Noise Reduction of Deep Groove Ball Bearing (6205) by Process Optimization - An Experimental Approach

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Abstract*: This paper presents a comprehensive study of the noise effect on deep groove ball bearing. Life of any rotatory components and machinery are depends on Ball Bearing so the bearing (DGBB) is crucial part of any rotary machinery and its failure causes disastrous failure of machinery. Noise level is the most important quality criteria of a ball bearing; it mainly depends on the following factors like Precision of the geometric forms (Track Profile, Curvature, and Talyrond etc.), Surface finish of the raceway and the balls, Cleanliness of the bearing, Type of lubricants etc. This paper mainly defines the experiment done on 18 random bearings, effect of different parameters of bearing to maintain a noise level by using DMAIC technology, and pareto chart after identification, reduction of noise has been done, which improves quality of bearing, cost effective & directly improves the quality of machine.

Index Terms*: Curvature, Deep Groove Ball Bearing, DMAIC, Track Profile, Talyrond, Pareto Chart.

I. INTRODUCTION

Deep groove ball bearings are particularly versatile. They are suitable for high and very high speeds, accommodate radial and axial loads in both directions and require little maintenance. Deep groove ball bearings are the most widely used bearing type, they are available in many designs, variants and sizes; improvement in quality of DGBB increases rapidly, by optimizing the different cutting parameter, it improves the surface finish of deep groove ball bearing. The focused problem in this study is noise, and to eliminate this problem improvement in the surface texture of inner and outer track of the bearing is essential. Poor surface texture has become a big issue, especially for the automobile industry. DOE tool and DMAIC methodology is being used to define the method and technologies to identify the optimum parameter and its significant effects on ball bearing & on its component, after getting hypothetical result by using regression analysis the equation has been formed to identify the major optimum solution and reduce the level of noise [3].

II. METHODOLOGY

Noise level is the most important quality criteria of a ball Bearing. It mainly depends on the following factors:

a. Precision of the geometric forms (Track Profile, Curvature, Talyrond etc.).
b. Surface finish of the raceway and the balls.
c. Cleanliness of the bearing.
d. Type of lubricant.

DMAIC methodology is a very common and successful 6-sigma technology to define the method and process to reduce the noise reduction in deep groove ball bearing. This section discuss reduction of noise rate in deep ball bearing by comparing Inner Race and Outer race of balls with different parameters (Ra, Rmax, Pt, Talyrond) at National Engineering Industry (NEI), Jaipur (India) using DMAIC cycle.

A. DEFINE PHASE

The main aim of this phase is to clearly solve the commercial problems; achieve goals, potential resources, venture possibility and high-level project timeline. As per venture contract, the core objective of this study is to reduce noise rate in ball bearing by improving quality and eliminating defects from 8373 PPM against target of 7716 PPM.

Graph A.a., shows Overall, in-house NOISE rejection of Assembled Ball Bearing in 2017-18, showing the reduction rate from July, 2015 to January, 2017 in parts per minute (PPM).

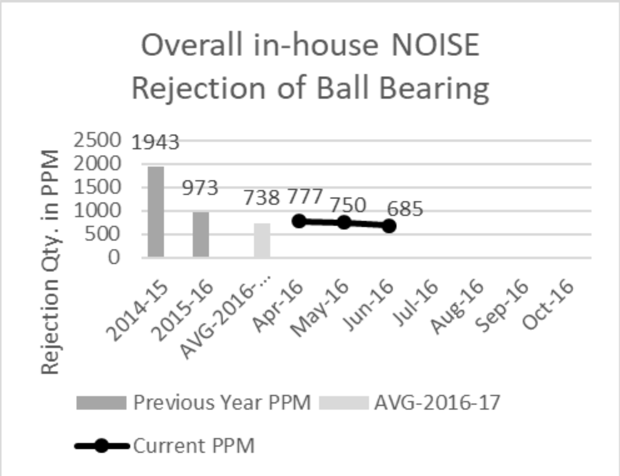

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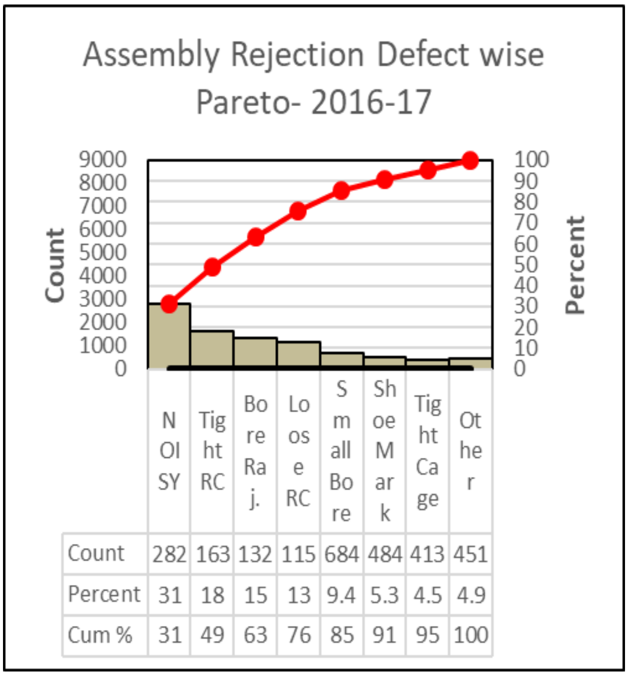
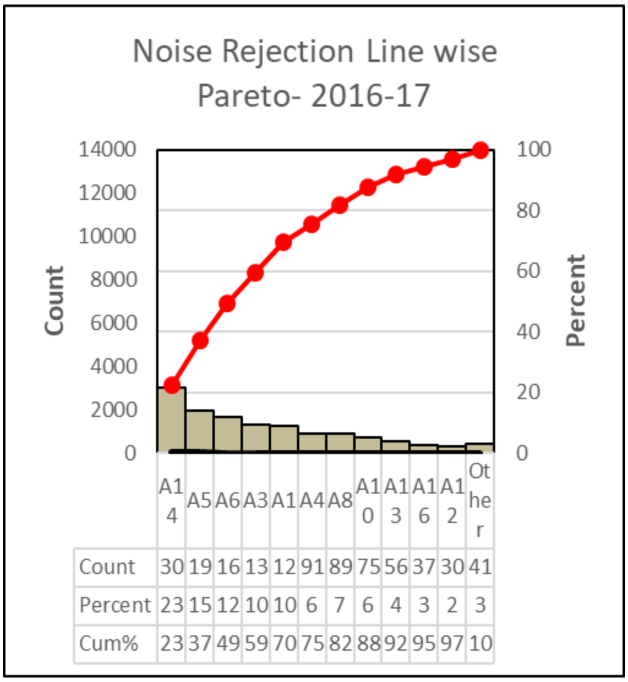
Chart A. a. & A. b., Shows line wise Characteristics Pareto & Major characteristics.

Pareto graph is a column graph. Differentiating major factors contributing to problem from other factors, which have less contribution. Thus, it helps fixing priority to take first.





***Inference*:** NOISE rejection is contributing 30.9% (2016-17) of overall assembly rejection.

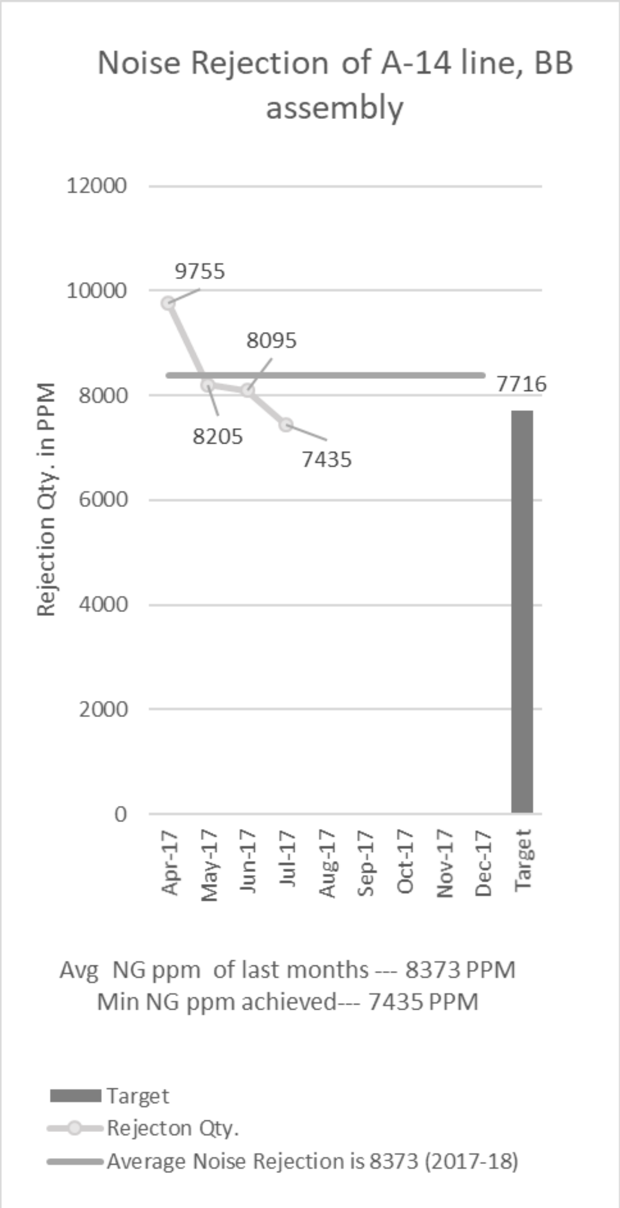
***Inference*:** A-14 line is contributing highest (23%) in overall assembly NOISE rejection.

B. MEASURE PHASE

From the quality data of N.E.I. Ltd. for the pre-dispatch inspection (PDI), the first time through (FTT) trend chart and the defect trend chart is generated.

The analyze phase segregates the top origins behind the defects produced with the help of fishbone (Ishikawa) diagram. [10]

Graph B.a., shows to reduce Assembled Bearing NOISE rejection from 8373 PPM to 7716 PPM on A-14 line.



Projected saving on A-14 line on target achievement

Average- 8373 PPM
Target- 7716 PPM
Saving- 657 PPM
Average monthly production = 1, 30,000
Annual Production = 15, 60,000

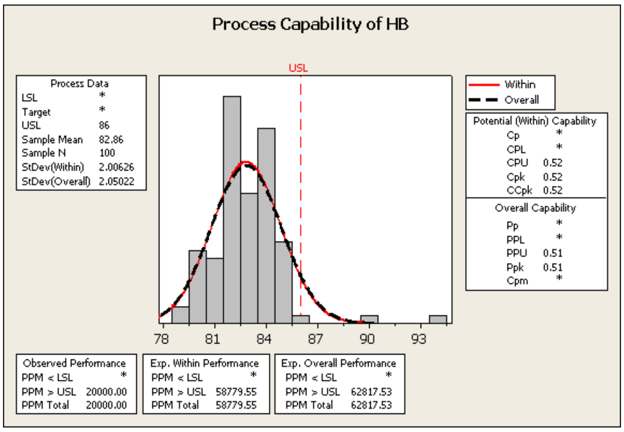
 Annual rework saving
(657*15, 60,000*9.25)/10, 00,000 = Rs. 9481.00

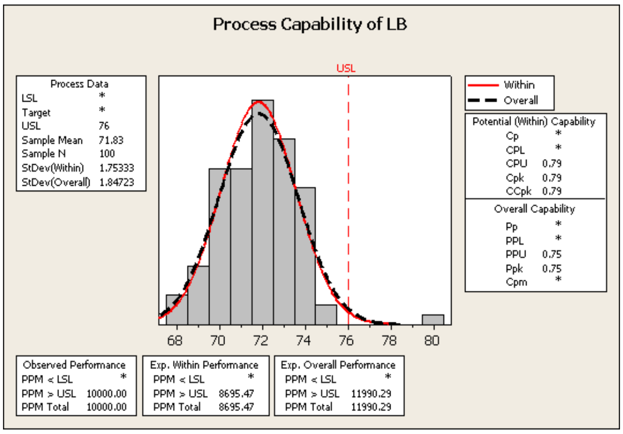
- Profit Saving
  (657*20*15, 60,000)/10, 00,000= Rs. 20,498.00

Total saving = Rs. 29,979 approx.

Projected saving on all line on target achievement
Annual saving = Rs. 6, 00,000 approx.

Chart B.a. & B.b., shows the Process Capability of High band and Low band.





Inference: Process capability is < 1.67 for HB value
Inference: Process capability is < 1.67 for LB value

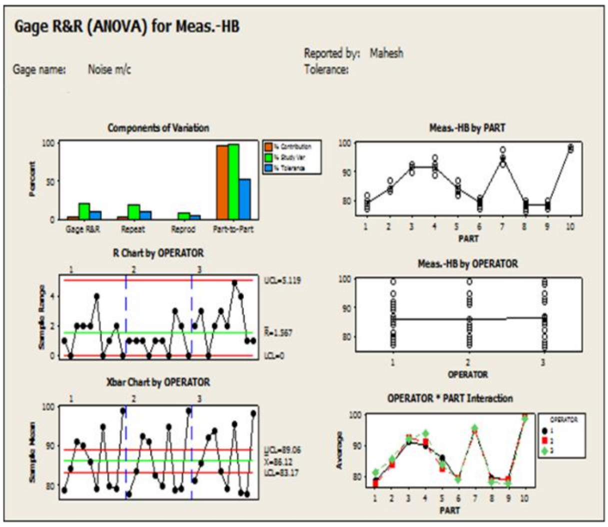
Quick win opportunities

- Work head square ness of Outer race grinding m/c was high. It was find about 40μm against limit of max. 10μ Work head square ness corrected. Improvement in Track Talyrond observed. Yearly preventive check-sheet reviewed for taking care of this accuracy
- Riveting pressure was high. Cage marks observed in some balls in some bearings. Riveting pressure reduced from 4.6 to 3 kg/cm2.
- NOISE machine Spindle run out found unto 10μm.Spindle corrected; now spindle run out is less than 2 μm [4].

Gage repeatability and reproducibility *(R&R)*, is a statistical tool used for the measurement of amount of variation system arising from the measurement device and the people taking the measurement.

Showing *R&R* graphs & readings for High Band & Low Band by using ANOVA Tool.

Chart B.c. & B.d., shows the Gauge *R&R* High band.



Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	2.4889	4.11
Repeatability	2.0833	3.44
Reproducibility	0.4056	0.67
OPERATOR	0.0000	0.00
OPERATOR*PART	0.4056	0.67
Part-To-Part	58.0981	95.89
Total Variation	60.5870	100.00

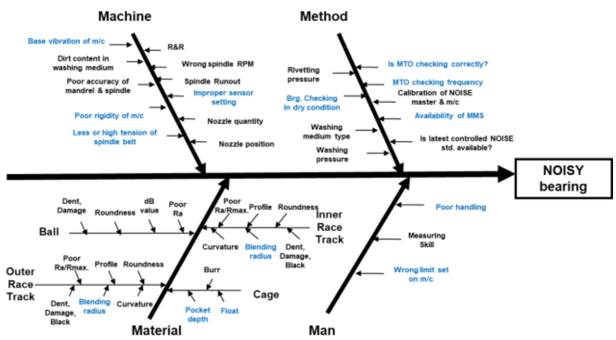
Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	1.57762	9.4657	20.27	11.01
Repeatability	1.44338	8.6603	18.54	10.07
Reproducibility	0.63683	3.8210	8.18	4.44
OPERATOR	0.00000	0.0000	0.00	0.00
OPERATOR*PART	0.63683	3.8210	8.18	4.44
Part-To-Part	7.62221	45.7333	97.92	53.18
Total Variation	7.78377	46.7026	100.00	54.31

Number of Distinct Categories = 6

Inference: Gage *R&R* for High Band is OK; this is not the cause of problem.

A fishbone diagram, also called a cause and effect diagram or Ishikawa diagram, is a visualization tool for categorizing the potential causes of a problem in order to identify its root causes, *14 factors are mainly responsible out of 42*.

Diagram B.a., shows the Cause-Effect Diagram (Fish Bone) NOISE [3].



Inference: Number of responsible factor found are 14.

Table B.a., Shows the Cause-Effect Matrix (NOISE)

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Cause-Effect Matrix - NOISE			NOISY Bearing	
		Customer Priority	10	
	Process Step	**Process Input**		**Total**
1	Outer Races	O/R Track Surface finish	9	90
2	Outer Races	O/R Track Rmax	9	90
3	Outer Races	O/R Track Talyrond	9	90
4	Inner Races	I/R Track Surface finish	9	90
5	Inner Races	I/R Track Rmax	9	90
6	Inner Races	I/R Track Talyrond	9	90
7	Outer Races	O/R Track Profile	9	90
8	Outer Races	O/R Track Curvature	9	90
9	Outer Races	O/R Visual	9	90
10	Inner Races	I/R Track Profile	9	90
11	Inner Races	I/R Track Curvature	9	90
12	Inner Races	I/R Visual	9	90
13	Balls	Ball Talyrond	9	90
14	Balls	Ball Surface roughness	9	90
15	Balls	Balls Visual	9	90
16	Washing	Dirt content	9	90
17	Balls	Ball dB value	9	90
18	Cage	Appearance	9	90

Ranking scale 1 – 10, here only those factors has been shown which are on priority after filtering

Inference: Total no. of inputs found is 18 for NOISY bearings.

C. ANALYZE PHASE

Process / Product Failure Modes and Effects Analysis (FMEA) is define in analyze phase, the goal of the DMAIC analyze is to recognize the possible root causes for the process problem being addressed and then confirm actual root causes. This is very essential to rectify the problem to eliminate it. [4, 13]

Table C.a., Process / Product Failure Modes and Effects Analysis (FMEA)-Ball Bearing Assembly.

Process Function	*Potential Failure Mode*	*Potential Effects of Failure*	*SEV*	*Potential Cause(s)/ Mechanism(s) of Failure*	*OCC*	*Current Process Controls*	*Current Process Control detection*	*DET*	*RPN*
Outer Track Ra	Roughness out of specification	Abnormal Vibration & NOISE	6	improper Track blending chamfers, machining allowances	10	--	- Lot audited as per sample plan - 100% Noise checking of Bearing in Assembly	6	360
				g ston e		vid ed	Noi se che cki		
				Incomplete superfinishing : Honing stone broken/ Honing stone worn out		Stone wear signals are provided on Superfinishing machines	- Lot audited as per sample plan - 100% Noise checking of Bearing on Noise Tester in Assembly		
Outer Track Profile **Outer Race**	Profile value out of specification	Abnormal Vibration & NOISE	6	Improper Track blending chamfers, machining allowances	10	--	- Lot audited as per sample plan - 100% Noise checking of Bearing in Assembly	6	360
				Incomplete superfinishing : Honing stone broken/ Honing stone worn out		Stone wear signals are provided on Superfinishing machines	- Lot audited as per sample plan - 100% Noise checking of Bearing on Noise Tester in Assembly		
Outer Track Rmax	Roughness out of specification	Abnormal Vibration & NOISE	6	improper Track blending chamfers, machining allowances	10	--	- Lot audited as per sample plan - 100% Noise checking of Bearing in Assembly	6	360

Inference: There are 12 numbers of causes whose RPN is >75

Table C.b. shows the Factor wise tool to be used

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S. no.	Factor (X)	Data Type	Output (Y)	Data Type	Tool to be used
1	Outer Race Ra	C	NOISE	C	Fitted line plot
2	Outer Race Rmax.	C	NOISE	C	Fitted line plot
3	Outer Race Pt	C	NOISE	C	Fitted line plot
4	Outer Race Talyrond	C	NOISE	C	Fitted line plot
5	Outer Race Visual	D	NOISE	C	Interval Plot
6	Inner Race Ra	C	NOISE	C	Fitted line plot
7	Inner Race Rmax.	C	NOISE	C	Fitted line plot
8	Inner Race Pt	C	NOISE	C	Fitted line plot
9	Inner Race Talyrond	C	NOISE	C	Fitted line plot
10	Inner Race Visual	D	NOISE	C	Interval Plot
11	Ball Visual	D	NOISE	C	Interval Plot
12	Dirt Content	D	NOISE	C	Interval Plot

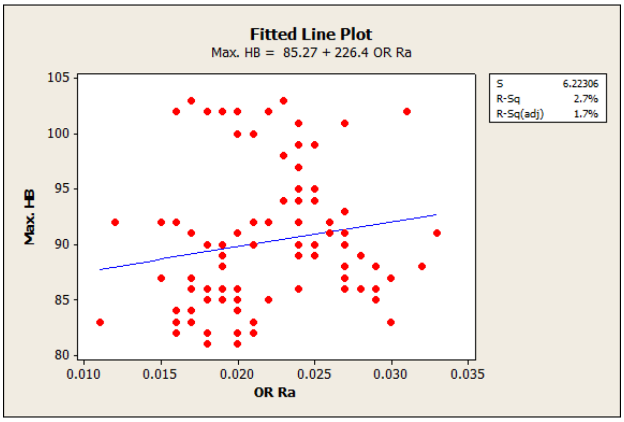
Data collection plan was make for 12 factors & appropriate graphical tools selected.

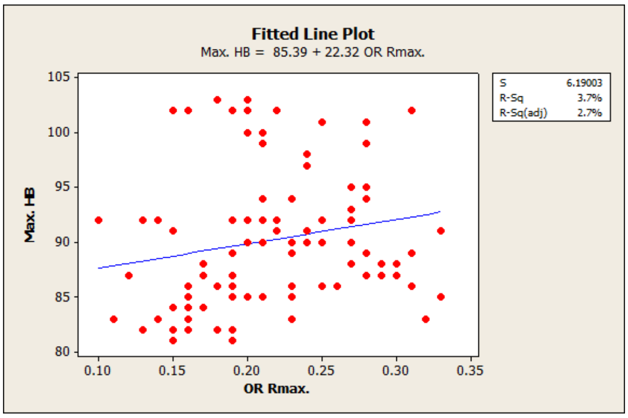
Table C.c. Shows Data Collection Check Sheet

Qty.	Brg. No.	NOISE One side HB	NOISE One side LB	NOISE Other side HB	NOISE Other side LB	HB OK/NG	LB OK/NG	Inner Track R_a	Inner Track $R_{max.}$	Inner Track P_t	Inner Track Talyrond	Inner Track Visual	Outer Track R_a	Outer Track $R_{max.}$	Outer Track P_t	Outer Track Talyrond	Outer Track Visual	Ball Visual	Dirt Content	Cage
	Spec.	86	76	86	76			0.025	.20 µm	2 µm	1.5 µm	OK	0.025	.20 µm	2 µm	1.5 µm	OK	OK/NG	< 0.411mg/pc	--
1	1	88	72	86	71	NG	OK	0.02	0.24	1.03	1.30	OK	0.02	0.29	1.42	1.25	OK	OK	OK	OK
2	2	85	73	87	72	NG	OK	0.03	0.37	1.22	0.85	OK	0.02	0.28	0.97	1.95	OK	OK	OK	OK
3	3	94	85	94	88	NG	NG	0.01	0.13	0.55	5.00	dent	0.02	0.28	1.04	1.20	OK	OK	OK	OK
4	4	99	90	100	91	NG	NG	0.01	0.14	0.99	6.55	dent	0.01	0.18	1.48	3.50	OK	OK	OK	OK
5	5	94	90	94	88	NG	NG	0.02	0.24	0.79	4.80	dent	0.02	0.28	1.87	2.20	OK	OK	OK	OK
6	6	99	76	89	73	NG	OK	0.01	0.19	0.99	1.35	dent	0.13	1.09	3.20	3.10	OK	OK	OK	OK
7	7	103	90	103	80	NG	NG	0.02	0.29	1.93	1.15	OK	0.02	0.21	3.31	2.40	OK	OK	OK	OK
8	8	98	78	99	81	NG	NG	0.02	0.25	1.93	0.90	dent	0.27	1.66	3.53	3.00	OK	OK	OK	OK
9	9	103	84	101	77	NG	NG	0.02	0.24	2.79	1.55	OK	0.01	0.14	2.83	1.35	OK	OK	OK	OK
10	10	89	78	91	77	NG	NG	0.02	0.21	1.80	1.80	dent	0.01	0.21	0.61	3.85	OK	OK	OK	OK
11	11	103	90	91	70	NG	NG	0.01	0.15	0.40	0.60	dent	0.01	0.18	1.21	0.85	OK	OK	OK	OK
12	12	93	69	93	73	NG	OK	0.02	0.20	0.79	1.20	dent	0.02	0.27	1.76	1.25	OK	OK	OK	OK
13	13	86	71	103	80	NG	NG	0.01	0.16	0.64	1.20	dent	0.02	0.20	1.23	1.55	OK	OK	OK	OK
14	14	102	77	84	70	NG	NG	0.01	0.14	0.67	1.65	dent	0.01	0.15	1.31	0.90	OK	OK	OK	OK
15	15	98	74	100	75	NG	OK	0.01	0.19	0.94	1.45	dent	0.02	0.20	1.65	0.95	OK	OK	OK	OK
16	16	103	80	103	84	NG	NG	0.02	0.21	1.71	0.60	OK	0.07	0.58	0.51	2.25	OK	OK	OK	OK
17	17	82	80	84	80	OK	NG	0.01	0.15	0.41	0.45	OK	0.01	0.11	0.56	5.20	OK	OK	OK	OK
18	18	88	81	88	80	NG	NG	0.01	0.16	0.82	1.30	OK	0.01	0.12	1.59	5.35	OK	OK	OK	OK
19	19	94	75	97	76	NG	OK	0.01	0.16	0.55	0.65	dent	0.09	0.80	2.01	1.95	OK	OK	OK	OK
20	20	87	76	88	76	NG	OK	0.02	0.24	1.33	1.20	OK	0.01	0.11	1.21	4.15	OK	OK	OK	OK

Terms: R_a- Surface Roughness, P_t- Profile, $R_{max.}$ Max. Roughness, NG- Grinding.

Graph C.a. & C.b. shows Analysis of Outer Race Ra v/s Noise Grinding & Outer race Rmax. V/s Noise Grinding

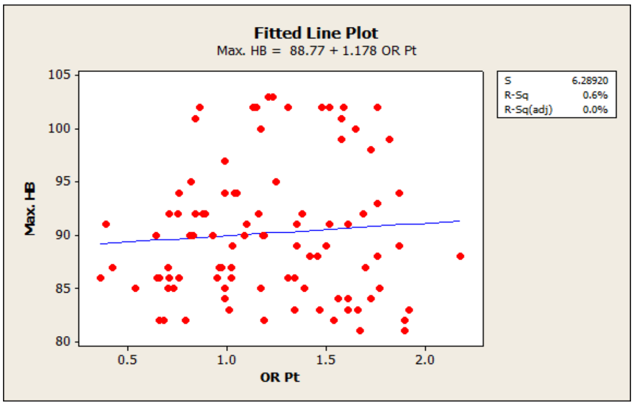




Inference: There is no relation between Outer Ra and NOISE NG.

Inference: There is no relation between Outer Rmax and NOISE NG.

Graph C.c & C.d. shows Analysis of Outer Race Profile v/s Noise Grinding & Outer race Talyrond v/s Noise Grinding



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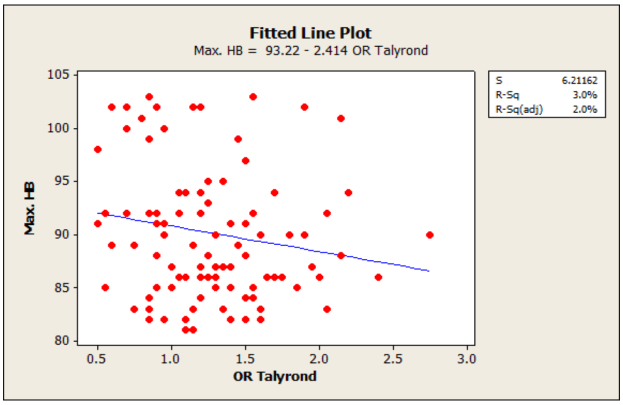
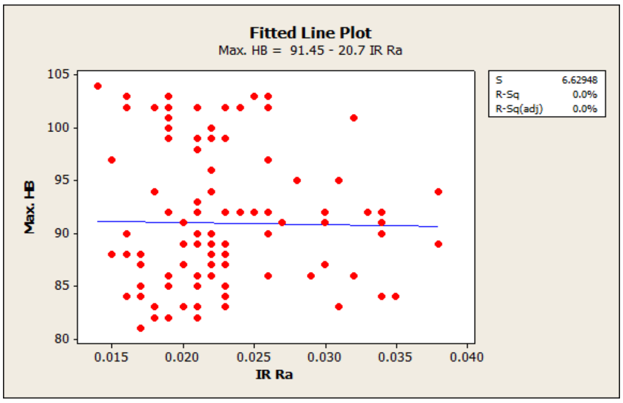
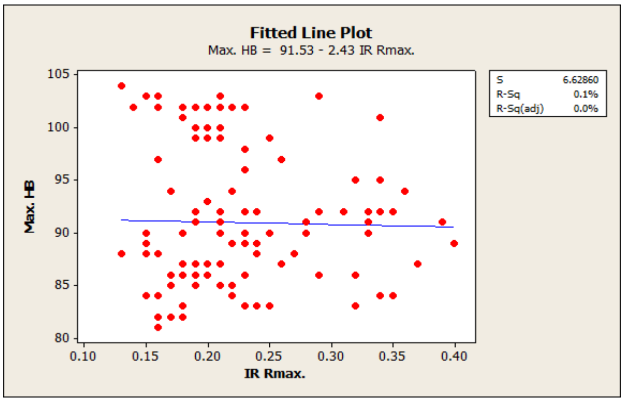


Inference: There is no relation between Outer Race Profile v/s Noise Grinding.

Inference: There is no relation between Outer races Talyrond v/s Noise Grinding.

Graph C.e. & C.f. shows Analysis of Inner Race Surface Roughness v/s Noise Grinding & Inner race Maximum surface roughness V/s Noise Grinding.

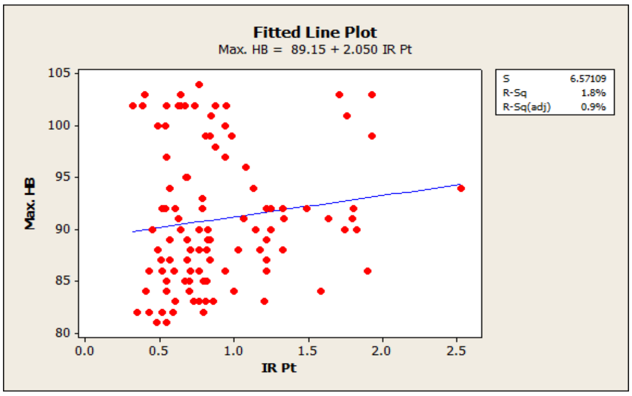


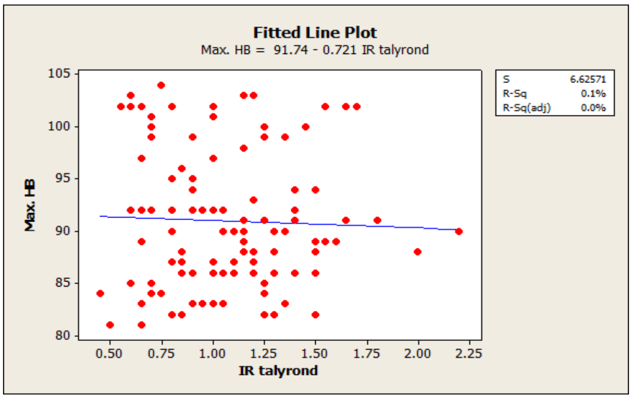


Inference: There is no relation between Inner Surface Roughness value and NOISE Grinding.

Inference: There is no relation between Inner Maximum Roughness value and Noise Grinding.

Graph C.g. & C.h. shows Analysis of Inner race Profile v/s Noise Grinding & Inner race Talyrond v/s Noise Grinding.

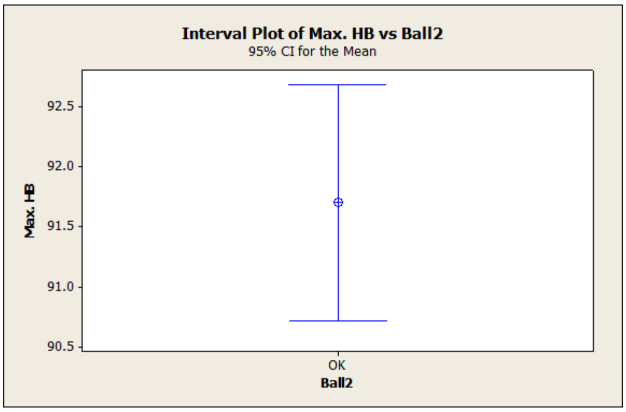




Inference: There is no relation between Inner Race Profile v/s Noise Grinding.

Inference: There is no relation between Inner Race Talyrond v/s Noise Grinding.

Graph C.i. & C.j. shows Analysis of Ball v/s Noise NG & Dirt content v/s Noise Grinding.



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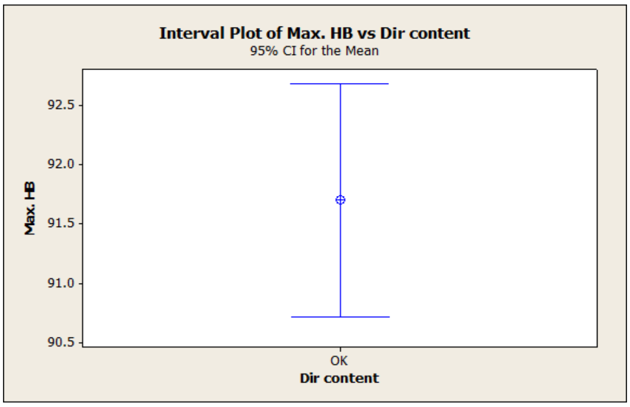
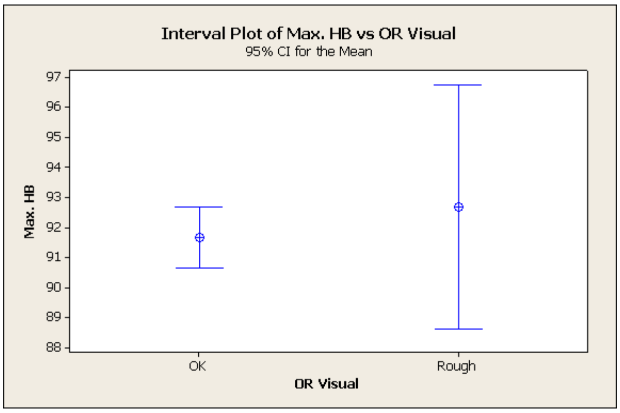
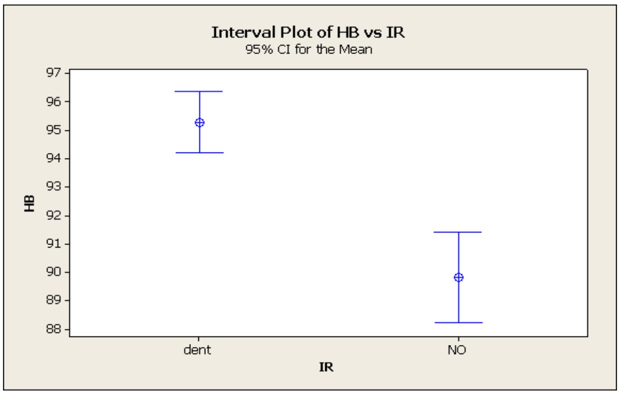


Inference: There is no relation between Ball v/s Noise Grinding.

Inference: There is no relation between Dirt content v/s Noise Grinding.

Graph C.k. & C.l. Shows Analysis of Outer Race visual v/s Noise Grinding & Inner Race Visual v/s Noise Grinding.

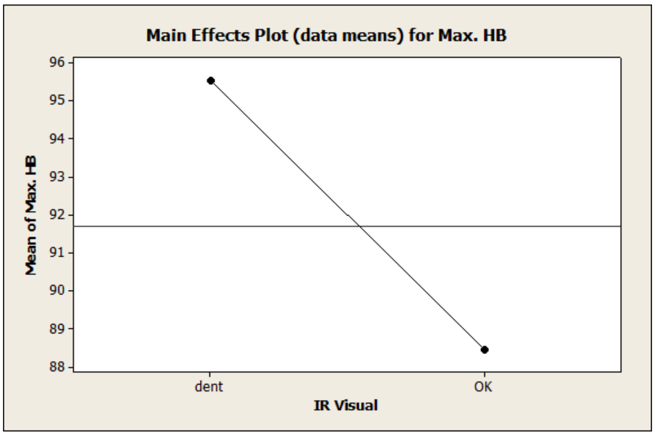




Inference: There is no relation between OR visual v/s Noise NG.

Inference: There is no relation between Inner race visual v/s Noise Grinding.

Graph C.m. Shows Analysis of Inner Race Track Dent v/s Noise Grinding Main effect plot.



Inference: There is a relation between Inner race dent and NOISE Grinding

Inference: Dent on Inner Race track will lead to NOISE rejection

Two-Sample T-Test and CI: NOISE, IR visual
Two-sample T for NOISE, shown in Table below.

IR visual	N	Mean	StDev	SE Mean
dent	25	97.56	3.01	0.60
no dent	25	84.48	2.04	0.41

Difference = mu (dent) - mu (no dent)
Estimate for difference: 13.0800
95% CI for difference: (11.6099, 14.5501)
T-Test of difference = 0 (vs not =): T-Value = 17.96.
P-Value = 0.000 DF = 42

P-Value = 0.000 DF = 42 this factor is significant. Therefore, for NOISE rejection significant factor is Inner Track Visual (dent on Track).

D. IMPROVE PHASE

The main goal of the improve phase is to recognize the solution to the problem that the project aims to address. Identify inventive solutions to eradicate the key root causes in order to fix and avert method problems. 1-way ANOVA for Inner Race Visual v/s HB value is the exact technique to solve this problem. Therefore, counteractive actions are taking for root causes [10].

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Table D.a. Shows 1-way ANOVA for Inner Race Visual v/s High Band value or Confirmative Experiment for Inner Race Visual Grinding and OK for High Band value.

One-way ANOVA: HB. Versus Dent.
Source DF SS MS F P
Dent. 1 512.0 512.0 48.00 0.000
Error 6 64.0 10.7
Total 7 576.0
S = 3.266 R-Sq = 88.89% R-Sq(adj) = 87.04%
Individual 95% CIs For Mean Based on
Pooled StDev
Level N Mean StDev -------+---------+---------+---------+--
NO 4 83.50 1.29 (-----*------)
YES 4 99.50 4.43 (------*-----)
-------+---------+---------+---------+--
84.0 90.0 96.0 102.0
Pooled StDev = 3.27

Inference: If there is Dent on Inner racetrack, then it will lead to NOISE rejection with HB value in range of 96 ~ 102 HB. Therefore, there should not be any dent on Inner Race Track surface, otherwise bearing will be rejected in NOISE.

E. CONTROL PHASE

Control phase is about to maintain the changes made in the improve phase. To ensure continued and sustainable success it will work. For controlling Update data's, documents, business process and training records are properly required. A Control chart can be useful during the control stage to evaluate the constancy of the enhancements over time by allocation as a guide to continue monitoring the process and provide a response plan for each of the measures being supervise in case the process becomes unstable [8,10].

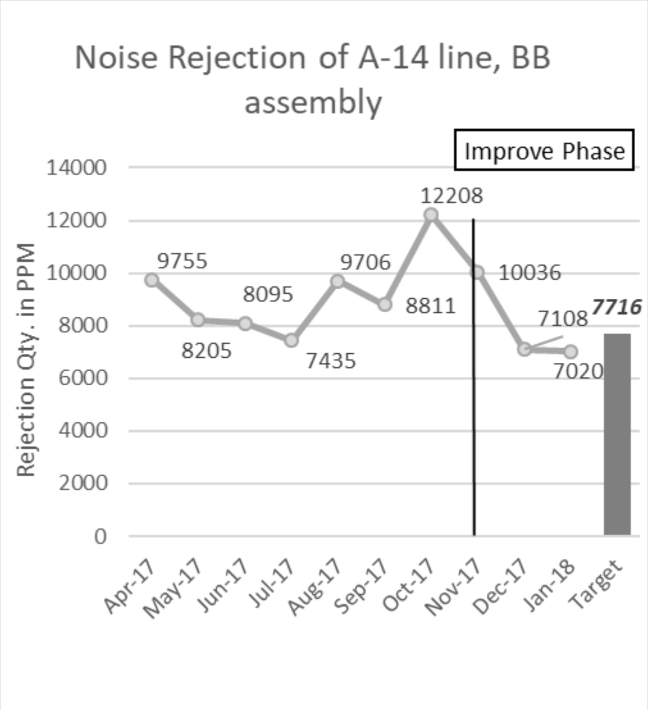
Control action plan:

a. Slide plate of Inner Race bore grinding m/c changed.
b. Tool verification system for the grinding line developed.
c. Inlet Channel of Inner Race ATDC gauge modified (Width & Slope reduced, and made straight).
d. Stoppers in conveyors after IR Track grinding & PP gauge replaced from Metallic to soft material Hylem.
e. Washing m/c after super finishing (Both IR & OR) replaced by improved washing m/c for effective washing.

III. RESULT

A Phase Summary is defined in the form of DMAIC (Define, Measure, Analyze, Improve and Control) methodology to show the process of reducing noise rejection of DGBB by optimizing cutting parameters. However, after experiments & graphical representation in Pareto chart and regression analysis (MINITAB) the result shows that the dents occurred in inner racetrack are responsible for rapidly increasing noise. After taking corrective actions, the rejections were within acceptable limit.

Graph 3.a. shows Noise Rejection Graph



IV. CONCLUSION

Now a day, Six Sigma is a very common theme followed in industries to increase the productivity and reduce defect rates. In this study DMAIC cycle has been utilized to reduce the reduce the noise reduction rate in ball bearing industry. As per the first stage of DMAIC cycle, it has been defined that the noise generated by ball bearing should be minimized. In the second stage, all the data of pre-dispatch inspection (PDI) for first time through has been collected and Pareto analysis was applied to get the major faults with the help of Ishikawa diagrams the root causes of major defects. In fourth stage, the main root causes were eradicated to prevent the process problems. In last stage, the changes made in improve stage have been continued exploiting control values.

- Noise Rejection in 2015-167151 ppm
- From Sep-16 to Jan-17 1164 ppm
- Rejection Reduced 5987 ppm

Total production from Jul-16 to Jan-17 (Project started in Jul-16) 13,35,722

Bearing Saved in no. 7,997
Total cost @ Rs. 14 /- per Brg. 1,11,958

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Thus, after conducting the DMAIC cycle, major parameters like Surface finish, Surface roughness, profile and Talyrond were compare with High band and low band of ball bearing and then the reason found that due to inner dent the noise was created now tool verification system is made for all grinding lines to verify all tooling's at a particular frequency, roundness, surface roughness and high band were almost near the standard limits. Hence, Bearing NOISE rejection rate is improved and the noise rejection is now 7716 (2016-17) ppm from 8373 ppm, saving is 657ppm.

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It is optional. The preferred spelling of the word "acknowledgment" in American English is without an "e" after the "g." Use the singular heading even if you have many acknowledgments. Avoid expressions such as "One of us (S.B.A.) would like to thank ... ." Instead, write "F. A. Author thanks " *Sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page*.

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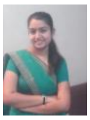

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