Positional Accuracy Improvement Through Pareto and Cause and Effect Analysis in CNC Machine Tools

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The performance of milling and boring operation on ‘Gear Housing’ in CNC Milling Machine (DC-45), in terms of positional error and accuracy of the job, and a wide variation of the job in terms of quality improvement have been investigated. First of all the problem has been defined. The ‘vital few’ from ‘trivial many’ problems has been established through Histogram followed by Pareto Analysis, and then Cause and Effect Analysis. The problem has been investigated through Ishikawa diagram and finally preventive and corrective action has been taken for the positional accuracy. An improvement has been achieved in the process by the application of the corrective measures and total elimination of errors has been obtained.

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1 Introduction

Accuracy of machined component is one of the most critical considerations for any manufacturer. Many key factors like cutting tool and machining conditions, resolution of the machine tool, the type of work-piece etc., play an important role. The three major types of errors are geometrical, thermal and cutting-force induced errors.

Before we look into the problem, we need to clearly understand what we mean by accuracy and error. Error is defined as the difference between the actual response of the machine to a command issued according to the accepted protocol of that machine’s operation and the response to that command anticipated by the protocol. Accuracy on the other hand, is defined as the degree of conformity of the finished part to dimensional and geometric specifications {Hoken [1]}.

1.1 Positional Errors

Errors can be classified into two categories namely quasi-static errors and dynamic errors. Quasi-static errors are those between the tool and the workpiece that are slowly varying with time and related to the structure of the machine tool itself. These sources include the geometric/kinematics errors, errors due to dead weight of the machine’s components and those due to thermally induced strains in the machine tool structure. Dynamic errors on the other hand are caused by sources such as spindle error motion, vibration of the machine structure controller errors etc. In a typical CNC machine tool, more than 70% of the geometric errors are attributed to Quasistatic errors. Geometric and kinematic errors of the machine tool form the basic inaccuracy of the machine tool. Some of the various geometric and kinematic errors that are generated can be listed as: (a) positioning errors; (b) straightness...
errors; (c) angular errors; (d) squareness and perpendicularity errors; (e) backlash error; and (f) contouring error [Ramesh et al. [6,7]].

Other errors like tool wear and fixturing errors add to the overall inaccuracy of the machined component. Errors in fixturing are caused by fixture set-up and geometric inaccuracies of the locating elements and by fixture flexure. In case where the workpiece is restrained by a small area of contact with the fixture, the errors due to deformation or lift-off of the workpiece could cause significant errors. Workpiece displacement is dependent on several factors like position of the fixturing elements, clamping sequence, clamping intensity, type of contact surface etc. Thus workpiece displacement could be a significant source of machine error.

### 1.2 Pareto analysis

Pareto discovered a universal relationship between value and quantity. He used a technique for assessing uneven distribution of wealth. Pareto analysis helps in the identification of vital few from the trivial many at a glance.

Pareto diagram is a column graph, drawn after data collection for the purpose of differentiation between the vital factors that contribute most to the unsatisfactory situation from other trivial ones. Normally this technique is being used for fixing priorities for selection of the problem to be taken up serially, listed after brainstorming and data collection. It is also used for tackling the major factors responsible for any problem. In some cases the problems listed out may be grouped on the basis of their nature, and their recurrence can be projected in terms of percentage.

The identified problems are first grouped in specific categories. The total factors are considered to be 100%.

Then, certain percentages are given to each factor according to its weight in the problem, which is worked out through data collection.

Horizontal axis on a graph represents the working system in percentage in descending order, whereas vertical axis as percentage in percentage contribution.

Pareto diagram is used for significant improvements in production and services of the working system. These diagrams show the vital and most important areas that have to be concentrated first, leaving the trivial issues to be taken up subsequently.

### 1.3 Cause and Effect Analysis (Fish bone diagram)

Kouru Ieshikaw introduced this diagram in 1943 at the Kawasaki iron works, Japan. A cause and effect diagram is an effective investigating tool for pictorial representation of various facts about the causes that result in a specific case. This diagram has become useful due to its visual impact.

A large rejection of job has been observed in machining of gear housing; gear frame, cylinder block and magneto cover due to positioning errors. In the present paper Pareto and Cause and Effect analysis have been made to achieve accuracy in position of drilling holes in gear housing. The results in this paper are useful for designers wishing to choose error characteristics, while controlling/ predicting the effects on volumetric error in the work space.

Geometrical and kinematics errors constitute the basic inaccuracy of a machine tool. A great amount of work, over the last decade, has gone into this area. As a result, modern day machine tool manufacturers are able to achieve accuracies in the range of 0.005 mm on account of improved design methodologies and advanced materials technology.

The fixture also contributes to machine inaccuracy in two ways. Those errors generated on account of the deformation of thin-walled work pieces under the influence of the clamping force do not form a part of the basic machine inaccuracy. This error has various facets to it like the stiffness of the workpiece, the clamping force employed to prevent lift-off during machining, the depth-of- cut etc. The geometric errors generated are on account of the basic design of the fixture like locator and clamp geometry, their placement, the clamping sequence etc. This is so because in general purpose machines, and especially in the case of special purpose machines (SPM), the fixture forms an integral part of the machine tool and thus contributes to its basic accuracy [Ramesh et al. [6]].

While the aforementioned errors are the major contributors to the inaccuracy of the machine tool peruse, a significant role played by errors produced within the fixture-tool-workpiece system that grossly affect the overall accuracy of workpiece. A fixture is a machine element that serves to hold and restrain the workpiece during machining. The accuracy of the machined component is directly related to the effectiveness with which the fixture is able to restrain the workpiece without any relative displacement between two. Spherical-tipped locators and clamps are often use for the restraint of work pieces within machining centre. In these applications, workpiece
displacement within the fixture during clamping and machining can be significant source of workpiece geometric error \cite{Fan & Burdekin \[2\]}. Workpiece displacement is caused by contact region deformation, slip and/or lift-off. The magnitude of workpiece displacement during clamping and machining is dependent on the process design parameters and the fixture design parameters. If the workpiece is insufficiently restrained or if the fixture is weak in comparison with the cutting force, slip or deformation, respectively, are bound to occur at the fixture-workpiece interface. The primary aim in the design of a fixture is, therefore, to control the workpiece geometric error resulting from manufacturing through the analysis of the proposed fixture design and its effectiveness in producing the desired accuracy on the workpiece. Workpiece displacement could be a significant source of geometric error. Significant displacement of workpiece is likely to take place during clamp actuation.

CNC manufacturers, worldwide are currently facing a big challenge to reduce conversion costs in order to be competitive in the market. In mechanical engineering, the process usually begins with a team review of the materials and the processes. The tooling cost and any production machinery costs are estimated and finally feasibility established with a return on investment (ROI). Re-use of existing machinery and capabilities are often essential. This concept involves not only product quality but also process improvement and process capability. Hence process capability improvement is one of the most improvement parameter for measuring and improving tool to become world class manufacturer. This project is designed to identify the key factors that impact effectiveness for positional error, accuracy of the job and wide variation of the job in terms of quality.

\cite{Cetinkunt & Tsai \[3\]} have developed a computer software package for positioning accuracy calibration and analysis on NC machine tools. They have identified two components of positioning error namely (a) systematic errors consisting of progressive, cyclic and reversal errors and (b) random errors revealing repeatability of measured data.

\cite{Lee, et al. \[4\]} has developed a comprehensive method for calibration of volumetric positioning accuracy on CNC machine.

\cite{Trankle \[5\]} has developed mathematical models to estimate the cutter point deviation and the angular deviation of the cutter axis direction due to the positioning errors along each axis. The angular deviations were independent of the positioning errors along the translational axis. He has developed the four loci: (a) cutter axis direction angle deviation; (b) cutter point position deviation due to the positioning errors along the translational axis; (c) cutter point position deviation due to the positioning errors along the rotational axis; and (d) superposition of (b) and (c).

\cite{Leu \[6\]} has investigated experimentally the robot accuracy and its improvement. He has divided the position error sources into five groups namely kinematics error, robot structure error, sensor error, servo control error, and algorithmic and computational errors.

\cite{Ramesh et al. \[7\]} have reviewed the work done in analyzing the various sources of errors that are usually encountered on machine tools and the methods of elimination and compensation employed in these machines.

\cite{Kiridena & Ferreira \[8\]} have developed computer programs for implementing the models and generating error contours or maps showing the variation of the different components of machine’s volumetric errors and for optimization of five axis capabilities of a machine’s accuracy. They have also discussed an approach to model the effects of positioning errors of machine’s axes on the accuracy (positioning and orientation) of the cutting tool in the work space.

\cite{Cetinkunt & Tsai \[9\]} have shown position error compensation of robotic contour end-milling, and three-dimensional cutting force dynamics has been developed. The position error has been analyzed in the cutting process through reference point by using force sensor. The tip position error has been estimated with the aid of wrist-force sensor which has been compensated in feed forward control form. The quantitative results were obtained from the digital computer simulations of the dynamic mode of the system.

For structurally rigid fixtures and work pieces, contact region deformation, slip and lift-off are the predominant modes of workpiece displacement during clamp actuation and machining. Studies have shown that locator and clamp geometry, locator and clamp placement, clamp actuation intensity, clamping sequence, machining parameters and tool path all have a significant effect on work piece displacement. The work done by \cite{Hockenberger et al. \[10\]} on the analysis of workpiece displacement within a machining fixture, it was assumed that the workpiece and the fixture are rigid everywhere except within the small vicinities of the contact region. Both the locators and the clamps of the fixture have spherical tips that make the contact with the workpiece. In the set-up used, the workpiece was placed in contact with the locators. This established the workpiece reference frame with respect to the fixture reference frame. During clamping and subsequent machining, the workpiece was found to displace within the fixture. This displacement is due to a combination of localized deformation, slip and lift-off at the contact regions on
account of the effect of forces exerted by the locators and the clamps at the contact regions, the resultant machining force and the gravitational force.

The purpose of this paper is to describe a method for estimating a new process approach for improvement in the CNC technology in mass manufacturing and CAD/CAM system. Study has been carried out on a ‘Gear Housing’ of an automobile engine in a production center, which has a large machine shop with various CNC machine tools. In the production centre various capacity of work in terms volume and size for different operations may be carried out.

2 Specific Problem

In gear housings, holes are provided to fit the shafts into it. But during boring operations, the drilled holes used to be eccentric on two parallel faces of the cast iron housing due to positional inaccuracy.

It has been observed that the dimensions of four holes are not within the specified or required tolerance limit of Φ 100 K6 as per data given in Annexure 1. The positional accuracy holes in x & y coordinate direction is also not coming properly. It is random in nature. Sometimes it goes (+) or sometimes it goes (–). The position of the dowel holes are also not coming correctly. It differs by 0 to 50 µ.

The gear housing on {Deckle DC-45 [11]} has been shown in Fig.1 and its fixture has been shown in Fig. 2. The detail dimensions of the holes to be provided on the two parallel faces of the gear housing are shown in Fig.3. First of all priority have been established, as under, through data collection and brainstorming for this specific problem.

Positional Error
Accuracy of the work
Wide variation of job in terms of quality

Now the effort has to be made to minimize these errors so as to get the desired and acceptable level of accuracy. Four holes are to be drilled of 100 mm diameter, tolerance of 100 K6 (+4 –18) two on either side of the housing.

2.1 Machine’s Specification {Deckle DC-45 [11]}:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working Range</td>
<td>(800[X]×630[Y]×710[Z])mm.</td>
</tr>
<tr>
<td>Position Tolerance</td>
<td>0.001mm (1µ)</td>
</tr>
<tr>
<td>No. of tools used:</td>
<td>40</td>
</tr>
<tr>
<td>Indexing</td>
<td>360°×1° (Max. Angle of Rotation= 1°)</td>
</tr>
<tr>
<td>Accuracy of Indexing</td>
<td>± 3 sec</td>
</tr>
<tr>
<td>Maximum Weight of job</td>
<td>1102lbs/500kgs</td>
</tr>
<tr>
<td>CNC Rotary table (Indexing)</td>
<td>Y − axis</td>
</tr>
<tr>
<td>Resolving Accuracy</td>
<td>0.001mm/sec</td>
</tr>
</tbody>
</table>

2.2 Machining Operation Performed:

At first, face milling has been done on both sides with Φ 100-face mill- carbide cutter, inserted type, Φ 100 Boring Tool, 900 approach angle- inserted type with 900 approaches. Then rough boring has been done to Φ 99 with boring tools, inserted type 90 0-approach angle. Finish boring operation has been done to 100 K6 with CBN (Cubic Boron Nitride). Final face milling done with the help of Φ 100-face mill carbide cutter inserted 900 approach angles.

2.2.1 Rpm and Feed Calculation for Face Milling Operation: In the Face Mill Cutter, Φ 80 face mill cutters (ceramic tip), cutting speed 600 mm/s, feed 0.15 mm per tip and six tips have been used.

Thus, Total feed will be 0.15x6 = 0.9mm / Revolution.

Again, RPM of the tool = (CuttingSpeed × 1000)/(3.14 × d) = (600 × 1000)/(3.14 × 80) = 600000/25.12 = 2388.535

Now, table feed i.e. Actual feed given to the job will be = 2388.535 × 0.9 = 2149.6815 mm/ rev
2.2.2 Φ100 K6 Boring Operations: In boring operation, Φ100 Boring Tool has been used with cutting speed 100 and feed 0.15 mm/ tip (one tip has been used).

Thus, RPM = \( \frac{100 \times 1000}{3.14 \times 100} = \frac{100000}{30.86} = 321.6821 \approx 322 \)

Therefore, Table Feed = 321.68 \times 0.15 = 48.225 = 48 mm/ Rev.

Then, Φ100 boring operation has been done, where the cutting speed is 600 mm/sec and feed is 0.06 mm/ tip (one tip used)

Thus, RPM = \( \frac{600 \times 1000}{3.14 \times 100} = 1910.828 \)

Actual table feed given to this job is 1910 \times 0.06 = 114.64868 mm
Fig. 1: Gear housing Deckle DC-45                            Fig. 2: Fixture for gear housing

Fig. 3: Drawing for the machining operation (All dimensions in mm).

2.2.3 Final face mill operation: Then face mill operation has been carried out with \( \Phi \) 100 face mill cutter, at cutting speed of 150 mm/sec and feed 0.15 mm per tip, whereas in the face mill cutter seven tips have been used. After the operation, the job has been measured in the Co-ordinate Measuring.

3 Pareto Analysis

The identified problems have been first grouped into specific categories. The total factors of the problem have been considered as to be 100%. The Positional Error has been assigned 86%, variation of job in terms of quality has been given as 10% and accuracy of the work as 04% as shown in Fig. 4.

![Pareto analysis for Gear Housing](image)

It is clear from the Pareto analysis (Fig. 4) that if 86% of the problems in the area pertaining to positional accuracy of the job is tackled and solved, then there would be a tangible and positive improvement in the performance of CNC machining center. So, for solving the positional accuracy, we have to find out the root cause of the problem through Cause and Effect (Fishbone/Ishikawa) analysis.

4 Cause And Effect Analysis

This technique is used for identifying the causes associated with this particular problem. The causes have been identified through brainstorming and then establishing different cause categories like bed taperness, improper speed and feed, improper torque given to the fixture and inaccurate dowel position as well. Then all the causes have been allocated and placed under the appropriate major cause category. The root causes have been identified and these root causes should be amenable to action.

5 Problems Investigated And Observation In Dc-45 Machine Tool

It has been observed that locator and clamp geometry, locator and clamp placement, clamp actuation intensity, clamping sequence, machining parameters and tool path have significant effect on work place displacement. All
It is clear from the Pareto analysis (Fig. 4) that if 86% of the problems in the area pertaining to positional accuracy of the job is tackled and solved, then there would be a tangible and positive improvement in the performance of CNC machining center. So, for solving the positional accuracy, we have to find out the root cause of the problem through Cause and Effect (Fishbone/ Ishikawa) analysis.

4. CAUSE AND EFFECT ANALYSIS

This technique is used for identifying the causes associated with this particular problem. The causes have been identified through brainstorming and then establishing different cause categories like bed taperness, improper speed and feed, improper torque given to the fixture and inaccurate dowel position as well. Then all the causes have been allocated and placed under the appropriate major cause category. The root causes have been identified and these root causes should be amenable to action.

Fig. 5: Cause and Effect analysis (Fishbone Diagram).

these are affecting the positional accuracy of the work including bed taper. After proper investigation of the problem, the bed taper and other inaccuracies have been measured as under.

**Bed taper by 0.0147° with x, y and z axis by -180 µ with respect to x axis**

\[ \tan \theta = \frac{0.045}{175} \]

Or, \[ \theta = tan^{-1}\left(\frac{0.045}{175}\right) = 0.0147° \]

**Difference between dowel position (fixture) and hole is ±0.2 mm. Machine backlash through x-axis is 10µ.**

Change in casting behavior has been observed due to uneven torque given without using torque meter i.e. uneven force given to the job. Hydraulic leakage has been observed from pallet locking and unlocking cylinder, due to worn out guide rings. X-axis drive coupling has been found loose due to friction. It was found that fixture is not correctly holding the job for giving the required accuracy of 10µ.

6 Preventive Measures And Corrective Actions

The following preventive measures and corrective actions have been taken to eliminate the positioning error.

6.1 Adjustment of Machine Bed:

The following procedures have been carried out for the adjustment of machine bed by adjusting the GIB (Supporting Device).

First of all, all mechanical parts have been cleaned with non-lead gasoline. Then, for proper balancing of machine bed, the movable ‘GIB’ has been adjusted with respect to the fixed ‘GIB’. The flat surface of the fixed ‘GIB’ has been ground to 20µ on the surface grinding machine for proper alignment.
accuracy of the work including bed taper. After proper investigation of the problem, the bed taper and other inaccuracies have been measured as under.

\[ \theta = \tan^{-1} \left( \frac{0.045}{175} \right) = 0.0147^\circ \]

500 MM

0.045 MM TAPER HEIGHT

175 MM

FIG. 6: Bed taper.

After fixing the fixed GIB with respect to movable GIB, the movable GIB has been adjusted with the help of adjustable screw.

The friction problem has been solved by properly aligning and tightening the bolts. Problem of hydraulic leakages has been sorted out by putting new seals in pallet locking and unlocking cylinder. The torque has been calculated for the fixture for holding the job and to prevent it from the change in inter-molecular structure of the cast iron jobs. The following procedures have been adopted to find out the torque and proper Cutting speed and feed for the face milling and boring operations.

6.2 Procedures for Finding the Torque:

The following data has been used for properly designing the fixture.
- Diameter of the screw for the bolt = 20 mm
- Cross sectional area of the washer with respect to contact portion with job
  - Diameter of the washer = 50 mm
  - Thickness of the washer = 10 mm

Now torque has been calculated both theoretically and practically. The average torque has been applied as the clamping force on the bolt of the fixture.

**First Procedure (Practical procedure):**

Area of the contact portion will be:

\[ \pi \left( \frac{D}{2} \right)^2 \times 10 = \frac{3.14}{4} \times (50)^2 \times 10 = 19625 \text{ mm}^2 \]

We know that, for screw threads \( \frac{3}{4} \) to 10 inches, the clamping force required is 1200 lbs. Also we know that,

\[ 1 \text{ inch} = 2.4 \text{ mm} \]

\[ \frac{3}{4} \text{ inch} = \frac{3}{4} \times 2.4 = 18.75 \text{ mm} \approx 20 \text{ mm (bolt diameter)} \]

Again, 90 lbs = 400 N,

Thus, 1200 lbs = \( \frac{400}{90} \times 1200 \text{ N} = 5280 \text{ N} \)

Clamping pressure = Force/ Area = \( \frac{5280}{19625} \text{ N/mm}^2 = 0.26 \text{ N/mm}^2 \)

500 MM

Machine Bed

ADJUSTABLE GIB

ADJUSTABLE SCREW

FIXED GIB

FIG. 7: Alignment of bed
Now torque has been calculated both theoretically and practically. The average torque has been applied as the clamping force on the bolt of the fixture.

6.2.1 First Procedure (Practical procedure): Area of the contact portion will be:

\[ \pi/4 \times D^2 \times 10 = 3.14/4 \times (50)^2 \times 10 = 19625 \text{mm}^2 \]

We know that, for screw threads \( \frac{3}{4} \) to 10 inches, the clamping force required is 1200 lbs. Also we know that, 1 inch = 2.4 mm

Or, \( \frac{3}{4} \) inch = \( \frac{3}{4} \times 2.4 \times 2 = 18.75 \text{mm} \approx 20 \text{mm} \) (bolt diameter)

Again, 90 lbs = 400 N
Thus, 1200 lbs = (400/90) \times 1200 N = 5280 N

Clamping pressure = Force/ Area = (5280/19625) N/ \text{mm}^2 = 0.26 N/ \text{mm}^2

If co-efficient of friction \( \mu \) is 0.15 (assumed) and nominal screw diameter is ‘D’, then the torque will be,

Torque (T) = 0.2 \times D \times P

Where, D= nominal screw diameter, and P = clamping pressure

For cleaned and lubricated screw threads, the co-efficient of friction reduced to around 0.10, which is assumed to be the best condition.

Torques ‘T’ for various values of \( \mu \) is as under,

For coarse thread:

\[ T = 0.164 \times D \times P, \mu = 0.12 \]
\[ T = 0.139 \times D \times P, \mu = 0.12 \]
\[ T = 0.115 \times D \times P, \mu = 0.08 \]

For fine thread:

Torque, T is 3-5 % less ie 95% to 97 % to that of coarse thread.

For cast iron, co-efficient of friction, \( \mu = 0.15 \) to 0.17

For, Diameter of bolt, D = 20 mm and Clamping pressure, P = 0.269N/ \text{mm}^2

Thus, the torque required on each bolt of the fixture (one bolt on either side) is 1.07 N.

6.2.2 Second Procedure (theoretical procedure): The force developed by screw can be calculated using following formula [Joshi [12]; Boyes [13]]:

\[ F_s = (F_h \times L)/ R \tan (\alpha + \theta) \]

Where,

\[ F_s = \text{force developed by the screw} \]
\[ F_h = \text{pull or push applied to spanner} \]
\[ R = \text{pitch radius of the screw threads} \]
\[ \alpha = \text{helix angle of the threads} \]
\[ \theta = \text{friction angle of the thread} \]
\[ L = \text{length of the spanner or lever} \]

We know that 12 mm hexagonal bolt with 100 mm long wrench and 10 Kgs manual pull can develop 700 kg-N of clamping force along the axis of the screw.

Pressure = Force/ Area

It was found in one case that the maximum one hand pull was 125 lbs i.e. 556 N for a 25 year old person. Let the one hand pull, Ph for an Indian to be 500 N.

Thus,

\[ F_s = (500 \times 260)/10 \tan (60 + 8.53) = 13000/\tan 68.53 = 13000/2.53 = 5118.11N \]
\[ Ph = 500N \]

\[ L = 260 \text{mm length of the spanner} \]
\[ R = \text{pitch radius of the screw thread} = 100 \text{mm} \]
\[ \alpha = 60^\circ \text{ in metric system} \]
\[ \theta = \text{friction angle of the thread} \]
\[ \mu = \tan \theta = 0.15 \]

Or, \( \theta = \tan^{-1} 0.15 = 8.53 \)

Area of the contact portion will be \( \pi \times D^2 \times 10 = (3.14/4) \times 50^2 \times 10 = 19625 \text{mm}^2 \).

Again, Pressure = Force/ Area = 5118.11/19625 = 0.260N/ \text{mm}^2

Torque, T = 0.2 \times 20 \times 0.26 = 4 \times 0.26 = 1.04N
Thus, we find that in the first case torque, T is 1.07 N and in second case torque, T is 1.04 N. So, the average torque will be 1.055 N. Therefore, the average torque, T will be applied as the clamping force on the bolts of the fixture.

6.2.3 Speed and Feed Calculation: The cutting speed and feed has to be given to the job correctly for various operations, and these parameters are calculated as per detail given below.

We know that, \( VT^n = C \) (Taylor’s Equation)
Where, \( V \) = cutting speed
\( T = \) Tool life
\( C = \) Constant (for cast iron 1/12, for carbide steel 1/7 to 1/8 and for steel 1/18)

The effect of feed and depth of cut on tool life is calculated as:

\[ \text{Effect of feed and depth of cut on tool life} = \frac{257}{(\text{Tool life} \times \text{Feed} \times \text{Depth of cut})} \]

For milling operation, using HSS Tool, speed will be 20-30 mm/min, and for face mill speed will be 0.35 mm/tooth. For milling operation using carbide tool (recommended) speed will be 70-100 mm/m, for face mill feed will be 0.35 mm/tooth, when the approach angle is 90° (corner angle).

Further recommended Tool Geometry for positional accuracy has been tabulated in Tab. 1.

**Tab. 1: Recommended Tool Geometry**

<table>
<thead>
<tr>
<th>Axial Rack Angle</th>
<th>Radial Rack Angle</th>
<th>Corner Angle</th>
<th>End Cutting Edge Angle</th>
<th>Axial Relief Angle</th>
<th>Radial Relief Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 – 30</td>
<td>5 – 10</td>
<td>45</td>
<td>5 – 10</td>
<td>4 – 7</td>
<td>4 – 7</td>
</tr>
<tr>
<td>Tool Geometry for HSS tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 – 11</td>
<td>5 – 11</td>
<td>45</td>
<td>5 – 10</td>
<td>4 – 7</td>
<td>4 – 7</td>
</tr>
<tr>
<td>Tool Geometry for Brazed Carbide tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 – 11</td>
<td>5 – 10</td>
<td>45</td>
<td>5 – 10</td>
<td>4 – 7</td>
<td>4 – 7</td>
</tr>
<tr>
<td>Tool Geometry for Throwaway Carbide tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The gear housing measurement data has been taken before and after the corrections and it is presented in Tab. 2 and Tab. 3 respectively. The inaccuracy before and after corrections has been noticed to be in the range of 0.124 to 0.01 mm and 0.02 to 0.012 mm respectively. It is an appreciable and significant improvement; and has resulted to zero rejection.

7 Conclusions

Bed taper-ness has been eliminated by adjusting the GIB as mentioned above and other problems such as backlash, difference in dowel positions have also been reduced by the application of proper torque on bolts of the fixture. Proper speed and feed of the tool with respect to the work piece specification has also been maintained and proper carbide tool and tool material has also been used. Thus, a major and vital problem of positional error has been eliminated to a great extent, which in turn improved the dimensional accuracy of the work and it has also reduced the wide variation in dimensions of the job in terms of quality. Thus, after the implementation of all above corrective measures as regard to positional accuracy, a remarkable improvement has been achieved. This may also help in error free or zero defect products in CNC machining.

The Pareto Analysis followed by Cause and Effect Analysis has proved to be very useful tool in identifying the root cause of error in CNC Machine tools.

Acknowledgements The authors are thankful to Indo Danish tool Room, Jamshedpur (India) for giving the opportunity to do the improvement work at CNC milling machining centre such as Deckle DC-45 machine for Gear Housing Component.

**References**


Table 2: Gear Housing Measurement Data before Correction

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Hole 1 Nominals as Y=0,Z= -110</th>
<th>Hole 2 Nominals as Y=0,Z= -244.5</th>
<th>Hole 3 Nominals as Y=0,Z= -110</th>
<th>Hole 4 Nominals as Y=0,Z= -244.5</th>
<th>LΦ0.01</th>
<th>1, 2 Total Deviation (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-10 58-B</td>
<td>Y= +0.082 Z= -109.940</td>
<td>Y= +0.083 Z= -244.444</td>
<td>Y= -0.047 Z= -109.952</td>
<td>Y= -0.052 Z= -244.457</td>
<td>0.01</td>
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<tr>
<td>S-9 455-A</td>
<td>Y= 0.048 Z= -109.955</td>
<td>Y= +0.015 Z= -244.454</td>
<td>Y= -0.069 Z= -109.918</td>
<td>Y= -0.058 Z= -244.412</td>
<td>0.088</td>
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<tr>
<td>S-9 331-A</td>
<td>Y= 0.065 Z= -109.908</td>
<td>Y= +0.051 Z= -244.443</td>
<td>Y= -0.052 Z= -109.908</td>
<td>Y= -0.051 Z= -244.41</td>
<td>0.031</td>
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</tr>
<tr>
<td>S-6 15011</td>
<td>Y=0.056 Z= -109.935</td>
<td>Y= 0.068 Z= -244.443</td>
<td>Y= -0.068 Z= -109.957</td>
<td>Y= -0.038 Z= -244.462</td>
<td>0.038</td>
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</tr>
<tr>
<td>S-10 A-29</td>
<td>Y= +0.111 Z= -109.886</td>
<td>Y= +0.084 Z= -244.385</td>
<td>Y= -0.059 Z= -109.934</td>
<td>Y= -0.024 Z= -244.437</td>
<td>0.124</td>
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</tr>
<tr>
<td>S-9 463-A</td>
<td>Y= 0.080 Z= -109.875</td>
<td>Y=+0.064 Z= -244.379</td>
<td>Y= -0.065 Z= -109.958</td>
<td>Y= -0.069 Z= -244.457</td>
<td>0.026</td>
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<tr>
<td>S-10 A-292</td>
<td>Y= +0.050 Z= -110.026</td>
<td>Y= +0.044 Z= -244.53</td>
<td>Y= -0.045 Z= -110.066</td>
<td>Y= -0.087 Z= -244.567</td>
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<tr>
<td>S-10 226-A</td>
<td>Y= -0.013 Z= -109.978</td>
<td>Y= -0.001 Z= -244.483</td>
<td>Y= -0.041 Z= -109.982</td>
<td>Y= -0.039 Z= -244.498</td>
<td>0.027</td>
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</tr>
<tr>
<td>S-9 425-A</td>
<td>Y= 0.002 Z= -110.01</td>
<td>Y= +0.018 Z= -244.499</td>
<td>Y= -0.054 Z= -109.976</td>
<td>Y= -0.074 Z= -244.470</td>
<td>0.073</td>
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<tr>
<td>S-10 406-A</td>
<td>Y= -0.019 Z= -110.014</td>
<td>Y= -0.013 Z= -244.51</td>
<td>Y= -0.013 Z= -244.510</td>
<td>Y= -0.038 Z= -109.957</td>
<td>0.068</td>
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<tr>
<td>S10, 358-A</td>
<td>Y= -0.039 Z= -109.963</td>
<td>Y= -0.008 Z= -244.461</td>
<td>Y= -0.023 Z= -109.958</td>
<td>Y= -0.016 Z= -244.459</td>
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<tr>
<td>S-10, 400-B</td>
<td>Y= -0.029 Z= -109.99</td>
<td>Y= -0.003 Z= -244.482</td>
<td>Y= -0.045 Z= -109.947</td>
<td>Y= -0.073 Z= -244.442</td>
<td>0.109</td>
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</tr>
</tbody>
</table>
Table 3 Gear Housing Measurement Data after Correction

<table>
<thead>
<tr>
<th>Sample no</th>
<th>Hole 1 Nominals as</th>
<th>Hole 2 Nominals as</th>
<th>Hole 3 Nominals as</th>
<th>Hole 4 Nominals as</th>
<th>Φ0.01 1, 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y=0, Z= -110</td>
<td>Y=0, Z= -244.5</td>
<td>Y=0, Z= -110</td>
<td>Y=0, Z= -244.5</td>
<td></td>
</tr>
<tr>
<td>S-10</td>
<td>Y= 0.018, Z= -110.01</td>
<td>Y= 0.006, Z= -244.5</td>
<td>Y= -0.012, Z= -110.0</td>
<td>Y= -0.003, Z= -244.505</td>
<td>0.018</td>
</tr>
<tr>
<td>S-10</td>
<td>Y= 0.015, Z= -110.00</td>
<td>Y= -0.006, Z= -244.49</td>
<td>Y= -0.012, Z= -110.01</td>
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</tr>
<tr>
<td>S-10</td>
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<td>Y= -0.005, Z= -244.5</td>
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<tr>
<td>S-6</td>
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<td>Y= 0.008, Z= -244.51</td>
<td>Y= 0.01, Z= -110.01</td>
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<td>Y= 0.005, Z= -244.50</td>
<td>Y= -0.01, Z= -110.01</td>
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<tr>
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<tr>
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</table>