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Design and Implementation of Automated Predictive Magnetic Abrasive Finishing Machine

Dr. Ali H. Kadhum
Baghdad University- Al-Khwarizmi College of Engineering- Automated Manufacturing Engineering Department-Al-Jadriia, Baghdad, Iraq

Omar C. Kadhum,
Baghdad University- Al-Khwarizmi College of Engineering- Automated Manufacturing Engineering Department-Al-Jadriia, Baghdad, Iraq

Abstract
Magnetic abrasive finishing (MAF) is one of the non-traditional methods, that produce high quality condition of surface roughness (Ra) and is primarily controlled by magnetic field. This process can remove materials depending on magnetic energy.The aims of this research have been made to design and implement MA automated predictive machine, which plays an important role to the values of parameters (voltage of electromagnetic, magnetic pole velocity, working gap, and working time) to obtain the desired values for Ra.The microcontroller (Arduino Mega) was used for controlling the four parameters, and can predict the working time from regression model using optimum values parameters. The automated machine can be programmed to control the electromagnetic voltage, the poles rotation, working gap, turn on and off the rotation of workpiece, and working time.The results indicated that the optimum parameters for the surface roughness are calculated according to Taguchi method and the S/N ratio, and the optimum values before automated the machine are voltage (7V), the working time (7min), poles speed (30r.p.m) and the working gap (1mm) for Ra. The results also indicated that the predict values for Ra is nearly equal to the values from the automated machine about 95% for Ra, that mean the automated predictive MA machine are very efficient.
Keywords: Automated Machine, MAF Method, Arduino, Surface Roughness.

1. Introduction

The principle work of magnetic abrasive finishing with the magnetic abrasive powder, the current or the magnetic flux density is passed through the coil to produce the magnetic field. The pole is rotating with the powder along the workpiece, as shown in figure 1. The magnetic field provides the abrasive powder with the energy; the energy is used to generate cutting and finishing forces. The rotation of the pole makes the friction between the workpiece and the magnetic abrasive powder. By this way, the material can be removed from the workpiece [1-3].

D. K. Singh, et al. investigated the parameters of MAF process, using Taguchi design of experiment. They tried to find the important parameters that influencing on the surface quality. The results were concluded that within the range of parameters evaluated, a high level of voltage (11.5 V), a low level of working gap (1.25 mm), a high level of rotational speed (180 RPM), and a high level of grain mesh number (1200 µm) are desirable for improving Ra. Linear regression models for change in *R*a, indicate that the change in Ra increase with increasing in voltage and decreasing in working gap [4].

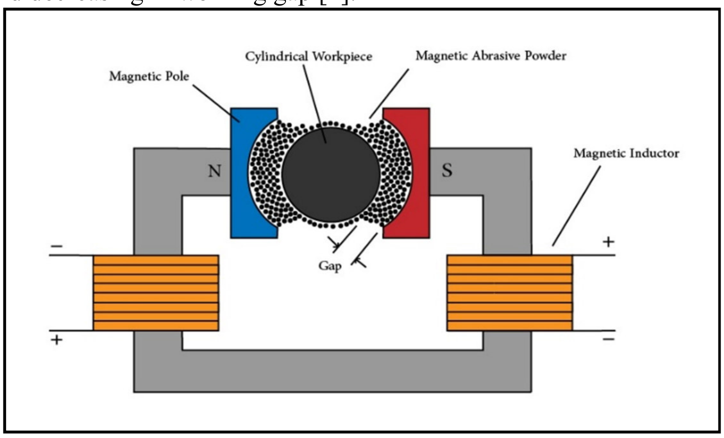

Figure 1. Scheme of magnetic abrasive finishing process [4]

C-T Lin et al. employed MAF process to conduct free-form surface abrasion of stainless SUS304 material operations. The operations were demonstrated using a permanent magnetic finishing mechanism, installed at the

CNC machining center. The experimental data was collected using the Taguchi experimental design. The optimal operation condition was a working gap of 2.5 mm, a feed rate of 10 mm/min, and an abrasive mass of two grams. Spindle speed (1000 rpm) was applied to the confirmation tests due to convenience and cost [5].

The automated MAF machine is less study by researchers. The idea of this study is design and implemented an automated machine for MA, using Arduino mega as a micro controller. The automated MA machine can be programmed to control the electromagnetic voltage, speed of the poles rotation, rotation the poles into two directions, working gap (cross feed to finish stepper workpiece), longitudinal Feed, turn on and off the rotation of workpiece, working time, to determine the desired value of Ra.

The objectives of this work are Design and implementation automated MAF machine used to control the parameters automatically through a computer by using microcontroller (Arduino Mega). Determine the optimum value of parameters and a regression models for the machining parameters to predict the surface roughness by using regression method. Interring the values of optimum parameters (voltage of electromagnetic, magnetic pole velocity, and working gap) and predicted models of Ra, in the program of Arduino, that helps the automated machine itself to predict the Ra, thought changing the working time.

2. Implementation of automated Magnetic Abrasive Finishing Machine

2.1. Hardware Components

The automated magnetic abrasive finishing machine has been designed and implementation in two-steps, the first step was preparation and assembly the hardware component, the second step was preparation of electronic circuit.

The important hardware components of automated magnetic abrasive finishing machine will describe in the following sections:-

2.1.1. Making of the Electromagnetic Inductor and the Magnetic Poles

In the magnetic abrasive finishing process, an electromagnetic inductor was made in a specific details because it plays an important role in the finishing the surface layer. In this automated machine, two electromagnetic inductors have been manufactured, as shown in figure 2. The core was formed from the iron with a 10mm hole along it to allow the shaft of poles rotate inside, the diameter of core is 40 mm, the length of the core is 100 mm while the number of turns of copper wire is 2500 in three levels, the diameter of the wire of the coil is 0.8 mm. The Couples of magnetic poles have been designed with a chamfer on the rear of poles to concentrate the magnetic flux on the workpiece. A rounded iron shaft has been used to manufacture these magnetic poles by using the lathe machine to get the desired shape as shown in figure 2.

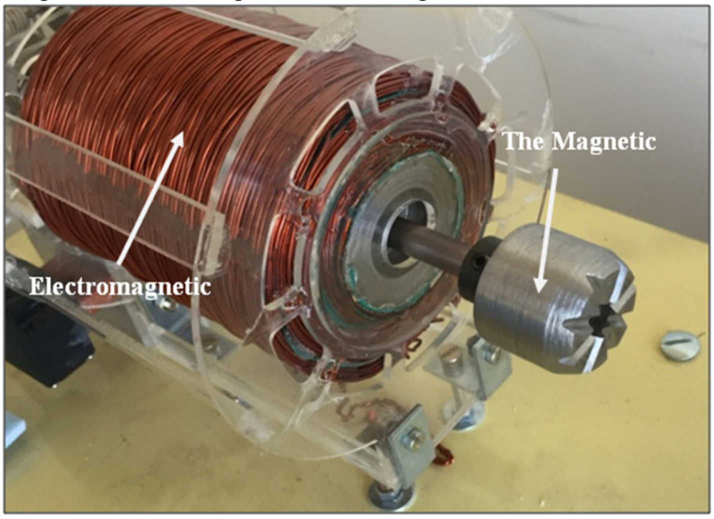

Figure 2.The electromagnetic inductor and the magnetic pole

The DC motors rotate the two magnetic poles oppositely to each other. Each pole was connected to the DC motor by a shaft, passing through the core of electromagnetic as shown figure 3. Every DC motor was connected with stainless steel shaft by a worm gear to increase the torque.

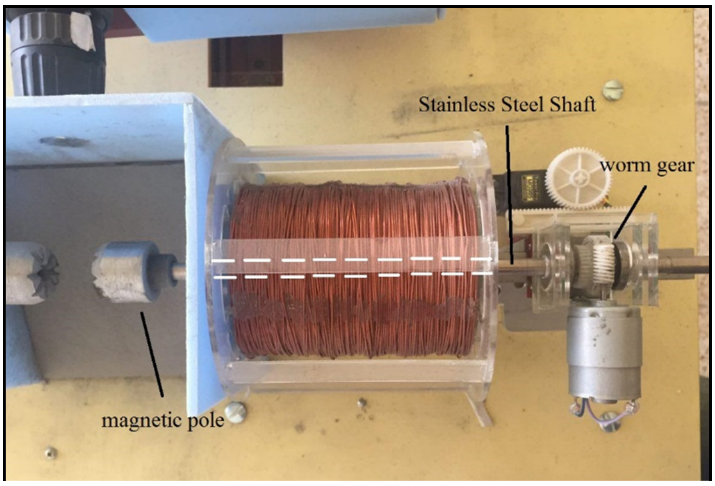

Figure 3.The magnetic poles after assembly

2.1.2. AC Motor to Rotate the Workpiece

An Ac motor has been used to fix the workpiece and rotate it with speed 720 rpm, 220V Operating voltage. The fixed AC motor was controlled by a relay that controlled by the Arduino mega controller to get on or off, also it was connected with a manual switch to get off in emergency case, illustrated in the Fig.4.

2.1.3. DC Motors to Rotate the Poles

Two DC motors with gears have been used to rotate the shaft of magnetic poles as shown in Fig.4. The speed of the motors was between 30-150 rpm. They connected to the Arduino by a DC motor driver to control the motors with desired speeds. The powering voltage was 26V as illustrative in Fig.4.

2.1.4. Servo Motors Used to Control the Gap

Couple of servomotors has been used to adjust the gap between the workpiece and the tip of magnetic poles automatically. There are fixed behind the electromagnetic inductor to move the shaft of magnetic poles through it to get the desired gap, as illustrative in figure 4.The servomotors controlled by the Arduino mega.

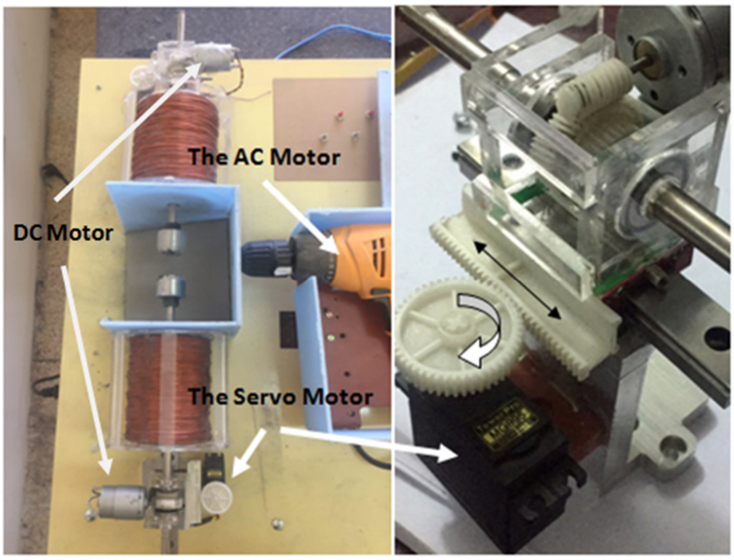

Figure 4.The servomotors, DC and AC motors

2.2. The Circuit Diagram and Powering of the Machine

Arduino mega is a board support by ATmega2560. It has 54 digits (I/O) input/output pins 15 of them used as Pulse Width Modulation (PWM) outputs, 16 pins for analog inputs, quartz crystal for a 16 MHz, a USB connection and other properties.

The L298N H-connect module are utilized in this project with engines that have a voltage of in the vicinity of 5 and 35V DC to control the two DC motor that rotate the magnetic poles with their directions.

TIP121 is an NPN transistor as a potential switch being used to operate the electromagnetic inductors are given. Three transistors are used for each electromagnetic inductor as shown in figure 5, because of the TIP121 can pass current 1.5A and the each one of electromagnetic inductors needs to 2A; therefore, three transistors and heat sink are used to protect the circuit from damage.

The heart of automated machine is the Arduino Mega as shown in figure 5. where input signals are given to Arduino mega from the computer by the Arduino software integrated development environment (IDE), the output signals of Arduino are given to all of the component that connected with the Arduino such as the electromagnetic inductors, DC motors, AC motor and servo motors, to control them specifically.

Three power supplies (AC Convertor to DC) are needed. One for providing 19 Volts, 4A for powering the two of electromagnetic. The second 23 Volt for the DC motors, and the third 5V for supplying the electronic components, Arduino and for stepper motor. The figure 5, describes the connecting of powering wires and electronic components how connected each other.

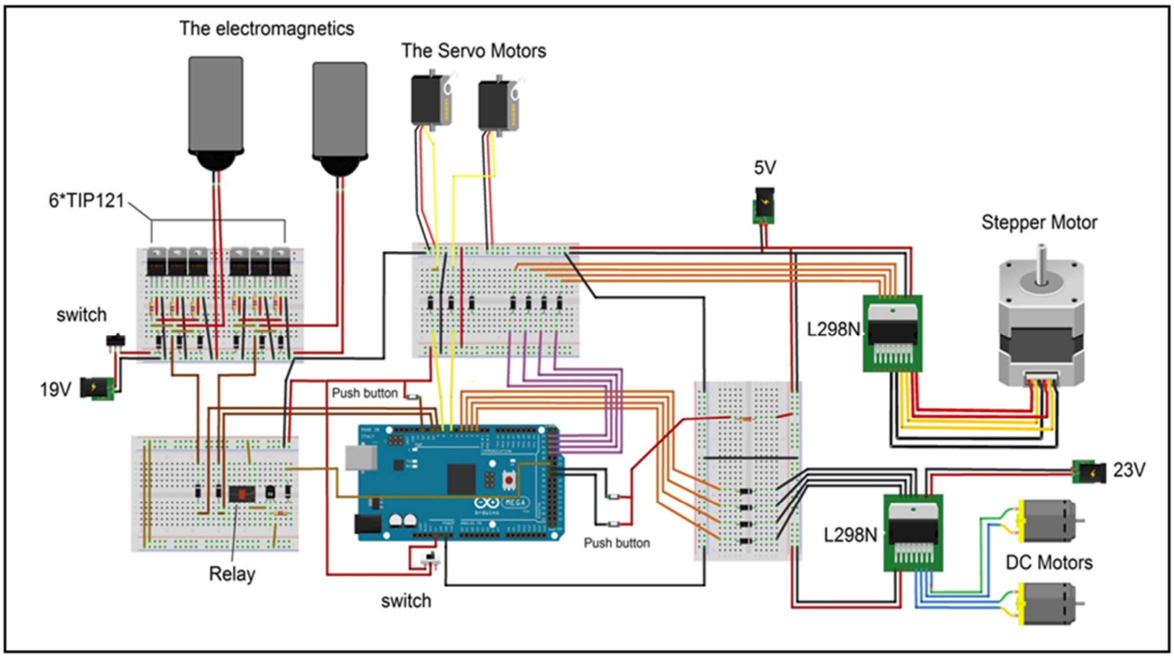

Figure 5.The scheme of the electronic circuit

3. Experimental Tests before and after Automated MA Machine

3.1. Selection the Parameters and their Levels

In this work, the variables have effects on the surface roughness and material removal in the MAF process, in this research four parameters were chosen (voltage, magnetic poles velocity, working time, working gap), with five levels for each parameter. The selection of the parameters and their levels is listed in the Table.1.

Table.1. MAF Parameters and Their Levels

Parameter			Unit	Levels				
				1	2	3	4	5
1	Voltage	X_1	V	3	4	5	6	7
2	Magnetic poles velocity	X_2	rpm	30	60	90	120	150
3	Working time	X_3	min	3	4	5	6	7
4	Working gap	X_4	mm	1	1.5	2	2.5	3

3.2. Determination of the Orthogonal Array

The experiments were designed based on the orthogonal array (OA), to reduce the number of the experiments, from the MINITAB17 software. The four parameters with the five levels are used in the present investigation to perform the most effective experiments (25 experiments) from the overall experiment (625 experiments). This array has twenty-five rows and four columns and each row represents a trial condition while each column accommodates specific process parameters. Therefore, twenty-five experiments were according to the selected OA by Taguchi technique [6].

3.3. Choose the Workpieces and the Magnetic Abrasive Powder

The materials are used, as work piece in this research is stainless steel 304 cylindrical shape, the dimensions length is 120 mm and diameter is 10 mm. The ferromagnetic abrasive powder is an important part in the magnetic abrasive finishing process. In the experiments, used the powder included 66% of the iron with 34% of the tungsten carbide.

4. Experimental Results by Automated MAF machine

After all the experiments of MA process are carried out the surface, roughness for each workpiece is measure. The ΔRa was calculated by measuring the surface roughness (Ra) by tester TR220, for each workpiece three times before automation MA machine and three times after automation of MA machine, and then obtain the average value, and then we take the difference between the two cases. Table.2 shows the data set for the Minitab software for surface roughness.

Table.2. the Probability of Experiences and Their Results

	Voltage	Poles speed	Time	Gap	Δ Ra
1	3	30	3	1	0.08
2	3	60	4	1.5	0.023
3	3	90	5	2	0.023
4	3	120	6	2.5	0.019
5	3	150	7	3	0.14
6	4	30	4	2	0.236
7	4	60	5	2.5	0.039
8	4	90	6	3	0.03
9	4	120	7	1	0.261
10	4	150	3	1.5	0.056
11	5	30	5	3	0.04
12	5	60	6	1	0.133
13	5	90	7	1.5	0.097
14	5	120	3	2	0.203
15	5	150	4	2.5	0.026
16	6	30	6	1.5	0.067
17	6	60	7	2	0.024
18	6	90	3	2.5	0.069
19	6	120	4	3	0.01
20	6	150	5	1	0.055
21	7	30	7	2.5	0.334
22	7	60	3	3	0.011
23	7	90	4	1	0.145
24	7	120	5	1.5	0.163
25	7	150	6	2	0.387

5. Optimization the Parameters of MAF Process for Surface Roughness.

Taguchi Method is a statistical approach used to optimize the process parameters and improve the quality of components that are manufactured. In this work, (MINITAB 17) software was used to analyze the result to get the optimum parameter for MAF process.

The results have been analyzed by using S/N ratio to obtain the optimal level for each process parameter that has larger effect of the quality surface. The optimal level of each the parameter with Ra steel 304 is calculated according to the large value of the S/N ratio, and mean. The plot of the mean and S/N ratio is as shown in figure 6a and figure 6b, so in this case the optimal parameters which effected on the Ra steel is voltage (7V), the time (7min), poles speed (30 rpm), but working gap for both the mean value and the S/N ratio are difference as shown in table.3a.

The optimum level of the S/N ratio for gap is 1mm shown with red color and the optimum level of the mean results is 2mm shown in the blue color. For this situation, we need to make a prediction. This can be used to predict the optimum level of S/N ratio and mean, then choosing the optimum level that depends on the large value of the S/N ratio as shown in table.3b.

Table.3a. the main effect of the S/N ratio and mean ΔRa steel

Response Table for Signal to Noise Ratios				
Level	Voltage	Poles speed	Time	Gap
1	-27.71	-19.09	-24.64	-18.62
2	-21.54	-29.97	-26.76	-23.44
3	-22.28	-24.65	-25.94	-19.94
4	-28.88	-23.11	-22.78	-25.39
5	-17.89	-21.49	-18.19	-30.92
Delta	10.99	10.87	8.56	12.3
Rank	2	3	4	1

Response Table for Means				
Level	Voltage	Poles speed	Time	Gap
1	0.0572	0.15127	0.0838	0.1348
2	0.1245	0.04613	0.0879	0.0813
3	0.0997	0.07293	0.0641	0.1746
4	0.0449	0.13127	0.1273	0.0974
5	0.2081	0.13267	0.1711	0.0462
Delta	0.1632	0.10513	0.1069	0.1284
Rank	1	4	3	2

S/N ratio optimization
Mean optimization

Table.3b. the prediction of the mean and S/N ratio

S/N ratio			
Voltage	Poles speed	Time	Gap
7	30	7	1
Mean		S/N ratio	
0.34464		-2.81389	

Mean			
Voltage	Poles speed	Time	Gap
7	30	7	2
Mean		S/N ratio	
0.38444		-4.13039	

Depending on this table, the working gap in the optimum levels is 1mm.

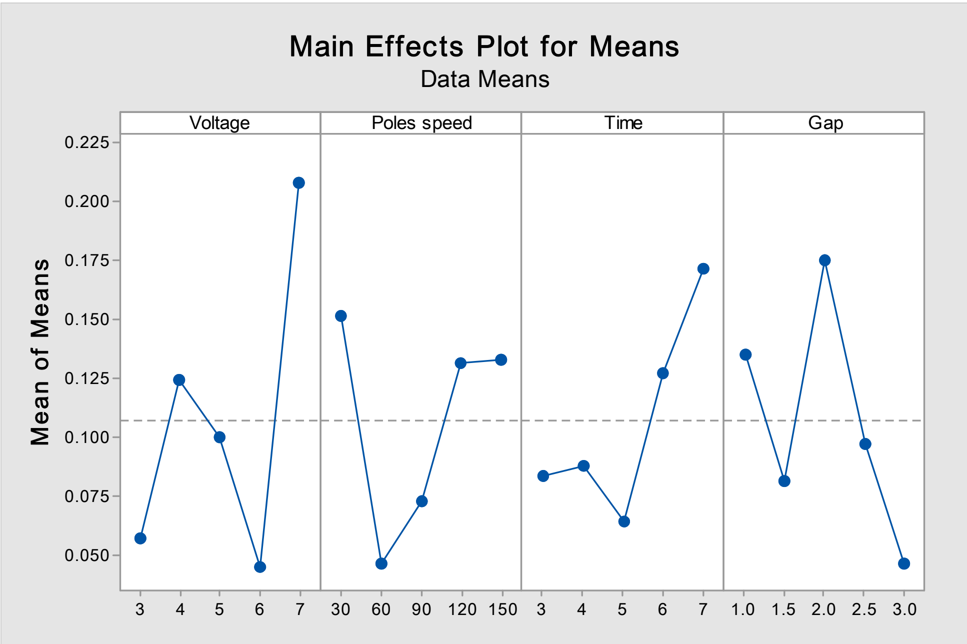

Figure 6a.The mean effect with parameters for ΔRa

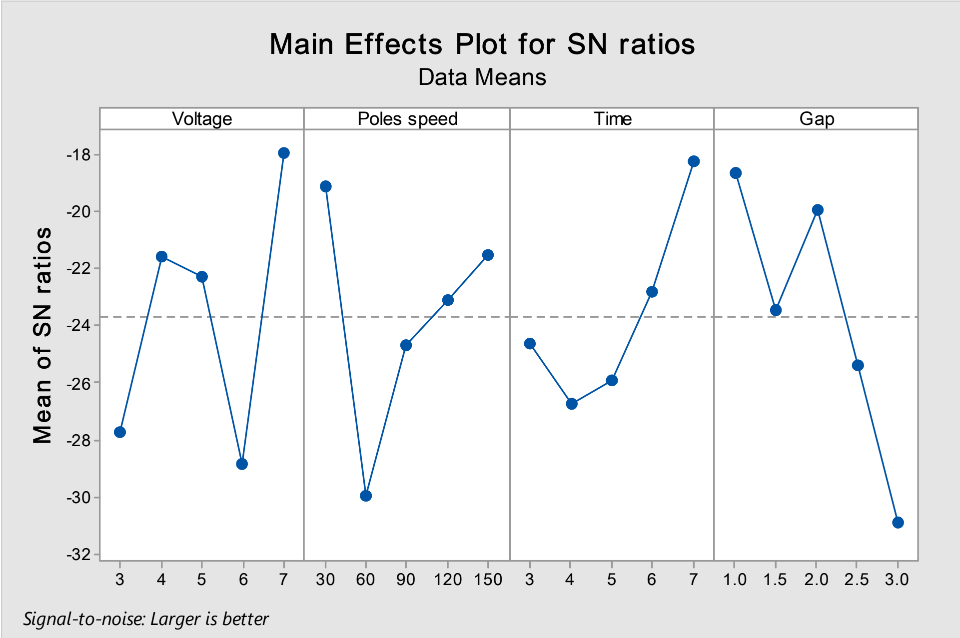

Figure 6b.The S/N ratio effect for ΔRa

6. Regression Model for the MAF Process

Regression is a statistical measure that attempts to determine the strength of the relationship between one dependent variable and a series of other changing variables (known as independent variables). Multiple regression uses two or more independent variables to predict the outcome. Regression takes a group of random variables, thought to be predicting Y, and tries to find a mathematical relationship between them. This relationship is typically in the form of a straight line (linear regression) that best approximates all the individual data points. By using MINITAB software, the regression equation for estimating the surface roughness has been obtained as the following:

The Results of Regression Equation for ΔRa

$$\mathbf{\Delta Ra} = 3.37 + 1.90\, \mathbf{X_1} - 0.0002\, \mathbf{X_2} + 0.528\, \mathbf{X_3} - 4.319\, \mathbf{X_4} \qquad \ldots.. (1)$$

Where:

X1: Voltage (V)

X2: Poles speed (rpm)

X3: Working time (sec)

X4: Gap (mm)

7. The Automated Machine works as Predicted Machine

By using the optimum values of parameters in the MA machine software:

First step: Interring the prediction models in the program of the Arduino for Ra.

Second step: the optimum values of the three parameters (voltage of electromagnetic, magnetic pole velocity, and working gap) except the fourth parameter (the working time) used in the prediction regression model.

$$\Delta\, \mathbf{Ra} = 3.37 + 1.900\, \mathbf{(7)} - 0.0002\, \mathbf{(30)} + 0.528\, \mathbf{(Working\ Time)} - 4.319\mathbf{(1)} \qquad \ldots\ldots.(2)$$

Third step: entering the desired value of Ra in the automated machine:-

$$\mathbf{(Desired\ \Delta Ra)} = 3.37 + 1.900\, \mathbf{(7)} - 0.0002\, \mathbf{(30)} + 0.528\, \mathbf{(Working\ Time)} - 4.319\mathbf{(1)} \ldots.(3)$$

Fourth step: the machine will work thought working time that calculated automatically from the predicted model. Then the machine will stop automatically after the working time is over, according to the predicted working time, the code of Arduino program after entered the prediction regression model and the optimum values of the three parameters. The difference between the points of the numerical from eq. (3) and the experimental of Δ Ra is 95%.

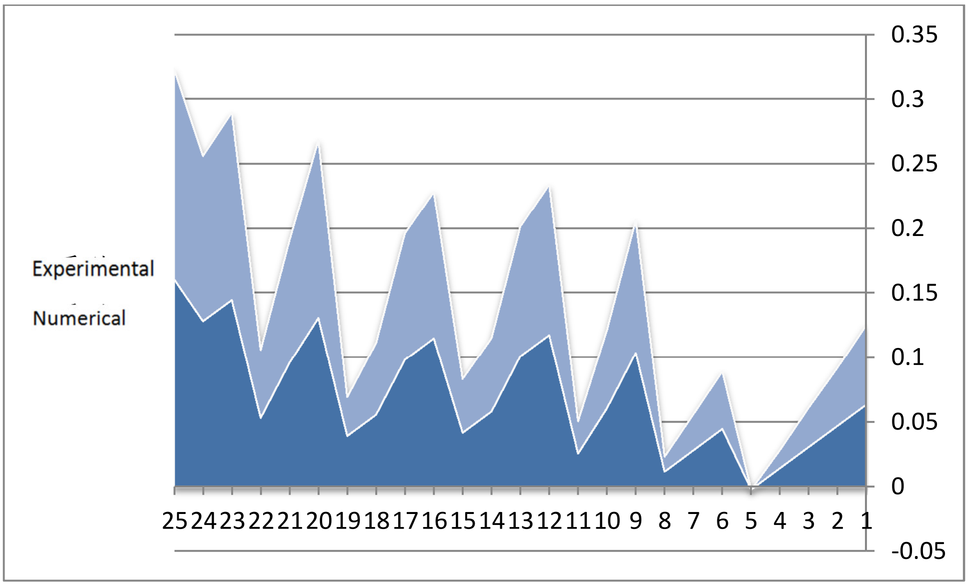

Figure 6. The numerical and experimental result of Δ Ra

8. Conclusion

The conclusions of this research are summarized as:

1. Success of automated MAF machine that has been designed and implemented used to finish different shapes (stepper shafts) with the one degree of surface roughness (Ra) for all steps in MAF process, by using micro controller (Arduino Mega).
2. This automated machine can control the working gap with constant distance for any change in the steps; also, the automated machine can predict the values of parameters that gives the desired values for Ra, that improve the MAF method.
3. Automated machine can obtain predictive model with optimum values for the parameters, and can be programmed to control the electromagnetic voltage, the poles rotation, working gap (cross feed), turn on and off the rotation of workpiece, and working time, to determine the desired value of surface roughness.
4. The results indicated that the optimum parameters for surface roughness are calculated according to Taguchi method and the S/N ratio. The optimum values before automated the machine are voltage (7V), the working time (7min), poles speed (30r.p.m) and the working gap (1mm), this values nearly equal after MA automated the machine . The optimum values of parameters and predicted models of Ra was used in the programming of Arduino, to help the automated machine itself to predict the values of Ra and MR thought changing the working time. the results also indicated that the predict values for Ra was nearly equal to the values, before and after the automated machine is about 95% for Ra, that mean very efficiency predict and controlled automated machine.

The optimum parameters (voltage of electromagnetic, magnetic pole velocity, and working gap) and predicted models of Ra was interred in the program of Arduino, to help the automated machine itself to predict the Ra thought changing the working time.

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