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Determination of Counterweight Using CAMB in Rotary Fixture and Optimization of Cutting Force for Interrupted Cuts with Case Study

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ABSTRACT

In order to manufacture any product at desired quality of machining, optimum parameters are to be selected for machining. The aim of the present work is to optimization of the process parameters (Cutting Speed, Feed, Depth of cut) for machining the Bearing cap having interrupted cuts. Computer Aided Mass Balancing (CAMB) methodology is used for determining the counterweight for rotary fixture. The performance characteristics are studied by using the orthogonal array, signal-to-noise ratio, and the ANOVA from Taguchi method for interrupted cuts of boring operation and effect of Cutting force for balanced and unbalanced rotary fixture.

Introduction

Turning is most common machining method on lathe machine. In case of lathe machine turning, facing, grooving, boring (internal turning) operations are performed. It is very common to machine the regular round shaped work-pieces on lathe machine. Present work includes the interrupted cuts for machining. The work-piece is bearing cap of one of the famous tractor company. The work-piece is made of the material cast iron. Rotary fixture is designed for machining. Facing, internal grooving and boring (internal turning) are the operations to be performed on this work-piece. As the work-piece has the geometry like half round shape, during machining the tool is to be machining in 180^{o} only and at 180^{o} tool is at idle (no cutting takes place) condition. Since, it affects on the cutting forces acting on the tool and also the parameters like speed, feed and depth of cut should be optimized.

Fixture is unbalanced due to mounting of the work-piece is at one side of the face plate, so fixture must be balanced by adding the counterweight on rotary fixture to minimize the effect of cutting forces acting on the tool. The fixture can be balanced by dynamic balancing machine. In this study rotary fixture is balanced by Computer Aided Mass Balancing (CAMB) methodology. There are unbalanced frequent jobs are to be machined on lathe or CNC in XYZ Company and balancing the fixture for every work-piece is not economical. So, the methodology for balancing the rotary fixture is used to calculate counterweight to be added on rotary fixture. This method of balancing the rotary fixture is supposed to be continuously used in this industry.

Computer Aided Mass Balancing for Rotary Fixture

The balancing is the term related to the rotational motions. The balancing is done by adding the counterweight or by Unbalanced mass removal. These methods performed on balancing machine. In case of regular production of such types of jobs of different geometrical shapes on lathe machine or CNC machine, it is very time and money consuming process to balancing of every rotary fixture. The Computer Aided Mass Balancing (CAMB) methodology can help to overcome these types of problems in very cheap balanced rotary fixture developing charge. In this paper 3D high end modeling software '3D high end modeling software 'Creo 2.0'' is used to predict/calculate the counterweight to be added on rotary fixture well before manufactured. Hence there is no need to be balance the rotary fixture after manufacturing, as it gives the value of counterweight to be added.

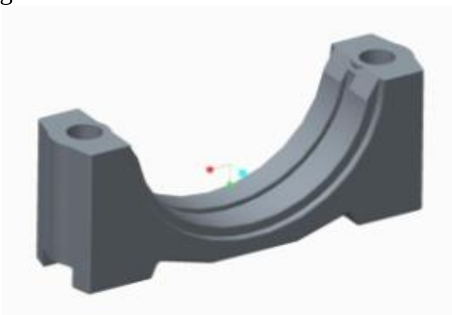

Figure 2.1. 3D view of work-piece

C. G., weight of fixture are determined in 'Creo 2.0'. Center of gravity is offset from axis of rotation of rotary fixture in x axis by -204.99 mm and in y axis by 218.23 mm and in z – axis by 73.58 mm. According to principles of mechanics, ΣF = 0 and ΣM = 0.

Figure 2.2. 3Dview of rotary fixture with Clamped work-piece

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By using parallelogram law of forces Resultant unbalanced mass (R) and its line of action terms of angle (α) in X axis are calculated. By using principle of perpendicular axis theorem of moment of inertia Resultant moment is determined.

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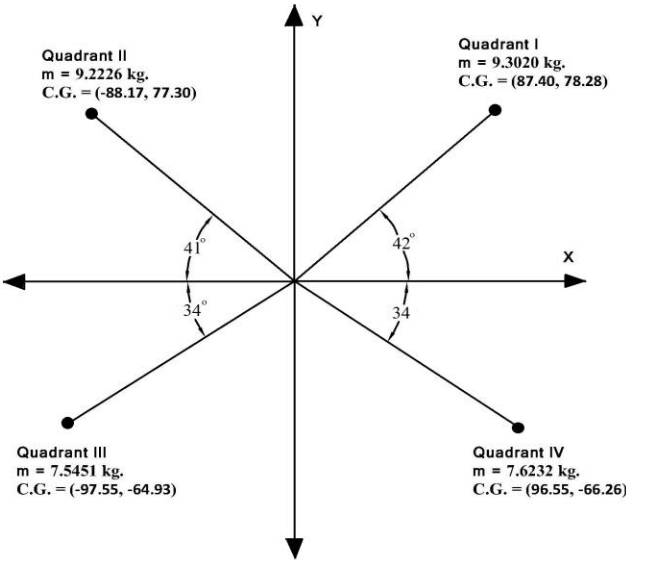

Figure 2.4. Weight and Centre of Gravity in all quadrants

We get the 2.3087 kg. counterweight for balancing the fixture. Determined counterweight location is exactly opposite side of the work-piece mounted on the rotary fixture, so the fixture is balanced. It helps to minimize the forces acting on the tool at the time of interrupted cuts.

Experimental detail

For the experimentation following parameters are selected by considering the work-piece material, lathe machine specifications. L9 orthogonal array is selected for experimentation from MINITAB 17 to perform different combinations.

Effect of balancing on cutting force

From S/N ratio analysis, the cutting force is influenced due to depth of cut. To analyze the effects of balancing on cutting force graphs of depth of cut Vs. cutting force are drawn at each cutting speed level.

At the cutting speed of 200 rpm and depth of cut 0.25 mm, cutting force is constant for both balanced and unbalanced fixture. But at depth of cut of 0.5 mm and 0.75 mm the cutting force is very large as compared to the machining on balanced rotary fixture. The cutting force at 0.5 mm and 0.75 mm depth of cut is 3 kgf.

The cutting force at 0.5 mm depth of cut is 1 kgf. And at 0.75 mm depth of cut, it is 2 kgf. At the cutting speed of 275 rpm and depth of cut 0.25 mm, cutting force is 3 kgf. for unbalanced fixture and for balanced rotary fixture it is 1 kgf. The cutting force for unbalanced fixture at 0.5 mm depth of cut 5 kgf. and at 0.75 mm depth of cut is 6 kgf. The cutting force decreases by balancing the rotary fixture as determined in graph.

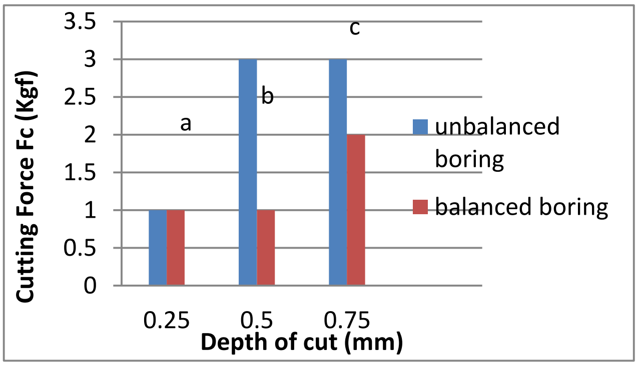

Figure 4.1. Depth of cut Vs. Cutting force (Fc), cutting speed: 200 rpm; feed: 0.10, 0.15, 0.20 mm/rev at the three regions a, b and c, respectively

At the cutting speed of 275 rpm and depth of cut 0.25 mm, cutting force is 4 kgf. for unbalanced fixture and for balanced rotary fixture it is 1 kgf. The cutting force for unbalanced fixture at 0.5 mm depth of cut 2 kgf. and at 0.75 mm depth of cut is 6 kgf. The cutting force decreases by balancing the rotary fixture to 2 kgf. for 0.5 mm depth of cut and 3 kgf. for 0.75 mm depth of cut.

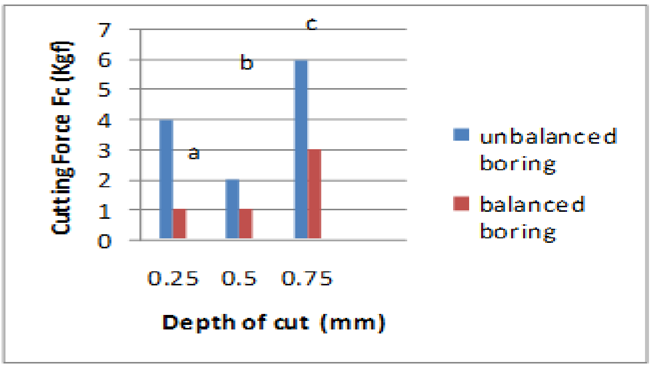

Figure 4.2. Depth of cut Vs. Cutting force (Fc), cutting speed: 275 rpm; feed: 0.10, 0.15, 0.20 mm/rev at the three regions a, b and c, respectively

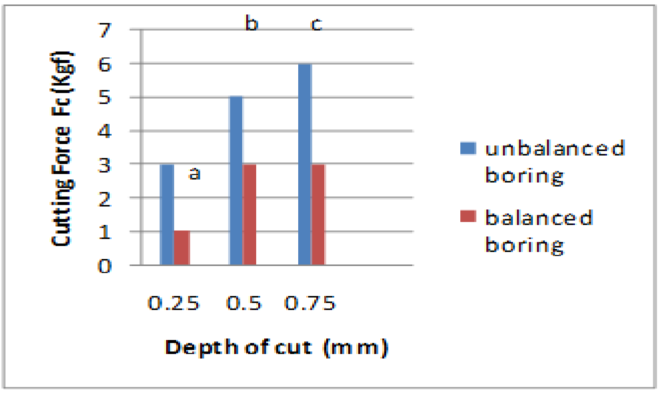

Figure 4.3. Depth of cut Vs. Cutting force (Fc), cutting speed: 400 rpm; feed: 0.10, 0.15, 0.20 mm/rev at the three regions a, b and c, respectively

Analysis and discussion

Figure 5.1 presents main effect plot of the S/N ratio for three control parameters cutting speed, feed and depth of cut for boring operation (balanced rotary fixture).

Effect of cutting Speed

The effect of parameter cutting speed on the cutting force values is shown above for S/N ratio. The cutting force is decreases with increase in cutting speed from 200 rpm to 400 rpm. So, the optimum cutting speed level is 275 rpm.

Table 2.1. Centre of gravity of all quadrants

Quadrant	Co-ordinates of CENTRE OF GRAVITY (mm)		α (^{o})	m_i	$F_H = X_i = m_i \cos \alpha_i$	$F_V = Y_i = m_i \sin \alpha_i$
	X_i	Y_i				
1	87.40	78.28	42	9.3020	6.9127	6.2243
2	-88.17	77.30	41	9.2226	-6.9604	4.5664
3	-97.55	-64.93	34	7.5451	-6.2552	-4.2192
4	96.55	-66.26	34	7.6232	6.3199	-4.2628
-	-	-	$\sum$	33.6929	0.017	2.3087

Table 2.2. Resultant (R)

$\sum F_H^2$	$2.89*10^{-4}$
$\sum F_V^2$	5.33
$\sum F_H^2 + \sum F_V^2)$	5.3302
R	2.3087

Table 3.1. Levels of input parameters

Parameters	Level 1	Level 2	Level 3
Speed (rpm)	200	275	400
Feed (mm/rev)	0.1	0.15	0.2
Depth of cut (mm)	0.25	0.50	0.75

Table 3.2. L9 Orthogonal Array

Trial No.	Speed (rpm)	Feed (mm/rev)	DOC (mm)
1	200	0.10	0.25
2	200	0.15	0.50
3	200	0.20	0.75
4	275	0.10	0.50
5	275	0.15	0.75
6	275	0.20	0.25
7	400	0.10	0.75
8	400	0.15	0.25
9	400	0.20	0.50

Table 4.1. Experimental Results and Analysis using S/N ratio:

Expt. No.	Cutting Speed (rpm)	Feed (mm/rev)	DOC (mm)	Unbalanced Rotary Fixture		Balanced Rotary Fixture	
				Fc1	S/N Ratio	Fc2	S/N Ratio
1	200	0.10	0.25	1	0.000	1	0.00000
2	200	0.15	0.50	3	-9.542	1	0.00000
3	200	0.20	0.75	3	-9.542	2	-6.02060
4	275	0.10	0.50	5	-13.979	3	-9.542
5	275	0.15	0.75	6	-15.563	3	-9.5424
6	275	0.20	0.25	3	-9.542	1	0.000
7	400	0.10	0.75	6	-15.563	3	-9.54243
8	400	0.15	0.25	4	-12.04	1	0.000
9	400	0.20	0.50	2	-6.020	1	0.000

Table 5.1. Response table mean S/N ratio for cutting force factor and significant interaction of boring for balanced rotary fixture

	Level	Cutting Speed (rpm)	Feed (mm/rev)	DOC (mm)
Mean S/N Ratio	1	-2.006*	-6.361	0.000*
	2	-6.361	-3.180	-3.180
	3	-3.180	-2.006*	-8.368
	Delta	4.354	4.354	8.368
	Rank	2.5	2.5	1

Table 5.1.1. ANOVA for cutting force

Sr. No.	Factor	DOF	SS	MSS	F	P	% Contribution
1	Vc	2	1.555	0.777	7.00	0.12	20.58
2	f	2	1.555	0.777	7.00	0.12	20.58
3	DOC	2	4.222	2.111	19.0	0.05	55.88
4	Error	2	0.222	0.111			
5	Total	8	7.555	-	-	-	-
S=0.333333 R-sq=97.06% R-sq(adj)= 88.24%							

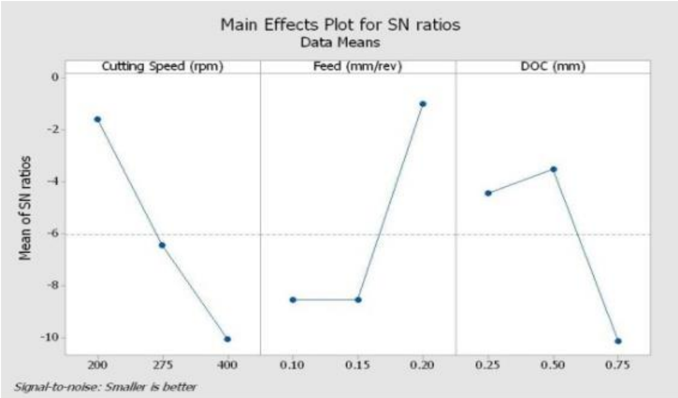

Figure 5.1. Effect of cutting Speed, feed and Depth of cut on Fc

Effect of feed

The effect of parameter feed rate on the cutting force values are shown above for S/N ratio. Its effect is constant up to 0.15 mm/rev and further increases up to 0.20 mm/rev. So, the optimum feed rate level is 0.15 mm/rev.

Effect of Depth of cut

The effect of parameter depth of cut on the cutting force values is shown above for S/N ratio. Its effect is increases up to 0.50 mm and then decreases with increase in depth of cut. So, optimum depth of cut is 0.25 mm.

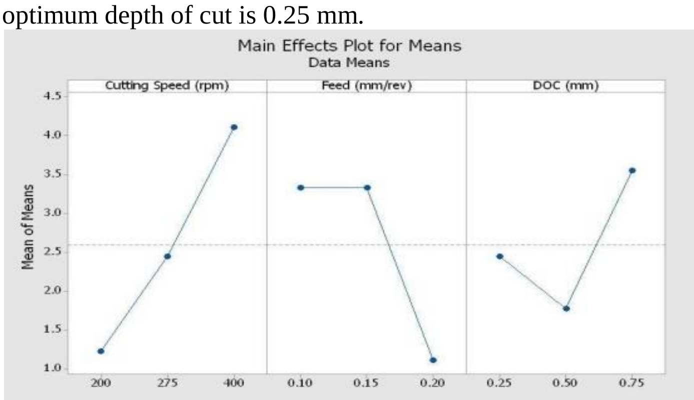

Figure 5.2. Main effect plot for Fc

The figure 5.2 shows the main effect plot for cutting force. The cutting speed has linear relationship with the cutting force; it increases with increase in cutting speed. Effect of feed is constant up to 0.15 mm/rev and decreases at 0.20 mm/rev on cutting force. Effect of depth of cut decreases at 0.50 mm and increases at 0.75 mm.

As experiments are performed for cutting speed in the range of 200 to 400 rpm, feed in the range 0.1 to 0.2 mm/rev and depth of cut in the range of 0.25 to 0.75 mm, significance of cutting force was determined by signal to noise ratio analysis as shown in table 4.1. In table 5.1 starred values shows corresponding highest S/N ratio values showing best levels for each process parameter. Significance of machining parameters (Difference between max. and min. values) indicates that depth of cut is significantly contributing towards machining performance as difference gives higher values. Therefore, most influencing parameter is depth of cut. The S/N ratio analysis shows that optimized process parameters corresponding to cutting force are Vc=200 rpm, f=0.2 mm/rev and DOC=0.25mm.

The interaction plot indicates that at higher speed the cutting force increases and as speed decreases the cutting force also decreases. It is seen that from interaction plot the cutting speed and depth of cut, feed and depth of cut affects more on cutting force.

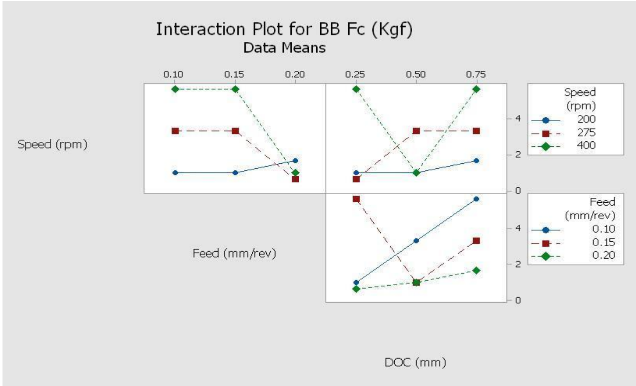

Figure 5.3. Cutting force Interaction plot of boring for balanced rotary fixture (BB- Boring for balanced fixture)

Analysis of Variance

The results of ANOVA for the cutting force of unbalanced rotary fixture are shown in Table 5.1.1. This analysis is carried out for a significant level of α=0.05 (confidence level of 95%). The main effect of depth of cut (the most significant parameter), Cutting speed (significant below the depth of cut) are significant. It is evident that 55.882% depth of cut is contributing on cutting force than the other cutting parameters. The cutting speed and feed are the parameters contributing at same level i.e. 20.589% for interrupted cuts on balanced rotary fixture.

Conclusion

An integrated approach is used for performing this study. Actually VMC is the best solution for performing these types of jobs. But by using lathe machine or CNC machine we simply perform these types of operations. The balancing of rotary fixture is done by analytical method using ‘Creo 2.0’. VMC costs very high, but by using lathe or CNC cost can reduce and CAMB is methodology can give us counterweight for balancing of rotary fixture. Interrupted cuts like facing, turning, boring (internal turning) can harm the tool. These forces are optimized by Taguchi method.

It is recommended that the frequently rotary fixture balancing need not be done, simply CAMB analytical method can give counterweight. This method can be used for regular routine balancing of the rotary fixture, hence it saves time and cost.

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