

**Six Sigma Implementation in Small Scale Industry - A Case Study in Foundry**Bhupender Singh¹, Anit Bansal²¹P.G. Student- Department of Mechanical Engineering,
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Abstract: The way, in which Six Sigma has taken its advantage in abroad, we can expect same results in India too. This even happened in large companies but small scale industries could not take its benefits as they can. Only few of the Indian SSI's have implemented Six Sigma. It is due to various reasons but lack of knowledge is also a big reason for that. If few of these industries move forward and adopt Six Sigma than it is an inspiration for other industries also. For this initiative an attempt has been made by implementing Six Sigma in small scale foundry which was affected by high rejection of products due to various defects. This study gives overview of various tools and techniques for DMAIC implementation, ground status of SSI's and success of Six Sigma in foundry.

Keywords: Six Sigma, Small Scale Foundry, DMAIC, Casting Defects

1. Introduction

1980s, the revolutionary decade for manufacturing industries when Bill Smith first introduced Six Sigma in a television manufacturing industry "Motorola". Now, after more than 25 years of development Six Sigma spread all over the world. Lot of benefit has been taken by large scale industries by improving and controlling the processes and designs through Six Sigma in India also.

The fields that must require improvements in there conditions are Indian small scale industries. Many times these industries works in no profit, no loss condition and some time it gives only loss. Even in good condition the profit remains small due to high production cost. There is also not so much profit in Janta Foundry due to this problem and only one way seen to compensate this problem is Six Sigma.

2. Small Scale Foundry: An Overview

Now a day, competition between manufacturing industries becomes high. Small scale foundries are also a part of this competition. Even for these foundries this is a do or dies condition. The main problem in these industries is high rate of defective products which are rejected by costumer or inspector. Due to these defective products, the cost of production become so high and profit remains low. In lack of budget these industries are working with low quality tools and equipments. They can't even spent money on safety. If they gain some more profits then they can upgrade their foundries and this only happens when production of defective parts decreases. Six Sigma is a quality tool and can help these industries to make their process more efficient but due to less examples of success of Six Sigma in Indian small scale industries, owners didn't believe on the performance of Six Sigma. They are afraid to spend money on a totally different concept that is not much used in Indian small scale industries.

3. Six Sigma

Definition of Six Sigma has been a fundamental issue addressed in the literature. Even after three decades in practice, a commonly agreed definition of Six Sigma is yet to be developed. In common term we can say that Six Sigma is a method that provides organizational tools to improve the capability of business process. This increase the performance and decrease process variations. Six Sigma improves profits, employee morale, and quality of products or services. According to (Weiyong Zhang, 2009) Six Sigma review shows that different definitions can be categorized into four types

3.1 Different Definitions of Six Sigma**i. Six Sigma as a Defect Rate Metric**

The very first definition of Six Sigma is that it is a defect rate metric, specifically, it means 3.4 DPMO. This is actually the origin of the name Six Sigma. Statisticians have used the Greek letter Sigma (σ) to refer to standard deviation.

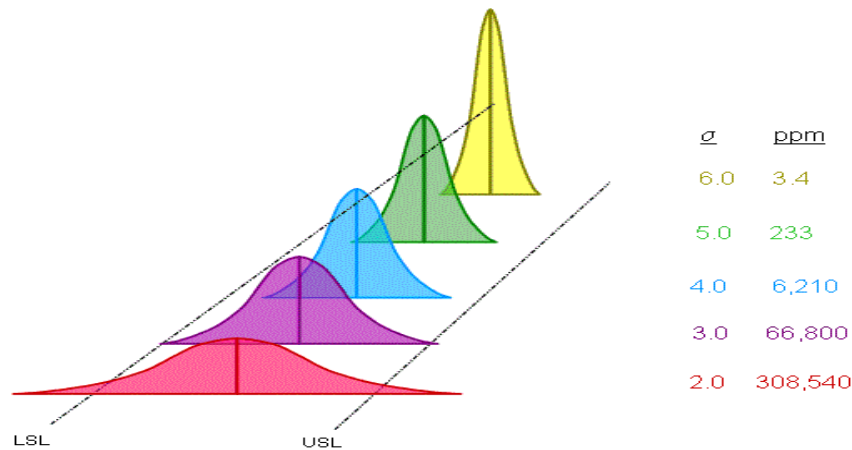


Figure 1: Six Sigma as defect rate metric

Six Sigma is simply six standard deviations. What it truly means is that a process is highly capable that customer specifications are actually six standard deviations away from the process center.

ii. Six Sigma as an Improvement Method

A more common definition of Six Sigma is that it is a set of tools and techniques for problem solving or process improvement. It is an improvement method that holds the set of tools and techniques together.

iii. Six Sigma as an Improvement Program

A good definition of Six Sigma is given recently by (Schroeder et al, 2008) Six Sigma is an organized, parallel structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives. This definition captures several distinctive characteristic of Six Sigma: an organizational approach, statistical tools and techniques for variation reduction, a structured method, and metrics orientation, although it leaves out the aspects of customer orientation and project-based implementation (Zhang and Xu, 2008).

iv. Six Sigma as an Improvement Philosophy

Six Sigma has been defined as an improvement philosophy, particularly by GE. GE claims that Six Sigma is its business strategy, corporate culture, company DNA and value, and “the way we live” (GE, 2002). Some Six Sigma advocates also hold the same view. Regardless of the terms used, the essence is to define Six Sigma as an improvement philosophy. Defining Six Sigma as an improvement philosophy is very inspiring and it could lead to major cultural change and performance improvement in an organization.

3.2 Six Sigma Process with 1.5 Sigma Shift

According to this idea, a process that fits 6 sigma between the process mean and the nearest specification limit in a short-term study will in the long term fit only 4.5 sigma – either because the process mean will move over time, or because the long-term standard deviation of the process will be greater than that observed in the short term, or both.

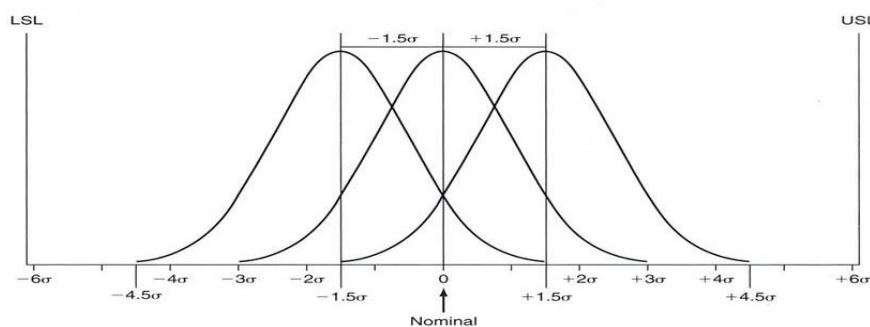


Figure 2: Six Sigma Process with 1.5 Sigma Shift

Hence the widely accepted definition of a six sigma process is a process that produces 3.4 defective parts per million opportunities (DPMO)

3.3 Process Sigma Level

To find out the current sigma level of an industry is known as process sigma level. If an industry produces one million of products and 3.4 products are defective from them then we can say that it is a 6 sigma level. To find out correct process sigma in any condition a formula converts DPMO value to sigma level has been developed by (Schmidt and Launsby, 1997) as

$$\sigma = 0.8406 + \sqrt{29.37 + 2.221 \ln DPMO}$$

Defects per million opportunities as

$$\frac{\text{Defective parts} \times 10^6}{\text{Total parts}}$$

4. Methodology

There are two different methods used in six sigma. DMADV is used when it's a design problem and no process exist or if exist does not impact on study And DMAIC is used where a process exist and impact the defects in production. Most of the industries have a problem with both design and process so that six sigma DMAIC is best fit in this condition

4.1 Different Phases of DMAIC

DMAIC is used where process based manufacturing is done and problem occurs at any part of the process. DMAIC methodology can define and analyze the problem, makes best solution for this and control it forever with continually improvements. As shown by name DMAIC has five different phases. These five steps are:

- i. Define phase
- ii. Measure phase
- iii. Analyze phase
- iv. Improve phase
- v. Control phase

All of these have different objectives. The main objectives of different phases are:

i. Define Phase

- Confirm the process is causing problems.
- Define the goal by developing a "Goal Statement"
- Define process by developing maps of the process
- Define your customer and their requirements

ii. Measure Phase

- Determine how the process currently performs
- Look for what might be causing problem
- Ensure your data is reliable

iii. Analyze Phase

- Closely examine the process
- Visually inspect the data
- Verify the cause(s) of the problem

iv. Improve Phase

- Select the practical solutions
- Develop maps of processes based on different solutions
- Select the best solution(s)
- Implement the solution(s)

v. Control Phase

- Ensure the process is being managed and monitored properly
- Expand the improved process throughout organization
- Apply new knowledge to other processes in organization
- continuously improve the process
- Share and celebrate the success

5. Sand Casting & Casting Defects

Sand Casting or Sand Molded Casting is a metal casting process characterized by using sand as the mold material. It is relatively cheap and sufficiently refractory even for steel foundry use. A suitable bonding agent (usually clay) is mixed or occurs with the sand. The mixture is moistened with water to develop strength and plasticity of the clay and to make the aggregate suitable for molding. The term "sand casting" can also refer to a casting produced via the sand casting process. Sand castings are produced in specialized factories called Foundries. Over 70% of all metal castings are produced via a sand casting process.

5.1 Steps Involved in Casting

1. Initially a suitable size of molding box for creating suitable wall thickness is selected for pattern. Sufficient care should also be taken in such that sense that the molding box must adjust mold cavity, riser and the gating system (runner and gates etc).
Next, place the drag portion of the pattern with the parting surface down on the bottom.
2. The facing sand is then sprinkled carefully all around the pattern so that the pattern does not stick with molding sand during withdrawn of the pattern.
3. The drag is then filled with loose prepared molding sand
4. Ramming of the molding sand is done uniformly in the molding box around the pattern. Fill the molding sand once again and then perform ramming. Repeat the process three four times,
5. The excess amount of sand is then removed using strike off bar to bring molding sand at the same level of the molding flask height to completes the drag. The drag is then rolled over and the parting sand is sprinkled over on the top of the drag.
6. Now the cope is placed on the drag pattern and alignment is done using dowel pins
7. Sprue and riser pins are placed in vertically position at suitable locations using support of molding sand. It will help to form suitable sized cavities for pouring molten metal etc.
8. Fill the cope with molding sand uniformly. Strike off the excess sand from the top of the cope.
9. Remove the cope and the gate is then cut, connecting the lower base of sprue basin with the mold cavity.
10. Rap and remove the patterns and repair the mold suitably if needed.
11. Remove sprue and riser pins and create vent holes in the cope with a vent wire. Clamp the cope with drag.
12. Pour molten metal in pouring basin till, the metal came out from riser.

5.2 Casting Defects

1. Scab

Sand inclusion and slag inclusion are also called as scab or blacking scab. They are inclusion defects. Look like there is slag inside of metal casting. These irregularly formed sand inclusions, close to the casting surface, combined with metallic protuberances at other points. Sand inclusion is one of the most frequent causes of casting rejection.

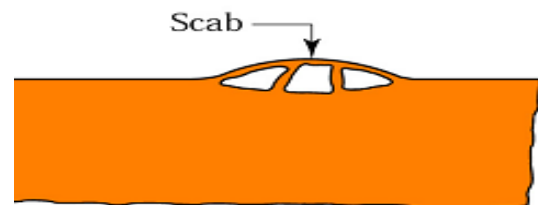


Figure 3: Scab in casting

It is often diagnose, as these defects generally occur at widely varying positions and are therefore very difficult to attribute to a local cause. Areas of sand are often torn away by the metal stream and then float to the surface of the casting because they cannot be wetted by the molten metal.

Possible Causes

- Break-up of mould sections during stripping of patterns, core setting or assembling of molding flasks
- Uneven compaction of moulds, compaction too high in places.
- Low compact ability of sand
- Pouring rate too high, with heavy impact against mould wall surface resulting in erosion
- Ladle too far above pouring basin
- Pouring time too long

2. Cold lap or Cold shut

Cold lap or also called as cold shut. It is a crack with round edges. Cold lap is because of low melting temperature or poor gating system. When the metal is unable to fill the mould cavity completely and thus leaving unfilled portion called misrun. A cold shut is called when two metal streams do not fuse together properly. As shown in fig 7.2 a crack of round edge separates the two metal streams. Outside metal from this crack is provably broken when part is under working. Cold shut are caused when molten metal flow comes into contact with the cooler die surface and solidifies filling of the mould. Another flow of metal fills in the mould and lies on the previous metal instead of melting it, which causes the crack. This most likely is due to inadequate mould temperature.

Possible Causes

- Lack of fluidity in molten metal
- Faulty design
- Faulty gating
- Lack of temp. maintained in furnace
- Impurities in metal

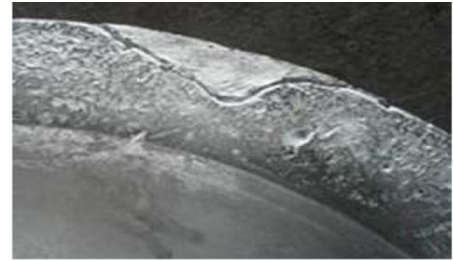


Figure 4: Cold shut in casting

3. Shrinkage

Shrinkage defects occur when feed metal is not available to compensate for shrinkage as the metal solidifies. Shrinkage defects can be split into two different types: open shrinkage defects and closed shrinkage defects. Open shrinkage defects are open to the atmosphere, therefore as the shrinkage cavity forms air compensates. There are two types of open air defects: pipes and caved surfaces. Pipes form at the surface of the casting and burrow into the casting, while caved surfaces are shallow cavities that form across the surface of the casting.

Closed shrinkage defects, also known as shrinkage porosity, are defects that form within the casting. Isolated pools of liquid form inside solidified metal, which are called hot spots. The shrinkage defect usually forms at the top of the hot spots. They require a nucleation point, so impurities and dissolved gas can induce closed shrinkage defects. The defects are broken up into macro porosity and micro porosity (or micro shrinkage), where macro porosity can be seen by the naked eye and micro porosity cannot.

Possible Causes

The density of a die casting alloy in the molten state is less than its density in the solid state. Therefore, when an alloy changes phase from the molten state to the solid state, it always shrinks in size. This shrinkage takes place when the casting is solidifying inside a mould. At the centre of thick sections of a casting, this shrinkage can end up as many small voids known as 'shrinkage porosity'.



Figure 5: Shrinkage

4. DIMENSIONAL ERRORS

Pattern making, molding and casting, if not properly carried out, give rise to dimensional faults. If dimension of any product are not match with costumer requirements, it is known as dimensional defect. Some of main dimensional defects are irregular thickness at different points, less then tolerable diameter of gear or pulley, irregular pitch of gear, misalignment of parts etc. Dimensional errors can only checked by measuring tools.

Possible causes

- Low strength and plastic properties of pattern material
- Lack of rigidity in assembled mould
- Low sand strength or badly rammed
- High pouring speed
- Incorrect equipments

6. RESULTS AND DISCUSSION

6.1 Define Phase

This step identifies the pain area or the process that needs improvement. It also defines the nature of the problem.

Tools used:-

1. Current State Analysis
2. Cause and Effect Diagram (Minitab)

3. Pareto Chart (Minitab)

1. Current State Analysis:-

Janta Foundry & Repairing Works manufacture approximately 28000 parts every year with the help of foundry tools available in the company. Company has only 5-6 permanent customers who order machine parts. Most importantly, company neither has any standard manufacturing process nor any safety rule and regulations. The company has been started since 2001 and they have only 5-6 consumers who are buying parts.

Second, currently the company has **Oil & Air Fired Furnace** which is not as fast as other modern furnaces like Gas Fired Furnace, Cupola Furnace etc. So implementing machine with more features and more advance technology will also be helpful. Furthermore, using the better quality polishing machine will also help company to get better quality of product.

Third, currently there is no inspection of quality of product manufactured because they think that they are manufacturing better quality product without any fault. However, the manufacturing process produces defects like: Improper dimensions of teeth of gear and the waste category as a result of improper feeding of raw materials and poor quality of raw material. It is the poor quality of raw material that becomes the focus within the DMAIC process in this thesis. The poor quality of raw materials results in blow holes, pin holes, cavity and scab in production. It is clear from evidence that by improving the quality of raw material resin input, Janta Foundry will reduce the number of defective parts and improve the quality of the final product.

Finally, from information it is clear why the DMAIC methodology will be useful in this application. The tools will reveal current data and production system information in order to provide a foundation to expand the business in right direction with all necessary calculations.

2. Cause and Effect Diagram (Minitab)

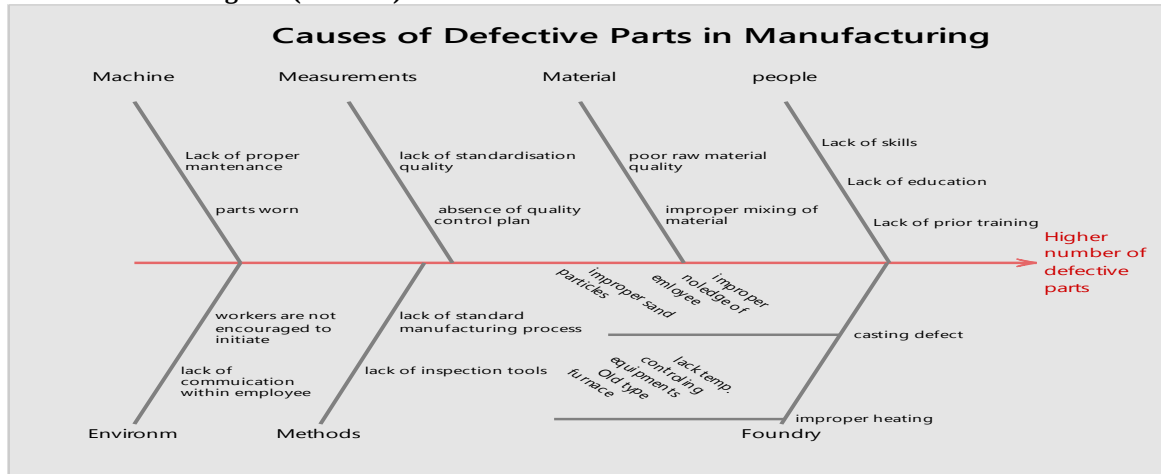


Figure 6: All possible Causes that increase rejection in Foundry

3. Pareto Chart (Minitab):-

A Pareto Chart is a basic quality tool used to highlight the most frequently occur defects, or the most common causes for a defect. This specialized type of bar chart is named for Vilfredo Pareto.

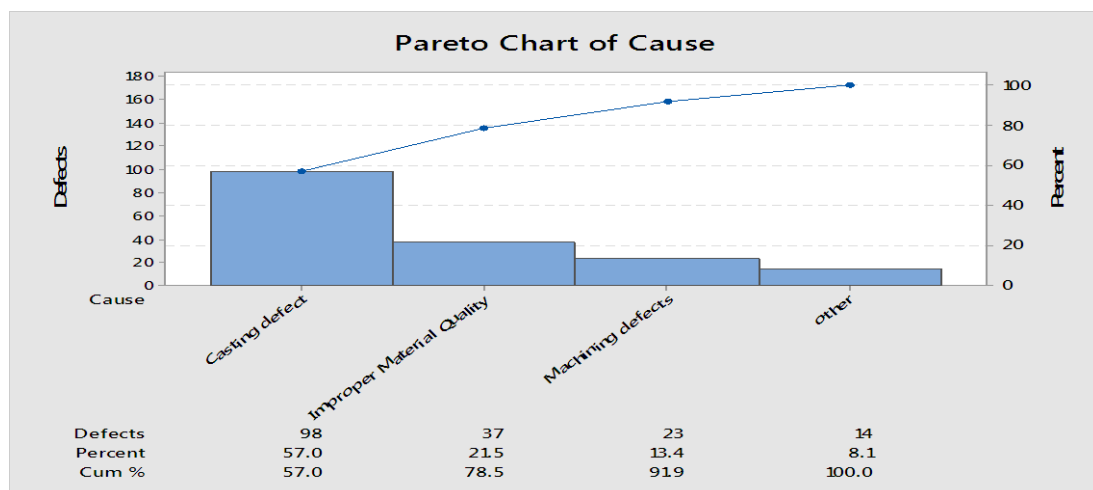


Figure 7: Pareto Chart for cause of Defects

By ordering the bars from largest to smallest, a Pareto chart can help you separate the “vital few” from the “trivial many”. These charts reveal where the largest gains can be made.

In define phase, we define the main problem which is required to be solve. There are many problems shown in cause and effect diagram but effect frequency can't calculate so to know main problem which cause most in all of them we need to analysis them one by one and to do so Pareto chart is suitable.

In this study analyzed different type of causes result defect in 1761 parts during 15 days for define phase

6.2 Measure Phase

This is accomplished by making measurements and collecting data from current state of Manufacturing Process in Janta Foundry and Repairing Works. This step is a little more time-consuming as compared to the Define phase of the six sigma methodology. This phase will clearly shows parameters that will be used to measure performance improvement.

Tools Used:-

1. Time Series Plot
2. Gage R&R Study

1. Time Series Plot

Time series plot is used to compare different type of data with respect of time. When a data calculated in a time manner then we can use time series plot. In time series plot we can analyze different type of cause affect a particular work.

By analyzing Pareto chart it is clear that the main cause is in casting. To calculate problem and to know by this problem came, time series plot is necessary

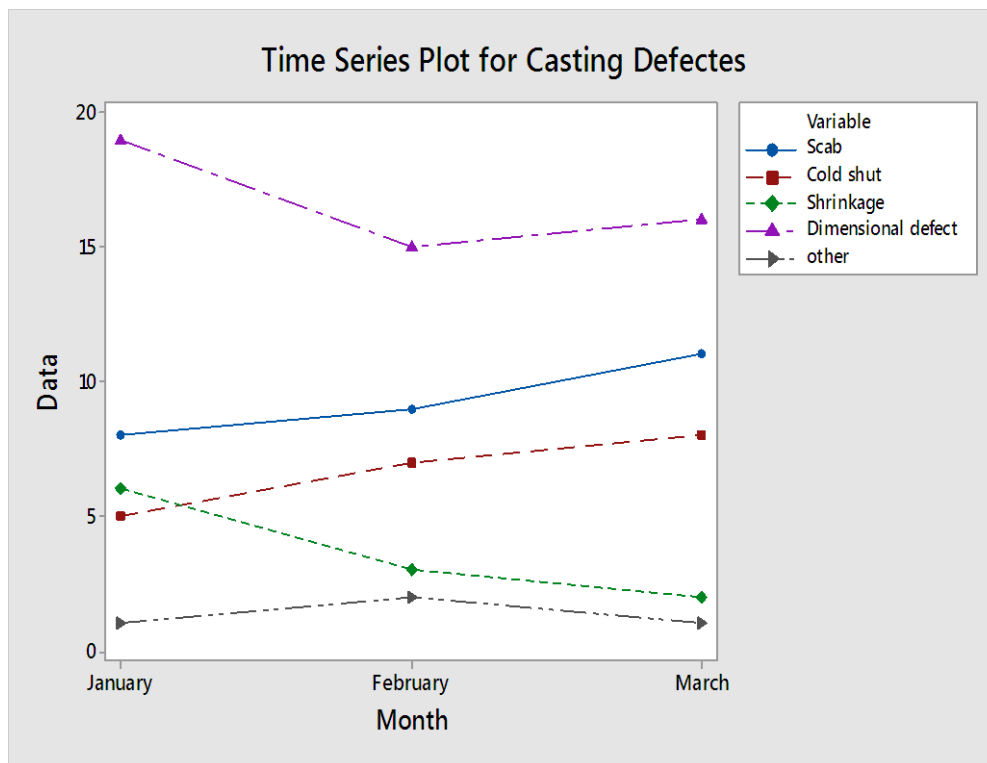


Figure 8: Time series plot for casting defects

2. Gage R&R Study:-

As shown above, most defective parts have any dimensional problem. The purpose of Gauge R&R study is to ensure that the measurement system is statistically sound. Gauge repeatability and reproducibility studies shows that how much of the observed process variation is due to measurement system variation.

In Janta foundry a special type of gear needs to a combine machine repairing workshop. They give a pattern and some important dimensions. One of the main dimensions is internal diameter. Accurate diameter required is 4.6 cm with an allowance $\pm .05$ cm. we done a measurement test with help of Gage R&R study. Two operators take two trials on each gear.

Table 1: Readings of Internal Diameter of 10 Gears by 2 Operators

Seq. No.	Operator	Trial	gear	Readings (Diameter, cm)	Seq. No.	Operator	Trial	gear	Readings (Diameter, cm)
1	1	1	4	4.62	21	2	1	4	4.63
2	1	1	3	4.64	22	2	1	5	4.60
3	1	1	8	4.68	23	2	1	2	4.56
4	1	1	7	4.69	24	2	1	9	4.57
5	1	1	2	4.54	25	2	1	8	4.65
6	1	1	5	4.58	26	2	1	1	4.61
7	1	1	1	4.61	27	2	1	7	4.67
8	1	1	6	4.60	28	2	1	3	4.66
9	1	1	9	4.57	29	2	1	6	4.57
10	1	1	10	4.67	30	2	1	10	4.68
11	1	2	9	4.56	31	2	2	7	4.68
12	1	2	7	4.69	32	2	2	2	4.53
13	1	2	3	4.63	33	2	2	3	4.65
14	1	2	8	4.67	34	2	2	9	4.58
15	1	2	10	4.69	35	2	2	6	4.59
16	1	2	4	4.60	36	2	2	4	4.61
17	1	2	6	4.58	37	2	2	1	4.60
18	1	2	1	4.62	38	2	2	8	4.66
19	1	2	2	4.55	39	2	2	5	4.59
20	1	2	5	4.58	40	2	2	10	4.69

Table 2: Gage R&R Result

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0113297	0.067978	23.00	0.68
Repeatability	0.0113297	0.067978	23.00	0.68
Reproducibility	0.0000000	0.000000	0.00	0.00
Operator	0.0000000	0.000000	0.00	0.00
Part-To-Part	0.0479459	0.287676	97.32	2.88
Total Variation	0.0492664	0.295598	100.00	2.96

This result shows that gages are in right condition. Present study variation in result is 23 % and is lower than 30% which means the gages are in good condition so no need to change them

6.3 Analysis Phase:-

Analyze the system to identify ways to eliminate the gap between the current performance of the system or process and the desired goal. In this phase, an action plan is created to close the 'gap' between how things currently work and how the organization would like them to work in order to meet the goals for a particular product or service.

Tools used:-

1. Process Capability Test: - It is a graph that compares the output reading with required output. It is a main analysis tool. A frequency curve compares overall frequency and within frequency. Target point shows the required frequency point of readings.

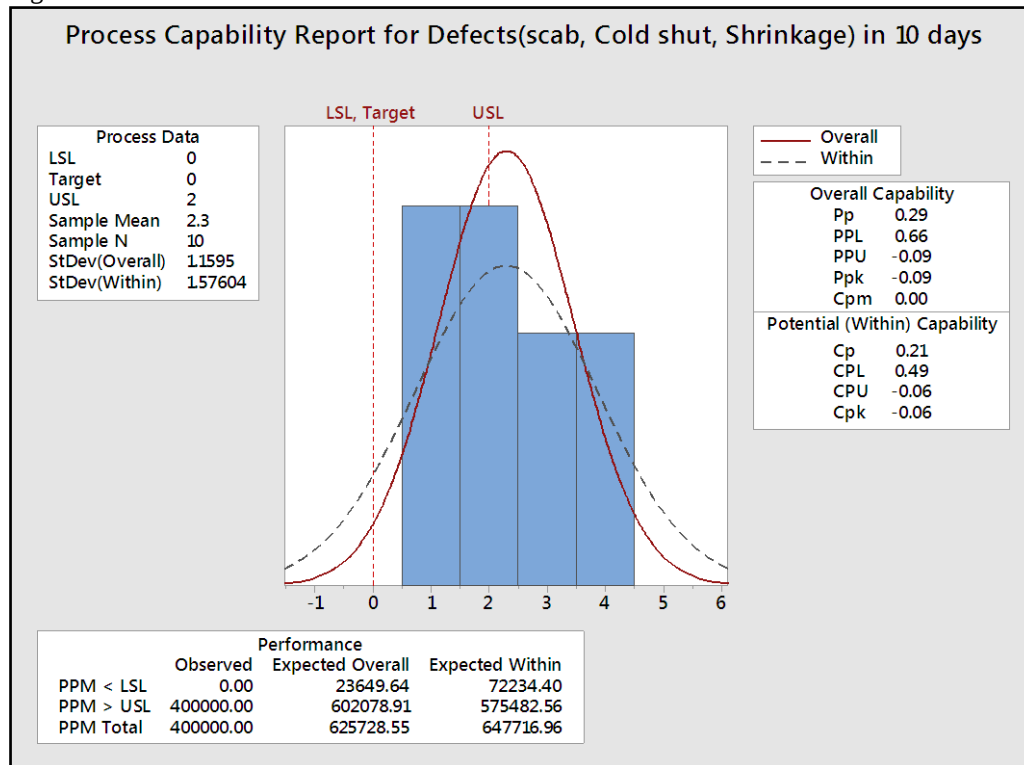


Figure 9: Process Capability Report for all Defects

From this table it is clear that the defects are out of tolerance and needs improvement in the process.

6.4 IMPROVE PHASE

The Improve phase is the fourth step of the DMAIC process is the point where the hard work of defining, measuring and analyzing pays off - the point where the ideas for process improvement are formulated and implemented. Janta Foundry requires many changes and some of them are too expensive but some of them are easy and affordable and has been implemented. These changes are

1. Pattern Material

In Janta foundry pattern is used of same metal as casting. Due to this reason changing in dimension for allowance is very difficult. And manufacturing part is of same size as requirements but machining and polishing allowance is negligible. If a part is defective from surface and allowance is negligible then a single option is to reject it.

Due to these reasons pattern material is changed from metal to wooden. Because wooden pattern can easily improved for different type of allowance and it's easy in handling.

2. Measuring Instrument

In Janta foundry major improvement is done as measuring instruments. In foundry various type of calipers and gages are available but due to lack of knowledge of workers, simple tools were used like steel rule and tape-scale etc. this major problem causes various dimensional problems and important to eliminate it.

To replace calipers with simple scales, first of all workers should have proper knowledge of measuring equipments. So that improvement is start with training of calipers like vernier caliper, outside and inside calipers, height gages and micrometers to workers.

3. Temperature Control

In Janta foundry temperature measuring equipments are not available for high temp (1200°C to 1400°C). So that temp of molten metal is fully dependant on sense of workers.

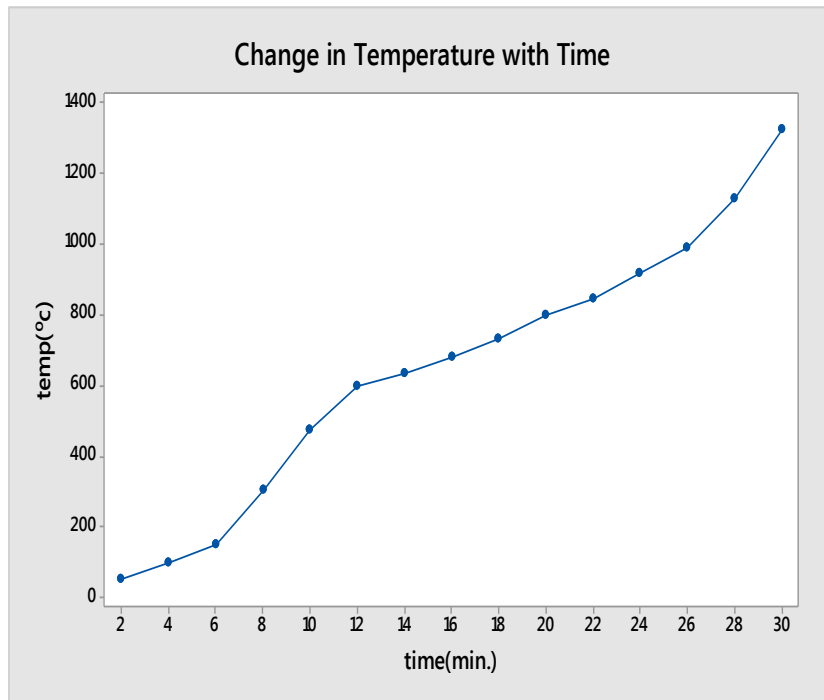


Figure 10: Change in Temp With Respect to Time

Some time due to wrong guess of workers, temperature variations takes place and defects like shrinkage and cold shut arises. To compensate this problem, time and temp relation study is helpful for us.

Oil and air fired furnace with 0.14 H.P air blower and 2 KW electric motor at 2800 rpm and 10:1 air-diesel ratio can produce 1100°C temp in 30 kg metal after a time approximate 27 minutes. To take accurate molten metal pouring temp (1170°C-1200°C), blower is to be off after 29 minutes. After this improvement, more accurate temp of metal is obtained every time

Another thing to improve accuracy in temperature measuring, a rod of same material is used. A long rod of same metal is dipped in molten metal. After required time (29 minutes) rod ejected from molten metal and checked. If it melts completely then operation is stopped otherwise few more time is given to complete melt.

4. Introducing Standard Allowance

After pattern material improvement, it's easy to do some changes in dimension of pattern. To decrease defection of product, allowances must be added in pattern that can easily cutout by machines after casting. For different type of part and product best way is to use standard allowance. In Janta foundry, defects due to surface shrinkage can easily fixed by standard shrinkage allowance.

Table 3: Standard shrinkage allowance

material	dimension	Shrinkage allowance (inch/feet)
Cast iron	Up to 2feet	0.125
	2 feet to 4 feet	0.105
	Over 4 feet	0.083

6.5 CONTROL PHASE

The main objective of the Control stage is to statistically validate that the new process or design meets the objective and benefits sought through the project and well implement and maintain the action items created in improve phase. Determine if additional improvement is necessary to achieve project goal.

Tools used:

1. Control chart :-

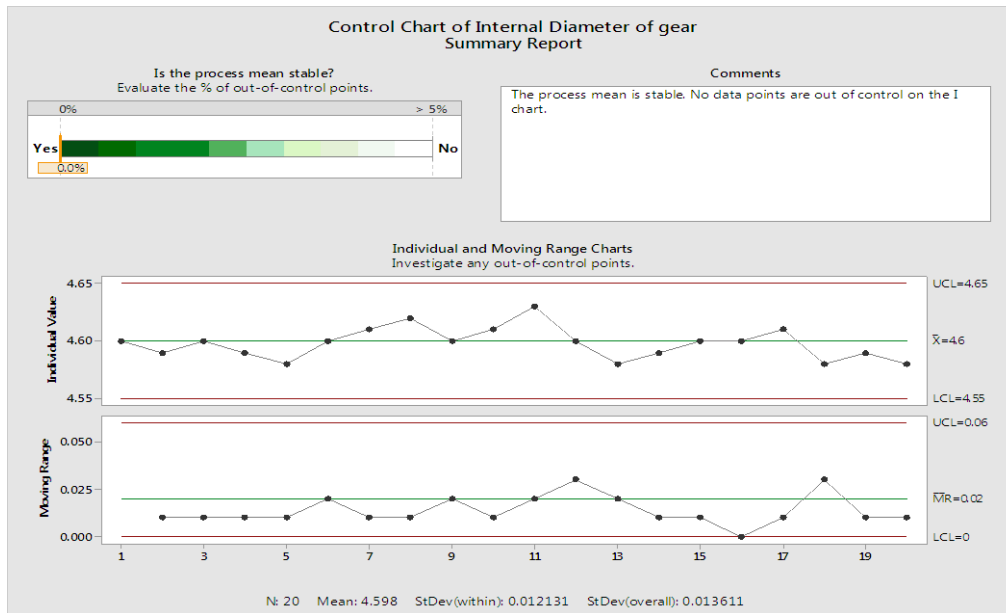


Figure 11: Diameter Control Chart

This control chart shows that after implementing improvements, all dimensions are in control. Graph shows continue decreases in variation of internal diameter of a gear.

7. RESULTS

The Control Chart (fig. 11) shows success of Six Sigma in Janta Foundry. It gives stability to the process so that it works continuously on same quality variables.

Comparison of old data in Janta foundry and data after improvements gives all results and success of Six Sigma. To compare old process and new one different type of tools can be used in Minitab.

7.1 Tools Used:-

1. Before/After Capability Comparison

Data in define phase which is collected in January 2017 gives old data to compare with a data collected in April 2017 after improvement phase. This data is then analyzed in Minitab. As shown in fig, process before improvement was not capable and defects per units was high. After implementing Six Sigma an amazing progress in efficiency takes place. This process is more efficient and defective parts are less than older process.

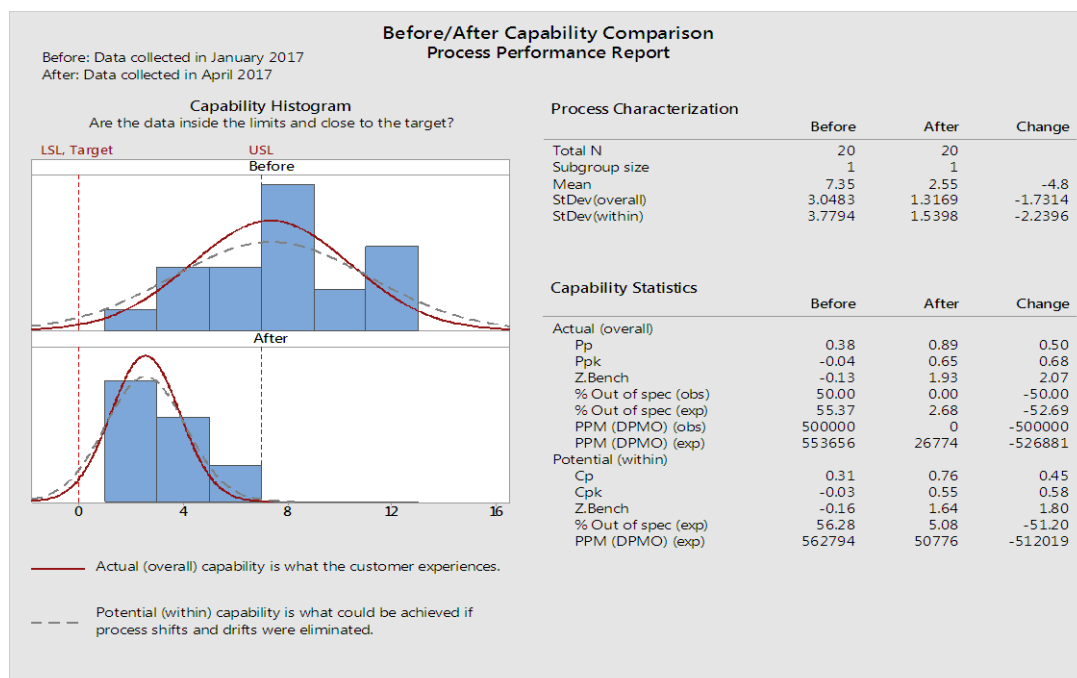


Figure 12: Before and After Capability Comparison

7.2 Improvement in Process Sigma Level:-

1. Before Six Sigma implementation:-

No. of opportunities = 1 million
No. of defects = 97287
% defects = 9.73%
Sigma level = 2.8σ

2. After Six Sigma implementation:-

No. of opportunities = one million
No. of defects = 32882
% defects = 3.29%
Sigma level = 3.37σ

66.14% of decries in defects are achieved by six sigma. After this implementation more than 300,000 rupees extra profit can be gained in this year. Due to increase in quality of product more buyers are attract towards Janta foundry and we can expect much better results after a time. Dimensional error was a main defect before six sigma and only 70 to 72% accurate parts are produced but now 98% to 99% accuracy is achieved in each part after Six Sigma implementation.

8. CONCLUSION

The research conducted in this thesis shows that this work can bring innovation and technology to India. There is also a definite business need for implementing Six Sigma's DMAIC methodology into India, particularly in Indian small scale industry where improvement opportunities in manufacturing are clearly identified. In this research it is clear that a small company having 12 employees can increase its benefit by 72% decrease in dimensional errors, shrinkages and scab is also reduced by 69% and production increased by 8%.

The opportunity at Janta Foundry has clearly indicated that educational level of the employees should be considered while implementing the DMAIC's tools. For example, training has to be given to employees in Janta foundry when it's required to exchange tools with calipers for accurate dimensions. This shows that alternative training approaches should be considered in order to sustain this methodology within an organization, like keeping it simple.

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