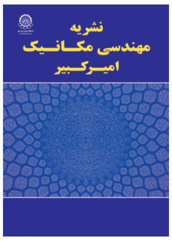

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(3) (2018) 189-192
DOI: 10.22060/mej.2017.12146.5269

Numerical Analysis and Optimization of Magnetic Flux Density in the Polishing Process with Magnetorheological Fluid

A. Esmaeilzare, A. Bagheri Ardakani, M. Rezaei*, A. Rahimi

Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran

ABSTRACT: In the finishing process of optical parts, achieving minimum surface roughness and high profile precision are of great importance. Due to brittle nature and high hardness of these materials, the finishing process will induce surface and subsurface damages which can be removed by a polishing process. One of these processes is magnetorheological finishing. In this process, the rheological property of magnetorheological fluid changes by the inducted magnetic field at material removal region. In the present study, finite element analysis has been carried out to optimize the magnetic flux density in the material removal region. In order to analyze the magnetic field, the effective parameters on the amount of magnetic flux density are identified and their influence is investigated. Taguchi design of experiment method was used to reduce the number of numerical runs. By considering the finite element results and fabrication restrictions, the genetic algorithm is used for the optimization of parameters. The magnetorheological system was made with the optimized parameters and the amount of magnetic flux density was measured. The results show that the variations of poles angle, poles and the wheel wall thickness have remarkable influence on magnetic flux density in the material removal region.

Review History:

Received: 10 November 2016
Revised: 17 April 2017
Accepted: 7 May 2017
Available Online: 17 May 2017

Keywords:

Finishing process
Magnetorheological fluid
Optical parts
Finite element analysis

1- Introduction

The applied material in the optic system can be materials such as lens, prism, mirrors, windows and so forth. The common mechanical feature of these materials, which are used in optical parts is their brittle and hard nature resulting in complex procedures of their production [1, 2]. It is also noteworthy that these parts must have a high precision profile and low surface roughness (*Ra*<1 nm) due to their application in the optical system. For this reason, the production procedure of these materials should observe specific criteria that address this issue [3].

Finishing method using magnetorheological (MR) fluid is one of the major approaches in finishing optical parts with a high precision, which attracts a great deal of attention in recent years. In this process, an MR fluid is used containing carbonyl Iron (CI), non-magnetic abrasive, water or non-aquatic carrier fluid accompanying surfactants [4-6].

In this paper, the purpose is to achieve a higher Magnetic Flux Density (MFD) in material removal region. In this way, geometrical parameters in magnetic transformation system design are investigated. These parameters are the thickness of magnetic poles (t_p), the angle of poles (θ), air gap (g), wheel thickness (t_s) and wall thickness (t_w). These parameters are investigated in five levels to show their effects on the whole process. For this purpose, the finite element method is applied using Maxwell software for the magnetic analysis. Then, the genetic algorithm is used to optimize these parameters to reach the highest magnetic flux density.

2- Design and Modeling of Finishing System

All the geometrical parameters affecting magnetic flux density are shown in Fig. 1.

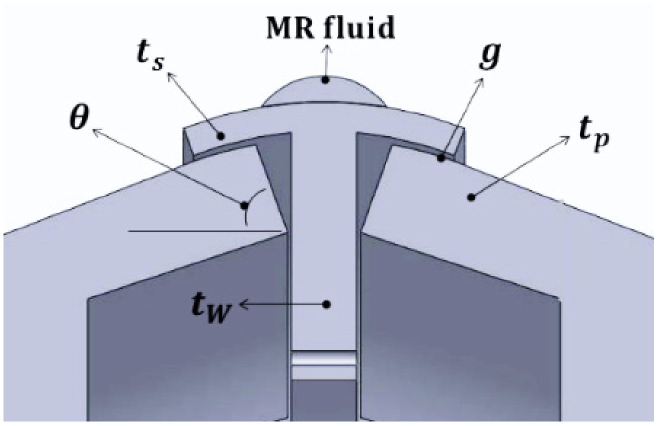

Fig. 1. Effective geometric parameters on magnetic flux density in the material removal region

To investigate the impact of these parameters on Magnetic Flux Density (MFD) in material removal region, each parameter is considered in five levels. Taguchi method is employed to reduce the number of Finite Element Analysises (FEM). The number of Maxwell runs is reduced to 25. In Table 1, variations of geometrical parameters are mentioned.

Table 1. Ranges of geometric parameters

Parameters	Unit	Values of parameters
Poles thickness (t_p)	mm	12, 13, 14, 15 , 16
Wheel thickness (t_s)	mm	4, 5, 6, 7, 8
Wall thickness (t_w)	mm	6, 7, 8, 9, 10
Poles angle (θ)	degree	70, 75, 80, 85, 90
Air gap (g)	mm	0.2, 0.4, 0.6, 0.8, 1

Corresponding author, E-mail: smrezaei@aut.ac.ir

3- Results and Discussion

3- 1- Statistical analysis

Table 2 shows the results of FEM in material removal region for MFD considering geometrical parameters using Taguchi method.

In order to define the effect of each geometrical parameter on maximum MFD in material removal area, the variance analysis approach in design-expert and Minitab software is implemented. The relation between variables parameter and maximum MFD is:

$$B = 866 - 49.3t_s - 29t_w - 185.2g - 63.18t_p + 0.62\theta + 1.28t_s t_w + 12.6gt_p + 2.1t_s^2 + 1.5t_p^2 \quad (1)$$

As can be seen in Fig.2, the reduction of wheel thickness has the most impact on MFD, by increasing this value, the MFD will be decreased in the removal region. It is also noticeable that the wheel and poles thickness has a nonlinear trend in relation to MFD. At first, the wheel and poles thickness is increased, then it reaches a specific amount after increasing the thickness, and the MFD will rise. Also, as the air gap decreases, the MFD will be increased. Poles angle is totally different and the increase in poles angle leads to a rise in

Table 2. The finite element analysis results of maximum magnetic flux density on material removal region by changing geometric parameters

Geometrical Parameters					MFD
g, mm	t_s, mm	t_w, mm	t_p, mm	θ	B, mT
0.2	4	6	12	90	176
0.4	5	6	13	85	124
0.6	6	6	14	80	97
0.8	7	6	15	75	82
1	8	6	16	70	70
0.4	4	7	14	75	128
0.6	5	7	15	70	103
0.8	6	7	16	90	102
1	7	7	12	85	82
0.2	8	7	14	80	76
0.6	4	8	16	85	140
0.8	5	8	12	80	110
1	6	8	13	75	88
0.2	7	8	14	70	80
0.4	8	8	15	90	78
0.8	4	9	13	70	118
1	5	9	14	90	107
0.2	6	9	15	85	96
0.4	7	9	16	80	83
0.6	8	9	12	75	76
1	4	10	15	80	123
0.2	5	10	16	75	102
0.4	6	10	12	70	92
0.6	7	10	13	90	90
0.8	8	10	14	85	77

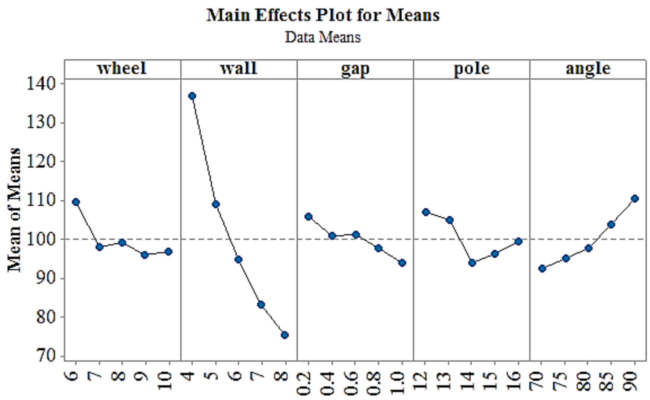

Fig. 2. The effect of geometric parameters on mean magnetic flux density

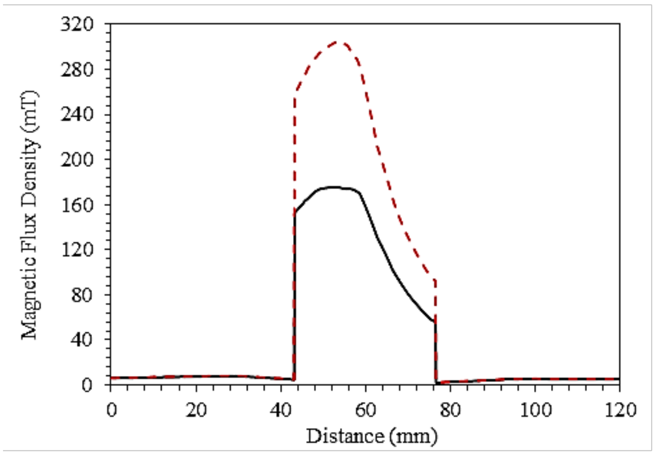

Fig. 3. The magnetic flux density distribution in an optimized condition

MFD. Fig.3 illustrates the optimal MFD distribution using a genetic algorithm. Maximum MFD in material removal region in finishing procedure using MR fluid is investigated to this end.

3- 2- Evaluation of FEM results

For evaluation of experimental and modeling results for MFD, a gauss meter (MG-3002 Lutron Inc.) is used. To measure the field, gauss meter is fixed in a specific point and MFD along the axis of the wheel is measured using a milling machine. The filled point in Fig.4 shows the measured results in comparison to FEM results. As can be seen in this figure, there is a good consistency between experimental and numerical results. The maximum difference, in this case, is seven percent.

4- Conclusions

In this paper, these results are achieved in MFD investigation in material removal region in finishing process using an MR fluid.

1. The FEM analysis results showed that there is no magnetic saturation in the magnetic transmission system.
2. The geometrical parameters had a great influence on maximum MFD. The wall thickness had the greatest impact whereas air gap and wheel thickness had the least effect.

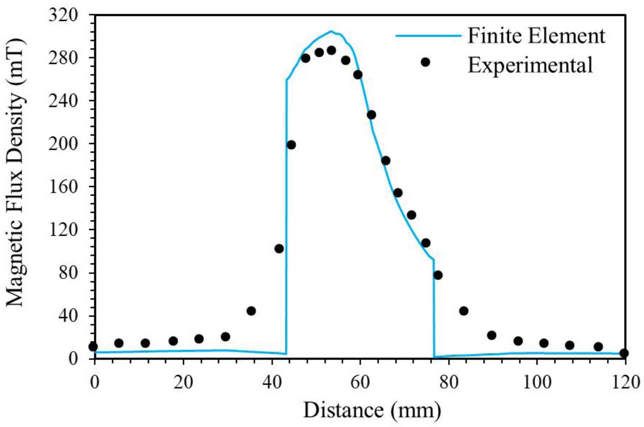

Fig. 4. Evaluation of experimental and numerical result

3. The amount of poles angle had a great impact in which by rising to 90 degrees, the MFD value increasingly rises.
4. Statistical analysis depicted that all of the picked parameters had an effect on MFD and the proposed a model for variance analysis is highly precise for MFD calculation (with less than 0.01 error).
5. The results of a genetic algorithm for MFD evaluation in material removal region show that by using optimized parameters, the MFD value rises from 0.17 to 0.3 Tesla.
6. The experimental and numerical results had a good consistency and the maximum error was just under seven percent, which was mainly due to the assembly error or guess meter.

References

[1] A. Esmaeilzare, A. Rahimi, S. Rezaei, Investigation of subsurface damages and surface roughness in grinding process of Zerodur® glass–ceramic, *Applied Surface Science*, 313 (2014) 67-75.

[2] J.C. Lambropoulos, T. Fang, P.D. Funkenbusch, S.D. Jacobs, M.J. Cumbo, D. Golini, Surface microroughness of optical glasses under deterministic microgrinding, *Applied Optics*, 35(22) (1996) 4448-4462.

[3] Z. Yao, W. Gu, K. Li, Relationship between surface roughness and subsurface crack depth during grinding of optical glass BK7, *Journal of Materials Processing Technology*, 212(4) (2012) 969-976.

[4] B.J. Park, F.F. Fang, H.J. Choi, Magnetorheology: materials and application, *Soft Matter*, 6(21) (2010) 5246-5253.

[5] S. Salzman, *Optimal magnetorheological fluid for finishing of chemical-vapor-deposited zinc sulfide*, University of Rochester, 2016.

[6] C. Miao, *Frictional forces in material removal for glasses and ceramics using magnetorheological finishing*, University of Rochester, (2010).

Please cite this article using:

A. Esmaeilzare, A. Bagheri Ardakani, M. Rezaei, A. Rahimi, Numerical Analysis and Optimization of Magnetic Flux Density in the Polishing Process with Magnetorheological Fluid, *Amirkabir J. Mech. Eng.*, 50(3) (2018) 577-588.

DOI: 10.22060/mej.2017.12146.5269