Estimation of Fluid Pressure in the Process of Magnetorheological Flow Finishing By Using Comsol Multiphysics 4.4

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Abstract: The use of magnetorheological fluids for finishing is one of the most promising smart processes for the fabrication of ultra-fine surfaces, particularly three-dimensional millimeter or micrometer structures. This paper presents the 3D model of pressure distribution in the process of magneto-rheological flow finishing. The effect of working gap on pressure distribution is studied by using Comsol Multiphysics 4.4. Also effect of different viscosity of fluids on development of pressure distribution is studied. The 3D model shows behavior of pressure distribution for magnetic field and for nonmagnetic field. The model also shows the behavior of velocity change, Von-misses stress and stress tensor in z direction. The results are compared with well published paper.

Keywords: Magnetorheological Fluid, Comsol Multiphysics, Pressure distribution, Von-misses stress.

1. Introduction

Manufacturing automation and manufacturing with high precision are two main thrust areas in the manufacturing technology. The need for high precision was felt by manufactures worldwide to improve interchangeability of components, improve quality and longer wear/fatigue life [1].

Final finishing operation in manufacturing of precise parts is always of concern owing to their time consuming, labor intensive, and least controllable nature. The traditional finishing processes alone are often incapable of producing the required surface characteristics. In some cases these processes can be used but they require expensive equipment and long processing time, finally making them economically incompetent.

Surfaces on the materials are generally produced by a variety of material removal processes. The surfaces subjected to friction and wear require lubrication and they may vary in initial surface topography, depending on the particular use involved. For most parts, these surfaces play a useful role in the service life of the component. It is a well established fact that the fatigue life is strongly influenced by the surface finish and surface treatment. Fatigue failures generally nucleate at the surface defects of engineer- ing components. Therefore, surface conditions become an important factor influencing the fatigue strength of the component because irregular and rough surfaces generally exhibit inferior fatigue properties [2]. As surface roughness increases, problems such as fluid flow resistance and optical loss increase, resulting in a decrease in efficiency. Therefore, in some applications, a surface polishing process is required during or after fabrication process.

Single crystal silicon is a widely used material in semiconductor industries for making IC chips. Moreover, it is also a preferable material for cryogenic applications and synchrotron beamline as a silicon strip mirror due to its immensely favorable properties. Single crystal silicon has been the primary substrate material for both internally and contact cooled x-ray mirrors [3].

2. CMMRF process and MR polishing fluid

2.1 CMMRF Process

A CMMRF apparatus (Fig. 1) was designed and fabricated keeping in view the fundamental mechanisms of the process and basic functional requirements [4, 5]. The rotary motion to the MR polishing brush is provided by the vertical rotational system which is driven by a three-phase induction motor, and its speed (rpm) is controlled by an independent variable frequency drive (VFD). Another motion system controls the feed rate in the x-direction though VFD. The stroke length is controlled with a relay unit and limit switches.

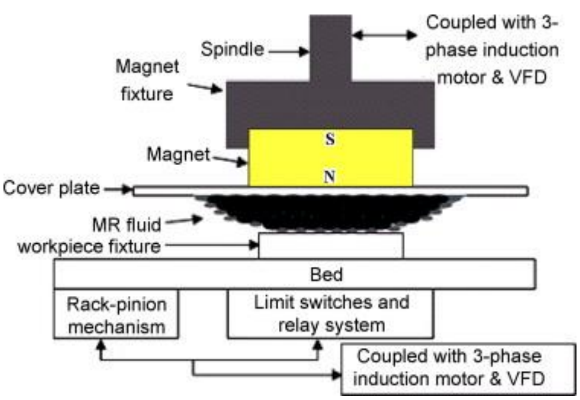

Figure1. Schematic diagram of experimental setup of CMMRF process

The CMMRF process utilizes pad flexibility of smart magneto-rheological (MR) polishing fluid brush that acts as a tool. Its rheological behavior is controllable by means of magnetic field. In this process, a magnetic levitation force [6] is transferred to the active abrasive particles.

During material removal in CMMRF process, two actions simultaneously take place, namely, chemical reaction and magnetic assisted mechanical abrasion. Chemical reaction of silicon with cerium oxide, deionized water, colloidal silica, hydroxyl ions and oxygen are used to convert silicon & silicon dioxide into chemically passivated layer (soft complexes of silicon). The chemically passivated (soft) layers are then easily swept away by magnetically controlled mechanical action [7].

Since polishing pad (brush) is generated by MRP fluid, pressure (P) can be obtained from shear stress (τ). Figure 2(a) shows combined effect of CMP and MRF, whereas, chemical passivation and subsequent magnetic assisted mechanical abrasion is explained in Figure 2(a) & 2(b) with free body diagram. In this investigation, copper metal has been selected to carry out the experimentation with suitable oxidizers and additives in magnetorheological polishing (MRP) slurry.

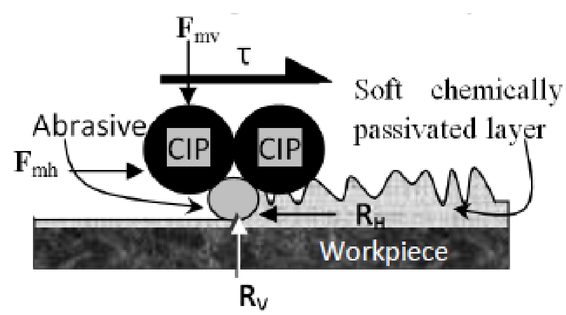

Figure2: a) Free body diagram of MRP particles

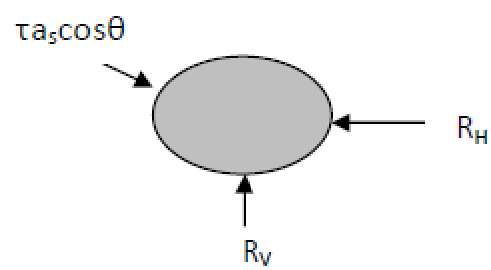

Figure2: b) Free body diagram of abrasives

Rv= Reaction Force in vertical direction, RH= Reaction force in horizontal direction, angle of contact is θ, Cosθ=d1/(d1+d2); as=shear area on CIPs, and Diameter of CIPs and Abrasives are d1& d2 respectively. Fmv & Fmh are magnetic force on CIPs along vertical and horizontal directions respectively

2.2 MR Polishing Fluid

MR polishing fluid consists of deionized water (DI), abrasives (SiC, Al2O3, or CeO2) and ferromagnetic particles (Fe). To avoid sedimentation of ferromagnetic and abrasive particles, glycerol (soluble in water) was added. Either iron particles or carbonyl iron particles (CIPs) are used as ferromagnetic particles. MR polishing fluid forms a polishing brush (FMAB) which is magnetically sensitive. DI water as base material is chemically active on the (Si) work surface.

Fine particles provide better surface finish but they have agglomeration problems, which generate scratches on the work surface. Glycerol is used to prevent solid particles from agglomeration and sedimentation. Two types of MR polishing fluid are prepared, one with single type of abrasive (CeO2) and another with two types of abrasives CeO2 and SiC (or Al2O3). The first one is softer than the second one. The fluid compositions are given in Table 1, where the mean diameter of Fe is 55 mm, CIP (HS grade) is 2 mm, CeO2 is 5 mm, and Al2O3 is 6 mm. Figure 3 shows variation in particle size of CIPs observed under a scanning electron microscope (SEM).

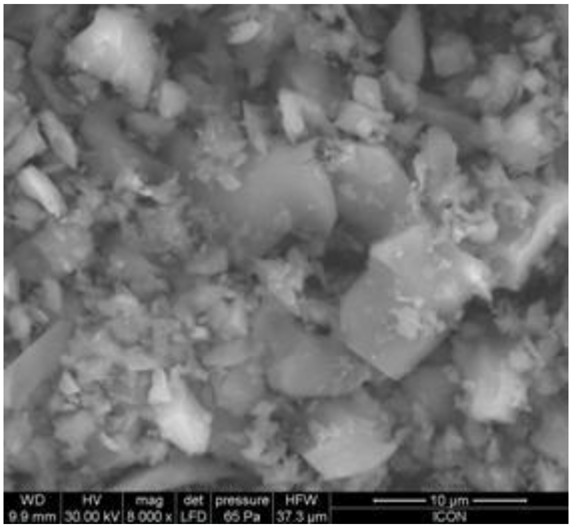

Figure3: SEM image of CIPs.

3. Use of COMSOL

3.1 Specification of Problem:

Swirl flow is an unusual application that involves steady rotational flow around an axis. Rather than modeling this process in 3D, the CFD Module provides a 2D axisymmetric physics interface where the flow in the rotational direction is still included in the equations. This example shows the effect of a rotating cylinder on the flow in a container as shown in Figure 3.1. The diameter, thickness of rotating disc is 5mm, 0.5mm respectively. The working gap between the fluid and workpiece is 0.4mm. The angular velocity is taken as 100rpm, 200rpm and 300rpm.Such applications are often used in chemical kinetic experimental devices known as rotating disk electrodes.

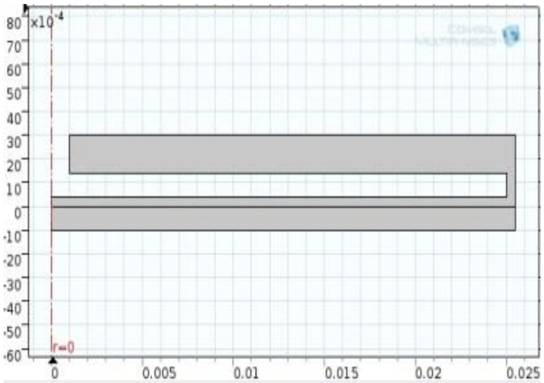

Figure3.1: Geometry of rotating disc.

3.2 Meshing of Geometry

Structured meshing method is used for meshing the geometry in Comsol Multyphysics. The 3D geometry of rotating disc with coarse mesh is as shown in Figure3.2.

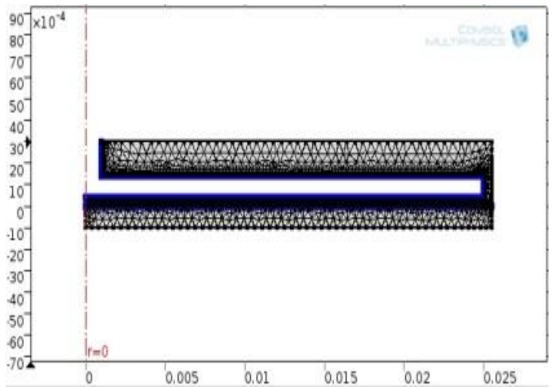

Figure3.2: Two dimensional geometry of rotating disk with coarse mesh.

3.3 Material Properties

MR fluid is used as working fluid. The dynamic viscosity of water is 60Pa-sec.

3.4 Boundary Condition

A no slip boundary condition was assigned for the fluid at the wall surfaces, where velocity is set to zero.

4. Results

The various results are obtained for rotating disc for different parameters as follows. The Comsol Multiphysics is used for obtaining flow and stress pattern of rotating disc. The rotating spindle speed is used in this analysis is optimizes speed based upon the experimental work. The speed is 100rpm, 200rpm and 300rpm.

Spindle Speed = 100RPM
Working gap = 0.4mm
Viscosity = 60Pa-s

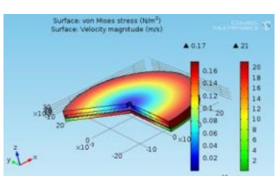

Figure4.1:Von-misses Stress

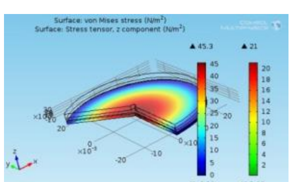

Figure4.2: Stress tensor

Spindle Speed = 200RPM
Working gap = 0.4mm
Viscosity = 60Pa-s

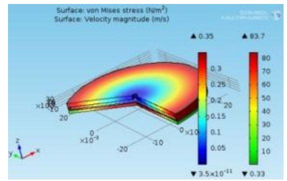

Figure4.3: Von-misses Stress

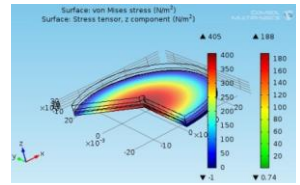

Figure4.4: Stress tensor

Spindle Speed = 300RPM
Working gap = 0.4mm
Viscosity = 60Pa-s

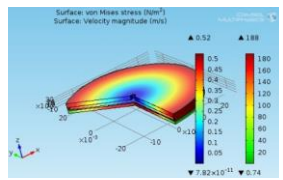

Figure4.5: Von-misses Stress

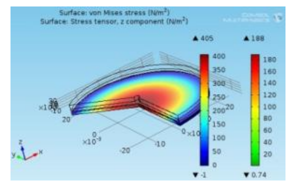

Figure4.6: Stress tensor

4.1Result table

Sr. No.	Parameters	Stress tensor (N/m^2)	Von-misses stress (N/m^2)	Velocity (m/s)
1	Spindle Speed = 100RPM Working gap = 0.4mm Viscosity = 60Pa-s	45.3	21	0.17
2	Spindle Speed = 200RPM Working gap = 0.4mm Viscosity = 60Pa-s	180	83.7	0.35
3	Spindle Speed = 300RPM Working gap = 0.4mm Viscosity = 60Pa-s	405	188	0.52

5. Conclusion

In this paper behavior of pressure distribution is studied as per requirement. COMSOL MULTIPHYSICS4.4 process has been used to obtain flow and stress distribution in rotating disc. The effects of different spindle speed on velocity change and stress distribution of rotating disc. As speed is increasing stress tensor, von-mosses stress and velocity is increasing and vice a versa.

6. Reference

1. Keown, PA, The role of precision engineering in manufacturing of the future. *Annals of CIRP*, **36,** 495-501, (1987).
2. Bayoumi MR, Abdellatif AK, Effect of surface finish on fatigue strength, *Engineering Fracture Mechanics*, **51(5),** 861–70 (1995).
3. Khounsary A, Fernandez P, Assoufid L, Mills D, Walters D, Schwartz J, Design, fabrication, and evaluation of an internally cooled silicon carbide mirror, *Review of Scientific Instruments*, **73(3),** 10.1063/ 1.1436550, (2002).
4. Ranjan P, Development of nanofinishing technology for silicon substrate, M.Tech Thesis, IIT, Kanpur, (2009).
5. Singh DK, Investigations into Magnetic Abrasive Finishing of Plane Surfaces, Ph.D. Thesis, I.I.T. Kanpur, India, (2006).
6. Jain VK, Singh P, Kumar P, Sidpara A, Das M, Suri VK, Balasubramaniam R, Some Investigations into Magneto-Rheological Finishing (MRF) of Hard Materials, Proceedings of the ASME International Manufacturing Science and Engineering Conference Held at Purdue University (USA), (2009).
7. Jain VK, Ranjan P, Suri VK, Komanduri R, Chemo-mechanical magnetorheological finishing (CMMRF) of silicon for microelectronics applications, *CIRP Annals Manufacturing Technology*, **Vol59,** 323-328 (2010).