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Research article

Effect of Machining Parameters on the Surface Roughness of Hot Die Steel

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A B S T R A C T

H13 tool steel is frequently used in hot work dies, hot forging, hot extrusion, and mold materials for casting ferrous and nonferrous materials. Surface roughness is of key importance in case of dies and moulds, as it insures the finish of the final product. After studying the work done by the researchers in field of machining and its impact over surface roughness, it was found that machining behaviour of H13 steel at the annealed state is not being studied. The surface finish obtained during turning of H13 steel are not studied on a greater scale, so the present study includes the analysis of finish (surface roughness) generated. Turning operation is carried out on the CNC machine at dry condition with an aim to find systematically the effect on surface roughness by distinct machining variables like feed rate, depth of cut and speed. RSM model using Box Behnken design is used to predict the roughness developed during turning of annealed H13 steel using carbide tool. It was found that feed rate and the depth of cut have a direct relation with the surface finish and the value of surface roughness increases with increase in these parameters. On the other side, cutting speed has a less impact over the surface roughness & is inversely related.

1. INTRODUCTION

The H13 Tool Steel finds its large application in the industry as because of the high hardenability of the material gives its usage in pressure die casting, extrusion tools, forging dies, hot shear blades, stamping dies and plastic moulds. H13 die steel is machined at its annealed state (17 HRC), it is important to carry out a proper study so as to overcome the machining and tooling cost that is faced generally when H13 steel is used in the hardened state (48 HRC) [1-4]. Ojolo et al. [3]

studied the tool life under dry conditions of machining. The work made use of 3 materials for the cutting tool and three work materials. Spindle speed, feed & depth of cut were taken as parameter. Taguchi experimental design and the analysis using ANOVA was carried out. The results concluded that the spindle speed, depth of cut & feed rate what directly affecting the tool life. Arseculаratne et al. [5] examined the machining of hardened AISI D2 steel with PCBN tools. AISI D2 steel of hardness 62 HRC with PCBN tools was investigated and the most practical feeds and speeds were discovered to be between 0.08 and 0.20 mm/rev and 70 and 120 m/min, respectively, and the majority of the PCBN tools that were evaluated had their lives end mostly as a result of flank wear. The lowest speed tested (70 m/min) produced the maximum acceptable values of tool life and volume of material removal, suggesting that this speed is more appropriate for machining the chosen tool/work material combination. Lower feeds led to greater tool life values, however the maximum feed utilized produced the greatest volume of material removal. N. Sandberg [6] investigated the Tool Steel's excellent performance machinability. This study examined the impact of silicon on the machinability of high-performance tool steel using two hot work steels. It was discovered that H13's low Si content improves toughness, decreases oxidation resistance, lowers the ferrite-to-austenite transformation temperature, and reduces machinability. Further, the impact of machining variables on surface roughness during the machining of hardened EN24 Steel with coated carbide inserts was investigated by Das et al. [7]. The findings shown that feed and cutting speed have the greatest effects on surface roughness parameters (Ra and Rz), whereas depth of cut has the least impact on surface roughness (Rz) and the least impact on surface roughness (Ra). In order to determine the ideal range of surface roughness parameters (Ra and Rz), additional analysis was done on the experimental data. The Surface Roughness Analysis and Experimental Investigation on Hard Turning of AISI D2 Steel with Coated Carbide Insert were researched by Srithar et al. [8]. This study describes the use of a coated carbide insert in the machining of an AISI D2 steel work piece with a hardness of 66 HRC. The steel's rolled grains are visible in the microstructure along the material's direction. The presence of carbide, which enhances strength and wear resistance, and fine cementite grains containing chromium and other alloys at the grain boundary are visible in the microstructure. The significance of hard turning AISI D2 steel is covered in this essay. Using the preset cutting parameters, investigations were conducted on a traditional lathe. The findings indicate that when hardened steel is machined, increased cutting speed reduces surface roughness. When AISI D2 steel is machined using a coated carbide insert, the surface roughness rises due to the progressive increase in feed rate and depth of cut. Pal et al. [9] investigated the use of artificial neural networks to forecast surface roughness in order to turn AISI H13 steel with the least amount of lubrication possible. For a certain number of cycles, several networks with varying architectures were evaluated using a combination of input and output responses set aside for this purpose. When the analysis's output was contrasted with the earlier outcome, it became clear that the ANN's predictions and the experimental findings agreed. Suresh et al.'s [10] investigation focuses on how machining parameters affect tool wear and surface roughness while turning hard steel using ceramic tools. The TiCN ceramic tool with PVD coating is utilized in full song dry machining conditions. The experiment was designed using the response surface approach notion from CCD. The results show that the most important element impacting tool wear was cutting speed, which also revealed the abrasion wear mechanism. For surface roughness, on the other hand, the most important factor influencing wear was feed rate. Using RSM, Kumar et al. [11] investigated the machinability of AISI H13 hot working die tool steel final turning with CBN cutting tool inserts. The authors examined the effects of machining variables on cutting forces, surface roughness, and cutting-edge temperature were investigated in the finish turning of AISI H13 die tool steel with CBN inserts. The work piece hardness was determined to be in the range of 45–55 HRC. The H13 hot work steel with CBN inlay performs best when its finish is turned. It was discovered that this would be a good substitute for grinding, and that we might get surface polish as high as 0.10 micrometers by choosing the right settings. Zang et al. [12] investigated the use of combined ceramic and CBN cutting tools for turning tool steel. Different combinations of cutting speed, feed rate, and depth of cut were taken into account while using two different hardnesses of steel for the work material. The relationship between the cutting parameter, cutting forces, and surface roughness was determined using ANOVA. The two tools that were employed produced the lowest cutting forces when using the ceramic tool and the lowest surface roughness while using the CBN tool. Tool wear and surface roughness during the machining of AISI D2 tool steel were examined by Kundor et al. [13]. A number of cutting experiments were conducted as part of their investigation to confirm the alteration in the work piece's surface roughness brought on by growing tool wear. The tests were conducted in dry conditions with a variety of speed and feed combinations. Next, the surface roughness of the machined surfaces was assessed. They discovered that during the initial cutting, mechanical wear or abrasion usually predominates. Under all cutting circumstances, roughness levels were shown to be nearly continuously correlated with the development of flank wear. It suggests that tool life is not significantly impacted by surface roughness. The impact of cutting variables on cutting force and cutting temperature during pocketing operations has been examined by a number of researchers [14–16]. Their research focused on examining how cutting parameters affected temperatures and cutting pressures when using contour tool path approach for pocket operation. Two distinct pocket shapes were used in this investigation. According to the results, the Taguchi technique may be used to identify the important component in the contour tool route strategy's pocketing operation. The cutting force was shown to be mostly determined by the feed rate, with the depth of cut having a less significant effect. Hafiz et al.'s [17] model used response surface methods to calculate and forecast surface roughness. AISI H13 was the work material utilized, and a milling machine was used to complete the machining. The experiments were planned using central composite design, and the suitability of the resulting model was assessed using the ANOVA approach. The outcome shows that cutting speed is the primary factor that determines surface roughness, with feed rate coming in second. With regard to surface roughness, the depth of cut had less of an effect.

Following an analysis of the machining research and its influence on surface roughness, the following research needs were identified: The analysis of research articles has led to the conclusion that there is a lack of study on the effect of machining on the surface roughness of annealed H13 die steel. The hardened H13 die steel is primarily used to examine surface roughness effects. Thus, the current study's goal is to examine the effects of various machining factors, such as feed rate, depth of cut, and speed, on the surface roughness of steel from annealed H13 dies.

2. MATERIAL AND METHODS

H13 steel is very versatile steel that is mostly used in hot work condition. It is a chromium-molybdenum alloy steel that finds usage at both hot and cold tooling work. The chemical configuration of AISI H13 die steel is given in the Table 1.

Table 1. Elemental configuration of H13 die steel.

Steel	Weight %age of alloying elements							
	C	Cr	Mo	Mn	V	Si	S	P
H13	0.356	5.100	1.264	0.346	1.123	0.964	0.025	0.022

The most desirable feature of H13 i.e. the hot hardness helps H13 overcome the thermal fatigue cracking which occurs because of the periodic and repeated heating and cooling cycles that occur during hot work applications. Owing to its excellent mixture of the high toughness and heat checking H13 is the mostly widely used steel compared to any other tool steel. Physical properties of H13: Density: 7750 kg/m^3, Specific gravity: 7.75, Machinability: 65% to 70% of a 1% carbon steel [18-24]. In the present research cylindrical work piece of length 100 mm and diameter of 16 mm are cut to be machined on CNC machine for the turning operation. Since the BBD generated 17 runs for the experiment, 17 work pieces were cut from 3 cylindrical rods of 600 mm using hand saw. The use of handsaw prevented impartment of any red hardness. As the hardness of the steel is very less the cutting of the samples was not a tough task. However, coating can be performed on tool to improve their performance [25-28].

The tool used in this research work is a carbide tool with designation as CCMT 09T308 MT (Fig. 1). It is a positive 80 rhombic insert that is used for medium hardness of steel, stainless steel and cast iron. The basic configuration of the tool is given below:

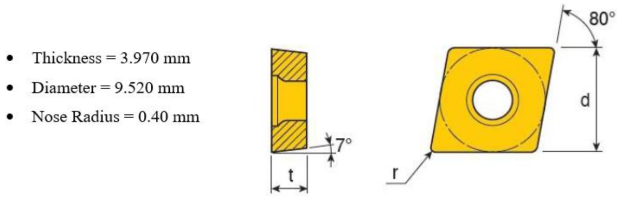

Fig. 1. Carbide tool details.

In this research work Box Behnken design (BBD) is adopted for designing and modelling the experiment. The various input parameters along with its different levels used in this thesis work are shown in Table 2.

Table 2. Cutting variables for experiment.

Parameter	Level			Units
	(- 1)	(0)	(+1)	
Feed rate	0.050	0.075	0.100	mm/rev
Depth of cut	0.250	0.375	0.500	mm
Cutting Speed	60.00	90.00	120.00	m/min

3. EXPERIMENTAL SETUP

The Fig. 2. describe the experimental setup in which the CNC machine is shown which is attached to the lathe tool dynamometer and the computer software.

Fig. 2. CNC turning centre.

Table 3. Specifications of CNC lathe m/c used.

Specification	Value
Swing over bed	400 mm
Turning diameter	225 mm
Turning length	300 mm
Speed of Spindle	30 - 5000 rpm
Power Chuck	165 mm
Spindle Motor	5.5 / 7.5 kw
X – axis Stroke	125 mm
Z – axis Stroke	325 mm
Max. No. of Tools in Turret	8
Rapid Traverse	20 m / min
Tail stock	Hydraulic

Surface roughness tester used in the experiments is of Mitutoyo company with series SJ-301 (Fig. 3). It is capable of performing measurement in any orientation including vertical an upside down. Optical accessories such as height gauge adaptor, allow measurements to be performed efficiently in various situations and setups.

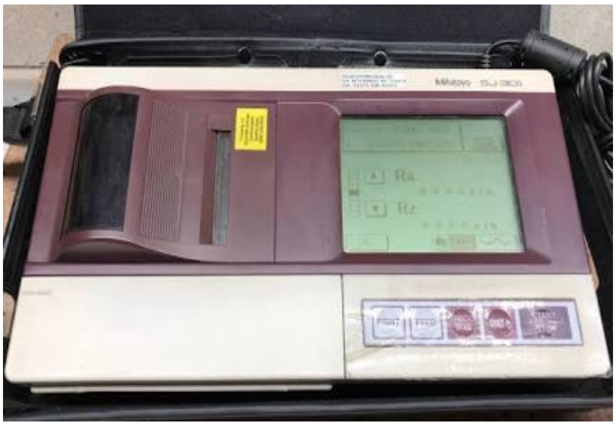

Fig. 3. Surface tester.

- Resolutions 0.01 micrometre
- Filter 2RC, PC75, Gauss
- Measuring Profile P, R, Din, Motif

4. RESULT AND DISCUSSION

In present study feed rate, depth of cut & cutting speed are considered and their possible combinations are brought up to cover the entire experiment set. The input parameters range and DOE is given in Table 4 and 5.

Table 4. Input parameter range.

Parameter	Level			Units
	(- 1)	(0)	(+1)	
Feed rate	0.050	0.075	0.100	mm/rev
Depth of cut	0.250	0.375	0.500	mm
Cutting Speed	60.00	90.00	120.00	m/min

Table 5. Design of experiment using Box Behnken design.

Std	Run	Feed (mm/rev)	Depth of Cut (mm)	Cutting Speed (m/min)
8	1	0.100	0.375	120.000
4	2	0.100	0.500	90.000
10	3	0.075	0.500	60.000
15	4	0.075	0.375	90.000
17	5	0.075	0.375	90.000
14	6	0.075	0.375	90.000
16	7	0.075	0.375	90.000
7	8	0.050	0.375	120.000
2	9	0.100	0.250	90.000
6	10	0.100	0.375	60.000
12	11	0.075	0.500	120.000
1	12	0.050	0.250	90.000
11	13	0.075	0.250	120.000
3	14	0.050	0.500	90.000
9	15	0.075	0.250	60.000
5	16	0.050	0.375	60.000
13	17	0.075	0.375	90.000

The machined surface of H 13 die steel is shown in Figure 4.

Fig. 4. Machined surface of H13 die steel.

4.1 Analysis of variance (ANOVA) for surface roughness

Table 6 displays the variance analysis for the surface roughness. The three input variables are represented as: A- feed rate, B- depth of cut and C- speed. Significance over the surface roughness and even their combination is shown.

The Table 6 represents the value of the F- value 13.54 which implies that the model is significant. The probability that the function could change because of the noise then its possibility is only 0.12%. The probability value < 0.05 indicate the model terms that are significant and in the case of the surface roughness generated we can find out that the C, AC, C^2 are significant terms of our model generated using ANOVA technique.

Table 6. ANOVA for surface roughness.

Sum of Source	Sum of Squares	DoF	Mean Square	F Value	p-value Prob > F	
Model	0.5422	9	0.0602	13.5382	0.0012	Significant
A	0.0091	1	0.0091	2.0474	0.1956	
B	0.021	1	0.021	4.7211	0.0663	
C	0.3872	1	0.3872	86.9972	< 0.0001	
AB	0.0016	1	0.0016	0.3594	0.5677	
AC	0.0552	1	0.0552	12.4081	0.0097	
BC	0.0156	1	0.0156	3.5106	0.1031	
A2	0.0144	1	0.0144	3.2375	0.1150	
B2	0.0019	1	0.0019	0.4373	0.5296	
C2	0.0348	1	0.0348	7.8341	0.0266	
Residual	0.0311	7	0.0044			
Lack of Fit	0.0196	3	0.0065	2.2851	0.2208	Not significant
Pure Error	0.0114	4	0.0028			
Cor Total	0.5734	16				
Std. Dev.	0.0667		R-Squared		0.9456	
Mean	0.8182		Adj R-Squared		0.8758	
C.V. %	8.1533		Pred R-Squared		0.7197	
PRESS	0.3327		Adeq Precision		14.0226	

The table above shows the value of different parameters like R- Square, Adjusted R- Square etc and their impact over the model. The value of the Predicted R-Squared value is close to the Adjusted R- Squared value which states the justification of the regression model for the surface roughness. The value of the adequate precision ratio for the developed model is 14.0226 which is greater than 4 which provides the explanation that the model has an adequate signal to noise ratio to allow the model to be used effectively. The correlation coefficient R^2 is 0.94 which is close to unity explains the reliability of the generated model for the surface roughness.

The final developed equation for the surface roughness model is:

$$\text{Surface roughness} = 0.76 + 0.034A + 0.051B - 0.22C + 0.020AB + 0.12AC + 0.063BC + 0.058A^2 - 0.022B^2 + 0.091C^2 \quad (1)$$

Here, A- feed rate, B- depth of cut and C- speed.

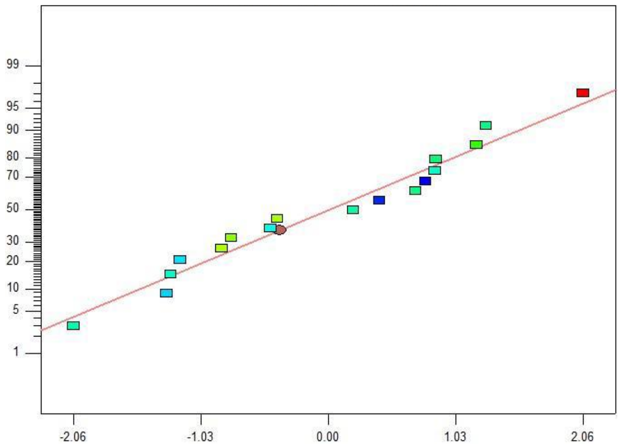

Fig. 5. Normal plot of residuals.

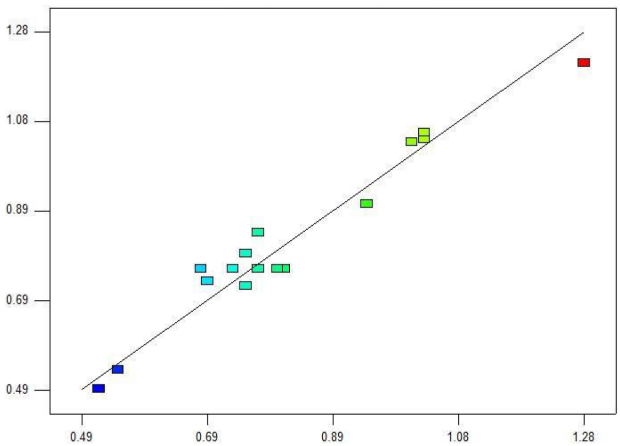

Fig. 6. Predicted vs actual plot for surface roughness.

Terms having (+) symbol show synergetic effect whereas terms with (-) symbol show antagonistic effect on the response. The Normal plot of residuals and Predicted vs actual plot for surface roughness is depicted in Fig. 5. and 6 respectively.

We find that the residuals (Fig. 5) are lying on a straight path which tells that the errors are normally distributed. It also explains that the experimental runs are scattered unevenly within a particular range set. Fig. 6. depicted the graph of the predicted results of response to the experimental result obtained for surface roughness. The above results signify the reliability of the model developed using BBD for the prediction of the surface roughness.

4.2 Impact of individual parameter on surface roughness

Perturbation curve is a methodology that is used for representing the effect of the input parameter over the output response and find out their impact over the model generated. Perturbation plot is a plot which provides silhouette views of the response surface (Fig. 7). This plot really helps when choosing constants and axes for contour and three-dimensional charts. When all other elements are maintained constant at the reference value and each factor travels away from the selected reference point, the perturbation plot for response surface designs illustrates how the response varies. The default reference point, or the coded zero level of each factor, is placed by Design-Expert at the center of the design space.

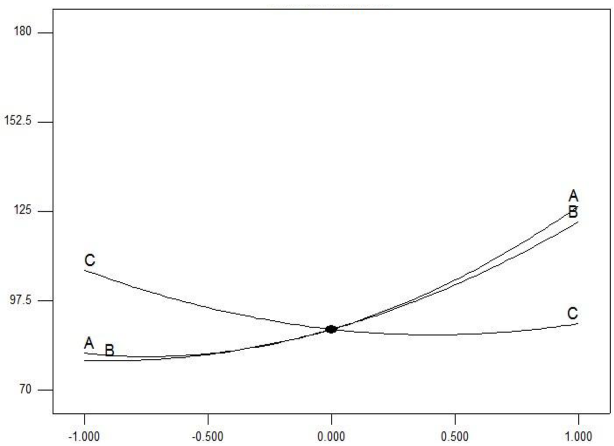

Fig. 7. Perturbation plot.

The Fig. 7. shows the interaction of three parameters on the output response. The Y-axis of the graph shows the surface roughness value for which the input parameters are showing their effect, while the X-axis represents the levels of the input parameter in coded units. The -1 represents the minimum value of the input parameter and +1 symbolizes the input parameter's maximum value. The cutting speed shows an inverse relation with the surface roughness and is the most key influencing factor. The surface roughness value decreases with increasing cutting speed. This occurs because of the high temperature which causes the plasticity of the material thus engaging in reduction of the surface roughness. The value of feed rate and depth of cut show direct relation to the surface roughness and this phenomenon is basically because of increase in the contact surface area. The Fig. 8. to 10 shows the interaction plots in 3D. The impact individual parameter is brought about by keeping the one parameter constant and the entire focus is made over the factor under consideration.

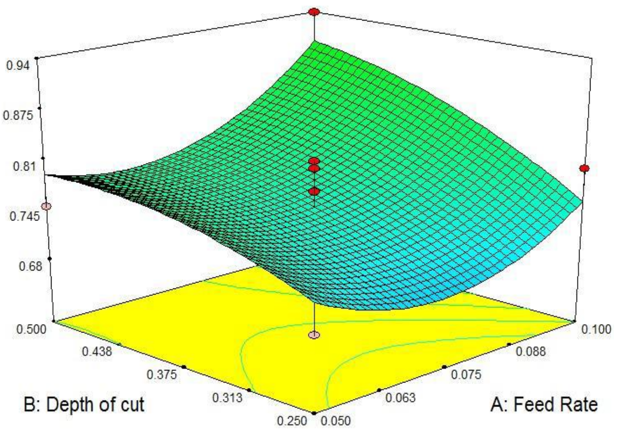

Fig. 8. 3D plot for feed rate and depth of cut.

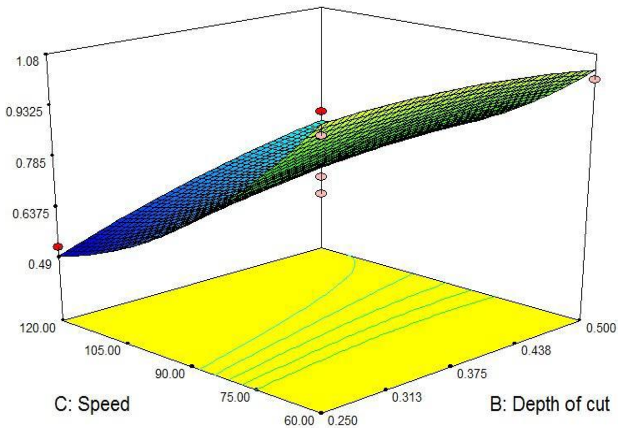

Fig. 9. 3D plot for depth of cut and speed.

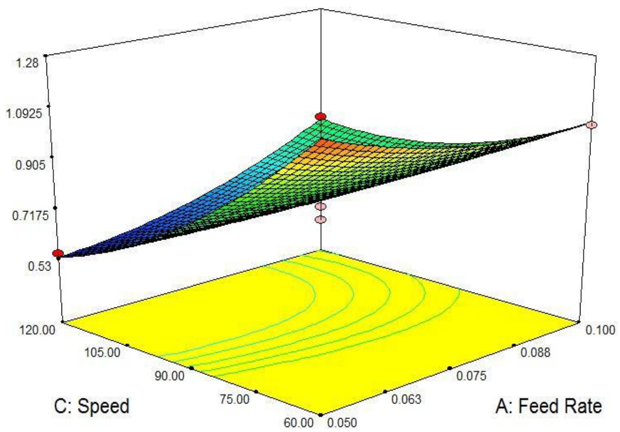

Fig. 10. 3D plot for feed rate and speed.

4.3 Numerical optimization

The confirmation test carried using numerical optimization technique in which we set the goal required for the response and find the optimal solution. This method helps to find points prediction for optimal setting of response. Table 7 shows the result obtained by the optimizing method.

Table 7. Numerical optimization result matrix.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A	is in range	0.05 mm/rev	0.1 mm/rev	1	1	3
B	is in range	0.25 mm	0.5 mm	1	1	3
C	is in range	60 m/min	120 m/min	1	1	3
Surface roughness	minimize	0.52 µm	1.28 µm	1	1	3
Solution						
Number	**Feed Rate**	**Depth of cut**	**Speed**	**Surface roughness**	**Desirability**	
1	0.055 mm/rev	0.251 mm	111.03 m/min	0.49 µm	1	

5. CONCLUSIONS

The work done in the present research deals with the machining of the H13 tool steel in annealed state w.r.t. three-input variables and the output response surface roughness. The developed RSM model using BBD is employed to predict the surface roughness produced after turning of annealed H13 steel using carbide tool and the following conclusions were drawn out:

- The feed rate and the depth of cut have a direct relation with the surface roughness but the impact of these two components has shown slow increasing impact over the value of the surface roughness.
- The cutting speed is the most influential factor for the surface roughness values. The cutting speed is inversely related to the surface roughness value.

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