Decreasing Defects in Plastic Injection Molding and Vibration Welding Processes Through Statistical Process Control

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Abstract - The goal of this study is to decrease a particular defect seen on condenser dryer water tanks, which are manufactured through plastic injection molding and vibration welding. Water leakage problem encountered on these tanks were aimed to be minimized through statistical process control techniques. Initially, the water leakage problem and its criticality was determined by presenting the cost of this problem. After determination of the problem, manufacturing workflow was provided. Next, cause-and-effect diagram presenting the potential causes of water tank leakage was created and the root causes were discussed in detail. Then, control charts were created to examine the process stability. In addition, initial process capability analysis was conducted through which poor capability was revealed. It was determined that both injection molding and vibration welding processes were among the root causes of water leakage problem. Therefore, improvement efforts made included mold maintenance and cleaning, and usage of custom fixtures on the welding machine. After improvements took place, final control charts were created and process capability analyses were re-conducted. Results revealed the fact that the improved molding process was in control and the process capability was enhanced dramatically. In addition, the significance of the improvements made were verified through hypothesis testing. The improvements were standardized for sustainability. Finally, as an additional remedial action, a new automated leakage testing system was designed and utilized as a replacement for the previous manual system. This action also decreased the amount of faulty water tanks that are shipped to the customer.

Keywords: Household appliances, Quality improvement, Plastic injection molding, Statistical process control, Vibration welding

İstatistiksel Süreç Kontrolü ile Plastik Enjeksiyon ve Titreşim Kaynak Süreçlerinde Hataların Azaltılması

Öz - Bu çalışmanın amacı, plastik enjeksiyon kalıplama ve vibrasyon kaynağı ile imal edilen kondenser kurutucu su tanklarında görülen belirli bir kusuru azaltmaktır. Bu tanklarda karşılaşılan su sızıntısı sorununun istatistiksel süreç kontrol teknikleri ile en aza indirilmesi hedeflenmiştir. Öncelikle bu problemin maliyeti ortaya konularak su kaçağı problemi ve önemi belirlenmiştir. Problem tespit edildikten sonra imalat iş akışı verilmiştir. Ardından, su deposu sızıntısının olası nedenlerini gösteren neden-sonuç diyagramı oluşturulmuş ve kök nedenler ayrıntılı olarak tartışılmıştır. Daha sonra süreç kararlılığını incelemek için kontrol grafikleri oluşturulmuştur. Ek olarak, iyileştirme öncesi süreç yetenek analizi gerçekleştirilmiştir. Su sızıntısı sorununun temel nedenleri arasında hem enjeksiyon kalıplama hem de titreşim kaynak işlemlerinin olduğu belirlenmiştir. Bu nedenle yapılan iyileştirme çalışmaları arasında kalıp bakımı ve temizliği ile kaynak makinesinde özel fikstür kullanımı yer almıştır. İyileştirmeler yapıldıktan sonra son kontrol grafikleri oluşturulmuş ve süreç yeterlilik analizleri yeniden gerçekleştirilmiştir. Sonuçlar, iyileştirilmiş sürecin kontrol altında olduğunu ve süreç kapasitesinin önemli ölçüde arttığını ortaya koymuştur. Ayrıca yapılan iyileştirmelerin istatistiksel anlamlılığı ve önemi hipotez testleri ile doğrulanmıştır. İyileştirmeler sürdürülebilirlik için standartlaştırılmıştır. Son olarak, ek bir düzeltici faaliyet olarak, önceki manuel sistemin yerine yeni bir otomatik sızıntı test sistemi tasarlanmış ve kullanılmıştır. Bu iyileştirme aynı zamanda müşteriye sevk edilen hatalı su tankı miktarını da azaltmıştır.

Anahtar kelimeler: Ev aletleri, Kalite iyileştirme, Plastik enjeksiyon kalıplama, İstatistiksel süreç kontrolü, Titreşim kaynağı

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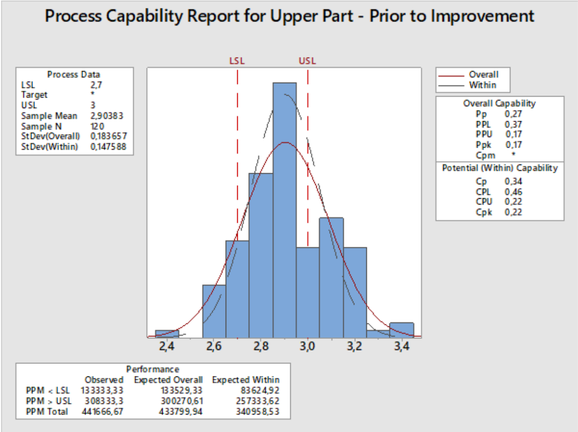
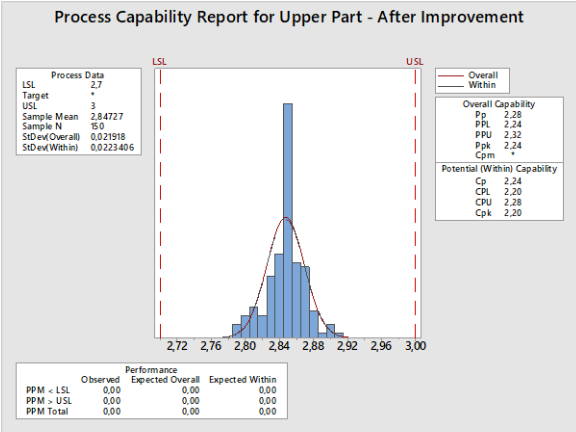
GRAPHICAL ABSTRACT





1. Introduction

A wide range of plastic goods are utilized at every aspect of our life. Accordingly, plastic manufacturing is among the most important branches of industry [1]. The plastic molding industry is a large and diversified one that produces many industrial and consumer products. Manufactured plastic products are used in different areas, including automotive, building materials, household appliances, electronics, disposable items and medical products. The production of plastic parts that have complex forms can be carried out at low cost by injection molding process [2]. Therefore, injection molding is frequently used in the production of a wide range of plastic parts and components [3].

In injection molding process, plastic pellets are melted, injected into a cavity and then cooled into a new solid form. However, traditional manufacturing techniques for plastic products, such as injection molding, can limit the shape of components. Hence, it becomes necessary to join components to create more complex geometries. Vibration welding is among the techniques of joining components [4]. Vibration welding provides a robust process for physically joining thermoplastics to construct complex hollow final products from simpler injection-molded components without utilization of an external heat source, adhesive, or mechanical fastener [5]. Therefore, the weld interface is composed of the same material as the welded parts. Advantages of vibration welding include relatively short cycle times and energy efficiency [6]. In vibration welding, plastic components are heated by an oscillating friction movement of the joining surfaces, then plasticized and consequently welded together. Therefore, the joining of three-dimensional components is a challenge for vibration welding, as the components can be lifted off by the linear movement and the surfaces do not plasticize sufficiently [4].

Considering both injection molding and its complementary process - vibration welding, achieving the required quality level of manufactured parts is critical. Accordingly, in this study, the goal is to decrease a particular defect seen on molded-and-vibration-welded plastic products. In order to achieve this, condenser dryer water tanks, which are manufactured through plastic injection molding and vibration welding processes, were examined. Water leakage problem encountered on these tanks were aimed to be minimized through statistical process control techniques, including workflow, control charts, process capability analysis, cause-and-effect diagram and hypothesis testing.

The remainder of the paper is as follows, it introduces the product, continues with the determination of the problem and workflow, then discusses about the root causes in detail, provides the analyses regarding initial and final process stability and capability, and finally concludes with significance of the improvement.

2. Introducing the Product

A clothes dryer machine, also called as tumble dryer, is a white good which removes moisture from textile products such as clothes and bedding, after they are washed. There are two types of dryers, vented tumble dryers and condenser tumble dryers. In a condenser dryer the humid hot air is transferred to a condensing chamber where it is condensed into water. Then, this condensed water is collected and stored in a container, known as water tank, which is located at the bottom of the dryer. Therefore, a condenser dryer does not pump humid air out to its environment. In condenser dryers it is critical that water tank should be manufactured appropriately and does not leak. Water tank consists of two parts, upper and lower covers, shown in Figure 1. These parts are manufactured via plastic injection molding and assembled via vibration welding process.

Figure 1. Water tank upper and lower covers

3. Determination of the Problem

Dryer water tanks, which are manufactured in the study plant, are sent to a large white goods manufacturer, i.e. its customer company. Water leakage of water tanks was seemed as a minor issue, until this problem was encountered in 300 water tanks, out of 6000, that are manufactured and sent to the customer. The customer company returned the whole batch asking for a compensation of $7500. This returned batch has cost the study plant a total of $12500, in which $7500 was for compensation and $5000 was for labor and energy. Obviously, the problem of water leakage in the water tank component is definitely not desired by the customer company and by end-users. Therefore, it was decided to initiate an improvement study to eliminate this problem and also to design a new automation system for water leaking test, which was conducted manually, as a quick action plan.

4. Analyses and Results

4.1. Workflow

The water tank production workflow starts with inspection of incoming raw material, i.e. plastic pellets, then continues with feeding of these material into production lines, in which injection molding process takes place. Injection molding, through which a wide range of products are manufactured, is the most frequently used process for production of plastic components. In the injection molding process, initially plastic pellets are placed in the feeder hopper, then the plastic is melted in the injection barrel and finally, hot melted plastic is pushed into the mold, where it cools and solidifies into the final part. After both upper and lower parts of the water tank are manufactured via injection molding, visual audit is conducted. Then, vibration welding process takes place in order to join the two components. Vibration welding uses heat generated by friction at the interface of two components to produce melting in the interfacial area. When the surfaces-to-be-joined are heated, they are plasticized and subsequently welded together.

After main assembly takes place via vibration welding, the water tanks are subject to water leak testing. Finally, the tanks that pass the leak testing are sent to final assembly where final ring cap is assembled. Packed components are then shipped to the customer. The process workflow is given in Figure 2.

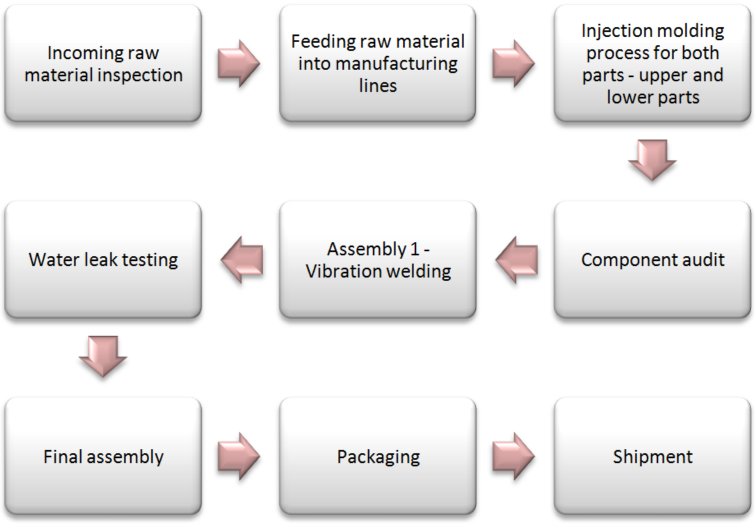


Figure 2. Process workflow

4.2. Cause-and-Effect Diagram

The cause-and-effect diagram presenting the potential causes of water tank leakage was created via Minitab (Figure 3). Water tank leakage issue can be attributed to causes related to machine, method, operator and material.

Machine related causes may be due to vibration welding machine as well as due to injection molding machine. When *vibration welding machine* related causes were examined it was seen that there was only one welding machine in the manufacturing plant, whereas, frequent model changes of produced parts were required. However, standard fixtures were used instead of custom ones for each different part-to-be-welded to save changeover time. For this reason, about 10 to 15 parts were scrapped whenever the model of the produced part was changed. Usage of standard fixtures were also causing slippage of the parts-to-be-welded which caused leakage problem. In addition, in order to adjust the fixture to the size of the parts-to-be-welded, a rubber band was attached to support the parts during vibration welding. It was examined that the rubber band, which wears out over time, causes dimensional differences in the final product produced leading to leakage problem.

On the other hand, when *injection molding machine* was examined it was seen that the ejector system was losing its required angle as it pushed the parts off of the mold. In addition, the molded parts, i.e. water tanks, had incomplete and partial fillings due to mold being old and its poor maintenance.

Regarding both *method* and *operator errors*, it was found that cracks occurred in the welding area of the water tanks produced during welding process due to improper placement of the upper and lower covers of water tanks on the fixture in the welding machine.

Finally, no issues regarding *environment* or *raw material* were found. Therefore, the main causes of water leakage problem were due to vibration welding machine.

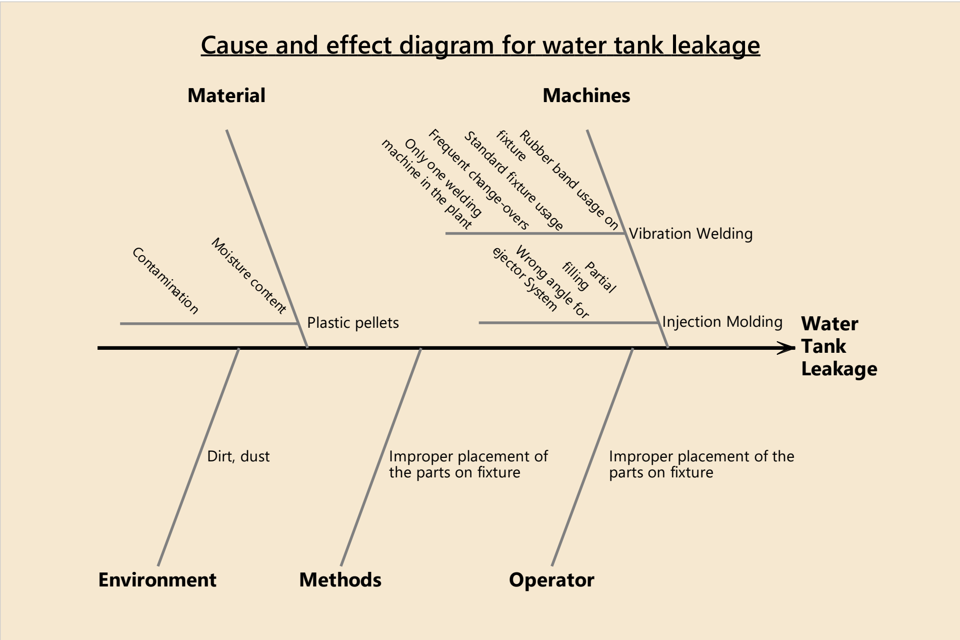


Figure 3. Cause and effect diagram

4.3. Initial Control Charts and Process Capability Analysis

In order to examine the injection molding process, length of the upper part filter area was measured for 10 consecutive hours, for samples of 15 units taken each hour. Then, $\bar{X} - S$ control charts were created via Minitab (Figure 4).

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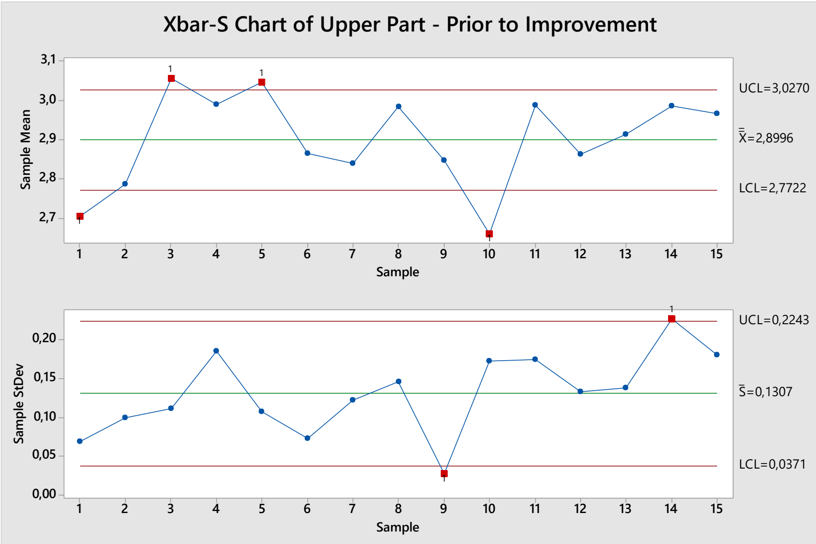

Figure 4. Initial $\bar{X} - S$ control chart

It was determined that 1st, 3rd, 4th and 10th samples were out of control in the $\bar{X}$ chart (Figure 4). It was determined that the 1st sample was the initial sample molded in that shift when machine parameters was not stable, therefore this sample was excluded from the data. Also it was determined that the injection pressure was very low while the 10th sample was being molded. Therefore, 10th sample was also excluded from the data and $\bar{X} - S$ control charts were re-created (Figure 5).

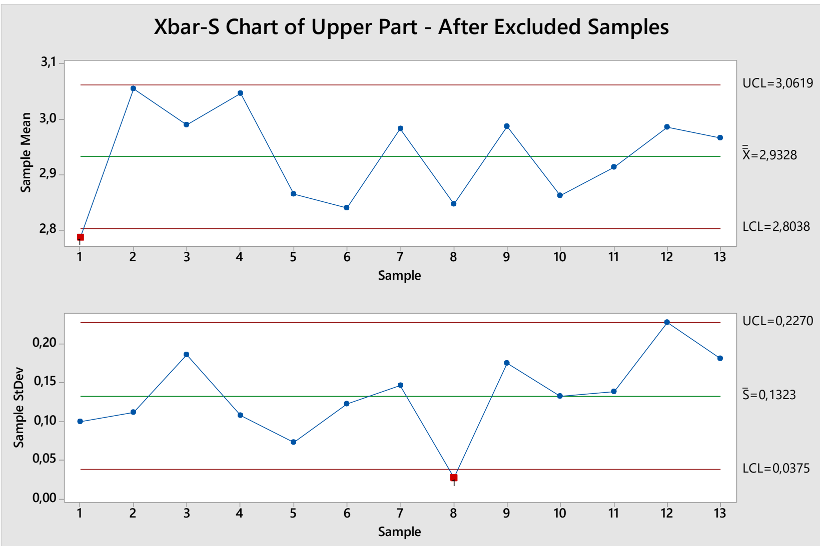

Figure 5. $\bar{X} - S$ control charts after 1st and 10th samples were excluded

After control charts were created for injection molding process, process capability analysis, which assesses the conformity of the process outputs with specification limits, was conducted. The specification limits are 2.70 - 3.00 cm for the length of the upper part filter area.

In order to conduct capability analysis, the data, which was collected for control charts, except for the excluded 1st and 10th samples, was utilized. Therefore, initial process capability analysis was run with a total of 120 measurements. The C_p value, was found to be 0.34 which indicates high variation with respect to specification interval and poor capability for the process (Figure 6). On the other hand, C_{pk} value was calculated as min(C_{pl} = 0.46; C_{pu} = 0.22)= 0.22, also indicating poor process capability which is not properly centered on the nominal value.

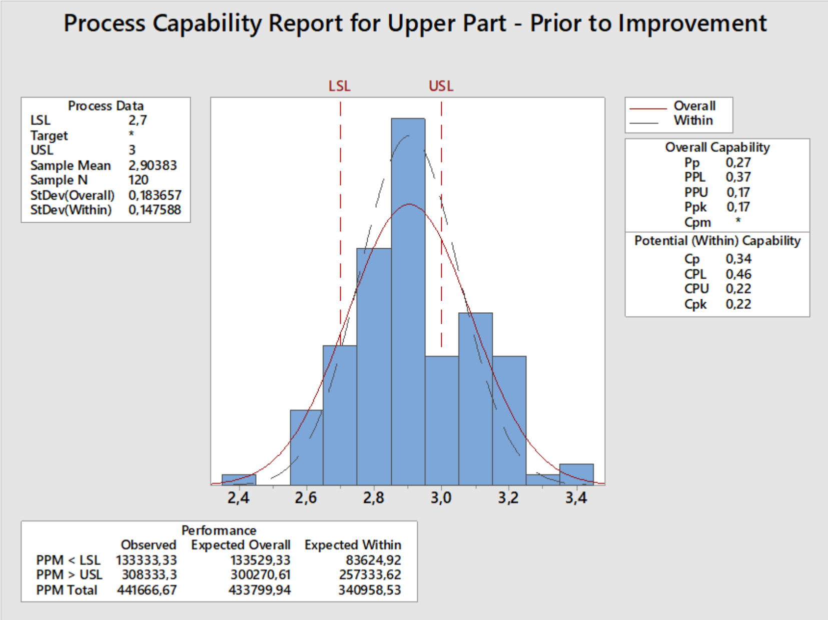

Figure 6. Initial process capability analyses

5. Improvement and Discussion

It was determined during root-cause analyses that both injection molding equipment and vibration welding equipment were among the root causes of water leakage problem. Standard fixtures were being used during welding operations to save changeover time. However, this situation resulted in scrapped parts, as well as, slippage of the parts-to-be-welded, which ultimately caused the water leakage problem. In order to eliminate these issues, the fixtures in the vibration welding was planned to be changed in every model change. Therefore, customized fixtures rather than standardized ones were started to be utilized during welding process.

Additionally, a rubber band was being attached to the welding machine to accommodate small dimension changes and to prevent parts from slipping during welding process. However, this band wears out easily and therefore, cannot provide full support for the parts for extended periods. This causes dimensional differences in the final product leading to leakage problem. As an improvement action, standard controls are set in place at the beginning of each welding process to change/renew the rubber band.

Moreover, the ejector system in the injection molding machine failed to run at its required angle as it pushed the parts off of the mold. In addition, the molded parts, i.e. water tanks, had incomplete and partial fillings due to poor mold maintenance. In order to overcome these issues, a detailed mold maintenance was conducted. First, the mold was completely disassembled, cleaned, and greased with new lubricants and inspected for signs of wear. Any part of the mold that was defective or damaged, including ejector pins, was repaired. Then, the mold was reassembled and a final systems check was run. In addition, shorter mold cleaning and greasing cycles were planned for proper tool maintenance and general preventative maintenance was scheduled. Also, it was planned that the molding machine operator would check the ejector system prior to each injection process initiates.

Finally, because cracks occurred on the water tanks due to improper placement of the upper and lower covers of water tanks on the fixture in the welding machine, welding operators had refreshment training on the welding machine components.

5.1. Hypothesis Testing for Significance of Improvement

After the improvements, i.e. detailed injection molding equipment maintenance, operator training efforts, and fixtures changes in the vibration welding process, were in place, the significance of these improvements were tested. Depending on these improvements, the study company ensures its customers that the water leakage defect rate for the water tanks that they manufacture will not be more than 1%. In order to test this claim, 300 randomly selected water tanks were examined. It was observed that only 2 of the water tanks examined had leakage problem. Hypotheses tests were conducted at 0.01 significance level. The null and alternative hypotheses for this test are:

$H_0: p' \leq 0.01$

$H_a: p' > 0.01$

where,

$n = 300$

$x = 2\ (defective\ water\ tank\ quantity)$

$p_0 = 0.01$

$\hat{p} = 2/300 = 0.006667$

$\alpha = 0.01$

$z_{table} = -2.325$

$$z_{calculated} = \frac{\hat{p} - p_0}{\sqrt{p_0(1 - p_0)/n}} = -0.58$$

Since $z_{calculated} = -0.58 > z_{table} = -2.325$, we fail to reject H_0 at the 0.01 significance level. Accordingly, p-value is 0.719 > α=0.01 level as seen in the Minitab output (Table 1). This indicates that the claim assuring less than 1% defect rate regarding water leakage in the water tanks was met. Therefore, the improvements made were successful.

Table 1. Minitab output for the hypothesis test of significance of improvement

Test of p = 0.01 vs p > 0.01

Sample	X	n	Sample p	Z-value	p-value
1	2	300	0.006667	-0.58	0.719

5.2. Final Control Charts and Process Capability Analysis

After improvements took place, control charts were re-created with 15 samples, which comprised 10 units each. As seen in Figure 7, the injection molding process was in control with no special causes.

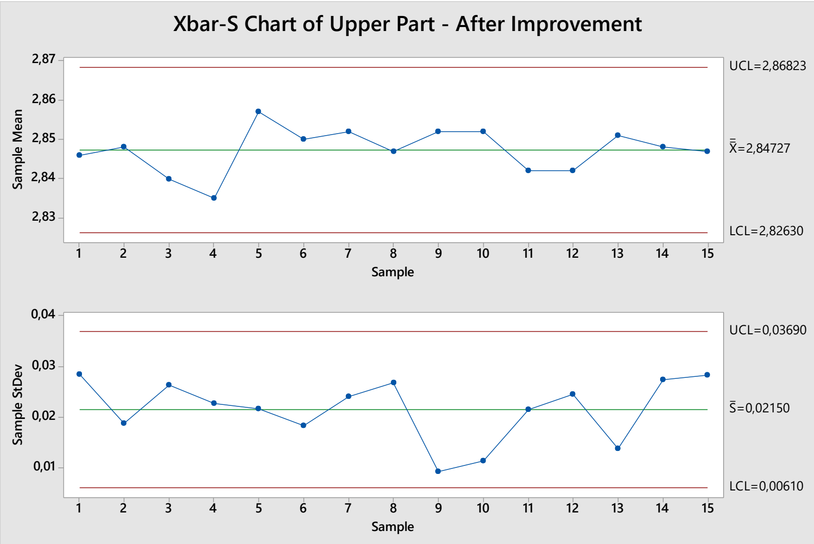

Figure 7. Final $\bar{X} - S$ control charts - after improvement

In addition, final process capability analysis was conducted to determine the level of improvement (Figure 8). The results revealed the fact that both C_p and C_{pk} values were improved. C_p value increased to 2.24 indicating very small variation with respect to specification interval, whereas, C_{pk} value was increased to 2.20 indicating a perfectly centered process on the nominal value. Since both indices were above 1.33, the required value, final process was capable of meeting specifications.

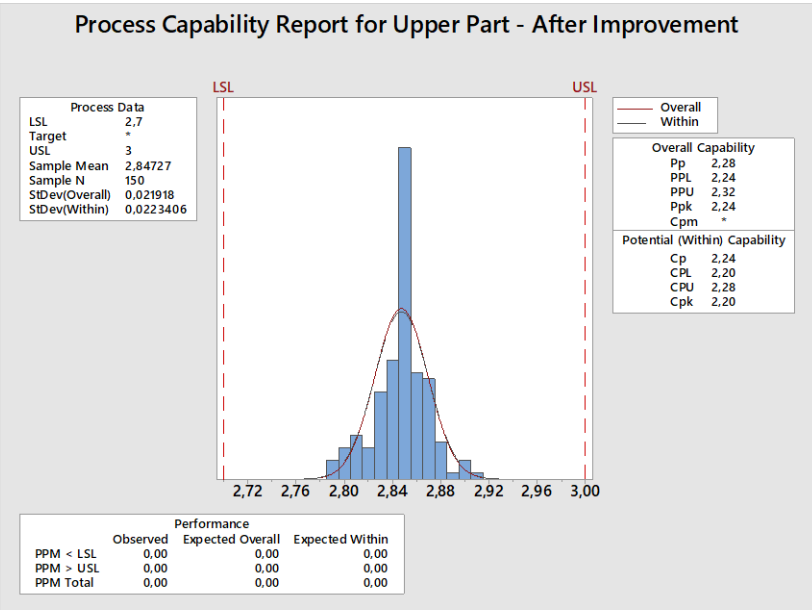

Figure 8. Final process capability analyses - after improvement

5.3. Additional Improvement in Water Leak Testing

In addition to improvements made on the injection molding and vibration welding processes, water leak testing process was also examined. Leak testing consists of mainly four steps; i) placement of the water tank on the test machine, ii) the tank is filled with water up to the max level on the tank, iii) if no water leakage was detected, water is drained through drainage hose and iv) the water tank is unloaded from the test machine. The leak testing was performed manually and some operator-related errors were determined after assessments.

It was determined that water level in the tank during the leak testing was below the max level, i.e. the specified level. This problem occurred due to the early removal of the filling hose from the tank by the operator. Also machine pressure-related errors existed. In addition, the water tank was being scratched while testing due to manual operations.

Moreover, at some times, leakage was failed to be detected due to the water remaining in the hose. This remaining water in the hose were spilled on the floor by mistake and it could not be understood which product had water leakage problem (Figure 9).

Figure 9. Water spill under the manual leak testing area

Finally, 100% leak testing could not be performed on all water tanks, because filling and draining of water from the tanks were performed at the same station. Therefore, some water tanks were being packaged and shipped to the customer without being tested due to confusion.

In order to prevent all these above mentioned problems due to manual operations, a new water leak test automation system was designed and started to be utilized. With this newly designed automated testing system, the primary purpose is to conduct 100% inspection on the final products and to ship them to the customer with zero defects (Figure 10).

Figure 10. Automated leak testing system

18 water tanks can be attached to the newly designed system. In this system, while filling operation is carried out in a water tank at the same time, drainage operation can be performed in a different water tank. Also, the problem of water pump pressure has been resolved.

With the new water leak testing automation system, the dependency on manual operations is eliminated. In the previous system, because the hose was manually attached and removed, water remaining within the hose used to spill on the floor and created a confusion about the leakage problem. This problem has been completely resolved by means of special plates in the new water leak test automation system. In the new system, water filling and drainage is done by the machine itself and a sensor is activated and a red light turns on as soon as water drops on the plate. After the red light turns on, the machine automatically stops and does not initiate until a new tank is installed and the plate is fully cleaned.

6. Conclusion

In this study, dryer water tanks, which are manufactured via plastic injection molding and vibration welding processes, were examined and water leakage problem were minimized through statistical process control techniques. First, the product was introduced for thorough understanding. Then, the cost of water leakage problem for the manufacturing company was provided and the criticality of the issue was put forward. After the determination of the problem, water tank manufacturing steps were explained as a process flow. Then, the cause-and-effect diagram depicting the potential causes of water tank leakage was constructed and the potential as well as the root causes were discussed in detail. Then control charts were created to determine whether the process was in control or not. In addition, initial process capability analysis was conducted through which poor process capability was revealed.

It was determined that both injection molding and vibration welding processes were among the root causes of water leakage problem. Therefore, efforts were made, such as mold maintenance and cleaning, and usage of custom fixtures on the welding machine, to improve these processes. After improvements took place final control charts and process capability reports were re-created. Results indicated that the improved molding process was stable and the capability of the process was enhanced considerably. Besides, the significance of the improvements made were confirmed through hypothesis testing. The improvements were standardized for sustainable achievement. Ultimately, as an additional corrective action, a new automated system for leakage testing was designed and started to be utilized as a replacement for the previous manual system. This action also decreased the amount of defective products shipped to the customer.

Plastic injection molding as well as vibration welding are among the most prominent processes across many industries. Accordingly, a wide variety of products are manufactured through these processes. Therefore, further improvement efforts, such as design of experiments, encompassing various other products can be achieved in both plastic injection molding and vibration welding processes.

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References

[1] Desai, D. and Prajapati, B. N. (2017). Competitive advantage through Six Sigma at plastic injection molded parts manufacturing unit. *International Journal of Lean Six Sigma*, *8*(4), 411-435. Doi: https://doi.org/10.1108/IJLSS-06-2016-0022

[2] Khavekar, R., Vasudevan, H. and Modi, B. (2017). A comparative analysis of Taguchi methodology and Shainin system DoE in the optimization of injection molding process parameters. In *IOP Conference Series: Materials Science and Engineering* (Vol. 225, No. 1, p. 012183). IOP Publishing.

[3] Maged, A., Haridy, S., Kaytbay, S. and Bhuiyan, N. (2019). Continuous improvement of injection moulding using Six Sigma: case study. *International Journal of Industrial and Systems Engineering*, *32*(2), 243-266. Doi: https://doi.org/10.1504/IJISE.2019.10021839

[4] Vogtschmidt, S., Fiebig, I. and Schoeppner, V. (2020). Vibration welding of components with angled areas in the direction of vibration. *Welding in the World*, *64*(11), 1843-1853. Doi: https://doi.org/10.1007/s40194-020-00964-6

[5] Patham, B. and Foss, P. H. (2011). Thermoplastic vibration welding: Review of process phenomenology and processing–structure–property interrelationships. *Polymer Engineering & Science*, *51*(1), 1-22.

[6] Troughton, M. J. (2008). *Handbook of plastics joining: a practical guide*. William Andrew: Norwich, NY, USA. Doi: https://doi.org/10.1016/B978-0-8155-1581-4.50005-