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Causes of Failure in Vertical Roller Mill Gear Box

S. A. Noonari [1], H. A. Khan [2], A. S. Memon [3], H. Shaikh [4]

[1, 2, 3] *Department of Mechanical Engineering Isra University Hyderabad, Sindh, Pakistan*
[4] *Pakistan Civil Aviation Authority Karachi, Pakistan*

[1] Shoukat.noonari88@yahoo.com

Abstract- The aim of this study to analyze the Failure Mode and Effect Analysis (FMEA) of Vertical Roller Mill (VRM) gearbox at Power Cement Limited Nooriabad Sindh Pakistan. To identify the appropriate corrective action for the failure modes, use the Risk Priority Number (RPN) as an indicator. It is computed on a scale from one to thousand by multiplying the severity, occurrence, and detection ranking levels. Comparing the RPN values of the components, those with an RPN of 40 or higher were deemed crucial components. The value of RPN is high in case of design error of gearbox as result of high RPN. So, the design error of gear box given first priority to be minimized. In case of Raw Material input machine the value of RPN is estimated high but less design error. Quality of raw material that is fed to the machine that is be good and that be fed as per requirement. Mechanical Overload also responsible for failure of sub components the value of RPN is higher due other causes of failure than the value of design error. RPN for the bevel pinion shaft and bevel wheel, both before and after corrective action was put in place, shows that when one of them fails, the others will also fail or need to be replaced. Other factors that might lead to the gearbox of a variable rate machine (VRM) failing include poor design, mechanical overload, debris or contamination, broken connections, inadequate site input, poor heat treatment of raw materials, errors in manufacture or assembly, and inadequate lubrication. In this study it is concluded that Mechanical Overload is responsible for failure of gearbox of vertical roller mill due to the value of RPN. In case of failure of sub components, the value of RPN is higher than other failures. Before and after the completion of corrective steps, the RPN for the bevel pinion shaft and bevel wheel indicates that failure of any one of them will result in failure or replacement of other.

Keywords- Vertical Roller Mill (VRM), Failure Mode and Effect Analysis (FMEA), Risk priority Number (RPN). Power Cement Limited (PCL), Design Error.

I. INTRODUCTION

In the modern era, cement is one of the most important and frequently used materials to construct a building or any infrastructure. The structures of buildings, bridges, roads, etc. are made of cement [1]. Due to the significant annual cement use its importance has been realized in both socioeconomic growth and development. According to the statistics released by the All Pakistan Cement Manufacturers Association (APCMA), By the end of 2023, Pakistan's annual production is projected to reach 99 million tons, up from 83 million tons in the previous year. The industry comprises 26 operational units with an annual production capacity of around 83 million tons. [https://www.google.com/search?q=cement+production+in+Pakistan]. Total production of power cement limited nooriabad in 2023 is 1.9 million [Annual report of power cement limited 2023]. The goal of this paper is to analyse the causes of production variance due to failure in vertical roller mill. The cement production data of 2023 quarterly based is collected from power cement limited. It is reported in table 01 that in the middle quarter 03 of 2023 cement production is low due to shutdown of plant because of failure of vertical roller mill.

Table.1: Quarterly Cement Production 2023

Cement Production	Quarter One	Quarter two	Quarter three	Quarter four	Total production tons	Total production millions
	478746 tons	550282 tons	579971 tons	315994 tons	1,924,996	1.9

The aim of this paper is to analyze the Cause of failure in Vertical Roller mill at Power Cement Limited that is located in Nooriabad District Jamshoro. In Vertical Roller mill there is a defect developed in the grinding equipment that cause the delay in cement production [2]. The analysis was carried out and the number of components were visualized to know the nature of the defect and it's causes. The grinding unit is used to grind the limestone, Calcium carbide, gypsum, phosphorous etc. This is the raw material that is feeded for further process. The Grinding unit having he components that is Rotary Feeder, Separator, Grinding Rollers, RockerArm, Grinding Table, Tension device, Mill stand and Housing. Cement plants are utilizing an expanding number of energy-saving, environmentally friendly and productive cement manufacturing machines as a result of the cement industry's ongoing development and transformation [3].

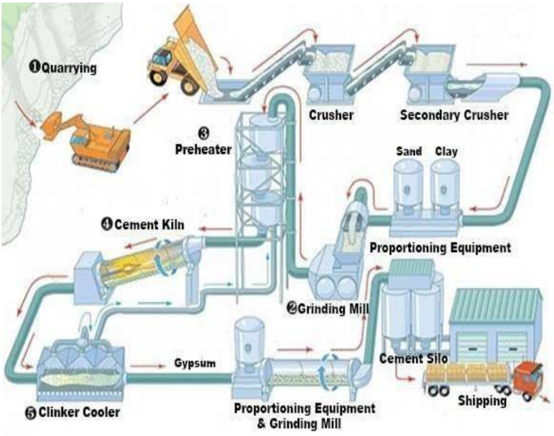

Fig. 1 Working Layout of Cement Plant [website Power Cement]

II. VERTICAL ROLLER MILL

Grinding, Drying and divided are done in one single machine. A vertical roller mill is mostly composed of a separator, grinding roller, rocker arm, grinding table, transmission device, lubricating device, hydraulic pressure device and soon. With its cutting-edge technology, it can perform integrated tasks such as grinding, drying, powder selection, and conveying. It also features low noise, low power consumption, excellent drying capabilities, and a straightforward procedure[4]. The vertical roller mill is innovative, environmentally friendly and efficient. While some systems function solely with a filter and two fans, others are configured with cyclones and three fans. To prevent operational issues, the ducts for gas recirculation and direct kiln gas operation to the filter should always be kept apart. In order to prevent excessive false air intake, the roller mill system requires specific sealing maintenance due to its high negative gas pressure operation. False air rates over 20% over the mill and fan are typical. Recirculating coarse material that falls through the nozzle ring back to the mill inlet is done by an external material circulation system that uses a bucket elevator [5]. When emptying the mill for maintenance, or when using a surge hopper in conjunction with a metal detector bypass, the bucket elevator can be utilized with ease. The mill's size is determined by its grinding capacity for low moisture and by the required gas flow rate for high moisture.

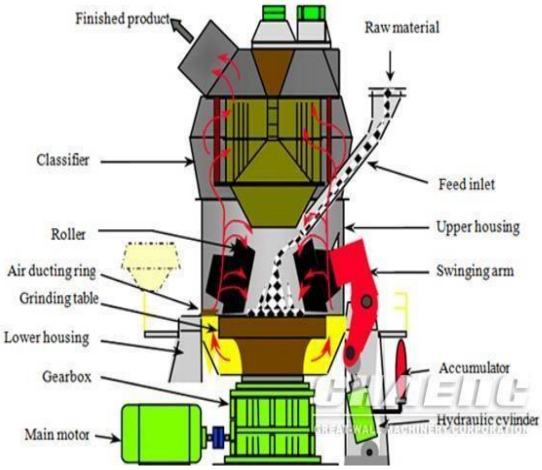

Fig. 2: Vertical Roller Mill
[Power Cement Document]

2.1 Features of Vertical Roller Mill

- Maximum coarse material feed size of 1.000 mm
- The efficient grinding process in a compact machine
- Operation at partial load70 -100%possible
- 20% maximum drying capacity with an extra hot gas generator
- A maximum of 450 °C for the mill inlet temperature
- More specialized maintenance staff required.
- Large grinding capacity in a single machine of up to 550 [t/h].

2.2 Parts of Vertical Roller Mill

The vertical roller Mill is assembled of many parts which are mention in Figure 3

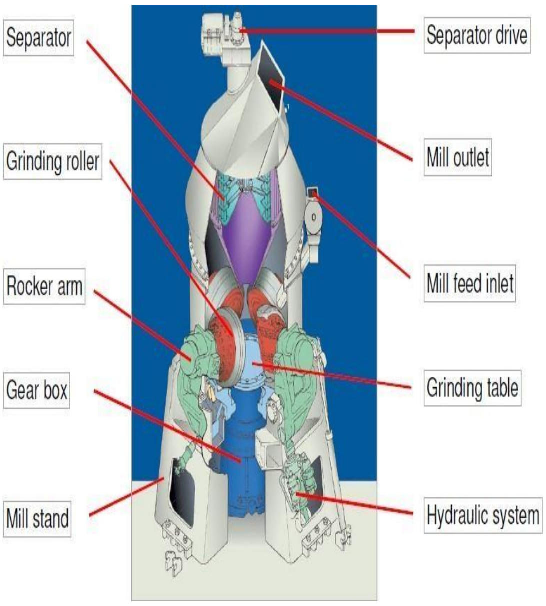

Fig.3. Parts of Vertical Roller Mill [Power Cement Document]

2.3 Working Principle of Vertical Roller Mill

The material bed milling working concept is utilized by both the roller press and the vertical roller mill. Only a small portion of the material particles come into direct contact with the mill's grinding parts during the grinding process; nevertheless, the material particles form a material bed as a result of the grinding parts' action, and as a result of stress transmission and particle interaction, the material particles are cracked, broken, and crushed. For a vertical roller mill the grinding parts are rollers and grinding disc. The rollers are the primary source of the pressure needed for grinding. At present the loading force is mostly created by hydraulic pressure. The center or side of the upper housing is where the material is put onto the grinding disc, and as it moves over the disc, the material layer is created. The grinding process is finished under the extrusion and shear forces between the material and the grinding disk as it moves between them. The heated air from the vertical mill's air inlet and a motor reducer moving disc power the vertical roller mill's operation.

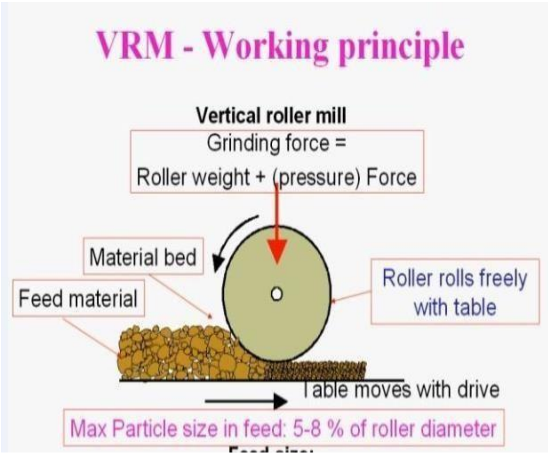

Fig.4: Working Principle of Vertical Roller Mill [Power Cement Document]

Material from the feed opening falls into the center of the grinding disc due to centrifugal force. An annular groove moves the material from the center to the edge of the disc, where it is compacted by broken and crushed material. The process continues to the edge of the grinding disc until the wind rings away and the large particles fall into the disc to be crushed. When materials flow through the upper portion of the separator, guide blades are lowered by the action of the cone bucket, allowing coarse material from a disc to be ground into a fine powder with the help of air. The powder is collected in a dust collector, which functions as a vertical mill for the product. During the drying gas process, the material comes into contact with the shell to get the necessary humidity for dry products. The necessary product thickness can be achieved by varying the speed of the separator rotor and the angle of the guide blade.

2.4 Bevel-Planetary Gearboxes

In the cement and power generation industries, vertical roller mills (VRM) are widely recognized as the most effective method for grinding raw materials. These mills are powered by powerful vertical output shafts and horizontal input shafts for gearboxes I VRM typically uses bevel-helical or bevel-planetary gearboxes. Because its output flange is rigidly attached to the mill grinding table, the gearbox is an essential part of the VRM. The general layout of the VRM is depicted in Fig. 1 with the gearbox at the bottom.

2.5 Parameter Saffecting Productivity of Vertical Roller Mill

One of the key mining equipment is the grinding mill. When grinding materials, a variety of factors affect the grinding mill's output, but the primary ones are the final product's particle size, the material's hardness, humidity, composition, and viscosity, as well as the effectiveness of the equipment's supporting measures. It is necessary to modify the influencing elements after evaluating them in light of the current circumstances.

III. VARIOUS PARTS OF VERTICAL ROLLER MILL

The chances of failure of different parts of VRM exist due to the heavy-duty performed. There are different reasons for the failure of VRM

3.1 The Dam Ring Segment

The dam ring is used for grinding tables on the vertical raw mill or vertical cement mill. It is the key component for the vertical mill. The grinding roller dam ring could control the material flow leaving the grinding zone for the vertical mill by controlling the material bed thickness. The vertical raw mills and vertical cement mills' grinding efficiency can be improved by the dam ring. Furthermore, the dam ring is a consumable cement spare part. The original parts that come with a vertical mill wear out quickly and need to be replaced. Especially if a wear pattern is identified, since these components will soon disintegrate and allow leaks to occur through the mill body.

Fig. 5: New Dam Ring Segment and Worn Out & Deformed Dam Ring Segment [Power Cement Plant]

3.2 Temperature Sensor

Temperature control and monitoring is an important parameter in any cement industry. Since cement manufacturing processes involve harsh environments. So, it is important that the sensors deployed are capable of withstanding strong temperatures.

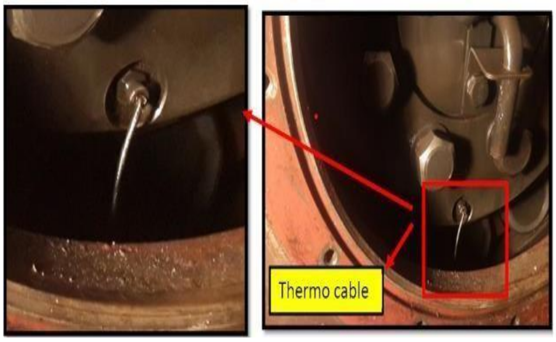

Fig. 6 Thermos Cable Used in VRM
[Power Cement Plant]

3.3 Rollers Bearing

Once the roller press was in use for a few years, the maintenance team made the decision to enhance predictive maintenance by retrofitting an online condition monitoring system. An automated alarm was raised to the operator seven months after the device was put into service due to a variation in the vibration patterns. Inside the rollers were metal ships with a significant number and size. In every roller, the first bearing's outer race has to pit, and the cage is also worn. The roller bearing housing is heavily contaminated.

Fig. 7 Roller Bearing
[Power Cement Plant]

All rollers should have their bearings replaced in accordance with their lifespan since metal ships appear on the roller housing and there is obvious pitting on the outer race. The oil tank and roller housing need to be thoroughly cleaned in addition to having the oil changed.

Fig. 8: Metal Ships Inside the Roller Bearings
[Power Cement Plant]

3.4 Raw Mill Scraper Plate

The scraper's wear plate and base plate are highly deformed. There are some missed wear plates. Two of the scraper platform's liner plates are warped as a result of the loose bolts. Remove the 2 defective lining plates for the scraper platform. Reinstall the worn-out wear plate and erect the ones that were missing. To protect the mobile scraper's blades from touch, retighten the fixation bolts holding the bottom lines of the scraper. Keep a minimum of 30 mm space between the stationary linings of the scraper and its moveable blades.

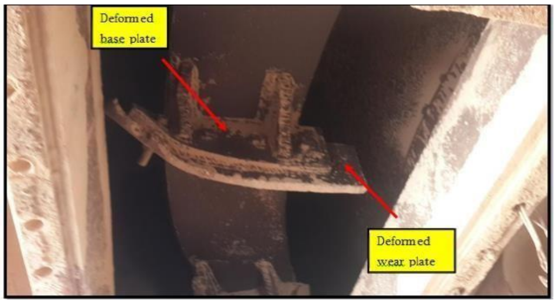

Fig. 9 VRM Scraper Deformed Wear Plate
[Power Cement Plant]

3.5 Hot Gas Nozzle Wanes

The guide vanes have a worn-out condition. The hot gas nozzles' flange is not properly supported. Use hardox steel to replace the worn-out guide vanes. Due to inadequate supporting, reposition the hot gas flange. Blind directs the direction of the vanes to save wear.

Fig. 10 VRM Hot Gas Nozzle Wanes
[Power Cement Plant]

3.6 Grinding Roll Hub

The hub mounted on the roll shaft is a crucial part of the grinding roll assembly, and the effectiveness and condition of the vertical roller mill are directly impacted by the hub's quality. Typically, the conical structure design is incorporated between the hub and the roller sleeve to enable future disassembly and maintenance. It is cast with high-quality alloy material which has good wear resistance and is difficult to break. Excellent workmanship smooth and flat surface which is conducive to improving the grinding efficiency. Before leaving the factory flaw detection shall be carried out on the force bearing surface to ensure that it has a strong force-bearing capacity and can operate safely and stably.

Fig. 11 VRM Grinding roller
[Power Cement Plant]

3.7 Fatigue on VRM Rocker Arm

One of the essential components of a vertical roller mill is the rocker arm, whose primary function is to transmit the hydraulic cylinders pressure to the grinding roller so that it becomes the feed bed's grinding force. At a short interval, a newly mounted rocker arm hook joint out of four rocker arms on the vertical raw mill (VRM)of a cement plant was found broken, just of recently the head of the hydraulic jack piston was broken which was replaced with a hydraulic jack. The rocker's arm is actuated by hydraulic jack and its unit.

Fig. 12 VRM Rocker Arm [Power Cement Plant]

3.8 The Failure of VRM Separator

A common piece of machinery in cement plants' raw mill and grinding systems is the cement mill separator, also known as the cement separator. The separator's job is to separate the finer from the coarser particles in order to prevent material condensation, prevent over grinding in the mill, and increase the grinding efficiency of the milling system.

Fig. 13 The Separate or of VRM [Power Cement Plant]

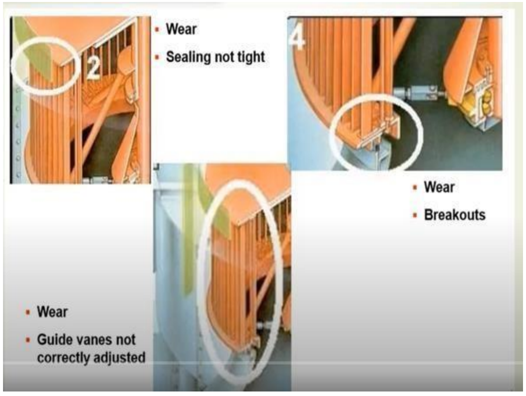

Fig. 14 Potential Problems of Separator of VRM
[Power Cement Plant]

3.9 Causes of Failure of Vertical Roller Mill Gear Box

During the Working of vertical roller mill there are few factors highlighted in table 02 which causes failure of Vertical roller mill and also discuss its remedies

Table. 02: Failure Causes and Remedies

S. No	Factor	Explanation	Cause of failure	Remedies
01	Mill feed size	The performance of a vertical mill is affected by the size distribution and particle size of the mill feed material.	The mill may become unstable and vibrate more than usual if the size and distribution of the feed are abnormal. In any event, a large feed size will lower the mill's production rate. Vibrations and unsteadiness in the grinding bed can result from too fine particles in the feed material or separator rejection.	Usually, the crusher's bars can be adjusted to reduce the mill feed size, or a recycle screen can be installed.

02	Feed to Mill	The primary goal is to feed the mill consistently.	Feed rate variations intensify the mill's unsteady operation and, in the worst case scenario, cause mill stoppages. If sticky materials are not handled properly, they might cause issues with hopper extraction and jam transfer points, which can eventually lead to variations in feed rates.	There must be no metal fragments in the mill feed material. Increased metal fragments cause the diverting gate to operate more frequently, which varies the feed. The grinding table's middle is filled with material. The feed is then uniformly distributed to the grinding rollers by centrifugal force.
03	Hydraulic Pressure	The mill's material load should be matched with the hydraulic pressure. In order to provide adequate cushioning, the accumulator must be charged with the necessary nitrogen pressure.	significant circulating load, significant pressure loss, and possible mill overfilling will arise from insufficient hydraulic pressure for the mill load.	A weakening of the bed and greater vibration are the results of applying too much hydraulic pressure for the load.
04	Dam Ring	To account for the wear that results from frequent grinding on tables and roller liners, dam rings are changed based on the lifespan of the components. It is also used to regulate the bed depth, which affects vibration and grinding effectiveness.	Material retention on the table is impacted by dam ring height.	increased bed depth, an excessive dam ring, ineffective grinding, and high power consumption. excessive vibration, poor bed depth, excessive external circulating load, and low dam ring.

IV. RESULTS AND DISCUSSION

In this section failure mode and analysis, the causes of Vertical roller mill gear box are discussed

4.1 Failure Modes and Effect Analysis

Failure Modes and Effects Analysis (FMEA) is a proactive, systematic approach to process evaluation that identifies potential failure sites and modes as well as the relative impacts of various failures to determine which process components most require modification. With the use of the FMEA tool, we can stop System, Product, and Process issues before they start. By finding system, product, and process improvements early in the development cycle, it lowers costs. It gives precedence to acts that lower the likelihood of failure.

4.2 FMEA Analyses

- Potential reasons for a machine or product to fail
- possible consequences of failing
- Possible reasons for failure (such as flaws in the material or the design)
- Deficits in manufacturing and processing, service circumstances, etc.)
- evaluates existing process safeguards,
- establishes a risk priority metric

4.3 Procedure for Conducting FMEA

4.3.1 Severity of failure mode

The importance of an effect of a failure mode is measured by its severity. Application of Design Failure Modes and Effect Analysis (DFMEA) to Vertical Roller Mill Gearbox The impact of the failure on the gearbox's performance determines the severity scale. Mean Time to Repair can be used to define severity ratings (MTTR). When opposed to failure modes with high MTTR, low MTTR failure modes might bethought of as less severe. The severity standards utilized in this study are discussed in Table 3.

Table.03: Values and Description of Severity

Value	Classification	Description
1	None	No effect on gear box operation
2	Minor Failure	Gear box in operable with minimal interface
3	Low Failure	Gear box in operable with significant degradation of performance
4	Critical failure	Gear box inoperable with equipment damage
5	Catastrophic failure	Gear box inoperable with destructive failure without warning

4.3.2 Occurrence

The possibility of one of the particular causes or mechanisms happening is called an occurrence. This step requires examining the reason behind a failure and the frequency of its occurrences. This can be accomplished by examining related items or processes and the documented failures associated with them. A design weakness is considered the cause of the failure. The occurrence rating standards utilized in this study are discussed in Table 4

Table. 04: Values and Description of Occurrence

Value	Classification	Example	Description
5	Inventible	Occasional Failure	Failure is unavoidable.
4	Frequent	Frequent Failure	failure that keeps happening on a regular basis
3	Low	Occasional Failure	Unexpected but not always frequent failures
2	Minor	Few Failure	Rare or irregular failure
1	None	Failure unlikely	Almost no failure occurs

4.3.3 Detection

The process of detecting a potential vulnerability or future mode of failure before a piece or component leaves the manufacturing operation or assembly location involves estimating how likely it is that the current process control will find it. When evaluating the ability of the present process control to halt the shipment of the component with this nonconformity, assume that the breakdown has occurred. Defining detection levels for a gearbox is very subjective.

Based on past experiences of failure occurrence and detection. Below is an illustration of how to rank the detection Table.05

Table. 05: Values and Description of Detection

Value	Classification	Description
5	Impossible	Root Causes not detected
4	Low	Low chances to detect root causes
3	Medium	Moderate chances to detect root causes
2	High	High chance to detect root causes
1	Almost certain or very high	Root Causes are easily detected

4.3.4 Risk Priority Number (RPN)

The indicator used to choose the best course of action for correcting failure modes is the Risk Priority Numbers. It is computed on a scale from one to thousand by multiplying the severity, occurrence, and detection ranking levels. The RPN is readily calculated by multiplying the severity, occurrence, and detection numbers once they have been determined.

RPN=Severity × Occurrence ×Detection

There is never a better RPN than a little RPN. It is possible to compute the RPN just for the design process or for the complete process. Finding the regions that need the most attention is simple once the calculation is complete. The engineering team generates the RPN and focused on the solution of failure modes.

Sample calculation for stripping process gear box is given below

The system calculates the risk priority number for each failure mode of a function as follows:

Step 1. It chooses the effect with the greatest severity S (highest number of valuation points).

Step 2. It chooses the cause with the greatest probability of occurrence O (highest number of valuation points).

Step 3. The system selects the detection action with the highest probability of detection D among all those assigned, provided that the action has at least the status Confirmed, if one or more detection actions are linked to the failure cause.

Step4. From the table values of severity, occurrence and detection values are calculated and they were obtained as 5, 5 and 1respectively.

Step5. RPN value calculated as

R.P.N.=S ×O ×D

Considering S =5, O=5and D =1 The R.P.N. =5 ×5 ×1 =25

Finding key components, or components with high RPN, comes next after determining the RPN for each component. The components with RPN values equal to or more than 40 were deemed important components based on a comparison of their RPN values.

4.4 Root Causes of Failure of Gearbox

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

4.5 Graph Between RPN and Causes

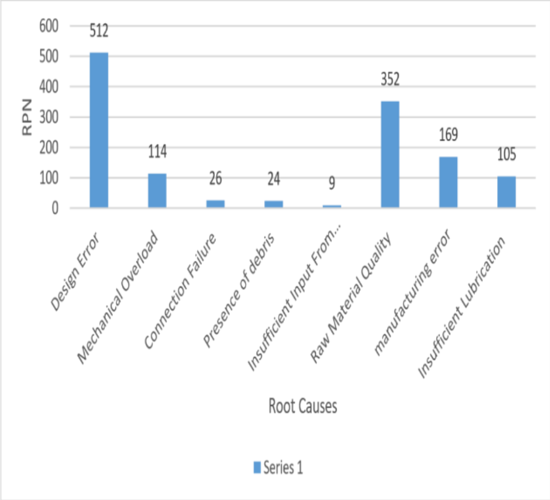

Fig. 15 Graph Between RPN and Causes

Design errors are the most common and the primary cause of failure, as shown by Fig. 15. To lessen the possibility of design faults for crucial components, remedial action was therefore done.

4.6 Graph Between RPN and Critical Components

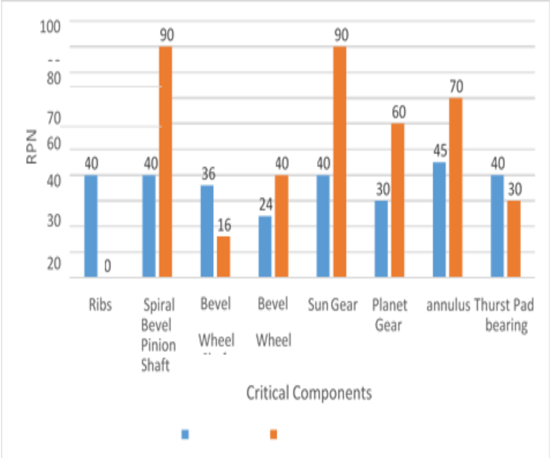

Fig. 16 Graph between RPN and Critical Components

Figure 16 shows the contribution of design error RPN in the total RPN of critical components. The corrective actions to reduce design errors for critical components are tabulated in Table 4

Figure 16 shows the contribution of design error RPN in the total RPN of critical components. The corrective actions to reduce design errors for critical components are tabulated in Table 6

Table .06 Corrective Actions

Critical Components	**Corrective Actions**
Ribs	FEA is used for both static and modal analysis of the casing. Sufficient rib reinforcement gives the case greater rigidity.
Spiral Bevel Pinion Shaft	The Key verifies that the tooth stresses correspond to the necessary service factor. After using FE to assess the shaft for fatigue stresses, it is determined that the design is safe. Review of the drawing checklist
Bevel Wheel Shaft	Through FEA, a static study of the shaft is conducted with various load scenarios and fatigue stresses, and it is determined that the design is safe.
Bevel Wheel	The Key verifies that the tooth stresses correspond to the necessary service factor. Through FEA analysis, the wheel's fatigue stresses are determined, and the design is deemed safe. Review of the drawing checklist
Sun Gear	FEA analyzes the bearing set for both static and dynamic axials thrust load. It is discovered that both the static and dynamic axial pressure on the pads are within the permitted range.
Planet Gear	The Key verifies that the tooth stresses correspond to the necessary service factor. Through FEA analysis, the wheel's fatigue stresses are determined, and the design is deemed safe. Review of the drawing checklist
Annulus	The Key verifies that the tooth stresses correspond to the necessary service factor. Through FEA analysis, the wheel's fatigue stresses are determined, and the design is deemed safe. Review of the drawing checklist
Thrust Pad Bearing	FEA is used to study the bearing system for both static and dynamic axials thrust loads. It is discovered that both the static and dynamic axial pressure on the pads are within the permitted range.

V. CONCLUSION

The aim of this study to investigate the Failure Mode and Effect Analysis (FMEA) of Vertical Roller Mill (VRM) gearbox at power cement limited Nooriabad Sindh Pakistan.

It is concluded that

- Mechanical Overload responsible for failure of gearbox of vertical roller mill due to the value of RPN.
- In case of failure of sub components, the value of RPN is higher than other failures.
- 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.
- The root causes of failure of gearbox of Vertical Roll Mill.
  i. Design Error
  ii. Mechanical Overload
  iii. Presence of debris/Contamination
  iv. Connection Failure
  v. The insufficient Input from Site
  vi. Raw Material Quality/Heat Treatment
  vii. Manufacturing or assembly Error
  viii. Insufficient Lubrication

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