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Analysis the Effect of Parameters for Surface Roughness on CNC Flat Grinder Machine Using Dressing Wheel Technology

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Abstract— *Besides conventional CNC lathes and milling machines, other machines play an important role in machining precision parts. Grinding is a finishing method where the quality of the machined surface is evaluated by many criteria such as surface roughness, geometric accuracy, productivity, and cost. The main factors affecting the gloss of the machined surface such as the technology mode, the stone repair technology, the machining program, the solution, and the smoothing mode, etc. In this article, research on dressing wheel technology, grinding wheel repair mode integrated with flat grinding machining program on CNC numerical control grinding machine affects the surface roughness. Grinding dressing wheel technology is carried out through three steps: Repair rough wheel, repair fine wheel, and repair wheel grinder without cutting. This paper presented an application of response surface methodologies (RSM) for analyzing the influence of technological factors on surface quality when running the main program combined subroutine of dressing wheel grinders. The effect of grinding parameters on the surface roughness was evaluated, and optimum grinding conditions for minimizing the were determined with high reliability.*

Keywords— *Surface roughness, Grinding Wheel dressing, Macro program, RSM.*

I. INTRODUCTION

In mechanical engineering, there are many different shapes and geometries: planes, circles, cones, and surfaces with complex geometric shapes. The universal flat grinder is mainly processed by the shape method, with simple profiles such as flat parts and step face details. When wanting to machine grinder complex profiles, need to repair the stone with specialized grinding jigs to have the shape of the stone to match the parties to be sharpened. Dressing wheel technology requires the use of complex jigs and through many installations, which is very time consuming, costs increase, surface gloss and accuracy significantly affect as shown in figure 1 [1, 2].

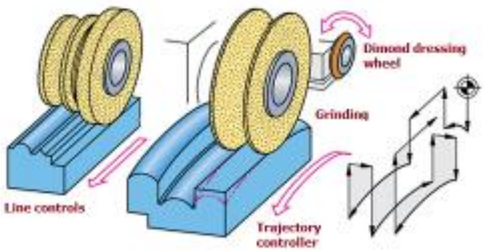

Fig. 1. Shape grinding on CNC machine.

Since then, the use of CNC flat grinders to perform the grinding process, including the stone repair program. Especially for surfaces with complex contours, the dressing wheel program makes a lot of sense. With the machining technology on the CNC flatbed grinder, we can be proactive about the grinding force through the contact surface between the stone and the part, thereby improving the surface gloss, productivity, and accuracy. public. The dressing is the key factor determining the surface micro-topography and surface macro-contour of the grinding wheel, which determines their grinding performance. “The key to grinding is dressing” has long been a consensus in the grinding community [3]. The stone correction has two purposes: contour correction and sharpening as shown in Figure 2.

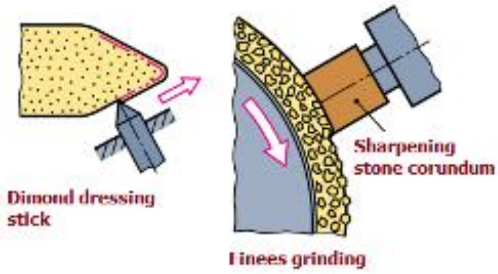

Fig. 2. Dressing classify.

The dressing wheel method is be set as follows:

- Truing wheel: to achieve the profile, grinding radius, and size within the allowable tolerance. When clamping the stone for the first time, ensure the accuracy of rotation (concentricity) and flat rotation (head runout).
- Dressing wheel: To expand the chip cavity by removing the binder and enhancing the cutting properties of each abrasive.

There are two types of dressing heads shown in figure 3: diamond and non-diamond sharp tips or rollers. Dressing wheel with a diamond head is often used through the method of rock removal after a double stroke of 0.04mm; the feed rate is 0.5 m/min. Dressing wheel with a soft grinding stone, made from green silicon carbide with grain size from 16 ÷ 25, grinding speed from 15 ÷ 25m/s, the stone wheel repair mode is selected as follows: main wheel speed is 25 ÷ 30 m/s; longitudinal feed rate 1.5 ÷2 m/min; radial feed rate 0.02 -0.04 mm/dual stroke [4].

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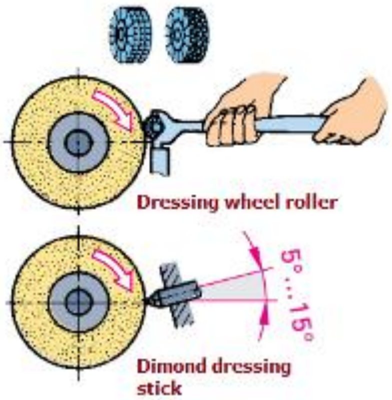

Fig. 3. Dressing cutting.

The grinding wheel life is the time interval between two stone repairs, depending on specific conditions such as surface size, material properties, stone characteristics, cutting mode, and stone repair mode, abrasive stone wear in 5-30 minutes. When fine grinding, stone durability will increase due to the reduction mode (stone speed, horizontal and vertical feed). Recent domestic studies are problematic: The dressing of forming grinding wheels for complex curved parts (e.g., aerospace gears, aspherical optical lenses) has been the bottleneck of wheel dressing technology [5]. It will be the research focus of the future grinding wheel mechanical dressing method. In addition, for the problem of dressing wheel dressing with different cross-section profiles and bond types, it is urgent to develop a composite dressing technology that combines the advantages of various processing methods, and to study its existence of multiparameter optimization problems to achieve efficient, precise dressing [6]; Research to improve the efficiency of the flat grinding process when fine grinding, has evaluated the lubrication, cooling, and cutting modes when grinding flat to choose a reasonable set of parameters when fine grinding on 90CrSi [7]; Optimization of cutting parameters for minimum the surface roughness when grinding SKD11 steel on cylindrical grinder [8]; Many other research works on grinding technology such as dressing technology for diamond grinding wheels [9], screw precision grinding methods using CBN grinding wheels [10]; Precision grinding of screw rotors using CNC method [11].

This paper focuses on analyzing parameters of grinding technology affecting surface roughness on numerically controlled grinding machines combined with dressing subroutines with processing material SKD61 according to the RSM experimental design method.

II. CNC SURFACE CNC GRINDER

Surface grinding machines use a grinding wheel to completely remove the layer of material by smoothing the surface. Tolerances are generally achieved when grinding flat ± $2x10^{-4}$ inches and ± $3x10^{-4}$ inches for parallel surfaces. The surface grinder consists of a grinding wheel that removes irregularities, a part clamping device on the machine table, a magnetic table. Classification of flat grinders based on spindle position and the ability movement of table machine include: The spindle is horizontal with the reciprocating table; The spindle is horizontal with the turntable; Spindle is vertical with a reciprocating table or rotary table. CNC numerical control grinding machine used in this research has a horizontal spindle machine with a table that moves back and forth with the specifications described in Table 1[12].

TABLE 1. Specifications of CNC surface grinder

- Dimensions of the table: 655 x 150 mm
- X-axis travel: 400 mm
- Y-axis travel: 140 mm
- Z axis travel: 290 mm
- Load capacity of magnetic table: 80 Kg
- The workpiece size: 280x130x200 mm.
-Dimensions of grinding wheel: Out diameter:200mm; stone thickness:6: 32mm; Inner diameter: 31.75 mm.
- Spindle maximum speed: 2950rpm
- Accuracy of the machine: 0.005 mm.
- Control software: Mach 3

The main movement in the machine is the rotary motion of the grinding wheel driven by a 2.2kW 3-phase motor, with a maximum speed of n=2950 rpm and the tooling movement runs along the X, Y directions of the table, moving. The up and down movement of the grinding wheel bearing head in the Z direction is controlled automatically. The movement of the X, Y, Z axes are driven by a stepper motor with a maximum torque of 8N.m, in which the X-axis uses a rack-gear mechanism, and the Y and Z axes use a drive nut. The axes are set according to the coordinate axes, allowing the direction of movement of the machine mechanisms and the grinding wheel to be determined. The basic coordinate axes X, Y, Z with positive direction is determined according to the right-hand rule. The shape of the numerically controlled grinding machine and the coordinate system is shown in Figure 4 [13].

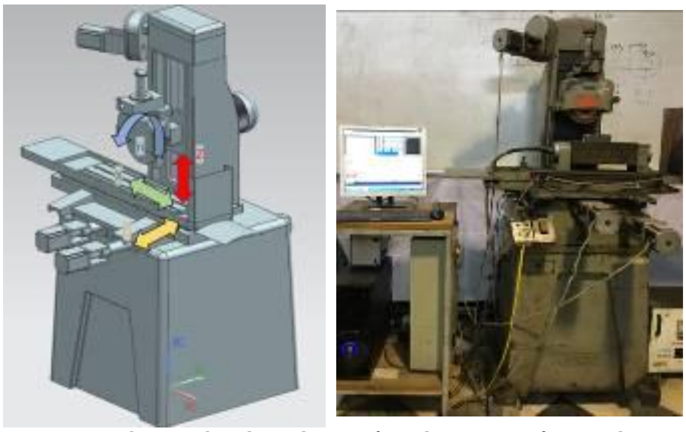
Fig. 4. Photograph and coordinates of grinding CNC surface grinding machine

The machine is controlled by Mach 3 software and the BOB MACH3 LPT CNC Circuit is used to receive data from the computer's LPT parallel interface to receive commands and control other actuators such as reading data from sensors, output motor control pulse, trigger the water pump relay. The BOB MACH3 LPT CNC circuit is designed to control five axes X, Y, Z, A, B, and a relay jack output, five input sensor

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readings, and a spindle control pulse output port (machining head). The circuit uses a USB port for direct power supply, the output control ports are isolated and are all buffered for the most stable signal. The control signal is sent from the computer to the control circuit, then the control circuit will process the signals and supply the appropriate control signal to other components of the system such as the driver that converts the motor signal to the axes, the inverter controls the spindle... or receives signals from the limit switches or emergency stop buttons to give a signal to stop the machine when the machine exceeds the working limit.

III. Experimet Design

A. Experiment on CNC surface grinder

With ordinary flat grinders, the machined surface is flat; when you want to grind flat with complex profiles, you need to install the jigs many times and repair the grinding wheel with complicated jigs for inclined grinding, grinding. convex, concave, concave, etc. to suit the details to be sharpened. In this study, the experimental grinding details are ground by a combination of the left inclined plane, right inclined plane, and plane. The workpiece drawing is shown in Figure 5.

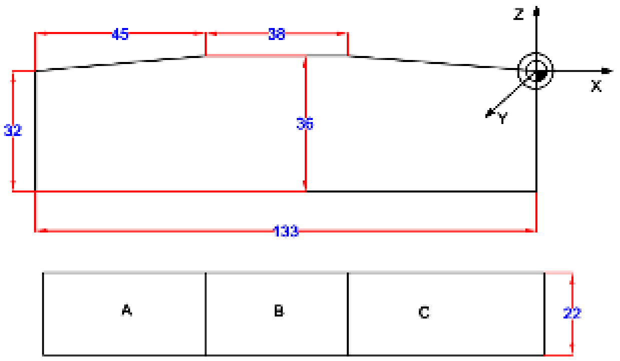

Fig. 5. Machining detail technical drawing

Therefore, instead of using stone repair jigs, design and build stone repair programs (subroutines) combined with machining programs for CNC grinders to simplify the stone repair process and save machining time to ensure machining quality. Evenly, without interruption. There are two methods of stone repair for surface A, C as follow:

- Fix the left inclined grinding wheel (A face) and fix the right inclined grinding wheel (C face).
- Continuous grinding of surfaces A, B, C by combining movements in the Z, X directions, only fixing flat grinding wheels. This way is conveniently chosen for programming on numerically controlled grinders, saves time on machining and setting the stone repair jigs, making flat stone repair easier to integrate with the main machining program.

The experiments are performed on SKD 61 metal detailing heat treatment to a hardness of 48~52 HRC as shown in Figure 4 requires grinding 2 inclined planes A, C, and plane B. The chemical composition of the material is shown in Table 2 below:

TABLE 2. Chemical composition of SKD 61 material

Material	C	Cr	Mo	P	S
SKD61	0.39	5.15	1.4	<0.03	<0.01

To process continuous grinding of 3 surfaces A, B, C, it is necessary to set up a database for CNC numerical control flat grinders based on the Custom Macro B program [14]. Because the machining surface has 2 inclined planes and 1 plane. So it is necessary to fix the stone according to the inclined profile first, then machine the B plane. When grinding on a CNC plane grinder, using axes X and Z simultaneously to process the inclined plane will reduce the machining time. The grinding layer thickness is 0.2 mm. The grinding wheel parameters and Grinding technology process are shown in Tables 3, 4.

TABLE 3. Grinding wheel parameters

Parameters	Value
Grinding stone type	A60PV
Material	Al_2O_3
Diameter mm	200
Center Diameter mm	31.75
Thickness mm	20

TABLE 4. Grinding technology process

Factors	Units	Coarse	Semi - fine	Fine
Wheel speed	rpm	2950	2950	2950
Feed velocity	mm/min	300	150	80
Depth of cut	mm	0.16	0.03	0.01
Grinding depth per pass	µm	0.02	0.01	0.005

After final finishing with 0.005 mm need two more runs are required to ensure the allowable surface gloss.

B. Set up dressing wheel database by Macro program.

Database (subroutine) in CNC programming is an important and necessary solution. It helps programmers of CNC numerical control machines to reduce programming time as well as the length of machining programs. Because a subroutine in CNC programming is a small piece of code that helps programmatically repeat a particular operation in the machining process. Macro program is very commonly used to set up databases for CNC numerical control machine tools. With the FANUC CNC numerical control machine tools, we have two types of Macro programs that can be used to set up the database: Custom Macro A program and Custom Macro B program [15].

To dressing wheel, we need to determine the wheel profile, through which to build the input parameters passed into the Custom Macro subroutine. General algorithm diagram of stone repair programs shown in figure 6.

The algorithm uses input values, including the thickness to be repaired (T) – calculated from the input parameters of the rock profile to be repaired and the thickness of each stone repair layer (j) – entered from Macro call. Running variable is t, rock thickness corrected. The running parameter here is the corrected rock thickness (t); when the dressing thickness is smaller than the stone to be repaired (T), it will run the stone repair and increase the repaired rock layer thickness. When starting machining. When the repaired stone thickness is greater than or equal to the thickness to be repaired (T),

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proceed to set the final stone repair layer thickness t=T and run the last layer dressing wheel. Illustrated contour dressing wheel as follow in figure 7.

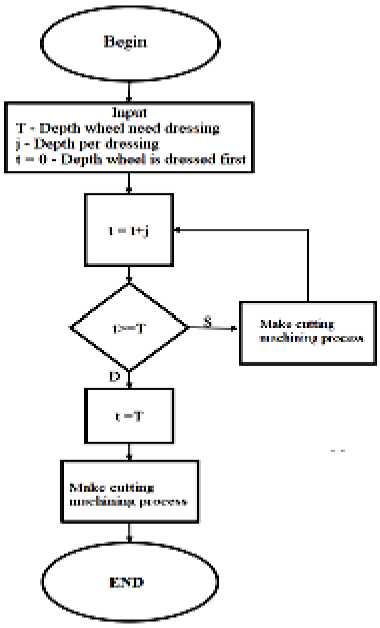

Fig. 6. Diagram of dressing wheel algorithm

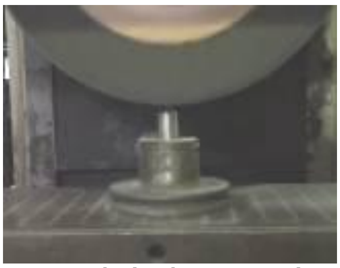

Fig. 7. Dressing wheel with a stationary diamond tip

The program includes a grinding wheel profile correction program and a detailed machining grinding wheel running program. These two programs are continuous, and on CNC numerical control flat grinders, a dressing wheel head on the machine table or a fixed dressing wheel head can be mounted at a position on the machine.

Structure calls the program to fix dressing wheel:

- Program syntax to run flat grinding wheel

G65 P9001 Uu Ww Xx Vv Yy Dd Ee Jj Kk Ii Ff

- Program syntax to run inclined grinding wheel.

G65 P9002 Uu Ww Xx Zz Aa Vv Yy Dd Cc Ee Jj Kk Ii Ff

Parameters are passed according to the parameter address specified by the Custom Macro B program

As much as the grinding wheel repair program goes, the machining program will be compensated for the corrected amount of stone, ensuring correct contact between the grinding wheel surface and the part surface during the grinding process. As a result, the machining accuracy of the required dimensions and surface roughness can be achieved. After programming, determine the "0" origin of the figure 8 part and check the grinding programs, we were using Cimco Edit toolpath simulation software shown in figure 9. Cimco Edit V8 is software for programming, editing, and simulating machining programs, which can simulate and control programming error problems. Programmable from CNC programming software (CAM), easy connection with CNC machining centres, CNC machine tools.

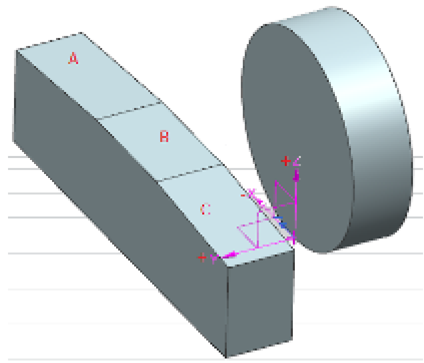

Fig. 8. Determine the "0" origin of the workpiece.

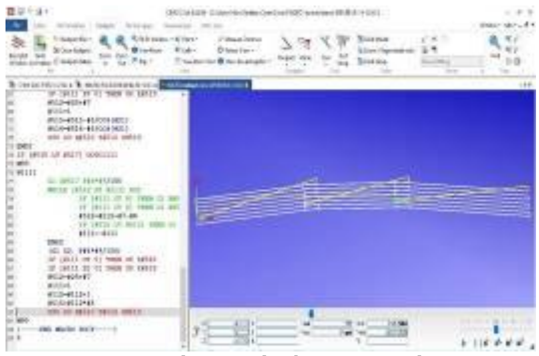

Fig. 9. Simulating toolpath on Cimco Edit V8

Especially Cimco Edit can intelligently program 3D to set up CNC programs with continuous, synchronized transitions. The software follows the standard of the user interface on the windows operating system, and all functions of Cimco Edit V8 can be activated using the Ribbon.

Subprograms:

- O9001 horizontal plane machining program.
- O9002 inclined plane machining subprogram

Program summary

```
%
O1369
(-- PROGRAM GRINDING SURFACE --)
G00 G17 G21 G40 G49 G80 G90 G91;
G28 Z0;
(-- START MOTION --)
N10
(-- Call Macro program grinding for A face --)
G65 P9002 U0. W-4. X45. Z0. A[ATAN [4/45]] V0. Y22;
…
(-- Call Macro program grinding for B face --)
G65 P9001 U45. W0 X83. V0. Y22. D20. E0.15 J0.02 K100;
…
(- Call Macro program grinding for C face --)
```

```
G65 P9002 U83. W0. X133. Z4. A[ATAN [4/50]] V0. Y22.
C200 D20 E0.15 J0.02 K10 I10 F300;
…
 (-- END MOTION --)
M09
M05 G91 G28 Z0.
G28 X0. Y0.
G90
M30
```

C. Experimental results and discussion

The detailed image of machining and result surface A, B, C after finish machining grinder is shown in Figure 10,11.

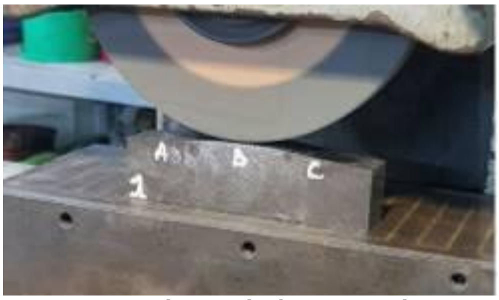

Fig. 10. Simulating toolpath on Cimco Edit V8

Fig. 11. Surface after machining grinder

Surface roughness values for the grinder surface are measured using the surface roughness tester called “Taylor Hobson's Subtonic surface roughness meter”. It works with two parameters, Ra and Rz, the most frequently specified process control measurement with high reliability and ±5% accuracy.

For each workpiece, the measurement is taken at many different locations to find the absolute surface finish. The result surface roughness of A, B, C faces shows in Table 5. From the measurement results shown in table 5 and table Anova Analysis in table 6 show there a difference in Ra values for each pair of surfaces. The F-ratio, which in this case equals 1.68303, is a ratio of the between-group estimate to the within-group estimate.

TABLE 5. Result surface roughness (Ra - µm) A, B, C faces

Run no	Ra of A face		Ra of B face		Ra of C face	
	Before grinding	Fine grinding	Before grinding	Fine grinding	Before grinding	Fine grinding
1	2.85	0.37	3.62	0.27	3.12	0.32
2	2.75	0.33	3.99	0.3	2.72	0.31
3	2.41	0.29	3.4	0.2	2.36	0.27
4	2.52	0.31	2.65	0.4	2.65	0.25
5	2.22	0.31	2.41	0.3	2.61	0.25
6	2.42	0.28	3.12	0.30	2.92	0.27
7	2.37	0.29	2.95	0.29	3.02	0.31

TABLE 6. ANOVA Table

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.0038	2	0.0019	1.68	0.2138

This procedure compares the data in 3 columns value of surface roughness for A, B, C faces after fine grinding. It constructs various statistical tests and graphs to compare the samples. The various plots will help you judge the practical significance of the results and allow you to look for possible violations of the assumptions underlying the analysis of variance, as shown in figure 12, 13.

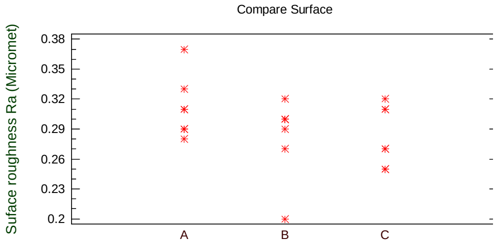

Fig. 12. Compare Ra after machining grinder of A, B, C face

Fig. 13. Box and Whisker Plot compares Ra of A, B, C

D. Optimizing technology parameters

Using experimental planning to organize experiments to ensure enough experiments to obtain the required reliability objective function. The application of response surface methodology (RSM) in the optimization of analytical methods is presented Current experimental models: Behnken Box Model, CCD, and CCF, CCI and model for Plaskett – Busmen screening experiment [16, 17]. With the optimal analysis of technological factors affecting the roughness of the machined surface, the Behnken Box model is selected to satisfy both orthogonal and rotational properties in the survey area; the experiments are suitable, the number of experiments is suitable. Applying the model to design experiments in research with 3 influencing factors of technology which is both orthogonal and rotational in the investigation area and optimized with three factors - Speed of grinding wheel Nd [rpm]; t - Depth of cut [mm]; S – Feed rate [mm/min]. Table 7 gives parameter values of the factor.

TABLE 7. Experimental factor value

Factor	Units	-1 lever	+1 lever
Speed of Wheel (Nd)	rpm	2500	2950
Feed rate (S)	mm/min	80	120
Depth of grinding (t)	µm	5	10

Process the surface grinding SKD61 in the order and obtained the test results according to Box - Behnken model

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shown in Table 8. Repeat 5 experiments at the centre, will run 17 experiments.

From the data results and using data analysis software, in which the full theoretical regression function model of the influencing parameters has the form it shows that [18] :

$$R_a = a_0 + a_1A + a_2B + a_3C + a_4AB + a_5AC + a_6BC + a_7A^2 + a_8B^2 + a_9C^2 \quad (1)$$

In which: A – Wheel speed (rpm)
B – Feed rate (mm/min)
C – Depth of cutting (µm)
a_i – Theoretical Model parameter

TABLE 8. Experimental results

Run. No	Nd (rpm)	S (m/min)	t (µm)	Ra (µm)
1	2725	100	8	0.31
2	2950	100	5	0.25
3	2725	100	8	0.29
4	2725	100	8	0.32
5	2725	100	8	0.3
6	2500	80	8	0.24
7	2725	120	10	0.31
8	2500	100	10	0.37
9	2500	120	8	0.34
10	2950	100	10	0.33
11	2725	100	8	0.28
12	2500	100	5	0.34
13	2725	80	10	0.36
14	2725	80	5	0.2
15	2725	120	5	0.29
16	2950	80	8	0.24
17	2950	120	8	0.26

Use data processing software Design Expert, ANOVA for Response Surface full Quadratic Model as shown in table 9:

TABLE 9. ANOVA for Response Surface Quadratic Model

Parameter	df	Mean square	F - value	P-value
Model	8	3.946E-003	9.73	0.0021 significant
A	1	5.976E-003	14.73	0.0050
B	1	4.236E-003	10.44	0.0120
C	1	0.011	25.92	0.0009
AB	1	1.600E-003	3.95	0.0823
AC	1	7.414E-004	1.83	0.2133
BC	1	4.271E-003	10.53	0.118
A^2	1	6.579E-003	0.014	0.9084
B^2	1	4.106E-003	10.12	0.0130
C^2	1	3.374E-003	8.32	0.0204
Residual	8	4.056E-004		
Lack of Fit	*4*	*5.611E-004*	*2.24*	*2.24 not significant*

From the ANOVA Table 9, it is observed that The Model F-value of 9.73 implies the model is significant. P -Value less than 0.05 indicate model terms are significant. In this case A,B, C, BC, B^2, C^2 are significant model terms. The "Lack of Fit F-value" of 2.24 implies the Lack of Fit is not significant relative to the pure error. There is a 22.64% chance that a "Lack of Fit F-value" this large could occur due to noise. Therefore, the regression function for surface roughness after removing the less influential factors is as follows equation (2):

$$R_a = a_0 + a_1A + a_2B + a_3C + a_6BC + a_8B^2 + a_9C^2 \quad (2)$$

The results of ANOVA analysis are shown in Table 10.

Table10. ANOVA for Response Surface Quadratic Model after parameter optimization

Parameter	df	Coefficient estimate	F - value	P - value
Model	6	0.29	8.72	0.0017 significant
A	1	-0.026	14.73	0.0105
B	1	0.023	10.44	0.0203
C	1	0.036	25.92	0.0015
BC	1	-0.032	10.53	0.0200
B^2	1	-0.031	10.12	0.0219
C^2	1	0.03	8.32	0.0338
Residual	10			
Lack of Fit	6		*3.06*	*0.1495 not significant*

The Model F – the value of 8.72 implies the model is significant. The final equation in Terms of coded factors as follows:

$$R_a = 0.29 - 0.026Nd + 0.023S + 0.036t - 0.032St - 0.031S^2 + 0.03t^2 \quad (3)$$

The influence of the parameters is shown in Figure 14,15.

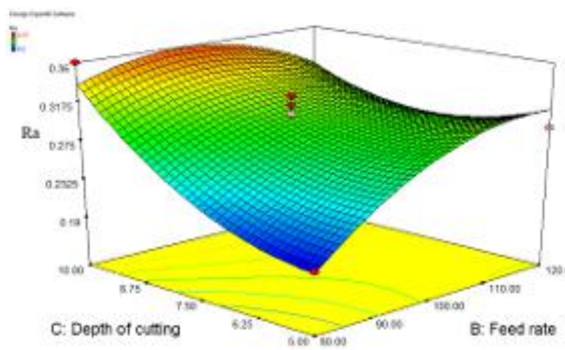

Fig. 14. Effect of cutting depth, cutting speed on surface roughness.

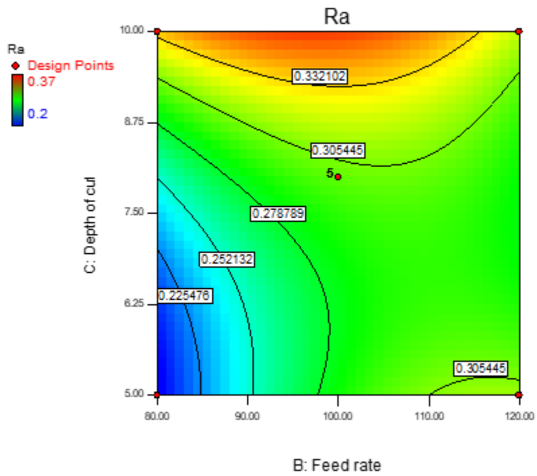

Fig. 15. Effect of cutting depth, cutting speed on surface roughness contour type.

Figure14 shows the three-dimensional interaction response surface plot in terms of depth of cut and feed rate. It has been found that the surface roughness value increases with increase in table speed and depth of cut. It clearly represents that depth of cutting has a major effect on surface roughness as when compared to feed rate which affects surface finish slightly.

Figure15 shows the contour response surface plot for Ra in terms of feed rate and depth of cut. It has been found that at feed rate, depth of cut, the surface roughness value goes on decreasing depends on two main factors feed rate and depth of cut.

From the data analysis, it is possible to choose the optimal processed pine fish to achieve high surface gloss, for reference value Nd = 2835 [rpm]; t = 5 [µm]; S = 80 [mm /min], Ra can reach value as 0.176 [µm] depending on the control value on the machine. The results of parameter optimization for surface roughness to have the smallest value are simulated on the contour graph of Figure 16.

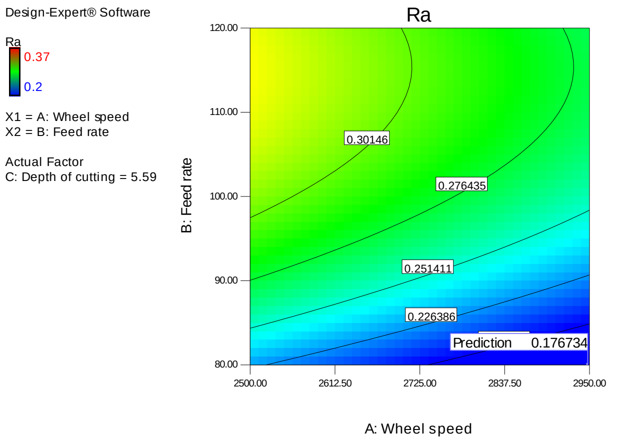

Fig. 16. The graph of the min roughness value with optimal technological parameters

IV. Conclusions

Parameters affecting surface roughness during surface grinding on numerical control machine integrated with dressing wheel programs are evaluated based on experimental planning according to surface treatment method and data processing for reliable results. The experimental results and analysis, the results obtained are the following conclusions.

1. The influence of flat grinding technology parameters on surface roughness was evaluated using the Box - Benken method. The depth of each grinding pass is an important parameter then the stone speed. Optimum grinding conditions can minimize geometrical errors and improve machined surface quality.
2. The experimental regression function showing the relationship between Ra and the parameters of grinding technology was built from experimental results with high reliability.
3. Grinding conditions suitable for different surface roughness values can be selected. The optimal level to obtain minimum surface roughness in CNC flat grinding wheel integration subroutine is point prediction at wheel speed 2848 rpm, feedrate 80 mm/min and depth of cut 5 m then Ra can reach 0.1767µm.

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