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Optimization of the Cutting Parameters of SS 304 for CNC Turning Operation

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*Abstract—**Quality and productivity play significant role in today's manufacturing market. Quality of a product can be described by various quality attributes. The attributes may be quantitative or qualitative. In on-line quality control controller and related equipments are provided with the job under operation and continuously the quality is being monitored. If quality falls down the expected level the controller supplies a feedback in order to reset the process environment. In off-line quality control the method is either to check the quality of few products from a batch or lot (acceptance sampling) or to evaluate the best process environment capable of producing desired quality product. This invites optimization problem which seeks identification of the best process condition or parametric combination for the said manufacturing process [2]. If the problem is related to a single quality attribute then it is called single objective (or response) optimization. If more than one attribute comes into consideration it is very difficult to select the optimal setting which can achieve all quality requirements simultaneously. Otherwise optimizing one quality feature may lead severe quality loss to other quality characteristics which may not be accepted by the customers. In order to tackle such a multi-objective optimization problem, the present study applied extended Taguchi method. The study aimed at evaluating the best process environment which could simultaneously satisfy requirements of both quality and as well as productivity. This study investigates the effects of various parameters such as depth of cut, speed and feed on the material removal rate and surface roughness of the SS304 in a CNC turning machine.***

Keywords— SS304, Taguchis DOE, CNC,S/N ratio,ANICA,Regression

I. INTRODUCTION

Turning process is performed to modify shape, dimension, and surface roughness of a work piece by removing the unwanted material it in the form of chips [3]. The theory of metal cutting and chip formation are complicated, not only plasticity but also thermodynamic and mathematical analysis are involved. Turning is one of the most widely used metal removal processes in industry. Turning is largely used to mate with other parts in die, aerospace, automotive and machinery design also in manufacturing industries. This paper investigate the cutting parameters of SS 304 in CNC turning machine and optimize these cutting parameters like depth of cut, speed and feed.

II. LITERATURE REVIEW

H. Yanda conducted an experiment on optimization of material removal rate, surface roughness and tool life on conventional dry turning of fcd700 (2010).Experimental results demonstrate that the optimal condition of the responses cannot be achieved simultaneously with a particular combination of control parameters settings because the optimum condition of the turning process is concerned with minimizing surface roughness, while maximizing the MRR and tool life. For instance, the optimum Ra and MRR are obtained at highest level of cutting speed. To obtain maximum MRR, cutting speed should be set as high as possible and feed rate also should be set as high as possible. Based on FEM simulation, the higher feed rate will give more number of meshes, result more interface contact area and more MRR. Higher cutting speed should cause more velocity in creating the deformed chip, and this resulted in more MRR. The simulations results of MRR were agreeable with MRR experiment results and the errors are less than 17%.

K.Saravanakumar done Optimization of CNC Turning Process Parameters on INCONEL 718 Using Genetic Algorithm (2012).He found that the optimum combination of input parameters for maximization of material removal rate is found to be cutting speed 79.99m/min, feed rate 0.25mm/rev, depth of cut 0.1mm and best fitness value is 2122.23mm3/min.

M. Naga done Optimization of Performance Measures in CNC Turning using Design of Experiments(RSM) in 2010.The present study develops the model for three different parameters namely speed, feed and depth of cut for turning process in CNC LATHE on aluminum material using response surface method(RSM).The second order models have been validated with the analysis of variance. It is found that the feed and depth of cut have more significant effect while speed has less significant effect on MRR and feed and depth of cut has equal significance on surface roughness(R).

H. K. Dave did Effect of machining conditions on MRR and surface roughness during CNC Turning of different Materials Using TiN Coated Cutting Tools – A Taguchi approach and his founding are

1) The analysis of the experimental observations highlights that MRR in CNC turning process is greatly influenced by depth of cut.

2) It is found that if speed is increase then MRR would increase and positive inserts are superior as compare to negative inserts for more MRR.

Bikram Jit Singh did a study on the Behavior study of cutting parameters on Material Removal Rate for a non-ferrous material while turning on a CNC turning center (2012).Considering the individual parameters, had been found that depth of cut and cutting speed to be the most influencing parameter, followed by and feed rate. Maximum material removal rate is achieved at cutting speed 150 m/min, feed rate of 0.17 mm/rev and at a depth of 2 mm.

III. METHODOLOGY

A. Work Piece

SS304 is the basic alloy. Type 304 (18-8) is an austenitic steel possessing a minimum of 18% chromium and 8% nickel, combined with a maximum of 0.08% carbon. It is nonmagnetic steel which cannot be hardened by heat treatment, but instead. Must be cold worked to obtain higher tensile strengths. The 18% minimum chromium content provides corrosion and oxidation resistance. The alloy's metallurgical characteristics are established primarily by the nickel content (8% mm.), which also extends resistance to corrosion caused by reducing chemicals. Carbon, a necessity of mixed benefit, is held at a level (0.08% max.) that is satisfactory for most service applications. The stainless alloy resists most oxidizing acids and can withstand all ordinary rusting. It is immune to foodstuffs, sterilizing solutions, most of the organic chemicals and dyestuffs, and a wide variety of inorganic chemicals. Type 304, or one of its modifications, is the material specified more than 50% of the time whenever a stainless steel is used. Because of its ability to withstand the corrosive action of various acids found in fruits, meats, milk, and vegetables, Type 304 is used for sinks, tabletops, coffee urns, stoves, refrigerators, milk and cream dispensers, and steam tables. It is also used in numerous other utensils such as cooking appliances, pots, pans, and flatware [4]. Type 304 is especially suited for all types of dairy equipment - milking machines, containers, homogenizers, sterilizers, and storage and hauling tanks, including piping, valves, milk trucks and railroad cars. This 18-8 alloy is equally serviceable in the brewing industry where it is used in pipelines, yeast pans, fermentation vats, storage and railway cars, etc. The citrus and fruit juice industry also uses Type 304 for all their handling, crushing, preparation, storage and hauling equipment. In those food processing applications such as in mills, bakeries, and slaughter and packing houses, all metal equipment exposed to animal and vegetable oils, fats, and acids is manufactured from Type 304.Type 304 is also used for the dye tanks, pipelines buckets, dippers, etc. In the marine environment, because of it slightly higher strength and wear resistance than type 316 it is also used for nuts, bolts, screws, and other fasteners. It is also used for springs, cogs, and other components where both wear and corrosion resistance is needed.

B. Experimental Details

DOE is a systematic approach to investigation of a system or process. A series of structured tests are designed in which planned changes are made to the input variables of a process or system. The effects of these changes on a pre-defined output are then assessed. For each input variable, a number of levels are defined that represent the range for which the effect of that variable is desired to be known. An experimental plan is produced which tells the experimenter where to set each test parameter for each run of the test. The response is then measured for each run. The method of analysis is to look for differences between response (output) readings for different groups of the input changes. Taguchi 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 varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations [2]. This 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. The Taguchi method is best used when there are an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

C. Taguchi's Design of Experiment

Design of Experiments (DOE) is an experimental strategy in which effects of multiple factors are studied simultaneously by running tests at various levels of the factors. Taguchi DOE is a powerful and efficient method over other traditional methods [5]. The main difference between Taguchi DOE and full factorial method is regards the number of experiments to be done. For a 3 factor- 3 level combinations the total experiments to be conducted in full factorial method is 27. Whereas in Taguchi DOE only 9 experiments has to be done [8]. For a DOE is a systematic approach to investigation of a system or process. A series of structured tests are designed in which planned changes are made to the input variables of a process or system. The effects of these changes on a pre-defined output are then assessed. For each input variable, a number of levels are defined that represent the range for which the effect of that variable is desired to be known [6]. The response is then measured for each run. The method of analysis is to look for differences between response (output) readings for different groups of the input changes [7]. These differences are then attributed to the input variables acting alone (called a single effect). MiniTab 16 software was used for generating the Taguchi's orthogonal array.

IV. EXPERIMENTAL PROCEDURE

For studying the degree of influence of the process parameters during CNC turning of SS 304, three factors, each at three levels are taken as shown in Table 1. In this research, nine experiments were conducted at different parameter levels. For this L9 orthogonal array was used, which has nine rows corresponding to the number of tests (Table 2).

TABLE I. CUTTING PARAMETERS

Parameters	Levels		
Cutting speed (M/Min)	120	140	160
Feed (MM)	0.08	0.1	0.12
Depth of cut (MM)	0.2	0.4	0.6

TABLE II. ORTHOGONAL ARRAY

Sl. No.	Velocity (M/S)	Feed (MM)	Depth of Cut (MM)
1	120	0.08	0.2
2	120	0.1	0.4
3	120	0.12	0.6
4	140	0.08	0.4
5	140	0.1	0.6
6	140	0.12	0.2

V. RESULT AND DISCUSSION

A. Surface Roughness

Adoption of Taguchi method of design of experiment is to reduce the number of experiments, yet cover the entire parameter space with the help of a special design of orthogonal array. The results of such experiments are then transformed into a signal to noise (S/N) ratio to measure the deviation of the performance characteristics from the desired values.

In the experiment, the desired characteristic for surface roughness is lower the better.

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i{}^2)\right] \quad (1)$$

TABLE III. SIGNAL TO NOISE RATIO FOR SURFACE ROUGHNESS

Sl NO	Speed	Feed	DOC	Surface Roughness	SNRA
1	120	0.08	0.2	1.50	-3.533
2	120	0.1	0.4	0.93	0.618
3	120	0.12	0.6	0.90	0.931
4	140	0.08	0.4	0.96	0.379
5	140	0.1	0.6	0.69	3.227
6	140	0.12	0.2	1.07	-0.590
7	160	0.08	0.6	0.69	3.206
8	160	0.1	0.2	0.74	2.627
9	160	0.12	0.4	0.80	1.942

Table 3 shows the average surface roughness value and their corresponding signal to noise (S/N) ratios.

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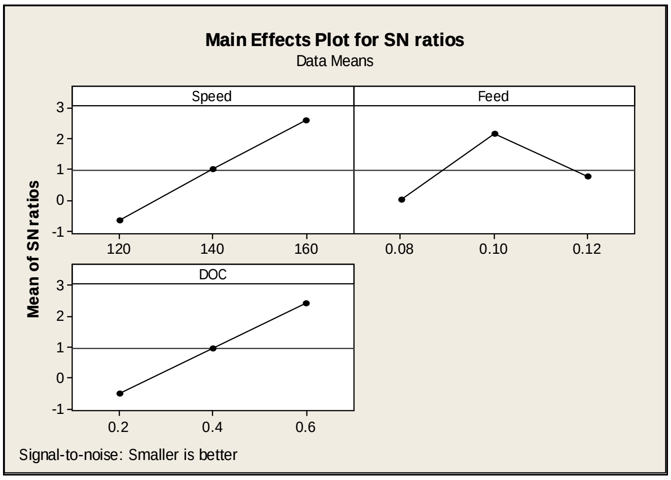

Fig. 1. Signal to Noise Plot for Surface Roughness.

The main effects of input parameters are shown in figure 1 with the help of Signal to Noise.

TABLE IV. RESPONSE TABLE FOR SURFACE ROUGHNESS S/N RATIOS (SMALLER IS BETTER)

Level	Speed	Feed	DOC
1	-0.6614	0.0172	-0.4989
2	1.00519	2.15741	0.97948
3	2.59173	0.7609	2.45491
Delta	3.25314	2.14021	2.95379
Rank	1	3	2

TABLE V. ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS

Source	DF	SS	MS	F	P	% of contribution
Speed	2	15.8776	7.9388	17.12	0.055	42.94
Feed	2	7.0838	3.5419	7.64	0.116	19.16
DOC	2	13.0874	6.5437	14.11	0.066	35.39
Residual Error	2	0.9273	0.4636			2.51
Total	8	36.9761				

Table 4 shows the response table of Signal to Noise ratios for surface roughness. Based on this analysis, low surface roughness is obtained at speed 160, feed 0.1, and DOC 0.6. In the analysis, speed is shown as the most influencing parameter followed by DOC and feed.

Based on the ANOVA results in Table 5 the percentage contribution of various factors to surface roughness is identifiable. Here, speed is the most influencing factor followed by DOC. The percentage contribution of speed and DOC towards surface roughness is 42.94% and 35.39% respectively.

The optimal combination is:
Speed = 160 M/MM
Feed = 0.1 MM
DOC=0.6 MM

Regression equation
Regression equation is used to find the optimum surface roughness at any cutting parameters. We can apply this equation for optimum values for surface roughness.
Surface Roughness = 2.87 - 0.00918Speed - 3.19 Feed - 0.860DOC

B. Machining Time

The results of taguchi experiments are then transformed into a signal to noise (S/N) ratio to measure the deviation of the performance characteristics from the desired values.

For machining time, the desired characteristic for machining time is lower the better.

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i{}^2)\right] \qquad (2)$$

TABLE VI. SIGNAL TO NOISE RATIO FOR MACHINING TIME

Sl NO	Speed	Feed	DOC	Machining Time	SNRA
1	120	0.08	0.2	58.72	-35.376
2	120	0.1	0.4	50.25	-34.023
3	120	0.12	0.6	42.69	-32.607
4	140	0.08	0.4	55.16	-34.832
5	140	0.1	0.6	44.72	-33.010
6	140	0.12	0.2	37.7	-31.52
7	160	0.08	0.6	49.53	-33.897
8	160	0.1	0.2	40.07	-32.056
9	160	0.12	0.4	32.47	-30.230

Table VI shows the average machining time value and their corresponding signal to noise (S/N) ratios.

TABLE VII. RESPONSE TABLE FOR MACHINING TIME

Level	Speed	Feed	DOC
1	-34	-34.7	-32.99
2	-33.12	-33.03	-33.03
3	-32.06	-31.45	-33.17
Delta	1.94	3.25	0.18
Rank	2	1	3

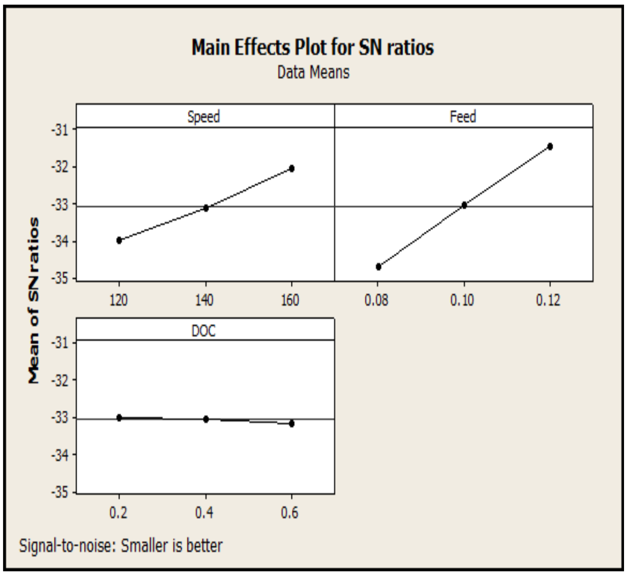

Fig. 2 .Signal to Noise Plot for Machining Time

Table VII shows the response table of Signal to Noise ratios for machining time. Based on this analysis, low machining time is obtained at speed 160, feed 0.12, and DOC 0.2. In the analysis, speed is shown as the most influencing parameter followed by DOC and feed.

TABLE VIII. ANALYSIS OF VARIANCE FOR MACHINING TIME

Source	DF	SS	MS	F	P	% of contribution
Speed	2	5.6653	2.83263	34.73	0.028	26.10
Feed	2	15.8243	7.91216	97.01	0.01	72.89
DOC	2	0.0564	0.02822	0.35	0.743	0.26
Residual Error	2	0.1631	0.08156			0.75
Total	8	21.7091				

Based on the ANOVA results in Table 8 the percentage contribution of various factors to machining time is identifiable. Here, feed is the most influencing factor followed by speed. The percentage contribution of feed and speed towards machining time is 72.89% and 26.1% respectively.
The optimal combination is:
Speed = 160 M/MM
Feed = 0.12 MM
DOC=0.2 MM

Regression equation
Regression equation is used to find the optimum machining time at any cutting parameters. We can apply this equation for optimum values for machining time.
Machining Time = 122 - 0.247 Speed - 421 Feed + 0.37 DOC

C. Material Removal Rate

The required result for MRR is high. High MRR means high production rate. So the desired characteristic for MRR is higher the better.

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{{y_i}^2}\right)\right] \qquad (3)$$

TABLE IX. SIGNAL TO NOISE RATIO FOR MRR

Sl NO	Speed	Feed	DOC	MRR	SNRA1
1	120	0.08	0.2	14.94	23.487
2	120	0.1	0.4	30.12	29.577
3	120	0.12	0.6	45.38	33.137
4	140	0.08	0.4	30.21	29.603
5	140	0.1	0.6	45.25	33.112
6	140	0.12	0.2	15.03	23.539
7	160	0.08	0.6	45.4	33.141
8	160	0.1	0.2	15.05	23.551
9	160	0.12	0.4	30.12	29.577

Table IX shows the average MRR value and their corresponding signal to noise (S/N) ratios.

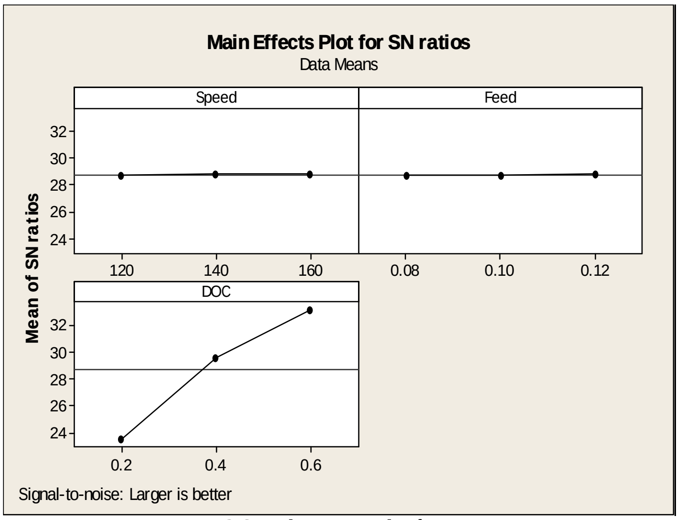

Fig. 3.Signal to Noise Plot for MRR

The main effects of input parameters are shown in figure 3 with the help of Signal to Noise ratio.

TABLE X. SIGNAL TO NOISE RATIO FOR MRR

Level	Speed	Feed	DOC
1	28.73	28.74	23.53
2	28.75	28.75	29.59
3	28.76	28.75	33.13
Delta	0.02	0.01	9.6
Rank	2	3	1

Table X shows the response table of Signal to Noise ratios for MRR. Based on this analysis, high MRR is obtained at speed 120, feed 0.08, and DOC 0.6. In the analysis, DOC is shown as the most influencing parameter followed by speed and feed.

TABLE XI. ANALYSIS OF VARIANCE FOR MRR

Source	DF	SS	MS	F	P	% of contribution
Speed	2	0.001	0.0004	0.037	0.733	0.00
Feed	2	0	0	0.04	0.965	0.00
DOC	2	141.537	7007686	61240.6	0	100.00
Residual Error	2	0.002	0.0012			0.00
Total	8	141.54				

Based on the ANOVA results in Table XI the percentage contribution of various factors to MRR is identifiable. Here, DOC is the most influencing factor. The percentage contribution of DOC is 100%.
The optimal combination is:
Speed = 120 M/MM
Feed = 0.08 MM
DOC=0.6 MM

Regression equation
Regression equation is used to find the optimum MRR at any cutting parameters. We can apply this equation for optimum values for MRR.

MRR = - 0.305 + 0.00108 Speed - 0.17 Feed + 75.8 DOC

D. Tool Wear

Tool wear should be minimum as possible while machining. In the experiment, the desired characteristic for tool wear is lower the better.

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i{}^2)\right] \quad (4)$$

TABLE XII. SIGNAL TO NOISE RATIO FOR TOOL WEAR

Speed	Feed	DOC	Tool Wear	SNRA
120	0.08	0.2	0.04	27.959
120	0.1	0.4	0.03	30.458
120	0.12	0.6	0.04	27.959
140	0.08	0.4	0.03	30.458
140	0.1	0.6	0.02	33.979
140	0.12	0.2	0.04	27.959
160	0.08	0.6	0.04	27.959
160	0.1	0.2	0.04	27.959
160	0.12	0.4	0.07	23.098

TABLE XIII. RESPONSE TABLE FOT TOOL WEAR

Level	Speed	Feed	DOC
1	28.79	28.79	27.96
2	30.8	30.8	28

3	26.34	26.34	29.97
Delta	4.46	4.46	2.01
Rank	1.5	1.5	3

Table XII shows the average tool wear value and their corresponding signal to noise (S/N) ratios

Table XIII shows the response table of Signal to Noise ratios for tool wear. Based on this analysis, low tool wear is obtained at speed 140, feed 0.1, and DOC 0.2. In the analysis, speed and feed are shown as the equal influencing parameter followed by DOC.
The main effects of input parameters are shown in figure 4 with the help of Signal to Noise ratio. From this fig its clearly notify that at which points the tool wear is less.
Percentage of contribution of each input parameter is found by using anova.

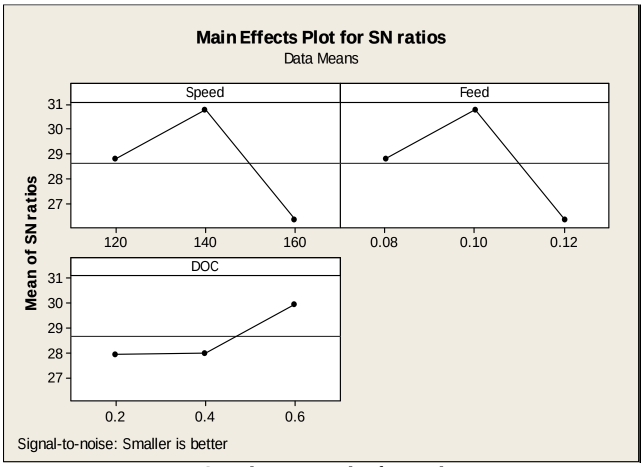

Fig. 4.Signal to Noise Plot for Tool Wear

TABLE XIV. SANALYSIS OF VARIANCE FOR TOOL WEAR

Source	DF	SS	MS	F	P	% of contribution
Speed	2	29.9376	14.9688	75.15	0.013	43.93
Feed	2	29.9376	14.9688	75.15	0.013	43.93
DOC	2	7.8762	3.9381	19.77	0.048	11.56
Residual Error	2	0.3984	0.1992			0.58
Total	8	68.1498				

Based on the ANOVA results in Table XIV the percentage contribution of various factors to tool wear is identifiable. Here, speed and feed are equal influencing factors followed by DOC. The percentage contribution of speed and feed towards tool wear is 43.93% and 43.93% respectively.
The optimal combination is:
Speed = 140 M/MM
Feed = 0.1 MM
DOC=0.6 MM

Regression equation

Regression equation is used to find the optimum tool wear at any cutting parameters. We can apply this equation for optimum values for tool wear.
Tool Wear = - 0.0344 + 0.000333 Speed + 0.333 Feed - 0.0167 DOC

VI. Conclusion and Future Work

In this study, CNC turning operation is done under various experimental conditions and the MRR, surface roughness, tool wear, and machining time were measured. 9 levels of experiments had been done. The most effecting factors on MRR is DOC, on surface roughness is speed and DOC, machining time is feed and speed, tool wear is speed and feed. From the regression equation the output parameters can be optimized for any machine with different combination of input parameters.

Multi objective optimization is not done in this paper and this can be optimized with the help of fuzzy logic or ANN.

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