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Determining of the Optimal Turning Parameters Using the Response Surface Methodology in Powder Metallurgical Tool Steel

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Abstract: The influence of cutting parameters on the surface roughness in turning of PMD 23 powder metallurgical (PM) steel was investigated in this work. With three different cutting speeds, feed rates, depth of cuts and two different types tool geometry of carbide inserts were determined as cutting parameters. Taguchi L_{18} orthogonal array was used to design of experiment. In order to find out the effect of cutting parameters on the average surface roughness (R_a) and prediction model of R_a, response surface method (RSM) was used. The results obtained by RSM revealed that the feed rate was dominant parameter on changes in R_a. The developed predicting model of R_a can be effectively used on PMD 23 PM steel within 95% confidence intervals ranges according to the experimental parameters. The parameters combination of low feed rate and low depth of cut with high cutting speed is suitable minimum surface roughness.

Keywords: Hard Turning; Surface roughness; Response surface method.

Toz Metalurjisi Takım Çeliklerinde Cevap Yüzey Metodu Kullanarak Optimum Tornalama Parametrelerinin Belirlenmesi

Özet: Bu çalışmada PMD 23 Toz Metalürjisi (TM) çeliğin tornalanmasında kesme parametrelerinin yüzey pürüzlülüğü üzerindeki etkileri araştırılmıştır. Üç farklı kesme hızı, ilerleme oranı, kesme derinliği ve iki farklı takım geometrili karbür uç tipi kesme parametreleri olarak belirlenmiştir. Deney tasarımı için Taguchi L_{18} ortogonal dizi kullanılmıştır. Kesme parametrelerinin ortalama yüzey pürüzlülüğü (R_a) ve R_a 'nın tahmin modeli üzerindeki etkisini belirlemek için cevap yüzey yöntemi (RSM) kullanılmıştır. RSM ile elde edilen sonuçlar, ilerleme oranının R_a'nın değişimi üzerinde etkin bir parametre olduğunu ortaya çıkarmıştır. R_a için geliştirilen tahmin modeli, deneysel parametrelere göre PMD 23 PM çelik için etkin bir şekilde %95 güven aralığı içinde kullanılabilir. Minimum yüzey pürüzlülüğü için düşük ilerleme oranı ve yüksek kesme hızı ile düşük kesme derinliği parametrelerinin uygun olduğu anlaşılmıştır.

Anahtar kelimeler: Sert tornalama; Yüzey pürüzlülüğü; Cevap yüzey metodu.

1. Introduction

The most efficient way of achieving the maximum industrial productivity on during production is to identify and apply the optimum production parameters. Although the material and tool manufacturer gives the product usage information to the manufacturer, this information are not including the all materials, tool and processing conditions. Especially from the perspective of the manufacturer, besides the new and efficient manufacturing processes (like hard turning) or most

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Bu makaleye atıf yapmak için
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effective statistically prediction methods (like response surface methodologies), adhere to traditional methods is not acceptable technological approaches. At this stage, emerging technologies and applications that combine experimental studies has come to the fore. This studies which aims to reduce energy consumption and improving the quality of products, based on the operational testing of the new material, tool and group of parameter, verification and validation statistically tests and optimization of new manufacturing processes completed.

According to the older studies, hard turning is a machining process which applied to the all industrial steels, specially hardened steels between 40-62 HRC, and eliminate the coolant, reduce the costs and improves the product quality [1-15]. The studies based on this process generally new materials like alloy steels, powder metal steels are selected and the materials surface roughness, cutting forces and tool wear status have been studied and optimized according to the different cutting parameters (feed rate, cutting depth, cutting speed) [1-6, 8-13, 15-21]. To the obtained results feed rate is the most effective parameter on surface roughness, the cutting speed and cutting depth are the mostly effect the tool wear and cutting forces on three different axial [1-5, 7-11, 13-16, 18-22]. Some of these studies focused on different tool types (CBN, Ceramic or Carbide, coated-uncoated etc.) and tool geometries (tool radius etc.)and they found out that the coated tools has the better performance, the wiper tools were better than the universal tool about the cutting force and surface roughness, the most common wear mechanism were crater wear and flank wear mechanisms on cutting tools [2-5, 7, 9, 11, 14-16, 18, 21-23]. This past experimental studies commonly supported by the statistically analyze methods. Most used statistically method for detecting the most effective parameter on work piece is Analyze of Variance (ANOVA), the other statistically study about finding the best parameter with the minimum experiment number is Taguchi Orthogonal Series, and the other method is Response Surface Methodology (RSM) for the developing predicting model, corresponding test about used parameters [1-4, 7-11, 13-15, 17, 18, 20-24].

The results were evaluated with regards to surface roughness Ra. In the study which was prepared in accordance with the literature survey; Selecting optimal process parameters in turning of PMD powder metal special steel using Taguchi method and Response Surface Methodology (RSM), Identifying the effect of each process parameters with analysis of variance (ANOVA) analysis were conducted.

2. Material and Method

In this study used work piece is the powder metal special steel PMD23, which made by Dörrenberg Edelstahl. PMD23 has got fine distributed carbide structure, segregation-free, high bending and compressive strength, very good grinding properties. This steel is used machining tools like milling cutters, drills or broaches, cold-work tools for cutting, stamping or deep-drawing dies applications. It is in form of 40 mm diameter and 150 mm length The chemical composition of workpiece material according to the Dörrenberg test certificate as follows: C:1.30; Cr:1.20; W:6.40; Mo:5.00; V:3.10 in wt%. The two different geometry tool carbide inserts which are made by SANDVIK Coromant was used in experiments. The carbide inserts ISO designation code is SNMG 120408 4205 and geometry of PF and MF. The insert was clamped onto with a designation of DSBNR-2020-M12 (approach angle: 75^o) tool holder. In the turning tests, only one cutting edge is used in each experiment.

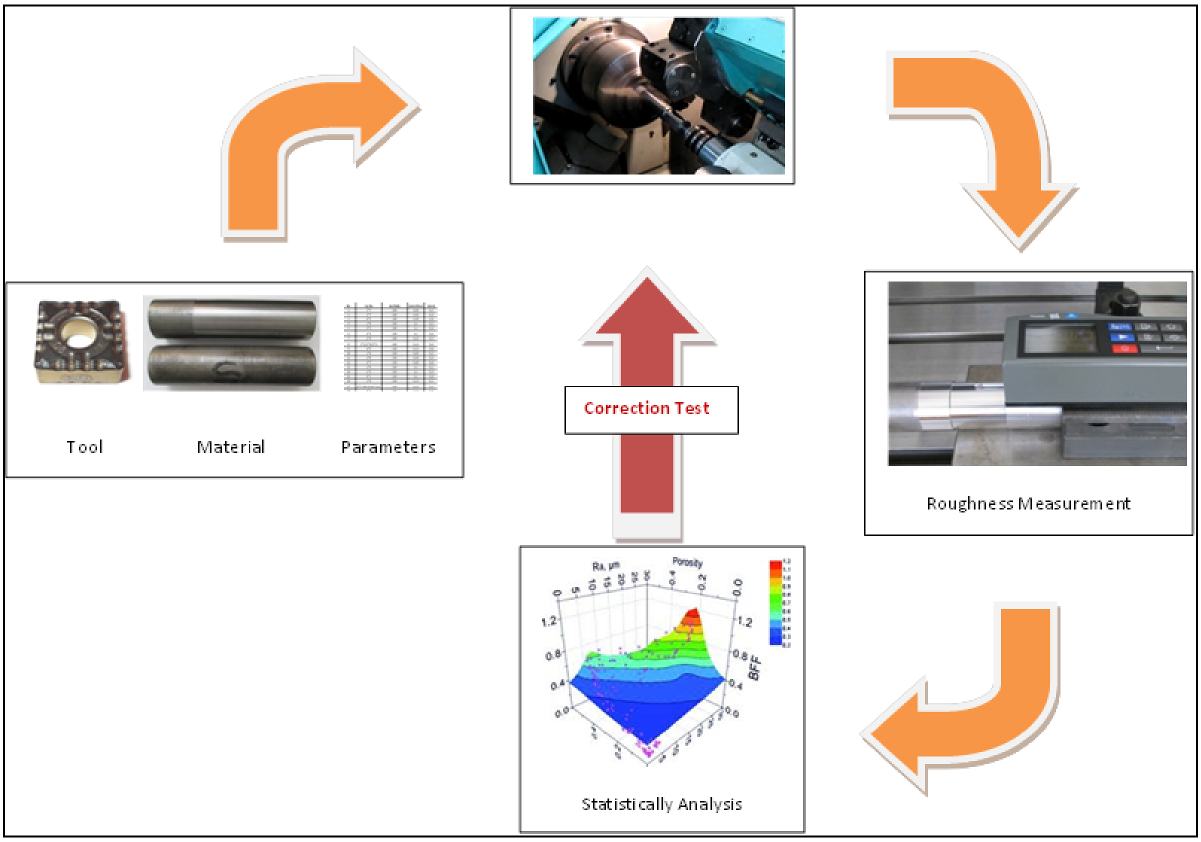


Figure 1 Experimental process.

The turning tests were conducted on YANG SL-20 CNC lathe having a maximum spindle speed of 4000 rpm and a maximum power of 12 kW. Taguchi L_{18} orthogonal array was used to design of experiment (Table 1.).

Table 1 Experimental design using L_{18} orthogonal array.

Test Number	**A**	**B**	**C**	**D**
	Tool Type	**Vc (m/min)**	**f (mm/rev)**	**ap (mm)**
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

The turning tests were performed with two cutting toll types (MF (15^o)-PF (17^o)), three different cutting speeds (Vc): 200-300-400 mm/min., feed rates (f): 0.1-0.2-0.3 mm/rev., and depth of cuts (ap): 0.5-1.0-1.5 mm in dry cutting condition. By means of the Taguchi method, industries are able to reduce product development cycle time for design and production, therefore decreasing costs and increasing profit. Besides, Taguchi design allows inspect the variability cause to by noise factors, which are usually passed over in the traditional design of experiment approach [25]. After the tests, the work pieces values of surface roughness (Ra) were measured by using TIME TR-200 roughness meter with a cut-off length of 0.8 mm. Average surface roughness value was calculating using value of surface roughness measured three different points on turning surface. The Response Surface Methodology (RSM) performed in order to correspondence the experiments on the average surface roughness (Ra). RSM is a mathematical and statistical technique used for establishing relationship between variables and responses. Besides, RSM is searching the importance of these variables on different performance criteria. Taguchi design and RSM were performed using Minitab software. The experimental process was given in Figure 1.

3. Results and Discussion

Measured and calculated surface roughness results after turning tests were given in Table 2. Using the RSM-stepwise based mathematical model have been developed with tool type, cutting speed, feed rate and depth of cut for R_a. R_a mathematical model for the turning of PMD 23 PM steel is shown in the following equation. The model presented correlation coefficient value of R^2=83.02% which indicated the goodness of fit between model and desired value. At first step, because the tool type insignificant, tool type was removed from the model in other steps. The statistically adequacy of R_a model was checked using ANOVA. From ANOVA table (Table 3), model is significant due to the value of P more than value of 0.05.

Table 2 Experimental results

Tool type	***Vc* (m/min)**	***f* (mm/rev)**	***ap* (mm)**	**R_{a1} (µm)**	**R_{a2} (µm)**	**R_{a3} (µm)**	**Means of R_a (µm)**
15	200	0.1	0.5	0.57	0.66	0.58	0.603
15	200	0.2	1	1.21	1.26	1.245	1.238
15	200	0.3	1.5	3.41	3.37	3.38	3.387
15	300	0.1	0.5	0.55	0.527	0.543	0.540
15	300	0.2	1	1.41	1.36	1.38	1.383
15	300	0.3	1.5	2.17	2.26	2.31	2.247
15	400	0.1	1	0.864	0.727	0.668	0.753
15	400	0.2	1.5	1.5	1.44	1.363	1.434
15	400	0.3	0.5	3.5	3.44	3.36	3.433
17	200	0.1	1.5	1.22	1.43	1.4	1.350
17	200	0.2	0.5	1.167	1.14	1.1	1.136
17	200	0.3	1	4.17	4.3	4.2	4.223
17	300	0.1	1	2.31	2.5	2	2.270
17	300	0.2	1.5	1.568	1.267	1.393	1.409
17	300	0.3	0.5	3.47	3.43	3.46	3.453
17	400	0.1	1.5	0.887	1.011	1.181	1.026
17	400	0.2	0.5	1.08	1.09	0.99	1.053
17	400	0.3	1	2.24	2.31	2.37	2.307

$$R_a = 1.67 - 0.00263\,Vc - 15.7\,f + 1.744\,a_p + 85.7\,f*f - 8.19\,f*a_p \qquad (1)$$

R^2=83.02% R^2 (adj)=75.95%

Table 3 ANOVA results for R_a model.

Source	**DF**	**SS**	**MS**	**F**	**P**
Model	5	17.5337	3.5067	11.73	0.000
Linear	3	13.8232	4.6077	15.42	0.000
Vc	1	0.7536	0.7536	2.52	0.138
f	1	13.0361	13.0361	43.62	0.000
a_p	1	0.0335	0.0335	0.11	0.743
Square	1	2.9378	2.9378	9.83	0.009
*f*f*	1	2.9378	2.9378	9.83	0.009
2-Way Interaction	1	1.2158	1.2158	4.07	0.067
*f*ap*	1	1.2158	1.2158	4.07	0.067
Error	12	3.5860	0.2988		
Total	17	21.1198			

The normal probability plot of the residuals (Figure 2) of RSM model revealed that the residuals lie close to normal line. When the errors are presented normal distribution, model is significant. From main effect plot as seen Figure 3, feed rate is the most significant factor affecting R_a. Feed rate is followed by cutting speed and depth of cut. According to these statistical confidence levels of 95%, the feed rate is the effective parameters (P: 0.000, F: 43.62). Statistically the cutting speed and depth of cut insignificant effect on surface roughness value in Figure3, Considering the slope in graphic surfaces on the feed rate R_a said to lead to more significant changes than other parameters. This situation complies with literature [5, 12, 13]. When it was seen curves of the cutting speed, feed rate and depth of cut in the graph, Cutting speed of 200 m/min to 300 m/min to quit when the value of R_a was observed a marked improvement. R_a value showed a significant deterioration when increase in feed rate. This may be associated with a marked increase in the chip section.

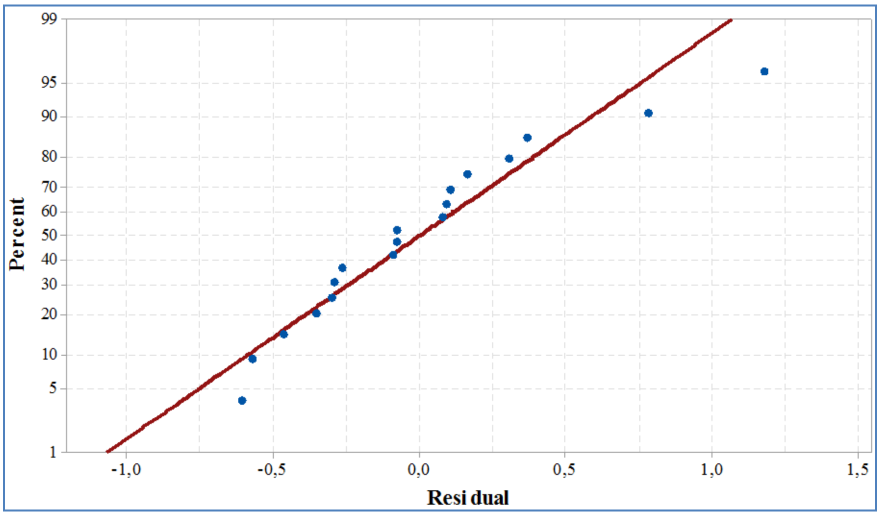


Figure 2 Normal probability plot of the residuals for R_a (μm)

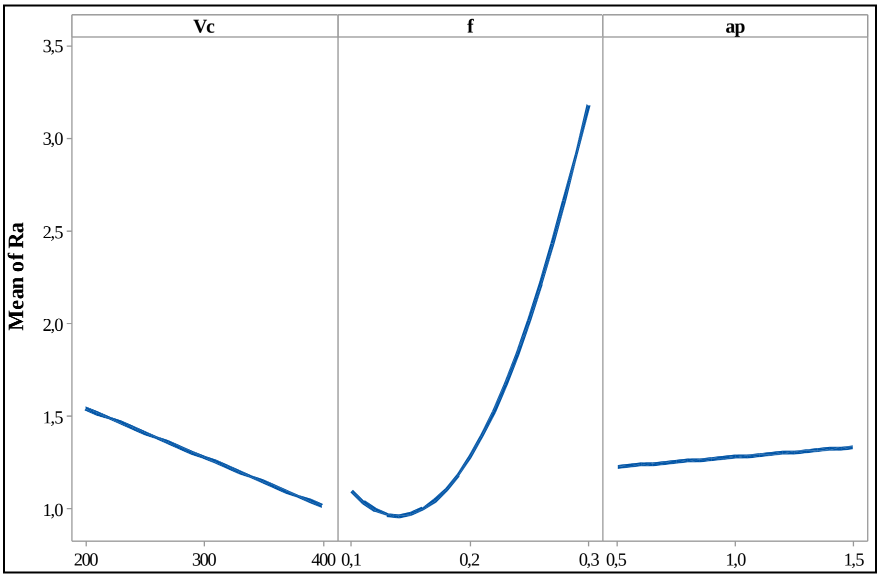
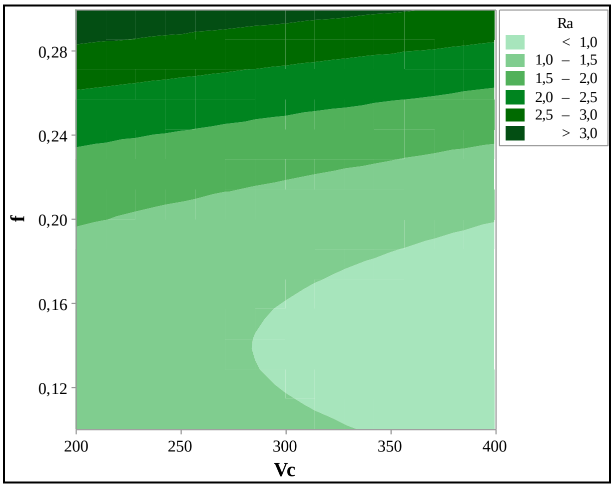
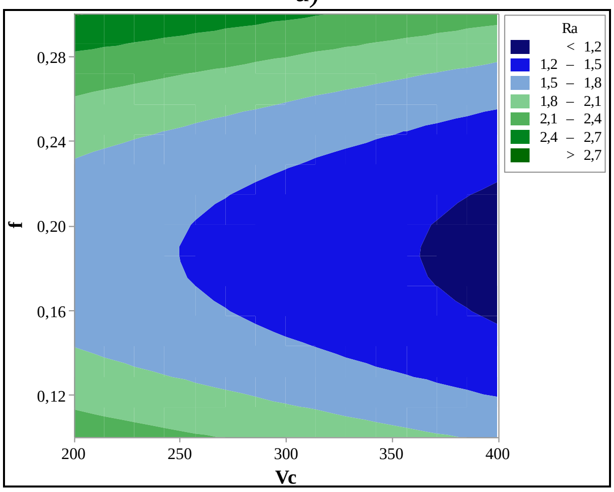


Figure 3 Main effect plot for R_a (µm)

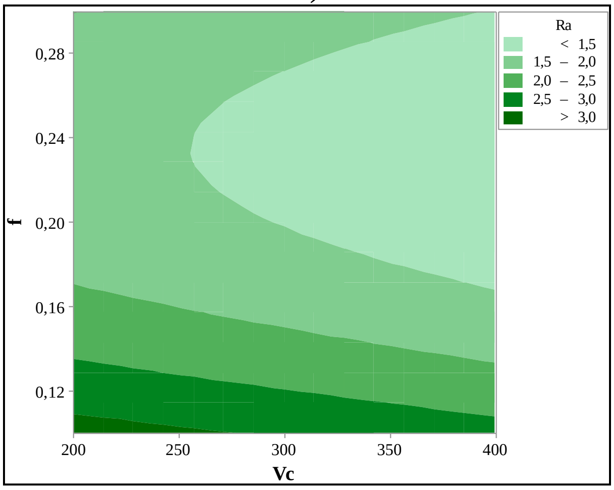
The contour plot of R_a versus *Vc*, *f* given in Figure 4. When analysing the Figure 4, minimum R_a value can be obtained with high level of cutting speed, low feed rate and depth of cut conditions. In Figure 4-a, minimum Ra values were obtained in cutting speed of 300-400 m/min and feed rate of 0.1-0.18 mm/rev at depth of cut of 0.5 mm. It is the roughness tends to increase in other cutting depth.



a)



b)



c)

Figure 4 Contour plot of R_a (μm) versus *Vc; f*
a) a_p=0.5 mm b) a_p= 1mm c) a_p=1.5mm).

According to the optimization plot (Figure5), the results of the analysis made by optimal process parameters based on the lower and upper levels of the parameters are *Vc*=400 m/min, *f*=0,1162 mm/rev and a_p=0.5 mm for R_a in turning of PMD 23 PM steel.

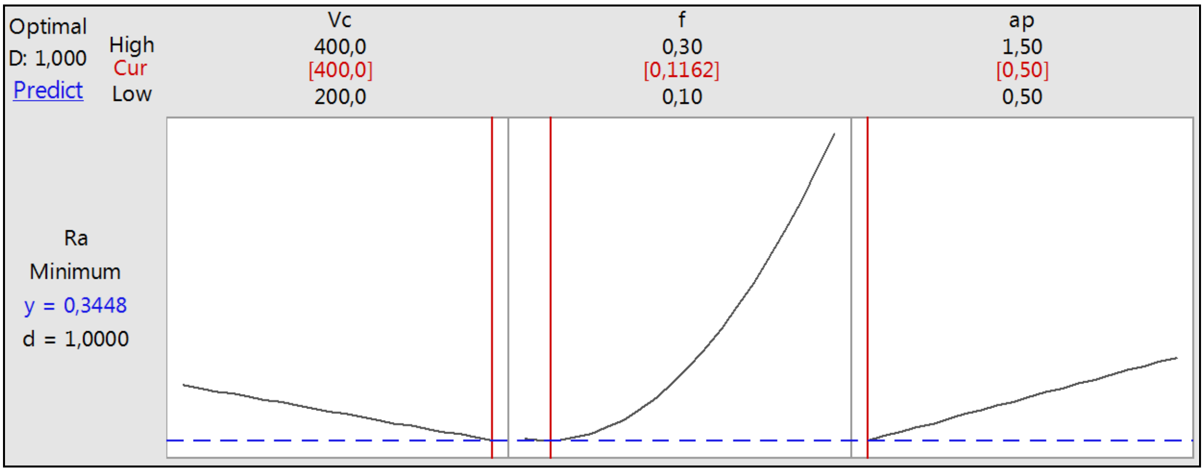


Figure 5 Optimization plot.

In the last step, control experiments were performed for optimum parameters proposed by the model. Predicted and experimental results are given in the Table 4. There are differences between predicted and experimental results. This may be associated with the R^2 value.

Table 4 Comparison of the prediction model and experimental results

Parameters	**Parameters levels**	**Values of R_a (μm)**	
		Prediction	**Experimental**
Cutting Speed (m/min)	400	0.3448	0.6
Feed rate (mm/rev)	0.1162		
Depth of cut (mm)	0.5		

4. Conclusions

- Mathematical model developed by using RSM can be adequate for R_a because of R^2 value. The predicted values were not found to be close to experimental values.
- The recommended model is significant as the values of probability (P≤0.05).
- According to the main effect plot and results of ANOVA, feed rate is the most significant factor affecting R_a followed by depth of cut and cutting speed.
- The surface roughness is sensitive to variations in feed rate. R_a values increased with increase in feed rate.
- The parameters combination of low feed rate and low depth of cut with high cutting speed is suitable minimum surface roughness.

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