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# Six Sigma Methodology for Improving Manufacturing Process in a Foundry Industry

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***Abstract —*** *Six sigma is a project-driven management approach that is relevant to all the fields starting from manufacturing to service industries. The main goals of six sigma are improving efficiency, profitability, and process capability. In this paper, six sigma methodology based on DMAIC approach is applied to a foundry industry. The scope of the study is limited to automated high-pressure green sand moulding line. The root causes of different casting defects are identified and various actions are recommended to improve the production process. As a result, the overall sigma level of the industry is improved at an acceptable level.*

***Keywords— Casting Defects, DMAIC, FMEA, RPN, Six Sigma.***

## I. INTRODUCTION

In the present scenario, quality has become one of the most important competitive strategic tools which many organizations have realized it as a key to develop products and services in supporting continuing success [1]. The use of quality tools and technique provides long-term dividends through lower costs and productivity improvements. The companies have recognized the importance of quality system implementation in a volatile business environment in maintaining effectiveness [3]. Specifically meeting the needs of the customers is critical and must be done much better and efficiently than it has done in the past. TQM incorporates the concepts of product quality, process control, quality assurance, and quality improvement. Besides TQM there is other quality system used to improve quality such as six sigma [2]. Six sigma focuses on the reduction and removal of variation by the application of an extensive set of statistical tools and techniques. This would lead to improved productivity, improved customer satisfaction, enhanced quality of service, reduced cost of operations or costs of poor quality, and so on. This paper mainly focused on the implementation of six sigma quality methodology through DMAIC approach to rectify the casting defects in a foundry industry. The defect data of six months is collected to evaluate the performance of the company. FMEA is used to analyze the various casting defects and their significance to make the casting defective. The root causes of defects are identified and improvement actions are suggested to eliminate defects. The adoption of six sigma has improved both the efficiency of the line and the production capability.

## II. METHODOLOGY

Six sigma provides a customer focused, well-defined methodology supported by a clear set of comprehensive tools for process improvement [6]. In this study, six sigma is exercised through a classified project-oriented approach through DMAIC cycle. The DMAIC cycle is a more detailed version of the Deming PDCA (Plan, Do, Check, Act) cycle with continuous improvement. The different phases (Define, Measure, Analyze, Improve, and Control) provide a problem-solving process in which specific tools has employed to turn a practical problem into a statistical problem, generate a statistical solution, and then convert that back into a practical solution [4].

## III. COMPANY BACKGROUND

The company has started with aim of production of all types of ferrous castings. It is a modern industrial casting unit with ISO 9002 certification. The unit has an optimum capacity of 18000 tons per annum and covers an area of 21500 sq. meters. The plant comprises of two distinct production lines, they are the conventional moulding line and high pressure moulding line. The company can manufacture ferrous castings of all grades and sizes ranging from 5kg to 8000kg. The high pressure moulding line is a semi-automatic system, which has used for mass production of small castings. The plant manufactures complex high precision items of mass production like cylinder block and cylinder heads for the entire range of automotive engines. The company has separate lines for the production of entire automotive castings from the smallest to the largest, such as housings, flywheels, pulleys, manifolds, brake drums etc. Apart from serving the diversified needs of the automobile industry, the company also manufactures pump castings, windmill hub, machine tools etc. Currently, the company faces many quality problems in their production unit. The rejection is occurring mostly in the production of engine cylinder frame. Therefore, the company implements six sigma methodology to identify the cause of defects and to improve the sigma level of the company.

## IV. SIX SIGMA IMPLEMENTATION

The rejection rate of engine cylinder frame was analyzed statistically using DMAIC methodology and suggestions for quality improvement are made to the company.

### 4.1 DEFINE PHASE

The purpose of this phase is to define the scope and goal of the improvement project in terms of customer requirements and to develop a process that provides these requirements. For defining the project, a project charter has made with all the necessary details of the project. The project charter is shown in Table 1. A good charter creates a roadmap for the team to achieve the changes as required by the management [7].

*Table.1: Project Charter*

| | |
|---|---|
| Project title | To reduce rejection rate of engine cylinder frame |
| Project objective | Targeting to bring down the present defective rate |
| Critical to quality | Percentage of casting rejections is high due to casting defects |
| Project scope | Green sand casting process and high pressure production line |
| Expected benefits | Quality and defect free products<br>Customer satisfaction<br>Cost saving due to defects |
| Schedule | Define – one week<br>Measure – two week<br>Analyze – three week<br>Improve – three week<br>Control – three week |

Before the process to be investigated, all circumstances have to be defined. The process mapping of the company that helps the team to understand entire casting process to reduce the variation in the production is shown in Fig.1.

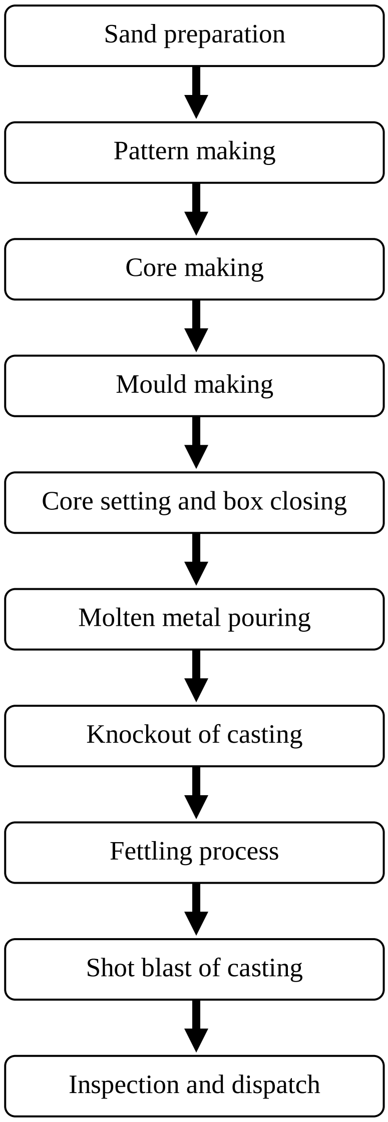


*Fig.1: Process Mapping of the Company*

### 4.2 MEASURE PHASE

The data was collected for six months continuously from July 2016 to December 2016 in the high pressure production line on the production of engine cylinder frame to track down the problem faced by this particular component. Table 2 shows the total production – rejection statement of the engine cylinder.

A Pareto chart was constructed as in Fig. 2, regarding the casting defects. It shows the various casting defects and their significance to make the casting defective.

*Table.2 Production– Rejection statement*

| Month | Quantity produced | Quantity defective | Defective percentage |
|---|---|---|---|
| July | 175 | 42 | 24.00 |
| August | 856 | 158 | 18.45 |

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| | | | |
|---|---|---|---|
| September | 823 | 170 | 20.65 |
| October | 590 | 50 | 8.47 |
| November | 960 | 93 | 9.68 |
| December | 983 | 172 | 17.49 |
| Total | 4387 | 685 | 15.61 |

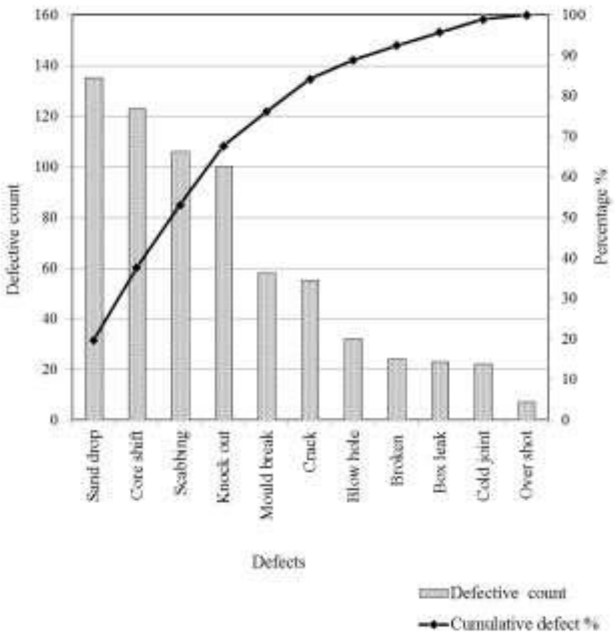


*Fig. 2: Pareto Chart for the Casting Defects*

It can be concluded by analyzing the Pareto chart that sand drop, core shift, scabbing, knockout defect and mould break are blow up as the prime reasons for 76% of the defective castings.

The calculation of sigma level is based on the number of defects per million opportunities (DPMO) [5]. In order to calculate the DPMO, three individual pieces of information are required as given below.

a) The number of units produced = 4387

b) The number of defect opportunities per unit = 11

c) The number of defects = 685

DPMO =

$$= \left( \frac{\text{No. of defective units}}{\text{No. of opportunities for defect} \times \text{No. of units}} \right) \times 1000000$$

$$\text{DPMO} = \left( \frac{685}{11 \times 4387} \right) \times 1000000$$

DPMO = 14194.83

The sigma level of the casting process is calculated using sigma calculator, which is found to be 3.7 sigma level.

4.3 ANALYZE PHASE

In this phase, the collected data is verified, analyzed, and ranked in order to discover the possible root causes and their impact on output. FMEA is used to identify the significance of casting defects. The potential failure modes and potential causes for each of the casting defects are identified, followed by the effects of failures on the product. The intensity of the defects caused on the casting is measured using risk priority number (RPN). It (from 1 to 1000) is an index obtained from the multiplication of three risk parameters, which are severity, detection, and occurrence. The evaluation of the three risk parameters is prepared on the numerical scale based on the reference manual developed by AIAG [8]. 1 to 10 ranking is adopted in this study due to ease of interpretation, and at the same time, accuracy, and precision, which is adapted to the particular risk situation of the process. The result of FMEA is shown in Table 3. They are based on the requirements of the high pressure moulding line of the company or final product.

The defect having higher RPN is given priority. The monetary loss due to casting rejection is considered as a measure of risk. The results help to concentrate on the defects that having higher RPN in the rejection of casting. The most significant defects are core shift and scabbing having the highest RPN of 576 for both of it. The RPN number of crack is 512 and of sand drop is 504 are the following priority defects. Later cold joint and mould break are the important defect to consider having RPN value of 392 and 336 respectively. The remaining defects are to be considered, but least priority.

*Table.3: FMEA Analysis*

| ***Failure*** | ***Failure mode*** | ***Failure effect*** | ***Failure cause*** | ***S*** | ***O*** | ***D*** | ***RPN*** |
|---|---|---|---|---|---|---|---|
| ***Sand drop*** | *Sand mould drops and cause similar shaped sand holes on the casting* | *Change in required shape and affect surface finish* | *Fast metal pouring* | *7* | *9* | *8* | *504* |
| ***Core shift*** | *Displacement of core from its seat* | *Undesirable variation in wall thickness and final shape* | *Fast metal pouring* | *8* | *9* | *8* | *576* |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scab** | *A portion of face of a mould lifts or breaks and the recess thus made is filled by metal* | *Sand is washed away and cavity is filled with metal. Change in required shape* | *High moisture content.* | *8* | *9* | *8* | *576* |
| **Knock out** | *Breakage of casting corners when it stuck on vibrator mesh plate* | *Affect surface finish* | *Damaged mesh plate* | *5* | *9* | *7* | *315* |
| **Mould break** | *Breakage of pattern print in the sand mould* | *Change in required shape* | *Jerking of the machine* | *6* | *8* | *7* | *336* |
| **Crack** | *Very thin parting lines on casting surface* | *Affect the mechanical properties of casting* | *Due to shrinkage of casting* | *8* | *8* | *8* | *512* |
| **Blow hole** | *Smooth round holes on casting surface* | *Change in required shape* | *High moisture content* | *3* | *7* | *7* | *147* |
| **Broken casting** | *Fractured sections of casting* | *Casting is separated into pieces* | *Operator fault* | *2* | *7* | *7* | *98* |
| **Box leak** | *Molten metal leaks in between mould box* | *Failed to obtain a casting* | *Mould box damage* | *3* | *7* | *7* | *147* |
| **Cold joint** | *Two metallic streams are not fused together* | *Change in required shape* | *Slow metal pouring* | *7* | *7* | *8* | *392* |
| **Over shot** | *Excess removal of metal from the surface* | *Change in required dimension* | *Operator fault* | *2* | *6* | *6* | *72* |

The details of casting rejection and subsequent monetary loss for six months are shown in Table 4. In this study, only castings rejected as scrap is considered in the estimation of the cost of rejection, the cost involved in reworking is not considered due to lack of significance because most of the defects in castings can be rectified through fettling and final finishing operations.

*Table.4: Casting Rejection & Subsequent Monetary Loss*

| Defect | Reworked quantity | Rejected quantity | Cost of rejection Rs.3000/unit |
|---|---|---|---|
| Core shift | 0 | 123 | 369,000 |
| Scabbing | 0 | 106 | 318,000 |
| Crack | 0 | 55 | 165,000 |
| Sand drop | 90 | 45 | 135,000 |
| Mould break | 15 | 43 | 129,000 |
| Broken | 0 | 24 | 72,000 |
| Box leak | 0 | 23 | 69,000 |
| Cold joint | 14 | 8 | 24,000 |
| Blow hole | 24 | 8 | 24,000 |
| Over shot | 0 | 7 | 21,000 |
| Knock out | 98 | 2 | 6000 |
| Total | 241 | 444 | 1,332,000 |
| Average | | 74 | 222, 000 |

The issue of core shift, scabbing, crack, sand drop, mould break, and cold joint of casting must be addressed first, eliminating these problems will result in a savings of Rs.1,140,000 more than for any other problem listed. The root cause for these casting defects is identified and listed as follows.

### 4.3.1 Scabbing, blow hole

The industry was using the reused sand for the mould making. Any variation from the specified limit of moisture content and total clay content may cause scabbing and blow hole in the casting. Therefore, three samples are tested to detect moisture content and total clay content and the results are shown in Table 5.

*Table.5: Percentage of moisture content and total clay content*

| Sample no | Moisture content (%) | Total clay content (%) |
|---|---|---|
| 1 | 5.1 | 7.4 |
| 2 | 4.8 | 6.9 |
| 3 | 5.4 | 7.9 |

The results revealed that the silica sand used for moulding has an average clay content of 7.4%, instead of company specification of 5-7%. The average moisture content of moulding sand is 5.1%, instead of company specification of 3-4%. Hence, the moisture content should be reduced in the sand by adding new silica sand.

### 4.3.2 Core shift, sand drop, cold joint

The pouring time should be maintained as per specified limit of 15-17 seconds. The pouring time tests for twenty random castings are performed to evaluate the casting defects such as core shift, sand drop, and cold joint. The test results are given in Table 6. It was found that castings with fast pouring have a chance for core shift and sand drop and the castings with slow pouring have chance for cold joint.

*Table 6: Estimation of Pouring Time*

| Sample no | Pouring time | Condition of the casting | Remarks |
|---|---|---|---|
| 1 | 10 | Rejected | Core shift |
| 2 | 15 | Good | |
| 3 | 16 | Good | |
| 4 | 12 | Defective/Rework | Sand drop |
| 5 | 15 | Good | |
| 6 | 17 | Good | |
| 7 | 19 | Good | |
| 8 | 21 | Defective/Rework | Cold joint |
| 9 | 14 | Good | |
| 10 | 13 | Defective/Rework | Sand drop |
| 11 | 11 | Rejected | Core shift |
| 12 | 16 | Good | |
| 13 | 11 | Defective/Rework | Core shift |
| 14 | 15 | Good | |
| 15 | 17 | Good | |
| 16 | 20 | Defective/Rework | Cold joint |
| 17 | 19 | Good | |
| 18 | 12 | Defective/Rework | Sand drop |
| 19 | 14 | Good | |
| 20 | 14 | Defective/Rework | Sand drop |

4.3.3 Crack

The reason for crack is due to shrinkage of casting. It is evident that the prominent reason is the shortage of molten metal in the casting process.

4.3.4 Mould break, box leak, knock out

In the company, the preventive maintenance is performed once in a week. Due to poor inventory management, preventive maintenance cannot be done efficiently. In the case of mould break, the main obstacle is the lack of materials or parts required for the maintenance at the right time. Also, in the maintenance schedule, there no provision for regular maintenance of the mould box. The mould box maintenance is performed only after the defect has occurred. This issue may cause the damage of box clamp. During knock out defect, it is noticed that the castings get defective during shake out process. The reason for this defect is low service life of vibrator mesh plate. The improper replacement and preventive maintenance schedule and poor inventory management are identified as the vital cause for knockout defect.

*Table 7: Improvement Actions*

| | Defect | Cause | Improvement action |
|---|---|---|---|
| 1 | Scabbing | High moisture content | New silica sand is added to reduce moisture content in the reused mould sand. |
| 2 | Core shift | High metal pouring rate | Maintain the pouring time from 15sec to 17sec |
| 3 | Sand drop | | |
| 4 | Crack | Shrinkage | Provide sufficient molten metal into mould. |
| 5 | Cold joint | Low pouring rate | Maintain the pouring time from 15sec to 17sec |
| 6 | Mould break | Jerking of machine | Revised the preventive maintenance schedule |
| 7 | Box leak | Damage to box clamp | Revised the preventive maintenance schedule and perform regular condition monitoring for mould box |
| 8 | Blow hole | Gas entrapped in metal | Decrease moisture content in sand and increase air ventilation |
| 9 | Knock out | Damage mesh sheet | Revised the preventive maintenance schedule and replacement schedule, and perform regular condition monitoring |
| 10 | Broken casting | Operator's fault | Give necessary instructions and training. Provide safety measures to operators. |
| 11 | Over shot | | |

4.3.5 Broken casting, overshot

The root cause of these defects is related to human factors such as operator's fault, lack of training, uncomfortable working environment, lack of safety measures and the working mentality of the worker. Considerably these defects have low risk priority compared to other defects. Overshot defect occurs when operator performs excess machining on the castings.

4.4 IMPROVEMENT PHASE

A number of solutions for the problem are suggested in this phase. The improvement actions recommended removing the defects in castings are shown in Table 7.

4.5 CONTROL PHASE

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In this phase, the various actions to control and maintain the improvements efforts in the process is initiated. In addition, the current sigma value is calculated with respect to new improvements. The data is collected after improvement for the month of March 2017 and is shown in Table 8.

*Table.8: Current Production - Rejection Statement*

| Month | Quantity produced | Quantity defective | Quantity rejected |
|---|---|---|---|
| March | 851 | 63 | 28 |

$$\text{DPMO} = \left( \frac{63}{851 \times 11} \right) \times 1{,}000{,}000$$

DPMO = 6730.05

The current sigma level is calculated as 4.0

Cost of rejection after improvement
(Rs.3000/unit) = 28×3000
= Rs.84,000

*Table.9: Result after Improvement*

| | Before improvement | After improvement |
|---|---|---|
| Sigma level | 3.7 | 4.0 |
| Cost of rejection | 222, 000 (July 2016 – December 2016; Six months average) | 84, 000 (March 2017) |

Table 9 shows the result after improvement. It reveals that the performance of the company had improved and the loss of company had decreased with compared to previous months. The standardization of the process is required for having the optimum results sustained in long run. The proper documentation of the process and appropriate training of the people related with the process should be conducted so that they can able to run the process effectively.

## V. CONCLUSION

Global competitiveness is making the manufacturing industries going through a tough challenge to produce high quality and customized products at low cost to meet the rocketing market demand. Six sigma was progressed as one of the powerful methodology in order to challenge these situations. It enhances the process efficiency by identifying and eliminating the defects. This paper executes the systematic application of the six sigma DMAIC methodology for reducing the rejection rate of casting in a foundry industry. The research findings show that the rejection rate of casting had reduced from 15.61% to 7.40%. As a result, the cost associated with rejection or scrap had reduced. In addition, complete organizational involvement and training of the employees and the encouragement of the people for participating in the six sigma improvement are initiated.

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