Performance Analysis of Vertical Machining Center through Process Capability

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Abstract- Process capability analysis ensures that processes are fit for industry company specification while reduce the process variation and important in achieving product quality characteristic. Its indices are to measure the inherent variability of a process and thus to reflect its performance. The main objective for this project is to predict current and future capability of the process to produce product within specification in the company and to investigate the product produced by the company to meet the customer's specification. This project focuses on Process Capability Analysis that had been applied in small and medium industry in the organization which includes select critical parameters, data collection, study on process capability and data evaluation. This project was successfully done by implementing and applying the capability study to the company. This case study is carried out at Jadhao Icons Limited at MIDC Amravati to study Process Capability analysis of Vertical Machining Center.

Keywords – Process Capability, standard deviation, process capability index Cp and Cpk, control charts

I. INTRODUCTION

Most manufacturing companies nowadays invested lots of money in order to buy the expensive machine tools that will help them to improve the quality and delivery time of the products that they produced. With all the high investment, users expect that the machine tools they purchase can fulfill all their requirements and needs which is to have the performance in machine accuracy. The users demanded that the machines they purchased need to have high flexibility, good running power, speed, accuracy and is capable of holding tight tolerances. The users expect that the machine will perform based on the standard specification in machining. Nowadays, manufacturing industries are facing problems in determining or verifying the machine tool accuracy. In the manufacturing sector, the accuracy of parts is very important because from the finish part we can evaluate the accuracy of the machine that produces the particular part. The method that can be recommended is by specifying the machine tool accuracy by conducting performance test to the machine that is likely to be used.
The one method that companies can imply is to ascertain the exact machine capability and performance by conducting an acceptance test which can be called as a 'Performance Test' for each of the machines they purchased. The performance test uses a methodology by machining the standard test piece and then from the finish part it can be evaluated from the measurement result compared to the standard. From the result, we can know either the machine that been tested has the capability or the desired accuracy.This case study is carried out at Jadhao Icons Limited at MIDC Amravati to study Process Capability analysis of Vertical Machining Center.

1.1 problem statement

Capability analysis is an excellent tool to demonstrate the extent of an improvement made to a process. It can summarize a great deal of information simply, showing the capability of a process and the extent of improvement needed. Having survey in an industry named Jadhao Icons at MIDC Amravati it is observed that before maintenance of VMC 45 T20 the manufacturing of Swing lever was not within tolerance. In this project the process capability analysis is made after maintenance to evaluate the performance of Vertical Machining Center in an industry named Jadhao Icons at MIDC Amravati. Process capability indices are calculated after the data had been collected.

1.2 Project objectives

1. Predicting the extent of variability that process will exhibit.
2. To predict current and future capability of the process to produce product within specification in the company.
3. To investigate the product produced by the company meet the

customer's Specification.

4. Reducing the variability of the manufacturing process.
5. Planning the interrelationship of sequential process.

II. PROCESS CAPABILITY ANALYSIS

2.1 Process Capability

Process capability studies are used for monitoring the capability of a process. This implies that it has to be based on some sort of collection of data from the process. In order to get a fair picture of the capability of the process, it has to be stable when the data is collected. After the collection of data from a process, the data may be assessed in several ways. One way to do the assessment is to use process capability indices, which provide numerical measures of the capability. Capability Requirement:

In current practice, a process is called ``inadequate'' if $Cp < 1.00$; it indicates that the process is not adequate with respect to the production tolerances spefications, either process variation needs to be reduced or process mean needs to be shifted closer to the target value T. A process is called capable if $1.00 \leq Cp \leq 1.33$; it indicates that caution needs to be taken regarding process distribution, some process control is required. A process is called satisfactory if $1.33 \leq CP \leq 1.50$; it indicates that process quality is satisfactory, material substitution may be allowed, and no stringent quality control is required. A process is called excellent if $1.50 \leq CP \leq 2.00$; it indicates that process quality exceeds ``satisfactory'' and a process is called ``super'' if $CP > 2.0$.

Table 1 summarizes the five conditions and the corresponding CP values (W.L Pearn and K.S. Chen2002).

Quality condition	**Cp Values**
Inadequate	$Cp < 1.00$
Capable	$1.00 \leq Cp \leq 1.33$
Satisfactory	$1.33 \leq Cp \leq 1.50$
Excellent	$1.50 \leq Cp \leq 2.00$
Super	$2.00 < Cp$

2.2. Process capability study steps

A process capability analysis is made of four things that is the actual process, performance information, action on the process, and action on the output. Using this information, it is possible to determine the proportion of output that will be acceptable. To conduct a process capability study, the following steps are needed. The general process capability study steps are:

1. Select Critical Parameter: Critical parameters need to be selected before the study begins. Critical parameters may be established from drawings, contracts, inspection instructions, work instructions, etc. Critical parameters are usually correlated to product fit and/or function.

2. Collect Data: A data collection system needs to be established to assure that the appropriate data is collected. It is preferable to collect at least 40 data values for each critical parameter. If this is not possible, corrections can be made to adjust for the error that is introduced when less than 40 data values are collected.

3. Establish Control over the process

A distinction between product and process should be made at this point. The product is the end result from the process. The product may be a physical item (Example: fabricated part). One may control the process by measuring and controlling parameters of the product directly or measuring and controlling the inputs to the process. It is ultimately desirable to establish control over the process by controlling the process inputs. On the other hand, process capability indices are always performed using the critical parameters of the product.

4. Analyse process data : The process data is to be analyse using control charts that whether the component under test is manufactured within tolerance limits or not. Calculation of process capability indices (C_p and C_{pk}) gives whether the process is capable or not.. If the process is not capable (out of control), the improvement to the process must be taken by the company.

5.Results and Conclusion

Having finished with the analysis process and after plotting control charts we get the results accordingly suggestions can be given.

2.3 process capability indices

Statistical methods are becoming more popular in industrial quality control. They are widely used to understand the natural variation in the industrial processes and help managers to make intelligent decisions. Focusing on process variation and for improvement purposes, process capability indices have been used excessively in the field of quality control. The purpose of these indices is to determine whether the manufacturing process is capable of producing final products which are within the customer specifications, often called design tolerances. The most common indices being applied by manufacturing industry are C_p and C_{pk}. C_p is the process capability ratio and is defined as follows:

$$Cp = \frac{\text{Allowable Process Spread}}{\text{Actual Process Spread}}$$

C_p= Process capability index that indicates process potential performance relating to the specification spread

Cp	PPM (Products Per Million)
0.5	133614
1	2700

Allowable process spread= (USL-LSL)
Actual process spread= 6σ

This can be also expressed as follows: $C_p = \frac{USL-LSL}{6*\sigma}$

Equation of C_p with upper and lower specification and process standard deviation

USL= Upper specification limit σ= Process standard deviation
LSL= Lower specification limit

C_p is the process capability ratio for off-center processes and is defined as the minimum value of one-sided upper or lower process capability ratios. If cp is greater than or equal to 1.0, the process would produce conforming parts. A cp value of less than 1.0 means the process would produce some nonconforming output. The greater this value, the better.

$Cpk = Min (Cpu , C_{pl})$

C_{pk}= Process capability index that indicates process actual performance by accounting for shift in the mean of the process within the upper and lower specification limit.

C_p cannot be used without both Upper and Lower Specifications Limits. Cp does not account for process entering. If the process average is not exactly centered in nominal, the Cp index will give misleading results. If the process is not centered, a better measure of actual capability is Cpk. One sided capability measures are as follows:

$$Cpu = \frac{USL - LSL}{3 * \sigma} \quad \text{OR}$$

$$Cpl = \frac{u - LSL}{3 * \sigma}$$

Equivalent, C_p value	Capability to produce nonconformance product, %
0.50	86.64
0.62	93.50
0.68	96.00
0.81	98.50
0.86	99.00
1.00	99.73
1.33	99.994

Equation of C_{pk} with upper and lower and two-sided specification limit

C_{pu}= C_{pk} for upper specification limit

C_{pl}= C_{pk} for lower specification limit

In the above equations, *USL* and *LSL* are the upper and lower design specification limits, μ and σ are the process mean and standard deviation respectively.

Table 2**:** Equivalent C_p value and capability to produce nonconformance product

Table 3 . Process Capability Index versus Defect Level

1.3	96
1.7	0.34
2	0.0018

III. METHODOLOGY

3.1 Machine used for process capability

Process capability is calculated over a long period of time and is influenced by manufacturing environment. Process capability is calculated within a short period .The impact of all the materials and parts must be eliminated this is used for to audit the quality behavior of the single machine. In this study the Vertical Machining Center which manufactures Swing Lever is selected to perform process capability analysis.

Vertical CNC Machining Center

Figure 1 : Vertical Machining Center

The vertical CNC machining center is a saddle type construction with sliding bed ways that use a sliding vertical head instead of a quill movement. The vertical machining center is generally used to machine flat parts that are held in simple fixture. Because the thrust forces in vertical machining are directed downward, such machines have high stiffness and produce parts with good dimensional accuracy. These machines are generally less expensive than horizontal spindle machines .The basis for all machine movement is the Cartesian coordinate system.

The table 4 shows specifications of Vertical Machining Center.

Specifications	Unit	BMV45	BMV45 T20
Clamping area	mm x mm	450 x 900	450 x 900
No./ Width/ CD of T-slots	No./ mm/ mm	5/ 18/ 80	5/ 18/ 80
Max. safe load on table	Kg	500	500
Distance from table to spindle face	Mm	100-600 (300 - 800)	100-600 (300 -800)
X-axis	Mm	600	600
Y-axis	Mm	450	450
z-axis	Mm	500	500
Feed rates	mm/ min	1-10,000	1-10,000
Rapid traverse X/ Y/ Z	m/ min	24/ 24/ 15	24/ 24/ 15
Power (Cont./ 30 min.	kW	5.5/ 7.5 (7.5/ 11)	5.5/ 7.5 (7.5/ 11)
Speed	Rpm	6,000 (8,000/ 10,000)	6,000 (8,000/ 10,000)
Taper		BT40	BT40
Number of tools	Nos.	-	20
Max. tool diameter with adj.	Mm	-	80/ 125
Max. tool length	Mm	-	250
Max. tool weight	Kg	-	8
Tool change time (tool to	Sec	-	9

No. of pallets	No	-	-
Pallet size	mm x mm	-	-
Max. safe load per pallet	Kg	-	-
Positioning	Mm	± 0.005	± 0.005
Repeatability	Mm	± 0.003	± 0.003
Machine weight	Kg	4,000	4,500
Total connected load	kVA	16	17
Pneumatic supply	Bar	6	6

3.2. Details of swing lever

The type of machine used in the evaluation is a Vertical Machining Center and the specific name is BMV 45 T20 Vertical Machining Center. This machine manufacture Swing lever. Since all the three axes are working during the manufacturing so swing lever is considered for process capability analysis. The detail drawing of swing lever is as shown below.

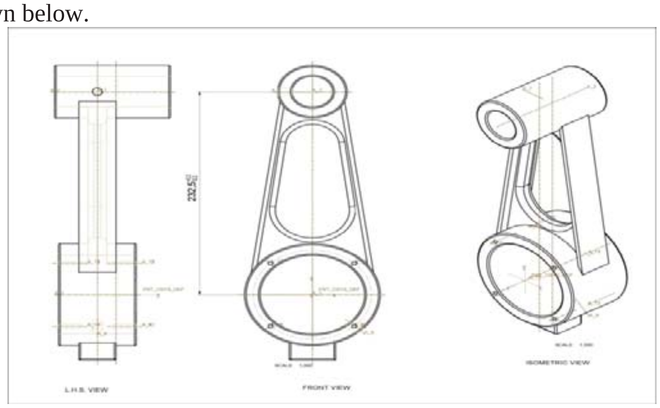

Figure 2 Details of Swing Lever

3.3 Select critical parameter

Critical parameters need to be selected before the study begins. Critical parameters may be established from drawings, contracts, inspection instructions, work instructions, etc. Critical parameters are usually correlated to product fit and/or function.

As discussed earlier the Vertical machining center is selected for process capability analysis. The vertical machining center manufactures Swing lever. From the drawings it is seen that the small variation in the readings of center to center distance of Swing lever may lead to rejection of the job. So the Center to Center distance of Swing lever is taken as critical dimension.

The details of Dimension are

Target Value = 232.5 mm
Tolerance = +/- 0.2 mm
Upper Limit = 232.7 mm
Lower Limit = 232.3 mm

3.4 Machines/equipments used for measurement

In this performance test, the measurement process is conducted by using a suitable metrology equipment to ensure the validity of the finish part which is base on the standard. The measurement value will be compared with the standards. For the very precise reading of critical parameter (center to center distance) the Co-ordinate Measuring Machine is used.

Co-ordinate Measuring Machine

Figure3 : Co-ordinate Measuring Machine

Important features of the CMM are :

(i) To give maximum rigidity to machines without excessive weight, all the moving members, the bridge structure, Z-axis carriage, and Z-column are made of hollow box construction.

(ii) A map of systematic errors in machine is built up and fed into the computer system so that the error compensation is built up into the software.98 Metrology and Instrumentation.

(iii) All machines are provided with their own computers with interactive dialogue facility and friendly software.

(iv) Thermocouples are incorporated throughout the machine and interfaced with the computer to be used for compensation of temperature gradients and thus provide increased accuracy and repeatability.

3.5 collection of data

A data collection system needs to be established to assure that the appropriate data is collected. It is preferable to collect at least 40 data values for each critical parameter. If this is not possible, corrections can be made to adjust for the error that is introduced when less than 40 data values are collected. So the readings of center to center distance of 40 number of components are taken for process capability analysis. As per the drawing from the design department, the following data is collected

Target Value = 232.5 mm

Tolerance = +/- 0.2 mm

Upper Limit = 232.7 mm

Lower Limit = 232.3 mm

The readings of Center to Center distance are as follows.

Sr. No	Readings of Center to center distance in mm	Sr. No	Readings of Center to center distance in mm
1	232.519	21	232.401
2	232.59	22	232.496
3	232.57	23	232.49
4	232.511	24	232.519
5	232.502	25	232.52
6	232.518	26	232.505
7	232.519	27	232.511
8	232.489	28	232.52
9	232.52	29	232.512
10	232.4	30	232.503
11	232.52	31	232.502
12	232.59	32	232.519
13	232.512	33	232.495
14	232.519	34	232.52
15	232.504	35	232.519

16	232.51	36	232.58
17	232.511	37	232.51
18	232.502	38	232.52
19	232.518	39	232.502
20	232.519	40	232.518

3.6 Estimating Standard Deviation

The standard deviation gives an idea of how close the entire set of data is to the average value. Data sets with a small standard deviation have tightly grouped, precise data. Data sets with large standard deviations have data spread out over a wide range of values. The formula for standard deviation is given below as equation. After collection of data the standard deviation is calculated.

$$\sigma = \sqrt{\frac{\Sigma (Xi - mean)^2}{n-1}}$$

Following parameters were found out to Calculate Standard Deviation

Sr. No	Lower Limit in mm	Readings of Center to center distance in mm	Upper Limit in mm	Mean in mm	Xi - Mean	$(Xi\text{-}Mean)^2$
1	232.3	232.519	232.7	232.512630	0.00637	0.000041
2	232.3	232.59	232.7	232.512630	0.07737	0.005986
3	232.3	232.57	232.7	232.512630	0.05737	0.003291
4	232.3	232.511	232.7	232.512630	-0.00163	0.000003
5	232.3	232.502	232.7	232.512630	-0.01063	0.000113
6	232.3	232.518	232.7	232.512630	0.00537	0.000029
7	232.3	232.519	232.7	232.512630	0.00637	0.000041
8	232.3	232.489	232.7	232.512630	-0.02363	0.000558
9	232.3	232.52	232.7	232.512630	0.00737	0.000054
10	232.3	232.4	232.7	232.512630	-0.11263	0.012686
11	232.3	232.52	232.7	232.512630	0.00737	0.000054
12	232.3	232.59	232.7	232.512630	0.07737	0.005986
13	232.3	232.512	232.7	232.512630	-0.00063	0.000000
14	232.3	232.519	232.7	232.512630	0.00637	0.000041
15	232.3	232.504	232.7	232.512630	-0.00863	0.000074
16	232.3	232.51	232.7	232.512630	-0.00263	0.000007
17	232.3	232.511	232.7	232.512630	-0.00163	0.000003
18	232.3	232.502	232.7	232.512630	-0.01063	0.000113
19	232.3	232.518	232.7	232.512630	0.00537	0.000029
20	232.3	232.519	232.7	232.512630	0.00637	0.000041
21	232.3	232.401	232.7	232.512630	-0.11163	0.012461
22	232.3	232.496	232.7	232.512630	-0.01663	0.000277
23	232.3	232.49	232.7	232.512630	-0.02263	0.000512
24	232.3	232.519	232.7	232.512630	0.00637	0.000041
25	232.3	232.52	232.7	232.512630	0.00737	0.000054
26	232.3	232.505	232.7	232.512630	-0.00763	0.000058
27	232.3	232.511	232.7	232.512630	-0.00163	0.000003

28	232.3	232.52	232.7	232.512630	0.00737	0.000054
29	232.3	232.512	232.7	232.512630	-0.00063	0.000000
30	232.3	232.503	232.7	232.512630	-0.00963	0.000093
31	232.3	232.502	232.7	232.512630	-0.01063	0.000113
32	232.3	232.519	232.7	232.512630	0.00637	0.000041
33	232.3	232.495	232.7	232.512630	-0.01763	0.000311
34	232.3	232.52	232.7	232.512630	0.00737	0.000054
35	232.3	232.519	232.7	232.512630	0.00637	0.000041
36	232.3	232.58	232.7	232.512630	0.06737	0.004539
37	232.3	232.51	232.7	232.512630	-0.00263	0.000007
38	232.3	232.52	232.7	232.512630	0.00737	0.000054
39	232.3	232.502	232.7	232.512630	-0.01063	0.000113
40	232.3	232.518	232.7	232.512630	0.00537	0.000029

$$\sigma = \sqrt{\frac{\sum (Xi - mean)^2}{n-1}}$$

$\sum (Xi - mean)^2 = 0.048003$ And n-1 = 40-1

= 39

$$\sigma = \sqrt{\frac{0.048003}{39}}$$

= 0.035082 mm

IV. RESULT ANALYSIS AND DISCUSSION

4.1 calculations of cp and cpk values

Actual process spread= 6σ

This can be also expressed as follows:

$$Cp = \frac{USL - LSL}{6 * \sigma}$$

$$Cp = \frac{232.7 - 232.3}{6 * 0.035082}$$

Cp = 1.9

Now the Equation of C_{pk} is

Cpk = Min (Cpu , C_{pl})

$$Cpu = \frac{USL - LSL}{3 * \sigma}$$ and

$$Cpl = \frac{u - LSL}{3 * . \sigma}$$

$$Cpu = \frac{232.7 - 232.3}{3 * .035082}$$

= 3.8

And

$$Cpl = \frac{232.51263 - 232.3}{3 * 0.035082}$$

= **2.02**

The minimum of the above value will be taken as value of Cpk.

Cpk = 2.02

C_{pk}= Process capability index that indicates process actual performance by accounting for shift in the mean of the process within the upper and lower specification limit.

4.2 Control chart interpretation

From the readings of Center to center distance of Swing lever the X-Control Chart is plotted. The readings are as follows

Sr. No	Readings of Center to center distance in mm	Sr. No	Readings of Center to center distance in mm
1	232.519	21	232.401
2	232.59	22	232.496
3	232.57	23	232.49
4	232.511	24	232.519
5	232.502	25	232.52
6	232.518	26	232.505
7	232.519	27	232.511
8	232.489	28	232.52
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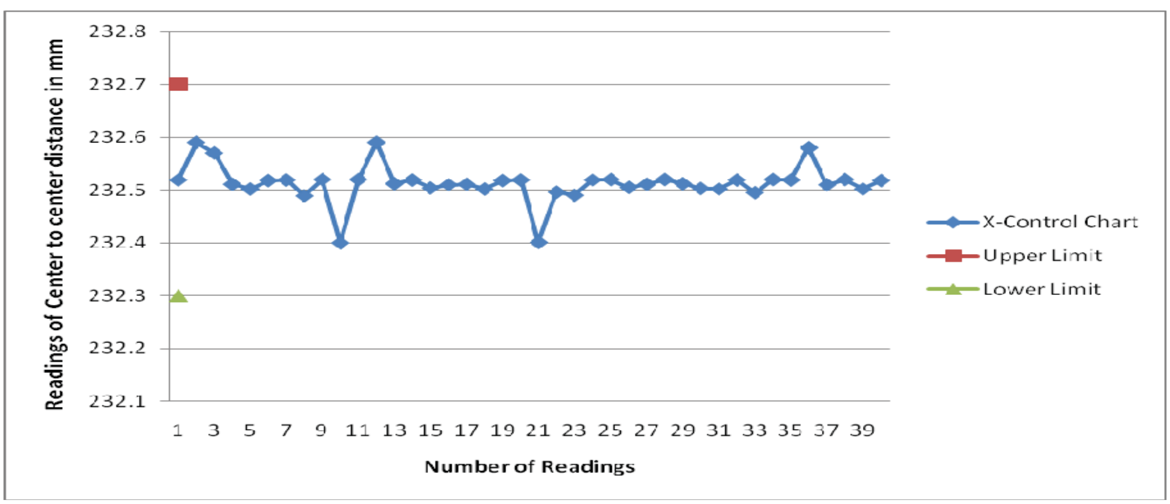
10	232.4	30	232.503
11	232.52	31	232.502
12	232.59	32	232.519
13	232.512	33	232.495
14	232.519	34	232.52
15	232.504	35	232.519
16	232.51	36	232.58
17	232.511	37	232.51
18	232.502	38	232.52
19	232.518	39	232.502
20	232.519	40	232.518

X-Control Chart



4.3 Histogram

From the readings of center to center distance the range of limits is decided and from that the frequency of occurrences is found out and from these values Histogram is plotted.

Bin(mm)	*Frequency*
232.366	0
232.433	2
232.5	4
232.567	30
232.634	4
232.701	0
More	0

Range in mm	
232.3	232.366
232.367	232.433
232.434	232.5
232.501	232.567
232.568	232.634
232.635	232.701

Figure 5 : Histogram

4.4 Result

From the X-control Chart and Histogram it is observed that the readings of center to center distance of Swing lever are within the tolerance limits and after calculating the process capability index Cp and Cpk the following results are summarised.

Table 6. Process Capability Indices for the Process Parameters

Machine Name	**Critical parameter**	**Process capability index**	**Value**	**Comment**
Vertical Machining Center (BMV45t20)	**Center to center distance of swing lever**	**Cp**	**1.9**	**Process is capable**
		Cpk	**2.02**	**Process is well centered**

V. CONCLUSION

Capability analysis helps to determine the ability for manufacturing between tolerance limits and engineering specifications. Capability analysis can be applied not only to production period but also to a machine or machine tool. Capability analysis gives the information about changes and tendencies of the system during production. It is used to determine the system tendencies between tolerance limits.

As it can be seen from the study accomplished, the process control and capability method is more effective for determining the quality problems and solving them in small and medium sized companies that manufacture parts by machining and develop more efficient processes in order to survive in the competitive market. Thereby, correct understanding of the components of variables, definition of factors causing variations and keeping them under control is all important for small sized companies.

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