International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 11, November-2018

Six Sigma Approach for Rejection Analysis in a Bearing Manufacturing Company through DMIAC Methodology: A Case Study

Er. Suresh Tiwari* & Dr. P. Sudhakar Rao**

*M.Tech. Scholar, Department of Mechanical Engineering, NITTTR, Chandigarh-160019
**Assistant Professor, Department of Mechanical Engineering, NITTTR, Chandigarh-160019

Abstract—This paper presents a Six Sigma approach undertaken within a needle bearing manufacturing company, by reducing rejection rate of assembly line and improvement in overall sigma level of bearing production with identification of different rejection criteria and reduction of cost of poor quality. The objectives accomplished by the application of Six Sigma approach to quality enhancement research work in the particular needle bearing manufacturing industry. Paper presents Six Sigma approach through five different phases: Define, Measure, Analyze, Improve, and Control (DMAIC). Some of the major findings while carrying out Six Sigma DMAIC tools and methodology on the assembly line of the company was: 1. the vital reason of the rejection of the bearing was due to needle missing from the bearings which is mainly due to loose pocket of welded cage. After repeatedly brainstorming session and applying DOE(Design of Experiment – L8 Orthogonal array), it is found that the reason is related to cage used in bearing. One more interesting finding was related to pocket where butt welding done where defect occurs more frequently. Hence, issues related to production of cage were minutely examined through DMAIC principle and sigma level of assembly line got improved. Six sigma tools used during the research work are SIPOC diagram, Measurement system analysis, Process mapping with identification of KPIV'S and KPOV'S, Current process sigma level, Pareto chart, Cause and effect diagram with cause validation table, Capability analysis, Control charts, DOE, Failure mode effect analysis(FMEA). This research work promotes the importance of six sigma and its application in the present day competitive manufacturing scenario. On the basis of one year data taken and one month after the research work, Increase in sigma level of assembly line was observed. This research work propose in exploring and providing a more clear view on an ongoing problem in the process of welded cage production and a suitable temporary solution was provided with a permanent long-term solution also proposed.

Keywords — DMAIC, Capability index, Sigma level. DOE, FMEA

1. INTRODUCTION

The word "Sigma" is a statistical term that informs us the current process of system is how mush lagging from almost perfect system i.e. from defect level 3.4 DPMO. It is a data based systematic system for achieving, maintaining and maximizing productivity which results business success. The basis of Six Sigma is a thorough knowledge of customer requirements i.e. what a customer actually wants for the product he is purchasing, disciplined use of facts and collected objective data, analysis by using statistical methods and ongoing efforts focused on optimizing production processes. Six Sigma revolves around a few key concepts:

- Critical to Quality: Attributes which is most important to the customer.

- Defect: The expectation of customer which is not fulfilled.

- Process Capability : The level of delivery by current process.

- Variation: What a the customer sees and feels about purchased product.

- Stable Operations: Ensuring an improved i.e. modified operation which is consistent and able to predict the process well before in time with respect to customer expectations. (1-3).

Six Sigma at many manufacturing organizations simply means a measure of quality that strives minimum rejection for achieving near perfection in that particular process. It is a well disciplined, data-driven approach and methodology for eliminating defects from manufacturing to achieve customer satisfaction from product to service. Six Sigma is a new, emerging, approach to quality assurance and quality management with emphasis on continuous quality improvements. The main goal of this approach is reaching the level of quality and reliability that will satisfy and even exceed demands and expectations of today's demanding customer. For the point of view of statistical representation, the Six Sigma describes level of quantitatively, means how a current process is performing. To achieve Six Sigma level , a process must capable enough to produce not more than 3.4 defects per million opportunities. A Six Sigma defect can be defined as anything which is not require to the customer specifications (4-6). A Six Sigma opportunity is then the total number of chances which results defective products. The automotive company, where research carried out uses other quality techniques but six sigma is not that popularized and is not being used. Now coming to the research work description, the research work strictly follows DMAIC Methodology as it divides the research work into five phases (Define, Measure, Analyze, Improve, and Control) which makes the research work systematic & at the same time easy to accomplish the final goal. The basic idea of Define phase of the research work is to completely understand the Process & target on specific types of defects which occur more frequently than rest of the defects. After narrowing down the area in which team has to focus more, then Begins the analyses phase in which several Brainstorming sessions combined with quality and analytical tools are used to find all the possible variations in the process & their corresponding root causes which may be affecting the quality of bearings, then Cause validation of all the listed potential root cause is done by discussed which will help to counter the problem & accordingly action plans were suggested. In the Control phase, several measures were implemented to ensure that improvement suggested in the action plan is carrying on in its suggested way without any interruptions(7-8).

Six Sigma is primarily implemented in any industries by using two system, one of which is known as DMAIC and another is belt-based training system. DMAIC methodology facilitates the companies to implement six sigma quality improvement system through stepwise five phases namely define, measure, analyze, improve and control. While other methodology i.e. belt-based training system facilitates the development of trained personnel with designations as Champion, Master Black Belt, Black Belt and Green Belt (Zu et al., 2008). While adopting DMAIC is affordable to all companies, implementing belt-based training system is so expensive that its adoption is affordable only to companies with high financial strength. This is due to the reason that, the original design of Six Sigma concept that emanated in Motorola and GE stipulates the spending of high amount of money for developing belt training system by appointing trainers and using costly infrastructure to train Six Sigma project team members (9-10). This is not only unaffordable to small size companies, but also, not economical from the point of view of the payback. In this context, it is observed that, small size companies can be benefited by adopting DMAIC explicitly and belt-based system implicitly. In the context of this observation, this paper reports a research in which DMAIC was applied in a bearing manufacturing company situated in Ranchi City of India.

02. LITERATURE REVIEW

Before beginning the case study reported in this paper, a literature review was conducted to study the research work of various researchers who have used DMAIC as problem solving methodology of Six Sigma principle in various manufacturing as well as service sectors. A search made in this regard in the literature area resulted in the identification of 10 papers reported such researchers.

For implementing DMAIC as problem solving tools all ten paper reporting the application of DMAIC in manufacturing as well service sector were reviewed during the conduct of literature survey being reported here. The researchers reported in these papers are briefly highlighted in this section and their application arenas and key tools and techniques employed during the DMAIC phases are enumerated in Table 1.1

Table 1.1 Application arenas of Six Sigma's DMAIC framework and the tools and techniques employed and their outcomes in manufacturing and service sectors:

Researchers' Name	Application arena	Key tools and techniques employed	Outcomes of research
Kumar & Sosnoski (2009)	Warp in Punches	Brain storming, Process mapping, Fish bone diagram, Histogram, Control Charts	With the help of new fixture warp reduced significantly
Rohini and Mallikarjun (2011)	Operation theatre	Project Charter, Statistical Charts, Fish Bone Diagram, Pareto Chart	Increased OT(Operation Theater) utilization
Prabu et al. (2013)	Submersible pump	Supplier Input Process Output and Customer (SIPOC) chart, Pareto chart, Project charter, Failure Mode Effect Analysis(FMEA), Cause & Effect Diagram, Design Factorial experimentation	Sigma level improved from 3.90 to 3.97.
Sharma and Rao (2014)	Crank shaft manufacturing	Project charter, Cause and effect diagram, Failure mode effect analysis(FMEA), Physical mechanism(PM) analysis for force effect analysis taking various reading of three iterations, Analysis of variation(ANOVA), Statistical quality control (SPC) chart : X and R chart.	Process potential capability index (Cp) value improved from 1.29 to 2.02 and process performance capability index (Cpk) improved from 0.32 to 1.45
Gupta et al (2017)	Tire manufacturing company	Voice of customer(VOC), Calculation of Process capability index (Cpk) by using statistical method with the help of collected data, Ishakawa diagram.	The standard deviation as increased from 2.17 to 1.69, The process performance capability index (Cpk) value was enhanced from 0.94 to 2.66.
Srinivasan et al. (2014)	Tube heat exchanger	CTQ-VOC, Pareto chart, Cause and effect diagram, Brain storming session.	Sigma level improved from 1.34 to 2.01
Srinivasan et al (2014)	Paint line defect	Project charter , VoP - CTQ, Pareto chart, Likert scale analysis(In which questionnaire were asked from 50 related person) Taguchi L27Orthogonal Array , ANOVA	Sigma level increased from 3.31 to 4.3
Srinivasan et al (2016)	Manufacturing of furnace nozzle	Pareto Analysis, Project charter, SIPOC(Supplier-Input-Process-Output-Customer) diagram, Gauge R-R, Cause and Effect Diagram, Tauchi's L9 Orthogonal array method, ANOVA	Sigma level increased from 3.31 to 3.67

Rana & Kausik (2018)	Automotive ancillary unit	SIPOC diagram, Process flow diagram, Root cause analysis by brain storming sessions Paired comparison and Multi variant analysis	Reduced cost of poor quality from Rs 120,000 per month Rs 16,000 per month making the saving of Rs. 1,04,000 per month.
Wijaya et al, (2018)	Shoe soles product	Pareto chart, SIPOC, Cause and effect diagram, FMEA, Delphi method, 5W1H (what, why, who, when, where, how)	The rework process caused manufacturing loss in time of 18.3 days of work and money about 49 million rupiahs were checked after implementing solution found.

2.1 Brief details of methodology adopted in above papers are explained herewith:

Kumar and Sosnoski [11] have applied DMAIC phases to implement Six Sigma concept to reduce the amount of warp that occurred in a company by name Wilson Tools during heat treatment of punches. During the Define phase, 'Pareto analysis' was conducted to identify the problem occurred in the Wilson tools. One of the problems identified was the warpage occurred in punches during heat treatment. Hence, the objective was set to reduce this warpage. During measure phase, 'Process capability analysis' was used to identify whether the process was capable or not. During analysis phase, warp of the process was measured by choosing 100 punches and measuring the same. Mean and standard deviation of warp were identified. Subsequently, 'cause and effect diagram' was used to narrow down the scope of the project to improve the heat treatment process. During the improve phase, process map and cause and effect diagram ere used to identify the action that will lead to the development of the warpage of punches during the heat treatment process. One of the findings of this Improve phase is that, hanging the punches in the fixture resulted in least amount of warp and variations. In order to control the process, the use of histogram and control charts are recommended for the usage. Finally, it is stated that, implementation of DMAIC phases has resulted in the improvement of process and saving of a considerable amount of money.

Rohini and Mallikarjun [12] have described the history of applying Six Sigma in healthcare industry. These authors have reported the case of applying DMAIC in a hospital situation in India. During the define phase, these authors have used project charter and high-level process map to identify the problem. During the measure phase, data on servicing the customers were ensemble. During analysis phase, these data were analysed and causes of deficiencies were depicted using cause and effect diagram. During the improve phase, brainstorming session was conducted to evolve solution for overcoming the problem identified. In order to control the process, supervisory activities were designed. These authors have shown that, after implementing DMAIC phases, Sigma level performance increased from 2.11 to 3.11 (in the case of first delay) and 3.4 (in the case of cancellation).

Prabu et al. [13] investigated the DEMAIC approach in production of submersible pumps. During the define phase, it is found that , a component by name stage casing of submersible pump was identified to have potential for overcoming many defects. By using Pareto chart it is found that casing defects and ovality play major roles in producing defective stage casing components and project charter chart is formed for the defect of ovality. In measure phase data of 750 units were examined and present sigma level was calculated. In analysis phase failure Mode effect analysis (FMEA) and cause and effect diagram reveled three main causes of defect. In improvement phase three reasons were considered to design factorial experimentation and best factors and levels for obtaining least ovality were found and special devices were designed to prevent ovality in stage casing unit. In control phase, it is suggested to use designed chuck. By using only DMAIC approach sigma level improved from 3.90 to 3.97.

Sharma and Rao [14] reported a case study related to process capability improvement of an crankshaft manufacturing process through DMAIC methodology. In define phase, stub end hole diameter was selected as critical to quality (CTQ) characteristics from functional and manufacturing point of view since timing belt pulley is located onto this hole and hence any variation in size of hole leads to incorrect timing of fuel combustion within the cylinder causing detonation and knocking.

In measuring phase, data of 900 components were collected for a period of 4 weeks in 3 iterations. While analysis stratum Process potential capability index (C_p) and Process performance capability index (C_{pk}) were calculated for all three iterations. Also root cause analysis was done with the help of cause and effect diagram, physical mechanism analysis and failure mode effect analysis (FMEA) followed by ANOVA for the iterations of data sets .

The predominate cause identified are worn out cutting tool inserts, worn out insert setting, v – block and non calibration of varnier caliper and tool setting mandrel. Finally by eliminating the causes one by one the C_p and C_{pk} values improved. For control phase the statistical process control chart i..e X-bar and R-bar control chart were implemented for monitoring the process. As a part of standardization of process some activities to be carried out were proposed.

Gupta et al. [15] reported a case study in which DMAIC was used in tire manufacturing company for decreasing the process variations of bead splice causing wastage of material. The problem was identified through voice of customer in the define step. During measure phase Process capability index (C_{pk}) was measured with the help of MINITAB which was 0.94 i.e. less than 1 showing the process was not capable. For analysis the data control chart were made and for finding the root cause of the problem Ishikawa diagram was used. In improve phase corrective action of the found causes from Ishakawa diagram were implemented and data were collected for calculating improved process capability index (C_{pk}) and fund the value 2.66 which shows that process is capable. To achieve performance of six sigma quality level the steps of DMAIC must be applied periodically, as the control phase recommendation.

Srinivasan et al. [16] reported case study related to enhancement of effectiveness of shell and tube heat exchanger through DMAIC methodology. In define phase, the critical to quality (CTQ) parameter was identified as effectiveness in shell and tube heat exchanger through Voice of Customer(VOC) and Pareto chart. In measure phase data collection was done and Pareto chart was constructed for finding severity of each factor. Also current Sigma level was found 1.34 with the help of MINITAB. In analyses phase cause and effect diagram was formed and brainstorming sessions were conducted to indentify major factors. In improve phase idea of introducing the fins over the base tube was found after fierce investigation and hence Sigma level increased from 1.34 to 2.01. In control phase the further improvement in overall efficiency of the furnace are advised to improve various other critical components of the furnace.

Srinivasan et al. [17] reported case study on reduction of paint line defect in shock absorber through Six sigma DMAIC methodology. In define phase Pareto chart, Voice of Business (VOB) and project charter used and found out that pretreatment as the critical stage in the spray paint process. Using Pareto analysis it was found that peel off and blisters are two vital defects that contribute nearly 80% of the total rejection rate in shock absorber manufacturing concern. In measure phase data were gathered and found the current sigma level was 3.31 with the help of MINITAB. In analysis phase cause and effect diagram was formed and Likert scale analysis was done. In Likert scale, the questionnaire was surveyed among 50 persons and customer and found that the cleaning temperature, phosphate P_H and phosphate temperature were most inferential causes. In improvement phase above causes were optimized by Taguchi experimental L37 (L27 means 27 reading were taken) Orthogonal Array(OA) . By using ANOVA optimum parameter were fund as: cleaning temperature - 70^{o}C, phosphate P_H as 3.5 and Phosphate temperature - 60^{o}C. In control phase the optimized data were used and found that improved sigma level 4.5 which was earlier 3.3 and advised to more work in similar manner to reach 3.4 DPMO (Defect per million opportunity).

Srinivasan, et al. [18] reported a case study on implementing DMAIC phases of Si Sigma Program in a furnace manufacturing company. In define phase, the drilling operation was identified as most critical quality factor in furnace nozzle. During measure phase, a sample of 50 furnace nozzle were studied and found that out of 50 nozzle, 07 of them were rejected. In analysis phase rain storming session were conducted and cause and effect diagram was made which revealed four major process responsible variables related to drilling were; 01. Speed, 02. Feed-rate, 03. Drill bit and 04. Tool geometry. Also Sigma value for current level of DPMO 35,000 was found to be 3.31. In improve phase only speed and feed were considered since management did not agree to change drill bit. Accordingly Taguchi L-9 Orthogonal Array experiment were conducted and found that the speed 1800 RPM and feed 0.3 mm /rev. was the optimum parameter for minimizing hole diameter deviation. In Improvement phase, improved Sigma level calculated and found that level increased from 3.31 to .67. In control phase a circular for instruction to the operators and supervisors were issued to run machine at seed 1800 RPM and feed 03. mm/rev.

Rana & Kausik [19] reported case study related to implementation of DMAIC Six Sigma methodology in automotive ancillary unit which was producing Hood latch lock. In define phase the problem “Hood not returning” was identified by voice of customer. In measure phase , the factors which were critical to quality were listed and after that Gauge R& R study were performed to determine whether the tools used were working properly or not. In analyses phase, root cause analysis was done and brain storming sessions were held and list of suspected source and causes of rejection was prepared for analyzing one by one. Then experiment Paired comparison and Multi variant analysis was applied and found that thickness of washer which was varying from cavity to cavity was causing main problem. During improvement phase, the tolerance of washer thickness was revised. During improvement phase the tolerance of washer thickness was revised and accordingly the mold was corrected. After the improvement phase, the results had shown a high improvement and cost of poor quality reduced significantly from Rs 120,000 per month to Rs 16,000 per month. In control phase a control plan for the mold tool was prepared to keep a check on the variation in washer thickness.

Athalia et al. [20] reported a case study for improving quality of shoe soles using DMAIC methodology. In define phase , the target was fixed to reduce the number of specific rejections of shoe soles. Also Pareto chart, brainstorming session and Delphi method to the expert of the manufacture were also used for finding out Critical to Quality (CTQ) factor such as (a). raw material, (b) operator, (c) press machine and (d) procedure some critical actors that caused the rejection cases, In measure phase process capability and sigma level were computed. In analysis phase brainstorming session for 4 round was done to identify critical factors responsible for rejection. Then fish bone diagram was formed and accordingly failure mode effect analysis (FMEA) was applied to rank between root causes and cause with high Risk Priority Number (RPN) were selected to be tackled. In improve phase 5WIH(what, why, who, when, where, how) were implemented to found out following solution; (a) hanging self modification, (b) pantone colour book , (c) drawing pedestrian line at rubber compound department,(d) make check sheet of pantone colour,(e) buying and using stop watch, and (f) shoe soles mold modification. In control phase ,control mechanism was designed to assure that implementation execution was aligned too the implementation plan and also developed a standardization process to make the solution would be implemented continuously.

3. IMPLEMENTATION OF SIX SIGMA- DMAIC PHASES

3.1 Define phase:

Problem statement: Assembly line at of the needle bearing company produces around 1,00,000 number of particular type of bearing(Having OD 28 mm X ID 22 mm & Width 12 mm) per year apart from various other types and sizes bearings, The Assembly line is well sufficiently fulfilling the demands of bearings although some up 'and down's do occur but most of the time it has managed to deliver conforming products of desired quantity to its customers.. There are three main parts, shell, cage and needle, produced by different lines of company and as required heat treatment of these parts are done in heat treatment section. One of the significant problem which assembly line is facing with a rejection rate of (1480 bearings of this particular type is getting rejected in every 30 working days), total rejected of this bearing last year = 17769 units, and total bearings on which rework is done during last year = 4746. Each defective bearing cost's about Rupees 220 Therefore 1323 Defective quantities has incurred an additional production cost of (Rupees/ year).Adding to this there are total 4746 rework cases with each rework causing cost around Rs.20 and also the Unnecessary waste of valuable ENERGY. The aim is to reduce these defective quantities by 75% to save (Rupees 216000) yearly and At least 50% reduction in rework also. This situation if not brought under control then it may also affect company's long-term goal of saving energy, money, and resources. In the red bin & yellow bin record Company keeps record of top thirteen rejection criteria for the bearing due to line lapse which are:

1. Rotation not OK.
2. Outer diameter rusty.
3. Rotation on Ring not OK.
4. Collet mark on OD.
5. Running tight.
6. Needle Missing.
7. Bottom damage.
8. E.C. (Envolocking Circle) under size
9. Tearing on bottom side.
10. Loose pocket.
11. Face crack.
12. Cage rusty
13. Width size not OK

As the company keeps the record of only top 10 rejection criteria, therefore the scope of this project was limited to targeting only these thirteen particular defects which were arising on the assembly line.The key metric which was used to evaluate the success of the research work were: DPMO (defects per million opportunities), Process yield, %defects, and sigma level (21-23).

SIPOC Diagram with Process flow diagram was also established which summarizes the whole cage manufacturing process and at the same time provides a high level overview of the people who are unfamiliar with the process and also helps to reacquaint people whose familiarity with the process has faded or become out of date several changes in the process with time. From SIPOC it was apparent that supplier to the cage line was store and customer to cage is heat treatment department, Input to cage line is annealed cold rolled strip and output is welded circular cage.

3.2. Measure phase

To measure the current performance level of the assembly line total last year data was collected from red bin and yellow bin file which the company maintains for the top criteria for rejection of bearings.
Sigma Level calculation based on last year data collected from red bin and yellow bin of company before Six Sigma research work:

Total units of bearing DB222812 produced = 980468.

Total no of defects = 17769.

Total opportunity per unit = 13.

Defects per unit = 17769/980468

Defects per opportunity = 17769/ (980468x13)

DPMO = 1394.

% Defects = 1.81.

% Yield = 98.19.

Sigma level = 4.48.

As the aim of the research work is to reduce the total number of defects by 75%, therefore, a number of defects should be not more than 60 per year and the expected sigma level after the research work is > = 4.96.

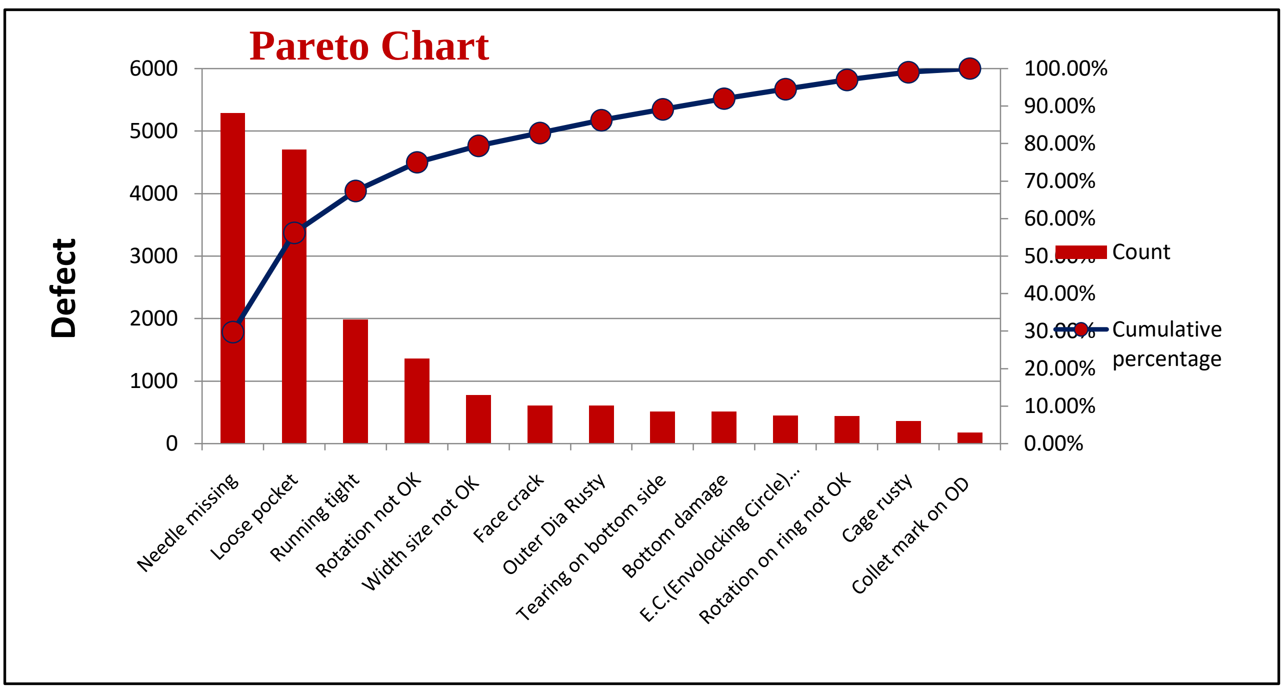

Fig.1.1 Pareto chart of 13 defects.

PARETO chart created (Fig.1.1) based on the data collected from the red bin analysis and from the chart it was observed that out of ten rejection criteria almost 80 % of the rejections were due to only 3 criteria's only. They are:

1. Needle Missing.
2. Loose Pocket.
3. Running Tight.

So as majority of the bearings are termed as defectives due to these three criteria therefore scope of the research work is now narrowed down to tackle only these three criteria's As a result out of 04 sections at the bearing manufacturing line the scope of our research work is narrowed down to only 01 section (welded cage production section) which can contribute directly or indirectly to the selected three defects types. Now a short detailed process chart of the process carried out at stations with their respective KPOV'S and KPIV'S was established (24-25).

Fig. 1.2 WELDED CAGE

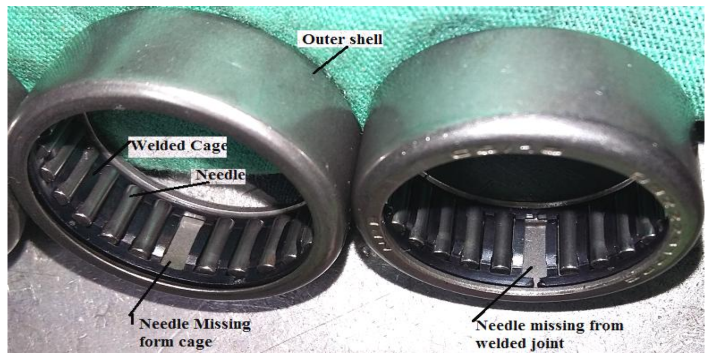

Fig. 1.3 IMAGES OF NEEDLE ROLLER BEARINGS WITH MISSING NEEDLE

04. CONCLUSIONS

The Six Sigma model emerged at Motorola in the 1980's. Thereafter, many papers reporting the applications of Six Sigma in all sectors emerged. While this trend continuous even today, a section of researchers found out that, the belt based training infrastructure of Six Sigma concept is quite expensive. Hence, a few researchers began to apply DMAIC in few sectors. On realizing the new trend of this research, the details of the literature survey presented in this chapter was carried out.

During the conduct of this literature survey, it was discernible that, the application of DMAIC is powerful enough to restrict the companies belonging to manufacturing and service sectors to produce goods and offer services by making mistakes less than 3.4.

In the context of drawing this inference, investigations were conducted while pursuing this work being reported here to examine the enhancement of sigma level performance in consequence to the application of only the DMAIC improvement methodology in needle bearing manufacturing environment.. The efficient operation of needle bearing is influenced by the employment of high quality bearing components. In this background, it is inferred that the application of Six Sigma's DMAIC phases is necessitated to improve the quality of the bearing components. In the context of drawing this inference, the investigations reported in the work were carried out in the case of applying Six Sigma's DMAIC phases in the bearing manufacturing environment.

REFERENCES

[01] B.S. Raghuwanshi, "Workshop Technology", Vol. II , 10th Edition, Dhanpat Rai and Co., 2010.

[02] W.D. Callister, Jr, "Material Science & Engineering: An Introduction", John Wiley & Sons, Inc. Publication.

[03] Kalpakjian and S R Schmid, "Manufacturing Engineering and Technology", 5th Edition, Pearson, 2006.

[04] Indian Statistical Institute, SQC & OR Unit, "Six Siga Grem Belt Programe-Study Material".

[05] Peter S. Pande, Robert P. Neumann, Roland R. Cavanaugh in his book "The Six Sigma way"- How GE, Motorola and other top companies are horning their performance, published by Tata McGraw Hill Co. Ltd, New Delhi.

[06] Subir Chowdhury, "Design For Six Sigma"-The revolutionary process, published by Dearborn trade, a Kaplan professional company, 2002.

[07] David M. Levine's "Statistics For Six Sigma Green belts" published by Darling Kinderley (India) Pvt Ltd- An Imprint of Pearson education, ISBN 81-317-1635-x.

[08] Craig Gygi, Neil DeCarlo and Bruce Williams, "Six sigma for dummies" published by Wiley publishing India Pvt. Ltd., 2006.

[09] Alan Larson, "Demystifying six sigma"- A companywide approach to continuous improvement, published by Jaico publishing house, Mumbai.

[10] Michael L. George, "Lean six sigma": combining six sigma quality with lean speed, published by Tata Mc Graw Hill professionals, 2002.

[11] Kumar, S. and Sosnoski, Michel. (2009) "Reflective practice using DMAIC Six Sigma to stematically improve shop floor production quality and costs", International Journal of Productivity and Performance Management, Vol. 58, No. 3, pp. 254–273.

[12] Rohini, R. and Mallikarjun, J. (2011) "Six Sigma: improving the quality of operation theatre', Procedia – Social and Behavioral Sciences", Vol. 25, pp.273–280.

[13] K.Prabu, J.Makesh, K. Naveen Raj, S.R. Devadasan and R. Murugesh (2013) "Six Sigma implementation through DMAIC: a case study" Int. J. Process Management and Benchmarking, Vol. 3, No. 3, 2013, pp.386–400.

[14] G.V.S.S. Sharma and P.S. Rao "A DMAIC approach for process capability improvement an engine crankshaft manufacturing process" J Ind Eng Int (2014) 10:65 DOI 10.1007/s40092- 014-0065-7 Springerlink.com, pp. 65:01-11.

[15] Vikash Gupta, Rahul Jain, M.L. Meena and G.S. Dangayach . "Six-sigma application in tire manufacturing company: a case Study" J Ind Eng Int DOI 10.1007/s40092-017-0234-6, Spinger, pp.01-10.

[16] K.Srinivasan,S. Muthu,S.R. Devadasan and C. Sugumaran," Enhancing effectiveness of Shell and Tube Heat Exchanger through Six Sigma DMAIC phases", 12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014, pp. 2064- 2071.

[17] K. Srinivasan, S. Muthu, N.K. Prasad and G. Satheesh," Reduction of paint line defects in shock absorber through Six Sigma DMAIC phases", 12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014,pp.1755-1764.

[18] K.Srinivasan, S.Muthu. S.R. Deadasan and C. Sugumaran, Enhancement of sigma level in the manufacturing of furnace nozzle through DMAIC approach of Six Sigma: a case study, Production Planning & Control, 2016 pp.01-13.

[19] Pardeep Rana and Prabhakar Kausik ," Initiatives of six-sigma in an automotive ancillary unit: A case study", Management Science Letters 8 (2018) 569–580,pp.569-580.

[20] Athalia Jesslyn Wijaya, Wildan Trusaji, Muhammad Akbar, Anas Ma'ruf and Dradjad Irianto, "Improving Quality of Shoe Soles Product using Six Sigma", IOP Conf. Series: Materials Science and Engineering 319 (2018), pp.01-06.

[21] NPTEL Module 1, Video Lectures on "Six Sigma" by T.P. Bagchi, IIT Khadagpur

[22] https://en.wikipedia.org/wiki/Six_Sigma

[23] https://www.isixsigma.com/new-to-six-sigma/getting-started/what-six-sigma/

[24] http://www.isixsigma.com

[25] www.exampleCG.com