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Investigation of Effect of Operating Parameters of A CNC Cylindrical Grinding Machine on Geometric Dimensioning and Tolerancing

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Abstract
Machining processes are met with dimensional and geometrical variations in a product during machining operation. The amount of variation needs to be more strictly defined for accurately machined parts. Geometric dimensioning and tolerancing (GD&T) definition provides the precision required for allowing manufacturing of most economical parts. Crankshaft flange is required to be machined with higher degree of precision. If geometrical accuracies are not met the crankshaft-flywheel assembly will cause wear, unbalance and vibration, leading to poor functionality. The face of crankshaft flange is evaluated for geometric tolerances- flatness and runout. A two level three factor factorial model is designed and analyzed on Minitab 16 software to identify the most affecting machining parameter among speed, feed and depth of cut on face flatness and face runout.
Keywords— Crankshaft, Cylindrical grinding, Geometric tolerances, Design of experiments, Flatness, Runout

I. INTRODUCTION

Crankshaft is the mounting structure for the engine's flywheel and is considered the most critical feature. Crankshaft flange is machined first on a CNC turning machine where its diameter and face are turned nearly to size and then brought to size on a CNC cylindrical grinding machine. High product quality can be achieved through careful selection of machine tools, their operating parameters and proper process control.[1]

The operating parameters of grinding process play the most important role, when the cylindrical parts are made close to tolerance. Thus, in order to achieve desirable part quality, the operating conditions such as job speed, feed rate and depth of cut, must be carefully decided and optimized for use.[2]

Flatness and runout are the most common measurements for identifying the geometrical accuracy of face of crankshaft flange.

Flatness is a surface form control. A perfectly flat surface is defined as having all its elements in the same plane. Flatness feature control frames create a tolerance zone which consists of the distance between two parallel lines. This control is useful in achieving surfaces capable of resting on mating planer surfaces without significant rocking. It is also used to limit pitting, bumping of a surface.

Runout is a two dimensional control capable of maintaining within a specified tolerance the circularity and coaxiality of a feature to a datum axis. If used on a surface that is 90˚ to the datum axis, it is capable of controlling wobble of that surface.[3] The better geometric control of finished product ensures proper seating of flywheel preventing unbalance and wear between mating surfaces.

Design of experiments (DOE) is an efficient tool and effective way to design the level of parameters that obtain optimality, since it can significantly reduce number of experiments while yielding acceptable results [4]. The parameter design for this study is two levels on each factor, job speed, depth of cut and feed rate. The study herein, has proposed a predictive empirical model for GD&T requirements to be used by designers while designing the crankshaft flange.

II. EXPERIMENTAL WORK

The scope of the study is confined to the cylindrical grinding machine Cinetic Landis 3SE CNC 389 series used for machining the crankshaft flange in Tata's Nano plant. Fig.1 represents the dimensional and geometrical tolerances requirements of the crankshaft flange. The face of the flange is to be machined within flatness and runout tolerance of 0.05mm and 0.03mm respectively.

Forged microalloyed steel 38MnSiVS5 is used for making the crankshaft for its better machinability and weldability.

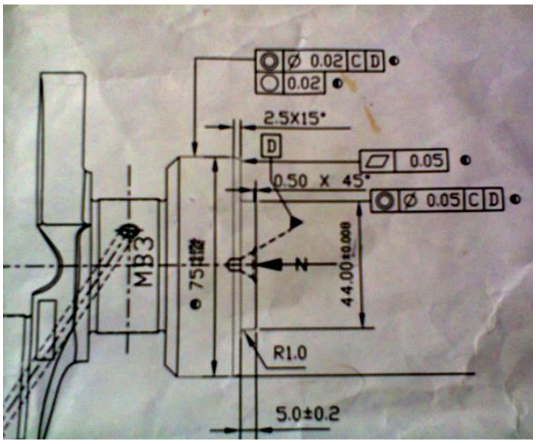

Fig. 1. Crankshaft flange

A. 2^3DESIGN

The three factors chosen for this experiment are wheel speed (A), feed rate (B) and depth of cut (C), each at two levels are of interest. The design is called 2^3factorial design and the eight treatment combination are represented in the table1.[5]

In running a two-level factorial experiment we usually anticipate fitting the first-order model, but we should be alert to the possibility that the second-order model is more appropriate. There is a method of replicating certain points in a 2^k factorial that will provide protection against curvature from second order effects as well as allow an independent estimate of error to be obtained. The method replicate consists of adding center points to the 2^k design. One important reason for adding the run at the design center points is that they do not affect the usual effect estimates in a 2^3 design.[6]

TABLE1.
2^3DESIGN WITH CENTER POINTS

Run	A	B	C	Labels
1	-	-	-	(1)
2	+	-	-	a
3	-	+	-	b
4	+	+	-	ab
5	-	-	+	c
6	+	-	+	ac
7	-	+	+	bc
8	+	+	+	abc
9	0	0	0	-
10	0	0	0	-
11	0	0	0	-
12	0	0	0	-

TABLE2.
OPERATING RANGE OF THE VARIABLE PARAMETERS

Machining parameters defined	Levels	
	Low (-)	High (+)
Job speed (rpm)	110	150
Feed (mm/s)	0.012	0.02
Depth of cut (mm)	0.04	0.10

B. EXPERIMENTAL RESULTS

As per the experimental plan and range shown in Table2 and 3, the experiments are run at random. The responses are generated by measuring the feature in Adcole gage. In Adcole gage, the part is loaded between centers and is rotated by headstock spindle, which has an optical angle encoder accurate to 0.001 degree. The part is measured by a follower which houses the laser system that takes radial measurements. Readout of the follower's position is made at every 1/10 degree of rotation of the part.

TABLE3.
EXPERIMENTAL RESULTS FOR 2^3 DESIGN

Sr. No.	Factors			Response	
	Speed (rpm)	Feed (mm/s)	Depth of Cut (mm)	Face flatness (mm)	Face runout (mm)
1	110	0.012	0.04	0.001	0.012
2	150	0.012	0.04	0.003	0.016
3	110	0.020	0.04	0.002	0.015
4	150	0.020	0.04	0.003	0.018
5	110	0.012	0.10	0.003	0.017
6	150	0.012	0.10	0.001	0.021
7	110	0.020	0.10	0.002	0.019
8	150	0.020	0.10	0.004	0.023
9	130	0.016	0.07	0.001	0.017
10	130	0.016	0.07	0.002	0.016
11	130	0.016	0.07	0.002	0.015
12	130	0.016	0.07	0.003	0.013

The results, hence obtained are fed into the Design Expert software (Minitab) for further analysis.

C. ANALYSIS

TABLE4.
ANALYSIS OF VARIANCE FOR FACE FLATNESS

Source	SS	DF	MS	F	P
A	0.00000112	1	0.00000112	1.69	0.285
B	0.00000112	1	0.00000112	1.69	0.285
C	0.00000012	1	0.00000012	0.19	0.694
AB	0.00000113	1	0.00000113	1.69	0.285
AC	0.00000112	1	0.00000112	1.69	0.285
BC	0.00000013	1	0.00000013	0.19	0.694
ABC	0.00000013	1	0.00000013	4.69	0.119
Curvature	0.00000038	1	0.00000112	0.56	0.508
Residual Error	0.00000200	3	0.00000067		
Pure Error	0.00000200	3	0.00000067		
Total	0.00001025	11			

TABLE5.
ANALYSIS OF VARIANCE FOR FACE RUNOUT

Source	SS	DF	MS	F	P
A	0.00002812	1	0.00002812	9.64	0.053
B	0.00001012	1	0.00001012	3.47	0.159
C	0.00004513	1	0.00004513	15.47	0.029
AB	0.00000012	1	0.00000012	0.04	0.849
AC	0.00000013	1	0.00000013	0.04	0.849
BC	0.00000013	1	0.00000013	0.04	0.849
ABC	0.00000013	1	0.00000013	0.04	0.849
Curvature	0.00001504	1	0.00001504	5.16	0.108
Residual Error	0.00000875	3	0.00000292		
Pure Error	0.00000875	3	0.00000292		
Total	0.00010767	11			

TABLE6.
ESTIMATED COEFFICIENTS FACE FLATNESS AND FACE RUNOUT

Term	Face flatness coefficient	Face runout coefficient
Constant	0.002375	0.017625
Speed	0.000375	0.001875
Feed	0.000375	0.001125
Depth of Cut	0.000375	-0.000125
Speed* Feed	0.000125	0.002375
Speed* Depth of Cut	-0.000375	0.000125
Feed* Depth of Cut	0.000125	-0.000125
Speed* Feed* Depth of Cut	0.000625	0.000125

D. EQUATIONS

1. 2^3 Design model

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_1 x_2 + \beta_5 x_2 x_3 + \beta_6 x_1 x_3 + \beta_7 x_1 x_2 x_3 \quad (1)$$

where,

y = function of model

x_1, x_2, x_3 = speed, feed, depth of cut respectively

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$ = coefficient

$x_1 x_2, x_2 x_3, x_1 x_3$ = interaction between speed and feed, feed and depth of cut, speed and depth of cut respectively

$x_1x_2x_3$ = interaction between speed and feed, feed and depth of cut, speed

1.1 Face flatness model

$$y = 0.002375 + 0.000375\ x_1 + 0.000375\ x_2 + 0.000375\ x_3 + 0.000125\ x_1 x_2 + 0.000125\ x_2 x_3 - 0.000375 x_1 x_3 + 0.000625 x_1 x_2 x_3 \quad (2)$$

1.2 Face runout model

$$y = 0.017625 + 0.001875 x_1 + 0.001125 x_2 - 0.000125 x_3 + 0.002375\ x_1 x_2 - 0.000125 x_2 x_3 + 0.000125 x_1 x_3 + 0.000125 x_1 x_2 x_3 \quad (3)$$

E. PLOTS

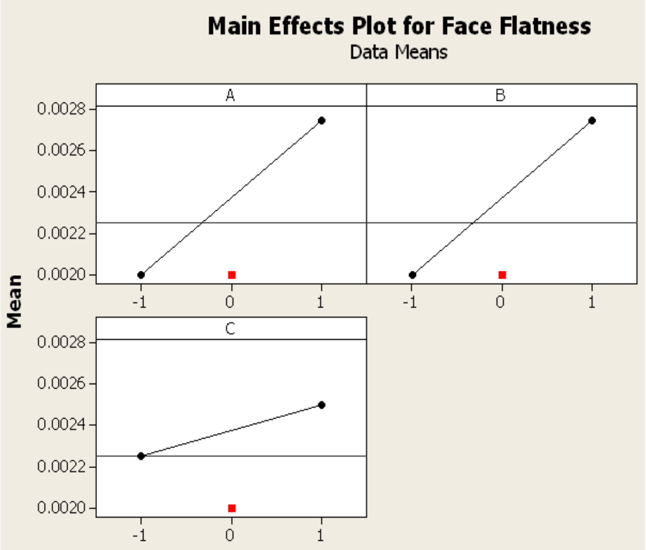

Fig. 2. Main effects plot for face flatness

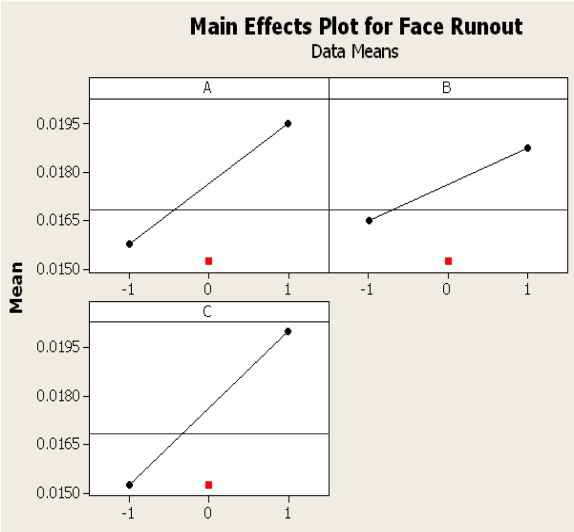

Fig. 3. Main effects plot for face runout

III. CONCLUSIONS

A CNC cylindrical grinding machine is a precision grinding machine. The investigation herein has derived relationship of grinding parameters and geometric tolerances.

Face flatness and face runout errors are least at 110 rpm, 0.012mm/s feed and 0.04mm depth of cut.

The analysis of variance for face flatness indicates that since the *p*-values of all the source of variations are greater than 5%, it is difficult to state which parameter significantly affects the face flatness error. The model hence developed is inadequate. However it could be used as a means to understand the most significant parameter that influences the geometry of the part. The most significant parameters that influence face flatness are speed and feed, followed by depth of cut. Interaction is also observed between speed & feed and speed & depth of cut. In order to develop an adequate empirical model further investigation is required with selection of wider range of variation for parameters.

The analysis of variance for face runout indicates that since the *p*-values for speed and depth of cut are almost equal and less than 5%, they are most significant parameters. Further investigation is required to understand the significance of feed with selection of wider range.

Main effects plot for both geometric tolerance errors indicate that the errors are minimum at lower values of the parameters. Face flatness and face runout errors increase with increase in the speed, feed and depth of cut.

Adherence to the predicted empirical models given by, Eqs. (2) and (3), will ensure control of face flatness and face runout so that economic and efficient parts are manufactured.

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