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Implementation of DMIAC Methodology to Improve Process Capability in Needle Bearing Manufacturing Company: 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 case study done in bearing manufacturing company for improving process capability of cage manufacturing section of the company. This objective is accomplished by the application of DMAIC methodology to quality enhancement research work in the particular needle bearing manufacturing industry. Paper presents Six Sigma approach through five different phases of DMAIC methodology which are: Define, Measure, Analyze, Improve, and Control (DMAIC). For defining critical to quality parameter, rejection data of last one year was taken from red bin kept in rejection area. From the collected data, it is observed that there were ten types of rejection generally occurred while inspection of bearing and as per the count of rejection data Pareto analysis was done. From Pareto analysis it is observed that there were only two main rejections which were responsible for 70% of total rejection. These both rejection types were related to pocket size of bearing only. For the undertaken project SIPOC and ARMI (Approval, Resource, Member, Interested party) diagram was formed to fix responsibility for the project work. Current level of process capability and Sigma level were calculated in measure phase and histogram chart was formed with the help of Minitab software. Then in analyze phase Root cause analysis was done by forming fish bone diagram and accordingly Failure Mode Effect Analysis(FMEA) was done to find out most vital causes for these particular types of rejection. Within analysis phase itself all key process input variable and key process output variables are examined and shown in process flowchart against each step of process. During improvement step, Design of Experiment (L-27 Orthogonal Array) was applied on welding parameters responsible for pocket formation of welding cage. Accordingly ANOVA was used to find out significant parameter for the rejection. To find out other vital issue related to rejection along with their possible solution, brain storming session was arranged consequently some inherent vital issues were came out which later on solved by the company. After implementation of finding of DOE and the brainstorming session it is observed that the process capability of the system was improve and at the same time Sigma level of the process also enhances significantly. Hence this research work shows the importance of Six sigma and its application in various medium scale company through DMAIC methodology.

***Keywords*— DMAIC, Process capability, Fish bone diagram, L-27 Orthogonal array, Sigma level, ANOVA**

1. INTRODUCTION

Almost all manufacturing companies are following various technologies and management models to improve quality level in their manufacturing area and striving to achieve zero defect manufacturing. Such type of system is required as the competition between the company has been increased significantly and customer also wants to purchase only high quality product these days irrespective of cost of product. The need of zero defect manufacturing is increasingly realized worldwide for the purpose of increasing profit and reducing the manufacturing cost also. For achieving zero defect manufacturing, one way is to implement a continuous quality improvement system and for achieving the same, some companies are adopting Six Sigma as the continuous quality improvement model for achieving defect free products.

Six Sigma principle was emerged in the late 1980s by Motorola Company. After that, this principle was popularized and was enhanced by General Electric (GE) which reported achieving zero defect manufacturing on implementing it. The word "Sigma" is a statistical term depicts the current quality level of the manufacturing process i.e. the current process is lagging how much 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. It is based on thorough knowledge of customer requirements i.e. what a customer actually wants for the product he is buying, disciplined use of facts and collected objective data, analysis by using statistical methods and ongoing efforts focused on optimizing production processes. (1-4). Six Sigma revolves around a few key concepts:

- *CTQ (Critical To Quality): the attributes of product which is most important to the customer.*

- *Defect: Cause of rejection of the product.*
- *Process Capability: The delivery capability of the process current in use.*
- *Variation: Various parameters of quality which varies in 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. (5-6).*

Six Sigma is mainly implemented by two types of system, one is through belt- based training system and another is known as DMAIC methodology based system. In belt-based training system, industries develop of trained personnel with designations as Champion, Master Black Belt, Black Belt and Green Belt. On the other hand DMAIC based methodology DMAIC facilitates the companies to carry out Six Sigma projects through five phases namely 1.define, 2.measure, 3.analyse, 4.improve and 5.control. On the other hand belt-based training system facilitates the development Between these two system DMAIC is affordable to all companies but at the same time implementing belt-based training system is too expensive to implement this system by small and medium scale company(7). In the context of above statement, it is observed that, small size companies can be benefited by adopting DMAIC explicitly and belt-based system implicitly (7-10). In the context of this observation, this paper reports a research in which DMAIC was applied in a bearing manufacturing company situated in capital of Jharkhand i.e. in Ranchi City.

2. PHASE WISE DMAIC METHODOLOGY IMPLEMENTATION:

2.1 DEFINE PHASE

As it is the first step of research work, a Six Sigma project charter was formed to detailed critical issue and for solving the problem. The details of received all customer complaint whether it was internal or external were examined, at the same time with the help of assembly in-charge of the company, selection of critical issue which was needle missing during assembly because of oversized pocket was done. One of the mostly produced bearing was selected for study and production and rejection data of last year were collected to examine the extent of issue. Then, Pareto analysis was conducted which again revealed the most critical issue is size of pocket while cage production. Further Supplier-Input-Process-Output-Customer diagram and ARMI worksheet was made for cage production, shown in Fig. 1 and Table 2 respectively.

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

As the company keeps the record of only top 13 rejection criteria, therefore the scope of this project was limited to targeting only these thirteen particular defects which were arising on the assembly line. Details of particular bearing production and rejection were collected and based on month-wise rejection data Pareto analysis was done to fine out most signification issue of production.

PARETO analysis done based on the data collected from the red and yellow bin and from the chart it was observed that out of thirteen rejection criteria almost 60 % of the rejections were due to only 02 criteria's only, which are:

1. Needle Missing, and 2. Loose Pocket.

So as majority of the bearings are termed as defectives due to these two criteria therefore scope of the research work is now narrowed down to tackle only these 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 two defects types and a project charter was developed accordingly as shown in Table 1.

TABLE 1 PROJECT CHARTER

Project objective	**To implement Six sigma quality in needle bearing manufacturing company by using DMAIC methodology**
Problem description	Deviation in pocket size in cage of bearing affects the holding of needle at its positions
VOC	Oversized pocket i.e. width more than 1.96mm (upper limit of size), it allows tilting of needles and also results in missing of needles.
Metrics	Number of customer complains rejection and sigma level.
CTQ parameter	Size of pocket of cage
Six Sigma tools	Pareto chart, SIPOC diagram, cause and effect diagram, FMEA analysis, DOE Orthogonal Array L-27 followed by ANOVA analysis, Brainstorming session.
Expected outcome of the project	Enhancement of Sigma level and reduction of rejection
Six Sigma team member	Head of cage production section, Quality head, Supervisor, Operator and author of the thesis.

As shown in the project charter, the Voice Of Customer (VOC), "oversized pocket" was the reason of needle missing or sometime allows tilting needle at its position makes bearing not fit for its purpose. Thus, six sigma quality project was defined by developing proper project charter.
After developing project charter, Supplier-Input-Process-Output-Customer (SIPOC) diagram for cage production was developed, which can be observed in Fig. 1.

S	I	P	O	C
Suppliers	**Input**	**Process**	**Outputs**	**Customer**
Store of company **(Purchased from strip manufacturing company)**	Cold rolled steel strip of size width X thickness = 9.6 mm X 0.75 mm	Forming → Piercing & Strip cutting → Round forming and welding	Welded cage	Heat treatment department
RESOURCES		**MAJOR PROCESS STEPS**	**CONTROLS**	
04 operators 2 supervisors 1 line in charge, 2 machines.			Training, calibration, maintenance, inspection, monitoring, procedures, instructions	

Fig. 1 SIPOC Diagram

The process involved was forming, punching, cutting in adequate length, and then providing circular shape with the help of forming dies and then welding to give complete cage shape. The forming, punching and round forming dies were responsible for providing size of pocket within limit which was 1.8 mm to 1.96 mm. At the same time the pocket which was welded as the most vital reason for over sized pocket since it depends on various parameters responsible of perfect welding. Hence development of SIPOC diagram provided information that welded pocket area was the Critical To Quality (CTQ) part of pocket formation and the reason of rejection of case and hence it should be subjected to investigation for achieving six sigma level of quality in the case of manufacturing of bearing and for this project the ARMI worksheet is shown in Table 2.

TABLE 2 ARMI WORKSHEET FOR PROJECT

Key Stakeholders	ARMI Worksheet				
	Define	Measure	Analyse	Improve	Control
Plant head (General Manager)	I	I	I	I	I
Departmental In-charge (Production)	A & I	A & I	A & I	A & I	A & I
Departmental In-charge (Quality)	A & I	A & I	A & I	A & I	A & I
Supervisors	I & R	I & R	I & R	I & R	I & R
Machine operators	I & M	I & M	I & M	I & M	I & M
A - Approval of team decisions I.e. sponsor, PROCESS OWNER					
R - Resource to the team, one whose expertise, skills, may be needed on an ad-hoc basis.					
M - Member of team – whose expertise will be needed on a regular basis.					
I -Interested party, one who will need to be kept informed on direction, findings.					

2.2. MEASURE PHASE

During Measure phase the sigma level of production of bearing was calculated by using collected data of rejection and production of last year found that prior to implementation of DEMAIC methodology it was 3.7. Then based on data related to welded cage production process capability level was found with the help of Minitab 17 as shown in Fig. 2.

Required Process Specifications: Mean = 1.88 mm with LSL = 1.80 mm, USL = 1.96 mm.

Current process mean = 1.93 mm

Over all capability:

$P_p = 0.46$ $P_{pk} = 0.16$ $C_p = 0.49$ $C_{pk} = 0.18$

The capability histogram shows that process is normal but the overall process mean is shifted to 1.9312 which is almost near upper specification limit (1.96).

X_{bar} & R chart suggest that process variation is not stable around its shifted mean as shown in Fig. 2.

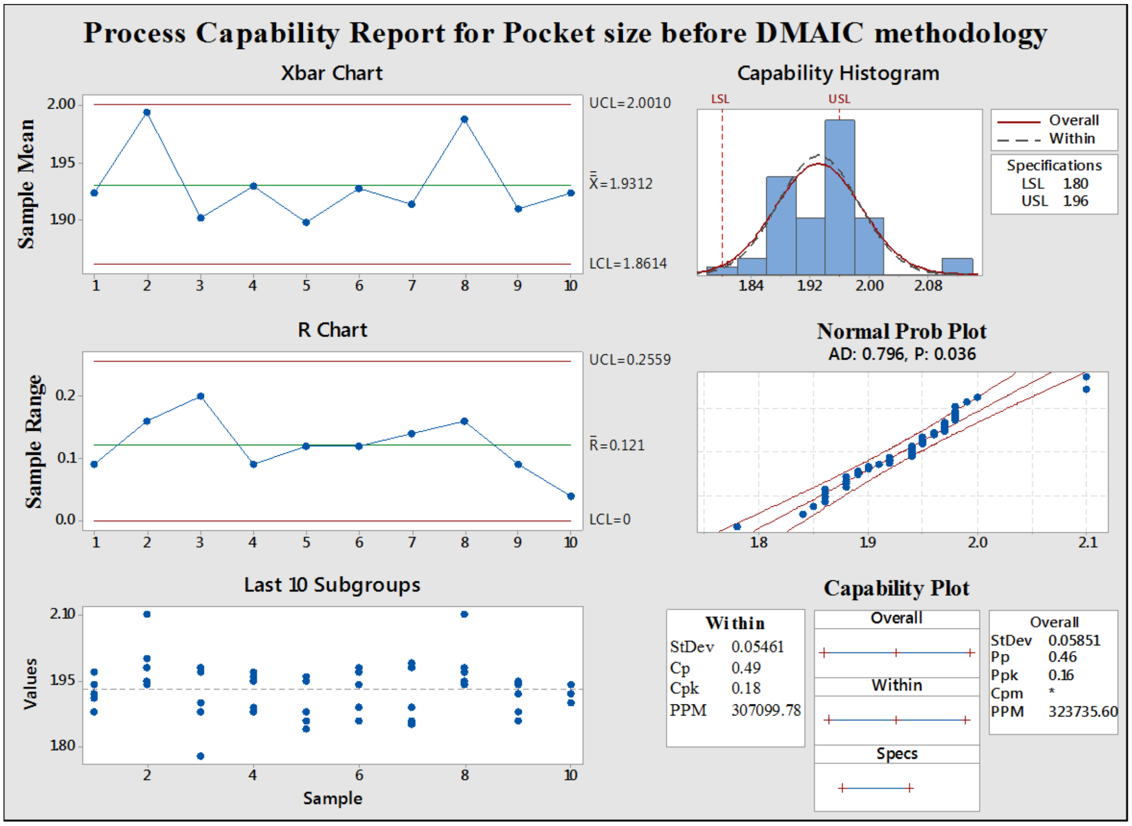


Fig. 2 Process Capability Analysis of Pocket Formation (*BEFORE DMAIC)*

2.3 ANALYSIS PHASE

With the help of the Pareto chart it is found that there were two main cause which were responsible for 70% of rejection. Main root cause among probable causes for rejections are analyzed by using Ishikawa diagram which is some time also called Fish bone diagram to eliminate packet defects (8-9). The prepared cause and effect diagram with reference to man, machine, method and material is shown in Fig. 3.

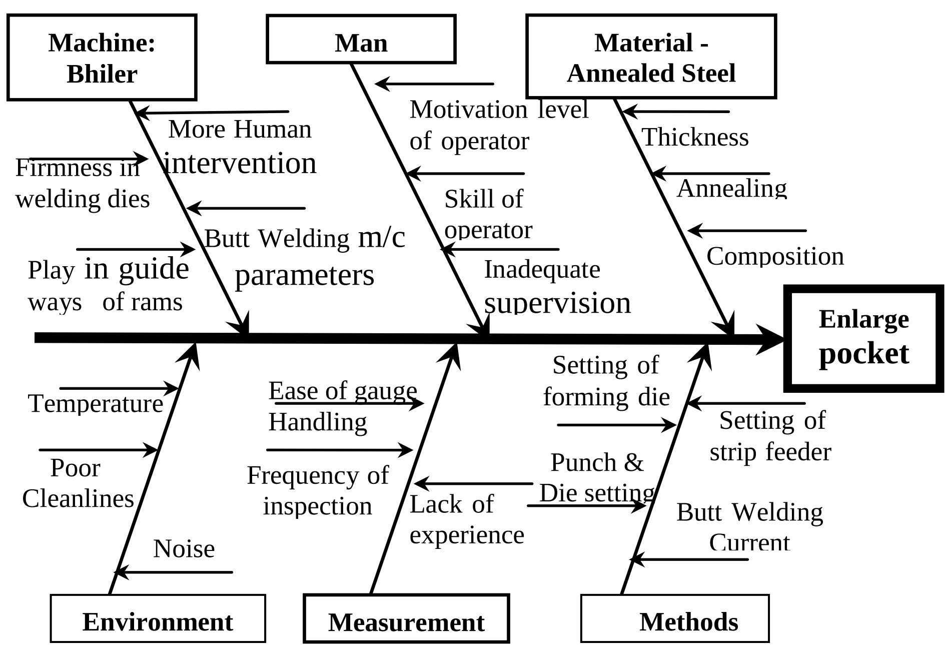


Fig. 3 Cause and Effect Diagram for Enlarge Pocket Size

Based on above shown cause and effect diagram, failure mode and effect analysis as shown in Table 3, was done and it is found welding unit and play in sliding parts are most influential causes for pocket size enlargement.

TABLE 3 FMEA ANALYSES FOR POCKET FORMATION PROCESS

FAILURE MODE AND EFFECTS ANALYSIS						
Item: Welded cage			Type : Process-pocket formation			
Potential Effect of failure	**Process steps**	**Potential failure mode**	**Severity (S) On scale of 1 -5**	**Occurrence (O) On scale of 1 -5**	**Delectability (D) On scale of 1 -5**	**Risk Priority Number (RPN)**
Loose Pocket (Process carried out at cage production machine and round forming unit is mainly responsible)	Inspection of input material parameters	Thickness not OK	**3**	**2**	**4**	**24**
		Not properly annealed	**4**	**2**	**4**	**32**
		Operator not attentive	**2**	**3**	**3**	**18**
	Machine setting	Punch & Die not ground properly	**4**	**2**	**5**	**40**
		Wrong adjustment of punch & Die	**4**	**2**	**4**	**32**
		Operator not attentive	**2**	**3**	**3**	**18**
		Adjustment of forming ram	**4**	**3**	**4**	**48**
		Adjustment of feed	**4**	**2**	**4**	**32**
		Not proper setting of feed length	**5**	**3**	**4**	**48**
		Griping cam not tight	**4**	**2**	**4**	**32**
		Cutting punch of developed length not proper	**4**	**2**	**4**	**32**
		Current and heat setting of welding unit not proper	**4**	**4**	**4**	**64**
	Machining	Sudden power cut	**4**	**2**	**4**	**32**
		Play in sliding part	**5**	**4**	**4**	**80**
		Voltage fluctuation	**4**	**2**	**5**	**40**
	Inspection of product	Inspection not done frequently	**4**	**3**	**4**	**48**
		Inspection gauge not calibrated properly	**5**	**2**	**2**	**20**

2.4 IMPROVE PHASE

As it was clear from Fish Bone Diagram and FMEA analysis that the welding unit was the most prominent cause for pocket enlargement and the parameter of the unit must be chosen properly to get better result. To identify the optimum value of three welding unit parameters, namely current, weld time and squeeze time, six sigma team members participated in brain storming session and team of Six Sigma team members suggested to find out most suitable value of these parameters for this particular cage. Hence, at this juncture, the scope of this investigation was restricted to identifying the best combination of the values of these factors, so as to reduce the pocket size deviation of the cage. In this situation, the Six Sigma team members decided to design and conduct the experiments. After the continuous and through discussion by keeping past experience in view, the levels are revealed as low setting which indicates level – 1, the actual setting as level - 2 and high setting of factors at level -3. The design factors and levels suggested for these experiments are shown in Table 4.

Table 4 FACTORS LEVELS CONSIDERED FOR WELDING PARAMETERS

Factors	Units	Level -1	Level-2	Level-3
Welding current	KA	0.7	0.8	0.9
Weld time	m sec	40	50	60
Squeeze	cycles	2	3	4

The Table 4 shows clearly that there are three factors and levels, which can be solved by construction either L9 or L27 Orthogonal Array (OA), where L represents the level of the trials at the same time 9 and 27 represent the number of trials. Based on the recommendation from six sigma team, the L27 OA has been constructed and experimental outcome of each set of parameter was taken by a dial vernier having least count of 0.01.

Based on outcomes of vernier the S/N ratio were calculated with the help of Minitab software by applying smaller the better characteristics which results in graph shown in Fig. 4.

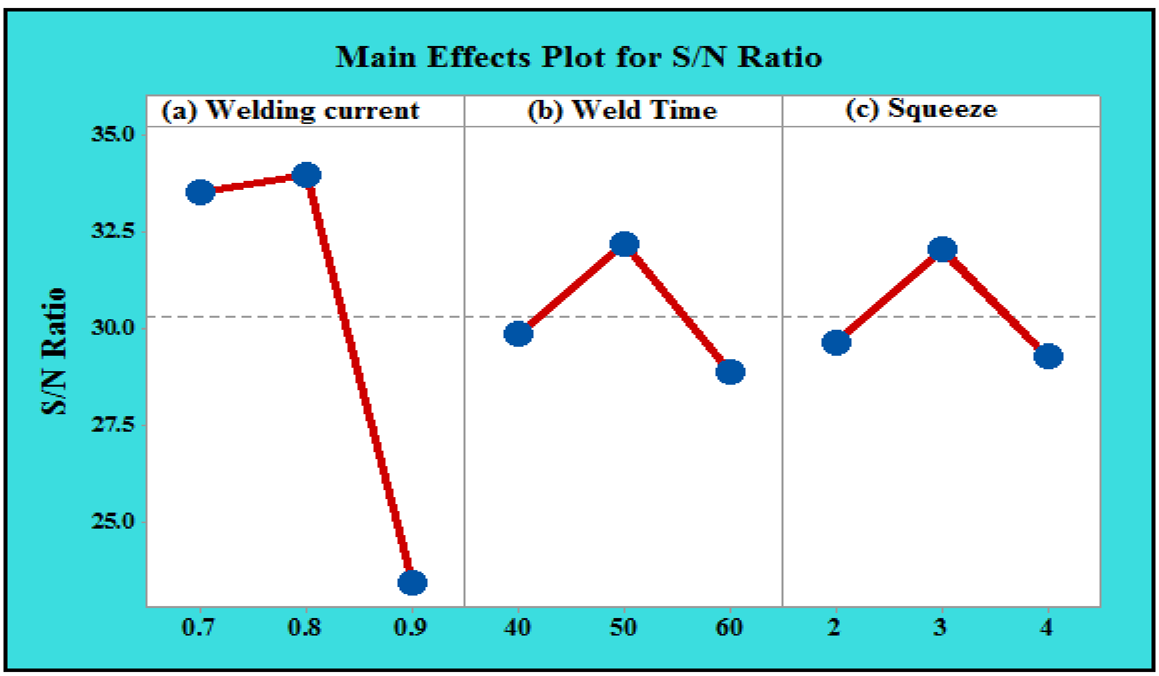


Fig. 4 Response diagram for Welding current, Weld time and Squeeze

Main effect plot for SN ratio shows that the optimal parameter for Welding current, Weld time and Squeeze are 0.8 KA, 50 m sec. and 3 cycles respectively. At the same time graph above revealed that welding current is most important parameter or we can say mostly influential parameter as the slope of the parameter is more than other parameters.

The main objective of the present work was to reduce the variation of pocket width in welding cage. Hence, further rigorous brain storming session for finding out other possible causes were done, first communication done with individual operators, supervisors and related line officers then all were summoned at a particular time and a meeting related to this problem was arranged. During brain storming session for the stated issues related to welded cage, the main reasons which were found for the cage related machine condition were, 01. Top slide of Bhiler machine number-02 was tilting because of play between the mating part and 02. Strip length variation for circular cage formation was also varying because of play in cutting dies (Table 5).

For rectification of the above stated issues, some critical bottleneck was identified and following actions were taken:

TABLE 5 FINDINGS OF BRAIN STORMING SESSION

Description of job	Action taken	Responsibility
01. Bhiler M/c-02 top slide (Rounding) tilting	New slide drawing will be made and parts to be made	Machine shop in-charge and design section in-charge
02. The strip of same width has to be given in machine after segregation.	Inspection of each coil for width started	In-charge of quality
03. Quality inspector should check the products running in the machine	Inspection at Bhiler machine started	In-charge of quality
04. Inspection process should be introduces before heat treatment, as the motive in that to eliminate the problem before heat treatment, as earlier inspection process was after Heat treatment	One inspector to be deployed for welded cage inspection in each shift.	In-charge of quality

3.5 CONTROL PHASE

This phase is carried out to sustain the improvements achieved in the improve phase for implementation of Six sigma methodology. As mentioned in the improvement phase section, the operators are required to set welding parameters welding current at 0.8 kA, weld time at 50 m sec. and squeeze at 3 cycles to get specified size of pocket of welded cage and reduce rejection due to oversize pocket in welded cage.

In order to sustain this implementation, two actions were carried out in the investigation being reported here. First, the lime in-charge is advisees to implement sift-wise statistical quality control chart formation for process out, so that if any process will be going out of control can be detected well advance in time. Besides this, in order to ensure that the knowledge of these levels of factors is exposed in a sustained manner, a chart containing these details was displayed in front of the Bhiler machine. This chart is shown in Fig. 5.

Name of machine : Bhiler

Name o supervisor : XXXXXXX

Operators are requested to produce Bearing Db 222812 at welding parameters shown in table

Welding current	0.8 kA
Welding time	50 m sec
Squeeze	3 cycles

Note: Supervisors are requested to check frequently while operation that the welding unit operates at above shown parameters.

Fig 5 Chart for Welding Parameter

3. RESULTS AND DISCUSSION

3.1 ANALYSIS OF VARIANCE

The analysis of variance (ANOVA) for S/N ratio has been computed in order to investigate the welding parameters which significantly affect the width variation of welded cage pocket. The data for each factor was tested for P value to find significance of each factor. The null hypothesis testing was valid when computed F value was less than standard F value and computed P value was higher than the standard P value, otherwise the factors significantly affects the quality characteristic.

In the present experiment, the standard F value for df1/df2=2/20, is 3.49(form standard table of value "F") and the standard P value was 0.05 for F distribution curve with 95% confidence level. It is evident from the Table 4.4 that:- the computed F values for the welding current (F value 9.74) is higher than standard F value at the same time welding time (F value 0.79) and squeeze (F value 0.62) are lower than standard F (4.76) value and the computed P value of welding current is lower than 0.05 i.e. lower than the standard P value indicating that current significantly affects the pocket width variation, as shown in Table 6.

TABLE 6: ANALYSIS OF VARIANCE FOR S/N RATIO

Source	DF	Adj SS	Adj MS	F	P	Contribution
Welding current	2	319.20	319.20	9.74	0.001	Most Significant
Welding time	2	25.75	25.75	0.79	0.469	Less Significant
Squeeze	2	20.30	20.30	0.62	0.548	Least Significant
Residual Error	20	655.29	32.76			
Total	**26**	**1385.78**				

The final step was to verify the reduction in the defects of cage after implementing the suggested counter-measures. The Taguchi method of design of experiments specifies that level of parameters which has the minimum S/N ratio as the optimum parameter. Therefore the level of process parameters which had the minimum S/N ratio was selected as the optimum process parameter for the final trial tests to verify. The details of rejections production of bearing for two month were considered and the data were put in MINIITAB 17, the achieved improved sigma and process capability level is shown in Figure 6.

3.2 Capability Analysis of pocket size punching operation after implementation of findings.

Data collection plan:

Data is collected in subgroups of size 5 each. Each day 4 subgroups were collected (2 in first half & 2 in second half) for 2.5 days, therefore total number of subgroups collected = 10.

Readings collected = 10 x 5 = 50. Capability analysis is done in Minitab-17 using these data as shown in Fig. 6.

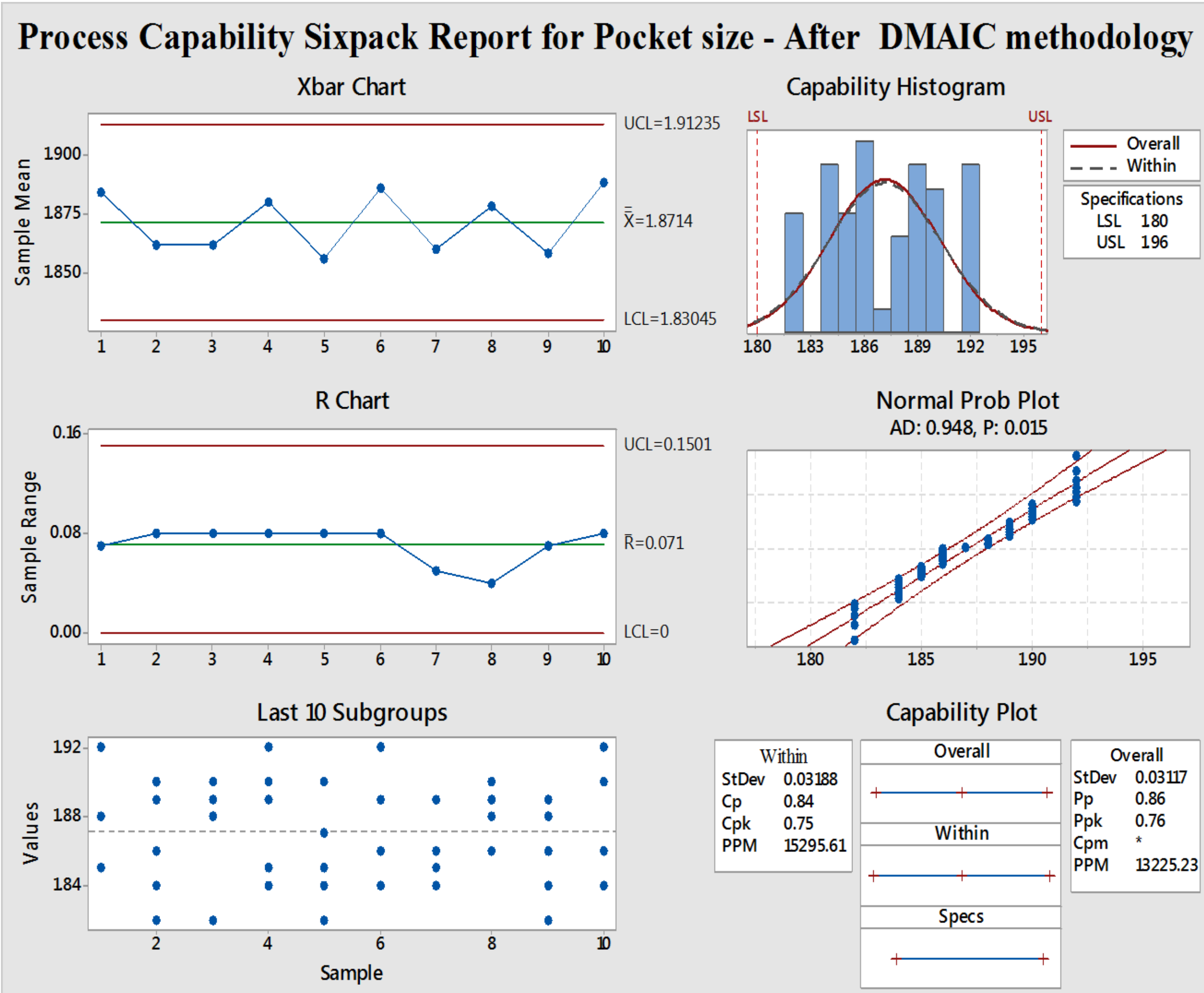
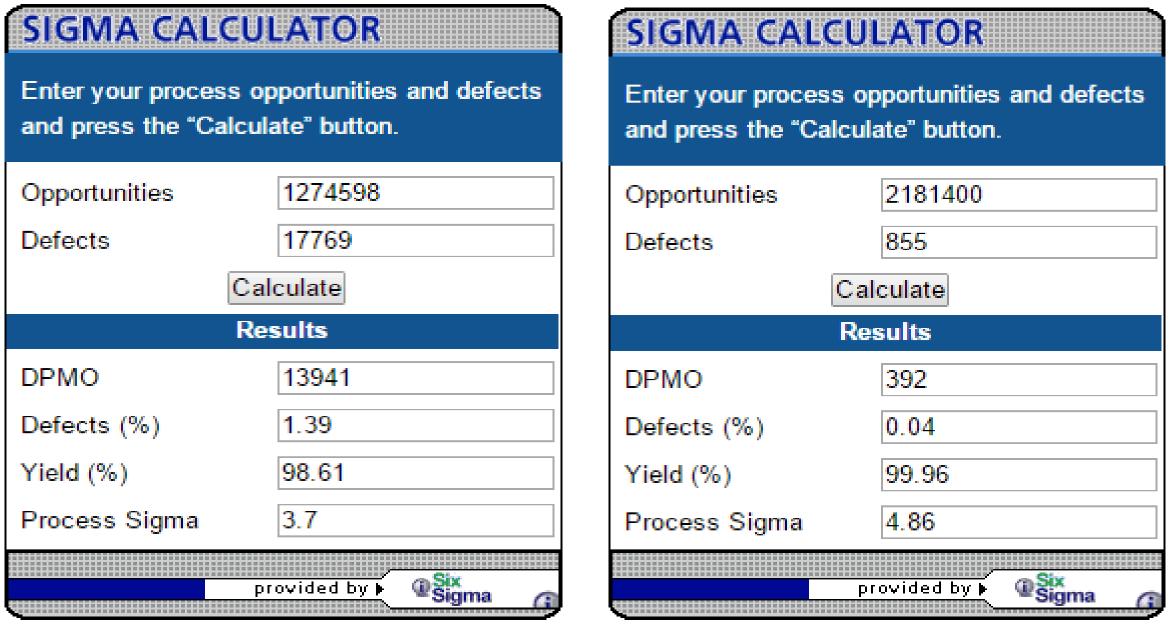


Fig. 6 Process Capability Analysis of Pocket Formation
(AFTER *DMAIC IMPLIMENTATION)*

Required Process Specifications: Mean = 1.88 mm with LSL = 1.80 mm, USL = 1.96 mm.
Current process mean = 1.87
Over all capability:
P_p = 0.86 P_{pk} = 0.76 C_p = 0.84 C_{pk} = 0.75
The capability histogram shows that process is almost normal.
X_{bar} & R chart suggest that process variation is stable around its mean.
Based on two month data related to production and rejection of bearing DB 222812 and calculating the value of modified DPMO as 392, the improved sigma level found was as stated below:

Sigma level corresponding to 392 DPMO = 4.86
i.e. after implement DEMAIC methodology improved Sigma level is 4.86

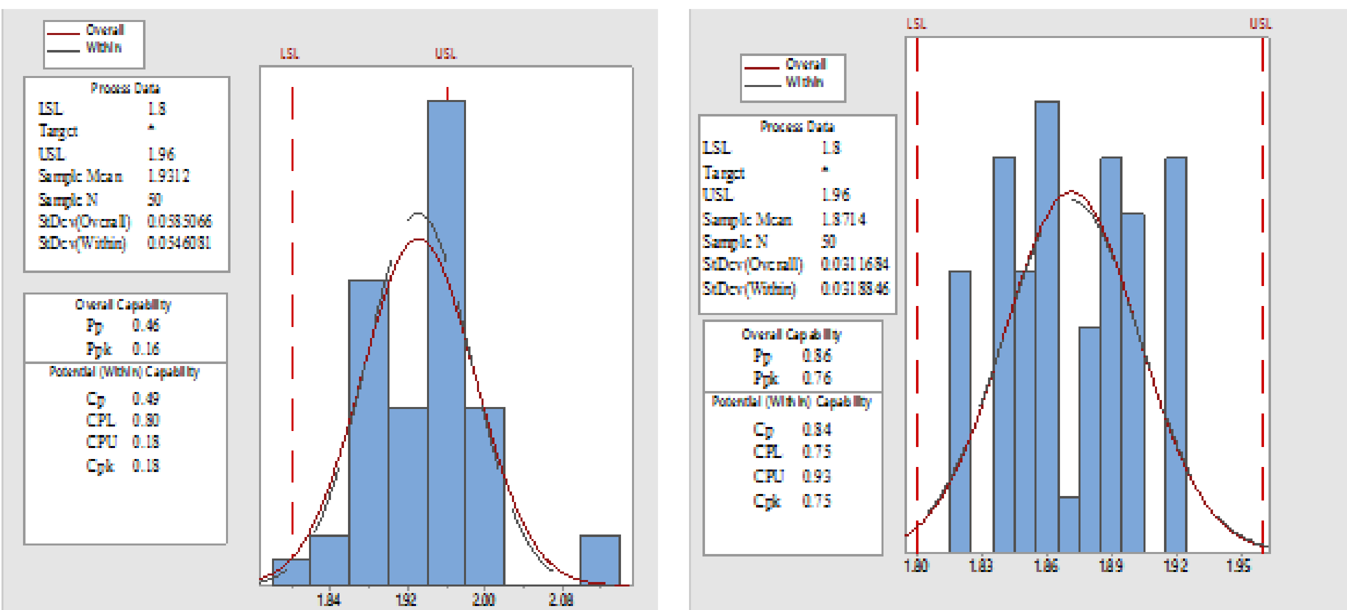
Comparison of improvement of sigma level of production of bearing and improvement of process capability and process capability index are shown in Fig. 7 and 8 respectively.



(a) Six sigma level 3.7 before DMAIC implementation

(b) Six sigma level 4.86 after DMAIC implementation

Fig. 7 Six Sigma Level- Before & After Dmaic Implementation (Courtesy: https://www.isixsigma.com/process-sigma-calculator/ [14])



(a) Process Capability Report for Pocket Size – Before DMAIC

Pp = 0.46 Ppk = 0.16
Cp = 0.49 Cpk = 0.18

(b) Process Capability Report for Pocket Size – After DMAIC

Pp = 0.86 Ppk = 0.76
Cp = 0.84 Cpk = 0.75

Fig 8 Comparison of Overall Process Capability

04. CONCLUSIONS

The Six Sigma model which was first emerged at Motorola in the 1980's. Thereafter, many papers reporting the applications of Six Sigma in all sectors like manufacturing as well as service sectors. While this trend continuous even today**,** a group of researchers found out that, the belt based training infrastructure for implementation of Six Sigma concept is quite expensive. Hence, researchers who are agree with implementation by using DMAIC methodology began to apply DMAIC in few sectors. On realizing the new trend of this research, the experimentation presented in this paper was carried out.

During the conduct of this research, it was discernible that, DMAIC methodology are being used for any type of firm, whether it is manufacturing or service sector it is powerful tool to solve the problem of any area and strong enough to make enable the companies belonging to service sectors and manufacturing to improve their quality level and reduce their defects even less than 3.4 defects or mistakes. Hence it is a tool which can be used by any company to improve their productivity level which is also called process capability.

In the context of drawing this inference, research were conducted while pursuing this work being reported here to examine the enhancement of process capability and 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. Taking consideration of this, it is determined that, by applying the principle of Six Sigma through DMAIC phases is necessitated to improve the level of quality of the components of bearing. 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.

Finally it is observed that there is significant change in process capability as well as in sigma level of the process.

5. SUGGESTIONS FOR THE FUTURE WORK

To make more quality conscious keeping view of competition of the market, the researchers and practitioners in future can concentrate on evolving solutions using Six Sigma's DMAIC that improve customer satisfaction ad will help to grow more strong as per concern of financial position. This is due to the fact that the companies top management with less revenue are more concerned with the cost occurring while implementing the Six Sigma principle through DMAIC phases. So it is suggested for the, researchers and practitioners can develop a framework for conducting cost benefit analysis that will reveal the financial benefits of implementing the solutions obtained by executing the Six Sigma's DMAIC phases. However, the following research areas are recommended to be undertaken for obtaining zero defects in this industry:

- Study need to be conducted by optimizing the process parameters related to the other defects which may improve the quality of production at its best.
- Study can be conducted for more components of bearing other than welded cage which require a great concern regarding defects minimization.
- Study can be done on the similar problem with a new innovative idea with the help of available simulation software.

Finally, in the context of these observations, this thesis is concluded by stating that DMAIC is a promising framework for enabling the firm to perform at six sigma level quality. However, several hindrances have to be overcome for the successful implementation of Six Sigma's DMAIC framework in companies.

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