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Optimization of Drilling Parameters of JIG Boring Machine

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ABSTRACT

In this project work an experimental study is being carried out for optimization of drilling process parameters of Jig boring machine to provide better tool life as well as high material removal rate (MRR). Taguchi method with L_9 orthogonal array is used, for design of experiment and for analysis purpose grey relational analysis with fuzzy logic is used. Four main process parameters spindle speed, feed rate, depth of cut , and drill tool diameter are investigated in order to minimize thrust force and maximize MRR . Mild steel is used as work material and high speed steel twist drill as tool. Mild steel is well known extensively used engineering material in various industries such as steel making, structural, aerospace and aircraft industries. For the accomplishment of our project jig boring machine is used. Jig boring machine almost like semi CNC machine in terms of precision and accuracy in fact the jig borer's development helped advance machine tool technology toward later NC and CNC development.

Keywords---- Optimization, Grey fuzzy analysis, JIG boring.

I. INTRODUCTION

The increase of consumer needs for quality of drilled holes in terms of precision and better surface finish has driven metal cutting industry to continuously improve quality of cutting process and jig boring machine is one of the most precise and efficient way to get the desired output. It is used to get the products, which require very low tolerances.

The jig boring machine used in project work is model no. 2450, the model 2450 precision jig boring machine is designed for drilling holes in jigs , fixtures and parts where high class accuracy is required for the center to center distance of drilled holes. The machine can also be used for laying out precision templates for checking linear dimensions and center to center distance. The model 2450 jig borer is not only a very precise machine for performing various boring operations but also a measuring machine for precision transpositions in the 'rectangular coordinate system'. The machine is also used for light milling jobs and is provided for this purpose with a power feed for the table and saddle.

Grey relational analysis (GRA) is used to solve complicated interrelationships among the multiple performance characteristic problems effectively. In GRA, system has a level of information between black and white. In other words, in a grey system, some information is known and some information is unknown. The grey means the primitive data with poor, incomplete, and uncertain information in the grey systematic theory, the incomplete relation of information among these data is called the grey relation. Grey relational analysis is to compare quantitative analysis between every sequence in the grey system dynamically, and to describe the relation degree between an objective sequence (a collection of measurements or experimental results) and a reference sequence in the grey system. The measure of relevancy between two sequences can be expressed as the grey relational coefficient, and then grey relational grade (GRG) is obtained by averaging the grey relational coefficient [2].

The theory of fuzzy logic provides a means for representing uncertainties associated with vagueness, imprecision and/or lack of information regarding the problem in hand. Zadeh suggested that set membership is the key to decision making when faced with uncertainty. A fuzzy set comprises of infinite number of membership functions that maps a universe of objects, say X, onto the unit interval [0, 1]. Thus uncertainty in the grey relational grade can be handled by fuzzy logic approach and thereby a fuzzy reasoning of multiple performance characteristics have been developed and is referred as grey fuzzy reasoning grade (GFRG). Fuzzy logic approach involves fuzzification of input data, rule inference and defuzzification [1].

II. REVIEW OF LITERATURE

An extensive literature review has been studied and observed for selecting drilling process parameters. A. Krishnamoorthy et al [2] have found effect of input parameters spindle speed, point angle, and feed rate on output responses as thrust force, torque, entry delamination, exit delamination and eccentricity of the holes. M. Saravanan et al [12] have selected feed rate and the torque of drilling tool as input parameters, and the optimization parameters selected are hole eccentricity and material removal rate. . Reddy Sreenivasalu et al have taken input parameters as Cutting speed, feed rate, drill diameter, point angle and cutting fluid mixture ratio and response as surface roughness and roundness error.

Different literature review has been presented to show the ranges of material used in drilling research work. M. K. A Mohd Ariffin et al [7] glass fiber reinforced plastic (GFRP) sandwich part number of BMS 4 – 17. Reddy Sreenivasalu et al have used Al 6061 alloy for their research work. Shivapragash et al. (2013) focused on composite Al-TiBr2.

There are different project work have been done on various kind of drilling machine, as per literature review. Yogendra Tyagi et al [4] have worked on CNC drilling machine, with a mild steel work piece and HSS tool. Arshad Noor Siddiquee et al [9] focused CNC lathe machine using solid carbide cutting tool on material AISI 321 austenitic stainless steel. Shivapragash et al. (2013) focused on multiple response optimization of drilling process for composite Al-TiBr2 to minimize the damage events occurring during drilling process. Taguchi method with grey relational analysis was used to optimize the machining parameters.

It was observed that the process parameters in drilling operation are optimized to get the product with higher quality, Taguchi technique for design of experiment and grey fuzzy technique for optimization are implemented successfully. All the review of literature has left the scope to study the optimization of the machining parameters spindle speed, feed rate, depth of cut, and drill tool diameter, and to investigate influence of all these parameters on material removal rate and thrust force.

III. MATERIAL AND METHOD

3.1. Material

Mild steel, also known as plain-carbon steel has a relatively low tensile strength, but it is cheap and easy to form. Mild steel is the least expensive of all steel and the most commonly used in nearly every type of product created from steel. Many of the daily use objects are made using mild steel, including automobile chassis, motorcycle frames.In our project mild steel contains 0.13% of carbon, manganese (Mn) 0.49%, silicon (Si) 0.20% , phosphorus (P) 0.017% , sulphur (S) 0.012%. A rectangular mild steel plate of size 250mm × 88mm × 18mm is used. The density is approximately 7.85 g/cm^3 (7850 kg/m^3 or 0.284 lb/in^3) and the Young's modulus is 210 GPa (30,000,000 psi), Melting Point (1400ºC) ,Bulk Modulus(140GPa)

3.2. Experimental parameters and their measurement: Input parameters

a. Spindle speed : The speed of a drill is usually measured in terms of the rate at which the outside or periphery of the tool moves in relation to the work being drilled. It is expressed in rpm (revolution per minute).

b. Feed rate : It may be defined as the relatively small movement per cycle of the cutting tool, It is expressed in millimeter per revolutions (mm/rev).

c. Depth of cut : It can be defined as the thickness of the material removed during machining. It is the cutting depth in the work piece by the tool.

d. Drill tool diameter : The diameter over the margins of the drill measured at the point.

Table 1 shows the input parameters and their levels taken for the experiment.

Table 1: domain of experiments

Factors	Unit	Level-1	Level-2	Level-3
Spindle speed(A)	rpm	200	800	2000
Feed rate(B)	mm/rev	0.03	0.06	0.09
Depth of cut(C)	mm	10	12	14
Drill diameter(D)	mm	8	10	12

Output parameters

a. Material removal rate: The material removal rate (MRR) in drilling is the volume of material removed by the drill per unit time. It can also be taken as weight of chip removed per unit time. The MRR was determined from the amount of material worn during the period of machining. The high precision digital balance meter precision up to 0.0001 gm was used to weigh the samples.

b. Thrust force: it may be explained as the force required by the drill tool during drilling operation. A drill tool dynamometer is used to measure the thrust force during processing.

3.3 Experimental set up

a. Jig boring machine

(a)

(b)

Fig. 1: (a) jig boring machine model no. 2450 and (b) drill tool dynamometer

Specification of jig boring machine

Capacity	Max. diameter of drilling : 40mm
	Max. diameter of boring : 250mm
Max. travel of table	Longitudinal : 10000mm
	Transverse : 600mm
Spindle	Max. travel of spindle : 250mm
	Max. vertical travel of spindle housing : 250mm
	Range of spindle speed : 200-2000rpm
	Range of spindle feed : 0.03-0.11mm/rev

Working conditions: the manufacturer guarantees precise operation of the machine only if following states are strictly observed. The machine should be mounted in a special room completely isolated from vibrations produced by the other machining operations nearby.

- Temperature in room should be 20±2ºC
- Humidity of the ambient air should not exceed 55 %

b. Drill tool dynamometer: This is strain gauge based Drill Tool Dynamometer and Micro Controller Based Digital Indicator designed to measure thrust and torque during drilling operation. This dynamometer is suitable for drilling a hole up to 25mm size in Mild Steel. It has Digital force indicators to measure force up to 250kg capacity. Figure 1 shows dynamometer.

d. Tool specification: For drill tool we have preferred is made of high speed steel tapered shank twist drills. The twist drills of 8 mm (flute length: 75 mm: overall length: 158 mm), 10 mm (flute length: 87 mm: overall length: 168 mm) and 12 mm (flute length: 100 mm: overall length: 182 mm).

3.4 METHODOLOGY

a. Design of experiment

The experiments were designed on the Taguchi's method. Taguchi has given a well defined matrix model called orthogonal array. Use of Taguchi's orthogonal array makes this process simpler by reducing the number of experiments. As per Taguchi method the total degree of freedom of selected orthogonal array must be greater than or equal to the total DOF required for experiment [16]. There are four process parameters for three level, so DOF required for experiment [4× (3-1)], i.e. 8, thus L9 orthogonal array were taken . Table 2 shows L9 orthogonal array.

Table 2: L9 orthogonal array

Sl. No.	A	B	C	D
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

b. S/N ratio to compute quality characteristics

This ratio has the three kind of characteristics which are 'larger the better' , 'smaller the better', and 'nominal the better'[9]. In our study we have two major output parameters thrust force, and material removal rate (MRR), So thrust force has considered for 'smaller the better' type and MRR for 'larger the better' type.

For larger the better type

$S/N\ ratio = -10 \log (1/n) \sum (1/y_{ij}^2)$ ….. (1)

For smaller the better type

$S/N\ ratio = -10 \log (1/n) \sum (y_{ij}^2)$ …..(2)

Where n is the number of replication for each experiment and y_{ij} is the response replication values.

c. Normalization of S/N ratio of the quality characteristics (data processing) using grey relational analysis

The grey theory is one of the important theories and can be used for the uncertainty, multi-input and discrete data. A grey system has a level of information between black and white. The grey relational analysis is a measurement of an absolute value of the data difference between sequences, and is also used to measure an approximate correlation between sequences. It is an effective means of analyzing the relationship between the sequences with less data and can analyze many factors. [1]

There are various methodologies of data pre-processing available for grey relational analysis. If the target value of the original sequence is infinite, then it has a characteristic of the ''higher-the- better''. The original sequence can be normalized as follows:

$$x_{ij} = \frac{y_{ij} - \min(y_{ij})}{\max(y_{ij}) - \min(y_{ij})} \quad \text{............(3)}$$

For lower-the-better criterion, the normalized data can be expressed as:

$$x_{ij} = \frac{\max(y_{ij}) - y_{ij}}{\max(y_{ij}) - \min(y_{ij})} \quad \text{..........(4)}$$

Where x_{ij} is normalized S/N ratio, y_{ij} is S/N ratio obtained from Taguchi analysis, min. y_{ij} and max. y_{ij} are the min. and max. value of S/N ratio respectively.

d. Computation of grey relational coefficient and grey relational grade:

The grey relational analysis is used to measure the relevancy between two systems. The sequences used in the grey relational analysis are called as a grey relational coefficient [2]. The grey relational coefficient can be calculated as:

$$c_{ij} = \frac{\Delta\min + \beta\,\Delta\max}{\Delta ij + \beta\,\Delta\max} \quad \text{...........(5)}$$

$\Delta_{ij} = |x_0 - x_i|$ is difference of the absolute value, also can be treated as quality loss, β is distinguishing coefficient whose value is adjusted to meet the systematic actual need and defined in the range between 0 and 1 , here $\beta = 0.5$, Δ_{min} and Δ_{max} are the min. and max. values. Grey relational grade is the average value of grey relational coefficient of all the response variables.

e. Computation of grey fuzzy reasoning grade:

MATLAB toolbox is used for finding the grey–fuzzy reasoning grade. The inputs of each variable are being converted into linguistic fuzzy subset with triangular membership function and there range is defined. The output is also undergone with same procedure and they have also been given triangular fuzzy subset.

Third stage is to generate fuzzy rule base, which is a series of IF, THEN control rule. In this project max min compositional operation of Mamdani is adopted.

For example let x_1, x_2, be the GRC, and A, B, C are the subsets with member ship function μ_A μ_B μ_C, then Mamdani is described as:

Rule 1: IF x_1 is A_1 and x_2 is B_1 THEN y is C_1
Rule 2: IF x_2 is A_2 and x_2 is B_2 THEN y is C_2
…………………………………………………
Rule n : IF x_1 is A_n and x_2 is B_n THEN y is C_n

And the member function for output can be expressed as

$$\mu_{c0}(y) = \mu_{A1}(x_1) \cap \mu_{B1}(x_2) \cap \mu_{C1}(y) \cup \ldots\ \mu_{An}(x_1) \cap \mu_{Bn}(x_2) \cap \mu_{Cn}(y)$$

where ∩ is minimum and U is maximum operation and $\mu_{c0}(y)$ is membership function of GFRG[16].

Last stage is defuzzification, so for this center – of – gravity method was adopted, and transform fuzzy inference output into crisp value, i.e. grey fuzzy reasoning grade (GFRG)

$$y_0 = \frac{\sum y\,\mu c0(y)}{\sum \mu c0(y)} \quad \text{...............(6)}$$

the large the value of GFRG indicates that the experimental results are close to ideally normalized value.

f. Performing ANOM

Analysis of means (ANOM) is performed to find the optimum level of combinations of process parameters , and it is obtained by calculating the average value of each process parameter at their corresponding level. For example, for parameter A the mean at level 1 is calculated by calculating the average of GFRG values which are obtained by using level 1 of parameter A, like in experiment run 1,2,3.[1] Graphs are also shown to show the relationship between GFRG and level of factors. The optimum combinations are chosen for each parameter by taking the maximum value of mean among all the levels.

IV. RESULT AND DISCUSSION

In this section the result obtained are presented

4.1 Grey relational analysis: As per the Taguchi orthogonal array, the experiments were performed one by one and three replications were taken for each experiment run. Table 3 shows the average value of response.

Table 3: Experimental data.

S. No.	Thrust (N)	MRR(gm/min)
1	91.528	4.792667
2	183.057	6.315333

3	150.3673	12.783
4	71.915	16.14567
5	140.5617	17.65367
6	222.2833	34.763
7	179.788	27.826
8	107.8723	68.24367
9	304.0463	52.293

Normalization of S/N ratio have been done through grey relational for normalization 'lower the better' formula eq. no. 4 is adopted for thrust force and 'higher the better' formula eq. no. 3 is used to normalize material removal rate data.

With the help of eq. no. 5 described in methodology grey relational coefficient for individual output parameter is calculated by taking the reference value all for one. Table 4 shows the values of grey relational coefficient (GRC) and grey relational grade (GRG)

Table 4: GRC and GRG.

Sl. No.	Thrust	MRR	GRG
1.	0.3634	0.3333	0.3483
2.	0.4908	0.3776	0.4342
3.	0.4463	0.4632	0.4547
4.	0.3333	0.5003	0.4168
5.	0.4329	0.5165	0.4747
6.	0.5444	0.6820	0.6132
7.	0.4864	0.6172	0.5518
8.	0.3074	1	0.6537
9.	1	0.456	0.720

4.2 Grey fuzzy reasoning analysis: Then by using MATLAB grey fuzzy reasoning grade is calculated. Fuzzy logic approach involves fuzzification of input data, rule inference and defuzzification. Fuzzification is the process of making a crisp quantity fuzzy using linguistic variables [1]. The grey relational coefficient of each input variables is been given triangular membership function as 'small' , 'medium' , and 'large' and their ranges are defined and then same procedure is adopted for GFRG and this been given five membership functions , shown in table 5 and by fig. 2 and fig.3.

Table .5: range of fuzzy subset used in experiment

Factors	Condition	Range	Membership function
For GRC	Small	0 – 0.5	Triangular
	Medium	0.25 – 0.75	
	Large	0.5 - 1	
For GFRG	Very small	0 – 0.4	
	Small	0.2 – 0.6	
	Medium	0.4 – 0.8	
	Large	0.6 – 1	
	Very large	0.8 – 1.2	

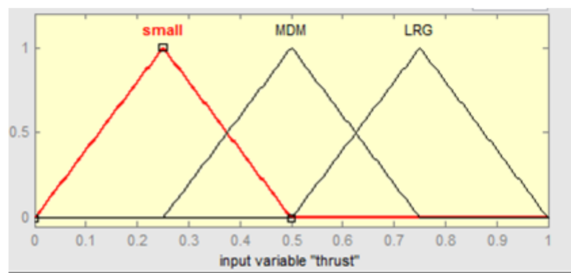

Fig. 2: fuzzification of input parameters

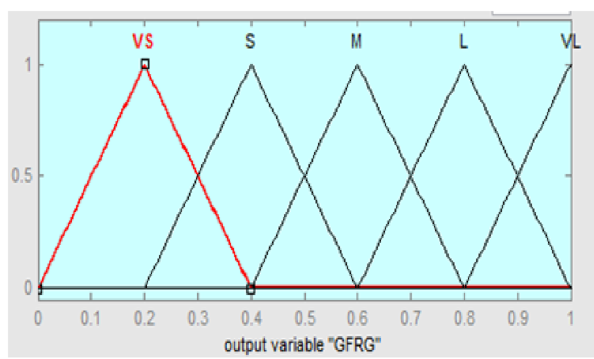

Fig. 3: fuzzification of output parameter

The rule inference system deduces or infers a conclusion based on a set of rules framed by the expert opinion or intuition. The structure of the rules is given as follows:

IF premise (antecedent) THEN conclusion (consequent)[17]

Mamdani's implication method of inference is applied in this work. It is used for yielding aggregation of fuzzy rules and is known as max–min inference method. So in rule editor tool box IF , THEN rule is activated to run the FIS based on table 6.

Table 6: fuzzy rule table, [16]

Grey fuzzy reasoning grade	Grey relation coefficient for MRR			
Grey relation coefficient for thrust		S	M	L
	S	VS	S	M
	M	S	M	L
	L	M	L	VL

The next step in fuzzy logic approach is defuzzification , Centroid method was used in work. The fuzzy logic approach provides improvement in grey relational grade that has a definitely lower uncertain output than that of grey relational analysis. After the rule generation in rule editor, defuzzification process can be seen in rule viewer. The grey fuzzy reasoning grade (GFRG) obtained as described, Table 7 shows the values of GFRG as obtained from predicted values of FIS for all the experiments and their rank. We can see that the maximum value of GFRG is 0.742. Previously which was 0.6732, it can be seen that experiment no. 6 has the optimum factor level combination.

Table no.7: GFRG and rank

Sl. No.	Grey fuzzy reasoning grade	GFRG rank
1.	0.3710	9
2.	0.49	7
3.	0.5	6
4.	0.473	8
5.	0.557	5
6.	0.742	1
7.	0.679	3
8.	0.661	4
9.	0.725	2

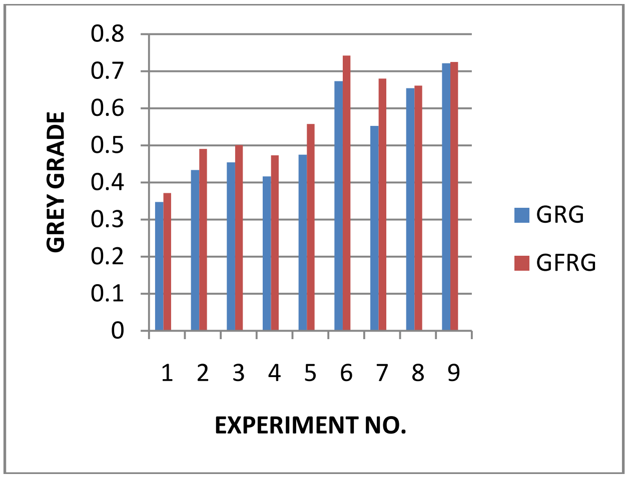

Fig. 4: comparison between GRG and GFRG

On comparing GRG and GFRG, it can be seen that there is an improvement in the values of GFRG, thus the uncertainty of data is reduced. fig. 4 shows that results. Response table 8 is obtained by calculating the average values of each input drilling parameter at its corresponding level. Optimum level of process parameters are chosen by selecting the maximum value of mean for that particular parameter and also can be seen by response graphs in fig. 5, so spindle speed should at level 3, feed rate at level 3, depth of cut at level 1, and drill diameter at level 2 are the optimum levels. The rank of max-min indicates most influencing parameter. So spindle speed is the most influencing parameter followed by feed rate, drill diameter and depth of cut.

Table 8 : Response table for grey fuzzy reasoning grade

Factors	Level-1	Level-2	Level-3	Max-min	Rank
Spindle speed	0.4536	0.5906	0.688	0.234	1
Feed rate	0.5076	0.572	0.655	0.148	2
Depth of cut	0.591	0.561	0.562	0.031	4
Drill diameter	0.551	0.637	0.5443	0.093	3
Total mean GFRG = 0.576					

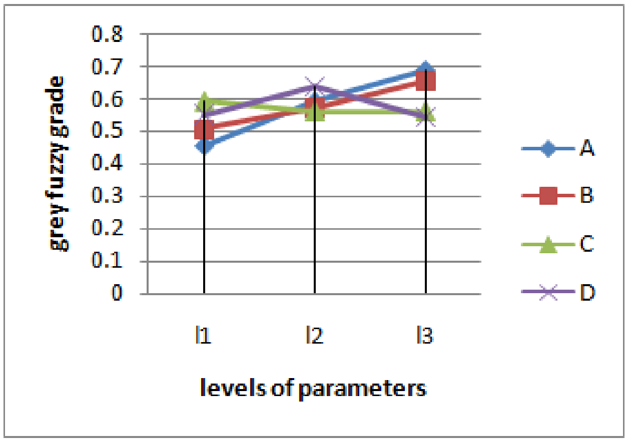

Fig. no. 5: response graph for parameters

4.3 Prediction of grey fuzzy reasoning grade and conformity test : After finding the suitable optimal parameters, it is necessary to predict the grey fuzzy reasoning grade theoretically. The grey fuzzy reasoning grade can be predicted by using the following equation :

$$\gamma ij = \gamma om + \sum_{i=1}^{k}(\gamma ol - \gamma om)$$

where γom is the mean value of the grey fuzzy reasoning grade and γol is the grey fuzzy reasoning grade at the optimum level and k is the number of influencing parameters that affect the multiple performance characteristics [2], table 9 shows the comparison results. Initial setting value spindle speed at level 1, feed at level 1, depth of cut at level 1, The initial value of grey fuzzy reasoning grade is 0.371, predicted value of GFRG is 0.843. . As our optimal level of process parameters do not match with any of the experiment performed in orthogonal array, we have performed three conformity test to validate our result. Our experimental value of GFRG is 0.747 by the conformity test we have found that the thrust force has reduced from 91. 5287 N to 78.252 N, and material removal rate has increased from 4.792 gm min^{-1} to 35.4306 gm min^{-1}.

Table 9: comparison of results of initial and optimum process parameter

Item	Setting level	Thrust force (N)	MRR (gm/min)	GFRG	Grade improvement
Initial	$A_1B_1C_1D_1$	91.52	4.79	0.371	
Predicted	$A_3B_3C_1D_2$	-	-	0.843	0.472
Experimen-tal	$A_3B_3C_1D_2$	78.25	35.43	0.747	0.376

V. CONCLUSION

In this project work, drilling of mild steel plate have been executed. Jig boring machine is used for this accomplishment, with independent factors as spindle speed, feed rate, depth of cut, and drill tool diameter, and dependent parameters as thrust force and material removal rate. Taguchi method is used for the performance of experiment with L_9 orthogonal array. Further optimization of process parameters was carried out using grey relational analysis integrated with fuzzy logic analysis to reduce the uncertainty of the data.

- Drilling parameters are optimized with respect to multiple performances in order to achieve maximum value of material removal rate and minimum value of thrust force in mild steel material.
- It was identified that spindle speed of 2000 rpm, feed rate at 0.09 mm/rev , depth of cut at 10 mm, and drill tool diameter of 10 mm is optimal combination of drilling parameters that produced a high value of grey fuzzy reasoning grade of 0.747 which is close to that of reference value.
- ANOM revealed that spindle speed is the most influencing parameter followed by feed rate, drill diameter and depth of cut.
- Compared to initial value our thrust force has reduced from 91.5287 N to 78.2589 N and material removal rate has increased from 4.792 gm min^{-1} to 35.4306 gm min^{-1}.
- Thus it is concluded that optimization procedure proposed in this project work significantly improves the drilled hole quality and increase the productivity in drilling of mild steel in jig boring machine.

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