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Analytical Hierarchy Process Framework for Reducing Rejection: A Bearing Cage Manufacturing Case Application

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Abstract—*In present manufacturing scenario, industries focus on achieving maximum productivity along with reducing rejection of the components manufactured. The primary objective of this study is to understand the rejection, where it occurs the most and what defects are occurring more frequently while manufacturing. This paper focuses on use of quality tools such as Process Flow Diagram, Pareto Chart, Ishikawa Diagram and Analytical Hierarchy Programming. Especially, Analytical Hierarchy Programming Technique was implemented to identify the relative importance of causes and by taking suitable action against the crucial causes for manufacturing of Brass Bearing Cages.*

Keywords: *Rejection, Analytical hierarchy process, Defect, Bearing Cages.*

1. INTRODUCTION

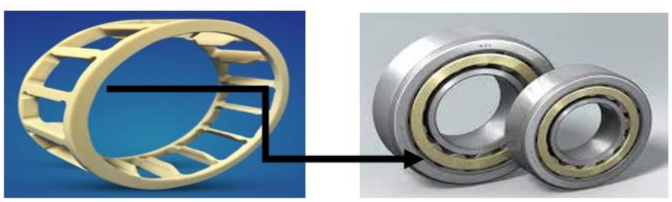

Fig. 1: Illustration of Cage in a Ball Bearing

Ball bearings are rolling element bearings that offer friction-free, smooth motion in rotary applications by separating the bearing races with balls [1]. From the incredibly small 1.50m diameter bearing for use with miniature medical devices and micro-motors to bearings over 3 metre in diameter for use in heavy-duty machinery, ball bearings are produced in wide range of sizes [2]. The mechanism used in each type of ball bearing varies, with rigid single row or radial ball bearings being the most popular. The spherical ball bearings carry axial or radial loads with swift, fluid motion as they make little contact with contained races.

A bearing cage's role is to maintain the right orientation of the rolling parts so they don't clump together [3].

The most widely used materials for bearing retainers are Steel, Polyamide, Brass and Bronze. From, all the types of materials mentioned, this paper focuses on Brass retainers. The part family of brass retainers consists of cylindrical roller bearing (CRB), Spherical roller bearing (SRB), Angular Contact ball bearing (ACBB), Deep Groove ball bearing (DGBB), Rivet Hole CRB (RHCRB) [3].

Process Flow Diagram

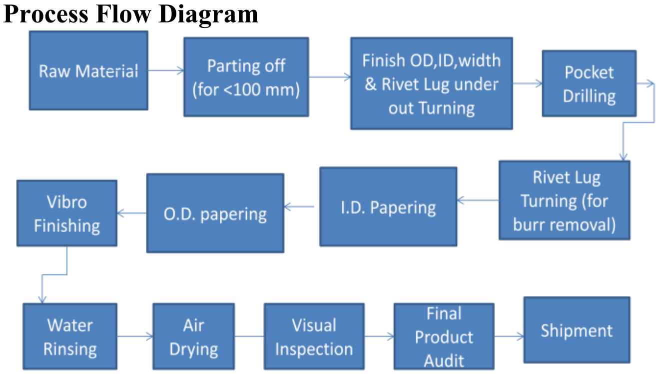

Fig. 2: Process Flow Diagram for a CRB

This is the simple Process Flow Diagram of a cylindrical roller bearing.

1. Raw material is the input material which comes from foundry after being cast in pipe form, being large in length.
2. Then it is being parted off in Lathe machine.
3. Then inner diameter (ID) and outer diameter (OD) machining is performed.
4. After ID and OD turning, material is advanced to VMC for Pocketing operation where pockets are generated on the outer surface.
5. After pocketing, if required turning is performed, instead Papering/Filing is carried out to remove burrs, chips on the edges.
6. Thereafter, Vibro Finishing is executed to enhance the surface finish of the cage.

7. After Vibro, Visual Inspection is put through to detect if there any defects generated and if generated where they are generated.
8. Ultimately, Final Audit Inspection report is carried out where a batch of the products are examined thoroughly by measuring all the dimensions as per drawing issued by the customer as per the Sampling Plan according to Statistical Quality Control, and to ensure that product is free from defects and is 'ready to dispatch' to the customer.

2. LITERATURE REVIEW

(Dr. Manish et.al, 2022) investigated the application of Cause and Effect diagram for identifying and controlling the wrong orientation of retainer of Deep Groove Ball Bearing during the assembly process. The study also showcased the 5W-3H concept in analyzing the identified problem [4].

(Mayank Jha et.al, 2013) suggested the use of Ishikawa diagram and Pareto Chart for identifying the rejection in an automobile assembly line and reducing the rejection of the same [5].

(A.Panwar et.al, 2020) proposed an AHP framework for determining the optimal process parameters for reducing the underfill defect at one of the leading gear forging industry [6].

(G.Mahendar Reddy et.al, 2012) aimed at the application of AHP technique for effective decision making in case of multi-criteria decision making at a manufacturing industry [7].

(K. Venkataraman et.al, 2014) described about the AHP technique to review the decision making process in the manufacturing industry and integrated Lean Manufacturing system to reduce rejection rate and increase process capability [8].

3. PROBLEM IDENTIFICATION

The bearing cage firm has a number of manufacturing divisions according to variety of materials used for cage manufacturing. For the purpose of our study, the rejection data was collected from all divisions for the past 6 months (which is a good experimental sample size) viz. July to December, 2022. To select the most affected division by rejection, we compare all the sections by plotting a Bar Chart.

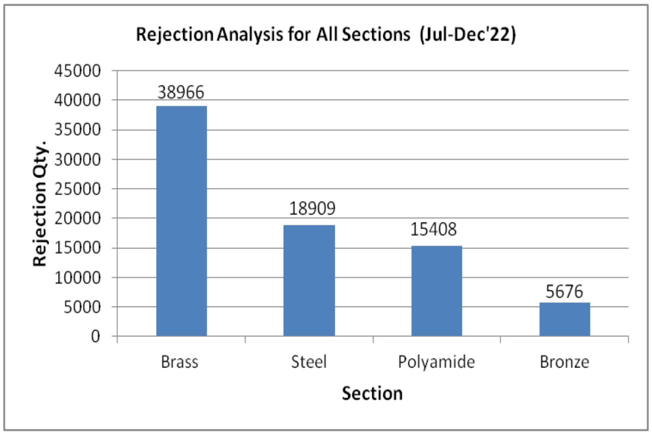

Fig. 3: Analysis of all mfg. divisions

From the above chart, it is evident that Brass Manufacturing division produces the maximum defect amongst all the divisions. Thus, focus was to reduce rejection for Brass Division. Also, for Brass division, there were 2 sections, one is Brass Foundry and other is Brass machine shop or Brass Shop.

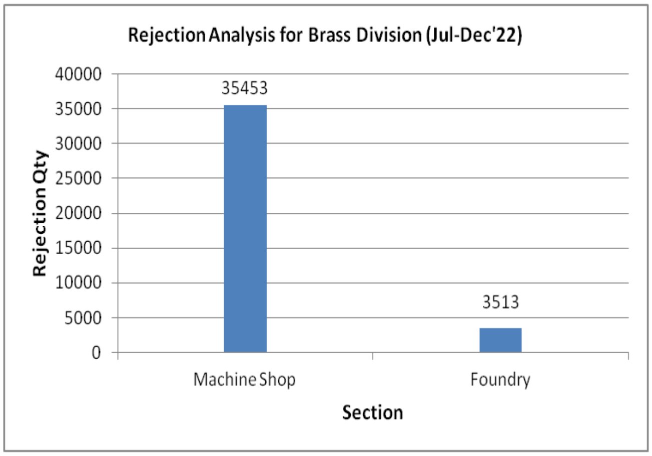

Fig. 4: Analysis of Brass Division

From the above chart, the study has narrowed down to Brass Machine Shop. For Brass Machine Shop, there are numerous machine cells in which manufacturing operations are carried out. Basically, machine cells are collections of equipment organized according to the goods or components that are manufactured.

At Brass shop, there a total of 8 machine cells. These machine cells consists of various machines such as CNC Lathe, VMC, HMC, Drilling machine, Deburring machine, Vibro machine. Funneling down the study to a machine cell, data of rejection were collected and plotted on a Pareto Chart.

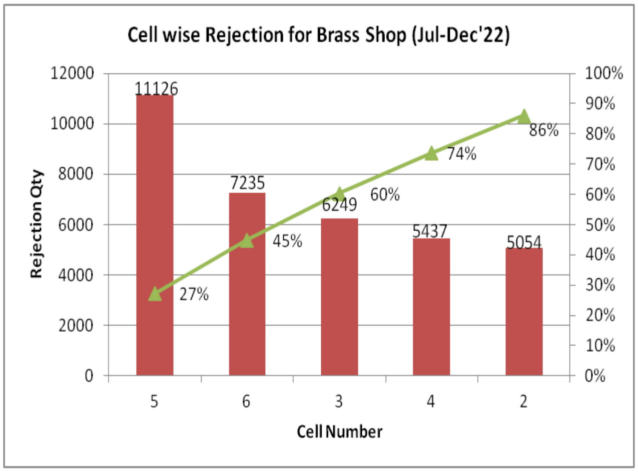

Fig. 5: Cell wise Analysis of Rejection

From the above plotted chart, it is clearly evident that highest rejection occurs in Machine Cell number 5 amongst all the machine cells. Furthermore, deep diving into the analysis of rejection for Cell No.5, rejection data was collected for the aforesaid 6 months and plotted on a Pareto Chart. There were a total of 43 different defects observed; out of which Bend, PCD O/S, Dent and margin O/S were the highest contributing to the rejection.

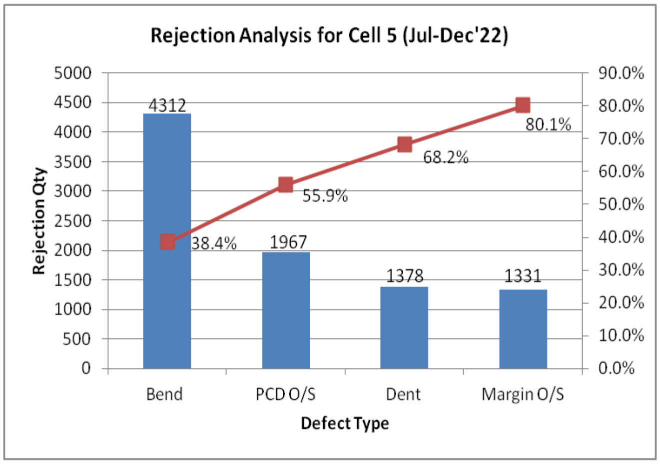

Fig. 6: Cell 5 Scrap Analysis

It is evident from the graph that Bend is occurring the most in Cell-5 out of all the defects. The cages are checked whether they are bent or not on a special flat inspection table at the visual inspection table.

Focusing more on Bend defect, it was aimed to reduce this defect in the upcoming months.

3.1 Fishbone/Ishikawa Diagram

An Ishikawa diagram is a cause-and-effect discovery tool that assists in identifying the cause(s) of flaws, variances, or process failures. To put it another way, it aids in the sequential layering of root factors that might otherwise contribute to an effect [9]. By doing Why-Why analysis and trying to find the potential causes of failure, a Cause-and-Effect diagram was plotted for the Bend defect for better understanding.

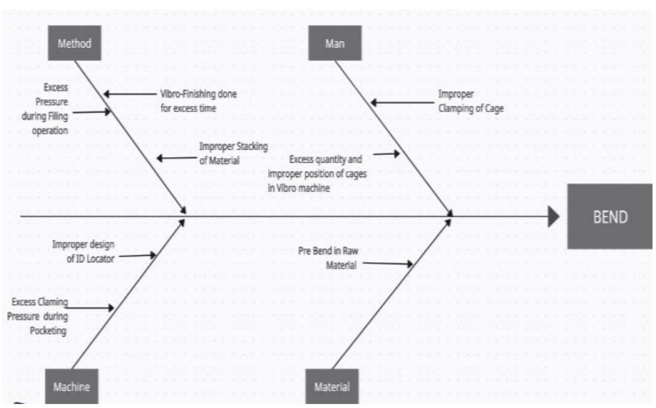

Fig. 7: Cause & Effect diagram for Bend

3.2 AHP Methodology

After finding all the potential causes, AHP Technique is introduced to find the relative importance between the causes and to find the most influencing cause amongst all the causes.

For applying the AHP technique, Direct Relationship Matrix is computed.

Table 1: Ratio scale for pair wise comparison [7]

Intensity of Severity	Definition	Explanation
1	Equal Importance	Two elements contribute equally
2	Moderate Importance of over one another	Experience and judgement slightly favour over other
3	Essential or Strong Importance	Experience and judgement strongly favour over other
4	Very strong importance	An element is strongly favored and its dominance is demonstrated
5	Utmost Importance	The evidence favoring one element over another is of the highest possible order of affirmations
1.5,2.5,3.5,4.5	Intermediate values between 2 adjacent judgement	Comparison is needed between two judgements
Reciprocals	When activity I is compared to j and assigned one of numbers, activity j is compared to I as its reciprocal	

Table 8: Abbreviations for Causes

Code	Causes
A	Vibro Finishing done for excess time
B	Excess Pressure during Filing Process
C	Improper Stacking of Material
D	Damaged ID Locator
E	Excess Pressure During Clamping W/P
F	Improper Handling of Cage
G	Excess qty. and imprper position of cages in Vibro
H	Pre-Bend of Raw Material

Table 3: Pair wise direct relationship Matrix

	A	B	C	D	E	F	G	H
A	1	2	3	1	2	1	2	5
B	0.5	1	3	0.333	0.29	0.29	1	3
C	0.33	0.33	1	0.2	0.29	0.5	1	3
D	1	3	5	1	1	2	4	4
E	0.5	3.5	3.5	1	1	1	3	4.5
F	1	3.5	2	0.5	1	1	1	5
G	0.5	1	1	0.25	0.33	1	1	4
H	0.2	0.33	0.33	0.25	0.22	0.2	0.25	1

The values in the above table are based on qualitative analysis by interacting with the operators and supervisors.

This matrix indicates the influences of causes with each other. For e.g., X_{12} i.e. 1st row 2nd element viz. **2** indicates that Cause-A is twice severe than Cause-B. Subsequently, X_{13} i.e. 1st row 3rd element viz. **3** indicates that Cause-A is thrice severe than Cause-C.

Conversely, X_{21} is the reciprocal of X_{12} and X_{31} is the reciprocal of X_{13}.

Further, adding all the column elements and then dividing all the column elements with that (added) value, we get a normalized matrix.

Now, taking average of all the row elements (A to H) we get the Criteria weights for each cause as under.

Table 4: Criteria Weights for Causes

	A	B	C	D	E	F	G	H	Criteria Wt.
A	0.199	0.136	0.159	0.221	0.327	0.143	0.151	0.169	0.188
B	0.099	0.068	0.159	0.073	0.047	0.041	0.075	0.102	0.083
C	0.066	0.023	0.053	0.044	0.047	0.072	0.075	0.102	0.060
D	0.199	0.205	0.266	0.221	0.163	0.286	0.302	0.136	0.222
E	0.099	0.239	0.186	0.221	0.163	0.143	0.226	0.153	0.179
F	0.199	0.239	0.106	0.110	0.163	0.143	0.075	0.169	0.151
G	0.099	0.068	0.053	0.055	0.054	0.143	0.075	0.136	0.085
H	0.040	0.023	0.018	0.055	0.036	0.029	0.019	0.034	0.032

Finally, it is needed to check whether our computation is consistent or not. So, for this multiply all the columns with its criteria weights and get the matrix as under.

Table 5: Weighted Sum Matrix

	A	B	C	D	E	F	G	H	Weighted Sum
A	0.188	0.166	0.180	0.222	0.358	0.151	0.171	0.158	1.594
B	0.094	0.083	0.180	0.074	0.052	0.043	0.085	0.095	0.707
C	0.062	0.027	0.060	0.044	0.052	0.075	0.085	0.095	0.501
D	0.188	0.249	0.300	0.222	0.179	0.301	0.342	0.126	1.909
E	0.094	0.291	0.210	0.222	0.179	0.151	0.256	0.142	1.546
F	0.188	0.291	0.120	0.111	0.179	0.151	0.085	0.158	1.283
G	0.094	0.083	0.060	0.056	0.059	0.151	0.085	0.126	0.714
H	0.038	0.027	0.020	0.056	0.040	0.030	0.021	0.032	0.263

After finding the weighted sum matrix, compute consistency ratio for all the row elements by dividing weighted sum with criteria weight.

Table 6: Consistency Ratio Table

Weighted Sum	Criteria Wt.	Consistency Ratio
1.594	0.188	8.471
0.707	0.083	8.499
0.501	0.060	8.345
1.909	0.222	8.594
1.546	0.179	8.646
1.283	0.151	8.516
0.714	0.085	8.355
0.263	0.032	8.336

Calculating, $\delta_{\max}$ as the average of all the consistency ratios in the last column.

$\delta_{\max}$ is computed as **8.4701**.

Also, to find consistency ratio (CR), Consistency Index (CI) needs to be calculated. The consistency index can be find by the following equation.

$$C.I. = \frac{\delta \max - n}{n-1} \quad [8]$$

Where, n = no. of causes. In our case n = 8.

C.I. = 0.0672 ….. (1)

Now, Reliability Index is determined from the below random consistency index table.

Table 7: Random Consistency Table

n	3	4	5	6	7	8	9	10
RCI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

From the above table, RCI corresponding to n=8 is,

R.I. = 1.41 ……….. (2)

For, Consistency ratio (CR),

$$C.R. = \frac{C.I.}{R.I.}$$

$$C.R. = \frac{0.0672}{1.41} C.R. = 0.05 < 0.1$$

Thus, AHP computation is consistent.

4. RESULTS & DISCUSSIONS

After completing AHP, the final matrix obtained is as below.

Table 8: Final Criteria Weight for each cause

Causes	Criteria Wt.
A	0.19
B	0.08
C	0.06
D	0.22
E	0.18
F	0.15
G	0.09
H	0.03

From this above table, it can be inferred that Cause-D, Cause-A and Cause-E which are improper design of ID Locator, Vibro Finishing done for excess time, Excess pressure during clamping process respectively influences the most amongst all the causes of failure for Bend defect.

Action Plan (Suggested)

1. By some minor modifications in design of tooling elements, bending occurrence can be reduced.

2. Also, by determining the optimum time for Vibro Finishing, bending can be reduced.
3. Material Handling Equipments can also be modified, to further reduce the Bend.
4. Lean Manufacturing Concept should be implemented to reduce material handling time and its travelling.

By AHP Calculations, the final criteria wei

Action Plan (Implemented)

1. For analysis in tooling elements, the inner groove depth in ID Locator was reduced to 3.25 mm from 4 mm to reduce the pressure on the Work piece in Pocketing operation.
2. The average clamping pressure by some operators was observed to be 9 bar, which was a little more than required, causing the cage to bend. Thus, new clamping pressure was modified to be set to 6 bar instead of 9 bar.
3. The optimum time for Vibro Finish was determined according to different sizes of cages as per their part families. If cages are kept for excess time, there is a possibility of the triangular grains striking repetitively to cages, causing it to bend.

After implementing these suggestions, there was a significant reduction in rejection due to BEND, as presented under.

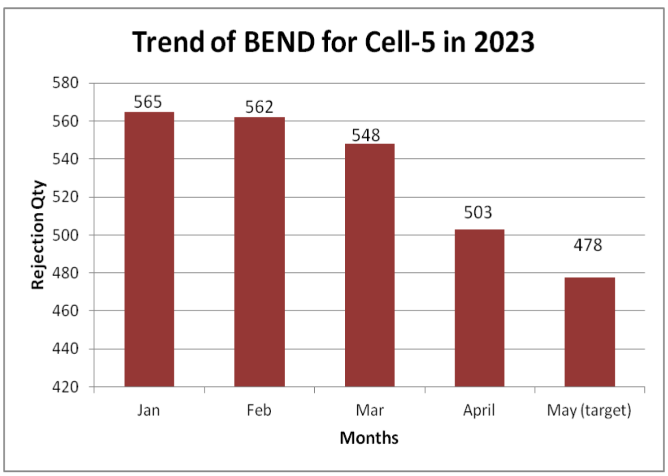

Fig. 8: BEND Trend for Cell No.5 in 2023

5. CONCLUSIONS

It can be inferred that by using the quality tools such as Bar Chart and Pareto Chart, an approach was made for problem identification and by tools such as Ishikawa Diagram and AHP, an approach was built towards the in depth analysis of the problem and suggesting the solutions for the same.

Key learnings from this study are as follows:

1. By applying statistical quality tools such as Bar Chart, Pareto Chart, Fishbone Diagram an approach was made funnel down to the most affected defect in the industry in terms of rejection.
2. Then by integrating the SQC tools with the Analytical Hierarchy Process, the most influencing causes for BEND were determined by the AHP algorithm.
3. After properly understanding the most influencing factors, suitable action plan was suggested to drive towards a sustainable solution.
4. By, implementing the suggested action plan, there was a drop by 11% in rejection due to BEND over the period of 4 months i.e. January 2023 to April 2023.

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