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ADVANCED FINE FINISHING PROCESSES

SEMINAR REPORT

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ABSTRACT

The technology is really spice of life. This seminar is all about latest technology which is useful for finishing materials with very high precision. These are the latest processes are called as Advanced Fine Finishing Processes. With the demand of stringent technological and functional requirements of the parts from micro- to nano-meter range, evolution of ultraprecision finishing processes became obvious need of the manufacturing scientists and engineers. The traditional finishing processes of this category have various limitations, for example complex shapes, iniature sizes, and 3-D parts cannot be processed & finished economically and rapidly. This led to the development of advanced finishing techniques like Abrasive Flow Machining, Magnetic Abrasive Finishing, Magnetic Float Polishing, Magneto-rheological Abrasive Finishing, and Ion Beam Machining. In all these processes except Ion Beam Machining, abrasion of the workpiece takes place in a controlled fashion such that the depth of penetration in the workpiece is a fraction of micrometer so that the final finish approaches towards the nano range. The working principles and the applications of these processes are discussed in this paper along with some recent research going on in these areas.

CHAPTER 1

INTRODUCTION

The developments in the material science have led to the evolution of difficult-to machine, high strength temperature resistant materials with many extraordinary qualities. Nano- materials and smart materials are the demands of the day. To make different products in various shapes and sizes, many times, the traditional manufacturing techniques do not work. One needs to use non-traditional or advanced manufacturing techniques in general and advanced machining processes in particularly. Later includes both, bulk material removal advanced machining processes as well as advanced fine finishing processes. Further, the need for high precision in manufacturing was felt by manufacturer world over, to improve interchange ability of components, improve quality control and longer wear / fatigue life. Achieving controlled surface finish on such components is equally important. Traditionally, abrasives either in loose or bonded form whose geometry varies continuously in an unpredictable manner during the process are used for final finishing purposes. Nowadays, new advances in materials syntheses have enabled production of ultrafine abrasives in the nano meter range without the need for combination (a process by which brittle materials are reduced in size).With such abrasives, it has become possible to achieve nanometer surface finish and dimensional tolerances. There is a process (ion beam machining), which can give ultra-precision finish of the order of the size of an atom or molecule of the substance. In some cases, the surface finish obtained has been reported to be even smaller than the size of an atom. This paper deals with some of the advanced fine finishing I machining processes like Abrasive Flow Machining (AFM), Magnetic Abrasive Flow Machining (MAFM), Magnetic Abrasive Finishing (MAP), Magnetic Float polishing (MFP), Magnetorhelogical Abrasive Finishing (MRAF), Elastic Emission Machining (EEM) and Ion Beam Machining (IBM).

CHAPTER 2

ABRASIVE FLOW MACHINING (AFM)

With today's focus on total automation in the flexible manufacturing system, the abrasive flow machining process offers both automation and flexibility .This process was developed basically to deburr, polish and radius difficult to reach surfaces and edges by flowing abrasive laden polymer, to and fro in two vertically opposed cylinders.

2.1 PRINCIPLE OF OPERATION AND WORKING

The medium is mixture of viscoelastic material and abrasive particles enters inside the work piece through the tooling. The abrasive particles penetrate in the work piece surface depending upon the extent of radial force acting on the abrasive particles. Due to tangential force, the material is removed in the form of chips.

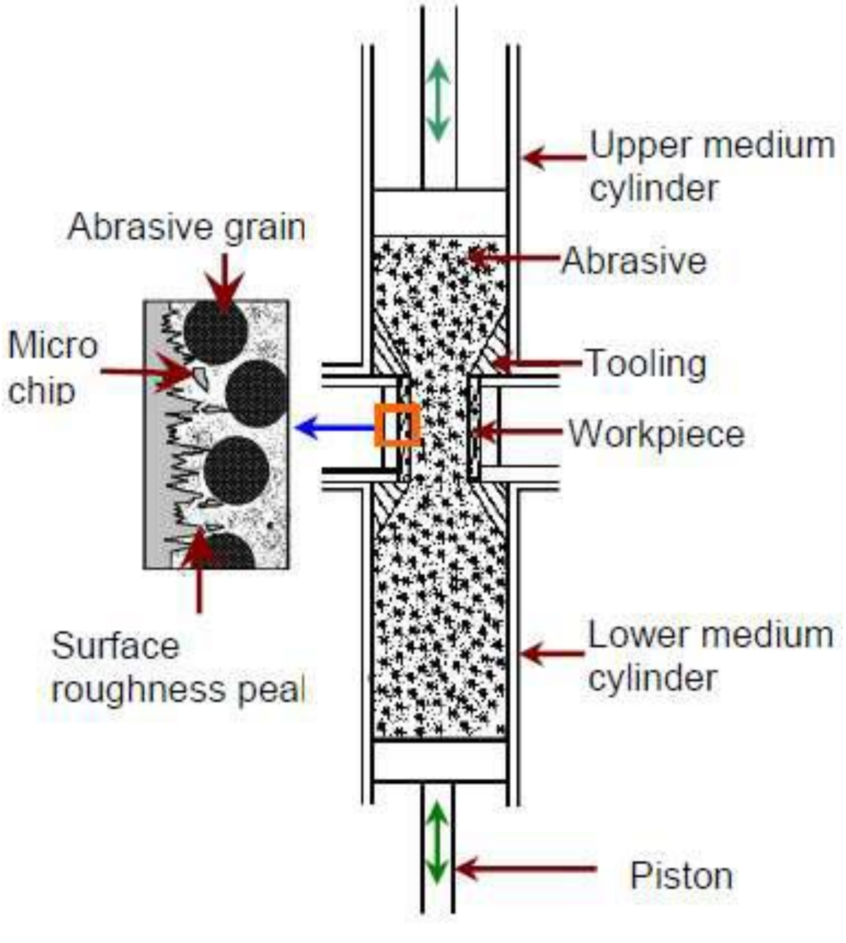


Fig 2.1.1 Schematic diagram of abrasive flow machining

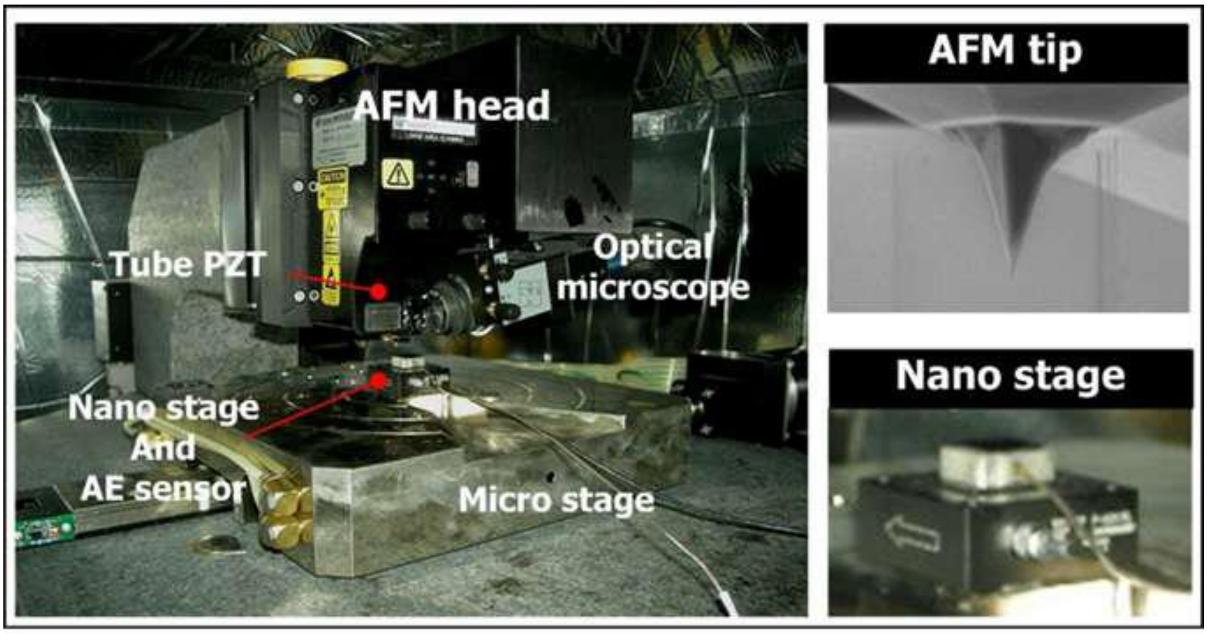
To investigate into the mechanism of material removal during AFM, their debris were collected and examined under the scanning electron microscope. It was found that very fine chips are produced. However, under certain machining conditions the occurrence of ploughing has also been observed. In this case, one may get almost zero material removal rate, and shining polished surface as has been observed during experimentation.

During the AFM process, medium cylinder, hydraulic cylinder and tooling also get abraded but comparatively first two wear much lesser than the third one due to lower pressure in the cylinders which are much larger in size. There are three major elements of the AFM system- Tooling, Machine, and Medium.

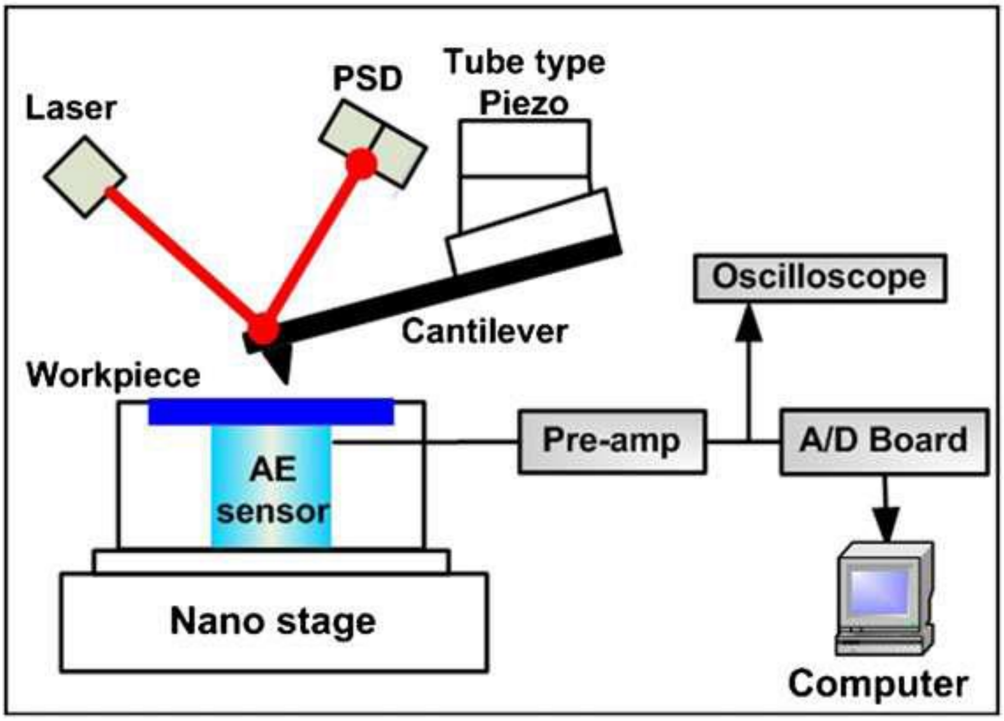
The tooling confines and directs the medium flow to the areas where abrasion is desired. The machine controls the process variables like extrusion pressure, medium flow volume and medium flow rate. The abrasive laden polymer is medium whose rheological properties determine the pattern and aggressiveness of the abrasive action.

From application point of view, it has some peculiar applications where no other traditional as well as advanced finishing process can work. For example, many small diameter holes (say, diameter = 3 mm and depth = 30 mm) can be finished at a time by controlling machining parameters. It is otherwise not possible. This process can be used to control surface finish of the cooling holes in a turbine blade or surface finish of stator and rotor blades of a turbine. Some work has been reported regarding the modelling of AFM process. Majority of these models are based on the simplified assumptions like medium is isotropic and homogeneous, medium properties are independent of the fluid temperature, and constant with time and space.

The abrasive grains are considered spherical in shape and subjected to uniform load, and all the grains are of uniform size. In real practice, it is not so. The surface irregularities on the work piece are assumed to be triangular in shape.



(a)



(b)

Fig2.1.2 AFM machining and monitoring system

(a) AFM machining and monitoring setup;

(b) Schematic of the process monitoring system.

2.2 ADVANTAGES

- Excellent process control
- Can finish both ID and OD of component
- Good control of radius generation
- Fully automated system capabilities
- Faster setup & quick-change tooling
- Faster change-over of media

2.3 DISADVANTAGES

- Fixture can be expensive
- High capital investment

2.3 APPLICATION

a.AFM in Aerospace Industry

- Improved surface quality
- Enhanced high cycle fatigue strength
- Optimized combustion and hydraulics
- Increased airflow
- Extended component life

b.AFM in Automotive Industry

- Enhanced uniformity and surface quality of finished components
- Increased engine performance
- Increased flow velocity and volume
- Improved fuel economy and reduced emissions
- Extended work piece life by reducing wear and stress surfaces

c.AFM in Medical Industry

- Eliminate the surface imperfections where dangerous contaminates can reside
- Improved functionality, durability and reliability of medical component.

CHAPTER 3

MAGNETIC ABRASIVE FLOW MACHINING (MAFM)

3.1PRINCIPLE OF OPERATION AND WORKING

The principle of working can be seen from where the application of magnetic field attracts and densities the magnetic abrasive particle near the inner wall of the work piece.

As a result, effective abrasive concentration increases near the wall as compared to the rest of the medium. It enhances the MRR as compared to normal AFM because of the two reasons:

(a) Effective concentration of the abrasive particles near the wall of the work piece increases,

(b) Radial force acting on the abrasive particles leading to the increased depth of cut and hence increased MRR and comparatively rapid improvement in surface finish in the initial stage

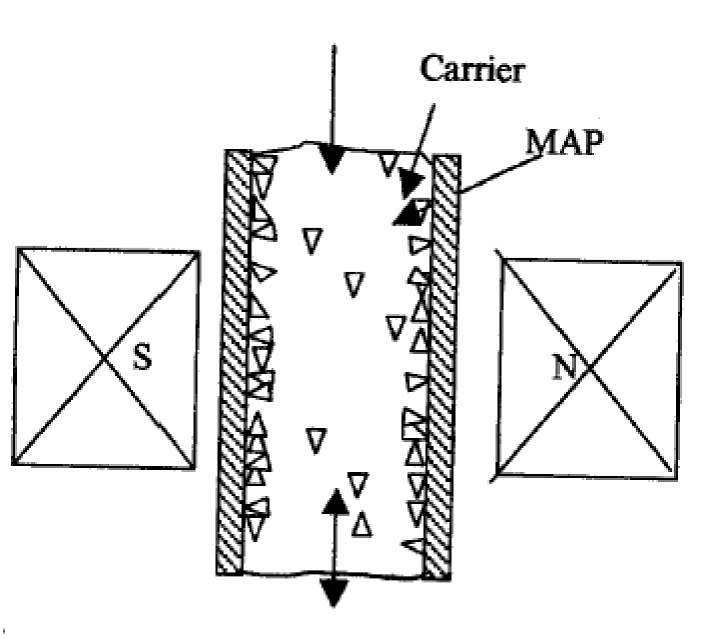


Fig 3.1.1 Schematic representation of MAFM

Fig 3.1.2 product before and after finishing

3.2 ADVANTAGES

- Easy clean-up
- Media temperature control generally not required
- Able to process larger parts
- Simpler tooling and part change-over
- Accurately replicates air or liquids natural flow
- Does not encapsulate work part in media

3.3 DISADVANTAGES

- Difficult to finish flat surfaces
- Cannot process blind holes

3.4 APPLICATIONS

- Automotive
- Aerospace
- Medicine
- Dies and Moulds

CHAPTER 4

MAGNETORHEOLOGICAL FINISHING (MRF)

Precision lenses are usually made of brittle materials such as glass, and they tend to crack during machining finishing. Even a single microscopic crack can drastically hinder a lens's performance and make it to fail in performing its intended function. Manufacture of a lens usually involves two operations - grinding and finishing. Grinding operation makes a lens close to the desired size while finishing removes the cracks and surface imperfections either created by grinding or could not be removed during grinding. Manual grinding and polishing are non-deterministic and a high local pressure may lead to subsurface damage. To take care of these difficulties,

4.1 PRINCIPLE OF OPERATION AND WORKING

Magneto rheological-finishing (MRF) process has been developed which is automatic in nature. MRF process uses Magneto rheological (MR) fluid, also known as smart fluid because it changes its properties under the influence of magnetic field.

MR fluid consists of colloidal suspension of magnetic particles and finishing abrasives randomly distributed. This smart fluid reversibly stiffens under the influence of a magnetic field. The stiffness is directly proportional to the strength of the magnetic field. This temporary finishing surface (stiffened fluid) can be controlled in real time by varying the field's strength and direction.

In MRF, a MR fluid ribbon is extruded between the work piece and the rotating wheel rim. As a result of extrusion, wear of the work piece (convex, concave, or flat) takes place. The extent of wear (or finishing) of the work piece is governed by MR fluid properties, magnetic field strength. Work piece material properties, rotational speed of the wheel and fluid pumping pressure. It has been reported that the surface accuracy is achieved of the order of 10-100 nm (peak to valley). MRF is capable to remove surface damage, correct the figure and polish/finish the surface.

To machine external surfaces, work piece is rotated in MRF solution, to obtain the required surface finish. In the present work, the job is submerged in the MR fluid andat the same time, polishing medium is rotated by imparting a rotational motion to the vessel also. By superimposing these two motions, smooth mirror finished surface can be achieved in comparatively less time.

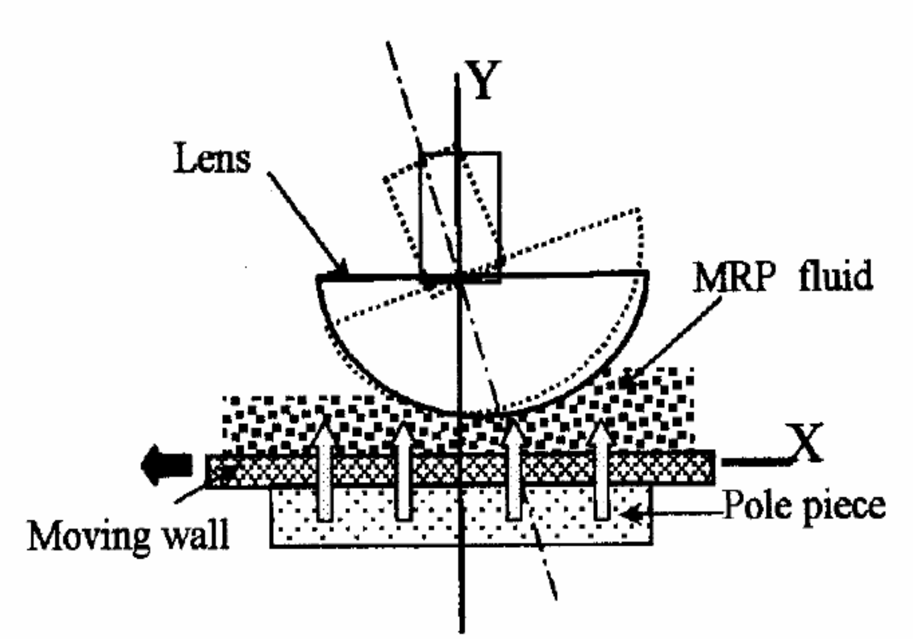


Fig4.1.1 MRF layout

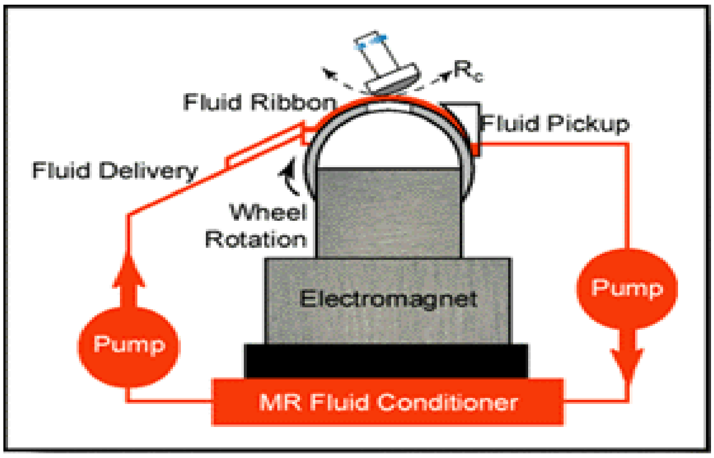


Fig 4.1.2 MRF working arrangement

4.2 MATERIAL REMOVAL RATE IN MRF

MRR = kPU = kW/x

P = Applied pressure,

U = Relative velocity between the MR fluid ribbon &work piece,

k = Empirical coeff. Depends on process which combines surface chemistry, abrasion effects & part-polisher contact, x=Coefficient of friction,

W = Rate of work done per unit area (Power input**).**

4.3 ADVANTAGES

- Very high precision finishing of lenses (spherical, flat & spherical).
- Surface Finish –0.8nm Ra
- Deterministic Finishing.

4.4 DISADVANTAGES

- Shape limitation.
- Standard MR-polishing fluid ineffective for polishing hard metals.

4.5 APPLICATIONS

- Optics Manufacturing
- High precision lenses
- Ceramics
- Semiconductor wafers

CHAPTER 5

MAGNETIC FLOAT POLISHING (MFP)

This process was developed for gentle finishing of very hard materials like ceramics, which develop defects during grinding leading to fatigue failure. To achieve low level of controlled forces, magnetic field is used to support abrasive slurry in finishing ceramic products like ceramic balls and bearing rollers. This process is known as Magnetic Float Polishing

5.1 PRINCIPLE OF OPERATION AND WORKING

The MFP technique is based on the Ferro- magnetic behaviour of a magnetic fluid that can levitate a non-magnetic fluid and abrasives suspended in it by magnetic field. The levitation force applied on the abrasives is proportional to the field gradient and is extremely small and highly controllable. It is a good method for super finishing of brittle materials with flat and spherical shapes.

The set up consists of a magnetic fluid containing fine abrasive grains and extremely fine ferromagnetic particles in a carrier fluid (water or kerosene). On the application of the magnetic field, the Ferro fluid is attracted downwards which is the area of higher magnetic field. At the same time, the buoyant force is exerted on non- magnetic material to push them upward which is the area of lower magnetic field.

The abrasive grains, the ceramics ball, and the acrylic float inside the chamber all being of non-magnetic material, are levitated by the magnetic buoyant force. The drive shaft is fed down to contact the balls and to press them down to reach the desired force level. The balls are polished by the relative motion between the balls and the abrasives.

The material used for this investigation is hot isostatically pressed (HIP) silicon nitride. This material is known for its very high hardness, high resist.anceto wear and high toughness (compared to other ceramic materials), and low density. The HIPing process begins with a powder form of the material. The powder material is then heated to about 1700 °C , in a nitrogen atmosphere, at high pressures of about 300 MPa. When in this state it is compacted into thedesired shape. Compared to other manufacturing techniques, it provides anearly fully theoretically dense product.

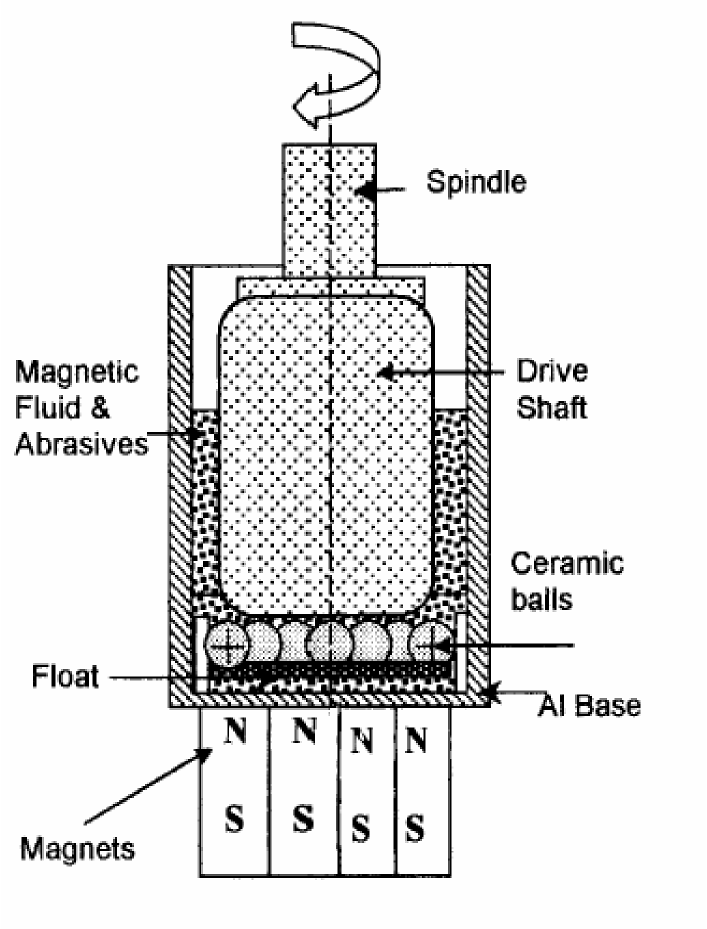


Fig 5.1.1 Schematic diagram of MFP process

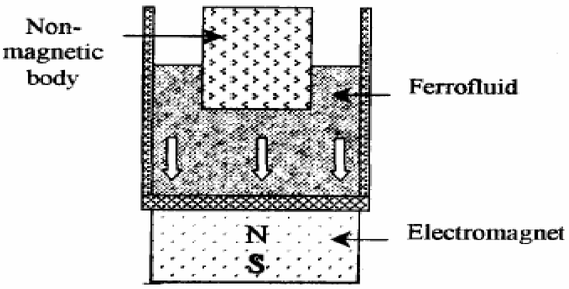


Fig5.1.2 Buoyant force acting on nonmagnetic body

5.3 ADVANTAGES

- High finishing rate
- Surface Finish –4 nm Ra
- Highly precise operation

4.4 DISADVANTAGES

- Roller shape is only used
- Difficult to control

3.4 APPLICATIONS

- Roller bearings
- Mechanical roller sections
- Aircraft applications

CHAPTER 6

ELASTIC EMISSION MACHINING (EEM)

This process removes material from the work piece surface to atomic level by mechanical methods, and gives completely mirrored, crystallographically and physically undisturbed finished surface. It can give surface of the order of atomic dimensions (~ 0.2 nm to 0.4 nm). Using ultrafine particles to collide with the work piece surface, it may be possible to finish the surface by the atomic scale elastic fracture without plastic deformation and the process is known as Elastic Emission Machining (EEM).

Elastic emission machining (EEM) is expected as one of the adequate techniques. EEM has been successfully developed for the fabrication of hard-X-ray mirrors, by which sub-30nm focusing was established under diffraction-limited conditions at the wavelength of 0.08 nm. In this achievement, the material of the mirror surface was single-crystal silicon, on which EEM is known to realize an atomically well-ordered surface.

6.1 PRINCIPLE OF OPERATION AND WORKING

EEM is a non-contact machining process, differing from conventional polishing, which uses an abrasive pad. The removal process in EEM solely depends on the contact between powder particles and the work piece surface. Fine powder particles are brought to the work piece surface by a flow of pure water, and the chemical reaction between the surfaces of the work piece and the particles results in the removal of surface atoms from the work piece. Therefore, atomic-order smoothness without crystallographic damage can be achieved.

The polyurethane ball used during EEM is of about 56 mm diameter. This ball is mounted on a shaft whose axis of rotation is inclined at about 45° to the vertical axis, and it is driven by a variable speed motor. The work piece is immersed in the slurry of zrO2 or A12O3 (size 20 nm) abrasives and water as carrier. The slurry is circulated in the gap by a diaphragm pump, and maintained at constant temperature with a heat exchanger.

The proposed mechanism of material removal due to slurry and work interaction involves erosion of the surface atom by the bombardment of abrasive particles without the introduction of dislocation.

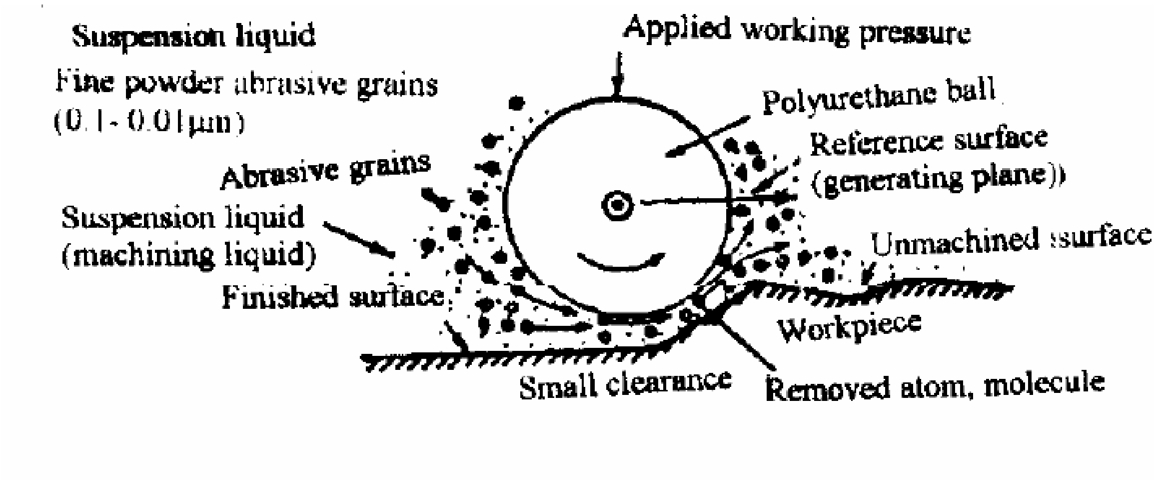


Fig 6.1.1 EEM Process arrangement

6.2EEM APPARATUS ANDEXPERIMENTAL SETUP

This system consists of a three-axis control system, which makes it possible to process any desired area on a work piece surface. A work spindle with a rotating-sphere head is suspended by a cross spring, similar to a pendulum, and the head is immersed in a tank of fluid mixture. The load acting on the rotating sphere is generated by applying a load to the work spindle

Increases in rotation speed and particle concentration cause an increase in the number of particles passing through the lubrication film per unit time. However, the number of particles supplied to the work piece surface per unit time, or removal rate, does not simply increase. This may be due to the presence of forces preventing particles from being supplied to the work piece surface. These forces can be considered to increase when the fluid flow velocity and the concentration of particles in the lubrication film increase.

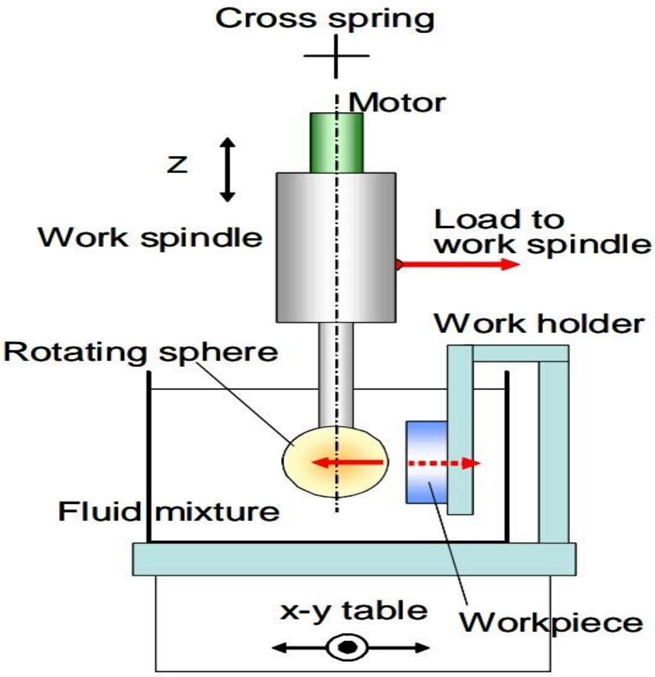


Fig 6.2.1 Schematic diagram of EEM apparatus.

6.3 ADVANTAGES

- Material removal up to atomic level
- Water is used as carrier in slurry
- High surface finish

6.4 DISADVANTAGES

- Wear of rotating sphere
- Shape limitation

6.5 APPLICATIONS

- Finishing of aircraft parts
- Industrial applications

CHAPTER 7

ION BEAM MACHINING (IBM)

Nano-technology is the target of ultra-precision machining having capabilities of producing surface finish of the order of 1nm or less which means approaching towards the ultimate surface finish.

7.1 PRINCIPLE OF OPERATION AND WORKING

Ion beam machining is a molecular manufacturing (or atomic size stock removal) process based on the sputtering off phenomenon of work material by bombardment of energised ions of 1 to 10 keV and current density of 1 mill amphere/cm2. This process can be applied to manufacture ultra-fine precision parts of electronic and mechanical devices. The sputtering off is basically a knocking out phenomenon of surface atoms of work piece by the kinetic momentum transfer from incident ions to the target atoms. Removal of atoms from the work surface will occur when the actual energy transferred exceeds the usual binding energy of 5- 10 ev. Ions of higher energy may transfer enough momentum such that more than one atom causes a cascading effect in the layer near the surface, removing several atoms. Ions of still higher energy may get implanted deep within the material after ejecting outseveral atoms or molecules. But the bombardment of so much high energy ions is not desirable to avoid any kind of damage to the work piece surface.

There are various factors that affect the machined surface characteristics. Such factors are properties of work material, ion-fetching gas, angle of incidence of ions, ion energy and current energy. IBM can be employed in many cases for example sharpening of a diamond style for profilometer having tip radius of about 10 nm, and asymmetric and aspheric mirrors for telescope. IBM is an ideal process for nano- finishing of high melting point, hard and brittle materials such as ceramics, semiconductors, diamonds, etc. However, surface roughness value increases with the increase in the size of grain structure, ion energy & current density.

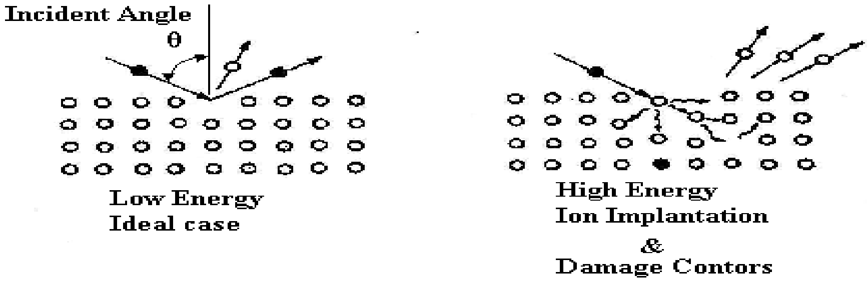


Fig 7.1.1 Ion beam machining

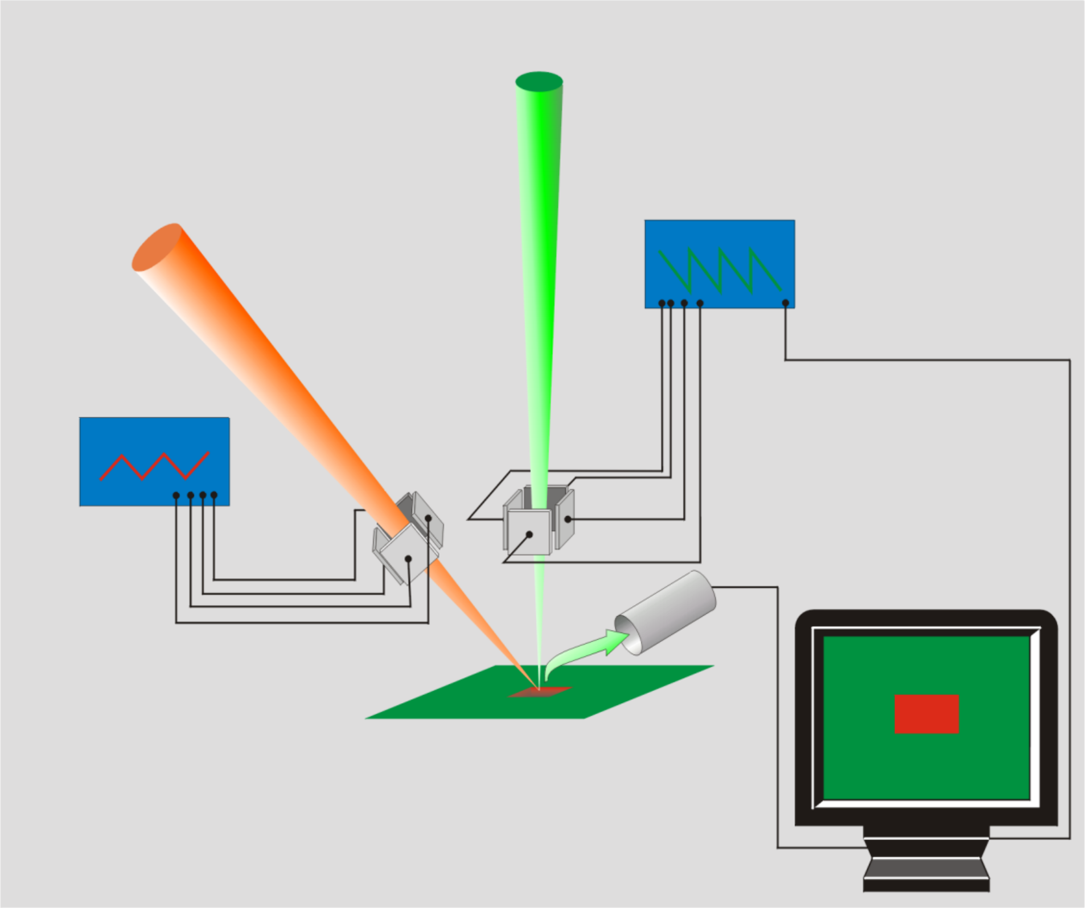


Fig 7.1.2 Computer controlled IBM process

7.2 ADVANTAGES

- Finishing of hard, brittle material such as ceramics semiconductors and diamond
- Surface finishes increases for incident angle 0 to 50
- Suitable for finishing of thin material

7.3 DISADVANTAGES

- Difficult to control

7.4 APPLICATIONS

- SEM Imaging
- Gas Injection System, Gas assisted etching
- Medical equipment finishing

CHAPTER 8

FINISHED SURFACE CHARACTERISTICS

The performance of the advanced fine abrasive finishing processes is evaluated by their achievable surface finish, from accuracy and resulting surface integrity. These fine abrasive finishing processes have shown to yield accuracy's in the nanometer range. The order of surface damage ranges from micrometers to nanometers in these advanced finishing processes. It makes their measurement a formidable task. Table summarise the attainable surface finish of four advanced fine abrasive finishing processes:

Sl.no.	Process	Work piece	Ra(nm)
1.	Elastic Emission Machining (EEM) with ZrO2 abrasives	Silicon	<0.5
2.	Magnetic Float Polishing (MFP) • Cr2O3 abrasives • Ceo2 abrasives	Si3N4	 9.1 4.0
3.	Magnetic Abrasive Finishing (MAF) • With diamond abrasives	• Si3N4 rollers • Stainless steel rods	40 7.6
4.	Magnetorheological Finishing (MRF) with CeO2 abrasives	Flat BK7	0.8

Table 8.1 Finished surface characteristics

CHAPTER 9

CONCLUSIONS

The importance of ultrafine finishing processes using abrasive as cutting tool, and their capabilities to achieve nanometer order surface finish is discussed. Working principle of seven such advanced finishing processes, viz. AFM, MAFM, MAP, MFP, MRAM, EEMand IBM have been explained in brief. It has been observed that the precise control of forces on abrasive particles using non-traditional methods discussed in this paper, proved useful in performing ultra precision finishing. Fine finishing of brittle materials like ceramics, glasses, and semiconductor wafers can be easily done in nanometer range. The exact mechanics of abrasive interaction with the work piece surface in most of these processes is still subject of in-depth research.

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