Process capability improvement of an eight-head liquid filling machine by the reduction in volume variation

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Abstract. Filling is the process in which liquid and semi liquid products are filled in a container according to the specified requirement. It has a wide range of importance in various industries like dairy products, oil & lubricants, pharmaceuticals, food and beverages, pesticides, chemicals and cosmetic products. Liquids of low to medium viscosity can be filled using these type of filling machines. Filling machine reduces the operational cost and it is not complex to handle where it contributes in obtaining high rate of liquid production in industries. In this paper filling capability factor of machine in a liquid filling line is studied in terms of statistical process control. Filling capability is increased by the application of total production maintenance. Upon continuous usage, the liquid filling spare parts deteriorate which causes volume variation. Define-Measure-Analyze-Improve-Control (DMAIC) approach is applied to analyze and solve this problem. The root causes for volume variation were identified and effective solutions were implemented to decrease the volume variation and thereby enhance the capability of filling.

Key Words: Variation, DMAIC, bottle filling, process capability

1. Introduction
Bottle filling is an important and most widely used process in industries such as pharmaceutical, oil, beverages, etc. This paper highlights the work done to improve the filling volume efficiency of filling machine line with reduced leakages, increase the accuracy of filling and to obtain higher output value of production. The manufactured bulk was processed and sent to filling section for final filling of bottles. The desired output was not obtained in production line of an eight-head filling machine. There was a variation in the volume of liquid filled in the bottle even after fine adjustment. Due to this, problems such as improper filling of manufactured bulk in bottles, overflow, and leakages on machine were observed. Automatic liquid filling machines are extensively used for filling wide variety of fluids [1-2].

Total productive maintenance is one of the maintenance techniques to improve productivity and effectiveness [3]. Quality maintenance is monitored using TPM as it aims at assuring zero defect conditions by understanding and controlling the process interactions between manpower, material, machines and methods that enables defects to occur [4]. Programmable logic controller based filling systems were described and automation design for liquid filling was suggested and compared with
The drawbacks of manual filling were studied and an automated liquid filling was designed for small scale bottling plants. This system was cost effective and also convenient to adopt [6]. Setting of right parameters, shut-off nozzle, flow metric filling machine, proper size of hopper, and comprehensive training for operators, capability issue of the filling machine can be solved [7].

The process capability analysis in the manufacturing of poly (ethylene-terephthalate) bottles for packaging of table oil was done. The performance of blow molding machine was monitored by measuring the volumes of blown bottles. Based on the collected data, the capability analysis of the blow molding process was conducted [8]. Statistical process control techniques were used to reduce the excessive variability in the process thereby reducing the waste and rework. Applications of these techniques in different manufacturing industries were reviewed and reported [9].

Seven QC tools can be sued in all process phases of product development. In modern production processes it is necessary to implement integrated quality management system that involves quality management, responsible environmental performance and safe working environment. There are new quality tools can be applied in industry and services [10]. Large scale training programmes were conducted and a variety of quality related research projects were carried out by the authors. The questions raised by organizations regarding the use of SPC have been listed and catalogue [11]. The applications of 7 QC tools in various manufacturing industries were studied and reviewed [12]. A step by step guide to conduct process capability study for machines was discussed and case studies were illustrated [13].

Literature review indicated that process capability of a liquid filling machine can be improved by application of DMAIC principle. Hence the current problem was approached by this technique to evolve an improved process.

2. Experimental
In the present case the filling volume variation was the problem faced by the liquid-filling company. The causes for this variation were analysed. Suitable design and dimensional modifications were done to the components which significantly reduced the fill-volume variation. Hence, the root causes associated with fill-volume variation were successfully addressed. Process capability and process capability index were represented to show the improvement in the process after the incorporation of changes in certain components. Therefore, the novelty of the work lies in identifying the specific causes for fill volume variation and rectifying the same to improve the overall performance of the process.

DMAIC approach was used to inspect the complete filling line including manufacturing, processing and filling was carried out. Data was collected for balancing the production line; factors affecting the process where identified and rectified by using total productive maintenance technique [14]. The defective components where reworked and replaced to specific dimensions for accurate fill, which increased the efficiency of liquid filling machine. In this problem, the filling production volume variation was defined accordingly by specified tolerance limit. Volume variation was measured accordingly for 100ml fill volume and it was observed that there was significant variation in fill volume. Experimentation was conducted for the 100ml bottle filling. Twenty samples of filled volume were taken from each of the rotating eight filling heads. Total of 160 samples was taken in continuous production flow for analysis. Based on the analysis of the data, action plan for improvement was chalked down and necessary modifications were made in the machine components. Process capability analysis was conducted post modification and comparison was drawn between before and after scenarios.

2.1. DMAIC Approach
DMAIC approach depicted in figure 1, is a methodology of systematic approach of process improvement which can be related to production, manufacturing, and design. It involves the use of statistical tools and techniques to analyze and improve process. It mainly aims at improving process
capability on continuous improvement with low defect rate. DMAIC approach is data driven cycle of improvement which define, measure, analyze, improve and control the process through systematic approach [15].

![DMAIC Cycle](image)

**Figure 1. DMAIC Cycle**

2.2. Production Levelling

Production levelling approach was used for the 8 head liquid manufacturing line by the sequence of manufacturing products in order to balance production. Waste elimination and minimizing differences in the work station were done to enhance the efficiency and flexibility of production line.

2.3. Statistical Process Control

The evaluation of process capability was done by statistical process control using Cp and Cpk values. Statistical Process Control (SPC) is an analytical decision making tool which can be used to monitor, control, analyze, manage, and improve a process by using statistic method [14]. It monitors and shows how a process is performing and how a process capability is affected by the changes to the process, Cp represents the process capability and Cpk represents the process capability index. It measures how close a process is running to its specification limit [15]. In filling process good process is interpreted by Cp>1.67 and Cpk>1.67. Figure 2 illustrates the cause-effect diagram for the existing process condition in this study.

![Cause-Effect Diagram](image)

**Figure 2. Cause-Effect Diagram**
The fill volume of 100 ml was considered for the proposed study as it was observed that there was significant variation in this category. Twenty samples of filled bottle from eight rotating heads were taken in continuous production flow, cumulating to 160 samples. The mean and standard deviation of fill volume for all the heads were calculated and tabulated as shown in table 1. For the recorded set of data the lower limit value is 96 ml and upper limit is 103.70 ml. The mean, standard deviation, process capability (Cp) and process capability index (Cpk) for each head was evaluated and tabulated in table 1. The values of Cp and Cpk are calculated using equation 1 and equation 2 respectively. USL is upper specification limit, LSL is lower specification limit, $\bar{X}$ = Mean value and, $\sigma$ = Standard deviation. The causes for this variation were analyzed and necessary corrective measures were implemented as discussed in further sections.

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

(1)

$$Cpk = \text{Min} \left( \frac{\bar{X} - LSL}{3 \times \sigma}, \frac{USL - \bar{X}}{3 \times \sigma} \right)$$

(2)

| Head Number | Mean (ml) | Standard deviation (ml) | Cp   | Cpk |
|-------------|-----------|-------------------------|------|-----|
| 1           | 97.775    | 1.9965                  | 0.6427 | 0.2963 |
| 2           | 97.810    | 1.9610                  | 0.6544 | 0.3076 |
| 3           | 97.775    | 1.9767                  | 0.6492 | 0.2993 |
| 4           | 97.450    | 2.1392                  | 0.5999 | 0.2259 |
| 5           | 97.275    | 2.1913                  | 0.5856 | 0.1939 |
| 6           | 97.450    | 2.1331                  | 0.6016 | 0.2265 |
| 7           | 97.435    | 2.1656                  | 0.5925 | 0.2208 |
| 8           | 97.660    | 2.5897                  | 0.4995 | 0.2136 |

Table 1. Mean, Standard deviation, Cp and Cpk for each head under current process

The required fill-volume was 100 ml. The values of mean in table 1 indicate that liquid filling machine under observation was not meeting this requirement, as it can be seen that mean value is below 100 ml. The standard deviation values recorded in table 1 point out that there is high variation in fill-volume for all the heads.

The interpretation of Cp and Cpk values are; Cp & Cpk <1.00, the process is poor or incapable, if the values lie between 1 and 1.67 then the process is fairly capable, and if the values are greater than 1.67 then the process is excellent or capable. The values of Cp and Cpk as indicated in table 1 are less than 1, which infer that filling capability of the eight-head filling machine has a poor process capability. The obtained values of Cp and Cpk clearly show that the process is not reaching the specification limit and has a large variation. The machine was not able to achieve the target filling volume of 100ml. This would further lead to serious issues related to customer satisfaction, loss in liquid, and clogging of the machine parts.

Analysis of the causes for this variation was done and the following modifications were done to the parts which had an effect on the filling process variation.

- Square block inner diameter was reduced by honing process to remove the worn surface in order to get a smooth finish.
- It was observed that Teflon seat of rotary valve damaged and hence it was replaced.
- Improper load distributions lead to bending of piston tie-rod. The piston tie-rod was replaced with a superior material.
Square block and rotary valve ratio was matched to 54mm: 54.5mm for better valve operation. Damaged washers were replaced to prevent air and liquid leakage. This prevented non-uniform load distribution. Cylinder bottom silicone O-rings were replaced with 1mm thickness O-rings to obtain a leak-proof fit.

3. Results and Discussion
The machine under study was overhauled by incorporating the modifications as stated in the above section. After refurbishing the machine, the experimentation was repeated to verify the improvement in process capability. The lower limit value is 99.4ml and upper limit is 101.9ml was observed during the filling experimentation. The mean, standard deviation, process capability (Cp) and process capability index (Cpk) for each head was evaluated and tabulated in table 2. The values of Cp and Cpk were calculated using equation 1 and equation 2 respectively. Figure 3 shows the box plots for heads versus filling volume after the causes were rectified. It can be inferred from figure 3 that the variations in filling volume has significantly reduced after incorporating the rectifications in parts which were the causes for variation.

![Figure 3. Box plots for heads versus fill volume for 100ml bottles before and after addressing causes for variation](image)

Figure 3 depicts the box plots for head versus fill volume, before and after addressing the causes for variation, which is done using Minitab software. The values of fill volumes corresponding to the heads H1-B up to H8-B are those obtained for the existing conditions where significant variation of fill volume can be observed for head 4, 5, 6, 7 and 8. Fill volumes corresponding to heads H1-A up to H8-A are for volumes after incorporating the modifications in the system. It can be observed from figure 3 that there is significant reduction in variation of fill volumes after addressing the causes for variation. The length of the box plots is greater for the heads H1-B to H8-B as compared to H1-A to H8-A. This
inference that the problems were correctly identified and rectifications were done to reduce the fill volume variation. The process capability study was done to verify the improvement after eliminating the causes for variation.

Table 2. Mean, Standard deviation, Cp and Cpk for each head after addressing causes of variation

| Head Number | Mean (ml) | Standard deviation (ml) | Cp  | Cpk  |
|-------------|-----------|-------------------------|-----|------|
| 1           | 100.345   | 0.3268                  | 3.9269 | 3.422 |
| 2           | 100.360   | 0.3178                  | 4.038 | 3.5032 |
| 3           | 100.425   | 0.3998                  | 3.2099 | 2.7305 |
| 4           | 100.135   | 0.3407                  | 3.7667 | 3.4879 |
| 5           | 100.260   | 0.4109                  | 3.123 | 2.790 |
| 6           | 100.185   | 0.3438                  | 3.7327 | 3.407 |
| 7           | 100.300   | 0.3494                  | 3.6729 | 3.2436 |
| 8           | 100.495   | 0.3410                  | 3.7634 | 3.132 |

The values of mean for all the heads was found to be greater than 100 ml, as recorded in table 2. The values of Cp and Cpk for each head were calculated and are depicted in table 2. It can be seen that the standard deviation has significantly reduced for all the heads. The values of Cp and Cpk are greater than 1.67 for all the eight heads. This is a clear indication of a good process capability and hence the root causes were addressed correctly. The variation in the process has been reduced, which lead to enhanced productivity and improved performance.

4. Conclusions
This study has highlighted the following outcomes, which are enumerated as follows:
- Process capability study for the filling heads gives the rate of filling and volume variation range.
- All the defective and deteriorated machine spare parts must be identified and changed by regular preventive maintenance.
- After the improvement of existing process, excess filling and leakage on the machine was eliminated completely and there was no loss of manufactured liquid bulk.
- Overall variation in filling volume was recorded and also the efficiency of the process had increased.
- The measurement of process capability is important in order to enhance productivity of a liquid filling process.
- Systematic and scientific approach using DMAIC gives the exact root cause of variation in any process.
- Total production maintenance plays an important role in obtaining better productivity yield and quality output.
- The above analysis shows that DMAIC approach can be successfully applied to solve the issues related to filling volume variation.

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