Defect Reduction in Fabricated Components using Root-Cause Analysis

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***Abstract*— Structural items include various fabricated and machined items. Various types of fabrication processes like welding, bending, riveting etc. and machining processes like grinding, milling and turning are carried out to produce different components. When these components are assembled to have final product, lots of problems are faced. Problems like restricted movements of one component relative to other, wear of components, failure of component in service etc. arise. So to avoid this, Root-Cause Analysis of these defects is carried out and production process is modified as per the results of analysis. Root-Cause Analysis consists of Why-why Analysis, Process sheets preparation, Design of Jigs and Fixtures if necessary and Design of Inspection gauges and templates for inspection purpose. Why – why analysis is also known as why tree and it is supposedly a simple form of Root-Cause Analysis. By repeatedly asking the question 'Why?', identification of issues and symptoms that can lead to root cause is done.**

Keywords*— Root-Cause Analysis(RCA), 5-Why Anaysis, Cause and Effect Diagram, American Gear Manufacturers Association (AGMA), Critical to Quality (CTQ), Fault Tree Analysis(FTA).

I. Introduction

The fast changing economic conditions such as global competition, declining profit margin, customer demand for high quality product, product variety and reduced lead–time etc. induce a major impact on manufacturing industries. Components are produced using various types of fabrication processes like welding, bending, riveting etc. and machining processes like grinding, milling and turning. While doing this, problems like restricted movements of one component relative to other, wear of components, failure of component in service etc. arise. So to avoid this, Root-Cause Analysis of these defects is carried out and production process is modified as per the results of analysis. Analyzing failures is a critical process in determining the physical root causes of problems. The process is complex, draws upon many different technical disciplines, and uses a variety of observation, inspection, and laboratory techniques.

II. Process Engineering

A. Process Sheet

Process sheet is a document which specifies standard practices those are needed to be followed in order to reduce non-conformities during fabrication and machining. It also specifies the critical dimensions i.e. critical to quality (CTQ) dimensions with stringent tolerances.

Process sheet includes following parameters:

i. General practice to be followed during cutting of sheets and plates.

ii. General practice to be followed during welding and drilling operation.

iii. Number of processes involved in manufacturing of components and Sequence of those manufacturing processes.

iv. Deciding parameters like feed, speed and depth of cut in turning operation.

v. Deciding parameters like current, shielding gas, material of electrode, root gap, electrode gap, voltage and type of currents i.e. AC or DC.

vi. Identification of CTQ (Critical to Quality) and correct process to achieve CTQ.

vii. 3 D representation of parts for better visualization purpose.

viii. Tests to be carried out like die penetration, blue matching and impact tests.

ix. General instructions to achieve the geometrical tolerances and specified dimensions.

B. Jig, Fixtures and Inspection Gauges

When the work piece is loaded on a machine tool, then it needs to be fixed so that accurate results are obtained. For this purpose, jigs and fixtures are to be designed to hold the work piece. Jig and fixtures are production work holding devices used to manufacture duplicate parts accurately. The correct relationship and alignment between the tool and work piece must be maintained. To do this, a jig or fixture is designed and built to hold, support and locate every part to ensure that each is machined within specified limits.

i. **Jig**: A jig is a special device that holds, supports or is placed on the part to be machined. It only locates and holds the work piece but also guides the cutting tool.

ii. **Fixture**: A fixture is a production tool that locates, holds and supports the work securely so the required machining

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operations can be performed. A fixture should be securely fastened to the table of machine upon which the work is done.

iii. **Gauges**: Gauges are to be designed for inspection purposes to check how accurate the component is produced. Gauges are of two types, GO and NO GO gauge.

iv. **Taylor's Principle:**

a. GO limit designation is applied to maximum material limit i.e. upper limit of shaft and lower limit of hole.

b. NO GO limit designation is applied to minimum material limit i.e. lower limit of shaft and upper limit of hole [1]

III. Root-Cause Analysis Tools And Techniques

Root-Cause Analysis (RCA) is a method that is used to address a problem or non-conformance.

Introduction

It is used for elimination of the cause and prevention of the problem from recurring. Root-Cause analysis is a completely separate process to incident management and immediate corrective action, although they are often completed in close proximity. Root-Cause Analysis cycle is shown in Fig. 1 below.

RCA is simply the application of a series of well known, common sense techniques which can produce a systematic, qualified and documented approach to the identification, understanding and resolution of underlying causes. Fig. 1 shows a typical Root-Cause Analysis Cycle.

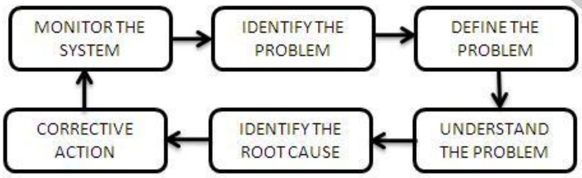

Fig. 1. Root Cause Analysis Cycle [1]

i. Identify the Problem: Identify the currently occurring situation. Determine the impact of the deficiency on the component, product, system and customer.

ii. Define the Problem: Try and use smart principles, i.e. Specify, Measure, Actions oriented, Realistic, Time constrained. Unless the problem is defined accurately, the RCA whole process may be prone to failure.

iii. Understand the Problem: Check the information, obtaining the real data regarding the problem, gaining a clear understanding the issues. This is when the various tools and techniques, such as cause effect, brain storming etc. can be used.

iv. Identify the Root Cause: Analyze the problem to identify the causes.

v. Corrective Action: List the possible solutions to mitigate and prevent recurrences of problem. Generate the alternatives. Develop implementation plan.

vi. Monitor the System: Test the corrective actions in pilot study. Measure the effectiveness of change. Validate improvements. Verify that problem is corrected and improves customer satisfaction.

A. *5 Why's Analysis (Gemba Gembutsu)*

The Five Whys approach to root-cause analysis is often used for investigations into equipment failure events and workplace safety incidents. The 5-Why method helps to determine the cause-effect relationships in a problem or a failure event.

It can be used whenever the real cause of a problem or situation is not clear. Using the 5-Whys is a simple way to try solving a stated problem without a large detailed investigation requiring many resources. When problems involve human factors this method is the least stressful on participants. It is one of the simplest investigation tools easily completed without statistical analysis. Also known as a Why Tree, it is supposedly a simple form of root cause analysis. By repeatedly asking the question, 'Why?', identification of issues and symptoms that can lead to the root cause is done. The 5-Why method (Refer Fig. 2) of root cause analysis deals with how the sequential causes of a failure event arose and it identifies the cause-effect failure path. 'Why' is asked to find each preceding trigger until root cause of the incident is found out. Unfortunately it is easy to arrive at the wrong conclusion. A Why question can be answered with multiple answers and unless there is evidence that indicates which answer is right, there are chances of getting the wrong failure path. This can be avoided by adopting some simple rules and practices of 5 – Why Analysis [2]. Fig. 2 shows diagram of 5 – Why Analysis method.

Fig. 2. 5 – Why Analysis Method [2]

B. *The Pareto Analysis*

Pareto analysis is an easy to use technique that helps to choose the most effective changes to make. It uses the Pareto principle i.e. the idea that by doing 20 % of the work, 80 % of the advantage of doing the entire job can be generated. Pareto analysis is a formal technique for finding the changes that will give the biggest benefits. Fig. 3 shows how significant few and insignificant many cab be identified and it shows importance of 80 % line [2].

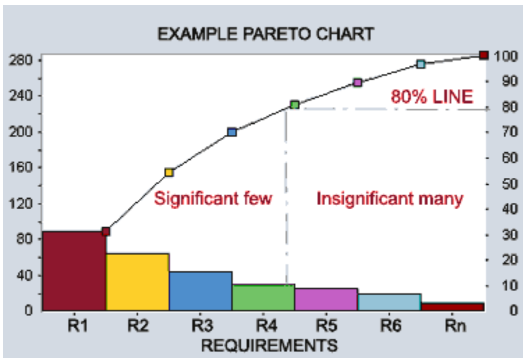

Fig. 3. Pareto Principle [2]

C. Cause and Effect Diagram

It is also known as Fishbone diagram and Ishikawa Diagram. This useful technique is used for more complex RCAs. This type of diagram identifies all the potential processes and factors that could contribute to a problem. Fig. 4 shows a basic Cause and effect diagram which indicates how equipment, process, people, materials, environment and management affect the system.

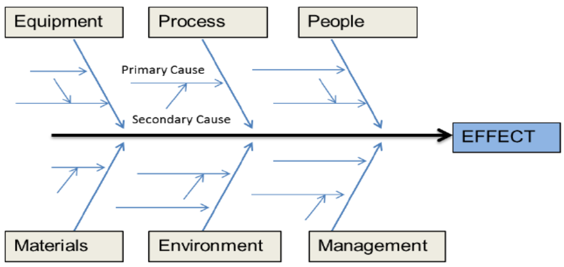

Fig. 4. Cause and Effect Diagram (Fishbone Diagram) [3]

E. Brain Storming

This includes following techniques

a. Collect as many ideas as possible from all the participants.
b. No secondary discussions should take place during the brain storming activities.
c. Do build on other's ideas.
d. Set a time limit for brain storming.

F. Fault Tree Analysis

This is a graphical method that provides a systematic description of the combinations of possible occurrences in a system, which can result in an undesirable outcome [3].

IV. CASE STUDY

The following issues are reported on gearbox model GH2 125 X manufactured by Magtorq India Pvt. Ltd.

A. Grease leak from input side of gearbox.

B. Damage to the output pinion teeth.

A. Grease leak from input side of gearbox

Gear box model GH2 125 X manufactured by Magtorq has a problem of grease leak. Figure 5 shows c/s of gear box and also indicates location of grease leak. So to avoid this, root-cause analysis is to be performed and the problem is solved.

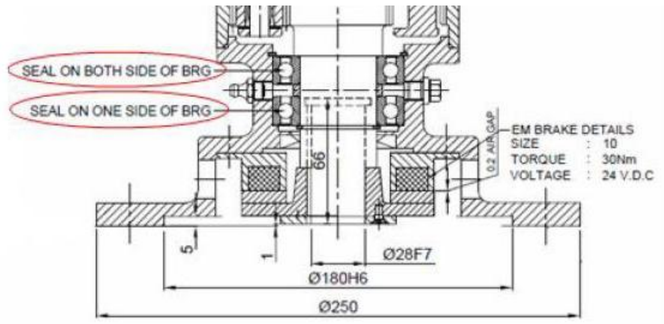

Fig. 5. Gear Box Cross Sectional view [4]

1) Possible causes for grease leak

TABLE I. POSSIBLE CAUSES [4]

Sr. No.	***Possible Causes***	***Possibility of occurrence***
1	Damage to seal lip during assembly	As the gearbox has operated for a reasonable period without leak, this is not expected.
2	Excess pressure build up inside	As the gearbox has operated for a reasonable period without leak, this is not expected. However the grease quantity can be reduced for future units to avoid pressure build up and proper breathing of gearbox.
3	Oil seal lip wear	Lip wear happens during service and hence the life of oil seal is limited. It needs to be replaced periodically. Periodic seal replacement plan to be implemented.
4	Seal running track wear	The seal running track on the shaft doesn't show any damage. The seal track hardness and geometry are as required for the seal used
5	Seal material	The seal material used is NBR. This is suitable for the operating temperature range. A change of material to Viton would give extended life at higher temperatures. However suitability for lower temperature to be checked
6	Sealing arrangement	The sealing arrangement is suitable for the application. However additional provisions can be made to prevent loss of lubricant due to seal failure

2) Expected Root-Cause of Seal Failure

The seal has served for certain period though the actual service period is not known. The lip wear due to service and the pressure build up inside the gearbox due to completely filled grease have caused the leakage.

3) Corrective Action

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Check the service period before the grease leakage was observed. Periodically inspect for grease leak. Change oil seal if leak is observed.

4) Preventive Action

In order to extend the seal replacement period and to prevent excessive grease leakage in case of seal wear, the following modifications are recommended.

i. Change the input shaft bearings to sealed type. The space between the bearings and that between the oil seal and the bearing are to be filled with grease.
ii. Reduce grease volume to give space for grease expansion and breathing during operation.
iii. Redesign gearbox to an 'L' type one so that the pressure of grease column on oil seal will be reduced [4].

B. Output Pinion Damage

Failure of pinion is reported of gear box. Fig. 6 and 7 show the severity of problem of wear on gear (pinion). Slew gear meshing with pinion remained intact. No wear observed.

Fig. 6. Pinion Completely Worn out [4]

Fig. 7. Dirt around the Pinion [4]

1) Failure Details

The below figure 8 indicates severe wear on the tooth flank. Typical wear appearances are shown in AGMA 1010. One example is shown below.

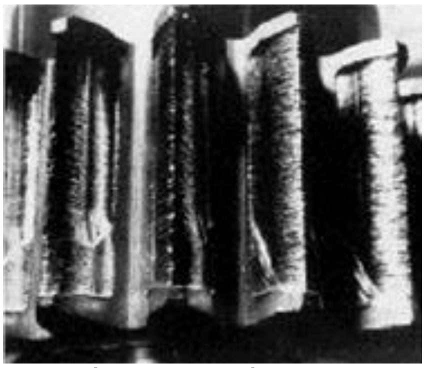

Fig. 8. Severe Abrasion Wear as Shown in AGMA 1010 [5]

Usually, the wear is negligible at the pitch point and increases towards the tip and root. This is due to the increase in sliding velocity. The wear volume is proportional to the contact pressure, sliding velocity and sliding distance.
This mechanism is evident from the pinion that is partially worn out. Figure 9 shows cross section of gear tooth. Recess due to wear is observed at the initial stage. Later on, this recess goes on increasing causing wear of pinion.

Fig. 9. Pinion with Line near the Pitch Line [5]

Every tooth mesh has some amount of wear in service. Those are usually very low with good lubrication and are of the order of a few microns. Increased amount of wear causes failure. This could be due to the following.

i. Lack of Lubrication film.
ii. Abrasion due to ingress of foreign particles
iii. Corrosion
iv. Overloads

2) Possible Causes

The following causes are identified and examined.

a. Overloads

The specified maximum continuous operational and peak operational torque values are considered for the design of gear teeth. It is assumed that the input torque from the motor is within the specified values. The brake is very rarely applied and is not expected to exert over loads. Hence this possibility is ruled out.

b. Design Aspects

The design stress reserve margins are reviewed and again recalculated for the used pinion material and reported. The same is reproduced below.

TABLE II. PITTING SAFETY FACTOR [5]

Torque/ Life	Through Hardened & Nitrided Pinion		Through Hardened Pinion (Not - Nitrided)		Carburised Pinion	
	Pinion	Gear	Pinion	Gear	Pinion	Gear
90 Nm/ 26214hrs	2.32	1.0	1.55	1.34	6.61	1.68
234 Nm/ 372 hrs	1.01	1.0	1.04	1.19	4.33	1.43

The above values are based on pitting criteria and not for wear. Through hardened and nitrided pinion is currently used. A through hardened pinion without nitriding also shows sufficient design margin. A case carburized pinion shows much higher design margin compared to others and hence it is recommended to use it for future units as an improvement [5].

c. Material and Heat Treatment

The raw material test reports of the pinions are reviewed and ensured that those are as per the specification requirements. The chemical, mechanical and nitriding hardness (specimen treated with the same batch).

In addition to the above, the failed pinions are further tested for the surface hardness. One of the pinion shows lower surface hardness compared to the other. As per table III, a pinion without nitriding and with just through hardening also gives sufficient design margin. Hence the surface hardness measured on the damaged pinions is not a cause for concern.

As per AGMA 2004, the minimum surface hardness required is 46 HRC. See table III from AGMA below. The steel equivalent to En24 is 4340.

TABLE III. MINIMUM SURFACE HARDNESS [5]

Steel Type	**Minimum Surface Hardness**	
	HR15N	**HRC**
4140	85	48
4150	85	48
4340	84	46
Nitralloy	90	60
EN40B, EN40C, 31CrMoV9	89	58

46 HRC is about 458 HV. Similar value is specified in AGMA 2101 also as a minimum requirement for through hardened and nitrided pinion.

Drawing for the pinion currently specifies the surface hardness as 650 HV. This shall be considered as the upper limit and the acceptable lower limit shall be considered as 460 HV as per AGMA requirement. In addition to the above, as per some of the literatures available on nitriding of En 24 or equivalent type of steel, the expected surface hardness is between 460 to 650 HV for the specified core hardness of about 300 BHN.

Hence the measurements of surface hardness on all damaged pinions are within acceptable limits based on the strength calculation.

d. Lubrication

Gear mesh needs to be lubricated to minimize wear and subsequent damage. The photographs (Fig.6 and 7) show bright metal particles and plastic flow. This is due to insufficient lubrication and thereby increased mesh temperature. Hence lack of lubrication is a potential cause for failure.

e. Abrasion

The above photograph (Fig.6 and 7) show a lot of dust around the pinion. This can contribute to abrasive wear**.**

f. Corrosion

If the pinion and slew gear are directly exposed to corrosive atmosphere, this would lead to corrosion and can accelerate the wear rate. This possibility is to be checked before eliminating [5].

g. Centre Distance Due to Assembly or Structural Deformation

The pinion in figure 6 and 7 show a linear depression at the tooth flank near the pitch line. The pinions also show visually higher wear between the tip and the pitch line. Check and ensure that this is not caused by centre distance error or structural deformations. It is assumed that the structure is designed with sufficient rigidity, the pinion and slew gear are assembled at the correct centre distance and no slip movement happened to pinion or slew gear due to load. The wear and contact depth are measured to check this and are found as expected. See figure 10 below. Hence these causes are eliminated.

Fig. 10. Depth of Wear Measurement [5]

The tip to root clearance between pinion tooth and slew gear tooth is expected to be about 1.25 to 2 mm when the gears are at correct centre distance. This may be checked during assembly.

h. Reverse Rotation

Reverse rotation of the drive train from antenna to the motor could cause the brake to slip. The whole brake slip torque could be applied to the pinion and gearbox during this. No such incidents or symptoms have been reported and hence is eliminated as a cause.

i. Effect of Varying Wind Load

The pinions tooth surfaces indicate fretting. This happens due to the continuous action of varying wind at the tooth contact. Wear happens due to this in combination with corrosion in the absence of lubricant. larger antennas have counter torque operation to avoid this. This also calls for adequate lubrication**.**

j. Pinion and Slew Gear Tooth Mesh Misalignment

The contact patterns on the failed pinions show full face contact though the pinion shows that the contact is shifted towards one end of the pinion. This may be checked and corrected at the time of assembly. However this can't be a cause for the failure and hence eliminated [6].

k. Why Pinion Suffered More Than Slew Gear

Typical gear calculations are done based on failure modes such as pitting and bending under defined operating conditions with proper lubrication. The calculated and reported safety margins are based on these failure modes. As explained above, the failure mechanism here is due to wear and not pitting or bending.

Some of the major factors influencing wear volume are; lubricant film thickness, contact pressure, sliding distance and the number of load cycles to which the mesh is subjected to. With almost 10:1 ratio, the pinion tooth gets loaded 10 times more than the slew gear teeth. This in addition to the increased mesh temperature due to lack of lubrication causes the pinion to fail faster. The slew gear teeth get more time to dissipate the heat as compared to pinion before it is loaded again.

The slew gear drawing shows the material as C45. The relative hardness also can influence the slew gear wear and hence it needs to be checked. The flank hardness of the slew gear is informed as 28-32 RC [6].

l. Corrective Action

a. It is suggested to define and implement a periodic maintenance and inspection plan to detect the condition of gearbox and slew gear on all installations.
b. This also helps to decide on the retrofit of corrective actions on other units in service. Apply lubricant more frequently and make sure that grease is present always on the teeth surface.

m. Preventive Action

a. An automatic grease lubrication system is suggested.
b. It is suggested to check the effectiveness of the protection cover to prevent dust ingress to the pinion and slew gear mesh, if not already available.
c. It is suggested to check the effectiveness of the protection cover against direct exposure of pinion and slew gear teeth to atmosphere.
d. A case carburized pinion shows much higher design margin compared to others and hence it is recommended to use it for future units.
e. It is suggested to specify the surface hardness of nitrided En 24 pinion as 460 to 650 HV on the drawing to give clear guidance on acceptance limits and avoid confusion.
f. It is suggested to define and implement a periodic maintenance and inspection plan to detect the condition of gearbox and slew gear on all installations.
g. Check tooth alignment and contact pattern during assembly.
h. Check for correct centre distance during assembly. The root clearance may be checked and recorded in addition to backlash.
i. Apply anticorrosive coating on the slew gear teeth. Slew gear manufacturers usually do this if demanded [7].

n. Conclusion

Various aspects of the complaints on grease leak and pinion tooth failure have been reviewed. Possible causes are analyzed and potential causes are identified. Corrective and preventive action plans are suggested.

V. ADVANTAGES OF ROOT-CAUSE ANALYSIS

The Advantages of Root-Cause Analysis are as follows

i. A system of problem solving methods aimed at identifying the root causes of the problems or incidents.
ii. By directing corrective measures at root causes, it is hoped that the likelihood of problem recurrence will be minimized.
iii. It is an easy exercise to use and apply.

V. CONCLUSION

The approach presented in this paper gives an analytical methodology to perform the root cause diagnosis of product service failures. The solution offered here gives interaction of design, process parameters and machines. The root cause and generate better and more comprehensive solutions than could be achieved by conventional brainstorming. The 5-Why root cause analysis method is simple in concept but requires real evidence, sure logic and great discipline in its use to find the root cause of a failure event or problem. 5-Why Table to the true root cause can be completed only if Why Tree for the occurrence is available. There are many incidents and events that can cause the top failure and all the causes and effects have to be found out. If the earlier found out causes go in the wrong direction, then the wrong things will be fixed and root causes will leave behind. The missed causes will sit in the business awaiting the next opportunity to instigate more strife and trouble.

REFERENCES

[1] Chetan Shrouti, Pasquale Franciosa, Darec Ceglerek, " Root Cause Analysis of Product Service Failure Using Computer Experimentation Technique ", Science Direct 2nd International Through-life Engineering Services Conference, 2013, pp. 44 – 49.

[2] Mike Sondalini, " Understanding How to use The 5-Whys for Root Cause Analysis", Plant, Equipment and Reliability Improvement, 1 Day Training Program, L & T, Pune, Date: 11/07/2013.

[3] Eyal Dassau and Daniel Lewin, " Optimization-based Root Cause Analysis" , Elsevier, 9th International Symposium on Process Systems Engineering, 2006, pp. 943 – 948.

[4] Geoff Vorley, " Root-Cause Analysis", Quality Management 1 Day Training Program, L & T, Pune, Date: 17/09/2013.

[5] James J. Rooney and Lee N. Vanden Heuvel, " Root Cause Analysis for Beginners", Quality Progress 1 Day Training Program, L & T, Pune, Date: 22/09/2013.

[6] M.A.Kenawy, A.M.Abdel-Fattah, N.Okasha and M.EL-Gazery, " Mechanical and Structural Properties of Ductile C.I." Egypt Journal, vol. 24, 2001, pp. 151-159.

[7] X. Zhang, J. Zevenbergen, T. Benedictus, " Corrosion Studies on Casting Steel in CO2 Storage Environments", Energy Procedia, vol. 37, 2013, pp. 5816 – 5822.