the finishing operation in the AFM and CFAAFM process. The analysis of results showed that there was significant enhancement of number of dynamic active abrasive particles in CFAAFM as compared to the AFM process.

Mamilla Ravishankar, V.K.Jain et al [14], (2009), in the research paper entitled, "Experimental investigations and modeling of drill-bit guided abrasive flow finishing (DBG-AFF) process", tried several modifications in AFF in order to enhance productivity. In this paper, a concept of rotating the medium along its axis has been introduced to achieve higher rate of finishing and material removal. This process is termed as drill bit-guided abrasive flow finishing (DBG-AFF) process. In order to provide random motion to the abrasives in the medium and to cause frequent reshuffling of the medium, the medium is pushed through a helical fluted drill, which is placed in the finishing zone. The experiments are carried out to compare AFF and DBG-AFF processes with AISI 1040 and AISI 4340 as workpiece materials. The performance of DBG-AFF as compared to AFF is encouraging, specifically with reference to percentage change in average surface roughness (% ΔRa) and amount of material removed. Modeling using non-linear multi-variable regression analysis and artificial neural networks are carried out to conduct parametric analysis and to understand, in depth, the DBGAFF process. The simulation data of neural network show a good agreement with experimental results.

R.S.Walia, H.S.Shan, P.Kumar et al [16], (2008), in the paper, “Morphology and integrity of surfaces finished by centrifugal force assisted abrasive flow machining”, explained that the surfaces are generated by erosion from random attack of abrasive grains. CFAAFMed surfaces are unidirectional but random in nature due to transient media flow conditions. In the present paper, surface morphology, surface microhardness, X-ray analysis, and surface compressive residual stress produced in the finished surface layer by CFAAFM process is described. The CFAAFM process was performed under different rotational speeds of CFG rod while keeping other input parameters constant during the experiments. The increase in surface microhardness and compressive residual stress of the workpiece with an increase in the rotational speed of CFG rod is attributed to the work-hardening surface that possibly occurs due to ‘throw’ of abrasive particles upon specimen surface.

The need for high-accuracy and high-efficiency finishing of materials is making the application of abrasive finishing technologies increasingly important. In order to cater to these requirements, abrasive flow machining (AFM) process is gaining importance day by day. The abrasive fine finishing processes use a large number of random cutting edges with indefinite orientation and geometry for effective removal of material with chip sizes smaller than those obtained during machining with tools having defined edges. Because of the extremely thin chips produced, abrasive machining allows better surface finish, close tolerances, and the generation of more intricate surface features. AFM is a nontraditional finishing process that is used to deburr, polish, radius, remove recast layers [17, 18]. In AFM, a semisolid media, consisting of an abrasive and a polymer-based carrier in a typical proportion, is extruded under pressure through or across the surface to be machined [19]. The abrasive grains are held tightly in place at this point and the media becomes a grinding stone, which conforms to the passage geometry [20]. The modeling of the AFM process is complex due to the little understood behaviour of the medium and the complicated and random nature of material removal and surface roughness. Both theoretical and empirical studies of the AFM process are greatly hampered due to the inherent random nature of distribution of grains into the medium and multiplicity of variables. The exact mechanism by which the individual abrasive particle accomplishes material removal is only partially understood. The review of literature reveals that experimental studies about the effects of various process parameters on material removal and surface roughness have been done by many researchers. Williams and Rajurkar [21] used a stochastic modeling and analysis technique called a data dependent system (DDS) to study the surfaces generated by AFM.

Continued improvements in product quality have become a necessity rather then an accessory. An improvement in product quality requires improvement in the efficiency and productivity of the process producing the product. The process must be capable of producing the desired product quality requirements effectively and economically [22]. The modern metal working industry has several challenges such as to control costs, decrease lead-time from design to production, improvement of product quality, and machining/ finishing of difficult to machine materials. The most labour intensive, uncontrollable area in the manufacture of precision parts involves final machining (or finishing) operations. Finishing operations can cost as much as 15% of the total machining cost in a production cycle [23]. The marginal cost of surface finish increases sharply for a roughness value of one micron. AFM is one of the processes capable of facing the above mentioned challenges. This process uses a specially formulated, pliable, plastic like abrasive laden media, which is forced to flow over edges and surfaces to be deburred, polished or radiused. Machining action occurs whenever the abrasive laden media passes through the restrictive passages. This process employs two vertically opposed cylinders piston fitted that extrude abrasive media back and forth through passages formed by the work piece and tooling. Together one up and one down stroke constitutes a process cycle [24]. The process was developed earlier to find a more effective method of deburring hydraulic control blocks, which were initially being deburred by hand. The media contains abrasive particles having random cutting edges with indefinite orientation and geometry for effective removal of material with chip sizes smaller than those obtained during machining with cutting tools having defined edges. Because of extremely thin chips produced in AFM the process can produce better surface finish and closer tolerances, generate more intricate surface features, and machine harder and difficult-to machine materials [25]. The process has found many applications in the fields of aerospace, automotive, electronic, die making, surgical implants, etc. and is being extensively used for removing recast layer from the surfaces generated by EDM. The AFM process can finish surfaces up to 0.05 µm, deburr holes as small as 0.2 mm, radius edges from 0.025 to 1.5 mm and hole tolerance up to ± 5 µm can be held [26]. It can offer as much as 90% time saving over hand finishing operations [27]. In the first few cycles the major part of the total improvement in the surface finish occurs with a minimal dimensional change (usually 0.013 to 0.025 mm). In order to cater to the requirement of high accuracy and high efficiency finishing of materials, AFM is gaining importance day by day. The AFM process has a limitation too with regard to achieving required surface finish. It is the time to achieve the required surface finish (cycle time). With the aim to overcome the difficulty of longer cycle time, the present paper reports the findings of a modification, which permits AFM to be carried out with additional centrifugal force applied onto the cutting media. The concept of hybrid machining processes (HMP) is currently gaining attention with the aim of achieving better performance of the modern machining processes. The

Underlying principle of hybrid-machining processes is to club the advantages and avoid or reduce the adverse effects (if any) of the constituent processes [28]. An example of HMP is the ultrasonic flow polishing that is the combination of AFM and USM in which surface finish improvements of up to 10:1 have been recorded [29]. Another hybrid machining process is the orbital flow machining process, which utilizes the principle of orbital grinding and AFM [30]. Still another example of HMP is the ultrasonic assisted grinding for the special application of machining the ceramics [31]. The finishing of metals by magnetic abrasive machining (MAM) has been studied by many researchers [32-36]. The main feature of MAM is that it employs very small machining pressure and is easily controllable with the help of input current to the electromagnet. Magnetically assisted abrasive flow machining (MAFM), which is the combination of AFM and MAF has been shown to give better results than obtained from individual AFM or MAF [37]. Literature survey indicated that though AFM had excellent characteristics as regards generation of super finish on inaccessible areas of work piece surface, limited efforts have hitherto been directed towards improving its overall efficiency. There appears to be need for more research contribution to develop modification of this process which will give better quality surface economically.

2.2 Objective

There are significant applications of finishing processes of internal straight or contoured holes in industries. For this purpose there are several researches going on in the field of Abrasive Flow Machining (AFM). In the extension of AFM process we have Rotational Abrasive Flow Machining (RAFM). There are huge complexity in the existing RAFM processes. So there are a lot of improvements can be done in the existing system.

A new design of R-AFM setup is to be incorporated having simple design. We can put a new perspective towards the process parameters of AFM as the product of rpm of motor and its self-induced magnetic field.

CHAPTER 3

SETUP

Rotational abrasive flow machining (RAFM) have more significant role in industries. For further research work there are more possibilities in the field of design of its setup. There are many flows in existing designs. Now the days the designs are for RAFM setups are very complicated. Researchers have been using a separate motor with some chain drive, belt drive or bevel gears etc. Now it can be replaced by placing work piece at the core of hollow motor shaft instead of rotating work piece separately. This improvement will help in reducing the complexity of the RAFM setup as well as it will have magnetic effect of rotor of motor. Thus this setup have very good surface properties outcome for internal profile of hollow objects.

Fig.[14] shows the schematic diagram of setup. Setup is consist of following parts:

3.1 Vertical Double acting AFM setup.
3.2 Motor
3.3 Variable Frequency Drive (VFD)
3.4 Taper Roller Bearing
3.5 Upper Job Fixture
3.6 Lower Job Fixture
3.7 Upper Bearing fixture
3.8 Lower Bearing Fixture
3.9 Fixture Holder Fastener
3.10 RPM Counter

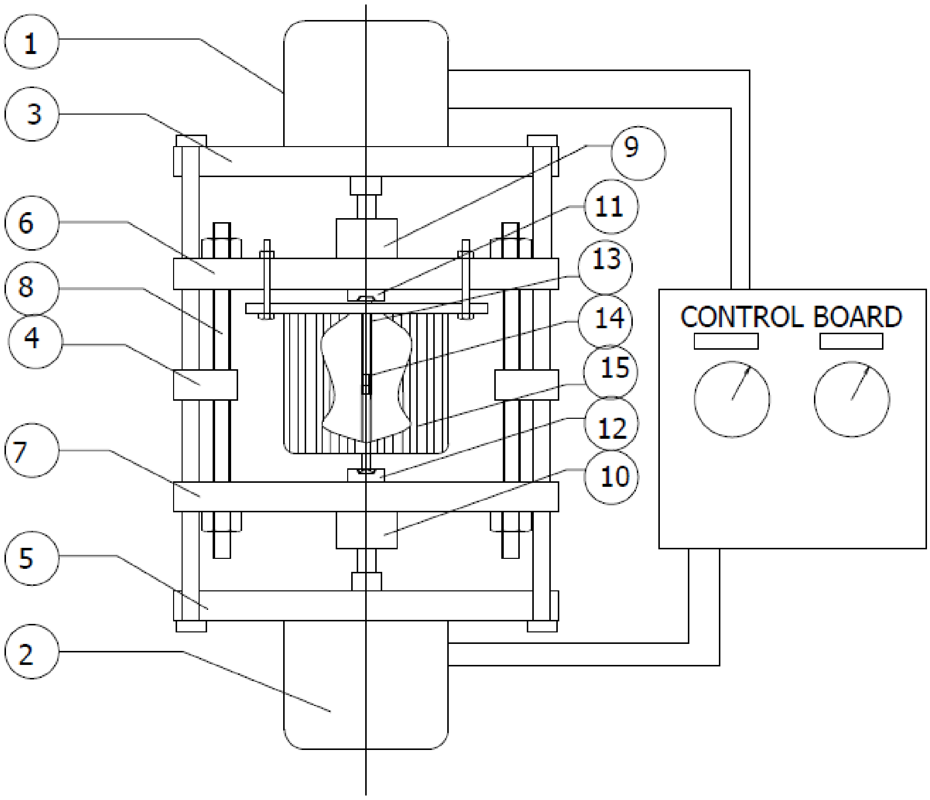

Fig14: Schematic of New RAFM

[Parts: (1,2)-Hydraulic Cylinder with ram, (3,4,5)-Machine Base Fixture, (6,7)-Work piece fixture holder, (8)- Fixture Holder Fastener, (9-10)- Media cylinder, (11-12)- Tapered roller bearing, (13)- Job holder, (14)- work-piece, (15)- Motor]

3.1 Vertical Double acting AFM setup

AFM machines dependent of their size are positive displacement hydraulic type systems, where work piece is held between two opposite media cylinders. By to and fro extrusion of media from one cylinder to the other, an abrasive action takes place whenever the media passes through narrow passage as it travels across the work piece. We can vary following process parameters if AFM process:

- Abrasive to media ratio
- Viscosity of media
- Extrusion Pressure
- Flow rate
- No. of cycle

The systems are provided with controls on hydraulic system pressure, clamping-unclamping of tooling or fixtures, volume flow rate of abrasive media, and advance and retract of media pistons.

- Specifications of Machine:
- Operating pressure 10-200 bar
- Flow rate 400 lit/min
- Media cylinder bore 70 mm
- Maximum distance between hydraulic rams 440 mm
- Maximum distance between Media cylinders 530 mm
- Stroke length of piston 50 mm

This machine has pressure control valves for both upper and lower cylinders. We can control the pressure between rams. It has separate levers to control upper and lower rams. The stroke of ram can be controlled manually. At every step of operation the operation can be aborted.

Figure 15.Vertical double acting AFM machine setup

3.2 Motor

The motor, fig.16 shows the cad model and fig17 shows image of motor used. For detailed Drawing refer ANNEXURE-1. It have hollow pipe at rotor rather than a solid shaft. The workpiece will be placed inside the hollow tube. For the setup we are using 1 Hp motor. The motor has following rated specifications:

- Power 1 Hp
- Type 3 phase, AC
- Rated voltage 200-240V
- Rated Amp 1.5Amp
- Rated Rpm 460 rpm
- Power factor 0.8
- Frequency 50 Hz

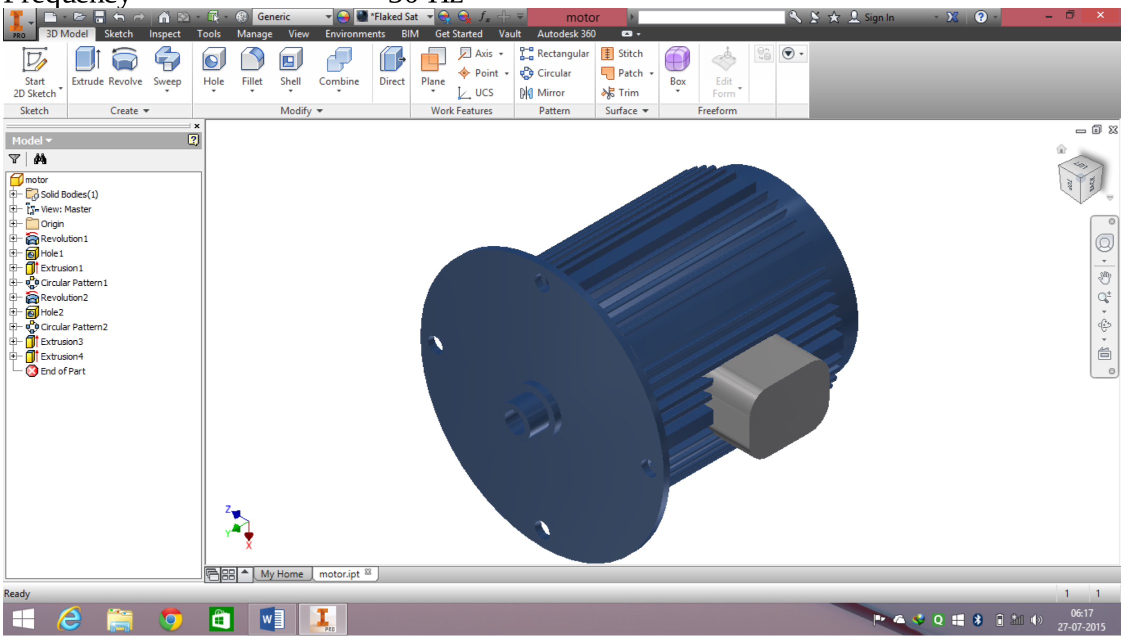

Fig.16: CAD model of motor

Fig.17: Image of Motor

3.3 Variable Frequency Drive (VFD)

We have used a VFD (Variable Frequency Drive) controller for the motor. The fig.18 shows the image of the VFD. The controller controls the motor rpm in terms of frequency of electric connection. Minimum frequency can be 0.0 Hz and maximum frequency can be upto 50.0 Hz. Controller have following specifications:

a. Frequency Range: 0-100 Hz
b. Maximum Power Range 1.5 Hp
c. Acceleration 0-50 Hz
d. Deceleration 50-0 Hz
e. Amp Range 0-10 Amp
f. Voltage Range 100-440V

Fig18: Image of VFD

3.4 Tapered Roller bearing

Tapered roller bearing is used to support the rotational setup from both ends. Due to tapered bearing it can withstand significantly against axial force. Fig.19 shows CAD model of bearing. The detailed drawing of the bearing is referred to ANNEXURE-2. There are two bearing placed at top and bottom of the motor.

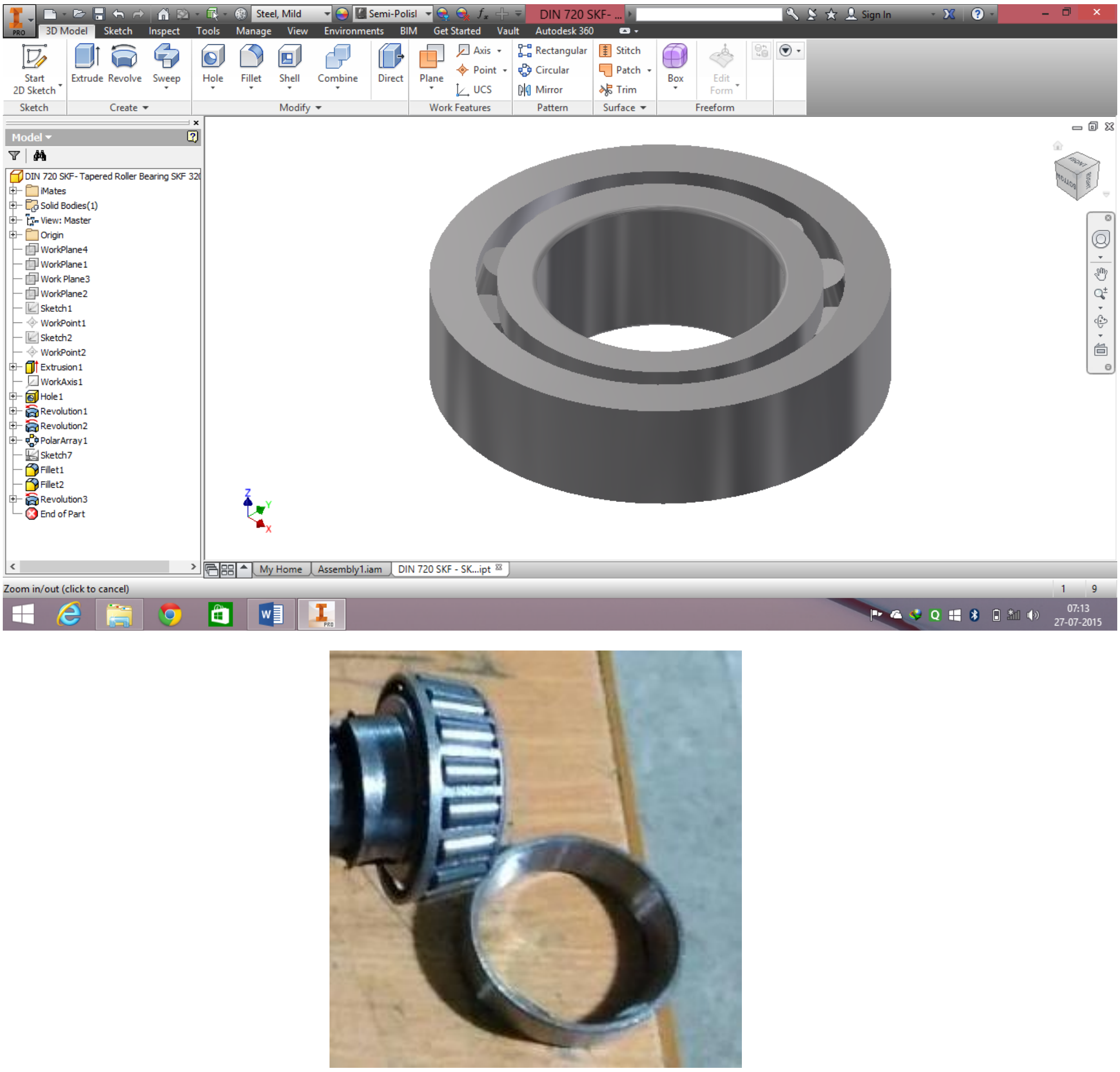

Fig. 19: Tapered roller bearing.

3.5 Upper Job Fixture

The cad model of upper job fixture is shown in fig.20. The image of it is shown in fig.21. This is made of nylon. This fixture is used to hold upper half of work piece. The work piece is tighten in the fixture with help of small screws. This whole fixture rotates with the motor hollow shaft. Its detailed drawing can be referred from ANNEXURE-4.

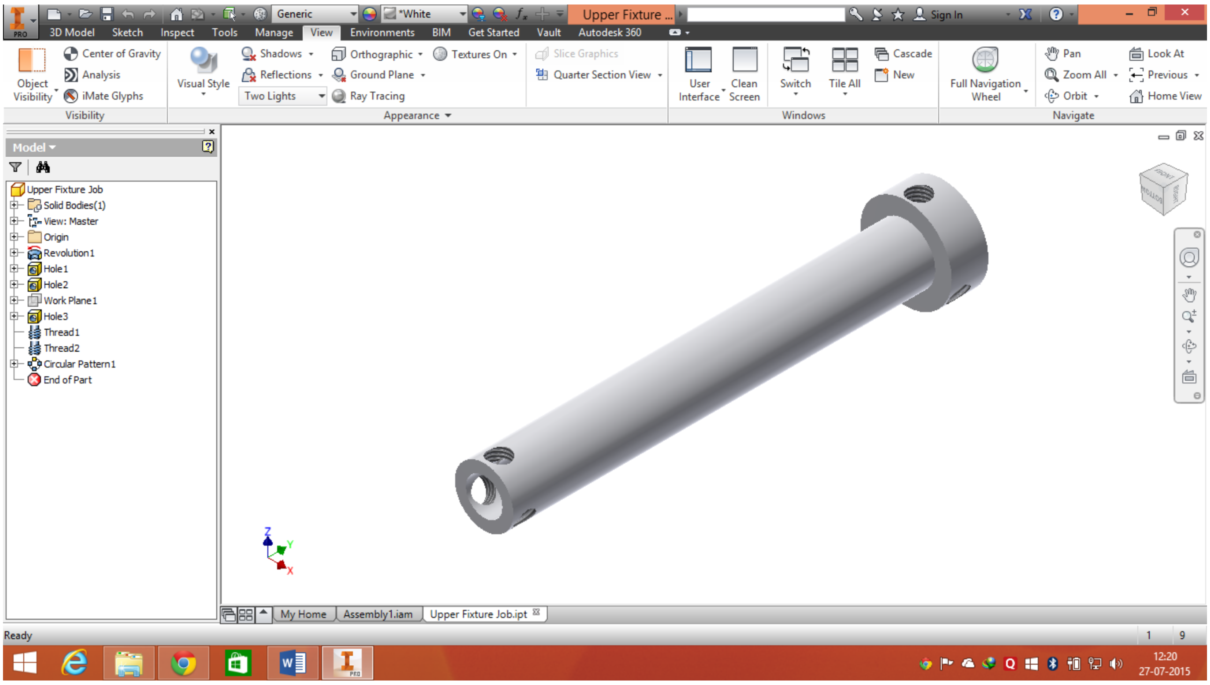

Fig.20: CAD model of Upper job fixture


Fig21: Image of Upper job fixture

3.6 Lower Job Fixture

The cad model of lower job fixture is shown in fig.22. The image of it is shown in fig.23. This is made of nylon. This fixture is used to hold lower half of work piece. The work piece is tighten in the fixture with help of small screws. This whole fixture rotates with the motor hollow shaft. Its detailed drawing can be referred from ANNEXURE-5.

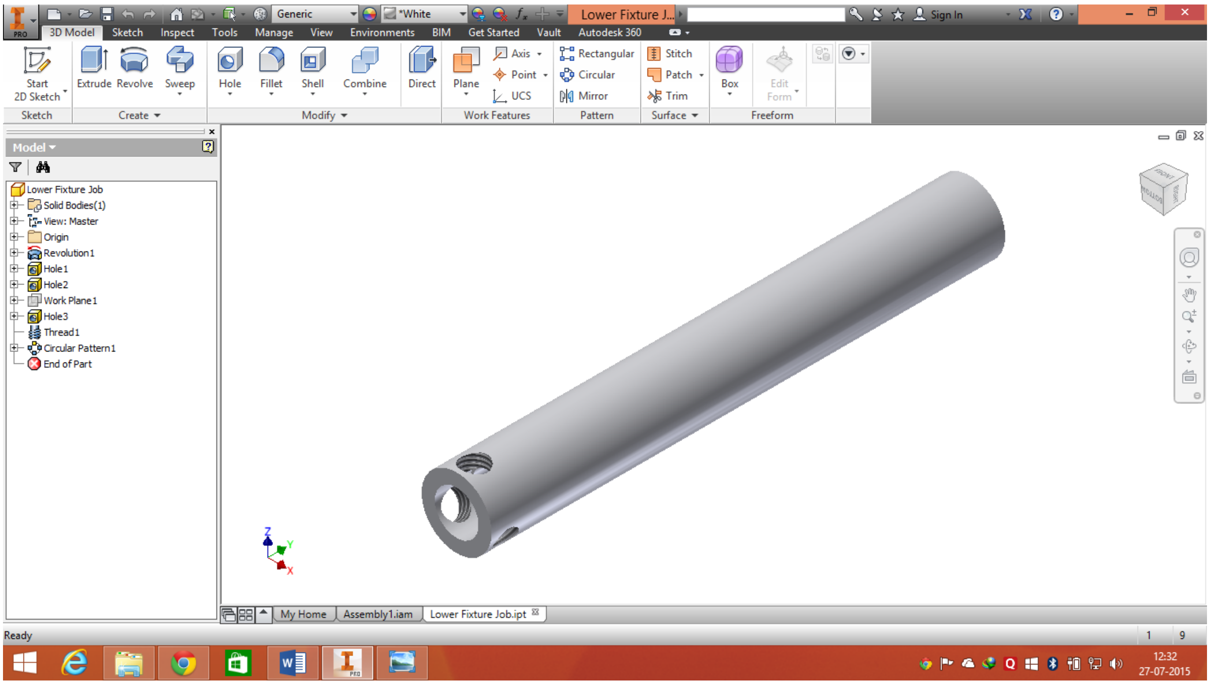

Fig.22: CAD Model of Lower Job Fixture

Fig.23: Image of Lower Job Fixture

3.7 Upper Bearing Fixture

Upper bearing fixture is made of nylon. It is used to transfer media from cylinder to the motor core and thus passing through the work piece. Outer race of bearing is fitted into this fixture while inner race is fitted on the motor shaft. It will be stationary with respect to motor. It is used to support a work piece which will be only in rotation and not affected with the magnetic field of motor. The cad model of upper bearing fixture is shown in fig.24. The image of it is shown in fig.25. Its detailed drawing can be referred from ANNEXURE-6.

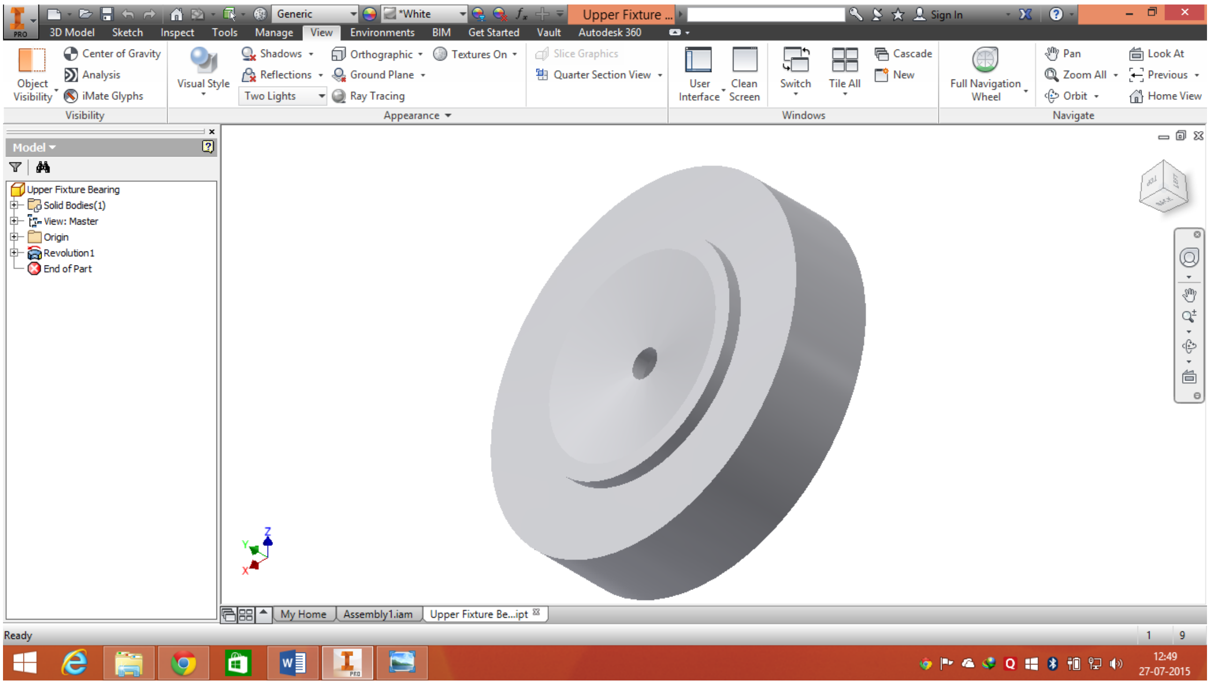

Fig24: CAD model of upper bearing fixture


Fig25: Image of upper bearing fixture

3.8Lower Bearing Fixture

Lower bearing fixture is made of nylon. It is used to transfer media from cylinder to the motor core and thus passing through the work piece. Outer race of bearing is fitted into this fixture while inner race is fitted on the motor shaft. It will be stationary with respect to motor. It is used to support a work piece which will be only in rotation and not affected with the magnetic field of motor. The cad model of lower bearing fixture is shown in fig.26. The image of it is shown in fig.27. Its detailed drawing can be referred from ANNEXURE-7.

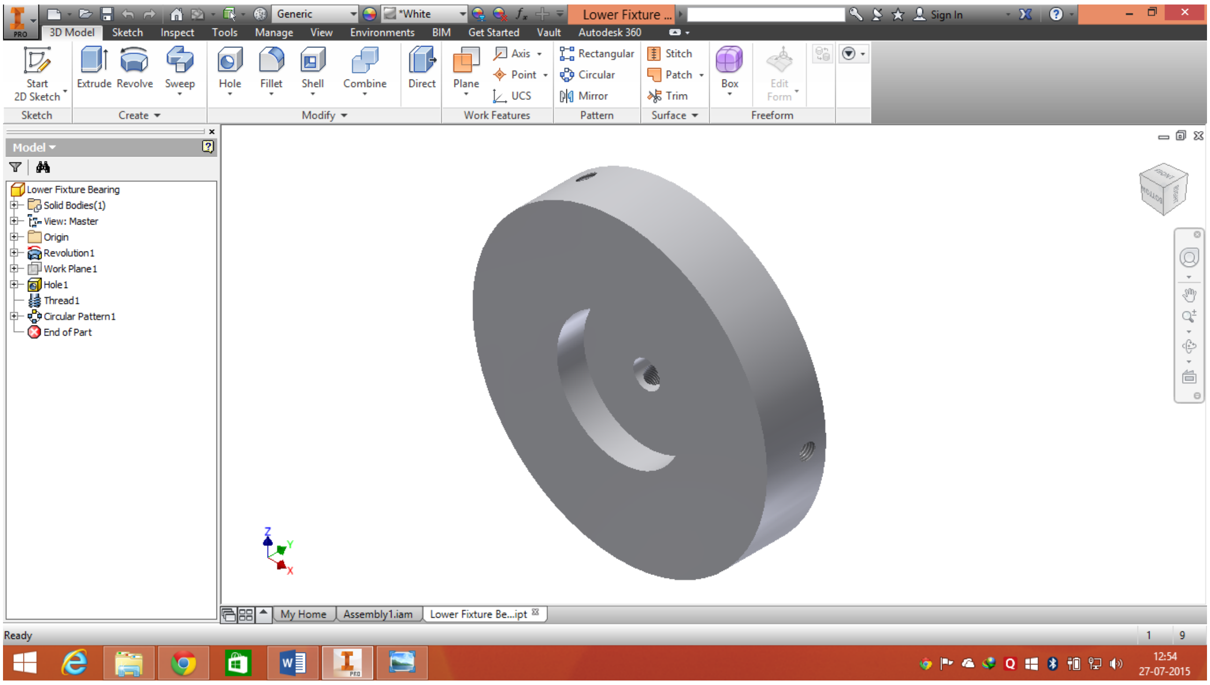

Fig.25: CAD model of Lower Bearing Fixture

Fig26: Image of Lower Bearing Fixture

3.9 Fixture Holder Fastener

These are 2 in numbers. It is a stud of 1 inch diameter and 19 inch length have 5 inches at both the ends. It is used to support and fix the whole setup with machine. The cad model of Fixture Holder Fastener is shown in fig.27. The image of it is shown in fig.28. Its detailed drawing can be referred from ANNEXURE-8.

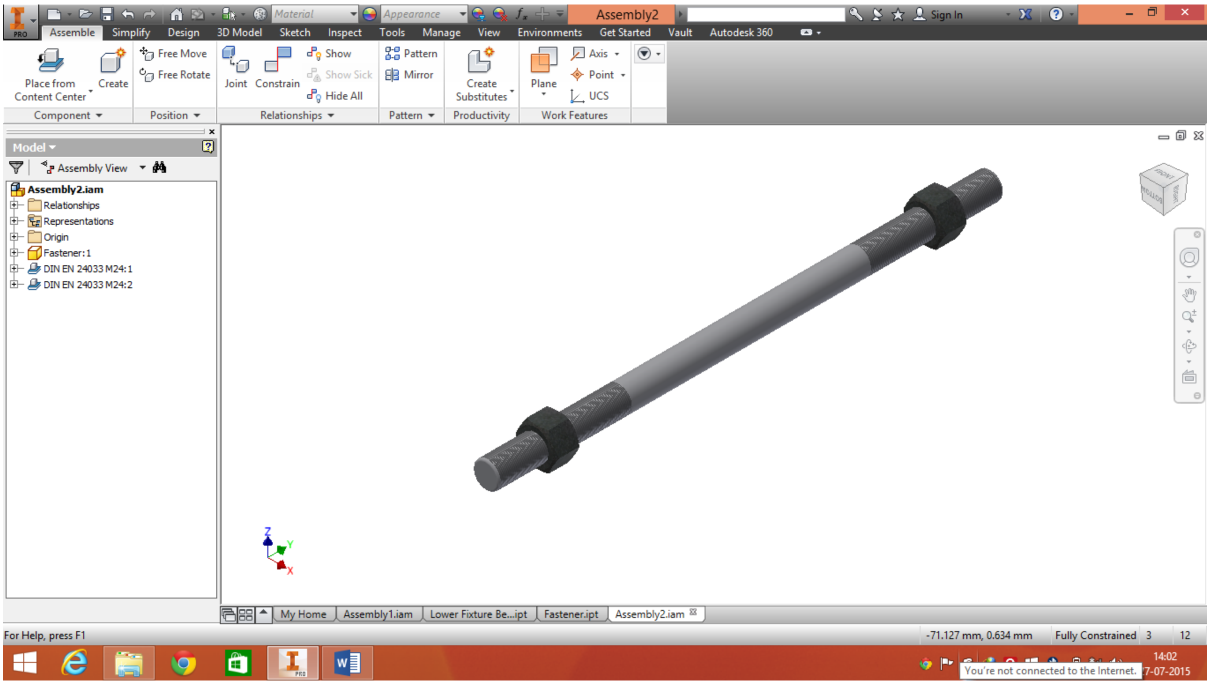

Fig27: CAD Model of Fixture Holder Fastener

Fig.28: Image of Fixture Holder Fastener

3.10 RPM counter

An electronics rpm counter is made to obtain rpm of motor while rotation. It is a laser type rpm counter. The image of it is shown in fig30.

Fig.30: RPM Counter

Assembly steps for setup

There are following steps for assembly of setup:

1. Put bearings inner race at motor shaft at both side. . Fig.31 shows the assembly.

Fig.31: Assembly step-1

2. Assemble work piece in Upper Job Fixture and Lower Job Fixture and tighten it with small screws. Fig32 shows the assembly.

Fig.32: Assembly step-2

3. Place this assembly into motor hollow shaft. . Fig.33 shows the assembly.

Fig.33: Assembly step-3

4. Assemble Upper bearing fixture and Lower bearing fixture with bearings. . Fig.34 shows the assembly.

Fig.34: Assembly step-4

5. Now this assembly should be fixed between media cylinder.
6. The motor flange should be bolted to upper media cylinder base.
7. Whole assembly should be clamped between both upper and lower rams.

Fig.35: shows the CAD model of assembly and Fig[ ] shows the image of assembly.

CHAPTER 4

EXPERIMENTAL DESIGN AND ANALYSIS

Design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics, these terms are usually used for controlled. A properly planned and executed experiment is of the utmost importance for deriving clear and accurate conclusions from the experimental observations. Design of experiment is considered to be a very useful strategy for accomplishing these tasks. The science of statistical experimental design originated with the work of Sir Ronald Fisher in England in 1920s. Fisher founded the basic principle of experimental design and the associated data-analysis technique called Analysis of Variance (ANOVA) during his efforts to improve the yield of agricultural crops. The theory and applications of experimental design and the related technique of response surface methodology have been advanced by many statistical researchers as Box and Hunter, Box and Draper, Hicks. Various types of matrices are used for planning experiments to study several decision variables. Among them, Taguchi's Method makes heavy use of orthogonal arrays.

4.1 Taguchi's experimental design and analysis

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there are an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

4.2 Philosophy of Taguchi method

1. Quality should be designed into a product, not inspected into it. Quality is designed into a process through system design, parameter design, and tolerance design. Parameter design, which will be the focus of this article, is performed by determining what process parameters most affect the product and then designing them to give a specified target quality of product. Quality "inspected into" a product means that the product is produced at random quality levels and those too far from the mean are simply thrown out.

2. Quality is best achieved by minimizing the deviation from a target. The product should be designed so that it is immune to uncontrollable environmental factors. In other words, the signal (product quality) to noise (uncontrollable factors) ratio should be high.

3. The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system wide. This is the concept of the loss function, or the overall loss incurred upon the customer and society from a product of poor quality. Because the producer is also a member of society and because customer dissatisfaction will discourage future patronage, this cost to customer and society will come back to the producer.

4.3 Taguchi Method Design of Experiments

The general steps involved in the Taguchi Method are as follows:

1. Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum; for example, the goal may be to maximize the output flow rate. The deviation in the performance characteristic from the target value is used to define the loss function for the process.

2. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified. For example, a temperature might be varied to a low and high value of 40 C and 80 C. Increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.

3. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter, and will be expounded below.

4. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
5. Complete data analysis to determine the effect of the different parameters on the performance measure.

4.4 Experimental Design Strategy

Taguchi recommends orthogonal arrays (OA) for lying out of experiments. These OA's are generalized Graeco-Latin squares. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns. The use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. The array forces all experimenters to design almost identical experiments.
In the Taguchi method the results of the experiments are analyzed to achieve one or more of the following objectives:

- To estimate the best or the optimum condition for a product or process.
- To estimate the contribution of individual parameters and interactions.
- To estimate the response under the optimum condition.

The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trend of influence of each parameter. The knowledge of contribution of individual parameters is a key in deciding the nature of control to be established on a production process. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percent contribution of each parameter against a stated level of confidence. Study of ANOVA table for a given analysis helps to determine which of the parameters need control.
Taguchi suggests two different routes to carry out the complete analysis of the experiments. First the standard approach, where the results of a single run or the average of the repetitive runs are processed through main effect and ANOVA analysis (Raw data analysis). The second approach which Taguchi strongly recommends for multiple runs is to use signal-to-noise (S/N) ratio for the same steps in the analysis. The S/N ratio is a concurrent quality metric linked to the loss function. By maximizing the S/N ratio, the loss associated can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The S/N ratio is treated as a response parameter (transform of raw data) of the experiment. Taguchi recommends the use of outer OA to force the noise variation into the experiment i.e. the noise is intentionally introduced into the experiment. Generally, processes are subjected to many noise factors that in combination strongly influence the variation of the response. For extremely 'noisy' systems, it is not generally

necessary to identify controllable parameters and analyze them using an appropriate S/N ratio. In the present investigation, both the analysis: the raw data analysis and S/N data analysis have been performed. The effects of the selected Helical AFM parameters on the selected quality characteristics have been investigated through the plots of the main effects based on raw data. The optimum condition for each of the quality characteristics have been establish through S/N data analysis. No outer array has been used and instead, experiments have been repeated three times at each experimental condition.

4.5 Loss Function and S/N Ratio

The heart of Taguchi method is his definition of nebulous and elusive term 'quality' as the characteristic that avoids loss to the society from the time the product is shipped [50]. Loss is measured in terms of monetary units and is related to quantifiable product characteristics. Taguchi defines quality loss via his 'loss-function'. He unites the financial loss with the functional specification through a quadratic relationship that comes from Taylor series expansion .

$$L(y) = k(y-m)^2$$

Where, L = loss in monetary unit

m = value at which the characteristic should be set

y = actual value of the characteristic

k = constant depending on the magnitude of the characteristic and the monetary unit involved.

The following two observations can be made

• The further the product's characteristic varies from the target value, the greater is the loss. The loss is zero when the quality characteristic of the product meets its target value.

• The loss is a continuous function and not a sudden step as in the case of traditional approach.

This consequence of the continuous loss function illustrates the point that merely making a product within the specification limits does not necessarily mean that product is of good quality.

In a mass production process the average loss per unit is expressed as:

$$L (y) = \{k (y_1-m)^2 + k (y_2-m)^2 + \ldots\ldots\ldots\ldots + k (y_n - m)^2 \}$$

Where

$y_1, y_2 \ldots\ldots\ y_n$ = values of characteristics for units 1, 2,........n respectively

n = number of units in a given sample

k = constant depending upon the magnitude of characteristic and the monitory unit involve

m= Target value at which characteristic should be set.

Equation can be written as:

$$L(y) = k\ (MSD)$$

Where MSD denotes mean square deviation, which presents the average squares of all deviations from the target value rather than around the average value.

Taguchi transformed the loss function into a concurrent statistic called S/N ratio, which combines both the mean level of the quality characteristic and variance around this mean into a single metric .The S/N ratio consolidates several repetitions (at least two data points are required) into one value. A high value of S/N ratio indicates optimum value of quality with minimum variation. Depending upon the type of response, the following three types of S/N ratio are employed in practice.

1.Larger the better :

$$(S/N)_{HB} = -10 \log (MSD_{HB})$$

Where

MSD HB = $\frac{1}{2}\sum_{j=1}^{R}(\frac{12}{yj})$

2.Lower the better :

$$(S/N)_{LB} = -10 \log (MSD_{LB})$$

Where

MSD LB = 1/R $\sum_{j=1}^{R}(y21)$

1. Nominal the best :

$$(S/N)_{LB} = -10 \log (MSD_{NB})$$

Where

MSD NB = $\frac{1}{R}\sum_{J=1}^{R}\left(y_j - y_0\right)^2$

R = Number of repetitions

It is to be mentioned that for nominal the best type of characteristic, the standard definition of MSD has been used. For smaller the better type the target value is zero. For larger the better type, the inverse of each large value becomes a small value and again the target value is zero. Therefore, for all the three expressions the smallest magnitude of MSD is being sought. The constant 10 has been purposely used to magnify S/N number for each analysis and negative sign is used to set S/N ratio of larger the better relative to the square deviation of smaller the better.

4.6 Taguchi Procedure for Experimental Design and Analysis

Figure illustrates the stepwise procedure for Taguchi experimental design and analysis. It is described in the following paragraphs.

(A). Selection of OA

In selecting an appropriate OA, the following prerequisites are required:

•Selection of process parameters and/or their interactions to be evaluated.

•Selection of number of levels for the selected parameters.

The determination of parameters to investigate, upon which hinges the product or process performance characteristics or responses of interest . Several methods are suggested by Taguchi for determining which parameters to include in an experiment. These are :

•Brainstorming

•Flow charting

•Cause-effect diagrams

The total degrees of freedom (DOF) of an experiment are a direct function of total number of trials. If the number of levels of a parameter increases, the DOF of the parameter also increase because the DOF of a parameter is the number of levels minus one. Thus, increasing the number of levels for a parameter increases the total degrees of freedom in the experiment which in turn increases the total number of trials. Thus, two levels for each parameter are recommended to minimize the size of the experiment. If curved or higher order polynomial relationship between the parameters under study and the response is expected, at least three levels for each parameter should be considered. The standard two-level and three-level arrays are:

a)Two-level arrays: L_4, L_8, L_{12}, L_{16}, L_{32}

b)Three-level arrays: L_9, L_{18}, L_{27}

The number as subscript in the array designation indicates the number of trials in that array. The degree of freedom (DOF) available in an OA is:

$f_{LN} = N-1$

Where f_{LN} = total degrees of freedom of an OA

L_N =OA designation N = number of trials

When a particular OA is selected for an experiment, the following inequality must be satisfied

$f_{LN} \geq$ Total DOF required for parameters and interactions.

Depending on the number of levels in the parameters and total DOF required for the experiment, a suitable OA is selected.

(B). Assignment of parameters and interactions to OA

An 'OA' has several columns to which various parameters and their interactions are assigned. Linear graphs and Triangular tables are two tools, which are useful for deciding the possible interactions between the parameters and their assignment in the columns of 'OA'. Each 'OA' has its particular liner graphs and interaction tables

(C). Selection of outer array

Taguchi separates factors (parameters) into two main groups:

- •Controllable factors
- •Noise factors

Controllable factors are factors that can easily be controlled. Noise factors, on the other hand, are nuisance variables that are difficult, impossible, or expensive to control. The noise factors are responsible for the performance variation of a process. Taguchi recommends the use of outer array for noise factors and inner array for the controllable factors. If an outer array is used the noise variation is forced into the experiment. However, experiments against the trial condition of the inner array may be repeated and in this case the noise variation is unforced in the experiment. The outer array, if used will have the same assignment considerations.

(D). Experimentation and data collection

The experiment is performed against each of the trial conditions of the inner array. Each experiment at a trial condition is repeated simply (if outer array is not used) or according to the outer array (if used). Randomization should be carried for to reduce bias in the experiment.

(E). Data analysis

A number of methods have been suggested by Taguchi for analyzing the data: observation method, ranking method, column effect method, ANOVA, S/N ANOVA, plot of average responses, interaction graphs, etc.. In the present investigation, following methods are used.

- •Plot of average response curves
- •ANOVA for raw data
- •ANOVA for S/N data

The plot of average responses at each level of a parameter indicates the trend. It is a pictorial representation of the effect of a parameter on the response. Typically, ANOVA for OA's are conducted in the same manner as other structured experiments . The S/N ratio is treated as a response of the experiment, which is a measure of the variation within a trial when noise tors are present. A standard ANOVA is conducted on S/N ratio, which identified the significant parameters.

(F). Parameter design strategy

Parameter classification and selection of optimal levels

ANOVA of raw data and S/N ratio identifies the control factors, which affect the average Kponse and the variation in the response respectively. The control factors are classified into four groups:

Group I : Parameters, which affect both average and variation

Group II : Parameters, which affect variation only

Group III : Parameters, which affect average only

Group IV : Parameters, which affect nothing

The parameter design strategy is to select the suitable levels of group I and II parameters to reduce variation and group III parameters to adjust the average values to the target value. The group IV parameters may be set at the most economical levels.

(G).Prediction of mean

After determination of the optimum condition, the mean of the response (u) at the optimum condition is predicted. This mean is estimated only from the significant parameters. The ANOVA identifies the significant parameters. Suppose, parameters A and B are significant and A2B2 (second level of both A and B) is the optimal treatment condition. Then, the mean at the optimal condition (optimal value of the response characteristic) is estimated as:

$$\mu = T + (a_2 - t) + (b_2 - t)$$

$$= A_2 + B_2 - T$$

T= overall mean of the response

A_1 B_2= average values of response at the second levels of parameters A and B respectively

It may sometimes be possible that the predicated combination of parameter levels (optimal treatment condition) is identical to one of those in the experiment. If this situation exits, then the most direct way to estimate the mean for that treatment condition is to average out all the results for the trials which are set at those particular levels .

(H). Determination of confidence intervals

The estimate of the mean (p) is only a point estimate based on the average of results obtained from the experiment. It is a statistical requirement that the value of a parameter should be predicted along with a range within which it is likely to fall for a given level of confidence.

This range is called confidence interval (CI). Taguchi suggests two types of confidence intervals for estimated mean of optimal treatment conditions.

- CI_{CE} - Confidence Interval (when confirmation experiments (CE)) around the estimated average of a treatment condition used in confirmation experiment to verify predictions. Get; is for only a small group made under specified conditions.
- CI_{POP} - Confidence Interval of population; around the estimated average of a treatment condition predicted from the experiment. This is for the entire population i.e. all parts made under the specified conditions.

The confidence interval of confirmation experiments (CI_{CE}) and of population (CI_{POP}) is calculated by using the following equations:

$$CI_{CE} = \sqrt{F_a\,(1, f_e)V_e\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$

$$CI_{POP} = \sqrt{\frac{F_a\,(1, f_e)V_e}{n_{eff}}}$$

Where

F_{α} (l, f_e) = The F-ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e., f_e = error DOF, N = Total number of result, R = Sample size for confirmation experiments, V_e = Error variance,

$$n_{eff} = \frac{N}{1 + [\text{DOF associated in the estimate of mean responce}]}$$

(I). Confirmation experiment

The confirmation experiment is the final step in verifying the conclusions from the previous round of experimentation. The optimum conditions are set for the significant parameters (the insignificant parameters are set at economic levels) and a selected number of tests are run under specified conditions. The average values of the responses obtained from confirmation experiments are compared with the predicted values. The average values of the response characteristic obtained through the confirmation experiments should be within the 95% confidence interval, $CI_{CE.}$ However, these may or may not be within 95% confidence interval, CI_{POP}. The confirmation experiment is a crucial step and is highly recommended to verify the experimental conclusions .

CHAPTER 5

PROCESS PARAMETER SELECTION AND EXPERIMENTATION

The main process parameters, which may affect the machining characteristics such as material removal and surface finish, are selected. The scheme of experiments is also discussed in this chapter. The experiments were conducted within the ranges of selected process parameters includes product of rpm and magnetic field of motor, no. of cycle, and different extrusion pressure. Surface finish were measured. The measured data are also tabulated in this chapter.

5.1 Selection of work piece

Brass work piece were prepared by drilling, maintain its initial surface roughness in the range of 2.6-3.6μm and dimension 10 mm OD x 8 mm ID x 16 mm length. Few work piece ready for machining is shown in fig.32. Work piece are cleaned by acetone and subsequently measurements of initial surface roughness and weight were taken. The surface roughness was measured in five different locations using Taylor Hobson. The internal cylindrical surface was finished by AFM process. Each work piece was machined for a predetermined number of cycles. The work piece was taken out from nylon fixture and cleaned with acetone before the subsequent measurement.

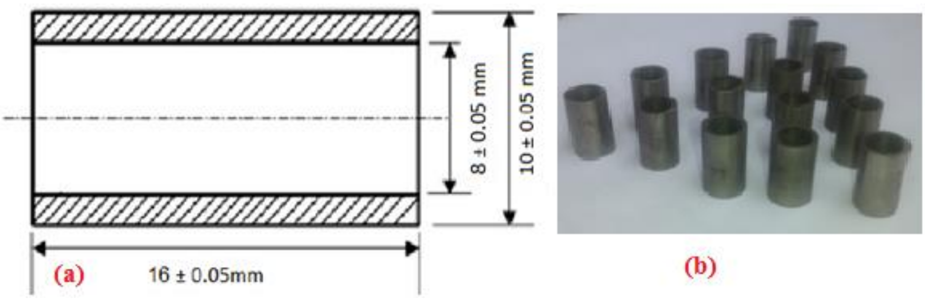

Figure36.(a),(b) Brass work pieces used in trials and its dimensional details

5.2 Response characteristics

The effect of these process parameters were studied on the following response characteristics of AFM process-

- Percentage improvement in surface finishing (ΔRa)

5.3 Selection of process parameter and their ranges

Table1: process parameter and their ranges

S. No.	Process Parameter	Range	Unit
1	Extrusion Pressure	5-35	MPa
2	No. of Cycle	1-9	Number
3	Temperature	32± 2	°C
4	Media Flow volume	290	cm^3
5	Capacity	25 + 25	Ton
6	Stroke length	96	mm
7	Hydraulic cylinder Bore diameter-2 No.	130	mm
8	Hydraulic cylinder Stroke	90	mm
9	Working Pressure	210	kg/cm^2
10	Maximum Pressure in the Cylinder	35	MPa
11	Stroke Length of Piston	300	mm
12	RPM (motor speed)	240	rpm

5.4 Percentage improvement in surface finishing

The surface roughness was measured at several random locations on the internal cylindrical surface of the cast iron work piece. The mean value was taken of the random values of roughness. Then the percentage improvement in surface finishing was calculated from the formula

$$\Delta Ra = \frac{(\text{Initial Ra} - \text{final Ra})}{Initial\ Ra} \times 100$$

5.6 Scheme of experiments

The experiments were designed to study the effect of some of the AFM parameters on response characteristics of AFM process. Taguchi parametric design methodology was adopted. The experiments were conducted using appropriate orthogonal array (OA). An L9 (a standard 3-level

OA) having 8= (9-1) degree of freedom was selected for the present analysis. The selected number of process parameters and their levels are given in the table:

Table 1.Process Parameters and their values at different levels

Symbol	Process Parameters	Unit	Level 1	Level 2	Level 3
N	No. Of Cycle	Numbers	5	7	9
P	Pressure	Bar	5	10	15
S*B=M At (F)	RPM *B At (Frequency VFD)	Gauss/min (Hz)	2×57= 114 10.3	3×104= 312 18.6	4×156= 624 27.9
Polymer to Gel ratio :1:1, Workpiece Material- Brass ,Abrasive type Fe_2O_3 & CiC, Mesh Size:180, Extrusion Pressure: 5 MPa, Media Flow Volume :290cm^3,Temperature:32 ± 2 °C, Initial surface roughness : 2.6 - 3.6 µm.					

Table 2. The L9(3^4) OA (Parameters Assigned) with Response

Exp. No.	Run Order	Parameters Trial Conditions				Response (Raw Data)			S/N Ratio (db)
		N	P	Hz	---------	R1	R2	R3	
		1	2	3	4				
1	1	1	1	1	1	Y11	Y12	Y13	S/N(1)
2	4	1	2	2	2	Y21	Y22	Y23	S/N(2)
3	7	1	3	3	3	Y31	Y32	Y33	S/N(3)
4	5	2	1	2	3	Y41	Y42	Y43	S/N(4)
5	8	2	2	3	1	Y51	Y52	Y53	S/N(5)
6	2	2	3	1	2	Y61	Y62	Y63	S/N(6)
7	9	3	1	3	2	Y71	Y72	Y73	S/N(7)
8	3	3	2	1	3	Y81	Y82	Y83	S/N(8)
9	6	3	3	2	1	Y91	Y92	Y93	S/N((9)
Total					Σ		Σ	Σ	
R1, R2, R3 represents response value for three repetitions of each trial. The 1's,2's, and 3's represents levels 1,2,3 of the parameters, which appear at the top of the column.(---) represents no assignment in the column. Yij are the measured values of the quality characteristics (response)									

PRECAUTIONS TAKEN DURING EXPERIMENTATION

While performing various experiments, the following precautionary measures were taken:

1. Each experiment is repeated three times to avoided experimental error.

2. The experiments repeated randomly in order to avoid bias, if any, in the results.

3. As the experiments proceeds the cutting edges of abrasive particles wear off and become dull which result in less favorable results are produced in later experiments secondly the particles of work piece material mixed with the media and as the time proceeds the volume of work piece material inside the media increases which deteriorate the finishing action. To avoid this large volume of the media is prepared and after each experiment the used media is taken out from the cylinder and throughout mixed with the fresh media contained in large container. The media for next trial is taken from this mix. For the limited number of experiments conducted, this would ensure with reasonable reliability that the media used for each of the experiment run contain approximately equal amount of fresh grains(grain with sharp edges)

4. Each set of experiments was performed at room temperature in a narrow range (32 ± 2°C).

5. Before any measurement was taken, the work-piece was cleaned with acetone.

6. The surface roughness was measured in the direction of flow of media and at several random points all over the cavity of the work-piece.

5.7 Experimentation

The three process parameters No. of Cycle, Pressure and VFD frequency will be used. Experiments were conducted according to the test condition specified by the L_9 OA (Table 3). Each experiment

Table 3. Experimental results of various response characteristics for Magneto Assisted RAFM and RAFM

Ex. No.	MARAFM								RAFM							
	% Improvement in Ra				mg- MR				% Improvement in Ra				mg- MR			
	Repetition			S/N	Repetition			S/N	Repetition			S/N	Repetition			S/N
	1	2	3	Ratio	1	2	3	Ratio	1	2	3	Ratio	1	2	3	Ratio
1	49	47	45	33.43	3.9	3.2	3	10.39	43	40	41	32.34	3.7	3	2.8	9.83
2	41	43	43	32.53	4.3	3.7	4.5	12.30	38	36	37	31.36	4	3.5	4.2	11.74
3	25	26	24	27.94	3.1	4.5	4.9	11.87	38	39	37	31.62	2.9	4.2	4.6	11.29
4	47	44	43	32.98	12.5	14.2	13.5	22.51	5	3	3	10.58	11.8	13.4	12.8	22.02
5	30	29	38	30.01	13.6	16.7	16.4	23.73	68	71	72	36.94	12.9	15.8	15.5	23.26
6	55	55	56	34.86	20.7	21.5	23.5	26.77	54	56	55	34.81	19.6	19.4	22.3	26.16
7	58	51	56	34.77	21.7	22.4	22.9	26.97	73	76	76	37.49	20.6	21.2	21.7	26.51
8	89	85	85	38.72	35.7	39.2	37.3	31.44	80	77	69	37.49	33.9	37.2	35.4	30.99
9	88	87	89	38.89	41.6	38.4	39.3	31.98	78	75	77	37.69	39.5	36.4	37.3	31.52
	T ΔRa = Overall mean of ΔRa=52.89%				TMR =Overall mean of MR =18.01mg				T ΔRa = Overall mean of ΔRa=52.51%				TMR =Overall mean of MR =17.02mg			

was repeated three times in each of the trial conditions. Thus twenty seven work-pieces were selected having initial surface in close range of (2.6 – 4.6 micron). In each of the trial conditions and for every replication, the percentage improvement in surface roughness. The data is recorded in Table 4.

CHAPTER 6

DISCUSSION OF RESULT

Detailed analysis and discussion of results of experiments.

6.1 Analysis and discussion of results

The standard procedure suggested by Taguchi was used to analyze the data. The average values and S/N ratio of quality/response characteristics for each parameter at different levels are calculated from the experimental data. The main effects of process parameters both for raw data and S/N data are plotted. The analysis of variance (ANOVA) of raw data and S/N data is performed to identify the significant parameters and to quantify their effect on the response characteristics.

6.2 Effect on percentage improvement in surface roughness for MARAFM

The average values of percentage improvement in surface roughness and S/N ratio for each parameter at Level L1, L2 and L3 are calculated and given in Table 2 and table 3.

6.2.1 Main effect of S/N (MARAFM)

Table-5: Response Table for S/N

LEVEL	No. of Cycle	P	Hz
L1	11.52	19.95	22.87
L2	24.34	22.49	22.26
L3	30.13	23.54	20.86
L2-L1	12.82	2.54	-0.60
L3-L2	5.79	1.05	-1.40
DIFFERENCE	-7.02	-1.49	-0.80

6.2.2 Main effects of % Improvement In Ra(MARAFM)

Table-6:Response Table for % Improvement In Ra

LEVEL	No. of Cycle	P	Hz
L1	3.90	13.03	20.89
L2	16.96	19.04	19.11
L3	33.17	21.94	14.02
L2-L1	13.06	6.01	-1.78
L3-L2	16.21	2.90	-5.09
DIFFERENCE	3.16	-3.11	-3.31

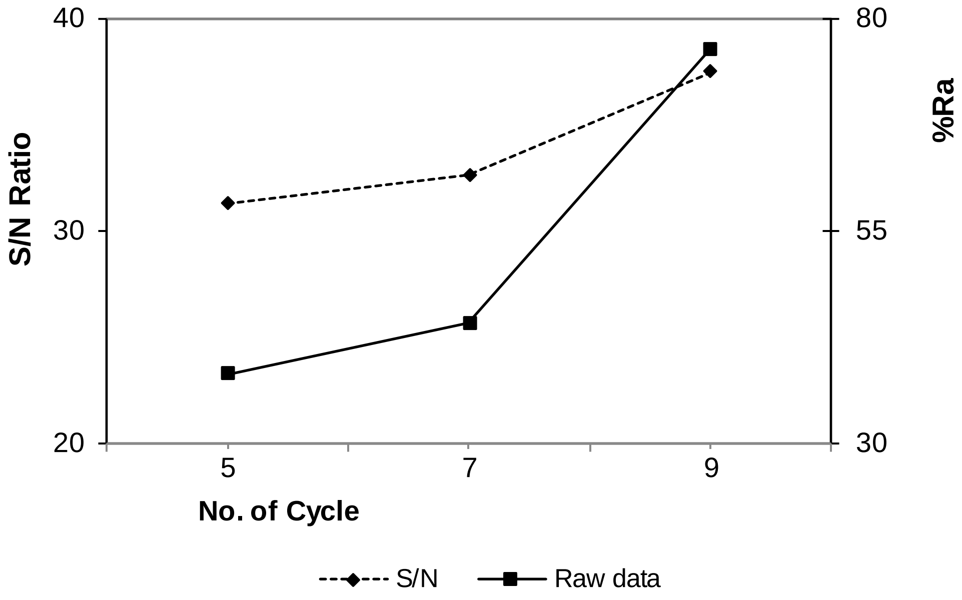

Fig.37: No of Cycle Vs % improvent. in Ra (MARAFM)

From Figure 37, It can be clearly conclude that as the number of cycle is increased the % surface finish is increased.

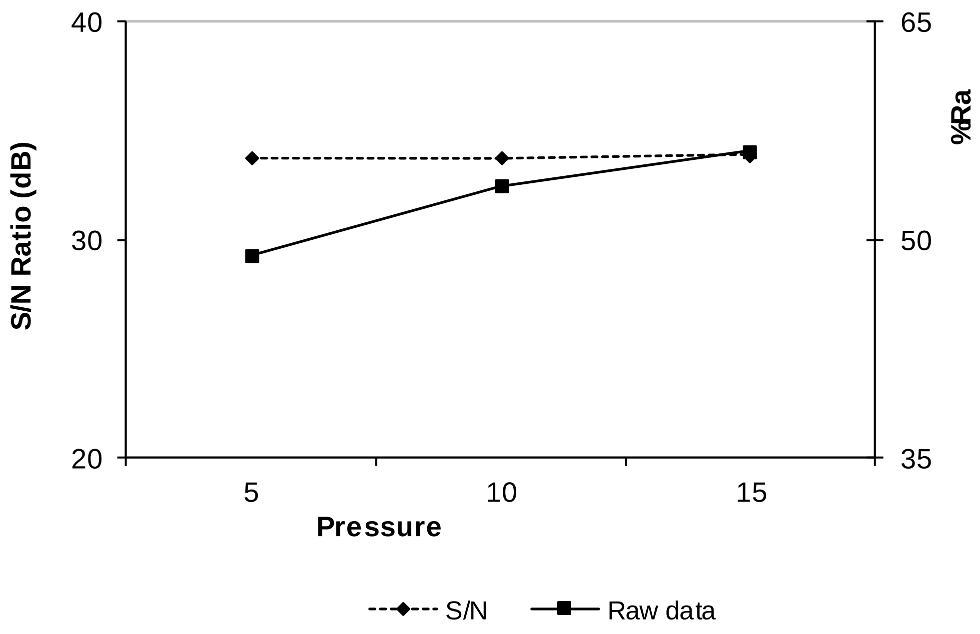

Figure 38.Effect of Pressure on S/N Ratio and % improvement in Ra (MARAFM)

From Figure 38, it can be clearly conclude that as the pressure is increased the % surface finish is increased.

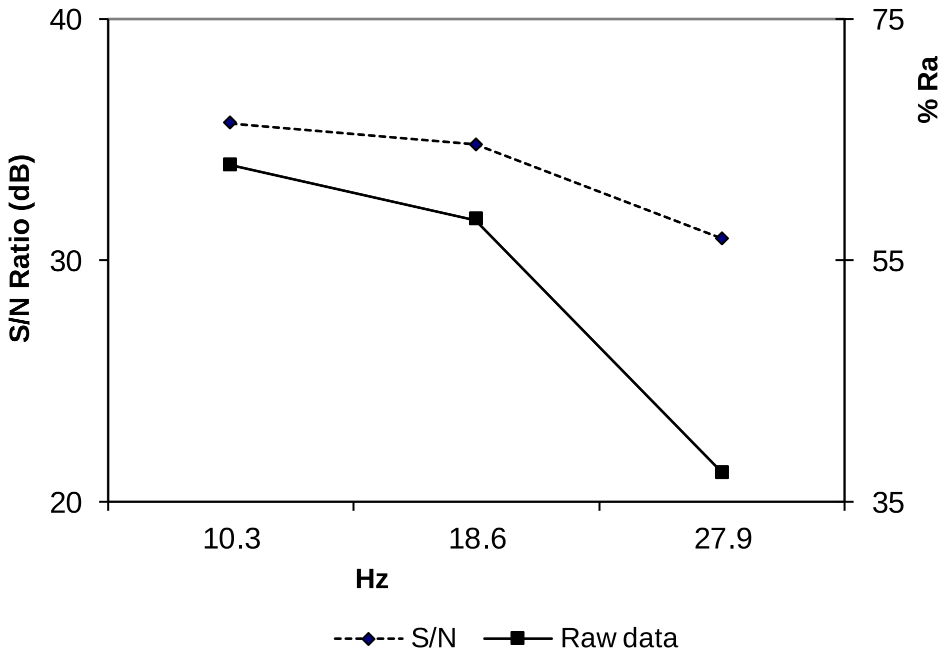

Figure39. Effect of Hz on S/N ratio and % improvement in Ra (MARAFM)

It can be seen from the figure 39 that as the rpm decreases the surface roughness value will increases. At the higher rpm of the process the rate of decrement of % Ra will increase.

6.3 Effect on percentage improvement in surface roughness for RAFM only

The average values of percentage improvement in surface roughness and S/N ratio for each parameter at Level L1, L2 and L3 are calculated and given in Table 2 and table 3.

6.3.1.Main effect of S/N RAFM

Table-7: Response Table for S/N(RAFM)

LEVEL	No. of Cycle	P	RPM
L1	30.0	25.0	33.1
L2	25.6	33.5	24.7
L3	35.7	32.9	33.5
L2-L1	-4.3	8.4	-8.3
L3-L2	10.1	-0.5	8.8
DIFFERENCE	14.4	-9.0	17.1

6.3.2 Main effects of % Improvement In Ra (RAFM)

Table-8: Response Table for % Improvement In Ra (RAFM)

LEVEL	No. of Cycle	P	Hz
L1	38	40.01	57.2
L2	43	60.89	39.1
L3	75	56.61	61.1
L2-L1	4	20.88	-18.1
L3-L2	32	-4.27	22.0
DIFFERENCE	28	-25.16	40.1

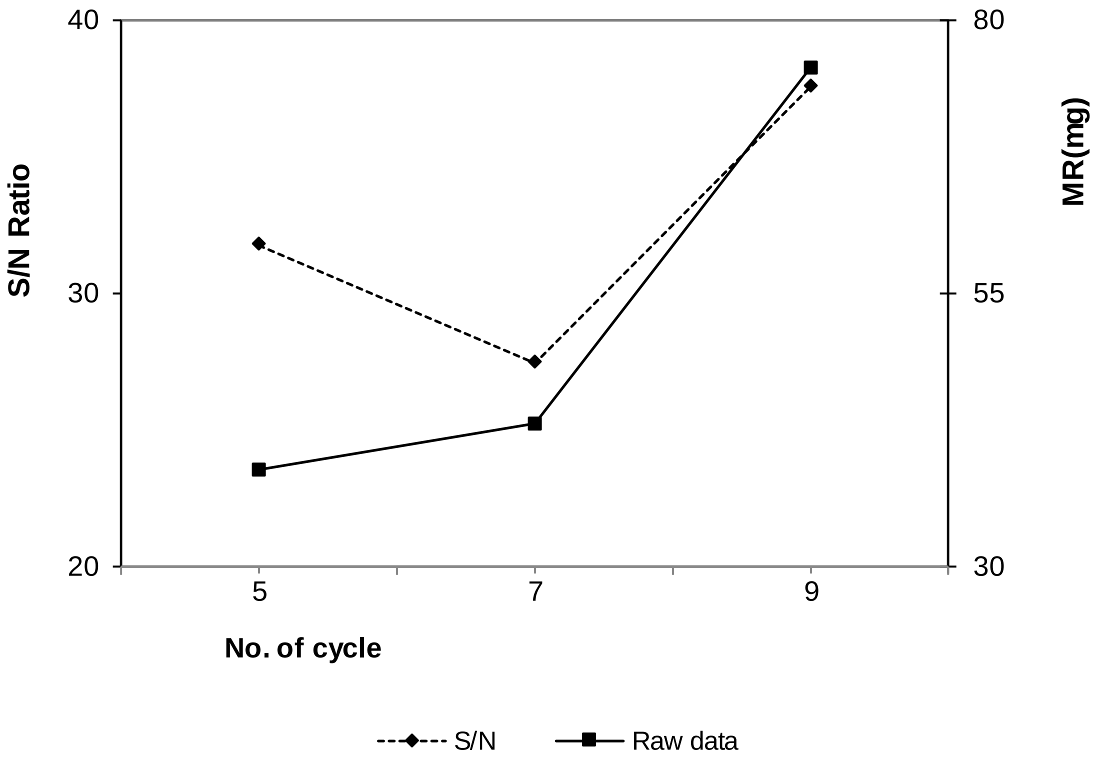

Fig.40: No of Cycle Vs % improvent. in Ra (RAFM)

From Figure 40, It can be clearly conclude that as the number of cycle is increased the % surface finish is increased after a certain level. With the increment of no. of cycles the surface finish of concerned profile increases because of passing time increases at the machining surface.

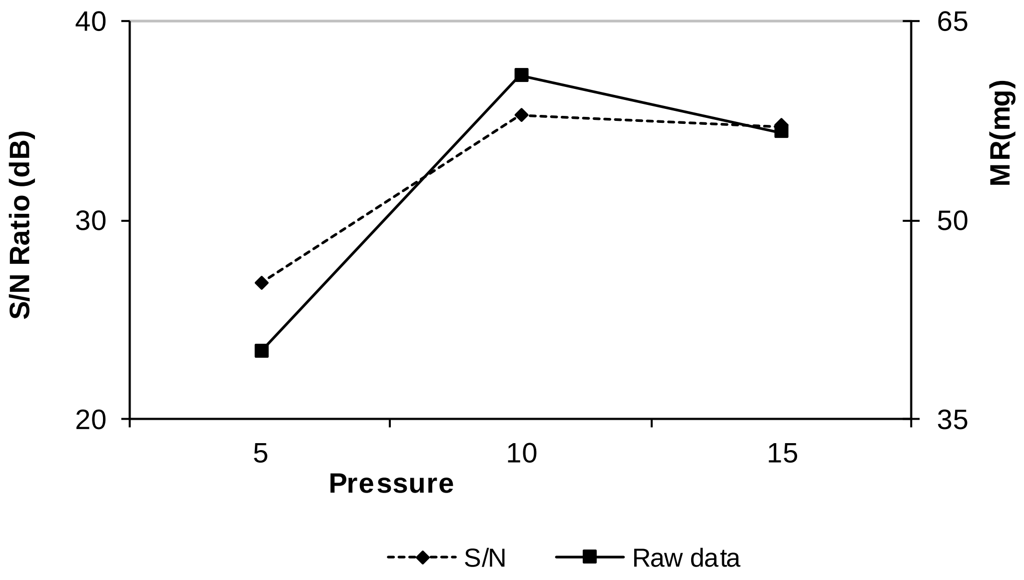

Figure 41.Effect of Pressure on S/N Ratio and % improvement in Ra (RAFM)

From Figure 41, it can be clearly conclude that as the pressure is increased the % surface finish is increased. After the second level the Ra value will slightly decreased due to high pressure contact of abrasive particles at surface..

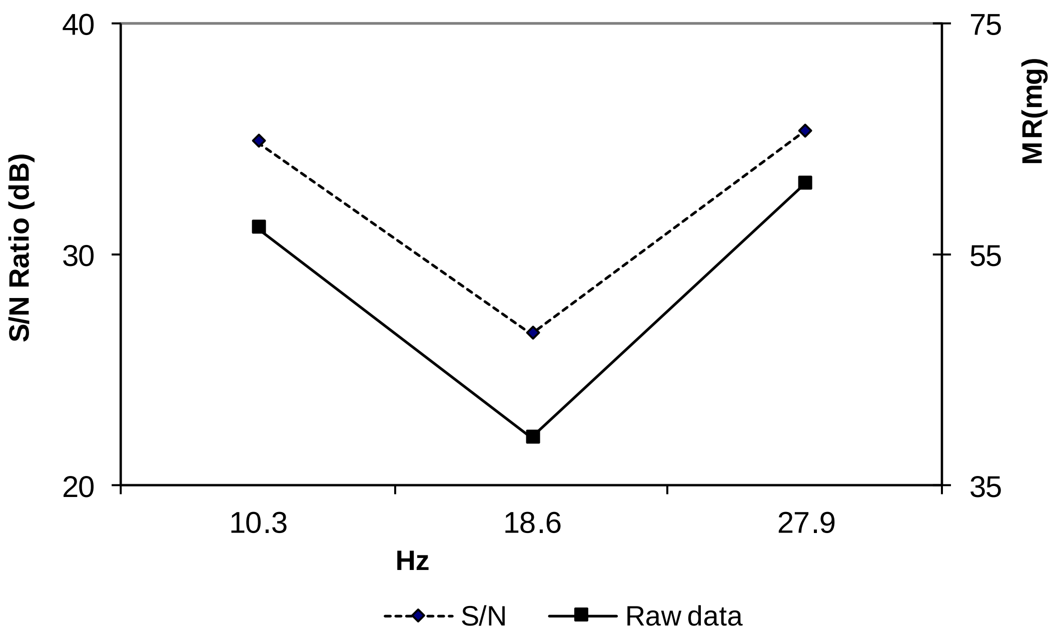

Figure42. Effect of Hz on S/N ratio and % improvement in Ra (RAFM)

It can be seen from the figure42 that as the rpm decreases the surface roughness value will increases. At the higher rpm of the process the rate of decrement of % Ra will increase.

6.3 Effect on ΔMR for MARAFM

The average values of percentage improvement in surface roughness and S/N ratio for each parameter at Level L1, L2 and L3 are calculated and given in Table 2 and table 3.

6.3.1.Main effect of S/N (MARAFM)

Table-9: Response Table for S/N

LEVEL	No. of Cycle	P	Hz
L1	11.5	19.9	22.8
L2	24.3	22.4	22.2
L3	30.1	23.5	20.8
L2-L1	12.8	2.5	-0.6
L3-L2	5.7	1.0	-1.4
DIFFERENCE	-7.0	-1.4	-0.8

6.3.2 Main effects of ΔMR (MARAFM)

Table-10:Response Table for ΔMR

LEVEL	No. of Cycle	P	Hz
L1	3.9	13.0	20.8
L2	16.9	19.0	19.1
L3	33.1	21.9	14.0
L2-L1	13.0	6.0	-1.7
L3-L2	16.2	2.9	-5.0
DIFFERENCE	3.1	-3.1	-3.3

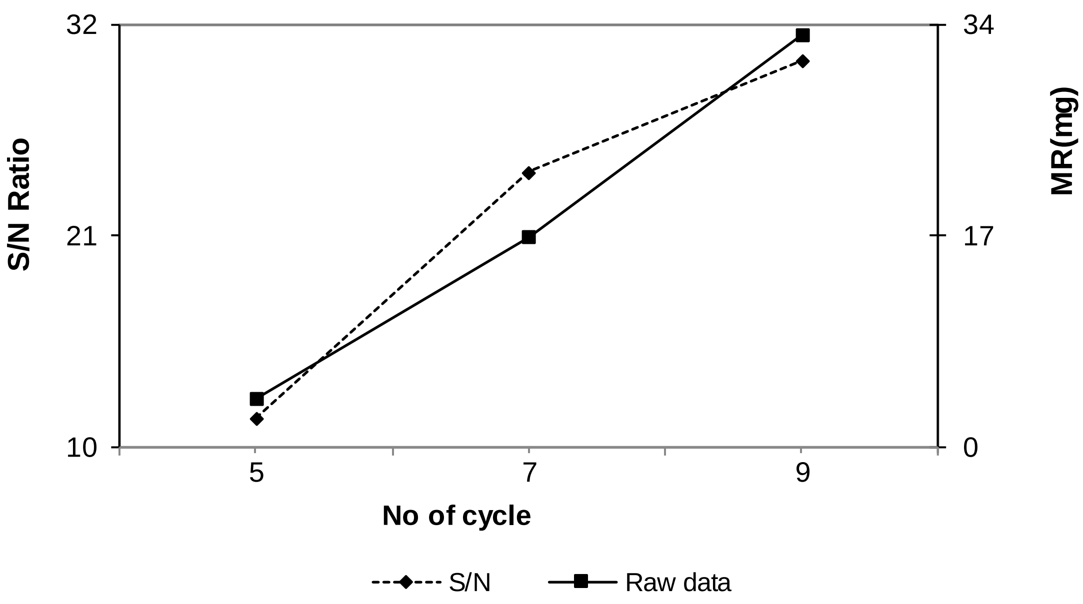

Fig.43: No of Cycle Vs % improvent. in ΔMR

From Figure 43, It can be clearly conclude that as the number of cycle is increased ΔMR is increased.

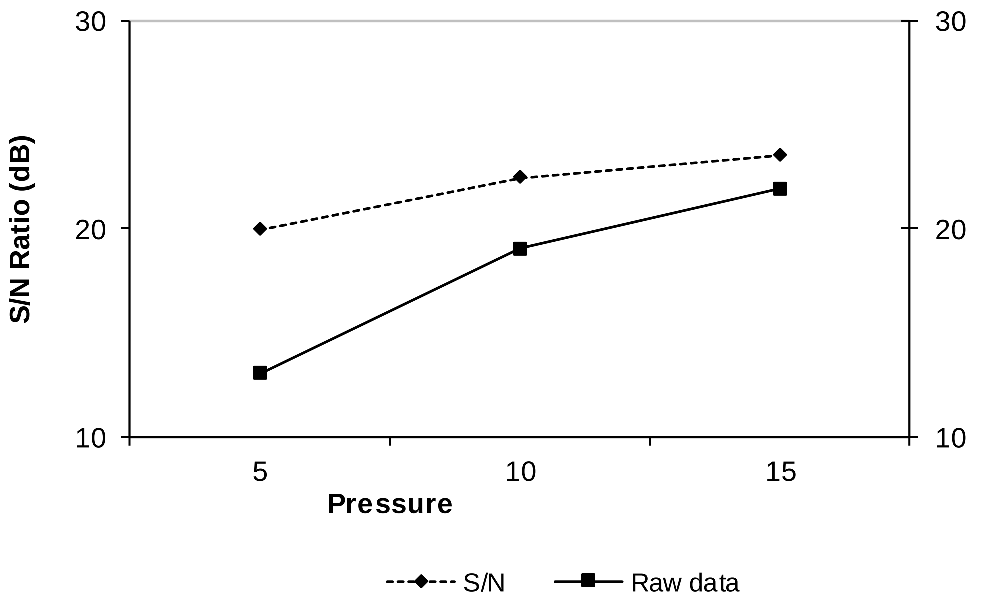

Figure 44.Effect of Pressure on S/N Ratio and MR (MARAFM)

From Figure 44, it can be clearly conclude that as the pressure is increased the ΔMR is increased. It is because of high pressure rubbing of abrasive particle at contact surface. The graph is intended to verify that at high pressure material removal rate is higher.

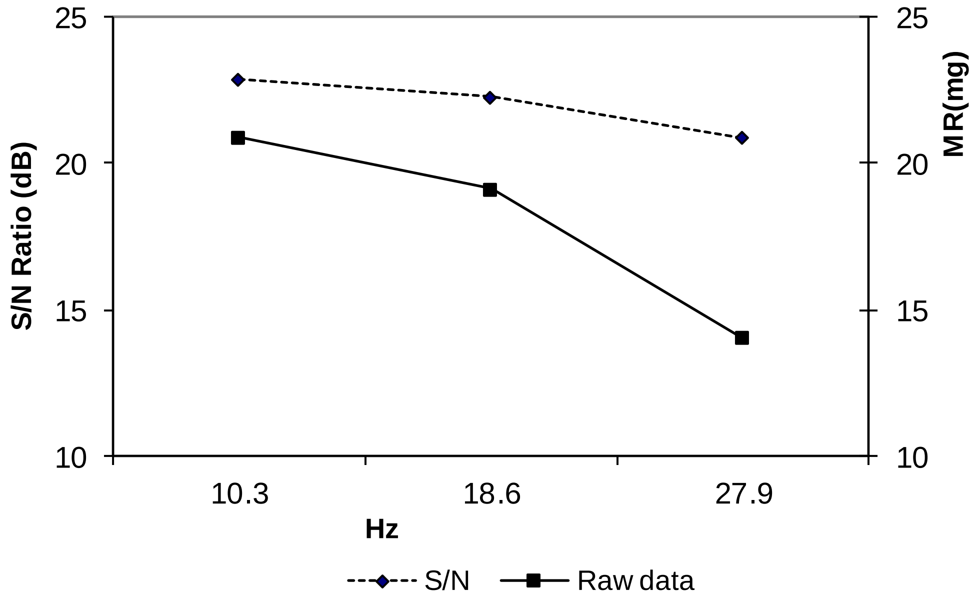

Figure45. Effect of Hz on S/N ratio and MR (MARAFM)

It can be seen from the figure45 that as the rpm decreases the surface roughness value will increases. At the higher rpm of the process the rate of decrement of ΔMR will increase. It is because of the fact that at high media rotation the abrasive particles become blunt and rounded so that their abrasive action got decreases.

6.4 Effect on ∆MR for RAFM only

The average values of percentage improvement in surface roughness and S/N ratio for each parameter at Level L1, L2 and L3 are calculated and given in Table 2 and table 3.

6.4.1.Main effect of S/N RAFM

Table-11: Response Table for S/N(RAFM)

LEVEL	No. of Cycle	P	RPM
L1	10.9	19.4	22.3
L2	23.8	21.9	21.7
L3	29.	22.9	20.3
L2-L1	12.8	2.5	-0.5
L3-L2	5.8	0.9	-1.4
DIFFERENCE	-6.9	-1.5	-0.8

6.4.2 Main effects for MR (RAFM)

Table-12: Response Table for MR (RAFM)

LEVEL	No. of Cycle	P	Hz
L1	3.6	12.3	19.7
L2	15.9	18.0	18.1
L3	31.4	20.6	13.2
L2-L1	12.2	5.7	-1.6
L3-L2	15.5	2.6	-4.8
DIFFERENCE	3.2	-3.0	-3.2

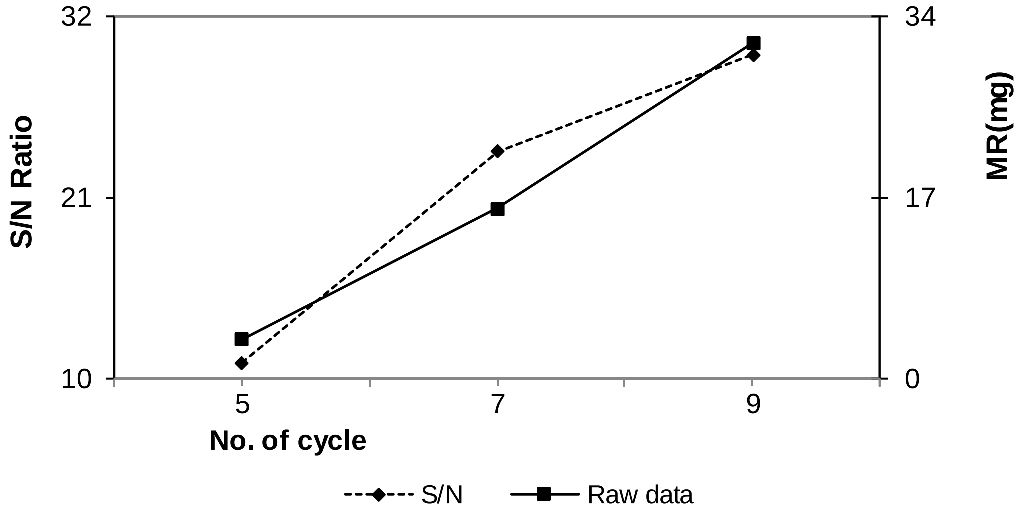

Fig.46: No of Cycle Vs MR (RAFM)

From Figure 46, It can be clearly conclude that as the number of cycle is increased ΔMR is increased.

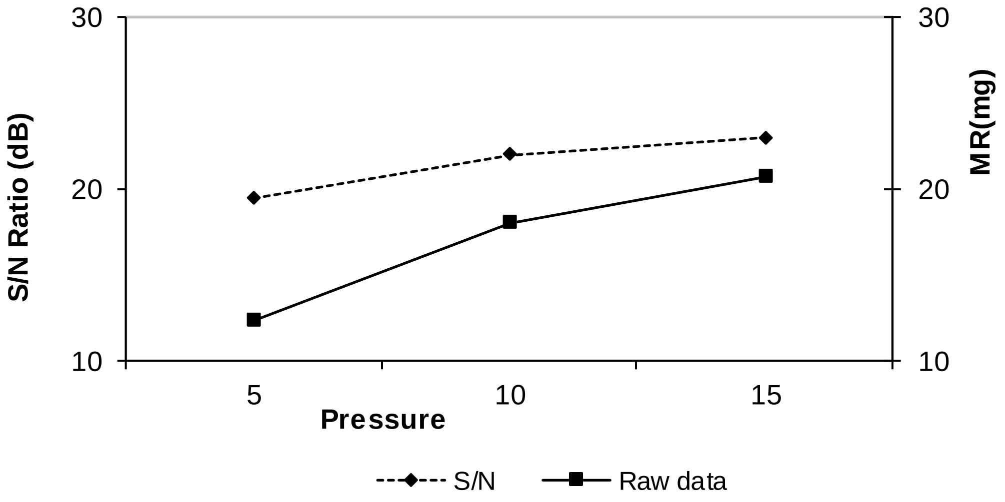

Figure 47.Effect of Pressure on S/N Ratio and MR (RAFM)

From Figure 47, it can be clearly conclude that as the pressure is increased the ΔMR is increased. It is because of high pressure rubbing of abrasive particle at contact surface. The graph is intended to verify that at high pressure material removal rate is higher.

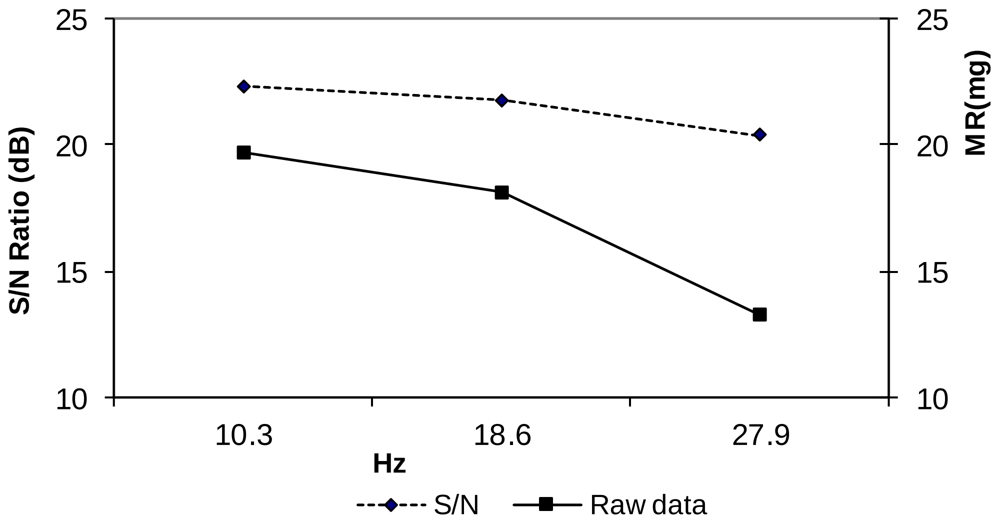

Figure48. Effect of Hz on S/N ratio and MR (RAFM)

It can be seen from the figure48 that as the rpm decreases the surface roughness value will increases. At the higher rpm of the process the rate of decrement of ΔMR will increase. It is because of the fact that at high media rotation the abrasive particles become blunt and rounded so that their abrasive action got decreases.

CHAPTER 7
CONCLUSION and FUTURE SCOPE

7.1 Conclusion

Following observations has been made from above results:

- **For MARAF**

A. it is found that higher the no. of cycle higher will be MR.
B. it is found that higher the no. of cycle higher will be %ΔRa.
C. it is found that higher Pressure higher will be MR.
D. it is found that higher Pressure higher will be %ΔRa.
E. it is found that higher RPM lower will be MR.
F. it is found that higher RPM lower will be %ΔRa.

- **For RAFM**

A. it is found that higher the no. of cycle higher will be MR.
B. it is found that higher the no. of cycle higher will be %ΔRa.
C. it is found that higher Pressure higher will be MR.
D. it is found that up to 10 bar %ΔRa will be increasing and afterword there will be decrement in % ΔRa with increment in pressure.
E. it is found that higher RPM lower will be MR.
F. it is found that with increment in rpm the %ΔRa go on decreasing for a particular rpm range and afterward again the %ΔRa will be increasing.

Rotational Abrasive flow machining (RAFM) process found to be more effective than Two-way AFM process in terms of attained surface roughness. Also we have improved lay profiles of machined surface. Design improvement in RAFM setup found more suitable for simple designs. RAFM process has very significant applications in industries. The existing designs can be replaced by this new design. This setup will be a simple one as well as cost effective. Due to helical relative motion of abrasive grains and work piece surface the uniformity at the surface finish will be attained. So the RAFM process has better surface finish.

7.2 Future Scope

Now the days there are a lot of research is going on to produce simple and cost effective designs of machines. So we can use this type of setup as the replacement of current RAFM setup. This type of RAFM setup can be used for finishing of internal profile of hollow objects like IC engine parts, aircraft parts, precession machinery etc.
The set up can be optimized against the self-induced magnetic field of motor windings. While placing the workpiece at the centre of motor core shaft the work piece experiences the magnetic field of motor core. So we can have small modification in designs of motor rotor to attain significant magnetic field at motor core. Thus this setup can be used for Magneto Assisted Rotational Abrasive Flow Machining (MARAFM). This setup can be very useful in developments of new hybrid AFM processes.

CHAPTER 8

References

[1] Rajesha S,Venkatesh G,Sharma A K,Kumar Pradeep, (2010), Performance study of a natural polymer based media for abrasive flow maching, *Indian Journal of Engineering & materials Sciences*,pp. 407-413.

[2] William R.E and Rajurkar K.P. (1992),Stochastic modeling and analysis of abrasive flow machining, *Trans. ASME, J Engg. For Ind*, Vol. 114, pp. 74-81

[3] Jain R.K. and Jain V.K. ,(1999), Abrasive fine finishing process-a review, *int . j. of Manufacturing science and Production*, Vol.2(1), pp. 55-68

[4] Williams R.E., and Rajurkar K.P.,(1994), Monitoring of abrasive flow machining using acoustic emission, *Proc. First S.M. Wu Symposium on Manufacturing Sciences,* Vol. 1, pp. 35-41

[5] Weller E.J. ,(1984), Nontraditional Machining Processes, 2nd edition, *SME*, pp. 52-65.
[6] Mamilla Ravishankar, V.K.Jain, J.Ramkumar, (2009), Experimental investigations into rotating workpiece abrasive flow finishing, *Wear 267*, pp. 43-51.

[7] V.K. Gorana, V.K. Jain, G.K. Lal, Experimental investigation into cutting forces and active grain density during abrasive flow machining, International Journal of Machine Tools and Manufacture 44 (2004) 201–211.
[8] V.K. Gorana, V.K. Jain, G.K. Lal, Forces prediction during material deformation in abrasive flow machining,Wear 260 (2006) 128–139.

[9] W.B. Perry, (1989), Abrasive flow machining – Principles and Practices, in Non traditional *Conference Proceedings*, pp. p.121–127.

[10] S. Singh, H.S. Shan, (2002), Development of magneto abrasive flow machining process, *International Journal of Machine Tools and Manufacture* 42, pp.953–959.

[11] S. Singh, H.S. Shan, P.Kumar, (2002), Wear behavior of materials in magnetically assisted abrasive flow machining, *Journal of Materials Processing Technology* 128, pp.155–161.

[12] R.S. Walia, H.S. Shan, P. Kumar, (2006), Abrasive flow machining with additional centrifugal force applied to the media, *Machining Science and Technology*. 10, pp.341–354.

[13] R.S. Walia, H.S. Shan, P. Kumar, (2007), Determining dynamically active abrasive particles in the media used in centrifugal force assisted abrasive flow machining process, *International Journal of Advanced Manufacturing Technology,* pp.1184–1188.
[14] Mamilla Ravi Sankar, S. Mondal, J.Ramkumar, V.K. Jain, Experimental Investigations and Modelling of Drill Bit Guided Abrasive Flow Finishing (DBGAFF) Process, *International Journal of Advanced Manufacturing Technology.*
[15] J. Hashim, L. Looney, M.S.J. Hashmi, Metal matrix composites: production by the stir casting method, Journal of Material Processing Technology, pp. 92–93.
[16] R.S.Walia, H.S.Shan, P.Kumar, (2008), Morphology and integrity of surfaces finished by centrifugal force assisted abrasive flow machining, *Int J Adv Manuf Technol* 39, pp.1171–1179.

[17] Kozak J, Rajurkar KP, Williams RE (1992) Material removal distribution and flow characteristics in abrasive flow machining. *Trans NAMRI/SME* 20, pp.145–150
[18] Perry WB, (1985), Abrasive flow machining: principles and practices, *Proc Non-Traditional Machining Conference, Cincinnati, Ohio*, pp 121–128
[19] Hull JB, Jones AR, Heppel ARW, Fletcher AJ, Trengove SA, (1992), The effect of temperature rise on the rheology of carrier media used in abrasive flow machining. *Surf Eng II*, pp.235–244
[20] Jain RK, Jain VK, Dixit PM, (1999), Modelling of material removal and surface roughness in abrasive flow machining process. *Int J Mach Tool Manuf* 39, pp.1903–1923
[21] Williams RE, Rajurkar KP, (1992), Stochastic modeling and analysis of abrasive flow machining, Trans ASME. J Eng Ind 144, pp.74–81
[22] Shan HS, (2007), Advanced manufacturing methods. Tata McGraw- Hill, New Delhi, India
[23] Rhoades LJ (1988) Abrasive flow machining. *Manuf Eng Nov:101*, pp.75–78
[24] Shan HS, Dubey, AK (1997), Micro machining by the flow of abrasives, pp 269–275
[25] Jain VK (2002) Advanced machining processes. Allied, New Delhi
[26] Jain RK, Jain VK (1999) Abrasive fine finishing processes- a review. *Int J Manuf Sci Prod* 2(1), pp.55–68
[27] Singh S (2002) Studies in metal finishing with magnetically assisted abrasive flow machining. *Dissertation, IIT Roorkee*
[28] Rajurkar KP, Kozak J, (1999), Hybrid machining process evaluation and development. *Online (http://www.unl.com)*
[29] Jones AR, Hull JB, (1998), Ultrasonic flow polishing. *Ultrasonics 36*, pp.97–101
[30] Gilmore JR, Rhoades LJ, (1997), Orbital polishing- an emerging technology. *SME, Buff and Polish Clinic, Schaumburg, IL*
[31] Spur G, Holl SE, (1996), Ultrasonic assisted grinding of ceramics. *J Mater Process Technol* 62(4), pp.287–293
[32] Takazazawa K, Shinmura T, Hatano E, (1985), Development of magnetic abrasive finishing and its equipment. *In: Proc Deburring and Surface Conditioning, SME Conference, Orlando, FL*
[33] Shinumura T, Yamaguchi H, (1995), Study on a new internal finishing process by the application of magnetic abrasive machining. *JSME Int Journal C 38(4)*, pp.798–804
[34] Kremen GZ, Elsayed EA, Rafalovich VI, (1996), Mechanism of material removal in MAP and the accuracy of machining. *Int J Prod Res 34(9), pp.*2629–2638
[35] Khairy AB, (2000), Aspects of surface and edge finishing bymagneto abrasive particles. *In: Proc of Int Conf on advanced Manufacturing Technology, Malaysia*, pp 77–84
[36] Yamaguchi H, Shinmura T (2000) Study of an magnetic abrasive finishing using a pole rotation system. *Precis Eng, J Int Soc Precis Eng Nano Technol* 24, pp.237–244
[37] Singh S, Shan HS, (2002), Development of magneto-abrasive flow machining process. *Int J Mach Tools Manuf 42*, pp.953–959