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Quality Improvement in Low Pressure Die Casting of Automobile Cylinder Head Using Six Sigma

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***Abstract*: Six Sigma is one of the best developing methodologies for quality confirmation and administration in Automobile parts manufacturing. In this research, Quality management tools such as Data Analysis, Pareto charts, Cause and Effect diagrams, Process capability study, Failure Mode Effect Analysis(FMEA), Design of Experiments(DOE), Visual and Control charts etc. are used in characterizing the problems to discover the underlying drivers for the problems and doing tests so as to propose improvements, through which the organization could acquire quality and soundness all the while. The project will be focused on the quality improvement of major defect in cylinder head which were produced by low pressure die casting machines in an Auto mobile manufacturing company. In this project the main defect cause this rejection is "Misrun" which is observed in low pressure die casting of cylinder head. Using the Six Sigma method the DPMO reduces from 16400 to 7800. Further improvement in the rejection is expected in the long run after the continous implementation of all the solutions.**

***Keywords:* Low Pressure Die, cylinder head, manufacturing company.**

1. INTRODUCTION

Six Sigma is popularly known as a philosophy and methodology that enhances quality by analyzing information with statistics to discover the main cause of quality problems and to execute controls. Statistically, Six Sigma alludes to a procedure in which the range between the mean of a process quality measurement and the nearest specification limit is atleast six times the standard deviation of the process. The statistical goals of Six Sigma are to fixate the procedure on the objective and decrease process variation.

Table 1: Sigma table

Sigma	Defects Per Million	Yield
6	3.4 World Class	100.00%
5	233	99.977
4	6,210.00	99.379
3	66,807.00	93.32
2.5	158,655.00	84.1
2	308,538.00 Non Competitive	69.1
1.5	500,000.00	50
1.4	539828.00	46
1.3	579.260.00	42.1
1.2	617.911.00	38.2

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1.1	655,422.00	34.5
1	691,462.00	30.9
0.5	841,345.00	15.9
0	933,193.00	6.7

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Initially Six Sigma practice was developed considering in view the yield as shown in table 1. This project mainly focused on six sigma quality philosophy that would be implemented in these studies in order to identify the current problem or rejection criteria facing by the company. The "Six Sigma" Philosophy used because, it provides a step-by-step quality improvement Methodology that uses statistical methods to quantify variation.

This paper involves the research on the factors causing rejection of engine cylinder head in two wheeler automobile industry using six sigma methodology.

The main defect found causes this rejection is "Misrun" formed during production of cylinder head on low press die casting machines. In order to study the problem a research has carried out on all LPDC machines and process by study the literature review on TQM, Six Sigma and PDCA philosophies and other reference for this analysis and research method.

2. SIX-SIGMA AS A QUALITY TOOL

In the mean time, latest quality philosphy to be embraced by organizations around the globe is known as "Six Sigma". The "Six Sigma" philosophy is considered to be originated by Mikel Harry (Harry and Schroeder, 2000).The "six sigma" philosphy was efficiently developed and utilized by Mikel Harry with the motorola corporation and the logic has had awesome accomplishment at the GE Corporation (Harry and Schroeder, 2000). Six sigma concentrates on the decrease and expulsion of variation by the utilization of statistical techniques and supporting programming. This intense business administration system has been utilized and improved by numerous world class association, for example, General Electric (GE), Motorola, Honeywell, Toyota, ABB, Sony, to give some examples from the long list. Six sigma utilizations in the service sector are still constrained although it has been embraced by means of many big service orientated agencies such as J P Morgan, American explicit, Lloyds TSB, Egg, metropolis bank, Zurich monetary services, BT, etc. Six sigma today has advanced simply from measurement of quality to an typical business development strategy for a big quantity of corporations around the globe.

The idea of six sigma was presented by Bill Smith in 1986, a senior engineer and researcher inside Motorola's communication division, because of issues connected with high guarantee claims. The accomplishment of the endeavors at Motorola was not simply accomplishing six sigma quality level rather the attention was on lessening rejection rate in procedures through the powerful usage of powerful and practical statistical equipment and. This would prompt enhanced efficiency, enhanced consumer satisfaction, improved nature of administration, lessened expense of operations or expenses of low quality, etc

A process that is in Six-Sigma control will produce no more than 3.4 defects out of every million units. One of the advantages off six-Sigma specuation is that it allows managers to readily describe the overall performance of a procedure in phrases of its variability and to look at different procedures utilizing a typical metric. This metric is defects per million opportunities (DPMO). This calculation requires three portions of information:

- Unit: The object produced or being serviced.
- Disorder: Any item or event that doesn't meet the customer necessities.
- Opportunity: A threat for a defect to occur.

A straightforward calculation is made using the following formula:

$$DPMO = \frac{\textit{Number of defects}}{\textit{Number of opportunities for error per unit x Number of unit}} \times 1{,}000{,}000$$

Sigma level (Z) = $0.8406+\sqrt{\{29.37-2.221\ln(DPMO)\}}$

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3. LITERATURE REVIEW

The new and latest Quality philosophy that was prevailing now a days in organization worldwide is known as "Six Sigma". Six sigma philosophy was considered to be started by Bill Smith a Motorola engineer. Bill Smith developed "six sigma" philosophy and successfully implemented in Motorola corporation that's why he was known as father of six sigma. Dr. Mikel Harry was also a Motorola engineer who was famous as a original frame maker of six sigma. Mikel Harry conducts many researches and developed six sigma models in motorola and in many other companies. The six sigma philosophy also achieved a great success in General Electric corporation. Many other companies as Honda, Sony, Ford etc had make large profit by adopting the "Six Sigma Quality" strategy.

The term "Six Sigma" has its name from a Greek letter sigma (σ). Sigma in statistics signifies "population standard deviation" . Six sigma in statistics suggests six standard deviations of population, which actually shows 99.9999998% of data population in its parametric meaning. The "Six Sigma" quality approach significance must not be dealt with as with its statistical importance yet "Six Sigma" quality approach has its name from a statistics. Six Sigma uses statistical methods and tools to improve quality, to decrease production cost, minimizing waste and rework, furthermore business operations smooth. The "Six Sigma" quality theory has its link with many of prevailing quality philosophies presented by Shewhart, Deming, Juran, Taguchi, and Ishikawa. The "Six Sigma" philosophy stimulates the working of prevailing philosophies by making an organized framework for regular improvement. The "Six Sigma" philosophy differs from prevailing quality philosophies in respect of focusing on financial performance.

Some scholars and writers said that the Six Sigma quality philosophy was started in 1960s. But on checking the historical data, the Six Sigma has its beginning as a measurement standard, the mathematics behind the Six Sigma was given by Carl Fredrick Gauss (1777-1855), he introduces the normal curve which is the starting of Six Sigma. Product variation was measured by using Six Sigma in 1920's, at the point when Walter Shewart gives "Three Sigma" hypotheisis for measurement of variation in output in 1922. He said that the process analyzation was required when output goes beyond three sigma limit. The "Three Sigma" theory gives a yield of 99.73% or can say 2,700 defects per million of output. This three sigma was sufficient for most companies till 1980s. Walter Shewhart introduces the Shewhart Learning and Improvement cycles in statistical analyzation was synchronized with management thoughts. Walter Shewhart cycle has a process of Plan, Do, Study, and Act or PDSA. Many other quality and measurement standards(Process capability ratio, Zero Defects, etc.) were came later, but the term"Six Sigma" was given by Bill Smith a engineer at Motorola corporation. In 1980s, Motorola seens that the measurement standard which they are using was obsolete, they measure defects in thousands of opportunities. A new measurement standard was set up for measuring the defects in per million opportunities thus developed the methodology of six sigma.

The Six Sigma philosophy was extraordinarily effected by the work of Fredrick Taylor, Henry Ford and Walter Shewhart in twentieth century. Motorola vice president Bill Smith, considered as the Father of Six-sigma. The Six Sigma quality initiative in Motorola was observed in 1960s but the actual implementation of six sigma concept was taken in 1980.(Henderson and Evans 2000). Acording to Harry and Schroeder(2000) THE Six Sigma has its starting at Motorola during a management meeting in 1979 when an executive sundry said that "The real problem is that our quality stinks". Sundry's words gives a stimulizer to Motorola and making a important connection between high quality and low production cost. The research in Motorola gives a wonderful result for their organization and a saving of more than $16 Billion was documented.

Fredrick Taylor gave the idea of breaking the systems into subsystems so as the performance of manufacturing process was increased. In Ford automobile company Henry Ford gaves his four points, continuous flow, interchangeable parts, labour division and reducing waste and idle time so as to produce a affordable priced automobile. Walter Shewhart developed the control charts which measures the variation and quality in various manufacturing process.

The Japanese Manufacturing organizations makes a vast change in their quality and manufacturing cost. This was depended on the works of Dr. W. Edwards Deming, Dr. Armand Feigenbaum, and Dr. Joseph M Juran. Dr. W. Edwards Deming proposed the change cycle of 'Plan-Do-Check-Act', famously known as the PDCA cycle. Dr. Joseph M Juran gave their theory of 'Quality Trilogy'. Dr. Armand Feigenbaum gave their concepts of 'Total Quality Control' (TQC). During 1960 and 1980, Japanese companies came to know that all employees in a organization is important for making high quality level so legitimate preparing was must be given to all. Any organization which is working for accomplishing

the six sigma must need to present the ideas of six sigma in its every day upgrades program and in administration choices in order to pick up the consumer satisfaction. Nowadays Six Sigma is the method of performing the business. Numerous Americans pioneers, for instance, Larry Bossidy of Allied Signal (now Honeywell), and Jack Welch of General Electric Company tells others the benefits of six sigma. Honeywell International uses the Six Sigma from early 1990. The Six Sigma was introduced for manufacturing and financial gains. The manufacturing and productivity gains was so high making the Honeywell as a benchmark. The Six Sigma model used by Honeywell was modified and optimized and gain their name as Six Sigma Plus.This new Six Sigma Plus model cares all branches of a business namely, sale and marketing, product design, production, business and planning. Though six sigma was introduced by Motorola but other companies have improved six sigma. Many changes and improvements were introduced in six sigma theory and its implementation expanded from manufacturing sector to service sector. A remarkable point of six sigma is that it can apply to any process and product. In business work as research and development(R&D), sales and marketing, administration and on time delivery process six sigma makes a great impact on work and customer satisfaction. It is a step wise step improvement process in which quantitative data was analyzed using statistical tools and techniques. It uses a heavy data analyzation. Academics and specialists worldwide had great interest in six sigma as directly heavy profits were associated with this technique.

4. THE SIX SIGMA METHODOLOGY

4.1 Introduction:

Six Sigma is a business or engineering management approach that is applied in establishments to drive and also continuously maintain transformational growth in the establishment.The Six Sigma approach focuses on realigning the process, based on the variations-those affect the process outputs- between the expected results and the actual results. The realignment process is done after a series of data collection and data analysis. Statistical process control tools are applied in measuring the variations in the process. Six Sigma acts as an indicator that projects the variations in the process. Once the process variation is determined, quality control tools are used to narrow down the causes that lead to the variations or the effects.

Manufacturing and mechanical engineering principles are then applied in rectifying the errors and improving the process. The basis of Six Sigma methodology is the DMAIC cycle. The DMAIC cycle is a more detailed version of the Deming PDCA cycles, which consists of four steps Plan, Do, Check, and Act within continuous improvement.

4.2 DMAIC Methodology:

4.2.1 Define Phase:

Characterize the project destinations by recognizing customer necessities regularly called "CTQs" "critical to quality", build up a group charter and characterize the process map.

- Identify the procedure or item for enhancement, recognize customers and make an interpretation of the customers needs into CTQs.
- The group charter includes determination of colleagues and characterizing their parts, building up the issue and objective explanations, deciding task scope, setting project turning points and setting up a business case to pick up administration support.
- Develop a effective process map interfacing the customer to the procedure.

The most applicable tools in this phase are the following:

Trend chart, Pareto chart, Process flow chart

4.2.2 Measure Phase:

Measure the current frameworks. Set up substantial and dependable measurements to screen progress towards the project objectives. Customers desires are characterized to decide "out of specification" things.

- Identify and depict the potential critical procedures/items. List and depict the majority of the potential critical procedures acquired from meetings to generate new ideas, historical information, productivity reports, failure investigation reports, examination of line aftermath and model the potential issues.

- Perform measurement framework investigation. Decide exactness, precision, repeatability and reproducibility of every instrument of gage utilized as a part of request to guarantee that they are competent.

The most applicable tools at this phase include the following:

Fishbone diagram, Process mapping, Preliminary Failure Mode and Effect Analysis.

4.2.3 Analyze Phase:

Examine the system to distinguish approaches to dispense with the gap between the present execution of the system or process and the craved objective. In this stage, project groups investigate basic explanations behind rejections. They utilize statistical investigation to look at potential variables influencing the result and try to recognize the most important causes. At that point, they build up an organized causes of components impacting the expected result.

- Isolate and confirm the basic procedures. Tight the potential causes of issues to the key few. Distinguish the relationship between input and output which straight forwardly influences particular issues. Check potential reasons for procedure variability and item issues.

- Perform procedure and measurement framework capacity studies. Distinguish and characterize the restrictions of the procedures. Guarantee that the procedures are equipped for accomplishing their most extreme potential. Recognize and evacuate all variation because of uncommon causes. Figure out what the sensible determinations are. Decide confidence intervals. A procedure is to be viewed as fit when it is in control, unsurprising, and stable.

The most applicable tools for this stage: Correlation/Regression Analysis, Analysis of Variances (ANOVA), FMEA (Failure Mode and Effect Analysis), Hypothesis testing methods, Cause & Effect Matrix.

4.2.4 Improve Phase:

In this stage, project groups look for the ideal arrangement and create and test an arrangement of activity for actualizing and affirming the arrangement.

The procedure is altered and the result is measured to figure out if the updated strategy produces results inside customers desires.

- Apply design of experiments. select the design of experiment elements and levels, plan plans of test execution. peform design of experiment to discover the most huge component.

- Conduct trials for variation reduction. actualize changeless remedial activity for counteracting extraordinary cause variation. show process stability and consistency.

The most applicable tools at this phase are:

Process Mapping, Process Capability Analysis (CpK), DOE (Design of Experiment).

4.2.5 Control Phase:

Control the new framework. Progressing measures are executed to keep the issue structure repeating. Regulate the enhanced system by altering arrangements, strategies, working guidelines and other administration system.

- Specify process control techniques. Set up on-going controls for the procedure taking into account avoidance of special cause variation utilizing statistical procedure control strategies.

- Document the correction procedure. Record every one of the procedures/ventures in correction stage utilizing the decision tree and response plan.

Most applicable tools at the Control phase include:

Control Plans, Statistical Process Control (SPC)charts, Check Sheets

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5. IMPLEMENTATION OF SIX SIGMA FOR LOW PRESSURE DIE CASTING UNIT

5.1 DMAIC - Define stage:

5.1.1. Define the prcess:

Before the process can be investigated, all circumstances have to be defined. Such circumstances are often described as SIPOC (Suppliers, Inputs, Process, Outputs and Customers). The circumstances around the casting of cylinder head are listed in chronological order below.

- Supplier - Material supplier,
- Inputs - Material,Aluminium Ingots,Resin Coated sand
- Process - Receive, Melting, Pouring in crucible of Casting Machines, Casting, Gate Cutting, Heat Treatment, Debburing, Dispatch
- Outputs – Cylinder Head
- Customers – Company Assembly line

5.1.2 Identify the current reject problem:

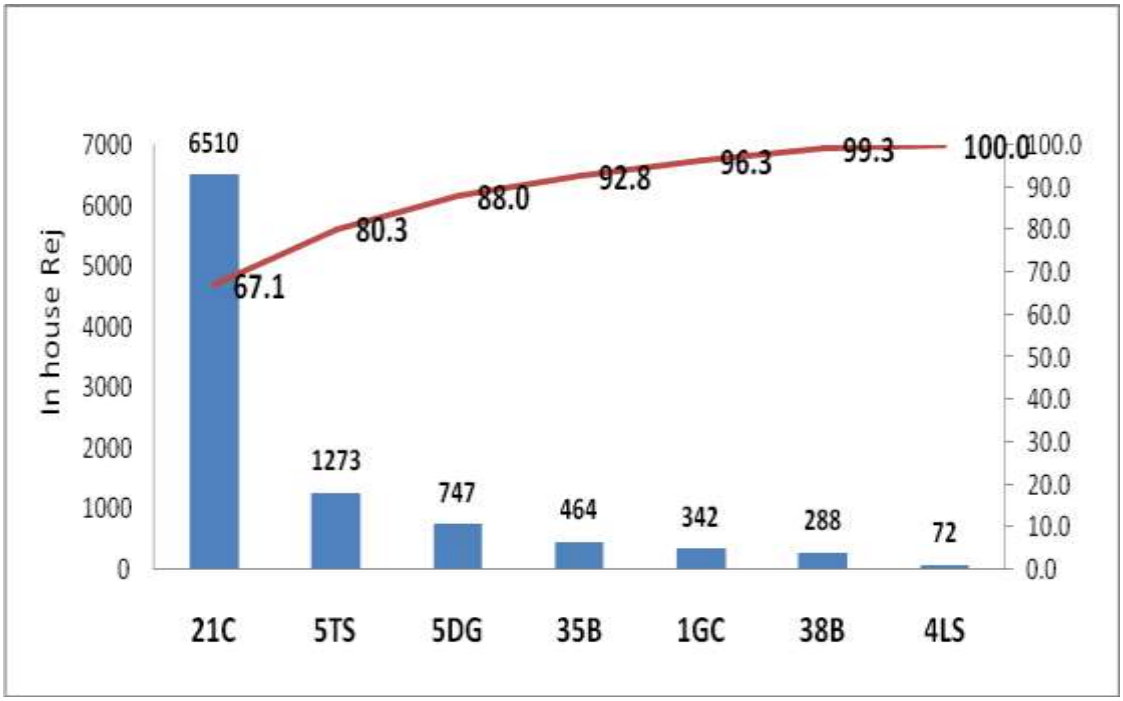

Figure 1: In house Rejection based on Models produced.

. The rejection data of LPDC of cylinder head for the month of December 2013 is shown in Figure.1. On comparing with previous months rejection data this data of December 2013 shows highest rejection. Figure shows that the model named 21C have highest contribution in rejection for the month of December 2013 which is 6510. Model 21C contributes 67.14 percent of total rejection for all models of cylinder head. Model 21C is taken for consideration as it has highest rejection rate.

5.2 DMAIC - Measure stage:

To find out the problem encountered by the model 21C the production line rejection of LPDC machines, six months data was collected from January 2014 to June 2014. In production lines six machines were producing the same model so each machine rejection data was collected. Defect per million opportunities(DPMO) was calculated for each month. The total production, rejection, DPMO and sigma level was shown in Table 2 for month January 2014 to June 2014.

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Table. 2: Total Production (Model 21C) and Sigma Level

MONTH	PROD.	MACHINE (REJECT QUANTITY)						TOTAL REJECTION /MONTH	DPMO	SIGMA
		LPDC 1	LPDC 2	LPDC 3	LPDC 4	LPDC 5	LPDC 6			
JANUARY	60000	1250	1245	1290	695	250	190	4920	16400	3.6379
FEBRUARY	75000	1400	1230	1050	760	450	210	5100	13600	3.7112
MARCH	66000	865	855	770	564	330	180	3564	10800	3.799
APRIL	62000	750	585	635	355	330	135	2790	9000	3.866
MAY	72000	806	685	615	465	318	135	3024	8400	3.8918
JUNE	78000	455	420	585	635	512	435	3042	7800	3.9187
TOTAL	413000	5526	5020	4945	3474	2190	1285	22440		

5.2.1. Basic steps to Compute Sigma level:

- Identify the CTQ
- Define defect opportunities
- Collect data on defects
- Compute DPMO
- Use Standard formula to arrive at the Sigma level

5.2.2. Formula used to compute Sigma level:

- Total pieces manufactured = P
- Total rejection = R
- Total CTQ = O
- Defect per unit (DPU) = R/P
- DPO = DPU/CTQ
- DPMO = DPO x 10^6
- Sigma level (Z) = $0.8406+\sqrt{\{29.37-2.221\ \text{In(DPMO)}\}}$

5.2.3. Computed Sigma level for January 2014

- Total pieces manufactured, P = 60000
- Total rejection R = 4920
- Total CTQ O = 5
- DPU R/P = 0.082
- DPO DPU/CTQ = 0.0164
- DPMO DPO x 10^6= 16400
- Sigma level $\sigma = 0.8406+\sqrt{\{29.37-2.221\ \text{In}(16400)\}}$ = 3.6379

5.3 DMAIC - Analyze stage:

Figure.2 shows the Pareto diagram for the defect type data for the month January 2014. These defects are of common types normally occurs on casting parts. Figure explains that Misrun defect are major contributor for rejection rate for

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month January 2014 which contributes almost 24 percent of total rejects. It is also noticed that LP3 machine contributes highest misrun defect. LP3 will be used to analyze root cause for misrun defect.

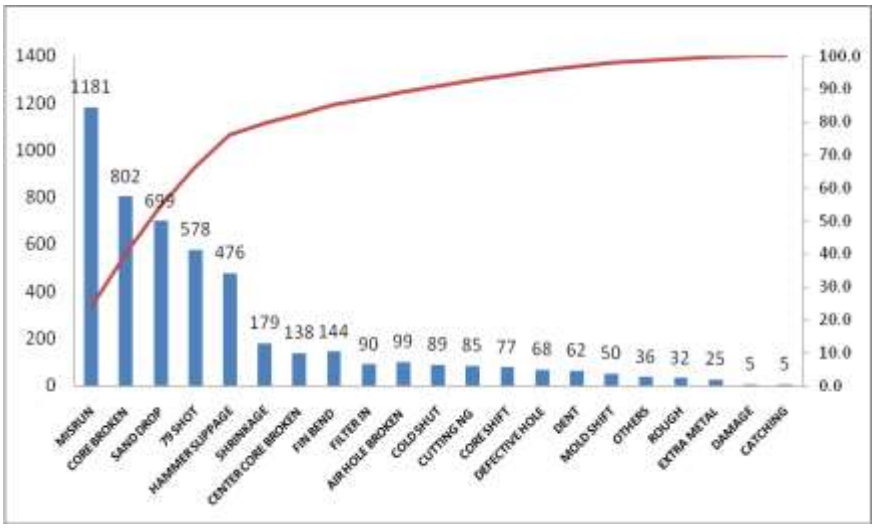

Figure: 2: Rejection data (defect wise) for the month Jan 2014

Figure: 3: Cylinder Head with Misrun Defect

5.3.1 Root cause analysis for Misrun defect:

Any wrong part production was caused by the factors Man, Machine, Material, Method and Enviroment.

The Machines contribution in producing misrun defect was high. Machines technical problems or improper machine setting lead to misrun rejection. Example, pressure leakage from crucible furnace air supply area or furnace packing area, pressure leakage from substalk area. Old machines and dies also causes rejections. Proper maintenance was needed in specified time to keep the machines in good working condition.

In man factor comes operators, if they have not sufficient experience or practice they might produce more rejects. Proper and specialized training is required for their good working. New operators must be regularly inspected by their leaders. Example, untrained worker might blow excess air in die which if trapped in die may produce blowholes or cavity, misrun. Unconsistent cycle time make the die cool, which effects the flowability of molten metal and creates voids and misrun.

The wrong working method is also a cause of rejection. It is the operators responsibility to know the right procedure and parameters of working. If operator not follow the right method of working rejections will be more. Example, if operator not blow air in upper mold properly or not removed the sand particles from mold properly there will be a chance of metal leakage and sand drop in casting.

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A good working environment is needed for less rejection in production. A stressfull, boring and long duty hour jobs makes the operator tired. Operator can loose concentration which results in rejection. Proper ventilation of air, proper lighting and making proper and sequential arrangement of machines and raw material produces a good working environment.

Material factor also plays important role in misrun defect. If aluminium alloy chemical composition was not good, it makes the molten metal to cool early or later which directly effects the casting properties of the part.

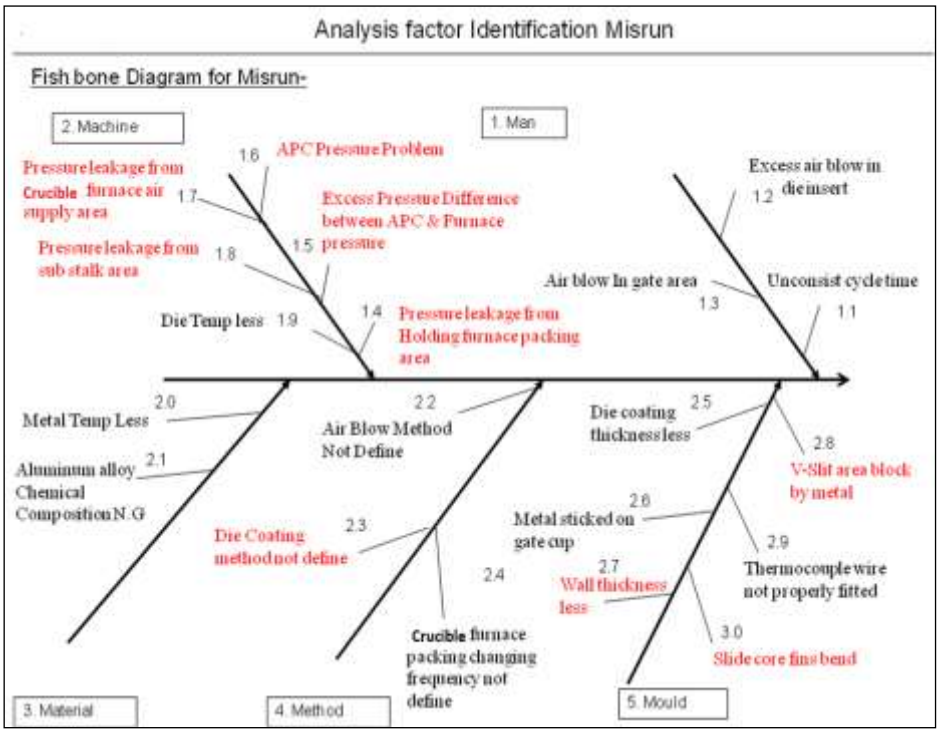

Figure:4: Root cause analysis for misrun

5.4 DMAIC: Improve stage:

On analyzing the six months rejection data, the January month data shows that the misrun defect was the major contributor to rejection in low pressure die casting. After drawing fishbone diagram for misrun defect several causes were identified for this major defect. From this two suggesstions were recommended to reduce defects.

The suggestion were

1. Reducing pressure difference
2. Maintaining Die and Metal Temperature

5.4.1 Reducing Pressure Difference From Crucible Packing:

In low press. Die casting process, there is need of refilling the crucible furnace of machine at every 4 hours. During metal pouring process the moten metal comes from melting furnace. in transfer ladle, which further transfer the metal to metal transfer trolley.

The metal transfer trolley pour the molten metal in crucible furnace of machine. after completion of pouring process the metal transfer trolley were removed from crucible furnace. At every time some molten metal droppen on crucible furnace packing which in turn creates a gap between crucible furnace and its cover which results in pressure loss.

In improving this loss a metal plate is provided on furnace packing to prevent fall of molten metal on furnace packing After pouring this metal plate was removed later this metal plate was named as furnace packing guard plate by the Engineering group

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5.4.2 Maintaining Die Temperature Within Specification:

The favourable Temperature of Die to make a good casting was from 360° C to 450° C. A temperature drop in die makes the flow ability of molten metal poor and molten metal cools rapidly without reaching to all places of mould creating the Misrun . After observation it is seen at time of metal pouring in machine's crucible furnace, the overhead fan was always ON which makes the open die temperature down .The overhead fan must be OFF at the time of pouring process.

Another reason was found which relates defect with man factor. At the time of core setting, the unskilled or new operator can take more time in core setting, or even can break the core which wastes the time and die temperature during this core setting comes down from the specification limit. A proper training was given to the new operators.

5.4.3 Maintaining Metal Temperature:

The molten metal temperature must be within specification limit. In case of removing slag from machine's crucible, unskilled worker takes more time in removing slag. At that time open crucible temperature and molten metal temperature comes down.

The proper knowledge was given to workers for removing slag with in specified time.

Figure 5 shows a run chart that represent the misrun trend after applying the technical improvement of Model 21C for all six machines in different time period of six months.

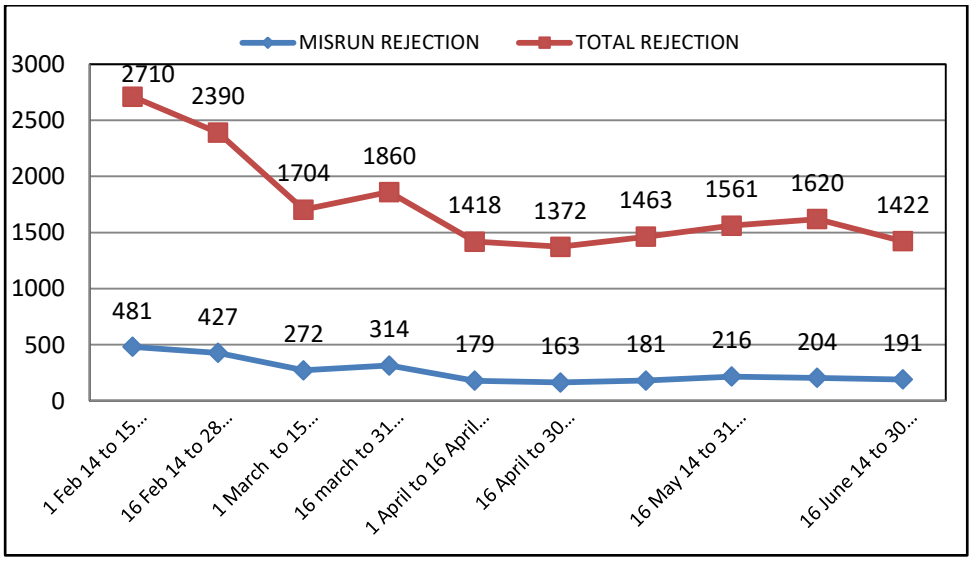

Figure.5: Misrun and total rejection Trend from 1Feb2014 to 30 Jan2014

Figure.6: Improvement in the sigma level

5.5 DMAIC- Control stage:

Control stage is another critical stage before finishing DMAIC philosophies. The control phase of six sigma is used to develop and implement process control plan to ensure sustenance of the improved process. It is to make sure that the process stays in control after the improvement have been implemented. The control phase helps in quickly detecting the out of control state. This stage will describe the steps taken to control. One of the common types of quality tool used is the control chart.

Control charts is another popular statistical process control tools which is used in this stage because it can detect abnormal variation in the process. In this operation we can use c-chart because c-chart can monitors the number of defects per inspection unit. Besides that c-chart also will monitor multiple types of quality in a product.

In this process of enhancing sigma level, control stage assumes a vital role ,as controlling is not for a specific timeperiod it is a continous process in this time of six months improvement and control was adopted simultaneously which enhances the sigma level.

6. RESULT AND CONCLUSION

6.1 Result:

The objectives of this project is to minimize the rejection quantity by applying six sigma methodology in a manufacturing unit. The objectives were successfully met. The suggestions given for the improvement were accepted by the company.

The overall result calculated after this study at low pressure die casting production line:

1. Current sigma level 3.6379 increases to 3.9187.
2. Defects per million opportunities (DPMO) reduces from 16400 to 7800.
3. Current Defect per unit (DPU) reduces from 0.082 to 0.039.
4. Unit quantity passed first time accelerates the rate of improvement.

6.2 Conclusion:

Six sigma is a breakthrough improvement strategy which can help to compete in globalized market. For successful implementation of six sigma company should have to follow correct methodology and steps in order to achieve operational and business excellence. In this case of cylinder head rejection many factors were observed for rejection. The main factors were man and machine factors, on which the study focuses. After implementing the improvements sigma level rises from 3.6379 to 3.9187. There are various other factors also causing rejections. Lack of preventive maintainenace of machines was also observed. As preventive maintainenace is a part of regular practice of every company ,it is not included in the study.

Target of 3.4 defects per million opportunities as per six sigma quality strategy is not easy. Selecting root cause of problem and preventing the reoccurrence of any hinderances, company can achieve this goal. However Japanese have several goals like zero defects etc. and believe that all targets must be ambitious so as to stretch our abilities. Six sigma provides a structured methodology to achieve this goal.

Therefore if Company have sincere approach for purpose they can surely reduce their rejects to this sigma level as per experience in this project regarding six sigma.

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