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PREDICTION OF HOLE ACCURACY BY USING LASER MACHINING

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Abstract: The aim of this study is to predict the hole accuracy which drilled by laser beam machining using Response Surface Methodology (RSM) within Minitab 17. ANOVA program and compare the results with the experimental values which performed under different cutting conditions Cutting speed (2, 2.5, 3, 3.5, 4 m/min) with power (600, 700, 800, 900, 1000 watt) and gas pressure assist (2, 3 ,4, 5,6 bar) so another parameters that using during operation remain constant. Experiments were conducted to predict the hole accuracy, the estimated result shows that there is good agreement between average experiments values and predicted values of hole accuracy (95.96%).

Keywords: Response Surface Methodology, laser beam machining, hole drilling, ANOVA program.

1. Introduction

The basic concept of laser is given by an American scientist Charles hard Townes and two soviet scientist's alexander Mikhailovich Prokhorov and Nikolai Gennediyevich Bassov. Manufacturing is the transformation of the materials into goods for satisfaction of human needs [1, 2].

In the engineering field, it is found to be a machining is an important area. It is noticed that, to fulfill the todays challenges, there is needed to use advanced technologies in production process. Now a day's precision equipment's used in various areas, this precision equipment attracts the use of very accurate and precision processes to make it [3].

Laser based machining process such as laser drilling is now a day's used for variety of materials to make holes from macro to micro range. Because of precision, low cost, less material loss and fatigue to operator, laser based machining processes find their application in various industries. In laser drilling process heat of laser beam is used to melt and evaporate the required area of material. Deep understanding of laser drilling

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process is required to get good quality of end product from manufacturing point of view. The quality of end product is determined by assessment of geometric features of laser drilled holes [4, 5, 6].

M.M. Hanon et al., [2012], [7], mentioned that Nd:YAG pulsed laser is used to drill alumina ceramic plates with 5mm and 10.5mm in thick. In this study the researchers employed two methods of laser drilling single pulse and multi-pulses (percussion). They concluded that is possible to control the geometry of the drilled holes by selection the suitable laser parameters such as peak power, pulse duration, repetition rate, number of pulses and focal position and the crater depth/pulse decrease in multi- pulse mode when compared with single pulse mode the reason behind that is the condensed presence of the resoildified materials which reduce the laser energy due to absorption.

Saad k. Sather et al. (2013) [8]: In this study, blind holes have been drilled in two types of ceramics one is alumina and the other is zinc oxide using CO2 continuous wave laser. In this work the effects of three laser parameters have been investigated: exposure time, focal position and power density. The results show that the increasing of exposure time increases penetration depth, entrance diameter and taper angle. Also for exposure time 50 sec resulting in similar penetration depth for both materials and at 41 sec gives the same taper angle for alumina and zinc oxide. In another hand increasing of distance from focal position increases entrance diameter and taper angle but, decreases penetration depth. Increasing of power density increases penetration depth and entrance diameter but, decreases taper angle. The generation of resoildified material has great effect on the crater shape where increasing exposure time cause distortion due to condensing huge amount of resoildified material on the side walls of the crater.

G.D. CHIOIBASU et al. (2015) [9]: A continuous-wave solid-state laser connected to a five-axis CNC machine was used to cut small-diameter holes in aluminum and carbon-steel sheets. Industrial nitrogen was used as the gas. The average hole diameters were between 200 µm (on the back) and 300 µm (on the face). The diameter of the tapered holes in the aluminum sheet decreased with increasing laser power and gas pressure. The best-quality holes were obtained at 600-W laser power and 16 bars gas pressure. For the carbon-steel sheet, the hole taper increased with increasing laser power and gas pressure. For the carbon-steel sheet, the best hole quality was obtained at 700 W laser power and 10 bars gas pressure. The molten material exiting the table during the laser-cutting process was not completely removed even with 20 bars of gas pressure. The hole taper depended on the laser power and gas pressure for both the aluminum and carbon-steel sheets.

Dr. K. H. Inamdar et al. (2016) [10]: In the present research, CO_2 laser trepanning drilling of 1.2 mm mild steel plates were taken out to examine the effect of laser parameters such as laser power, gas pressure and scanning speed on entrance circularity, exit circularity, HAZ and taper. It is found that both entrance and exit circularities were significantly influenced by laser power and gas pressure. HAZ mainly influenced by scanning speed as well as laser power and taper was significantly influenced by laser power. Both entrance and exit circularities increased with increase in laser power. Also as laser power increased the taper decreases. HAZ increased with increase in power but decreased with increase in scanning speed.

2. Experimental Work

The experimental work involve the Following

Work piece Materials: which is consist of low-carbon steel

also known as plain-carbon steel and Low carbon steel ,its dimensions length 100mm ,width 10 0 mm , thickness 4mm. It is now the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications.

Table (1): Chemical Composition of mild steel.

Chemical Composition							
Element %	C	Si	Cu	Mn	P	Cr	Mo
Content	>0.005	>0.005	0.0064	0.335	>0.005	0.0117	>0.005
Element %	Ni	Ti	Al	Co	Nb	V	Fe
Content	>0.005	>0.005	>0.005	>0.001	>0.005	>0.005	the remain

Laser Drilling system and Procedures

This section includes the laser drilling method which was used to drill samples, the parameters and the specifications of the laser system has been shown in Figures (1,2).So it can be seen that the laser head of the system and Table (2)gives the technical parameters of the laser system.

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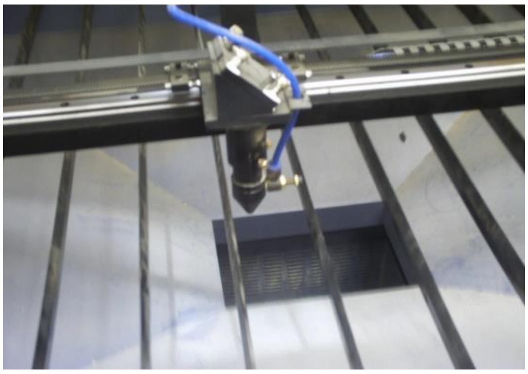
Figure (1): Laser System [5].

Table (2)Technical parameters oflaser system

laser power	700w
laser source	America /Russia IPG fiber laser resonator
pipe /tube processing(L*Φ)	L3000mm,Φ20-200mm (Φ20-300mm for option)
processing surface(L*W)	3000mm*1500mm
laser head	Switzerland ray tools
power supply	AC380 ±5% 50/60HZ(3phase)
Total electric power	15 KW
position accuracy X,Y and Z axis	±0.03mm
Acceleration	1g
Max load of working table	800Kg
Machine weight	5.3 T


Figure(2): Laser drilling head.

3. Design of Experiments

Response Surface Methodology (RSM) is an effective technique used in modeling and analysis of experimental parameters and their responses. The machining parameters were 3-factors and three levels of 20 samples made of AISI 1018 mild steel , the machining variables and their levels given in Table (3). The design of experiments was based on central composite design (CCD) contained from technology RSM as given in Table (3.2).

Table (3): Machining Parameters and Levels.

Cutting Parameter	Symbol	Level				
		-1.682	-1	0	1	**1.682**
Power (watt)	A	600	700	800	900	**1000**
speed (mm/min)	B	2	2.5	3	3.5	**4**
pressure gas (bar)	C	2	3	4	5	**6**

Table (4): Experiment design using RSM.

Run Order	power	speed	pressure gas
1	700	2.5	3
2	900	2.5	3
3	700	3.5	3
4	900	3.5	3
5	700	2.5	5
6	900	2.5	5
7	700	3.5	5
8	900	3.5	5
9	600	3	4
10	1000	3	4
11	800	2	4
12	800	4	4
13	800	3	2
14	800	3	6
15	800	3	4
16	800	3	4
17	800	3	4
18	800	3	4
19	800	3	4
20	800	3	4

4-Result and Analysis of Hole Accuracy

Data Analysis Response Surface Methodology (RSM) for Hole Accuracy

Prediction of hole accuracy using Response Surface Methodology (RSM)

A response surface methodology was applied to develop a second-order polynomial mathematical model to predict the hole accuracy using the experimental results. The coefficients of the independent variables were obtained from the (RSM) model, as shown in table (4) These coefficients were used to develop the mathematical model then obtain the following regression equation :-

$$Dia. = -23.08 + 0.03519\, x1 + 6.32\, x2 - 1.060\, x3 - 0.000012\, x1*x1 - 0.290\, x2*x2 - 0.0159\, x3*x3 - 0.00524\, x1*x2 + 0.001590\, x1*x3 - 0.000\, x2*x3 \quad \ldots\ldots\ldots(1)$$

Where:

Dia.: diameter of hole (dependent) (mm).
X1: power (independent) (w).
X2: speed of cutting (independent) (m/min).
X3: pressure gas (independent) (bar).

Table (5): coefficient of the independent variables for hole accuracy.

Independent variables	Coefficients	Independent variables	Coefficients
Constant	-23.08	X2*X2	-0.29
x1*x1	0.3519	X3*X3	-0.0159
X2	6.32	X1*X2	-0.00524
X3	-1.06	X1*X3	0.00159
X1*X1	-0.000012	X2*X3	0

The model is adequate to represent the relationship between machining response and the machining parameters. Since laser drilling is non-linear in nature, the linear polynomial will be not able to predict the response accurately therefore the second-order model (quadratic model) is used.

Analysis of variance (ANOVA) for the adequacy of the model is then performed in the subsequent step. The F ratio is calculated for 95% level of confidence. The p-values greater than 0.05 are not significant. It was observed that linear term X1,X2 and square terms X1 and X2 and interaction term X1 with X2 are significant are shown in Table(5) The ANOVA for hole accuracy is shown in the Table (6)

Table (6): Estimated regression coefficients for hole accuracy

Term	Coef.	SE Coef.	T- Value	P-value
Constant	1.6172	0.0744	21.74	0
x1	1.2517	0.0932	13.42	1
x2	0.3915	0.0932	4.2	1
x3	0.17	0.0932	1.82	1
x1*x1	-0.489	0.149	-3.29	1.08
x2*x2	-0.29	0.149	-1.95	1.08
x3*x3	-0.064	0.149	-0.43	1.08
x1*x2	-1.048	0.264	-3.97	1
x1*x3	0.636	0.264	2.41	1
x2*x3	0	0.264	0	1

Table (7): Analysis of variance for hole accuracy.

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value
Model	9	8.18918	0.90991	26.16	0
Linear	3	6.9962	2.33207	67.05	0
Square	3	0.44157	0.14719	4.23	0.036
Interaction	3	0.7514	0.25047	7.2	0.007
Error	10	0.34779	0.03478		
Total	19				

The determination coefficient (R^2) determine the degree of fit between the experimental and predicted data where higher value of R^2shows a better fit. The values of (R- sq) and R- sq. (adj) for hole accuracy are (95.93 %, 92.26%) respectively with the percentage of error (66.49%) for hole accuracy these show the observed variability in the independent variables. This means that the regression model provides an excellent clarification for relationship between the observed values (obtained from the experiments) and prediction values (obtained from the response surface model) for the dependent variable hole accuracy.

The normal probability plot of residuals for response (hole accuracy) are shown in Fig.(8) This plot for normal probability indicates the data that were normally distributed and variables influencing the response. The residual is the difference between the predicted values and observed values of hole accuracy. It can be seen the observed values regression model significantly fit.

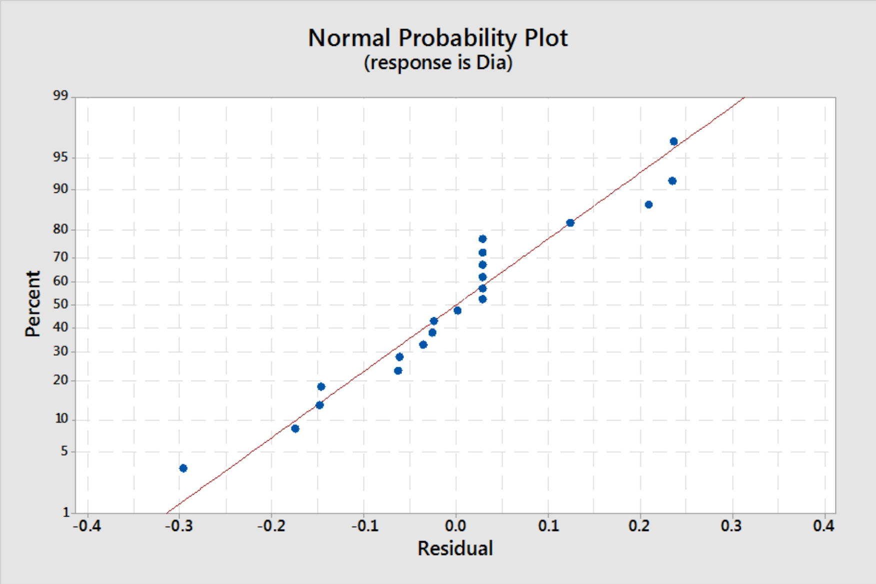


Fig.(3) normal probability plot of hole accuracy.

The result of hole accuracy from the regression model (predicted values by the RMS) and the true value (from experiments) are shown in Table (6). The comparison between predicted values and observed values are shown in Fig. (8). Can see the difference between the two values is very small where RMS model gives predictive results with high accuracy for all outputs. The main effect of each process parameter on hole accuracy can be studied by plotting based on models and predicted values for response by using RMS. The main effects plot of process parameters on hole accuracy for various levels are shown in Fig. (4).

It can be see that the power have highest effect on hole accuracy where hole accuracy increase with increase power that because high energy produce high temperature leading to removing more material. Also, hole accuracy increased with in increased cutting speed. The reason is increased energy with cutting speed and the longer period of the transformation of this energy into nozzle that occur by increased exposure time which leads to create a high spark with high temperature to melt and vaporize the material and from bigger craters on the work piece. So the pressure gas is important parameter on hole accuracy when it increase the hole accuracy also increase , so The reason is help to get the molten metal out to get a more regular hole, and it is considered a heat repellent. So these parameters significantly influence on hole accuracy, Then led to the conclusions, the high accuracy of the holes is correlated to the high power, cutting speed, and gas pressure assist.

Table (8) Measured value and predicted values of hole accuracy.

No. of exp.	Measured Dia.	Predicted value(mm)	Residual value
1	0.1	0.3969	-0.296898
2	1.68	1.85465	-0.174648
3	1.164	1.3124	-0.148398
4	1.696	1.72215	-0.026148
5	0.102	0.2489	-0.146898
6	2.318	2.34265	-0.024648
7	1.166	1.1644	0.001602
8	2.334	2.21015	0.123852
9	0.085	-0.12377	0.208773
10	2.344	2.37973	-0.035727
11	1.171	0.93598	0.235023
12	1.657	1.71898	-0.061977
13	1.62	1.38348	0.236523
14	1.66	1.72348	-0.063477
15	1.646	1.61716	0.028841
16	1.646	1.61716	0.028841
17	1.646	1.61716	0.028841
18	1.646	1.61716	0.028841
19	1.646	1.61716	0.028841
20	1.646	1.61716	0.028841

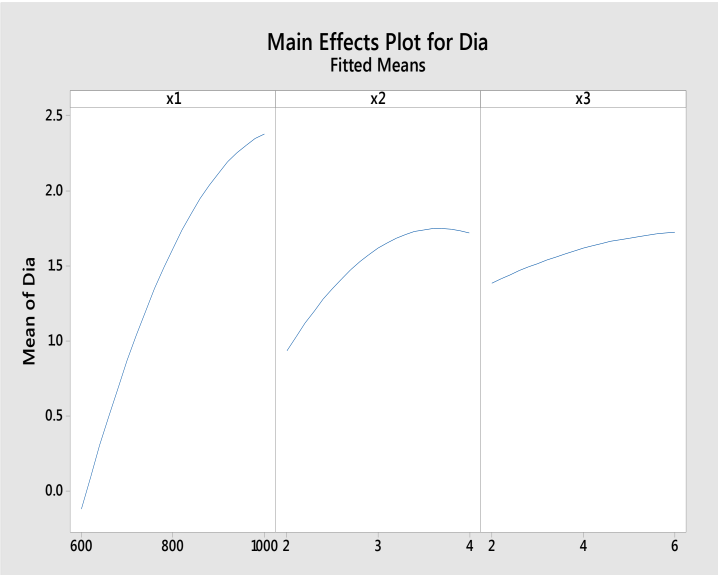


Fig. (4) The main effect plot.

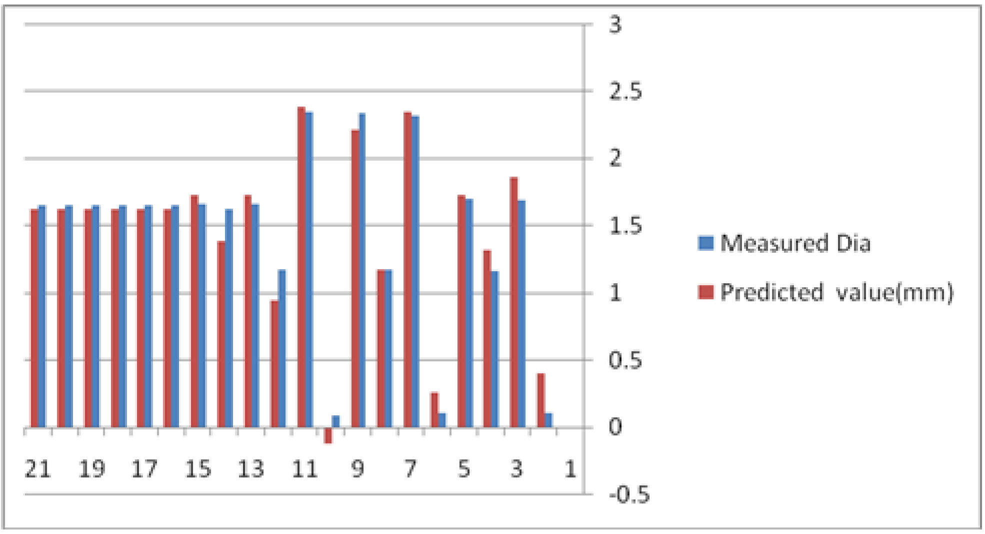


Fig. (5) Comparison between measured values and predicted values by RSM.

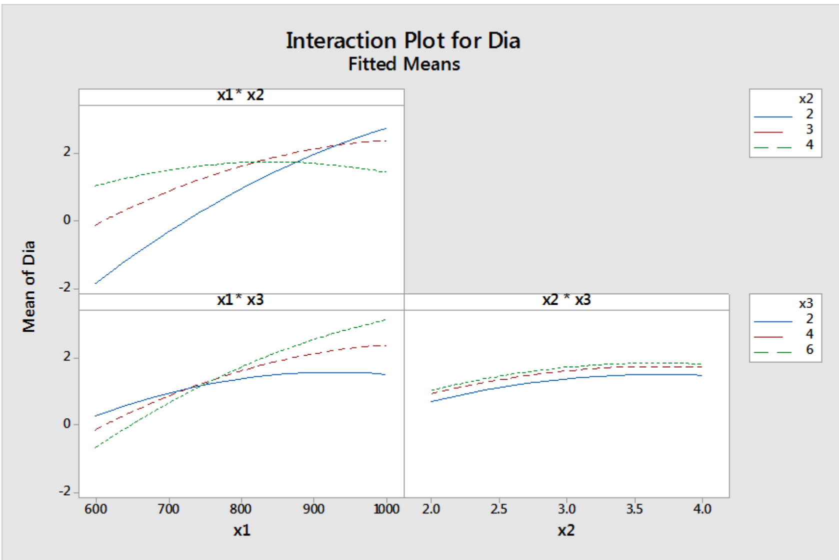


Fig. (6,7) The main effects of plot on hole accuracyand Interaction for dia.

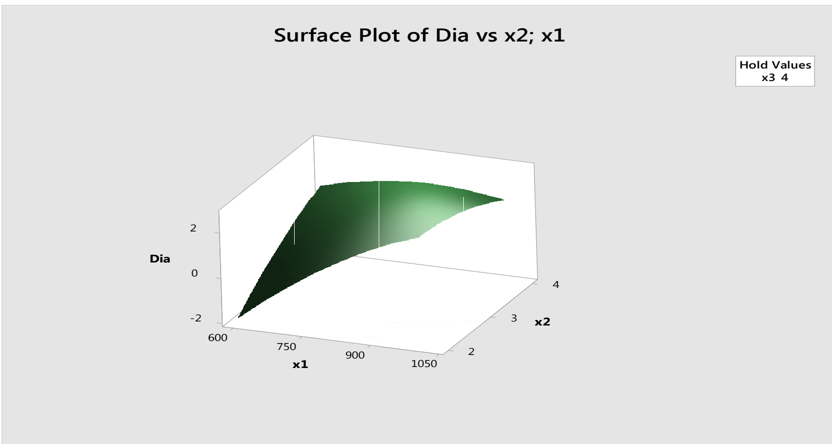


Fig.(8) surface plot of dia.

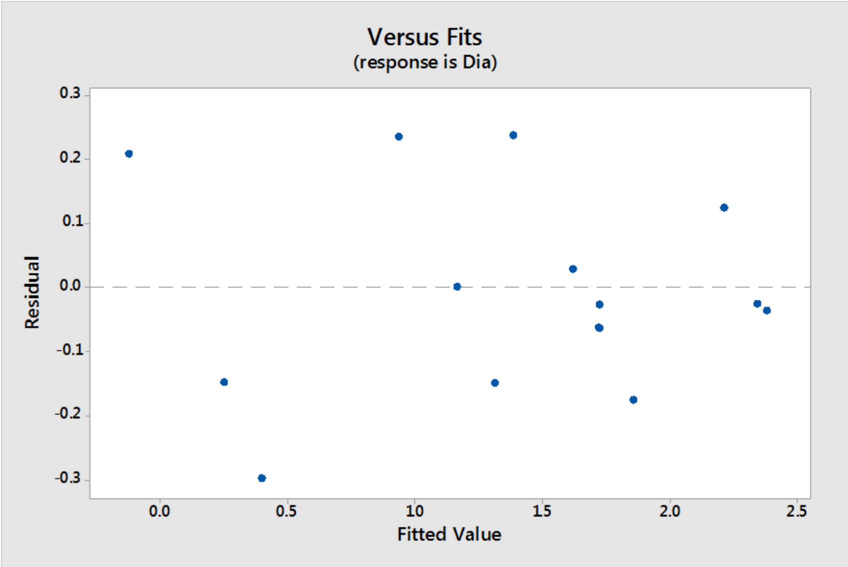


Fig.(9) Versus fits.

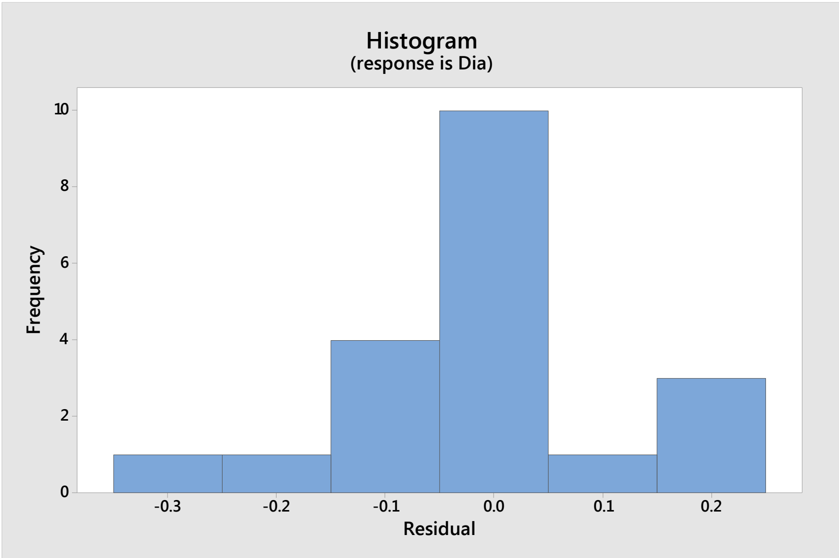


Fig. (10) Histogram.

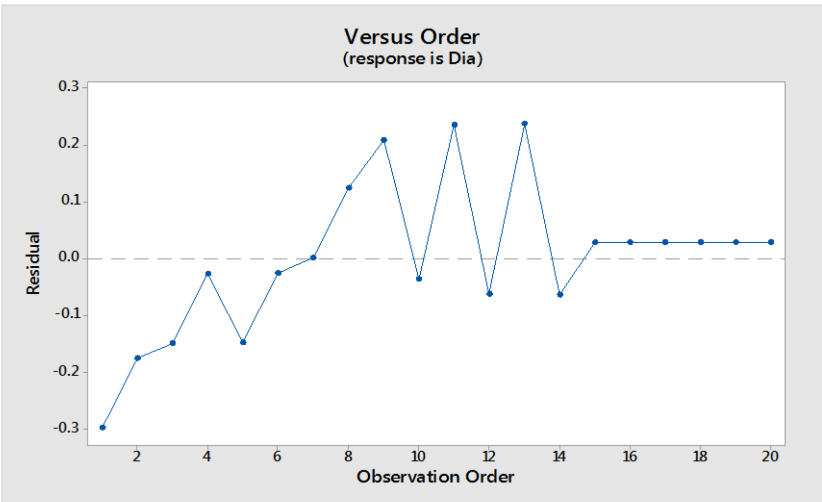


Fig. (11) Versus order.

5. Conclusions

This study demonstrates the effect of cutting conditions (cutting speed, power, gas pressure) on the hole accuracy that produced by laser beam machining with (RSM) Minitab.17 program calculations and reached to the following conclusions:

1- Theprediction accuracy of the hole in this research with RSM calculations are(R-sq95.96%)

2- 2-The multiple regression model by RSM predict hole accuracy (Dia.) with close agreement with experimental values .

3- Prediction of hole accuracy by RSM program lead to improve hole accuracy design and cutting condition.

4-Experments prove that increasing power to (1000 watt) lead to improve the quality of hole accuracy shape.

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