To Estimate The Range Of Process Parameters For Optimization Of Surface Roughness & Material Removal Rate In CNC Milling:

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***Abstract*: --- CNC milling has become one of the most competent, productive and flexible manufacturing methods, for complicated or sculptured surfaces. With the rising demands of modern engineering products, the control of surface texture together with high material removal rate has become more important. In this paper, the effects of various process parameters of CNC Milling like Spindle Speed (N), table feed rate (FR), depth of cut (DOC), step over (SO) and coolant pressure (CP) have been investigated to reveal their impact on surface roughness and material removal rate of hot die steel (H-11) using one variable at a time approach(OFAT). The experimental studies were performed on SURYA VF30 CNC VS machine. The processing of the job has been done by solid carbide four flute end-mill tools under finishing conditions. Prediction of surface roughness is very difficult using mathematical equations. The surface roughness (SR) increases with increase of table feed rate (FR), depth of cut (DOC), step over(SO) and decreases with increase in spindle speed(N) and coolant pressure(CP) & the material removal rate (MRR) directly increases with increase in spindle speed (N), table feed rate (FR) , depth of cut (DOC) and step over(SO).**

***Keywords*:--- CNC Milling; OFAT; Step Over; Coolant Pressure; Surface Roughness; Material Removal Rate**

INTRODUCTION:

To sustain in the global rivalry condition of manufacturing conditions, customer related, fast manufacturing strategies are becoming an unelectable manufacturing philosophy. Especially, inspection and determination of surface roughness in metal processing which has an important place in manufacturing industry has very high importance in the view of economical manufacturing. Surface specification can also be a good reference point in determining the stability of a production process.

Milling has been one of the most widely used metal removal processes in industry and milled surfaces are largely used to mate with other parts in die, aerospace, automotive and machinery design as well as in manufacturing industries Zhang et al., (2007). End milling has been the most common metal removal operation encountered. The most important interactions, that effect surface roughness & MRR of machined surfaces, were between the cutting feed and depth of cut, and between cutting feed and cutting speed.

Feed rate was the most significant machining parameter used to predict the surface roughness in the multiple regression models Lou et al., (1999). A systematic approach for identifying optimum surface roughness performance in end-milling operations has been presented by Taguchi parameter design at the minimum cost Yang and Chen, (2001).

Surface roughness has been significantly influenced by feed rate, speed and depth of cut Benardos et al., (2002). RSM can be utilized to create an efficient analytical model for surface roughness in terms of cutting parameters: feed, cutting speed, axial depth of cut, radial depth of cut and machining tolerance Oktem and Kurtaran, (2005).

Surface roughness of machined work piece depends on technological parameters (cutting speed; feed; cutting depth) and concluded that technological parameter range also plays a very important role on surface roughness Kromanis et al., (2008). The demand for high quality and fully automated production focus attention on the surface condition of the product, surface finish of the machined surface is most important due to its effect on product appearance, function, and reliability. For these reasons, it is important to maintain consistent tolerances and surface finish along with high MRR.

Among several CNC industrial machining processes, milling is a fundamental machining operation. End milling is the most common metal removal operation encountered. It is widely used in a variety of manufacturing industries. The quality of the surface plays a very important role in the performance of milling as a good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life.

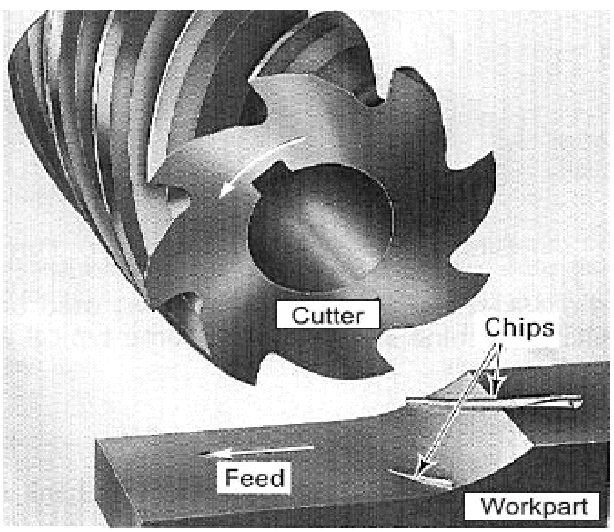

Fig. 1 Schematic representation of milling process

Following the review above, this study includes spindle speed, table feed rate, depth of cut, step over and coolant pressure as control variables. The effect of the machining parameters and their level of significance on SR & MRR has been statistically evaluated to determine the range of process parameters so that optimization can be conducted. Selection of appropriate machining parameters is an important step in the process planning of any machining operation. There are always many constraints that exist in the actual cutting condition for the optimization of the objective function. On satisfying these constraints, the optimum machining parameters are arrived.

I. MOTIVE OF STUDY

- To depict relationship between the controllable factors (spindle speed, feed rate, depth of cut, step over & coolant pressure) and the response factors (SR & MRR).
- To evaluate the working ranges of milling parameters for surface roughness and material removal rate for a particular work piece with a particular tool by applying statistical approach.
- To determine the dominant controllable factor for SR and MRR.

II. MATERIAL, TOOL & EXPERIMENTAL SETUP

Hot die steel H11 in the plate form of size 180x100x24 mm^3 was used to carry out the experimentation. The H-11 die steel plate blank has been heated to a temperature of 1025^{0}C with half an hour soak time followed by quenching in a 500^{0}C hot salt bath.

It was then tempered in three cycles with maximum temperature of 550^{0}C and 2 hours of soak time to obtain a final hardness of 55 HRC. The chemical composition of this material as obtained by EDAX (Electro Dispersive X-ray Spectroscopy) test is given in Table1.H11 die steel have been chosen because of high hardness, excellent wear resistance, hot toughness and good thermal shock resistance properties and have wide application in die and aerospace industry.

Tab. 1 Work piece composition

Constituent	C	Si	Mn	P	S	Cr	Mo	V
Composition (In %)	0.38	0.93	0.4	0.012	0.027	5.25	1.35	1.0

The experimental studies were performed on SURYA VF30 CNC VS machine (Figure 2).Various input parameters varied during the experimentation are Spindle speed (N), table feed rate (FR), depth of cut (DOC), step over (SO) and coolant pressure (CP). The effects of these input parameters were studied on surface roughness and material removal rate using one factor at a time approach. In OFAT all the machining parameters are kept constant and one parameter has been varied from its minimum to maximum values. The units of input parameters were taken as spindle speed (r.p.m), table feed rate (mm/min), depth of cut (mm), step over (mm) and coolant pressure (lb/inch2).

Fig. 2 Vertical CNC Machine Tool

In each experiment, one input variable was varied while keeping all other input variables at some mean fixed value and the effect of change of the input variable on the output characteristic i.e. surface roughness and material removal rate has been studied. Solid Carbide 4-flute end mill cutter of 10mm diameter was used in the experiments. The work piece material, H-11 hot die steel with 180 mm × 100 mm × 24 mm size was used, because the cuts were made lengthwise. During the experiments, cuts were made of 30mm length and 12mm width, whereas the cutter diameter was 10mm, the cutting of this extra width has been done by to and fro movement of the cutter and this was where the step over parameter has its application.

Surface roughness measurements in µm were repeated three times on respective cuts using a Surfcom 130A and the average value was considered as surface roughness value for the analysis purpose. The instrument for measurement of surface roughness has been shown with the help of figure 3.

Fig. 3 Surfcom 130A for measuring surface roughness

Material Removal Rate in mm3/sec was measured by using the following equations:

MRR = Volume Removed per unit time

Volume = Density ×Mass

Mass = Initial weight before cut – Final weight after cut

Density of H- 11 is 7805 kg/m3

For measuring the coolant pressure, the pressure gauge is attached to knobe of coolant supply using T-joint as demonstrated in figure 4.

Fig. 4 Pressure Gauge attached to coolant knobe

III. OBSERVATIONS:

Various experiments were performed to find how the output parameter varies with the variation in the input parameters. In the first set of experiments spindle speed (N) is varied from 500 r.p.m to 6000 r.p.m in the steps of 500 units. All other input parameters such as table feed rate, depth of cut, step over, coolant pressure were kept constant. The change in surface roughness and material removal rate due to change in spindle speed has been illustrated in Table 2. Fixed input variables in first set of experiments are: FR =910mm/min; DOC = 1mm; SO = 1 mm; CP = 1.2lb/inch2

Tab. 2 illustrating variation of response characteristics versus Spindle Speed:

S. No	Spindle Speed (rpm)	Surface Roughness (µm)	Material Removal Rate (mm3 /sec)
1.	500	1.734	14.23
2.	1000	1.673	15.07
3.	1500	1.578	15.87
4.	2000	1.502	16.03
5.	2500	1.289	16.32
6.	3000	0.948	17.02
7.	3500	0.999	17.69
8.	4000	0.811	17.79
9.	4500	0.773	17.99
10.	5000	0.864	18.79
11.	5500	0.912	18.99
12.	6000	1.146	19.14

In the second set of experiments table feed rate (FR) is varied from 238mm/min to 1414mm/min in the steps of 168 units.

All other input parameters such as spindle speed, depth of cut, step over, coolant pressure were kept constant. The change in surface roughness and material removal rate due to change in table feed rate has been depicted in Table 3. Fixed input variables in second set of experiments are: N =3500r.p.m; DOC = 1mm; SO = 1 mm; CP = 1.2lb/inch^2

Tab. 3 illustrating variation of response characteristics versus Table Feed Rate:

S. No	Table Feed Rate (mm/min)	Surface Roughness (µm)	Material Removal Rate (mm3/sec)
1.	238	1.079	4.26
2.	406	1.084	8.08
3.	574	1.183	11.1
4.	742	1.403	14.31
5.	910	1.415	17.38
6.	1078	1.419	21.1
7.	1246	1.758	24.08
8.	1414	1.871	27.25

In the third set of experiments depth of cut (DOC) is varied from 0.2mm to 1.6mm in the steps of 0.2 units. All other input parameters such as spindle speed, table feed rate, step over, coolant pressure were kept constant.

The change in surface roughness and material removal rate due to change in depth of cut has been illustrated in Table 4. Fixed input variables in third set of experiments are: N =3500r.p.m; FR = 910mm/min; SO = 1 mm; CP = 1.2lb/inch^2

Tab. 4 illustrating variation of response characteristics versus Depth of cut:

S. No	Depth of Cut (mm)	Surface Roughness (µm)	Material Removal Rate (mm3/sec)
1.	**0.2**	**0.566**	**17.94**
2.	**0.4**	**0.565**	**24.97**
3.	**0.6**	**0.499**	**36.29**
4.	**0.8**	**0.335**	**37.57**
5.	**1.0**	**0.325**	**45.62**
6.	**1.2**	**0.531**	**51.73**
7.	**1.4**	**1.416**	**51.89**
8.	**1.6**	**1.593**	**54.24**

In the fourth set of experiments step over (SO) is varied from 0.25mm to 2.0mm in the steps of 0.25 units. All other input parameters such as spindle speed, table feed rate, depth of cut, coolant pressure were kept constant. The change in surface roughness and material removal rate due to change in step over has been illustrated in Table 5. Fixed input variables in fourth set of experiments are: N =3500r.p.m; FR = 910mm/min; DOC = 1 mm; CP = 1.2lb/inch^2.

Tab. 5 illustrating variation of response characteristics versus Step Over:

S. No	Step Over (mm)	Surface Roughness (µm)	Material Removal Rate (mm3/sec)
1.	**0.25**	**0.923**	**10.85**
2.	**0.50**	**0.844**	**22.97**
3.	**0.75**	**0.627**	**30.70**
4.	**1.00**	**0.535**	**30.74**
5.	**1.25**	**0.774**	**46.32**
6.	**1.50**	**0.882**	**46.65**
7.	**1.75**	**0.883**	**51.33**
8.	**2.00**	**0.884**	**75.44**

In the fifth set of experiments coolant pressure (CP) is varied from 0.4 to 2.0lb/inch^2 in the steps of 0.4 units. All other input parameters such as spindle speed, table feed rate, depth of cut, step over were kept constant. The change in surface roughness and material removal rate due to change in coolant pressure has been shown in Table 6. Fixed input variables in fifth set of experiments are: N =3500r.p.m; FR = 910mm/min; DOC = 1 mm; SO = 1mm.

Tab. 6 illustrating variation of response characteristics versus Coolant Pressure:

S. No	Coolant Pressure (lb/inch2)	Surface Roughness (µm)	Material Removal Rate (mm3/sec)
1.	**0.4**	**0.67**	**30.31**
2.	**0.8**	**0.60**	**30.37**
3.	**1.2**	**0.54**	**30.20**
4.	**1.6**	**0.49**	**30.25**
5.	**2.0**	**0.46**	**30.28**

IV. RESULT & ANALYSIS:

The experiments were based on one factor experiment strategy. After analyzing the results of the experiments performed, various facts came into light.

The effect of spindle speed (N) on the output parameters has been predicted in Figure 5(a) & 5(b)

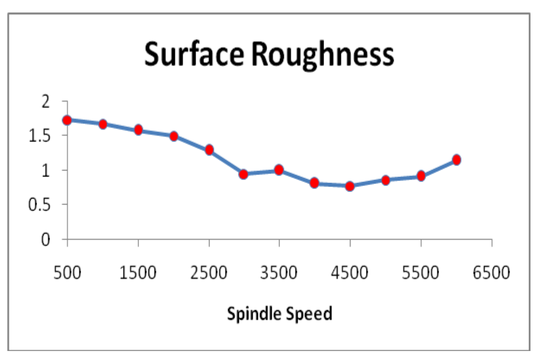

Fig. 5(a) Spindle speed vs. Surface Roughness

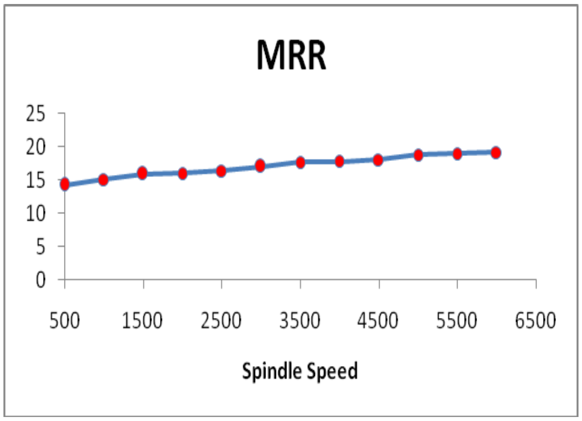

Fig. 5(b) Spindle Speed vs. Material Removal Rate

Graphs 5(a) and 5(b) implies that the surface roughness decreases with the increase in the spindle speed, but at very-2 high spindle speeds the roughness increases due to vibration in the machine tool and material removal rate increases with the increase in the spindle speed. So, this gives criteria for selection of spindle speed to get the desired surface roughness and material removal rate.

For the second set of experiments, the effect of table feed rate on output characteristics has been predicted in figure 6(a) & 6(b).

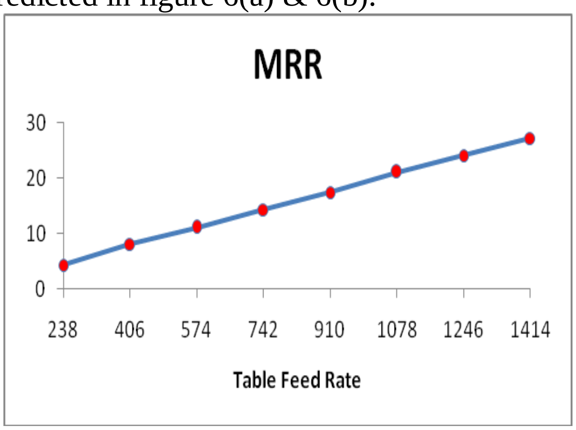

Fig. 6(a) Table Feed Rate vs. Surface Roughness

Graphs 6(a) and 6(b) implies that the surface roughness and material removal rate increases with the increase in the table feed rate. So, a mean value of feed rate can be adjusted to get the desired surface roughness and material removal rate.

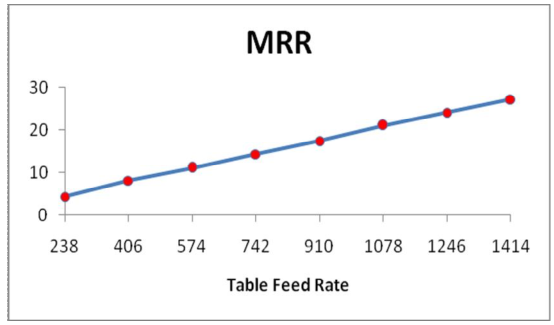

Fig. 6(b) Table Feed Rate vs. Material Removal Rate

For the third set of experiments, the effect of depth of cut on output characteristics has been predicted in figure 7(a) & 7(b).

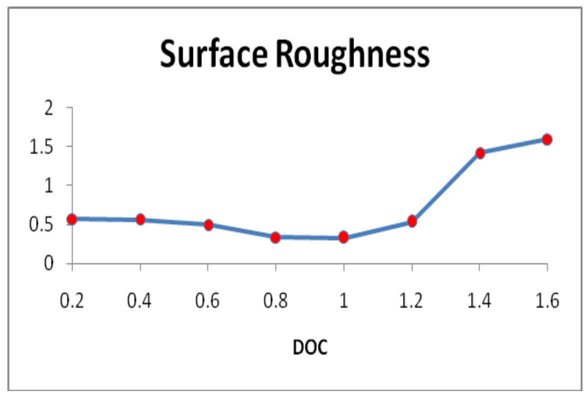

Fig. 7(a) Depth of Cut vs. Surface Roughness

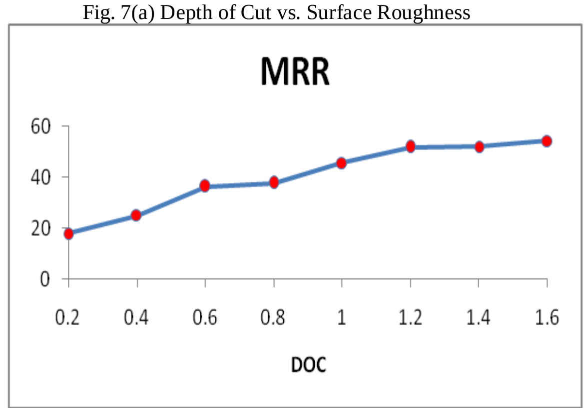

Fig. 7(b) Depth of Cut vs. Material Removal Rate

Graphs 7(a) and 7(b) implies that the surface roughness decreases in the start because depth of cut has been high due to poor penetration of tool, but as the values of depth of cut increases the tool deflection decreases and surface roughness decreases up to a certain limit say 1mm and after that again the roughness increases because of impact of large depth of cut and material removal rate increases with the increase in the depth of cut. So, an optimum value of depth of cut can be adjusted to get the desired surface roughness and material removal rate.

For the fourth set of experiments, the effect of step over on output characteristics is has been predicted in figure 8(a) & 8(b).

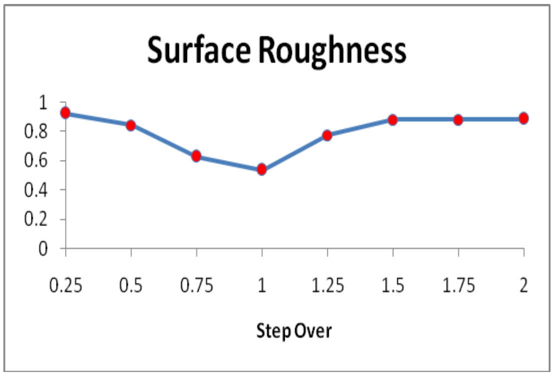

Fig. 8(a) Step Over vs. Surface Roughness

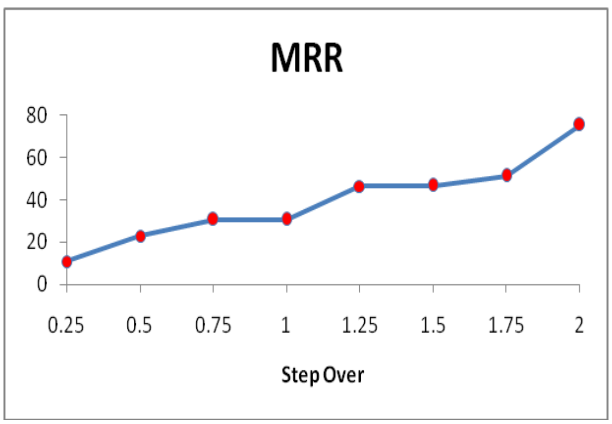

Fig. 8(b) Step Over vs. Material Removal Rate

Graphs 8(a) and 8(b) implies that the surface roughness decreases in the start because lower values of step over has been taken and at higher values of step over, the surface roughness goes on increasing due to wearing of surface and material removal rate also increases with the increase in the step over. So, an optimum value of step over can be adjusted to get the desired surface roughness and material removal rate.

For the fifth set of experiments, the effect of coolant pressure on output characteristics has been predicted in figure 9(a) & 9(b).

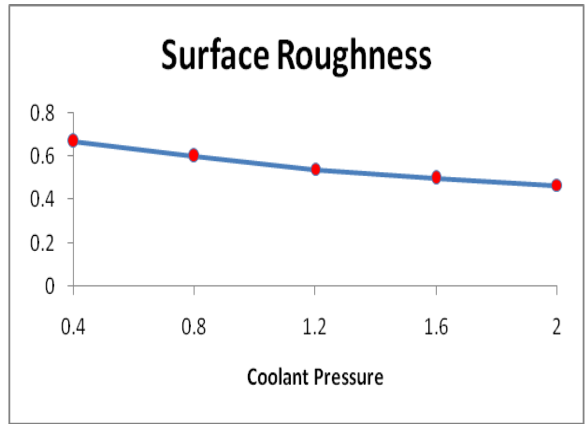

Fig. 9(a) Coolant Pressure vs. Surface Roughness

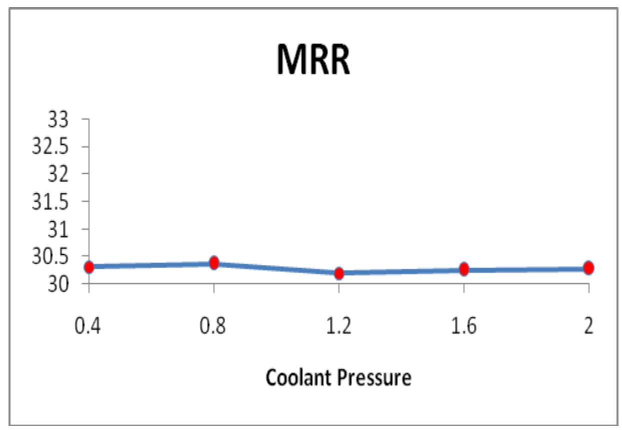

Fig. 9(b) Coolant Pressure vs. Material Removal Rate

The graph 9(a) and 9(b) implies that the surface roughness decreases with the increase in the values of coolant pressure though the variation is quite small and material removal rate is not much affected with the increase in the coolant pressure. So, on the basis of experimentation and the analysis of various plots the range of the various machining control variables can be estimated as in table 7.

Tab.7 depicting working ranges of control variables

S.No	MACHINE CONTROL VARIABLES	WORKING RANGES
1.	SPINDLE SPEED	1500-3900 r.p.m

2.	**TABLE FEED RATE**	**400-960 mm/min**
3.	**DEPTH OF CUT**	**0.4-1.2 mm**
4.	**STEP OVER**	**0.25-1.25 mm**
5.	**COOLANT PRESSURE**	**0.4-2.0 lb/inch2**

V. CONCLUSIONS:

With this work, the range of various control variables for a particular work piece (H-11) for a particular tool (solid carbide four fluted) can be predicted so that optimization can be done for surface roughness and material removal rate , because without knowing the working ranges of control variables the optimization done cannot be authenticated. Though some researchers in the past have carried optimization by taking the level values with the help of literature review but this cannot be considered as perfect criteria for selecting level values of each parameter. Surface Roughness has been significantly influenced by table feed rate and step over followed by spindle speed and depth of cut. Coolant pressure has a slight impact on surface roughness. On the other hand, MRR has been significantly influenced by depth of cut and step over followed by feed rate and spindle speed, whereas coolant pressure has no impact on the MRR.As a controversy, surface roughness values have been found high at small depth of cuts due to poor penetration and deflection in the tool though with the small increase in depth of cut values the roughness decreases up to a certain value and with increased values of depth of cut roughness again increases sharply.

In the nutshell, it can be said that coolant pressure has been found as a neutral parameter, whereas all other parameters affect surface roughness and material removal rate significantly, so optimum values of these parameters must be selected for effective machining by the machinist so that the production costs for a particular product can be optimized.

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