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Parametric Optimization of Hot Machining Process for Aisi4140 Material Using Grey Relational Technique

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Abstract: In the industries, there is a need of materials with very high hardness and shear strength in order to satisfy industrial requirements. So many materials which satisfy the properties are manufactured. Machining of such materials with the conventional method of machining was proved to be very costly as these materials greatly affect the tool life. So to decrease tool wear, the power consumed and increase surface finishes Hot Machining can be used. The L9 orthogonal array of a Taguchi experiment is selected for four parameters (speed, feed rate, depth of cut and temperature) with three levels (low, medium, and high) in optimizing the hot machining turning parameters on the lathe.

Keywords: Surface roughness, MRR (Material removal rate), Orthogonal array, Analysis of variance (ANOVA), Grey-Taguchi Technique.

1. INTRODUCTION

The basic of hot machining operation is to first soften the work piece is by preheating and thereby shear strength gets reduced in the vicinity of the shear zone. The use of hot machining has become very useful in the machining of high strength temperature-resistant (HSTR) alloys. Hot machining has two functions to perform, one, to machine some HSTR alloys which are unimaginable in the conventional machining method. Second, to improve tool life this eventually improves the production rate.

There are various techniques of hot machining which are subjected to requirements. The penetration of heat should be such that the shear zone is appreciably affected. Input rate of heat must be commendably high, so as to temperature sufficiently and quickly. Thermal damage done to work piece through distortion should be minimum. The installation and operation cost should be minimum. The operators in the operation should take safety measures into account. Temperature control should be quickly obtained.

1.1 CUTTING TOOLS

The most common tool materials that are used include the following:

1. High-speed steel (HSS)
2. Carbide
3. Carbon steel
4. Cobalt high-speed steel

Tool Holder: - WIDAX- PCLNR 2525 M 12 D 5F with 20 mm Shank.
Insert: - Kennametal insert with Grade: KC5525
ISO catalogue number:- CNMG120408RP
ANSI catalogue number: - CNMG432RP

1.2 ABOUT ANALYSIS SOFTWARE MINITAB 15

Minitab software is a statistics package used for analysis of experimental data. It was developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors. MINITAB 15 calculates response tables and generates main effects and interaction plots for Signal-to-noise ratios (S/N ratios) vs. the control factors. It provides a standard orthogonal array for Taguchi methodology for experiment design. It also performs regression analysis to establish a relation between two or more variables. It also helps in generating various types of tables and graphs.

2. EXPERIMENTAL SETUP

2.1 Work piece material

For performing hot machining, the selected material should be hard enough that at elevated temperature it should maintain the strength. Considering this, AISI 4140 as a work piece material is selected. The material is in the form of round bar and having 50 mm diameter and 280mm length. The material is heat treated by tempering at 870̊C and oil quenched and having hardness of 50 HRc (Rockwell hardness). The Chemical, Physical and Mechanical properties of material are shown below.

Table 1: Chemical composition of AISI 4140 steel materials

Material	C	Mn	Si	Cr	Mo	P	S
AISI 4140	.35 to .45	.45 to .70	.10 to .80	1.00 to 1.45	0.25 to 0.40	0.035	0.040

Table 2: Physical properties

Material	Density gm/cm	Melting Point (ºC)	Thermal Conductivity at 100 ºC (W/m k)	Coefficient of Thermal expansion (μm)/m ºC
AISI 4140	7.80	1425	44.5	12.5

Table 3: Mechanical properties

Material	Tensile strength (MPa)	Yield Strength (MPa)	% Elongation
4140	1050	685	14

2.2 Taguchi method for single objective optimization

Taguchi's methods of experimental design provide a simple, efficient, and systematic approach for the optimization of experimental designs for performance quality and cost. The main purpose of Taguchi method is reducing the variation in a process through the robust design of experiments. It was developed by Dr. Genichi Taguchi of Japan. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic.

2.1.1 Process steps of Taguchi method

1. Define the process objective
2. Identify test conditions
3. Identify the control factors and their alternative levels
4. Create orthogonal arrays for the parameter design
5. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
6. Complete data analysis to determine the effect of the different parameters on the performance measure.
7. Predict the performance at these levels
8. Confirmation experiments.

2.1.2 Signal -to- Noise (S/N) ratio

The objective of the problem statement is to obtain maximum value or minimum value of desired response. Taguchi method chooses to calculate the signal-to-noise ratio for finding an effective parameter for desired response value. To calculate the S/N ratio, experiments are conducted in a systematic manner. Taguchi's idea is to recognize controllable and noise factors and to treat them separately as a design parameter matrix and a noise factor matrix, respectively. Experiments are organized according to orthogonal arrays (OAs). Noise factors are changed in a balanced fashion during experiments.
The characteristics of S/N ratio can be divided into three categories smaller is better, Higher is better and nominal is best when the characteristic is continuous.
These characteristics are selected as per objective of the problem. They are calculated by the following equation.

(a) Nominal is the best characteristic

$$SNi = 10log\frac{y_i^{-2}}{s_i^2} \qquad (2.1)$$

(b) Smaller is better

$$SNi = -10\ log\left(\sum_{U=1}^{Ni}\frac{y_u^2}{Ni}\right) \qquad (2.2)$$

(c) Larger the better characteristic

$$SNi = -10\left[\frac{1}{Ni}\sum_{u=1}^{Ni}\frac{1}{y_u^2}\right] \quad (2.3)$$

$$\overline{y}_i = \frac{1}{Ni}\sum_{u=1}^{Ni} y_{i,u} \quad (2.4)$$

$$S_i^2 = \frac{1}{N_i - 1}\sum_{u=1}^{N_i}\left(y_{i,u} - \overline{y}_i\right) \quad (2.5)$$

I = Experiment number
u = Trial number
Ni = Number of trials for experiment i.

The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum, and current value of the parameter. If the difference between the minimum and maximum value of a parameter is large, the Values being tested can be further apart or more values can be tested. If the range of a parameter is small, then fewer values can be tested or the values tested can be closer together.

A matrix has a number of columns equal to the number of factors (parameters) to be considered, each column representing a specific factor. Within each column, we specify the levels (parameter setting) at which the factors are kept for experiments. The number of rows in a matrix represents the number of experiments that are to be performed. As the name suggests, the columns or orthogonal array are mutually orthogonal. Here, orthogonal is interpreted in the combinatory sense that is for any pair of columns, all combinations of factor levels appear an equal number of times. An orthogonal array design gives more reliable estimates of factor effects with fewer experiments that are needed in traditional methods.

Taguchi has tabulated 18 basis orthogonal arrays. An arrays name indicates the number of rows and columns it has and also the number of levels in each column. For example, L_{12} (2_{11}) has 12 rows and 11 columns each at 2 levels. The array can be directly used in many cases or modified to suit a specific problem. The number of rows of an orthogonal array represents the number of experiments. For an array to be a viable choice, the number of rows must be at least equal to the degrees of freedom required for the case study. The number of columns of an array represents the maximum number of factors that can be studied using that array. Usually, it is expensive to conduct experiments of the case study. The selection orthogonal arrays for a number of process parameter with respect to levels of variation of the parameter are listed in the table given below table no. 3.1 Analysis of variance techniques provides a mathematical basis for organizing and interpreting the experimental results. For each performance requirement, signal-to-noise (S/N) ratio is used. The cutting parameter range is suggested by the cutting tool manufacturers. Based on that, in this experiment, each parameter is varied by three different levels.

Table 4. Control Factors and Their Range of Setting for the Experiment

Control Variable	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Temperature (℃)
Level-1	30	.10	.04	55
Level-2	80	.15	.06	110
Level-3	125	.20	.08	220

The experiment table suggested by Minitab- 15 for L9 Orthogonal array is shown in Table 5.0

Table 5.0 Experiment design by use of L9 Orthogonal array

Sr.No	Parameter 1	Parameter 2	Parameter 3	Parameter 4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

RESULT

In this study experiment is performed in two times and experimental value of surface roughness Ra value (in µm), material removal rate (in mm3/min) and tool wear (in mm) measured are shown in Table 3.1.

Table 6. Result table for SR, MRR, and TW

Sr. No.	SR(µm)	MRR (cm3/min)	TW (mm)
1	12.60	0.75	0.06
2	8.22	3.04	0.045
3	6.21	6.60	0.031
4	3.00	3.50	0.013
5	10.50	9.00	0.053
6	7.50	5.60	0.035
7	5.30	8.00	0.031
8	1.60	6.00	0.014
9	2.35	16	0.056

3.1 Main effects plot of surface roughness

The main effects plot for S/N ratio of surface roughness verses cutting speed, feed rate, depth of cut and temperature, which is generate form the value of S/N ratio of surface roughness as per Table 6. in Minitabe-15 statistical software is useful to find out optimum parameter value for response variable. The graph generates by use of Minitab-15 statistical software for surface roughness is shown in graph 3.1.

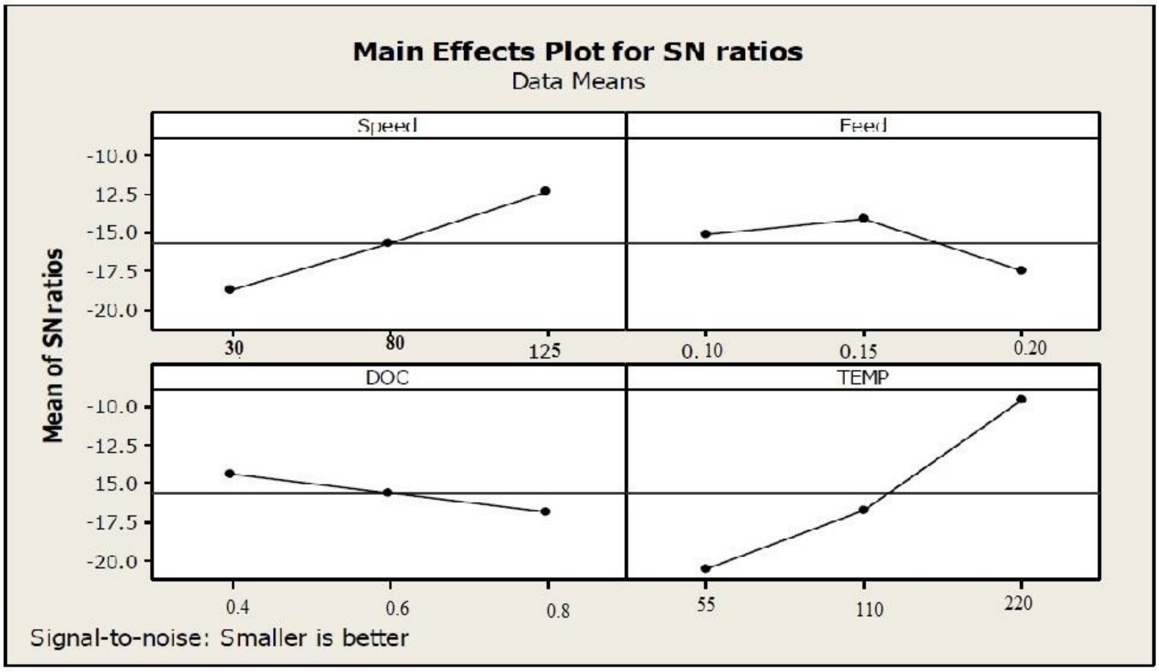

Figure.3.1: Mean effect plot of surface roughness vs. Cutting speed, Feed, DOC and Temperature

From the Figure 3.1 it is concluded that the optimum combination of each process parameter for lower surface roughness is meeting at high cutting speed (A3), medium feed rate (B2), low depth of cut (C1), and high temperature (D3). The S/N of the surface roughness for each level of the each machining parameters can be computed in Minitab 15 and it is summarized for finding out the rank of each effective parameter for a response.

3.2 Main effects plot of material removal rate:

The main effects plot of material removal rate verses cutting speed, feed rate, depth of cut and temperature, which is generally form the value of S/N ratio of material removal rate in Minitabe-15 statistical software is used to find out optimum parameter value for response variable. The graph generates by use of Minitab-15 statistical software for material removal rate is shown in figure 3.2.

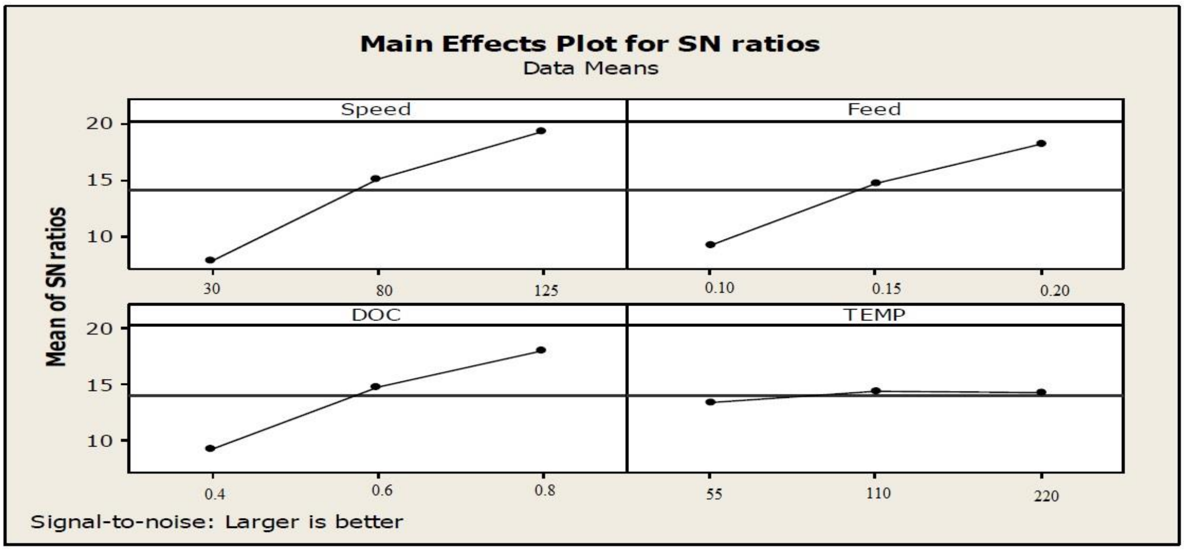

Figure.3.2: Mean effect plot of material removal rate vs. Cutting speed, Feed, DOC and Temperature

From the figure 3.2 it is concluded that the optimum combination of each process parameter for higher material removal rate is meeting at high cutting speed (A3), high feed rate (B3), high depth of cut (C3), and medium temperature (D2).
The S/N of the material removal rate for each level of the each machining parameters can be computed in Minitab 15

3.3 Main effects plot of Tool wear

The main effects plot of Tool wear verses cutting speed, feed rate, depth of cut and temperature, which is generally from the value of S/N ratio of material removal rate in Minitab-15 statistical software is used to find out optimum parameter value for response variable. The graph generates by use of Minitab-15 statistical software for Tool wear is shown in graph 3.3.

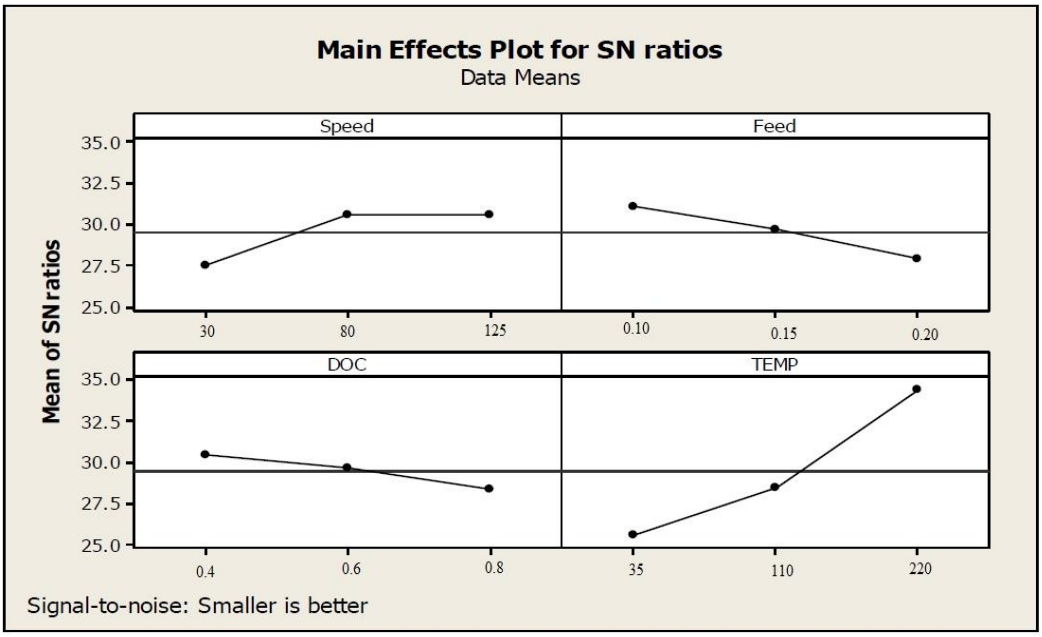

Figure.3.3: Mean effect plot of Tool wear vs. Cutting speed, Feed, DOC and Temperature

From the Figure 3.3 it is concluded that the optimum combination of each process parameter for lower tool wear is meeting at a medium cutting speed (A2), lower feed rate (B1), low depth of cut (C1), and higher temperature (D3). The S/N of the tool wear for each level of the each machining parameters can be computed in Minitab 15 and it is summarized for finding out the rank of each effective parameter for a response. The analyzed value of the mean of tool wear by use of the Minitab-15 statistical software is shown in Table 7.

Table 7. Response table of S/N ratio for tool wear

level	Speed	Feed	DOC	Temp.
1	26.50	30	29.45	26.23
2	30.53	28.52	28.65	29.50
3	30.51	26.80	27.38	35.30
Delta	3.28	3.30	2.07	8.75
Rank	3	2	4	1

4. MAIN EFFECTS PLOT OF GREY RELATIONAL GRADE

The following graph shows the main effects plot for GRG. Basically, the larger the gray relational grade, the better is the multiple performance characteristics. For the combined responses maximization or minimization, graph gives the optimum value of each control factor. Chart interprets that Level of Cutting speed A3 (125 m/min), Feed rate B1 (0.10mm/rev), Depth of cut C2 (0.6mm) and Temperature D3 (220℃) gives optimum result.

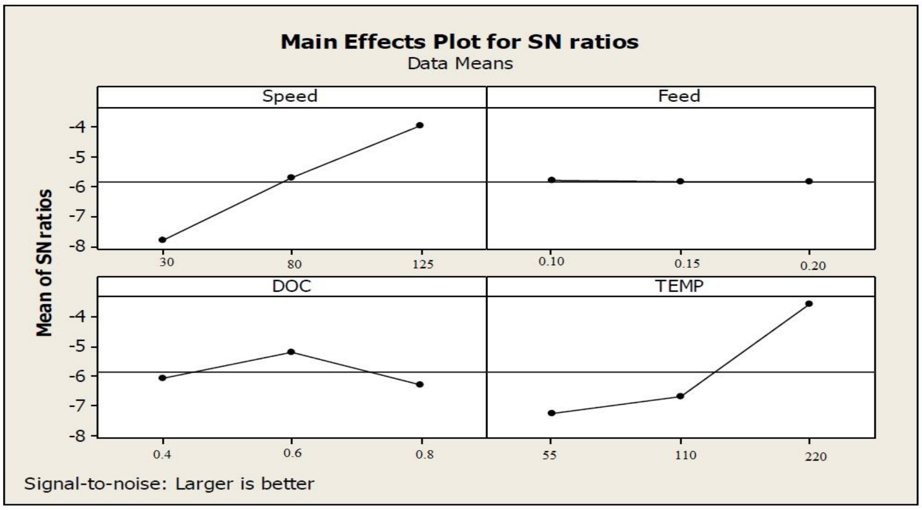

Figure 4.1: Mean effect plot of grey relational grad vs. Cutting speed, Feed rate, Depth of cut and Temperature

The effect of each hot turning process parameter on the grey relational grade at different levels can be independent because the experimental design is orthogonal. The mean of the grey relational grade for each level of the hot turning process parameters is summarized and shown in the following Table. In addition, the total mean of the grey relational grade for the 8 experiments is calculated and listed in following Table 8.

Table 8: Mean affects factors on gray relational grade

Level	Speed	Feed	DOC	Temp.
1	-7.709	-5.706	-7.062	-8.144
2	-5.610	-5.737	-6.075	-7.567
3	-3.875	-5.750	-7.367	-4.473

5. CONFIRMATION TEST

The final step in the experiment is to do a confirmation test. The purpose of the confirmation runs is to validate the conclusion drawn during the analysis phases. In addition, the confirmation tests need to be carried out in order to ensure that the theoretically predicted parameter combination for optimum results using the software was acceptable or not. The parameters used in the confirmation test are suggested by grey relational analysis. The confirmation test with optimal process parameters is performed at levels A3, B1, C2, D3 of process parameter takes 2.51 minute time for 100 mm length of cut and gives 1.40μm value, 5870.18 mm3/min material removal rate and 0.013mm tool wear is obtained.

CONCLUSION

6.1 Surface Roughness

1. Temperature is the most significant parameter for lower surface roughness value followed by speed, feed, and depth of cut.
2. Best parameter combinations for optimum surface roughness are: Speed (A) at level 3 (125 m/min), feed (B) at level 2 (0.15 mm/rev), Depth of cut (C) at level 1 (0.4 mm) and temperature (D) at level 3 (220℃).

6.2 Material Removal Rate

1. Cutting speed is the most significant parameter for higher material removal rate value followed by feed, depth of cut and temperature.
2. Best parameter combinations for optimum material removal rate are: Speed (A) at level 3 (125 m/min), feed (B) at level 3 (0.20 mm/rev), Depth of cut (C) at level 3 (0.8 mm) and temperature (D) at level 2 (110℃).

6.3 Tool Wear

1. Temperature is the most significant parameter for lower tool wear value followed by feed, speed, and depth of cut.
2. Best parameter combinations for optimum tool wear are: Speed (A) at level 2 (80 m/min), feed (B) at level 1 (0.10 mm/rev), Depth of cut (C) at level 1 (0.4 mm) and temperature (D) at level 3 (220℃).

Based on Grey Relational Analysis, for optimum surface roughness, material removal rate, and tool wear, the temperature is most significant parameter followed by speed, depth of cut and feed.

The optimal process parameters, for surface roughness, material removal rate, and tool wear, based on grey relational analysis are high cutting speed (125 m/min), low feed (0.10mm/rev), medium depth of cut(0.6 mm) and preheating temperature of 220℃.

By using Grey Taguchi analysis, the surface roughness increased by 3.34% and material removal rate and tool wear improve by 0.91 % and 13.34% respectively.

FUTURE SCOPE

The present work concentrated on optimization of turning process parameter in Hot Machining. The variables to be altered are cutting speed, feed, and depth of cut and temperature of the work piece. The parameters to optimize are taken as surface roughness, material removal rate, and tool wear. The experiment is conducted on a conventional lathe. The flame heating technique is used to preheat the work piece.

1. The same experiment can perform by changing parameter i.e. by taking parameters like tool geometry, tool run off, work piece material etc. or by taking a different level of the process parameter. Here also higher temperature level can be selected, to observe the clear effect of temperature on machining.
2. The tool wear criteria can be extended and tool life can also be found out. Also, the equation of tool life can be developed in terms of process parameters.

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