International Journal for Quality Research 7(4) 559–584
ISSN 1800-6450

Hagos Berhane[1]
Ajit Pal Singh

Article info:
Received 18 November 2013
Accepted 2 December 2013

UDC – 65.012.7

PROCESS PERFORMANCE EVALUATION USING HISTOGRAM AND TAGUCHI TECHNIQUE IN LOCK MANUFACTURING COMPANY

Abstract: *Process capability analysis is a vital part of an overall quality improvement program. It is a technique that has application in many segments of the product cycle, including product and process design, vendor sourcing, production or manufacturing planning, and manufacturing. Frequently, a process capability study involves observing a quality characteristic of the product. Since this information usually pertains to the product rather than the process, this analysis should strictly speaking be called a product analysis study. A true process capability study in this context would involve collecting data that relates to process parameters so that remedial actions can be identified on a timely basis. The present study attempts to analyze performance of drilling, pressing, and reaming operations carried out for the manufacturing of two major lock components viz. handle and lever plate, at Gaurav International, Aligarh (India). The data collected for depth of hole on handle, central hole diameter, and key hole diameter are used to construct histogram. Next, the information available in frequency distribution table, the process mean, process capability from calculations and specification limits provided by the manufacturing concern are used with Taguchi technique. The data obtained from histogram and Taguchi technique combined are used to evaluate the performance of the manufacturing process. Results of this study indicated that the performance of all the processes used to produce depth of hole on handle, key hole diameter, and central hole diameter are potentially incapable as the process capability indices are found to be 0.54, 0.54 and 0.76 respectively. The number of nonconforming parts expressed in terms of parts per million (ppm) that have fallen out of the specification limits are found to be 140000, 26666.66, and 146666.66 for depth of hole on handle, central hole diameter, and key hole diameter respectively. As a result, the total loss incurred due to variation in the measured quality characteristics in the same order is estimated as, 14076950, 7364675, and 18226962 INR. It is found that the combination of histogram and Taguchi technique helps to evaluate the overall performance of given process.*

Keywords: *Process performance, lock manufacturing, histogram, process capability, Taguchi technique*

1. Introduction

Today, an organization's ability to compete in changing global economy depends largely on the quality of products and services. Total quality management (TQM) has emerged as a key to competitive strategy management for business organizations in the global market place. Focus of TQM is on continuously improving performance by involving everyone in the organization and related with the organization, to delight the customers. Trends such as supply base reduction and consolidation, product and process design, production or manufacturing planning are increasing. For many companies, purchase accounts for 50% to 60% of sales amount and are the source of half of the quality problems.

The facilities selected for manufacture of a part are an important determination of the cost and quality of the resulting production. If the process and processing equipment selected are sufficiently accurate to meet the quality target as established by drawing tolerances, reasonable costs and acceptable quality can be expected. If they cannot consistently meet the quality target, high costs, scraps, and rework are inevitable outcomes. Even in the companies where a great deal is known about the capabilities of processing equipments, it is sometimes rare to have this information in such a form that it can be shared with designing engineers, planners, and methods engineers. Since such knowledge about the performance capability of processing equipment is essential to the proper functioning of a quality control program. Many companies have made scientific investigation of these capabilities as keystone of their entire product and process control program. In so doing, they were forced to develop techniques for this investigation that were more effective for quality control purposes than the old rule-of-thumb techniques that had prevailed for many years. One of the most useful techniques developed for this work is the process capability study. The histogram, control charts, and design of experiments techniques are used for the analysis of process and its capability.

Pungle *et al.* (2004) in their study of process performance evaluation using histogram and Taguchi techniques stated that, where production people might be satisfied that any item produced within specifications is as good as any other, the fact is that best quality is achieved by minimizing the deviation from the target or nominal dimension. This shows that ideal quality can be achieved only and only if the quality characteristic under consideration conforms to its intended or designed value.

A paper presented in ASQ's 52nd Annual Quality Congress Proceedings (1998) indicates that the use of process performance measures generated with data collected over extended periods, combined with performance analysis which decomposes sources of variation, provides quality practitioners the ability to answer questions about how their processes are performing and what opportunities exist for improvement. The graphical display of these measures allows one to view the improvement potential. This display may be used to compare multiple processes and characteristics and assist in improvement prioritization. Performance measures such as the ppm may be used to validate improvement efforts. If through-time stability is improved, tooling or station differences are minimized, and the process is brought on target, ppm will display an improvement (Petrovich, 1998).

A study conducted by Schulz (1995) among more than 150 automotive component suppliers in Germany, Europe, Japan and the U.S.A reveals basic relationships and determines the factors of success for an effective and efficient quality management. For obtaining higher product quality many

[1] Corresponding author: Hagos Berhane
email: hagosberhane@yahoo.co.uk

companies have adopted SPC tools.

Ishikawa (1985) provided a great deal of leadership in shaping the Japanese quality movement through his vision and activities associated with Japanese Union of Science and Engineers. Ishikawa developed the concept of true and of substitute quality characteristics. The "true" quality characteristics are the customer's view of product performance, expressed in the customer's vocabulary. "Substitute" quality characteristics are the producer's view of product performance expressed in the producer's technical vocabulary. The degree of match between true and substitute quality characteristics ultimately determines customer satisfaction. Based on his long experience in Japanese industry Ishikawa states that as much as 95% of quality related problems in the factory can be solved with seven fundamental qualitative tools, known as cause-effect diagram, stratification analysis, check sheet, histogram, scatter diagram, Pareto analysis, and control charts.

The concept of customer value represents a dramatic improvement over the traditional approach to quality, the "conformance to specified standards" approach. It extends the concept of quality to include user perception and use consequences. However, it still falls short of the concept of total quality, which stresses the importance of quality in every aspect of an organization. Perhaps the Japanese best express this broader and more holistic view of quality. Ishikawa (1985, p. 45) states; "Narrowly interpreted, quality means quality of product, broadly interpreted, quality means quality of work, quality of service, quality of information, quality of process, quality of division, quality of people, including workers, engineers, managers and executives quality of system, quality of company, quality of objectives, etc."

This total view of quality includes all the themes of quality, integrating them into a comprehensive approach to continuous improvement. The impact of variation on customers should also be considered. All parts from a certain operation may meet engineering specifications, but that does not mean that all parts equally meet customer's needs. Taguchi (1986) suggests that there is an increasing loss, for the produces, the customer, and society associated with increasing variability, or deviation from a target value that reflects the "ideal state". This relationship to variability can be expressed as a loss function.

The present study is devoted to analysis of performance evaluation of a process by using histogram and Taguchi technique at Gaurav International, manufacturers of locks and curtain fittings located at Gular Road, Aligarh, U.P., India.

2. Company background

Gaurav International started its manufacturing activities on a very small scale in early 1980's and now has emerged as a leading group in the manufacturing of brass hardware, aluminum hardware, black iron and ironmongery. The hardware items include, door fittings, window fittings, bathroom fittings, cabinet fittings curtain fittings, rail fittings, and accessories, hinges, fire fronts, and electric plates. All the manufacturing processes are performed under one roof situated in an area 50,000 sq. ft, except that different vendors supply the casting products.

The company has various sections, i.e. machining, fitting, polishing, lacquering and packing. All are equipped with latest plant and machinery. The company uses semi skilled workers and developed their skill levels through daily experience. The staffs of the company are assigned to various tasks based on their skill level like, supervisors, quality inspectors, machine operators working on drilling machine and hand press, polishing lacquering and packaging of jobs.

Various machines are used at different levels in the unit. Lancers are used for filing the job surfaces. Hand files are also used for filing the jobs that cannot be accommodated on the lancers. The power press is used to make the keyhole and lathe machines are used for turning handles. Machines carrying polishing and buffing wheels are also used to smoothen the surface of the job. Manufactured items are finally subjected to the following finishing processes as per requirement. These are chrome, satin chrome, satin nickel, black antique, gold antique, powder coating, gold finish, silver finish, combination finish, and power finish. The finish products are then packed using skin packing, single blister, double blister, or shrinkage package.

The company supplies these products to U.K, U.S.A., Australia, Germany, and South Africa. The company also serves a job system operation provided that the customer comes with specific product drawing or sample.

3. Histogram

Histogram is a chart that displays the frequency distribution of one measure or characteristic of data from a process. It is effective quality control tool, which is used in the analysis of data. The chart is used as a check on specific process parameters to determine where the greatest amount of variation occurs in the process, or to determine if process specifications are exceeded. This statistical method does not prove that a process is in a state of control. Nonetheless, histograms alone have been used to solve many problems in quality control.

The histogram evolved to meet the need for evaluating data that occurs at a certain frequency. This is possible because the histogram allows for a concise portrayal of information in a bar graph format. The histogram is a powerful engineering tool when routinely and intelligently used. The histogram clearly portrays information on location, spread, and shape that enables the user to perceive subtleties regarding the functioning of the physical process that is generating the data. It can also help suggest both the nature of, and possible improvements for, the physical mechanisms at work in the process.

Control charts are constructed, in essence, from a series of histogram, one for each set of data or subgroup data. Because histograms give additional information about a process often not evident a control charts, they are used as a corollary tool for process analysis.

Key points in histogram are:

- Provides an easy-to-understand means of displaying the variability of data.
- Does not show change over time, but represents a snapshot at a certain point in time, control charts may be used for trend analysis.
- Histogram shape often provides information that is not evident from control charts.
- Visual interpretations of histograms include the spread (i.e. variability), skew (i.e. normal or skewed, either right or left), and uniformity of shape.

Typical applications of histogram are:

- Display and compare process variability with expected variability.
- Verify whether a process is normally distributed or skewed.
- Determine whether two machines, processes, etc. are producing with same median, mean, and variability.
- Provide visual information that helps interpret the output of a process and to understand both common and special causes of variations when used with control charts.

*A. **Creating a histogram***

The following steps are used to construct a frequency histogram.

1. Count the number of data points (N) in the data set. There should be at least 50 data points.

2. Determine the range (R) of the data set by subtracting the lowest data value from the highest.
3. Based on the number of data points, divide the range into a number of equal size classes. As a rule of thumb, if N represents the number of data points, the number of classes should be approximately $\sqrt{N}$ (Mitra, 2004).
4. Calculate the classification width by dividing the R calculated in step-2 by the number of classes n.
5. Set boundary limits.
6. Tabulate a frequency table from the raw data to simplify the histogram construction.
7. Finally construct the histogram. Label the vertical axis (Y) to denote the frequency of the event observed or measured. Identify the class interval on the horizontal axis (X) and add appropriate title to describe the data represented.

B. ***Interpretations of Histogram***

Ideally, the histogram will create a picture that shows the variation of data values and simultaneously provide a reasonable level of data detail. If too few classifications have been chosen, little of the shape (except perhaps for a few large bars) will be seen. Conversely, if too many classes are shown, the shape of the data will be lost since some of the data will be empty, resulting in comb like toothed appearance.

The shape of the histogram is often the first indication of a problem with process that needs further investigation. Because these problems may not be identified by control charts, it is important to use histograms in support of statistical process control.

When combined with the concept of the normal curve and the knowledge of a particular process, the histogram becomes an effective, practical working tool in the early stages of data analysis. A histogram may be interpreted by asking three questions:

- Is the process performing within specification limits?
- Does the process seem to exhibit wide variation?
- If action needs to be taken on the process, what action is appropriate?

The answer to these three questions lies in analyzing three characteristics of the histogram.

- How well is the histogram centered? The centering of the data provides information on the process aim about some mean or nominal value.
- How wide is the histogram? Looking at histogram width defines the variability of the process about the aim.

What is the shape of the histogram? The data is expected to form a normal or bell-shaped curve. Any significant change or anomaly usually indicates that there is something going on in the process, which is causing the quality problem.

4. Taguchi technique

Quality engineering has the objective of designing quality into every product and corresponding processes. It directs quality improvement efforts upstream from the manufacturing process to the design phase and it is therefore referred to as an off- line quality control method. Taguchi’s off-line methods are effective in improving quality and cutting down costs at the same time.

In Taguchi’s method, quality is measured by the deviation of a characteristic from its target value. The ideal quality is therefore performance at target rather than within some specification tolerance limits. Taguchi suggested that a product imparts a loss to society when its performance is not on target. The loss includes any inconvenience, and monetary or other loss the customer incurs when he uses the product. Taguchi proposed that manufacturers approach the ideal quality by examining the total loss a product causes because of its functional variations from this ideal quality and any harmful side effect the product causes.

The primary goal of robust design is to evaluate these losses and effects and determine:

- Processes conditions that would assure the product made is initially on target, and
- Characteristics of a product, which would assure the product, make its performance robust (insensitive) to environmental and other factors not always in control at the site of use so that performance remains on target during the product's lifetime of use.

To enforce these notions Taguchi re-defined the quality of a product to be the loss imparted to society from the time the product is shipped. The loss caused to customer ranges from mere inconvenience to a monetary loss and physical harm when the quality characteristics deviate from the target.

A loss function is developed for this deviation. Uncontrollable factors, known as noise cause such variation and thereby lead to loss. Since the elimination of noise factors is impractical and often impossible, the Taguchi method seeks to minimize the effects of noise and to determine the optimal level of the important controllable factors based on the concepts of robustness (Mitra, 2004). The objective is to create a product/process design that is insensitive to all combination of the uncontrollable noise factors and is at the same time effective and cost efficient as a result of setting the controllable factors at certain levels.

5. Problem statement and methodology

Gaurav International is an export oriented manufacturing company, which is certified ISO 9001-2000. As part of its quality policy it recognizes customer satisfaction as prime ingredient for existence in the competitive market and profitability.

A preliminary discussion held with the general manager of the company reveals that the company does not have professional quality control personnel. Semi-skilled operators carry out all the inspection activities. As a result, reworks and scraps were observed at all stages of inspection points.

The objective of the present study has thus been specified as under.

- To study the lock manufacturing process using flow diagram.
- To evaluate the process performance using histogram analysis.
- To evaluate the process performance using Taguchi technique.

5.1 Methodology

Variability is inherent in nature and therefore in all manufactured products. No two objects are exactly alike though the differences between them may be too small to be detected by the naked eye. The primary objective of quality control is to keep the process stable. This stability, in turn, helps control the quality of the process. Once a process is under control the product quality can further be improved.

The first objective was to study the manufacturing process itself. This is achieved through on-sight observations and discussions with the manager of the company. Flow diagrams are prepared for the existing system of manufacturing of lever plates and handles-the major components of the final product.

The next aim of the study was to evaluate the process performance using Histogram. This technique is used to see the variation in process and to calculate the actual value of process mean, standard deviation, and process capability and process capability index performance.

The third objective of the study was to evaluate the same process using Taguchi technique. Taguchi methods, developed by Dr. Genichi Taguchi, refer to techniques of quality engineering that embody both statistical process control and new quality related management techniques. It is the conceptual framework of methodology for quality improvement and process robustness that needs to be emphasized. Taguchi loss function was used for the evaluation of the given process.

To accomplish the second and third studies, the following processes were selected for evaluation purpose. The first process was pressing operation using die tools for producing a key hole on the lever plate and squaring the round hole on the end of handle where spindle is to be fitted. The second process was reaming operation on the central hole of the lever plate in which the short arm of the handle is to be fitted into it.

Data collection was carried out based on measurement from depth of hole on the handle, internal diameter of the key hole of lever plate, and diameter of the central hole of the lever plate. The data collected from the depth of hole of the arm, internal diameter of keyhole and diameter of the central hole were used to prepare a histogram for the three of them. Next, the information available in frequency distribution table, the process mean, process capability from calculations, and specification limits provided by manufacturing concerned combined with histogram and Taguchi loss function were used to evaluate the performance of the given process.

For evaluating the above-mentioned processes, 30 samples each of sample size 5 are taken. In order to calculate the required parameters, such as process mean, process standard deviation, process capability indices, and Taguchi loss function the following standard formulae (Taguchi, 1986) were used.

The process mean (μ) was estimated by the sample mean $\left(\overline{X}\right)$ as:

$$\overline{X} = \sum_{i=1}^{n} X_i \div n \qquad (1)$$

where, n represents the number of observations in the sample. The process standard deviation was also estimated by sample standard deviation (s) as

$$s = \sqrt{\sum_{i=1}^{n} \left(X_i - \overline{X}\right)^2 \div (n-1)} \qquad (2)$$

If the distribution is close to normal, the process spread (PS) is

$$PS = 6s \qquad (3)$$

If the process is centered, a measure of the process capability is obtained by using Cp value, where

$$C_p = \left(USL - LSL\right) \div 6s \qquad (4)$$

where, USL and LSL are upper specification limit and lower specification limit respectively.

The Cpk index, which accounts for the location of the process mean was calculated by using Eq. (5).

$$C_{pk} = \min\left(CPU, CPL\right) \qquad (5)$$

where, CPU is upper capability index given by

$$CPU = \left(USL - \overline{X}\right) \div 3\sigma \qquad (6)$$

and CPL is lower capability index given by

$$CPL = \left(\overline{X} - LSL\right) \div 3\sigma \qquad (7)$$

In the process of accomplishing the third objective of the study, Taguchi's loss function was used to evaluate the process performance.

The parabolic loss function equation proposed by Taguchi (1986) for two-sided specification is given by,

$$L_T = K(X - \text{Target})^2 = K(X - T)^2 \quad (8)$$

where, L_T=the cost or loss incurred by measurement on an item, K=proportionality constant which is influenced by the financial importance of the quality characteristics, X = the actual measurement on the item, T=the target value or the most desirable optimal value of the measurement.

In the eq. (8), when the measurement is equal to the target value, the resulting cost or loss is zero. When the measurement is not on target, the cost incurred is proportional to the square of the distance to the target.

By using Taguchi loss function and referring to frequency distribution of histogram for depth of hole of the handle's arm, central hole diameter and internal diameter of keyhole, annual loss was calculated. In order to estimate the annual loss, prior information on the cost of handle, lever plate and monthly production rate for both parts was collected from the owner of the company.

5.2 Data collection

Data for constructing the histogram and evaluating the selected process using both techniques have been collected on day-to-day basis. Lever plates and handles are inspected based on measurement. Digital Vernier caliper having least count of 0.01mm was used for measuring the dimensions of depth of hole of the handle, central hole diameter of lever plate and key hole diameter. Two samples of size five of the selected quality characteristics are randomly checked from the process in a day to complete the data for 30 samples.

6. Data analysis and discussion

This section deals with the observations made and their interpretations on various quality aspects of the process under study. This is done through identification of the parameters that define the product quality, its measurements using digital Vernier caliper, grouping the data in frequency tables, drawing histograms, process capability diagrams and Taguchi loss function curves explaining probable causes of poor quality. An estimate of annual loss is also made by combining the mid cells obtained from the histogram and the loss function equation.

6.1 Lock manufacturing process

The study is conducted for two major components of a door fitting, lever plate and handle (Figures 1 and 2). These components make an interchangeable assembly with clearance fit between them. The component wise description of the process is explained as follows.

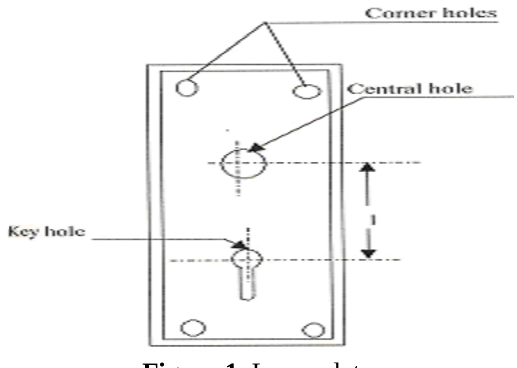

Figure 1. Lever plate

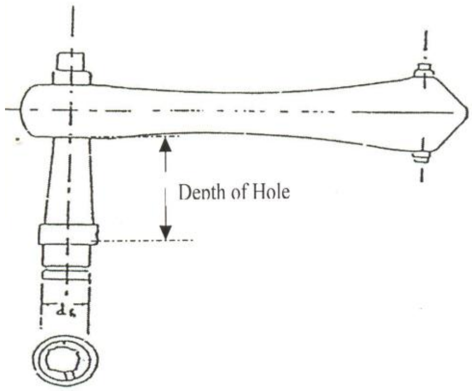

Figure 2. Handle

6.1.1 Lever Plate

As shown in Table 1 the manufacturing of lever plate begins with its casting process. The raw material is sent to the subcontractor for castining. On receipt of the cast product a quality check is applied for possible casting defects. The accepted lot is then sent for acid wash treatment. During this treatment sand particles at the inner surface of lever plate are removed. Then after, the lever plate is drilled at its four corners, followed by counter sinking of these holes to provide rest for screw head (Figure 1). Reaming of the central hole is also done at this stage. After this, the jobs are sent for filing on lancer machines. Then, the key hole is made using a power press. The semi-finished product is now inspected (Quality check-II) for possible surface defects in the internal diameter of the central hole and key hole. Inspected units are then buffed and polished to obtain a more uniform and smoother surface. Pressing the job against the rotating buffing and polishing wheels does this operation. A visual inspection is made to check the embedded iron particles and entrapment of gases below the metallic surface before the plates are washed with chemicals. This cleaning is done to further enhance shining. A chemical coating is provided through lackering on the surface to retain its luster for a longer period.

Table 1. Stepwise manufacturing process of lever plate.

Steps	Manufacturing process	Steps	Manufacturing process
1	Raw material	11	Washing with chemicals
2	Casting	12	Lackering
3	Quality check-I	13	Heating in furnace
4	Acid wash treatment	14	Quality check-IV
5	Drilling and reaming	15	Assembly
6	Filing by lancer machine	16	Quality check-V
7	Key hole by power press	17	Packing
8	Quality check-II	18	Quality check-VI
9	Buffing and polishing	19	Shipment
10	Quality check-III		

Finally the plates are heat treated in a furnace to protect the lacker against atmospheric conditions. Then inspection (Quality check-IV) is made to make sure that the surface of the plate is free of any scratches and the coating is applied evenly. After this, assembling of the lever plate with handle is followed by quality check-V for smooth functionality. Finally, packing process is done the packing condition itself is checked (Quality check-VI) before the items are shipped to their final destination.

6.1.2 Handle

The processes involved in manufacturing the handle are more or less same as that in the manufacturing of lever plates. First of all raw material is sent for casting to the subcontractor, then quality check is applied for casting defects (Table 2).

The accepted lot is sent for turning on lathe machine. Short arm of the handle is turned on lathe to ensure that its external diameter is fitted into the central hole of the lever plate. During casting, a round blind hole is made in the short arm, which is to take the square shape after its processing on power press.

Table 2. Stepwise manufacturing process of handle

Steps	Manufacturing process	Steps	Manufacturing process
1	Raw material	10	Washing with chemicals
2	Casting	11	Lackering
3	Quality check-I	12	Heating in furnace
4	Acid wash treatment	13	Quality check-IV
5	Turning on lathe an power press	14	Assembly
6	Quality check-II	15	Quality check-V
7	Filing by lancer machine and manually	16	Packing
8	Buffing and polishing	17	Quality check-VI
9	Quality check-III	18	Shipment

At quality check point-II damaged pieces are inspected. After that, part filing of goods is carried out on lancer machine and part of it is done manually. The unfinished goods are buffed and polished to obtain a more uniform and smoother surface. Then quality check point-III is applied to detect the iron particles. Rejected pieces are sent back to the casting and accepted goods are sent for washing with chemicals to clean the surface and to get enhanced shining. Then a chemical coating is provided through lackering to give it luster. After this stage, the handles are heat treated in a furnace to protect the lacker from atmospheric conditions followed by quality check-IV. Next, the inspected handles are assembled with lever plates and quality check-V is done to check whether smooth functionality is attained. Finally, the inspected pieces are packed after which the packing condition is checked for any possible mistakes in labeling and wrong number of pieces.

6.1.3 Assembly

Finished handles and lever plates are then assembled interchangeably by the fitter. This is done with the help of spring, fiber washer and lock. Then the assembly is checked whether the handles move properly in the central hole or not. After assembling and checking, jobs are packed and sent to for shipment.

6.2 Quality indicators

From the user's view of point, quality of the door fitting means smooth movement of the handle fitted into the plate and proper locking and unlocking through the key hole on the plate. It has been observed that during the manufacturing of each component, many inspection stations were scheduled to ensure the quality. But all the quality checks were based on visual and functional inspections (Tables 1 and 2).

6.2.1 Casting defects

Defects during casting of both the components are found to be a potential cause for poor quality. To detect these defects the cast pieces are inspected at quality check-I (Tables 1 and 2). Blow holes, swells and hot tears have been the common casting defects.

Blow holes are smooth and round holes appearing in the form of clusters of small holes below the surface of cast. Blow holes are caused by excessive moisture in the sand, low permeability of sand and insufficient venting. Keeping the properties of material intact, blow holes weaken the strength of the cast resulting in poor performance during the use of the product. Blow holes also affect surface finish causing poor appearance of the product.

A swell is an enlargement of the mould cavity by metal pressure, resulting in localized or overall enlargement of the casting. This is caused by inefficient ramming of the mould. Enlargement of casting results in more removal of metal from cast, this increases the time of machining that causes in increased labor cost.

Hot tears are the internal and external crack's occurring immediately after the metal has solidified. Cracks affect the strength of product and causing poor appearance resulting in poor performance during use.

Beside the above-mentioned defects, pockets of sands or ducts and scales of metals have been also observed inside the depth of hole. These might have been caused by improper pouring condition and uncontrolled pouring temperature.

6.2.2 Imperfection dimensions

Another source of variation in quality is the machining operations performed on the lever plate and handle. Drilling and reaming, sometimes lead to imperfect dimensions. The three dimensions that have been selected for this study, referring to (Figures 1 and 2) include,

- The depth of hole on the handle,
- The internal diameter of the key hole, and
- The internal diameter of the central hole of the lever plate.

The power press while squaring and shaping the blind hole at the end of the arm, producing the key hole in the lever plate and reaming operation on the central hole in the lever plate are some of the sources of variation on the dimensions.

6.2.3 Poor surface finish

As shown in Tables 1 and 2 the third inspection is carried out after the semi-finished products are buffed and polished. This is done to check whether some drop and entrapment of gases exists below the metallic surface. Impurities in brass (iron particles) come out during buffing. Worn out wheels or improperly dressed abrasive wheels were also responsible for poor surface qualities after polishing on both handles and lever plates.

6.3 Data analysis using histogram technique

Histogram technique helps us learn about the characteristics of a process, its operating state of affairs, and the kind of output we may expect from it. Like other quality control techniques, the use of histogram involves taking action to remove the identifiable factors that cause the output of a process to be unstable or off-target. Once the process is in a state of statistical control, if the output does not meet the desirable norms, such changes are the focus of quality improvement.

Because graphical methods are easy to understand and provide comprehensive information, they are viable tools for the analysis of product and process data (Mitra, 2004). The information they provide on existing product or process characteristics helps us determine whether these characteristics are close to the desired norm. It is difficult to get an idea of process characteristics just by looking at the individual data values gathered from the process. Such data is often voluminous. Frequency distributions and histograms summarize such information and present it in a format that allows us to draw conclusions regarding the process condition.

As described in the problem formulation the second objective of the present study is to study the process using histogram technique. For this the quality characteristic selected were the inside diameter of the central hole on the lever plate, the inside diameter of the key hole and the depth of hole at the end of the handle arm. Data were collected for each and their analysis using histogram technique is discussed hereafter step by step.

6.3.1 Depth of Hole on Handle

The data collected following measurement on the depth of hole on handle are given on Appendix A. Appendix A shows the depth of hole measured (in millimeters) on the handle, which was produced as blind hole during casting, squared and shaped by power press later on in a machine shop for 150 randomly selected parts (30 samples, each of size 5, were taken). Simply looking at the data in the Appendix A provides little insight about the process. Even though we know there is variability in the depth of hole, we can hardly identify a pattern in the data (what is the degree of variability?) or comment about the central tendency of the process (about which value are most of the observations concentrated?).

Using the data in Appendix A, a frequency distribution given in Table 3 is constructed. Here the, depths of hole are categorized into classes (42.45 to 43.18, 43.18 to 43.91 and so on), and the number, or frequency, in each group is also given. Care was taken to set the class or cell, boundaries such that there is no overlap between them. Classes are of equal width. Table 3 also depicts the relative frequency in each cell, which is found by dividing the frequency in each cell by the total number of observations i.e. 150. Table 3 also shows the cumulative frequency for each cell. The cumulative frequency for each class is the number of observations in that class and in all classes preceding it. The cumulative relative frequency of a class is simply the cumulative frequency for that class divided by the total number of observations (i.e. 150).

The following steps are used to construct a frequency histogram for the depth of hole on the arm/handle.

1) The largest and the smallest values were found to be 51.62mm and 42.81mm respectively. Thus, the range is for the depth of hole on handle is, R=51.62-42.81=8.81mm
2) For the 150 points, number of classes, n= $\sqrt{150} \approx 12$
3) Class width= $R \div n$ =8.81 $\div$ 12=0.73
   If we put the midpoint of the first class at 42.81, then we end up with 13 classes in order to account for the value 51.62. The midpoint of the first class is chosen as 42.81. Thus the first class includes values from 42.45 to 43.18. The upper boundary of each class is non inclusive, if we have a data point with a value of 43.18, it would be included in the second class. Such explicit labeling avoids ambiguity as to where to place observations and it avoids double counting.
4) Using the class boundaries and midpoints shown in Table 3, frequency histogram is constructed with the help of Minitab 14 software package (Figure 3).

The resulting frequency histogram is shown in Figure 3. This histogram gives us a sense of where the observations are cluster and the degree of their variability. Furthermore, it enables us to determine the conformance of the process with respect to established specification limits.

The specification limits for the depth of hole on handle is fixed as 47 $\pm$ 3mm. Here USL is 50mm, LSL is 44mm and the target value is 47mm. From the Figure 3, we can see that the actual center of the process or mean is at 45.9237mm (1.0763mm towards left from the target value) where out of the 150 observation points approximately 30 of them have been clustered on it.

The cumulative frequency in Table 3 also depicts that 126 of the 150 observation values have depth of hole less than 47.56mm. This shows that the process has been producing depth of hole much lesser than the target value that is 47mm. The prime reason for this is that the operator was using the tool when it was worn out. Beside, die pressure variation, presence of metallic scale and sand pockets, and variations in pattern size in casting are responsible for this variation.

Furthermore, the data that have been collected from the depth of hole using measurement were further analyzed through capability analysis to see whether the process was capable or not. In order to simplify the process capability analysis work, Minitab 14 software package is used and output is shown in Figure 3.

The sample mean and standard deviation for the 150 observations are shown in Figure 3 to be 45.9237 and 1.85811mm, respectively. The process potential Cp is 0.54. Since this is less than 1, it indicates that some amount of the product will be nonconforming, making the process incapable. Actual process performance as represented by the Cpk index is 0.35. The observed proportion of nonconforming as shown in Figure 3 is, ppm<LSL were found to be 120000 and ppm>USL were 20000. Moreover, the total ppm of nonconforming were found to be 140000.

6.3.2 Key hole diameter

The observation data collected using measurement on the key hole diameter indicated in Figure 1 are given in Appendix B. The key hole is produced by power press using a die. From quality control view of point, the size of the key hole must remain within the specification so that there will be proper fit with clearance between the key and the hole. For this study, 30 samples of size 5 were selected randomly and the size of the key hole was measured using the Vernier caliper having a least count of 0.01mm.

Using the data given in Appendix B, frequency distribution table is prepared as shown in Table 4. The key hole diameters are categorized into classes (7.77 to 7.83, 7.83 to 7.89 and so on).

The following steps are used to construct a frequency histogram for the key hole diameter.

1) The largest and the smallest values were found to be 8.46mm and 7.80mm respectively. Thus, the range for the key hole diameter is, R=8.46-7.80=0.66mm
2) For the 150 points, number of classes, $n=\sqrt{150}\approx 12$
3) Class width= $R \div n = 0.66 \div 12 = 0.055$

Using the class boundaries and midpoints shown in Table 4 frequency histogram is constructed with the help of Minitab 14 software package.

The fact that the value of Cp=0.76 is less than unity shows that the process is incapable and is producing PPM 〈 LSL = 13333.33 and PPM 〉 USL = 13333.33. Also, the total number of parts produced out of specification or proportion of nonconforming, ppm total is found to be 26666.67.

The capability analysis gives more detail about the process performance. Figure 4 is the Minitab output of capability analysis for the key hole diameter. The capability analysis output depicts that, sample standard deviation is 0.109633, and the actual mean of the process is found to be 8.24833mm, which is skewed by 0.04833 mm towards right. Similarly the process capability index, which is an indicator of the actual process center location, is 0.61 coinciding with the process upper capability index.

6.3.3 Central hole diameter

One of the most important quality characteristics of the lever plate is the center hole diameter. Its size has to be kept within the specification for perfect fit with the handle’s arm. As in the case of depth of hole on handle and key hole diameter, 30 samples of size 5 were randomly selected and observation was taken based on measurement using the digital Vernier caliper having least count of 0.01mm. The observation data is given in Appendix C. The data are arranged in ascending order starting 14.93 to 15.08, 15.08 to 15.23 and so on.

The following steps are used to construct a frequency histogram for the central hole diameter.

1) The maximum and minimum measured values on the central hole diameter are 16.76mm and 15.00mm respectively. Thus the range R is found to be, R=16.76-15.00=1.76mm.
2) For the 150 observation points, the number of classes is, $n=\sqrt{150} \approx 12$
3) Class width = $R \div n = 1.76 \div 12 = 0.15$
   Using the class boundaries and midpoints shown in Table 5 frequency histogram is constructed with the help of Minitab 14 software package.

The specification for the central hole diameter is set at 15.8+0.5mm. USL, LSL and target value is 16.30, 15.30, and 15.80mm respectively. The histogram shown in Figure 5 reveals that most of the observed values of measurement on the central diameter are falling on the left side of the specified center that is 15.8mm. This shows that most of the holes are found to have smaller diameter, which in turn, serves as an indicative to the fact that the size of the reamer which has produced the holes was small. Capability analysis is carried out to evaluate the process's performance. Figure 5 is the output of Minitab software, which displays the capability of the process.

The actual mean of the samples is found to be 15.6459mm, which is skewed towards left by 0.154mm, and samples standard deviation is 0.308976. Moreover, the process is incapable as the value of capability index Cp is 0.54. Also, the value of the actual process center location Cpk is found to be 0.37. As a result, the numbers of nonconforming ppm, PPM<LSL and PPM>USL are found to be 113333.33 and 33333.33. This gives total number of nonconforming ppm is 146666.67.

Table 3. Frequency distribution of depth of hole on handle

Class for depth of hole X (mm)	Mid-point (mm)	Frequency	Percentage relative frequency	Cumulative frequency
$42.45 \leq X < 43.18$	42.81	5	0.033	5
$43.18 \leq X < 43.91$	43.540	10	0.067	15
$43.91 \leq X < 44.64$	44.270	23	0.160	38
$44.64 \leq X < 45.37$	45.00	25	0.167	63
$45.37 \leq X < 46.10$	45.730	30	0.193	93
$46.10 \leq X < 46.83$	46.460	9	0.040	102
$46.83 \leq X < 47.56$	47.190	22	0.180	125
$47.56 \leq X < 48.29$	47.920	9	0.053	134
$48.29 \leq X < 49.02$	48.650	5	0.040	139
$49.02 \leq X < 49.75$	49.380	6	0.040	145
$49.75 \leq X < 50.48$	50.110	3	0.013	146
$50.48 \leq X < 51.21$	50.840	1	0.007	149
$51.21 \leq X < 51.94$	51.570	1	0.007	150

Table 4. Frequency distributions for key hole diameter

Class for depth of hole X (mm)	Mid- point (mm)	Frequency	Percentage relative frequency	Cumulative frequency
$7.77 \leq X \langle 7.83$	7.800	2	0.0133	2
$7.83 \leq X \langle 7.89$	7.855	0	0.0000	2
$7.89 \leq X \langle 7.94$	7.910	0	0.0000	2
$7.94 \leq X \langle 8.00$	7.965	2	0.0133	4
$8.00 \leq X \langle 8.05$	8.020	2	0.0133	6
$8.05 \leq X \langle 8.11$	8.075	5	0.0333	11
$8.11 \leq X \langle 8.16$	8.130	5	0.0333	16
$8.16 \leq X \langle 8.22$	8.185	31	0.2067	47
$8.22 \leq X \langle 8.27$	8.240	34	0.2267	81
$8.27 \leq X \langle 8.33$	8.295	37	0.2467	119
$8.33 \leq X \langle 8.38$	8.350	23	0.1533	142
$8.38 \leq X \langle 8.44$	8.405	6	0.0400	148
$8.44 \leq X \langle 8.49$	8.460	2	0.0133	150

Table 5. Frequency distributions for central hole diameter

Class for depth of hole X (mm)	Mid- point (mm)	Frequency	Percentage relative frequency	Cumulative frequency
$14.93 \leq X \langle 15.08$	15.00	4	0.027	4
$15.08 \leq X \langle 15.23$	15.15	5	0.033	9
$15.23 \leq X \langle 15.38$	15.30	21	0.140	30
$15.38 \leq X \langle 15.53$	15.45	27	0.180	57
$15.53 \leq X \langle 15.68$	15.60	29	0.193	86
$15.68 \leq X \langle 15.83$	15.75	22	0.147	108
$15.83 \leq X \langle 15.98$	15.90	22	0.147	130
$15.98 \leq X \langle 16.13$	16.05	14	0.093	144
$16.13 \leq X \langle 16.28$	16.20	1	0.007	145

$16.28 \leq X \langle 16.43$	16.35	2	0.0133	147
$16.43 \leq X \langle 16.58$	16.50	1	0.0067	148
$16.58 \leq X \langle 16.73$	16.65	1	0.0067	149
$16.73 \leq X \langle 16.88$	16.80	1	0.0067	150

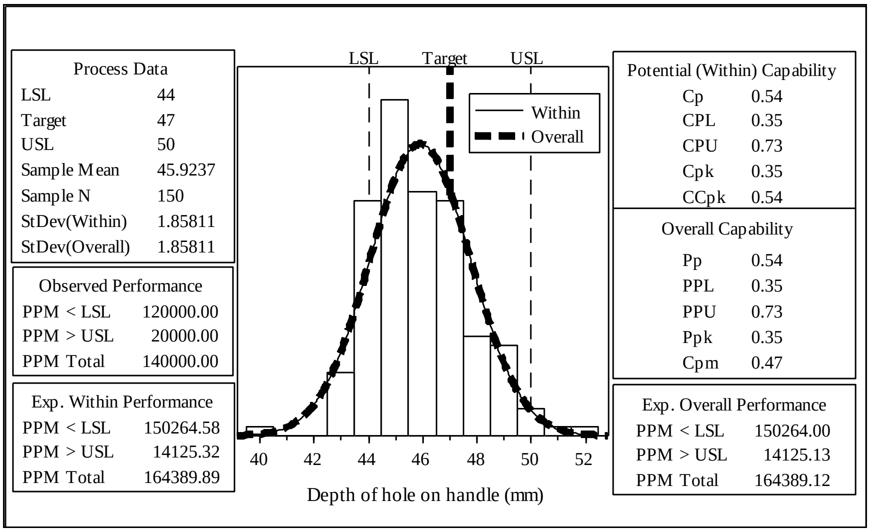

Figure 3. Minitab output of process capability analysis for depth of hole on handle

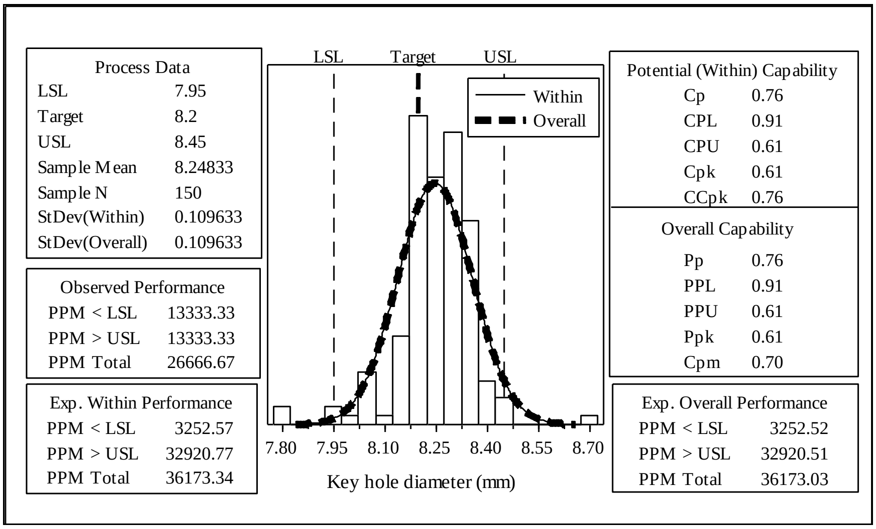

Figure 4. Minitab output of capability analysis for key hole diameter

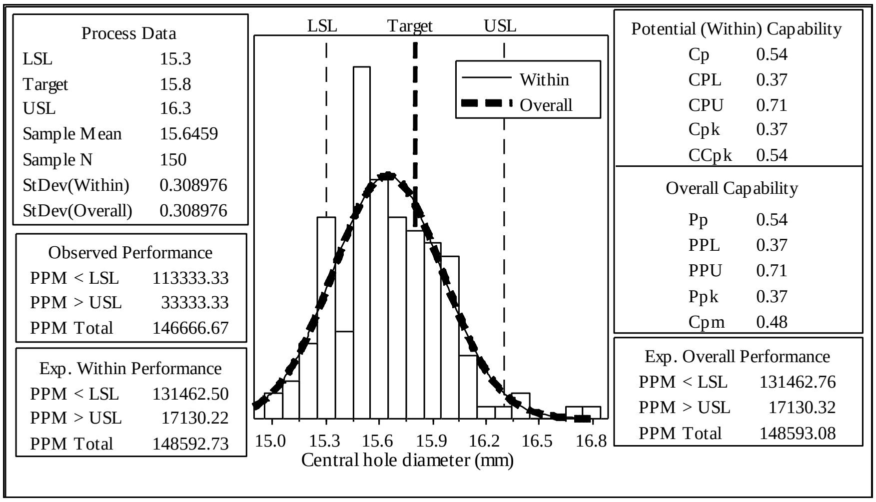

Figure 5. Minitab output of capability analysis for central hole diameter

6.4 Data analysis using taguchi technique

The third objective of the present study was to evaluate the process performance using Taguchi technique. With regard to individual process operations Taguchi focuses on their parameters, or the nominal dimensions and their tolerances, the allowable deviation from nominal, as established by their design engineers.

The parabolic loss function equation proposed by Taguchi for two-sided specification was used for the analysis of the process performance. The main purpose here is to estimate the loss that might happen due to parameter's deviation from meeting the proposed target value. The important parameters in Taguchi loss function are the constant of proportionality K, target value T and the value of actual measurement on item as per eq. (8). The constant of proportionality K, which is influenced by the financial importance of the quality characteristics or gives a monatory meaning to the Taguchi loss function, is an important parameter. To calculate its value two other parameters were defined.

Suppose the consumer's average loss is A, when the quality characteristic is at the limit of the functional tolerance (Δ) (Mitra, 2004). This loss represents costs to the consumer for repair or replacement of the product, with the associated dissatisfaction.

Using the Taguchi loss function we find the proportionality constant K as

$$K=A \div \Delta^2 \tag{9}$$

The loss incurred due to deviation from target was computed by combining Taguchi loss function eq. (9) and the histogram frequency tables are constructed.
The methodology adopted for calculating the loss explained stepwise as follows.

$$\text{Loss per part}=A \div \Delta^2 (X-T)^2 \tag{10}$$

where, A=cost of unit in INR, Δ^2 =tolerance specified for each item, X=cell mid point given in frequency tables in mm, and T=the target value or the most desirable optimal value of the measurement.

$$\text{Annual volume}=\text{Percentage relative frequency} \times \text{Monthly production rate} \times 12\text{months} \tag{11}$$

$$\text{Annual loss}=\text{Annual volume} \times \text{Loss per part} \tag{12}$$

The weekly production rate for the handle and lever plate and their respective cost per item is given in Table 6. For calculating the loss per part and obtaining the Taguchi loss function curve, MS Excel software was used.

Table 6. Unit cost and production rate

Part name	Unit cost (INR)	Production rate	
		Weekly	Monthly
Handle	25	24000	96000
Lever plate	32	24000	96000

6.4.1 Depth of hole on handle

The data collected using measurement from the depth of hole on handle was analyzed using Taguchi technique for possible loss due to variation in the size of the depth of hole. The cell midpoints and perecenatge relative frequency were taken directly from Table 7. The annual loss is computed following the steps discussed previously, and the summary of result is shown in Table 7.

To give more insight, a stepwise calculation is given here for first observation of Table 7. The unit cost (A), for handle is 25INR, and tolerance limit Δ for depth of hole on handle is 3 mm.

As per eq. (9), K= $25 \div 9$ =2.78

Table 7. Annual loss for handle due to variation on depth of hole

Cell mid-point (mm)	Loss per part (INR)	Percentage relative frequency	Annual volume	Annual loss (INR)
42.81	48.8060	0.033	38016	1855408.896
43.54	33.2810	0.067	77184	2568760.704
44.27	20.7191	0.153	176256	3651865.69
45.00	11.1200	0.167	192384	2139310.08
45.73	4.4839	0.200	230400	1033090.56
46.46	0.8106	0.060	69120	56028.672
47.19	0.1004	0.147	169344	17002.1376
47.92	2.3530	0.033	38016	89451.648
48.65	7.5685	0.060	69120	522720.00
49.38	15.7470	0.040	46080	725041.152
50.11	26.8884	0.020	23040	619508.736
50.84	40.9928	0.007	8064	330565.939
51.57	58.0600	0.007	8064	468195.84
Total	270.9307	1.00	1145088	14076950

Taking target value T=47, the loss per part for observation 1 of Table 7 becomes, as per eq. (10) Loss per part=$25 \div 9(42.81\text{-}47)^2$ =2.78(17.5561) = 48.8060INR As per eq. (11), Annual volume = $0.033 \times 96000 \times 12$ = 38016 handles. As per eq. (12), Annual loss = 38016×48.8060 = 1855408.896INR

In constructing Taguchi loss function curve displayed in Figure 9, the values of cell midpoint and loss per part given in Table 7 were used in x-axis and y-axis respectively. The curve clearly shows that when the measured quality characteristic value falls on the target, the loss incurred to the society or the company it self is zero and as the measured value falls far from the target to both sides, the loss increases in quadratic form. Maximum loss was observed when the value of quality characteristic is 51.57mm and loss is minimum at 47.19mm, which is closer to the target value.

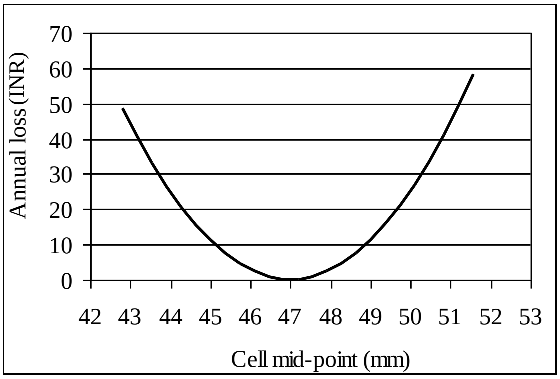

Figure 9. Taguchi loss function curve for depth of hole on handle

6.4.2 Key hole diameter

The procedure for calculating the loss due to variation in diameter of the key hole is the same as that has been discussed previously. The target value and tolerance limit are found to be 8.20 and 0.25mm respectively. Cost per unit is 25INR. After calculation; the value of K becomes 512.

Table 8, shows that the loss per part is higher when the diameter of the key hole is 7.8mm and minimum loss is found when the diameter value is 8.1850mm that approaches to the target value fixed at 8.2mm. The Taguchi loss function curve for the key hole diameter is plotted using the MS Excel software as loss per part versus cell midpoint and the output is given in Figure 10.

Table 8. Annual loss for lever plate due to variation in key hole diameter

Cell mid-point (mm)	Loss per part (INR)	Percentage relative frequency	Annual volume	Annual loss (INR)
7.8000	81.9200	0.0133	15321.6	1255145.472
7.8550	60.9408	0.0000	0.0	0.0
7.9100	43.0592	0.0000	0.0	0.0
7.9650	28.2752	0.0133	15321.6	433221.304
8.0200	16.5888	0.0133	15321.6	254166.958
8.0750	8.0000	0.0333	38361.6	306892.80
8.1300	2.5088	0.0333	38361.6	96241.582
8.1850	0.1152	0.2067	238118.4	27431.240
8.2400	0.8192	0.2267	261158.4	213940.96
8.2950	4.6208	0.2467	284198.4	1313223.967
8.3500	11.5200	0.1533	176601.6	1942617.6
8.4050	21.5168	0.0400	46080.0	991494.144
8.4600	34.6112	0.0133	15321.6	530298.96
Total	314.496	1.00	1144166	7364675

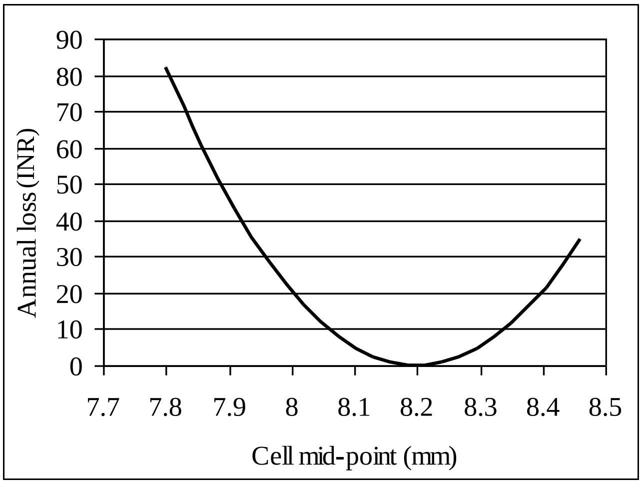

Figure 10. Taguchi loss function for key hole diameter

6.4.3 Central hole diameter

Target value for the central hole diameter is fixed at 15.8mm where as the tolerance limit and cost per unit of lever plate are 0.5mm and 32INR respectively. The value of K after calculation is found to be 128. Loss per part of lever plate is computed using MS Excel software. Moreover, the annual volume and annual loss are calculated in the same way as discussed previously (Table 9).

Table 9. Annual loss for lever plate due to variation in central hole diameter

Cell mid-point (mm)	Loss per part INR)	Percentage relative frequency	Annual volume	Annual loss (INR)
15.000	81.92	0.027	31104	2548039.68
15.150	54.08	0.033	38016	2055905.28
15.300	32.00	0.140	161280	5160960
15.450	15.68	0.180	207360	3251404.8
15.600	5.12	0.193	222336	1138360.32
15.775	0.32	0.147	169344	54190.08
15.900	1.28	0.147	169344	216760.32
16.050	8.00	0.093	107136	857088.00
16.200	20.48	0.007	8064	165150.72
16.350	38.72	0.0133	15321.6	593252.352
16.500	62.72	0.0067	7718.4	484098.048
16.650	92.48	0.0067	7718.4	713797.632
16.800	128.0	0.0067	7718.4	987955.20
Total	540.8	1.00	1152461	18226962

Both Table 9 and Figure 11 show that loss per part is observed to be high when the diameter of central hole diameter is measured as 15mm and the is loss found to be minimum when the value of diameter 15.75mm which is closed to the target value.

In general, the loss approached to zero as the measured values of the quality characteristics closes to target value and went high when the measured value deviated from target.

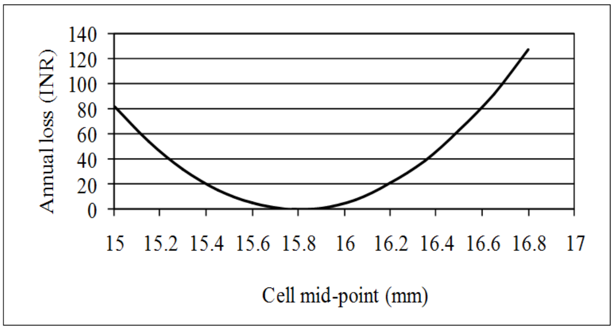

Figure 11. Taguchi loss function for central hole diameter

7. Data analysis and discussion

Based on the analysis of data and the discussion presented in the previous sections, findings of the study are summarized in the following sections. Suggestions for improving the product quality are also made based on the findings and conclusions.

7.1 Lock manufacturing process

The major operations and treatments involved in the manufacturing of lever plate and handle are identified as follows.

- Casting of the components by subcontractor.
- Machining of the cast on lathe, power press, drilling machine and lancer for the purpose of turning handles, making holes on the two components (Figures 1 and 2) and filing on the surface.
- Buffing and polishing of the semi-finished products to obtain a more uniform smoother surface.
- Chemical treatments given to further enhance shining and providing chemical coating to retain the luster for a longer period.
- Heat treatment protects the lackered surface from atmospheric conditions.
- Quality checks based on visual inspections are carried out at six stages, the first being after casting followed by second, third, and fourth checks for semi finished products, the fifth check after assembly and the last check after package.

7.2 Process performance evaluation

To evaluate the process performance, investigations have been conducted through the data collected using measurement against the following three parameters.

- Internal diameter of the central hole on lever plate,
- Diameter of the key hole,
- Depth of hole on the handle.

Frequency histograms were constructed to see the degree of variability and process spread, followed by capability analysis to have an idea regarding the potential of the process (Figures 3-5).

Furthermore, Taguchi loss function equation was applied for estimating the loss, which arises from variation in process performance.

The following paragraphs reveal the findings of this study.

- Process capability index (Cp) and annual loss for depth of hole on handle are obtained as 0.54 and 14076950INR respectively.
- Regarding to the key hole diameter, process capability index (Cp) and the annual loss associated with it are 0.76 and 7364675 respectively.
- For central hole diameter the process capability index (Cp) is found to be 0.54 with a corresponding annual loss of 18226962INR.
- Whenever the value of (Cp) is high, the corresponding annual loss is found to be low. This is observed in case of key hole diameter. Conversely, lower value of Cp is associated with higher amount of annual loss. This fact is shown in case of central hole diameter and depth of hole on handle (Table 10).
- The number of nonconforming ppm out of the lower specification limit (LSL) is 120000, 13333.33, and 113333.33 for depth of hole on handle, key hole diameter, and central hole diameter respectively (Table 10).
- Similarly the number of nonconforming ppm out of the upper specification limit (USL) is 20000, 13333.33, and 33333.33 for depth of hole on handle, key hole diameter, and central hole diameter respectively (Table 10).

Table 10 shows summarized results obtained by combining both histogram and Taguchi technique.

7.3 Suggestion for quality improvements

Since not all the individual units of handles and lever plates are found to meet specifications, the process involved in producing depth of hole on handle, key hole diameter, and central hole diameter are not inherently capable. Thus improvement is certainly required. There are no set rules to improve the quality that could be used under any situation. Quality improvement is a continuous process that can be achieved by reducing errors and implementing best suited methods, machines and manpower.

On the basis of the findings of the study, following suggestions are proposed to the owner of the company to further improve the quality of the process and ultimately the product.

- For defect free casting it is quite important to have correct ramming (neither too soft nor too hard), correct pouring temperature, less moisture content in the sand and providing proper allowances to the patterns. By employing these corrective measures, the variation on the dimension of the depth of hole on handles can be reduced to some extent.
- It is necessary to replace worn-out tools (dies and reamers) by new ones at the right time to prevent production of further defectives pieces.
- The company must adopt quality control technique based on measurement. Visual inspection can by no means catch components with wrong dimensions. Therefore along with the visual inspections, it is quite important to introduce measurement based quality checks after pressing, turning and drilling operations.
- The company must hire quality control engineer at least at diploma level.
- The owner of the company it is suggested to hire skilled workers, or to give them some training, and make tight inspection, only to that extent to remain competent in global market.

Table 10. Summarized results obtained by combining both histogram and Taguchi technique

Parameter	Depth of hole on handle (mm)	Key hole Diameter (mm)	Central hole diameter (mm)
Specification	47 ± 3	8.2 ± 0.25	15.8 ± 0.5
Process mean	45.9237	8.24833	15.6459
Standard deviation	1.858	0.109633	0.308976
Process capability (Cp)	0.54	0.76	0.54
PPM 〈 LSL	120000	13333.33	113333.33
PPM 〉 USL	20000	13333.33	33333.33
PPM total	140000	26666.66	146666.66
Process spread	11.31	0.657	1.851
CPU	0.73	0.61	0.71
CPL	0.35	0.91	0.37
Cpk	0.35	0.61	0.37
Annual loss in INR	14076950	7364675	18226962

Appendix A. Measurements on depth (mm) of hole on handle

Sample number	X_1	X_2	X_3	X_4	X_5
1	45.49	44.30	47.47	45.49	45.12
2	45.89	47.31	47.88	49.30	51.62
3	50.20	47.68	47.65	45.97	45.92
4	45.99	47.29	47.36	43.68	45.12
5	45.69	46.74	44.75	44.18	45.39
6	46.89	45.83	45.29	46.50	43.91
7	43.10	44.05	43.30	47.00	45.12
8	45.20	45.59	45.70	45.00	43.80
9	45.94	43.17	46.28	45.34	44.86
10	44.30	44.54	45.43	47.86	47.09
11	47.04	45.80	44.39	44.50	45.26
12	44.63	46.50	45.37	42.94	45.40
13	45.36	44.48	45.80	46.37	44.70
14	45.65	47.44	45.36	44.45	44.95
15	47.28	46.49	44.28	46.79	43.32
16	45.75	45.37	45.91	44.16	43.61
17	45.87	46.76	44.42	43.13	45.26
18	47.35	44.54	40.07	44.11	45.00
19	44.40	45.75	43.68	45.79	44.18
20	45.28	45.53	45.53	44.05	44.95
21	47.39	44.76	43.79	43.71	45.92
22	45.23	45.50	44.79	43.95	42.81
23	47.33	45.50	44.03	45.00	44.29
24	46.41	47.37	44.57	45.07	47.22
25	43.80	43.50	44.85	45.53	44.86
26	47.14	50.00	46.87	47.31	47.68
27	48.94	49.84	48.86	48.22	48.28
28	47.30	49.04	51.13	49.24	48.11

29	48.22	47.51	48.42	49.44	46.94
30	49.44	49.41	48.78	48.78	46.91

Appendix B. Measurements on key hole diameter (mm)

Sample number	X_1	X_2	X_3	X_4	X_5
1	8.24	7.80	8.13	8.34	8.20
2	7.80	8.05	8.20	8.13	7.96
3	8.21	8.00	8.34	8.70	8.06
4	8.26	8.27	8.11	8.19	8.28
5	8.22	8.24	8.22	8.07	8.19
6	8.21	7.95	8.28	8.26	8.22
7	8.18	8.14	8.26	8.21	8.03
8	8.34	8.37	8.33	8.20	8.18
9	8.18	8.26	8.29	8.35	8.29
10	8.37	8.18	8.37	8.28	8.37
11	8.29	8.30	8.14	8.28	8.36
12	8.19	8.17	8.22	8.22	8.28
13	8.31	8.21	8.16	8.33	8.34
14	8.30	8.34	8.19	8.19	8.26
15	8.17	8.20	8.21	8.07	8.35
16	8.18	8.32	8.43	8.28	8.33
17	8.28	8.31	8.30	8.34	8.25
18	8.28	8.33	8.33	8.40	8.29
19	8.39	8.25	8.28	8.25	8.22
20	8.33	8.06	8.23	8.26	8.29
21	8.24	8.27	8.30	8.30	8.22
22	8.17	8.25	8.25	8.31	8.29
23	8.18	8.31	8.17	8.18	8.29
24	8.24	8.34	8.32	8.21	8.34
25	8.30	8.17	8.27	8.24	8.46
26	8.28	8.22	8.28	8.37	8.25
27	8.26	8.42	8.20	8.24	8.32
28	8.29	8.18	8.22	8.18	8.38
29	8.25	8.44	8.23	8.24	8.36
30	8.22	8.38	8.30	8.25	8.27

Appendix C. Measurements on central hole diameter (mm) of lever plate

Sample number	X_1	X_2	X_3	X_4	X_5
1	15.93	15.67	15.76	15.51	15.75
2	15.00	15.45	15.51	15.57	15.75
3	15.60	15.24	15.26	15.32	15.31
4	16.70	15.27	15.71	15.74	15.53
5	15.56	15.96	16.09	15.34	15.84
6	15.93	16.76	15.76	15.00	15.76
7	15.18	15.47	15.48	15.06	15.60
8	15.43	15.26	15.36	15.73	16.44
9	16.05	15.13	15.48	15.82	15.96

10	15.26	15.41	15.05	15.42	15.84
11	15.47	15.22	15.32	15.74	15.51
12	15.45	15.19	15.93	15.80	15.50
13	15.54	15.25	15.71	15.33	15.62
14	15.49	15.54	15.36	15.94	15.42
15	15.24	16.41	15.27	16.07	15.62
16	15.90	15.59	15.50	15.68	15.37
17	15.52	15.88	15.58	15.90	15.30
18	15.60	15.68	15.21	15.72	15.58
19	15.90	15.50	15.34	15.53	15.66
20	15.90	15.93	15.93	15.46	15.60
21	15.49	15.58	15.78	15.49	15.32
22	15.58	15.64	15.50	15.85	15.55
23	15.56	15.31	16.31	15.82	15.49
24	15.87	16.01	15.55	15.45	15.50
25	15.91	15.65	16.02	15.96	15.51
26	15.98	16.15	15.47	15.84	15.54
27	15.84	15.33	16.04	15.56	16.01
28	15.68	15.97	15.99	15.80	15.67
29	15.55	15.99	15.98	15.74	16.09
30	15.99	16.11	15.71	15.79	15.65

References:

Ishikawa, K. (1985). *What is total quality control? The Japans way*. New Jersey: Prentice-Hall, Englewood Cliffs.

Mitra, A. (2004). *Fundamentals of quality control and improvement*. 2nd Edition, Delhi, India: Pearson Education Pvt. Ltd.

Petrovich, M.V. (1998). *Performance analysis for process improvement*. American Society for Quality 52nd Annual Quality Congress, Proceedings. www.roi-ally.com, 697-707.

Pungle, R.G., Tated, R.G., & Kalantri, S.S. (Sep. 10-12, 2004). *Performance evaluation of a process using histogram and Taguchi techniques. Proceedings of National Conference on Emerging Trends in Mechanical Engineering*. Padre Conceicao College of Engineering, Vena, Goa, India.

Schulz, H. (1995). *Quality pay off. Munich, Germany*. Werkstatt: 128, Carl Hanser Verlag Gmblt & Co., 8-10.

Taguchi, G. (1986). *Introduction to quality engineering, designing quality into product and process*. Tokyo: Asian Productivity Organization. 102-115.

Hagos Berhane **Ajit Pal Singh**

Defence University
College of Engineering,
Bishoftu
Ethiopia
hagosberhane@yahoo.co.uk

Defence University
College of Engineering,
Production Engineering
Department
Bishoftu
Ethiopia
singh_ajit_pal@hotmail.com