Case Study On Circularity Deviation Of Top Arm Holes In Self Centering Steady Rest

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Abstract: A study conducted in an Small and Medium scale Enterprise (SME) revealed that a Vertical Milling Centre (VMC) frequently faces circularity deviations while machining the Arm of a Self Centering Steady Rest. A cause and effect analysis is carried out to determine the probable causes of deviations. Further more a statistical analysis of the deviations using ANOVA revealed that the circularity deviations are related to the linear worktable movement of the VMC. In order to overcome the deviations VMC was recalibrated. After recalibration of VMC, an analysis on new sample revealed that there was no circularity deviations observed beyond the specified tolerance limits.

Index Terms: ANOVA, Circularity, F-value, P-value, Self centering steady rest, SME, Vertical Milling centre

1 Introduction

A steady rest is used for efficient centering and machining of long slender shafts. Self Centering steady rest shown in Figure 1 automatically centers the workpiece for performing machining operations. It has three rollers at approximately 120 degrees apart to hold the workpiece. These rollers move such that they always inscribe concentric circles between them. This feature along with the internal compensating system prevents the dislocation of work piece center under changing clamping pressure. This results in high centering accuracy. By mounting accordingly these steady rests can be used for turning outside diameters, inside diameters, facing, drilling, grinding, induction hardening etc

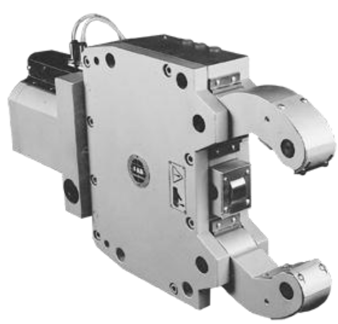

Figure 1. *Self Centering Steady Rest.*

Fenwick And Ravi (FAR) is a Small and Medium Enterprise (SME) working in Machine tool manufacturing sector and is established in the year 1990. They specialize in the manufacture of Bar feeders and Self centering steady rest for CNC turning centers, crankshaft web milling, crankshaft oil hole drilling , cylindrical drilling, cam shaft grinding etc. All the components required for these products are manufactured in their shop floor and they have stringent quality control procedures.

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2 Problem Description

The organization was faced with a problem of high rejection in the Vertical Milling Centre (VMC). The company management was not in a position to identify the root cause of the problem. In this context a study was undertaken to identify the causes and find the remedial measures to eliminate the causes. The Self centering steady rest comprises of cylindrical rollers mounted on two Arms and a third roller attached onto the body of the steady rest. High level of precision is required while manufacturing the Arm, which is an important component of the steady rest. The sketch of the Arm is shown in Figure 2. A slight deviation in the quality of Arms can lead to a rejection of the entire product. The Arm has three critical holes; pivot hole, front hole, a rear hole, and a pin hole. The Arm is made of EN8 steel and is machined using Vertical Milling Centre JYOTHI VMC 850 at a speed of 1500 rpm, using a micro Bore. The holes are machined within a tolerance of ± 0.005mm, the diameter and the location of the holes with respect to the central pivot hole is shown in Table 1. The pivot hole H2 is reference hole for drilling the remaining holes of the component. Thus the X and Y coordinates of the pivot hole H2 is taken as the origin and the coordinates of the other holes are measured with reference to H2

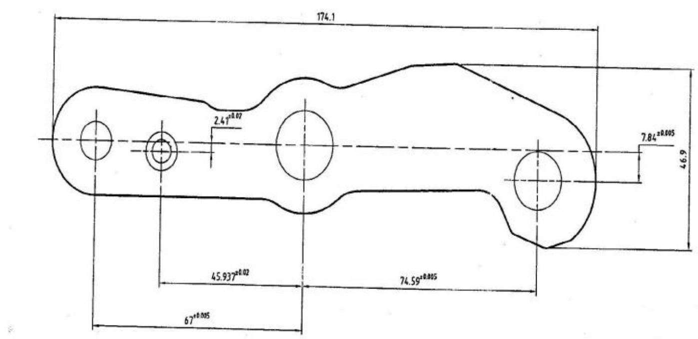

Figure 2 Sketch of Arm of Self Centering Steady Rest

Table 1 Arm Hole Specification			
Arm Holes	**Diameter**	**X Cordinate**	**Y Cordinate**
H1	15	-74.58	7.84
H2	18	0	0
H3	10	67	0

3 DATA COLLECTION

The organization manufactures the component in small batches of size varying between 2 to 20 components maximum in a batch. After initial set up of the fixtures on the worktable of the VMM is done, it is maintained till the entire batch is machined to avoid any errors. The important characteristics of holes such as circularity, cylindricity, and perpendicularity are measured using Coordinate Measuring Machine (CMM). The data regarding rejection for a batch of 6 Arms were collected for all the three holes H1, H2, and H3 for circularity, cylindricity and perpendicularity, and which is presented in Table 2.

Table 2 Deviations for Arm

Characteristic	(x,y) in mm	(-74.5 ,7.84)	(0,0)	(67,0)
	Component No:	H1	H2	H3
Circularity	1	0.0009	0.0009	0.0013
	2	0.0017	0.0002	0.0001
	3	0.0009	0.0023	0.0024
	4	0	0.0011	0.0028
	5	0.004	0.0019	0.0029
	6	0	0	0
Cylindricity	1	0.0035	0.0062	0.0008
	2	0.0024	0.0039	0.0012
	3	0.007	0.0061	0.0015
	4	0.0031	0.0061	0.0026
	5	0.0095	0.0034	0.0037
	6	0.0077	0.0031	0.0045
Perpendicularity	1	0.0048	0.0074	0.0048
	2	0.0043	0.0012	0.0024
	3	0.0094	0.0013	0.0035
	4	0.0066	0.0065	0.0071
	5	0.0089	0.0099	0.0117
	6	0.0027	0.0058	0.0156

As per geometric dimensioning and tolerancing, circularity tolerance (Figure 3(i)) is used to control the roundness of circular parts. In case of moving parts, circularity helps to ensure that the parts move smoothly and wear evenly. Cylindricity tolerance (Figure 3(ii)) is used when cylindrical part features must have good circularity and straightness. While circularity applies to cross section; cylindricity applies to the entire surface. Perpendicularity tolerance (Figure 3(iii)) specifies the degree to which the orientation of a right angled part varies. This feature is especially important in case of mating parts. Figure 3 shows the sketches of these characteristics.[1]

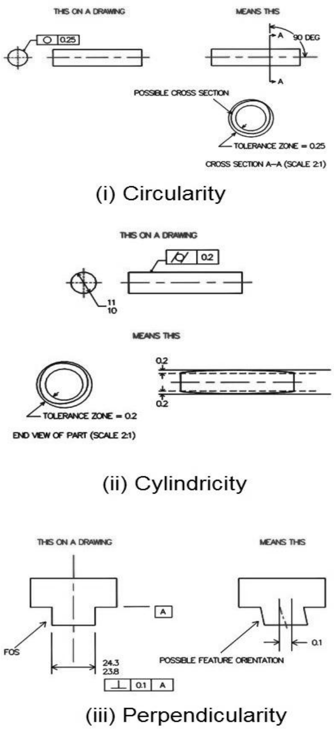

Figure 3 Characteristics of Hole

4 DATA ANALYSIS

To understand the causes of deviation, a brainstorming session was carried out involving all the concerned people, the outcome of the brainstorming was put in the form of the cause and effect diagram as shown in Figure 4. All the causes listed in the cause effect diagram were analysed and probable causes of errors are eliminated.

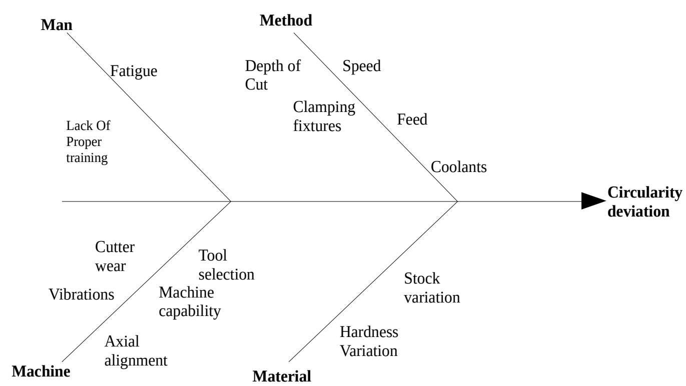

Figure 4 Cause and effect Diagram

5 ANALYSIS OF CAUSES

Previously the deviations were considered as effect of random causes until some serious rejections are encountered in the company. No scientific method was adopted to study the effect of work table traverse along x and y axis to have effect on machining quality characteristics. Hence it was decided to perform Analysis of Variance (ANOVA) on their relationship and interactions. ANOVA is an effective statistical tool to analyse the differences among group means and their associated procedures. It can be tested for a factor at various levels for responses [5].

5.1 Normality Test

Since the sample data available for analysis is less than 50 from a single production run, normality of the sample is to be ensured before carrying out the analysis. In such a scenario, Normal Probability plotting method is best suited. It is a graphical method to examine a process for statistical control even with 5 to 10 observations [6]. The method is as follows:

i. Arrange the observations in ascending order of their value
ii. For every observation Xi, calculate the corresponding value Fi = {i – 1/2}*100/n, where i relates to the rank of the observation as obtained in step1 and n is the total number of observations.
iii. Plot points (Xi, Fi) on the normal probability paper with Xi on the X axis and Fi on the Y-axis.
iv. Check whether the points plotted fall on the straight line reasonably well or not. In the former case, it can be inferred that the observations come from a normal distribution i.e., process is under statistical control. In the latter case, the observations do not come from a normal distribution. It means that assignable causes are present during data collection. Hence, fresh data should be collected, after taking action to ensure statistical control.
v. If the process is judged to be under statistical control, draw a straight line by eye judgement that fit plotted points best.
vi. Get X5, the value at X axis corresponding to the intersection of the fitted line and the line Y=5. Similarly get X95 and X50 (mean of the sample). Estimate of standard deviation of the sample is given by (X95 – X5) / 2.56
vii. A Probability Value (P-value)of less than 0.05 alerts about the non-normality of the data with 95% confidence.

Statistical software Minitab is used for statistical analysis of the data. The features like ability to perform normal probability plot and ANOVA in Minitab helped to ease the analysis.

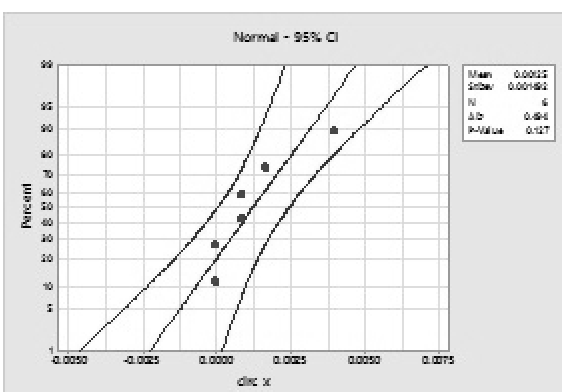

Figure 5 Normality plot of H1

Normality of the data collected for the arm is checked by Normal probability plot method with the help of Minitab. The result graph for readings of H1 for circularity in Table 2 is shown in Figure 5. The Probability value or commonly referred to as the P-value of 0.127 signifies that the sample of 6 observations comes from a normal population. Similarly each set of observed data is checked for normality so as to ensure that all the data comes from a normal population before performing ANOVA so that the results are accurate after analysis.

5.2 Analysis of Variance (ANOVA)

The factors considered for performing ANOVA was (i) X-axis worktable movement and (ii) Y-axis Table movement. For testing the first factor, three levels are considered i.e., -74 mm, 0 mm and 64 mm. Similarly for the second factor analysis, two levels are considered 0mm and 7.84 mm. For each of these levels the response characteristics; circularity, cylindricity and perpendicularity are tested for interaction. Lower Fisher value (F) with high probability value (P) ascertains that there is no interaction between the variables. Next step is to perform ANOVA for the various factors at different levels with the given responses at noted down in Table 2. ANOVA for testing the effect of worktable movement along x-axis on cylindricity of a hole given in Table 2 is calculated using the aid of MINITAB and is shown in Exhibit 1.

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Factor	2	0.000001	3.33%	0.000001	0.000000	0.26	0.776
Error	15	0.000024	96.67%	0.000024	0.000002		
Total	17	0.000025	100.00%				

Fisher Pairwise Comparisons

Grouping Information Using the Fisher LSD Method and 95% Confidence

Factor	N	Mean	Grouping
C3	6	0.001583	A
circ x	6	0.001250	A
C2	6	0.001067	A

Means that do not share a letter are significantly different.

Exhibit 1 ANOVA for Circularity along X axis movement

F value of 0.26 (Less than 1) and P value of 0.776 (greater than 0.05) helps to arrive at the conclusion that the worktable movement along the x-axis while boring the hole has no effect on the circularity of the holes .The average response graph shown in Figure 6 shows the expected deviation in circularity for different levels and is plotted by each level average.

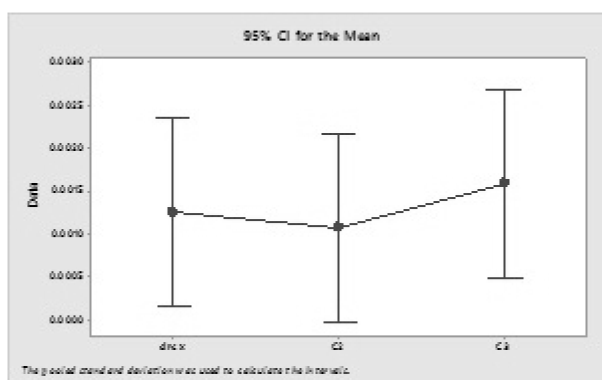

Figure 6 Response Graph

ANOVA conducted for data along X axis given in Table 2 can be summarised as given in Table 3. The result shows that there is an interaction of the worktable movement with the cylindricity of the Jig Bored Hole.

Table 3 ANOVA for X axis table movement.		
Characteristics	**F value**	**P Value**
Circularity	0.26	0.776
Cylindricity	3.8	0.046
Perpendicularity	0.89	0.432

Similarly ANOVA conducted for data along Y Axis as given in Table 2 can be consolidated to as given in Table 4. Since H2 and H3 has same coordinates (Y=0 mm), while calculation the data of H2 and H3 is grouped together to carryout ANOVA. The result shows that Y axis table movement has a greater F-value for cylindricity but since the P-value is not less than 0.05, it can be concluded to have no interaction with the work table movement.

Table 4 ANOVA for y axis table movement.		
Characteristics	**F value**	**P Value**
Circularity	0.01	0.905
Cylindricity	2.95	0.105
Perpendicularity	0.03	0.873

5 Results and Discussions

After performing ANOVA the final results of analyses are shown in Table 3 and Table 4. Circularity deviations along X axis gives an F value of 0.260 with a P value of 0.776, which confirms that there is no interaction of table movement with circularity of the hole. Whereas for Cylindricity along X axis the F value is 3.8 with a corresponding P value of 0.046, which signifies that, the table movement along X-axis has an interaction with the response variable of cylindricity. Similarly analysing the perpendicularity interaction with the table movement along the X-axis, shows that it has got no interaction with the factor. The Y axis table movement for the characteristics of hole circularity and perpendicularity has lower F value of 0.01 and 0.03 respectively signifies that there is no interaction between the respective factors and responses. The F value for cylindricity along Y axis has a higher value of 2.95, but since the associated P value is not less than 0.05, no interaction between the factor and responses were concluded. With this analysis, it was found that deviation in the X axis direction is considered as the cause for rejection. To overcome this problem it was decided to reorient the work piece on the worktable or completely recalibrate the machine. After discussion with company experts it was decided to recalibrate the machine.

6 Implementation of remedial measures

The CNC machine center was calibrated for linear axis Direct measurement of individual axis on the machine using LASER measurement system (LMS). The calibration measurement and analysis was done in accordance with ISO: 230-2:2006 for bidirectional accuracy of positioning, repeatability of positioning and systematic deviation of positioning. After recalibration, a sample data of 6 Arms machined on the same VMC was collected as given in Table 5. ANOVA was carried out on the sample data for X and Y axis interactions on the characteristics. The result of ANOVA is shown in Table 6 and indicates that there is no interaction between the factors and the levels for the response characteristics.

Table 5 Deviation of Arm for sample 2				
Characteristic	**(x,y) in mm**	**H1**	**H2**	**H3**
	Component No:	**(-74.5,7.84)**	**(0,0)**	**(67,0)**
Circularity	1	0.0009	0.0009	0.0013
	2	0.0017	0.0002	0.0001
	3	0.0009	0.0023	0.0024
	4	0	0.0011	0.0028
	5	0.004	0.0019	0.0029
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	2	0.0024	0.0039	0.0012
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	2	0.0043	0.0012	0.0024
	3	0.0094	0.0013	0.0035
	4	0.0066	0.0065	0.0071
	5	0.0089	0.0099	0.0117
	6	0.0027	0.0058	0.0156

Table 6 F-value for sample 2 ANOVA analysis			
Axis	**Circularity**	**Cylindricity**	**Perpendicularity**
X	0.32	0.92	0.26
Y	0.2	1.01	0

7.0 Conclusion

The circularity deviations observed in high precision components machined using CNC machines are related to deviations generating from the machine itself. It was observed that there is a circularity deviation along the X-axis direction. In order to overcome the deviation in the hole machining VMC was recalibrated. After the recalibration, Arms machined from the VMC were further analysed and found that there was no deviations beyond the tolerance levels. The ANOVA analysis carried out on the samples reveals that the deviations observed in the quality characteristics of a component could be due to the interactions between linear worktable movements of a machine centre.

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