International Journal Of Advancement In Engineering Technology, Management and Applied Science (IJAETMAS)
ISSN: 2349-3224 || www.ijaetmas.com || Volume 03 - Issue 07 || July 2016 || PP. 83-90

DFMEA of a Roller Mill Gear box

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ABSTRACT:

Design FMEA is structured method of identifying potential failure modes and providing corrective actions before first production run occurs. This paper aims to provide probable causes of failure, levels of effects of failure and corrective actions to be taken in the design phase for Bevel-Planetary Vertical Roller Mill Gearbox.

Keywords—*DFMEA, Bevel-Planetary Gearbox, Vertical Roller Mill, Risk Priority Number*

I.INTRODUCTION

1) Vertical Roller Mills:

Vertical roller mills (VRM) are well accepted as most effectual means for grinding raw material in cement and power generation industry. These mills are driven by heavy duty gearboxes with horizontal input shaft and vertical output shaft [i]. Generally, Bevel-Helical or Bevel-Planetary gearboxes are used for VRM. The gearbox is integral component of VRM as its output flange is rigidly connected with the mill grinding table. Fig. 1 shows the general arrangement of VRM with gearbox located at its bottom.

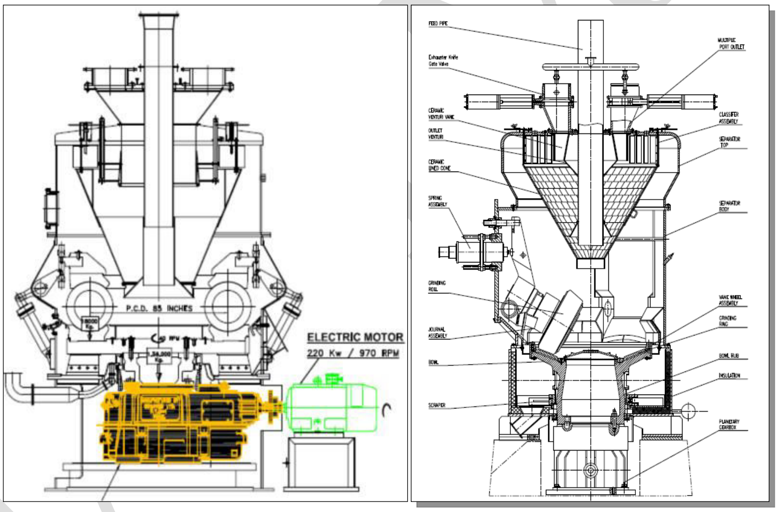


Fig. 1: VRM with Bevel-Helical Gearbox (Left) and Bevel-Planetary Gearbox (Right)

The output torque which is the foremost design criteria for the gearbox, has to be increased with increasing capacity of the mills [i]. This has put limitations on using Bevel-Helical gearboxes. Additionally, Bevel-Planetary gearboxes stand out with the following advantages over Bevel-Helical making them preferred choice for the application:

- Impervious to vertical impacts (grinding force) since the gears are isolated from the table or lower grinding bowl of the mill.
- Rigid because of round housing form.
- Precision machined because of the circular form.
- Easy to both assemble and disassemble because of the ease with which the thrust plates and the gears can be removed and due to the absence of gaskets necessary for sealing a split gear housing.
- Compact because the forces are being distributed in planetary stage.
- Quiet running because the high speed bevel stage being located deep within the gear unit.
- Efficient because of the loss –free coupling performance of planetary gear.

2) Design FMEA:

A failure mode can be defined as the way in which product, sub-assembly or component would fail to perform its intended function [ix]. DFMEA is a methodology to evaluate failure modes and their effects on the performance of a system in design phase. It is well defined approach to identify possible failure modes, estimate the effects of failure on operational condition of the system, prioritize the actions to reduce risk and evaluate design validation plan. DFMEA can be conducted when:

- New systems, products or processes are being designed
- Existing designs are being changed
- Carry over designs are used in new applications

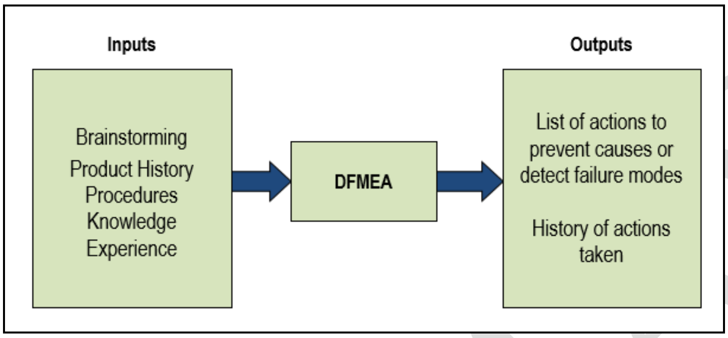


Fig. 2 gives a simplified concept of DFMEA indicating required inputs and desired output.

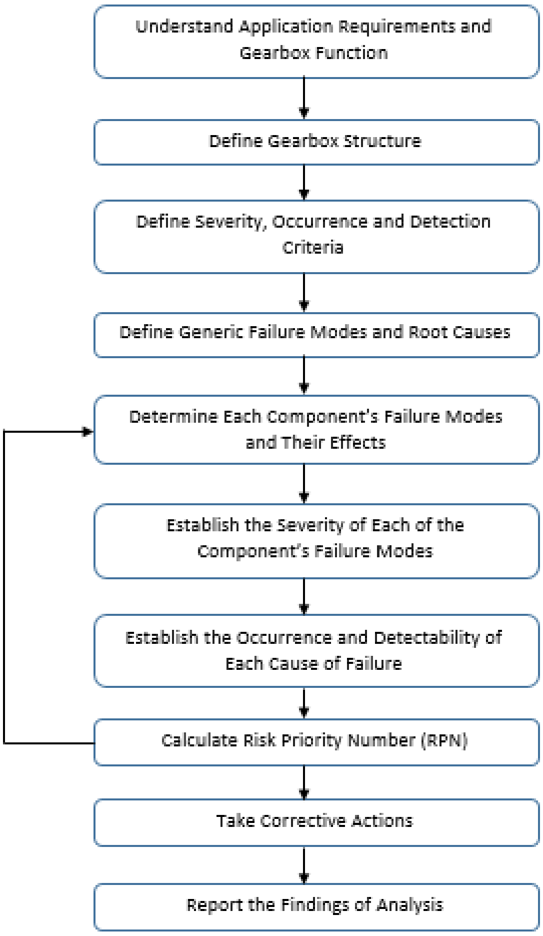
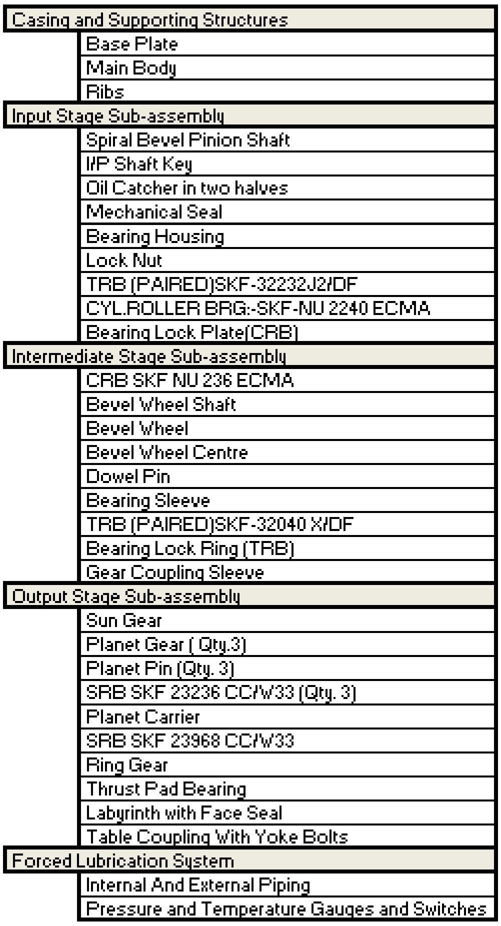


Fig. 2: DFMEA Concept

II.MATERIAL AND METHODOLOGY

The fact that the application of DFMEA to gearboxes by the manufacturers is irrefutable. However, there is no any published record of such application of DFMEA to a vertical roller mill gearbox. This paper documents the basic application of DFMEA to gearbox using the procedure adopted from *Failure Modes and Effects Analysis (FMEA) for Wind Turbine,* H. Arabian-Hoseynabadi, H. Oraee and P.J. Tanver [ii]. The procedure and analysis technique has been modified to make it appropriate for an industrial gearbox.

The flow chart in Fig. 3 explains the steps involved in DFMEA.

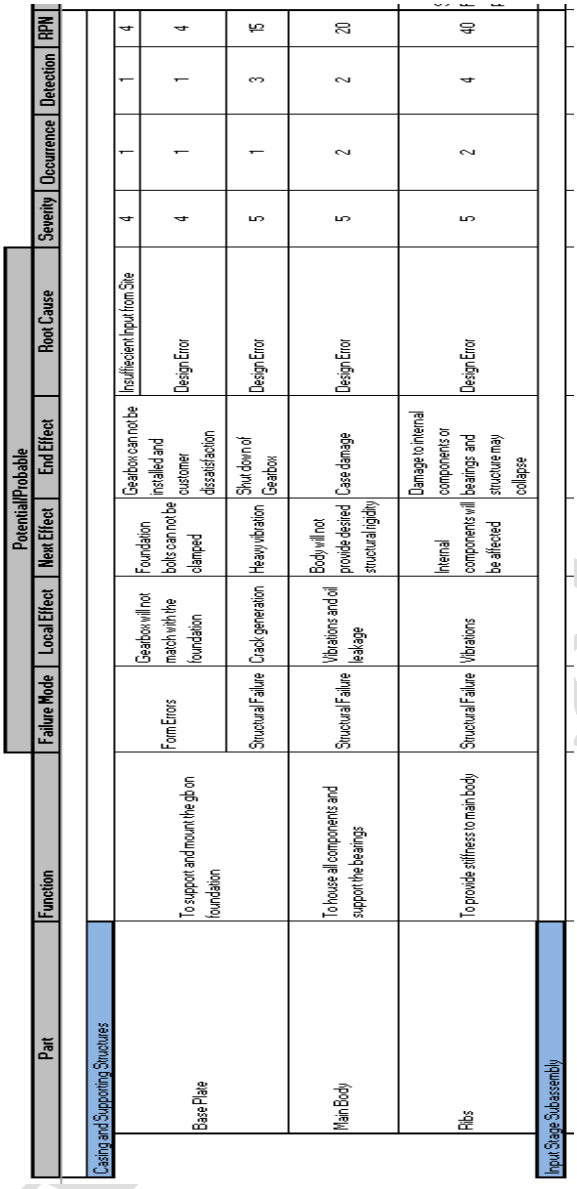


- Casing and Supporting Structures
  - Base Plate
  - Main Body
  - Ribs
- Input Stage Sub-assembly
  - Spiral Bevel Pinion Shaft
  - I/P Shaft Key
  - Oil Catcher in two halves
  - Mechanical Seal
  - Bearing Housing
  - Lock Nut
  - TRB (PAIRED)SKF-32232J2/DF
  - CYL.ROLLER BRG:-SKF-NU 2240 ECMA
  - Bearing Lock Plate(CRB)
- Intermediate Stage Sub-assembly
  - CRB SKF NU 236 ECMA
  - Bevel Wheel Shaft
  - Bevel Wheel
  - Bevel Wheel Centre
  - Dowel Pin
  - Bearing Sleeve
  - TRB (PAIRED)SKF-32040 X/DF
  - Bearing Lock Ring (TRB)
  - Gear Coupling Sleeve
- Output Stage Sub-assembly
  - Sun Gear
  - Planet Gear (Qty.3)
  - Planet Pin (Qty. 3)
  - SRB SKF 23236 CC/W33 (Qty. 3)
  - Planet Carrier
  - SRB SKF 23968 CC/W33
  - Ring Gear
  - Thrust Pad Bearing
  - Labyrinth with Face Seal
  - Table Coupling With Yoke Bolts
- Forced Lubrication System
  - Internal And External Piping
  - Pressure and Temperature Gauges and Switches

Fig. 3: DFMEA Procedure

1. Application Requirements and Gearbox function: The requirements of application and gearbox function are explained in introduction Section of this paper.

2.Gearbox Structure: The taxonomy used to define gearbox structure can be in the form of block diagram, cross-sectional diagram of gearbox, flow chart or simply enlisting the components in their sub-assemblies. Enlisting the sub-assembly wise structure ensures that the every component has been taken into consideration. Fig. 4 shows the structure of Bevel-Planetary VRM gearbox.



Part	Function	Potential/Probable Failure Mode	Local Effect	Next Effect	End Effect	Root Cause	Severity	Occurrence	Detection	RPN
Casing and Supporting Structures										
Base Plate	To support and mount the gb on foundation	Form Errors	Gearbox will not match with the foundation	Foundation bolts can not be clamped	Gearbox can not be installed and customer dissatisfaction	Insuffiecient Input from Site	4	1	1	4
						Design Error	4	1	1	4
		Structural Failure	Crack generation	Heavy vibration	Shut down of Gearbox	Design Error	5	1	3	15
Main Body	To house all components and support the bearings	Structural Failure	Vibrations and oil leakage	Body will not provide desired structural rigidity	Case damage	Design Error	5	2	2	20
Ribs	To provide stiffness to main body	Structural Failure	Vibrations	Internal components will be affected	Damage to internal components or bearings and structure may collapse	Design Error	5	2	4	40
Input Stage Subassembly										

Fig. 4: Gearbox Structure

3. Defining Criteria:

(a) Severity: Severity is the measure of importance of the effect of failure mode [viii]. Severity scale depends on the effect of failure on the performance of the gearbox. Severity rating can be defined using concept of Mean Time To Repair (MTTR). A Failure mode with low MTTR can be considered as less severe compared to that of with high MTTR. Table I shows the severity criteria used in this paper.

Criteria	Label	Value	Description
Severity	Catastrophic	5	Gearbox inoperable with destructive failure without warning
	Critical	4	Gearbox inoperable with equipment damage
	Marginal	3	Gearbox operable with significant degradation of performance
	Minor	2	Gearbox operable with minimal interference
	None	1	No effect on gearbox operation

Table I: Severity Scale

(b) Occurrence: Occurrence is the frequency with which a particular cause occurs and creates failure [viii]. In other words, it can be referred as probability of the cause of failure. The different levels of occurrence can be distinguished with the help of concept of Mean Time Between Failure. If time between failure due to particular cause is high then it will have less occurrence rating. Table II indicates the occurrence criteria.

Criteria	Label	Value	Description
Occurrence	Inevitable	5	Failure will definitely occur
	Frequent	4	Repeated failures with regular occurrence
	Occasional	3	Occasional but not necessarily regular failures
	Rare	2	Rare and irrregular failures
	Extremely Unlikely	1	Failure almost never occurs

Table II: Occurrence Scale

(c) Detection: Detection is the measure of probability that root cause of failure can be detected either by the gearbox control system or manual monitoring [viii]. Defining detection levels for a gearbox is very subjective. Based on past experiences of failure occurrence and detection, levels defined for detection are tabulated in Table III.

Criteria	Label	Value	Description
Detection	Impossible	5	Root cause cannot be detected
	Low	4	Low chance of detection of root cause
	Medium	3	Moderate chance of detection of root cause
	High	2	High chance of detection of root cause
	Almost Certain	1	Root cause very easy to detect

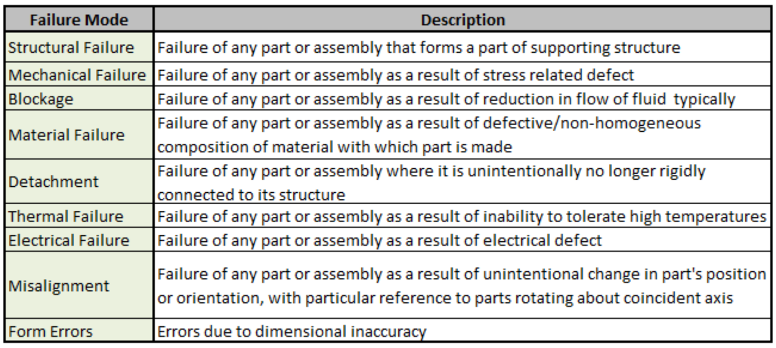
Table III: Detection Scale

4. Determining Failure Modes and Root Causes: For this phase of DFMEA previous records of service reports of gearboxes have been studied. A brainstorming session was arranged involving design, manufacturing, assembly and service teams. In this session by utilizing application knowledge and data of previous failures, potential/probable failure modes and their possible root causes were determined. Table IV gives the general root causes of gearbox failure.

Root Cause
Design Error
Mechanical Overload
Presence of debris/Contamination
Connection Failure
Insuffiecient Input from Site
Raw Material Quality/Heat Treatment
Manufacturing or assembly Error
Insufficient Lubrication

Table IV: General Root Causes

The potential failure modes of gearbox are tabulated in Table V.



Failure Mode	Description
Structural Failure	Failure of any part or assembly that forms a part of supporting structure
Mechanical Failure	Failure of any part or assembly as a result of stress related defect
Blockage	Failure of any part or assembly as a result of reduction in flow of fluid typically
Material Failure	Failure of any part or assembly as a result of defective/non-homogeneous composition of material with which part is made
Detachment	Failure of any part or assembly where it is unintentionally no longer rigidly connected to its structure
Thermal Failure	Failure of any part or assembly as a result of inability to tolerate high temperatures
Electrical Failure	Failure of any part or assembly as a result of electrical defect
Misalignment	Failure of any part or assembly as a result of unintentional change in part's position or orientation, with particular reference to parts rotating about coincident axis
Form Errors	Errors due to dimensional inaccuracy

Table V: Failure Modes

5. Conducting DFMEA: Fig. 5 shows the matrix used to carry out DFMEA of Bevel-Planetary gearbox.

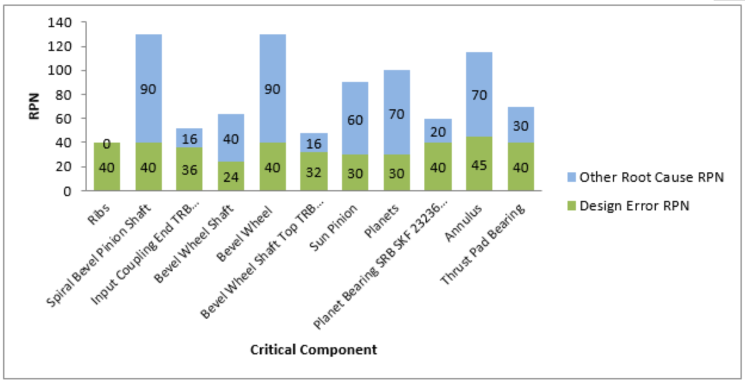


Fig. 5: DFMEA Matrix

The function of each component of sub-assembly has defined in the matrix. The failure mode for each component has been determined. The effects of failure were then categorised as Local effect, Next effect and End effect. This categorisation helps in identifying the root cause(s) easily and applying severity rating accurately. The relationship between failure mode and root cause may not be always one to one. A single failure mode may have more than one root cause. A Risk Priority Number is calculated using formula,

RPN = Severity × Occurrence × Detection

After calculating the RPN for every component, next step is to identify critical components viz. components with high RPN. By comparing the RPN values of components, the components with RPN equal to or more than 40 had been considered as critical components.

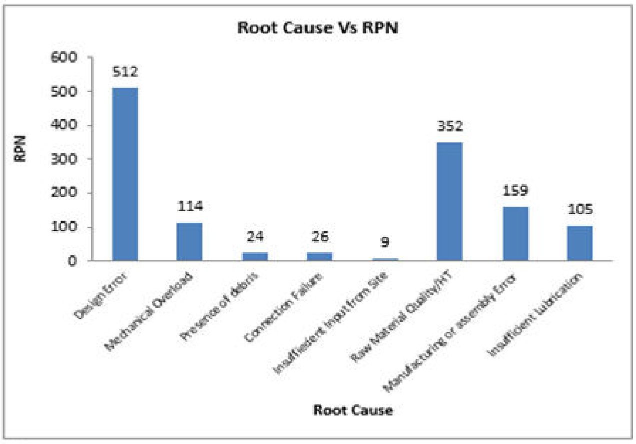


Fig. 6: Root Cause Vs RPN and Root Cause Vs Occurrence No.

From Fig.6 it is clear that occurrence of design error is highest and it is main cause of failure. Hence, corrective actions were taken to reduce risk of design error for critical components.
Fig. 7 shows contribution of design error RPN in total RPN of critical components.

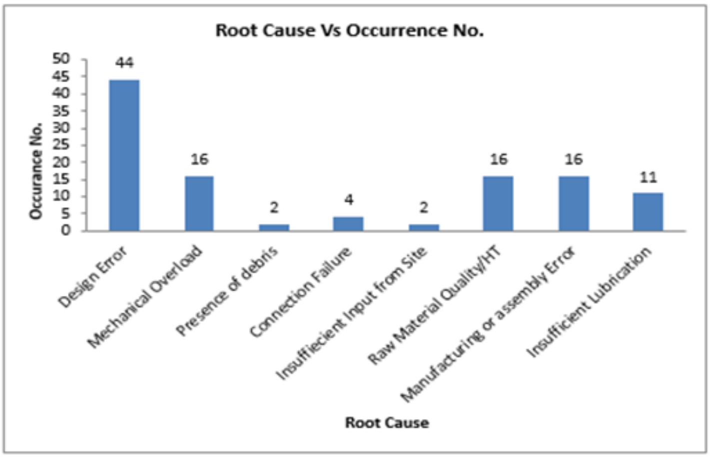
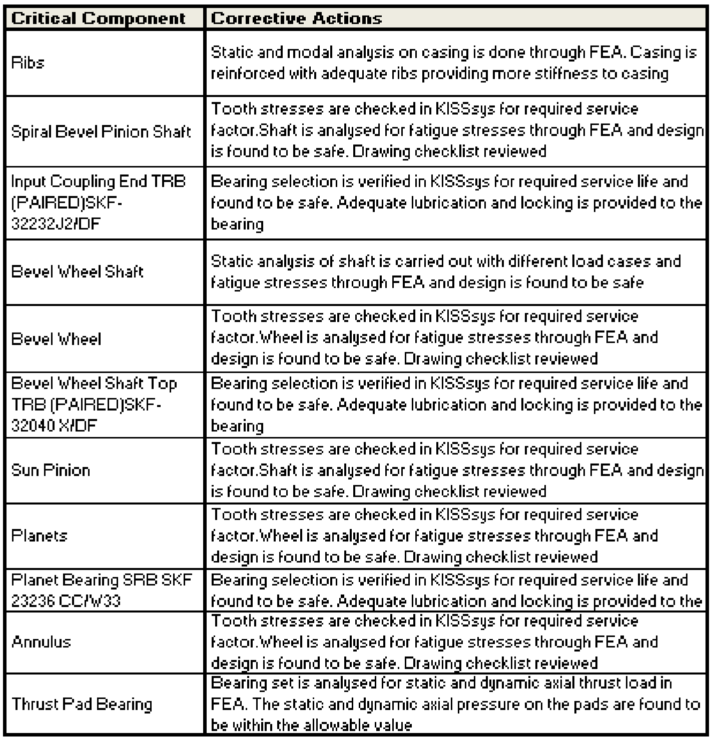


Fig. 7: Design Error RPN for Critical Components



Critical Component	Corrective Actions
Ribs	Static and modal analysis on casing is done through FEA. Casing is reinforced with adequate ribs providing more stiffness to casing
Spiral Bevel Pinion Shaft	Tooth stresses are checked in KISSsys for required service factor.Shaft is analysed for fatigue stresses through FEA and design is found to be safe. Drawing checklist reviewed
Input Coupling End TRB (PAIRED)SKF-32232J2/DF	Bearing selection is verified in KISSsys for required service life and found to be safe. Adequate lubrication and locking is provided to the bearing
Bevel Wheel Shaft	Static analysis of shaft is carried out with different load cases and fatigue stresses through FEA and design is found to be safe
Bevel Wheel	Tooth stresses are checked in KISSsys for required service factor.Wheel is analysed for fatigue stresses through FEA and design is found to be safe. Drawing checklist reviewed
Bevel Wheel Shaft Top TRB (PAIRED)SKF-32040 X/DF	Bearing selection is verified in KISSsys for required service life and found to be safe. Adequate lubrication and locking is provided to the bearing
Sun Pinion	Tooth stresses are checked in KISSsys for required service factor.Shaft is analysed for fatigue stresses through FEA and design is found to be safe. Drawing checklist reviewed
Planets	Tooth stresses are checked in KISSsys for required service factor.Wheel is analysed for fatigue stresses through FEA and design is found to be safe. Drawing checklist reviewed
Planet Bearing SRB SKF 23236 CC/W33	Bearing selection is verified in KISSsys for required service life and found to be safe. Adequate lubrication and locking is provided to the
Annulus	Tooth stresses are checked in KISSsys for required service factor.Wheel is analysed for fatigue stresses through FEA and design is found to be safe. Drawing checklist reviewed
Thrust Pad Bearing	Bearing set is analysed for static and dynamic axial thrust load in FEA. The static and dynamic axial pressure on the pads are found to be within the allowable value

The corrective actions to reduce design errors for critical components are tabulated in Table VI.

Table VI: Corrective Actions

III.RESULTS AND TABLES

After implementing corrective actions for critical components, once again RPN was calculated. The design error RPN was found to be decreased more than 50% for each critical component.
Fig. 8 shows the comparison of design error RPN before and after implementing corrective actions. The decrease in design error RPN values has also decreased the overall RPN for critical components.

Thus ensuring the robustness of design of gearbox. Fig. 9 shows the comparison of RPN for critical components before and after implementation of corrective actions.

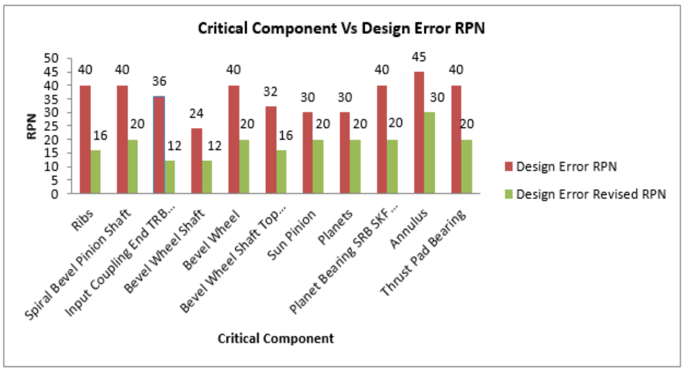


Fig.8: Comparison of Design Error RPN

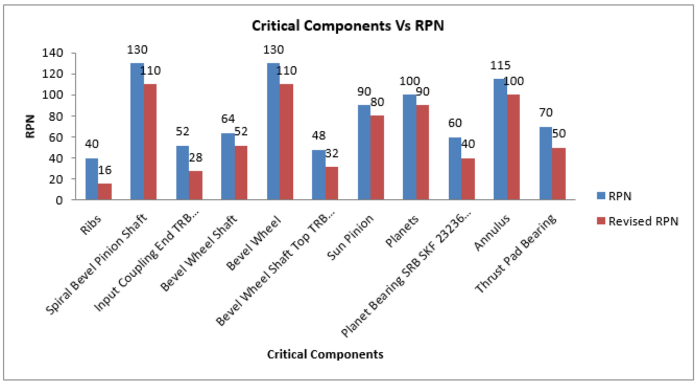


Fig. 9: Comparison of Overall RPN

IV.CONCLUSION

Occurrence number can be used effectively to identify highest contributing root cause to failure. Similar RPN for bevel pinion shaft and bevel wheel before and after implementation of corrective actions indicates that failure of any one of them will result in failure/replacement of other. Results obtained from design tools like FEA, KISSsys, can be compiled and used efficiently in DFMEA to decrease risk of failure and bring robustness in design of gearbox.

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