An Investigation on Effective Parameters in Cylindrical Surface Finishing of Hot Resistance Stainless Steel AISI 321 by Magnetic Abrasive Finishing (MAF) Method

O. Khalilorahmani*
Department of Mechanical Engineering,
Tehran Science and Research Branch, Islamic Azad University, Iran
E-mail: omid_987@yahoo.com
*Corresponding author

P. Saraean & **H. Soleimanimehr**
Department of Mechanical Engineering,
Tehran North Branch, Islamic Azad University, Tehran, Iran
Parisian Higher Education Institute, Qazvin, Iran
E-mail: saraeian@yahoo.com, soleimanimehr@gmail.com

Received: 19 April 2015, Revised: 5 June 2015, Accepted: 7 July 2015

Abstract: In this study, the three parameters of the abrasive particle size, distance of tool to the work piece, and the rotational speed of cylindrical surface finishing of steel AISI 321 by abrasive particles in the MAF magnetic field were studied. The advantages of this process that can be noted are lack of residual stress after the process and modification of the coaxial shaft. Surface roughness was considered as a function of rotational speed (RPM), the distance between tool and work piece (GAP) and the size of the abrasive particles. Special tools for finishing the cylindrical surface (shaft) were designed from mentioned material and the rotational motion of the shaft was provided by the lathe. Experiments were performed according to full factorial method, using abrasive powders consisting of a mixture of silicon carbide SiC with carbonyl iron Fe in different particle sizes and SAE40 oil. After the surface roughness measurement of the samples, the influence of various parameters on the final surface quality was evaluated. The results showed that in the mentioned stainless steel shaft finishing, variables of 1.Distance between tool and work piece, 2.Abrasive particle size, 3. Rotation speed, sequentially, have the highest influence on obtained surface roughness. Finally, by using neural network analysis, a better condition in terms of three parameters was obtained in order to achieve better surface finish.

Keywords: Abrasive Particles, Magnetic Field, Neural Networks, Surface Roughness, Tool Design, Steel AISI 321

Reference: Khalilorahmani, O., Saraean, P., and Soleimanimehr, H., “An Investigation on Effective Parameters in Cylindrical Surface Finishing of Hot Resistance Stainless Steel AISI 321 by Magnetic Abrasive Finishing (MAF) Method”, Int J of Advanced Design and Manufacturing Technology, Vol. 8/ No. 4, 2015, pp. 43-50.

Biographical notes: **O. Khalilorahmani** received his MSc in Mechanical Engineering from Science and Research Branch of Azad University. His research interests include Optimization in Manufacturing Process. **P. Saraean** received his PhD in Mechanical Engineering from Tarbiat Modares University. He is currently assistant professor of Mechanical Engineering. **H. Soleimanimehr** received his PhD in Mechanical Engineering from Tarbiat Modares University. He is currently assistant professor of mechanical engineering.

1 INTRODUCTION

With increasing technological advances, the need to introduce production techniques with more special capabilities is felt more than ever. In the meantime, the production of parts with high quality surface and package dimensional tolerances is of particular importance. Since these two items directly relate to the type of finishing process used in manufacturing the part or mold, using high precision and performance procedures is required in this field. Manufacturing silicon wafers, micro and nano machines, new space telescopes, eyepiece lenses etc. are a part of the needs that cannot be produced with traditional processes. Currently, known polishing methods are limited to the use of elastic tools, sandpapers, abrasive pastes, rotary felt etc.

According to Preston equation, the removal rate depends on two factors; the relative speed between tool and work piece and the contact pressure between them [1]. In the past few decades, magnetic abrasive finishing (MAF) has been highly regarded as one of the new methods of finishing surfaces. Abrasive powders are used in magnetic finishing with abrasive particles that are changed to form a brush in a magnetic field, and material removal operation is performed with a relative rotational speed between the tool and the work piece. The flat surfaces of inner walls and surfaces of the outer walls of cylinders of magnetic and non-magnetic materials can be finished by using this process [2]. Recently, some studies have been performed to improve its applications for the finishing of three-dimensional surfaces [3].

The finishing process of lenses is one of its industrial applications that can be pointed out. QAD machine has been an obvious example of the development of this technology in the past two decades [4]. Abrasive particles automatically become sharp during the process of MAF, and abrasive brushes are formed based on the downstream surface. Unlike traditional methods, there is no need to modify the tool shape, and machining forces are adjustable by the magnetic field. Because of the small size of the forces, the probability of creating microscopic cracks, particularly in brittle materials, is low [5]. In finishing by using the magnetic method, the ferromagnetic abrasive material is formed along the field lines by placing it in a magnetic field between a magnet and the workpiece, and by providing the required contact pressure. In the shaft finishing, the surface of the shaft is rotating at a small distance from the magnetic tool. As a result of moving the abrasive brush on the surface, the finishing of the workpiece will be observed. An abrasive brush usually is resulted from the combination of two powders of ferromagnetic powder and abrasive powder, and this combination is possible using three methods:

- No connection: The mechanical mixture of abrasive and magnetic powders without lubricants,
- Weak connection: The mechanical mixture with some lubricants for creating adhesion between particles,
- Connect: The sintering ferromagnetism and abrasive powders in high temperature and pressure in an inert gas environment,

In this paper, by focusing on the finishing process of magnetic stainless steel AISI321, the influence and order of process parameters on the final surface roughness are studied in addition to the design of a tool for finishing cylindrical steel surfaces by means of paid work. Finally, a diagram is introduced for predicting surface roughness by analysis of data resulting from empirical experiments using the neural network method. A lot of laboratory researches have been done to investigate the effects of MAF process parameters. Kumar et al. evaluated the effect of two parameters of GAP size and the peripheral speed of the work piece on surface roughness [6].

The effects of finishing time and abrasive grain size on the removal rate and quality of surface obtained for cylindrical parts using unbounded type of abrasive material (without connection) were studied by Chang et al. Mori et al. argued about the formation energy of abrasive brush. By selecting a work piece made of steel SUS 304, they studied the formation of a brush with bonded type powder (connected) of aluminum-iron oxide [7]. Singh et al. designed experiments using the Taguchi method to assess parameters influencing the quality of the surface [8].

Experimental tests showed that parameters of the GAP size and the voltage applied to the electromagnet are the most effective ones; and grain size and rotational speed, respectively, are in low and lower status. By using the finite element method, Yang et al. investigated properties of the surface resulting from applying three types of cylindrical magnets with shapes of the filling inside cylinder, the cylinder with a central hole or the cylinder with a central hole and the grooves on its surface.

Their study showed that a hole in the center of the cylinder along with slots on the surface of the magnet can be used to improve the quality of the surface in MAF. These slots on the surface of the magnet increase magnetic flux density up to 15% [9]. Previous experiments of researchers showed that abrasive particles with specific mesh size create a minimum surface roughness in a certain timeframe, and no significant change in decreasing the surface roughness is observed with increasing time. Therefore, there is an optimum time for each particle size.

As it is found from previous studies, little information is available for the results of performing MAF method on the ferromagnetic parts. Most activities have focused on non-magnetic materials. Since the parameters of the magnetic field intensity have a significant influence on the rate of removal and are the basic parameters in MAF, this field can also be provided by both permanent and electric magnets. The electric magnets with the field intensity of 1 Tesla have been used in most performed researches, but as an example, high volume coils, control circuits and cooling systems are needed for providing a field with the intensity of about 3 Tesla [10]. Since neodymium permanent magnets with small dimensions are able to provide the required field for the mentioned process, these types of magnets were used in this study, and the data obtained in previous studies were used to select the optimal shape of the magnet.

2 EXPERIMENTAL

This research was performed to finish the exterior surfaces of the shaft using MAF process, and investigate and analyze parameters influencing the process. For this purpose, designing was done according to the method in which the workpiece moves and the magnetic field source is constant (Figure 1-1).

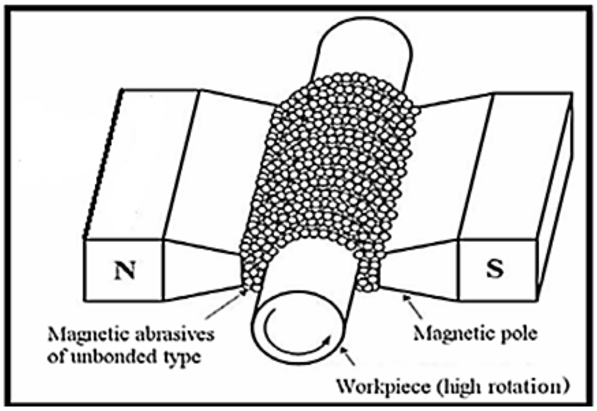

Fig. 1 Design of MAF experiment

Of course, the source of the magnetic field can have a linear vibration movement and can be adjustable which will increase the efficiency of the process, but it has no major role in the process, and it was built and designed for appropriate positioning of the workpiece in the generated fixture magnetic field (Figures 1-2 and 1-3). This fixture also was applied to maintain and move the magnetic poles S and N. The used mechanism causes the working gap to be adjustable.

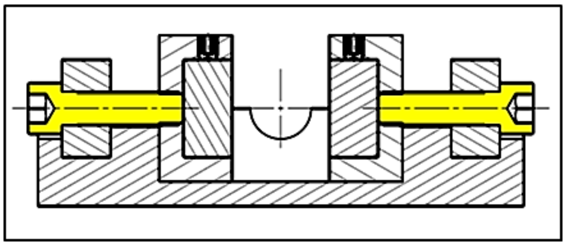

Fig. 2 Low profile of designed fixture with its accessories

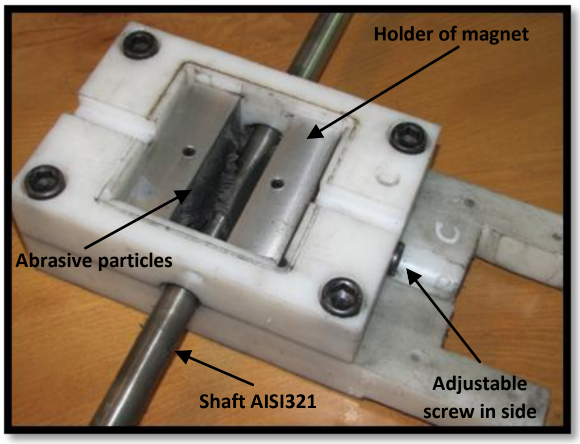

Fig. 3 Fixtures built for performing the test

In the current study, the strongest permanent magnet in the market, the Nd-Fe-B, has been used to create a magnetic field. The intensity of the magnetic flux between the surface is larger than (used in operations) 3700 Gauss and in the corner of the same surface is 4500 Gauss (Fig. 4)

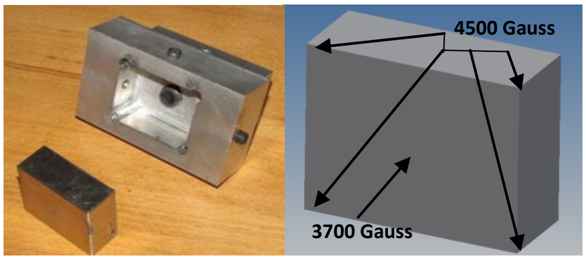

Fig. 4 Nd-Fe-B magnet with the Aluminum holder fixture

Magnet was completely inhibited by a fixture of aluminum (nonmagnetic) and also the distance of its surface from the axis of the shaft is completely adjustable by side screws.

Tests were performed on the outer surface of the cylindrical work piece made of stainless steel AISI321 and the rotation movement of the shaft was provided by the lathe spindle (Fig. 5).

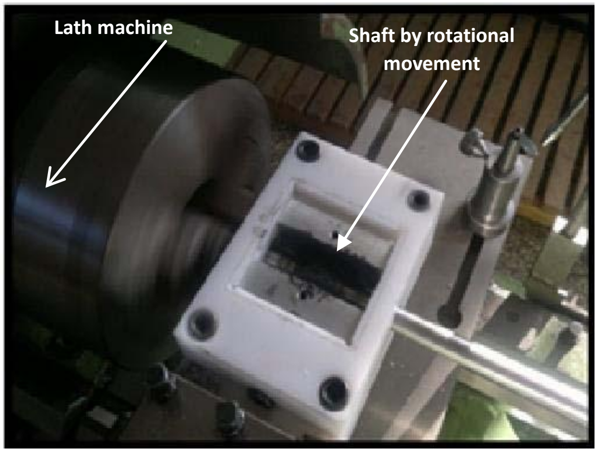

Fig. 5 Providing the rotation movement by the lathe spindle

Abrasive gel used in this study is obtained by mixing equal percentages of iron powder and SiC powder in the grain sizes of 100, 200 and 300 mesh size along with SAE40 oil [11]. Connection type of particles is “a weak connection”.

Previous experiments carried out by researchers showed that abrasive particles with specific mesh size create a minimum surface roughness in a certain timeframe, and no significant change in decreasing the surface roughness is observed with increasing time. Therefore, there is an optimum time for each particle size.

3 EXPERIMENTAL

The experiments have been performed using full factorial method for the three effective parameters. Shafts with the length of 70 cm and a diameter of 20 mm were applied to run the experiments. The average initial surface finish was 0.5036 micron. By running initial experiments and measuring different times, the time of 20 minutes for each test was considered. From table 1, figures 6,7,8 and 9 are obtained and improvement in surface finish is = ((1-surface roughness)/surface roughness)**.**

3.1. GAP effect on surface roughness

GAP is one of parameters with a significant impact on the surface roughness. Working GAP represents the amount of force on the abrasive particles in the magnetic field lines because by changing the GAP, the field intensity on abrasive gel particles will be high or low and its size is inversely related with the gap size. As can be seen in Fig. 6, working GAP has an optimal size, and surface roughness increases with the over reduction of the working GAP.

Table 1 Results of measured surface roughness in terms of micron for 27 experiments

Average of surface roughness Ra (micron)	Working gap (mm)	Rotational speed (rpm)	Abrasive particle size (mesh)	Number of experiment
0.5202	0.5	355	100	**1**
0.4944	0.5	500	100	**2**
0.5562	0.5	1000	100	**3**
0.4366	1	355	100	**4**
0.2555	1	500	100	**5**
0.3342	1	1000	100	**6**
0.51325	2	355	100	**7**
0.5312	2	500	100	**8**
0.3902	2	1000	100	**9**
0.6194	0.5	355	200	**10**
0.5412	0.5	500	200	**11**
0.4748	0.5	1000	200	**12**
0.417	1	355	200	**13**
0.4458	1	500	200	**14**
0.4428	1	1000	200	**15**
0.478	2	355	200	**16**
0.4908	2	500	200	**17**
0.5476	2	1000	200	**18**
0.4744	0.5	355	300	**19**
0.3996	0.5	500	300	**20**
0.527	0.5	1000	300	**21**
0.436	1	355	300	**22**
0.4142	1	500	300	**23**
0.482667	1	1000	300	**24**
0.4714	2	355	300	**25**
0.482	2	500	300	**26**
0.543	2	1000	300	**27**

This will happen because the magnetic field lines were formed as straight lines and caused abrasive particles to be engaged with the shaft vertically and penetrate to the work piece surface that caused an increase in surface roughness. In Fig. 6 it can be seen that the best surface smoothness is achieved in the working GAP of 1 mm.

Up to this amount, the increase in working GAP again leads to an increase in surface roughness and the reason is that excessive working GAP reduces the intensity of the magnetic flux, which leads to the reduction in the magnetic force that stimulates the abrasive particles which are sprayed out, and therefore, the magnetic abrasive brush is not well formed. By reducing abrasive particles pressure on the work piece, finishing operations are not performed favorably. In Fig. 6, the surface roughness increases with the reduction in the working GAP from 1mm. It is due to this, that the magnetic field lines are formed as straight lines and causing abrasive particles to be engaged with the shaft vertically and penetrate to the work piece surface that leads to an increase in surface roughness.

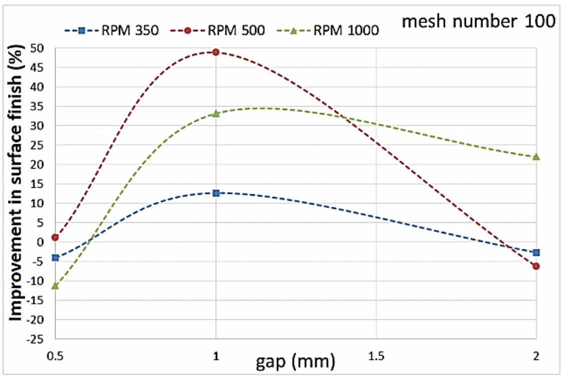

Fig. 6 Effect of working GAP on surface smoothness with particles of 100 mesh size and different speeds

With smaller abrasive particles (200 mesh size), different conditions are observed for surface finishing in different GAPs. In GAP of 0.5 mm, gel particles go down on the surface and cause the surface smoothness to be reduced. However, increase in the rotational speed partly makes up for this weak point (Fig. 7).

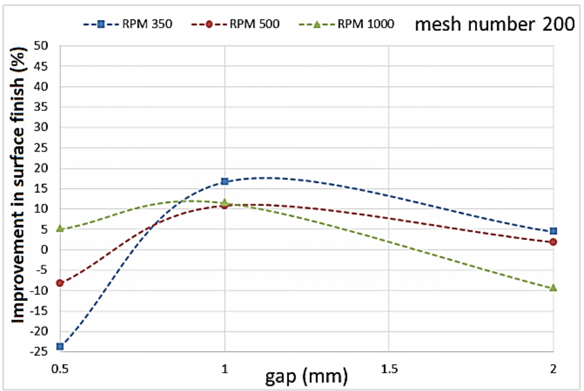

Fig. 7 Effect of working GAP on surface smoothness with particles of 200 mesh size and different speeds

The process is performed better in the GAP of 0.5 mm and 300 mesh size (Fig. 8), the result is the finest particles, and the optimal rotation speed is about 500 rpm. If the rotational speed increases to over 500 rpm, particles are sprayed out from around the shaft (1000 rpm). Finally, it can be concluded that high working GAP causes lower pressure of abrasive gel on the work piece and the efficiency will be reduced, and it also allows abrasive gel to spray at higher speed, and low working GAP (0.5 mm) causes particles to go down into the surface. Both of them lead to the reduction of surface smoothness in related experiments.

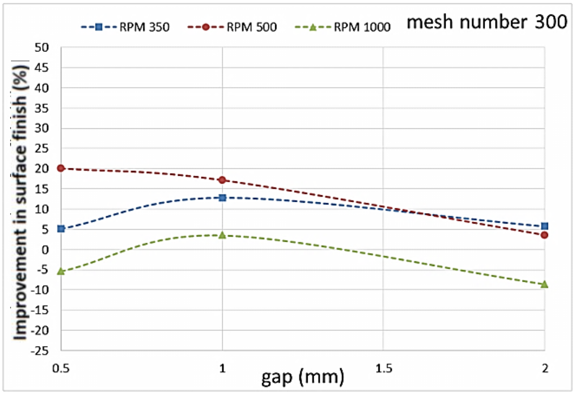

Fig. 8 Effect of working GAP on surface smoothness with particles of 300 mesh size and different speeds

3.2. The effect of rotational speed on the surface roughness

Investigating the rotational speed presented in the diagram (Fig 6) indicates that high rotational speed increases spraying of particles (1000 rpm in GAPs of 1 and 2 mm) and if the GAP is too small at this speed (1000 rpm in GAPs of 0.5 mm), it increases the particles, going down into the surface, and finally, it also causes the reduction of the surface smoothness. The work piece rotational speed up to 500 rpm improves surface smoothness, but the surface smoothness is reduced at higher speeds, because of the unstable formation of abrasive brush.

Finally, it can be concluded that high rotational speed causes spraying of abrasive gel, and if gel spraying is prevented by using a small working GAP, the particles penetrate into the surface of the work piece reducing the surface quality again. Therefore, it is better to have the rotational speed as high as possible and abrasive particles as coarse as possible (avoid spraying through increasing abrasive gel concentration).

3.3. The effect of abrasive particles size on the surface roughness

The diagram in Fig. 9 shows that a better result is achieved in GAP of 1 mm, particle size of 100 mesh and rotational speed of 500 rpm. Finally, it can be concluded that particles with small size do fewer and more delicate material removal and they need a high rotational speed to obtain more efficiency. Of course, the problem of dispersion from around the work piece is faced, and this problem can be partially solved by reducing the working GAP.

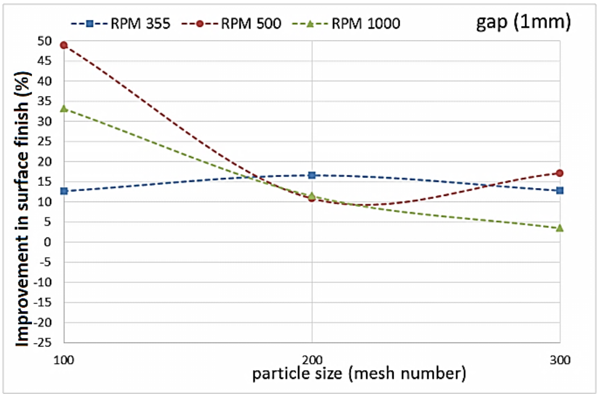

Fig. 9 Effect of abrasive particles' mesh size on roughness of output surface in GAP of 1 mm and different rotational speeds

A certain GAP exists for each particle size to achieve high efficiency. In these series of experiments for the particle size of 100 mesh and the particle size of 300 mesh they are 1 mm and 5.0 mm, respectively, but there is no appropriate GAP for the particle size of 200 mesh. Larger particles (100 mesh size) can be controlled more easily, and more suitable results can be achieved for the process by using them.

4 THE ANALYSIS OF EXPERIMENTAL RESULTS USING THE NEURAL NETWORK METHOD

These networks are composed of simple operating elements that process in parallel the information based on the instruction inspired from biological neural cells.

4.1. The important parameters of artificial neural network

When designing artificial neural networks, you should consider the following points:

- The network structure
- The number of network layers
- The number of neurons in each layer
- The training algorithm for parameter settings in the method of education with a teacher
- Bias values
- Threshold values
- Approximate amount of synaptic weights
- Selection of the neuron function

4.2. Neural network analysis of experimental tests

24 out of 27 tests were conducted to train the network, and the rest were conducted to test the network. The answer is provided in Table 2, column 4 output, and the accuracy of the neural network can be evaluated by comparing these values with actual values in column 4. The diagram Fig. 10, created based on data in Table 3, indicates that the created neural network is close to the actual test data.

Table 2 Column 4 and column 4 output show the accuracy of the network.

Column1	Column2	Column3	Column4	Column4 Output
200	500	0.5	0.5412	0.51914455
200	355	0.5	0.6194	0.55132157
100	355	1	0.4366	0.46474216

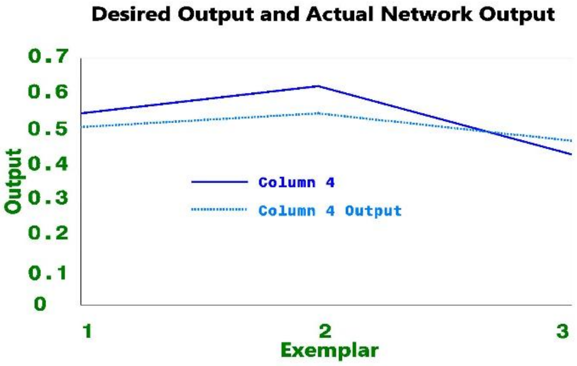

Fig. 10 Accuracy of network performance after training

Table 3 shows the matching function coefficient of the artificial neural network with the fact (r) that the closer this number is to 1, The more correct the created network answers are, and also in the mentioned table, the amount of Max Abs Error must be less than acceptable changes of surface finish numbers which should be less than 0.1 here.

Table 3 The closer the matching coefficient r is to 1, the more acceptable it is, and the maximum absolute error should be less than 0.1.

Performance	Column4
MSE	0.001971031
NMSE	0.351466019
MAE	0.039425312
Min Abs Error	0.022055338
Max Abs Error	0.068078434
r	0.997955862

4.3. Results of product numbers

Now, by having a trained artificial neural network whose accuracy is acceptable, we can desirably change all three parameters of working GAP, the rotational speed and the size of the abrasive particles to receive responses of each row (Table 4).

Table 4 Definition of the 3 virtual two level parameters to get better output of Ra

Average of surface roughness Ra (micron)	Working gap(mm)	Rotational speed(rpm)	Abrasive particle size (mesh)	Row
0.253991	0.8	400	50	**1**
0.477412	1.2	400	50	**2**
0.348491	0.8	700	50	**3**
0.239937	1.2	700	50	**4**
0.489527	0.8	400	150	**5**
0.494219	1.2	400	150	**6**
0.451252	0.8	700	150	**7**
0.244979	1.2	700	150	**8**

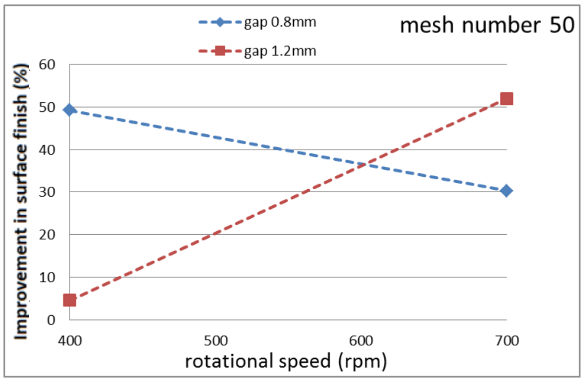

Fig. 11 Prediction of virtual parameters impacts on the process with the particles size of mesh number 50

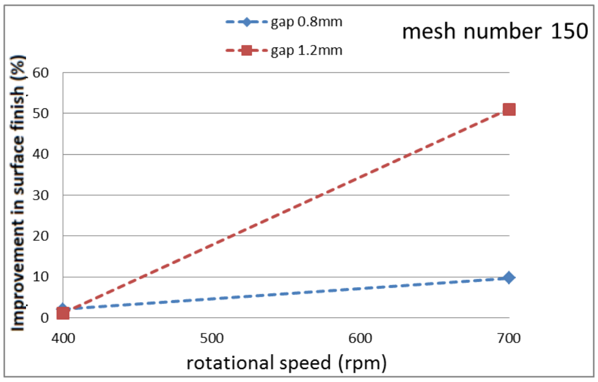

Fig. 12 Prediction of virtual parameters impacts on the process with the particles size of mesh number 150

Table 4 shows that the workpiece surface roughness will be better in new conditions (rows 1, 4 and 8). From table 4, figures 11 and 12 are obtained. Fig. 11 and Fig. 12 present optimized smoothness of the surface with defined rotational speed and gap for the particle size of mesh number 50 and 150, respectively, these data have been summarized in Table 4. As specified, particles size of 50 mesh are only suitable for gap of 0.8, and lose their effectiveness for higher gaps, and the surface finish value improves as the rotational speed of 400 rpm is achieved. Also, the smoothness of the surface for both 50 and 150 mesh size is improved by using the gap of 1.2 mm. In fact, the best smoothness of the surface is achieved by increasing rotational speed to 700 rpm.

5 CONCLUSION

The aim of this study is to investigate the suitable conditions for performing MAF on cylindrical surface of AISI321 workpiece. The results are as follows:

1. According to the performed tests, working gap has a direct impact on the MAF process, so that, in fact, the machining force will be set by adjusting the working gap. Optimization of a certain level is needed to get to the smoothness, and then the size and the rotational speed are impressive to achieve the desired surface finish.
2. Rotational speed increases the efficiency of the process in terms of sooner reaching the desired surface finish, but its excessive increase causes a negative impact on surface finish. The first is because of spraying most volume of formed abrasive brushes, and the second is because of the sinking of abrasive particles in the finished surface.
3. The analysis performed on the input and output of the neural network by using *Neurosolution* software shows that the better condition for shaft finishing of stainless steel AISI 321 is with abrasive particles of SiC, and iron powders of 150 mesh size, rotational speed of 700rpm and GAP of 1.2 mm, and iron powders of 50 mesh size, rotational speed of 700rpm and GAP of 1.2 mm, and iron powders of 50 mesh size, rotational speed of 400rpm and GAP of 0.8 mm.

REFERENCES

[1] Kalpakjian, S., Schmid, S., “Manufacturing Engineering and Technology”, Prentice Hall, 2001, pp. 541 -585.

[2] Jain, N. K., Jain, V. K., and Jha, S., “Parametric Optimization of Advanced Fine-Finishing Processes”, Int. J. Advance Manufacturing Technology, Vol. 34, No. 11, 2007, pp. 1191–1213.

[3] Ji, S. M., Xu, Y. M., and Chen, G. D., “Comparative Study of Magnetic Abrasive Finishing in Free-Form Surface Based on

Different Polishing Head”, Materials Science Forum, Vol. 675, No. 1, 2011, pp. 593-596.

[4] QAD machine from: http://www.qedmrf.com/polishing/mrftechnology, 2012, accessed on 2014.

[5] Jain, V. K., “Magnetic field Assisted Abrasive Based Micro-nano Finishing”, J. Materials Processing Technology, Vol. 209, 2009, pp. 622–638.

[6] Jain, V. K., Kumar, P., Behera, P. K., Jayswal, S. C., “Effect of Working Gap and Circumferential Speed on the Performance of Magnetic Abrasive Finishing Process”, Wear, Vol. 250, 2001, pp. 384–394.

[7] Mori, T., Hirota K., Kawashima Y., “Clarification of Magnetic Abrasive Finishing Mechanism”, J. Materials Processing Technology, Vol. 143-144, 2003, pp. 682–686.

[8] Singh, D. K., Jain, V. K., Raghuram, V., “Parametric Study of Magnetic Abrasive Finishing Process”, J. Materials Processing Technology, Vol. 149, 2004, pp. 22–29.

[9] Yang, L. D., Lin, C. T., and Chow, H. M., “Optimization in MAF Operations using Taguchi Parameter Design for AISI344 Stainless Steel”, Int. J. Machine Tools & Manufacture, Vol. 42, 2009, pp. 595–645 .

[10] Vahdati, M., Sepehr Afghan, A., “Finishing using Abrasive Particles in a Magnetic Field”, Modares Technical and Engineering Quarterly Journal, 6731, Spring 2008, pp. 55

[11] Rudy, M., Amirabadi H., “The Study of the Finishing Process of Magnetic Steel AISI 4140”, Monthlies Journal of Mechanical Engineering, December 2013, Tarbiat Modares University.