Quality is a state of a finished product, being free from defects, deficiencies and significant variations. This measure of an excellence can be brought about by the strict and consistent adherence to measureable and verifiable standards to achieve uniformity of output that satisfies specific customer or user requirements. This paper gives a proposed methodology for to increase the quality of a product manufactured in a grinding machine, using the various quality improvement tools like Process monitoring techniques, Cause and Effect diagram, Why-Why analysis and Statistical Process Control Charts. The key note in using these tools is because of ease way to detect the problems and solutions for the same. The quality improvement is accompanied by the changes in machining parameters of a grinding machine and the optimisation of those changes reflects as an increase in the acceptance level of the product in the world market.

**Keywords:** Quality improvement techniques, Process capability studies, Statistical process control, Process monitoring chart, Process capability index

**INTRODUCTION**

Manufacturing processes are often met with lot of variations in a product from the customer specified limits during the machining process and it is characterised by the strong effect on the quality of a product. The variations in a product are an inevitable one. No two products are identical in nature. The variations on a machine are due to either special (assignable) causes or chance (natural) causes (Mahajan, 2004). Sometimes, the variation occurs due to both of these causes, which affects the quality of a product severely. In a grinding operation, variations which arise as a result of these causes play a vital role in acceptance level of a product. These causes are detected using various quality improvement tools and finding remedies in a simply way. Process Monitoring Charts and Statistical Process Control techniques find to be a simplest
method among various quality improvement tools for detecting the variations in a product. The Process Monitoring charts are used for the purpose of identifying the chance and assignable causes. It gives a well-defined warning signal, if the process is going out of control. By using this technique, the reoccurrence of the defects or variations in a product can be rectified. The Statistical Process Control are the charts, where the average, range, standard deviations, process capability values can be determined by statistical approach.

These tools use the Process Capability index value as a major technique to verify whether any variations occurred on the grinding operation or not (Gijo, 2005).

**Process Capability Calculation**

Process Capability index value (Cpk) is calculated statistically using Statistical Process Control sheet and it is validated against the Sigma value to determine the rejection level of a product. The Cpk calculation is done with the use of Upper Specification Limit (USL), Lower Specification Limit (LSL) of a product, given from the customer side. By using these specification limits, USL and LSL, the Cpu and Cpl are calculated. Cpu is nothing but a statistic, which related the difference between USL and the centre line to the Standard deviation (\( \sigma \)) (Gijo, 2005). Cpl is also a statistic which relates the difference between the centre line and LSL to the Standard deviation (\( \sigma \)). The formula for calculating Cpu and Cpl is given below:

\[
Cpu = \frac{(USL - \overline{X})}{3 * \sigma}
\]

and

\[
Cpl = \frac{(\overline{X} - LSL)}{3 * \sigma}
\]

Sigma is the standard deviation value (\( \sigma \)) and \( \overline{X} \) is the average of the sum of all the values, i.e., mean of all observed values. From the calculated Cpu and Cpl values, one can determine the Cpk value from the formula, shown below:

\[
Cpk = \text{Minimum}(Cpu, Cpl)
\]

Each company is focusing to implement Six Sigma (6\( \sigma \)) quality on a product for to achieve nil (0.05 PPM) rejection level. Based on the Process Capability Index value, the rejection percentage is determined. As the variations is high, due to any one of those causes, affects the Cpk value and hence results in decline of the Sigma level. So, the Six Sigma quality level can be achieved in a grinding operation only when the variations on the grinding process are eliminated. This methodology not only suits grinding operations, but it is meant for all kind of machining processes like turning, milling, shearing, etc.

**ANALYSIS**

In grinding operations, the variation takes place during the machining process is majorly due to the parameters within the machine and these parameters can be acknowledged by brainstorming method. By brainstorming, the
motives for the causes occurred on a grinding machine are thoroughly analysed from various angles, to determine the significant and insignificant causes. From this method, the recognised possible causes for the variations are Tail stock clamping insufficient, Grinding wheel unbalance, Wheel head grinding speed, Work head rpm, Dressing frequency, Grinding wheel grade, Coolant flush ineffective, Coolant temperature, Coolant filtration, Improper checking method, Centre wear and misalignment, radius formation, Feed rate, Outer Diameter stock for grinding, Machine repeatability, Burr in centre, Hardness of the material, Dressing parameters and its norms, Wrong offset settings, Loading and unloading error and last but not least the cutting tool.

The above described possible causes are the main reasons for the occurrence of the variations in a product during grinding operation. Hence, these possible causes are scrutinised to find the significant and insignificant causes. From the above mentioned various possible causes, some may be eliminated by proper training to the personnel and by experience. This can be done by using Cause and effect diagram, a major quality tool, which differentiates the causes into 4M categories, namely Man; Materials; Machine; Methods (http://www.isixsigma.com/tools-templates/capability-indices-process-capability/process-capability-cp-cpk-and-process-performance-pp-ppk-what-difference/).

**Cause and Effect Diagram**

The cause and effect diagram clearly denotes the causes in 4 M s for a single effect of Size variation (Figure 1). These causes are labelled in green and red colors, where green color causes can be eliminated by proper training and experience and red color causes plays an important role in size variations of a product. By eliminating the green color labelled causes from the Cause and Effect diagram, we get both significant and insignificant causes, for the variations to occur in a grinding machine.

![Figure 1: Cause and Effect Diagram for the Size Variation by Considering the 4M’s](image-url)
From the mentioned causes in the Cause and Effect diagram, the Significant and Insignificant causes has to be determined. The Significant causes are the main reason for the variations in a grinding operation to happen. The Significant causes are taken into account for total elimination.

**Possible Causes**

When examine the possible causes after the removal of green marks from the Cause and Effect diagram (Figure 2), some causes are seems to be insignificant for the effect on a grinding machine to occur. The causes like Coolant temperature, Tailstock clamping insufficient, Wheel head grinding speed, Coolant temperature, Machine repeatability, Coolant flush ineffective, Centre misalignment and Burr in centre are termed to be insignificant because nowadays the CNC grinding machine are made to eliminate these causes before it

![Figure 2: Cause and Effect Diagram for the Size Variation by Considering Both Significant and Insignificant Causes as Possible Causes](image1)

![Figure 3: Cause and Effect Diagram Showing the Significant Causes for the Size Variation](image2)
comes to existence. By using various techniques like Poke Yoke, building of Servo motors with an encoder, the minor causes are totally eliminated to avoid the variations of a product. Hence, apart from these causes, rest of them are considered to be Significant and responsible for the variations in a grinding process to happen. The Significant causes are clearly demonstrated in by Cause and Effect diagram (Figure 3).

So, “a systematic analysis on these four causes, namely Work head speed, Feed rate, Dressing frequency, Cutting tool, may eliminate the variations occur on the product during grinding operations”. The analysed results needed to be optimized for the continuous improvement in a grinding machine, if not; the outcome products will have defects and leads to rejection. To prove this statement a detailed analysis should be made on a grinding machine.

EXPERIMENTATION

The four major causes, Work head rpm, Dressing frequency, Feed rate and Cutting tool are responsible for the variations to occur on a product during the grinding operation. So, an Industrial experimentation is carried out on a grinding machine to eliminate the variations occurring on a product by making some changes on these causes. These four causes are the key parameters in a grinding machine. Hence, an effect can be surely achieved, once a change is made on these causes.

The experimentation is carried out in a firm, where a numerous products are being manufactured. In that firm, a product is manufactured with more variations in size and they are facing lots of rejection. This situation

OBSERVATION

Initial Condition

The Worm shaft is the product being manufactured in the firm as a part of Hydraulic Power Steering. In that product, an operation of seal groove making is done in the grinding machine. The grinding machine is a FANUC programming one.

Initially, when observation is made on the grinding machine (HMT K130 U2), the process capability index (Cpk) was found to be 0.49 by using Process Monitoring Chart (PMC) and Statistical Process Control (SPC) with work head rpm of 170, feed rate of 1.1 mm/min throughout the depth, dressing frequency is done once in 10 components, cutting tool of open grain 19A 80 L8 VS. The Cpk value of 0.49 in that machine is due to the assignable causes.

The assignable causes can be eliminated by making changes in the four main significant causes in a grinding machine. So, a comprehensive analysis is done on the machine for to improve the Cpk value and reduce the rejection level in the grinding machine, using only the four main significant causes.

The PMC for the initial observation taken in the machine clearly shows the variations
of the product (Figure 4). The SPC analysis for the initial observation, which uses the statistical approach, is used to find the Standard deviation (Sigma) value. The SPC analysis for the value of Cpk 0.4911 is explained in detail using the SPC chart. The chart uses the formula for the calculation of X bar, Standard deviation and Process Capability index, generates as the value enters in the column. The SPC analysis clearly shows the values for 30 observations taken continuously on the product in the grinding machine (Figure 5).

The Cpk improvement in the machine will be carried out using showed Process Monitoring Chart (Figure 4), to find the point of occurrence of the variation and Statistical Process Control (Figure 5) for statistical approach to determine the process capability index (Cpk) value.

**ACTION**

The four significant causes are to be modified in the grinding machine for the sake of improvement in the Cpk value.

**Work Head Speed**

The initial action on a machine is taken to modify the work head speed from 170 rpm to 184 rpm. By using the quality tools such as Process Monitoring chart (PMC), the observation is monitored in the form of graph and it is validated in Statistical Process Control (SPC) analysis charts for to find the Cpk value. The result for the monitored observations can be attained, only after the observations are fed into the SPC analysis chart. The PMC for the monitored observations are clearly demonstrating the variations are occurred only due to chance causes (Figure 6).
improvement from the initial condition of the machine (Figure 7). The result becomes positive as the work head speed increases and Cpk value increases from 0.4911 to 0.8179. Hence the modification has a positive approach towards the Cpk value. Therefore, as there is a sign of increase in Cpk value as the work head rpm increases, because as the work speed increases the ‘arc of contact’ between the cutting tool and the work piece decreases. This decrease in arc of contact, leads to creation of less variations in size (Pankaj and Arunesh, 2009).

The graph shows the improvement in the Cpk value from the initial condition, i.e., 170 rpm, to the increase in the work head speed, i.e., 184 rpm, of the machine (Figure 8).

As there is a positive approach towards the Cpk value, as work head speed increases, further improvement in Cpk value, can be done by still increasing the work head rpm. So, the work speed is further increased from 184 rpm to 200 rpm, to see the effect of variation of the product.

The observations of the product at work head speed of 200 rpm are monitored using PMC and the variations are observed (Figure 9). The variations of the products falls on the
green zone, from PMC, means as the work speed increases, the variations are being controlled within the limits and also results in continuous improvement. As the variations are controlled, gives rise to the Cpk values as well.

The SPC chart shows the Sigma values and the corresponding result in Cp and Cpk values (Figure 10). As the work speed increases, the Cpk value again increases from 0.8179 to 1.0454. This also shows a positive attitude towards the Six sigma quality.

The Cpk improvement after the change in work head speed from 184 rpm to 200 rpm is clearly demonstrated using the graph (Figure 11).

The Cpk improvement after the change in work head speed from 184 rpm to 200 rpm is clearly demonstrated using the graph (Figure 11).

The Cp and Cpk value are increased as the work speed increases and this also favour the objectives. Hence, the speed can be further increased to see the changes on the product variations and as well as in the Cp and Cpk values.

So, the work head rpm is increased to 225 rpm from 200 rpm and notice the changes. As the speed increases, as mentioned earlier, the contact point between the work piece and the cutting tool decreases, results in the decline of the range in variations. This can be seen from the monitored observations in PMC, at
the work head speed of 225 rpm (Figure 12). The PMC shows the variations falls on the green zone, which denotes 100% acceptance of the product. The recording of data of each product on PMC is an easy process to find the deviations from the recommended specification limits of the product. By knowing this, the employer can make some changes to bring back the component into the green zone only if the deviation reaches yellow or red zone of PMC. Otherwise, the processes need not to be disturbed.

The SPC chart analysis shows an increase in the Cpk value from 1.0454 to 1.1806, when the machine is operated under the work head speed of 225 rpm (Figure 13). So, the work head speed works well for the improvement in quality of the product by reducing the variations. The Cpk improvement from the previously operating condition is shown through graph (Figure 14). The increase in work head speed results in the improvement of both Cp and Cpk values. Hence, the speed has been decided to increase further to visualize the changes in the variation of the product.
Therefore the work head speed is increased from 225 rpm to 250 rpm, and monitored the changes of the machine in PMC (Figure 15).

**Figure 15: The PMC for the Condition of Change is Dressing Frequency from 10 to 7 Components**

As the speed increases to 250 rpm from 225 rpm, the variation in the product is in control, but the vibration of the machine begins to increase and this ends in the formation of chatters on the product which leads to rejection of the component (http://www.nortonindustrial.com/uploadedFiles/SGindnortonabrasives/Documents/Toolroom%20Selection%20Chart%207505.pdf). This chattering formation is noticed on the first product after the change of speed from 225 rpm to 250 rpm. So, further process on this speed is stopped and the work head rpm of 225 is optimised in that machine.

From the four significant causes, one cause, i.e., the work head rpm has been altered and the changes are visualized. The next action is to take any of those remaining significant causes for alteration and see the changes reflect on the product.

**Dressing Frequency**

The dressing frequency is taken for further discussion and changes on the dressing frequency is done by keeping the optimised work head speed, i.e., 225 rpm in the machine. From the PMC of the product at various work speed, the variation of the component is high only after the 7th component in a dressing cycle of 10 components. Hence, the 8th, 9th and 10th component of the dressing cycle shows a high variation from the target value. So, the dressing frequency is made to change from 10 components to 7 components. As the dressing frequency is decreases, the dressing depth of cut needs to be decrease (Linke, 2008). So, the depth of cut is changed from 0.15 mm to 0.1 mm radially.

By implementing the above specified changes in that machine and data are collected. The PMC for the monitored observations at a dressing frequency of 7 components is demonstrated clearly (Figure 16).

The PMC shows the variations are fall on the green zone and denotes 0% rejection. But at the same, the cycle time of the process increases due to the reduction in the dressing frequency

The SPC chart analysis for the variations of the product under the condition of dressing frequency 7 components is shown in Figure 17, with the Cp and Cpk values and standard deviations. The change in dressing frequency shows an improvement in Cpk value from
But, due to increase in the cycle time of the whole process, further changes on the dressing frequency is stopped by optimising the changes in that machine and look for changing any of the remaining two significant causes.

**Feed Rate**

We take the feed rate concept for the further improvement in Cpk value. When the work piece is examined, the hardness of the material changes as the depth of the component increases due to the heat treatment process on it. The hardness of the component is about 1.1 mm along the depth in the total depth of 2.9 mm. Hence, the single feed rate of 1.5 mm/min is not sufficient for the removal of material of the whole depth of the component. So, stepped feed needs to be implement for the efficient removal of material.

Stepped feed in 3 stage as 1.7, 1.6, 1.4 mm/min is to be implement by keeping all other
changed process constant and the observations are carried out using the PMC (Figure 18). The PMC shows the values are inside the green zone and there are no possibilities of rejection of the component. Hence, the feed rate change gives a positive result for the objective.

The PMC shows the values are inside the green zone and there are no possibilities of rejection of the component. Hence, the feed rate change gives a positive result for the objective.

The SPC chart for the changed feed rate process reveals an improvement in the Cpk value from 1.4519 to 1.5013. The SPC chart shows an improvement in the Cp and Cpk values from the previous process and the change enhances the process further.

The increase in Cpk value is clearly shown through graph by comparing the previous changes with the change in the feed rate (Figure 20).

Further change in the feed rate cannot be done, because the supplementary change in feed rate affects the surface finish and optimise the change on the machine. Hence take the final significant cause, i.e., cutting tool.

Cutting Tool

Cutting tool in grinding machine is an abrasive and it is an important significant cause than others. The analysis on the cutting tool is a tedious process, since lot of parameters are involved in this such as abrasives, grid size, grade, structure and bond type. In all the previous process, the grinding wheel used is A 80 L8 VS.

This grinding wheel A 80 L8 VS has various explanations for each letters and numbers. The ‘A’ denotes the Aluminium oxide abrasive; ‘80’ denotes the fine grain size; ‘L’ denoted the Medium grade; ‘8’ denotes the Open structure; ‘V’ for the vitrified bond; ‘S’ for bond modification (http://metalwebnews.com/machine-tools/ch5.pdf).

In the above mentioned grinding specification, the structure is an open structure and during removal of huge depth more wear
occurs, results in minimum life of the wheel. So, the structure is taken as a defective parameter in that grinding wheel and it is to be replaced with a dense structure (http://www.grindwellnorton.co.in/GrindingTech/pdfs/FactorsAffectSelection.pdf).

As per the analysis, the dense structure wheel available in the inventory of the company is taken to replace this wheel for to examine any change is occurring in the variation of the component.

So, the dense structure wheel of specifications DA 80 K5 V10 is made to replace the previous cutting tool. The new wheel has a dense structure, ‘5’. Other than that, no other parameters are changed. By keeping the previously changed significant causes as optimised one and changing the new grinding wheel for the examination.

The observations are monitored and the data are noted in the PMC (Figure 21). The variations of the product fall within the green zone and hence the probability of rejection is 0%. Some process shows nil variations in the product and it falls exactly at the target value.

The product variations are very nearer to the target value. This may give raise to both Cp and Cpk value from the previous process. This can attained from the SPC chart analysis.

The SPC chart analysis (Figure 22) shows the Cpk value of 1.9359, which exceeds the objective of 1.67. This Cpk value denotes that the rejection of the product being manufactured in this machine is about 0.5 PPM. Hence, Six Sigma quality is implemented in HMT machine by improving the four major significant causes in a grinding machine.

The increase in the Cpk value from the previously operated condition to the change
in the cutting tool is clearly demonstrated using the line graph (Figure 23).

Finally, the work head speed of 225 rpm; dressing frequency of 7; stepped feed rate of 1.7, 1.6, 1.4 mm/min; dense structure cutting tool of specification DA 80 K5 V10 are optimised in the machine for the defects less and variations less product output. The total result of the project is shown with different stages of action of the corresponding Cpk value (Figure 24).

**CONCLUSION**

This improvement in the quality not only gives customer satisfaction, it also gains more profit to the organisation. The back tracking of the finished product is minimum hence this makes a way for reducing the time constraints.

The available time increases as a result of reduction in the re-work and backtracking of the products, the productivity increases rapidly. If all these are achieved in the machine, the cost of a product will play a major role. The organisation can give a product at a competitive price, than other firms and at the same time, deliver at a world class products.

This methodology is applicable for any kind of grinding machine for to improve the quality of the product. The four significant causes can be made into insignificant, if the analysis and approach to the existing problem in a right way. This method has to be done with careful premeasures and with the knowledge of the employer.

**ACKNOWLEDGMENT**

The authors sincerely thank RANE TRW Steering Limited, Viralimalai, Trichy, India, for their support and encouragement to perform a risky task without caring about their production and cost of the product. The authors would also like to thank K Sudhakar, V
Rajarajan, S Krishnadevarajan, G Rajkumar of RANE TRW unit.

REFERENCES


