Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 3, March : 2023

A Review of Fundamental Shaft Failure Analysis

Shibaprasad Parida[1], Soumyaranjan Swain[2], Sanjaya Kumar Raj[3*]

[1]Fourth Yea, B.Tech, Department of Mechanical Engineering, Nalanda Institute of Technology, Buddhist Villa, Chandaka, Bhubaneswar, 752014
[2]Fourth Yea, B.Tech, Department of Mechanical Engineering, Nalanda Institute of Technology, Buddhist Villa, Chandaka, Bhubaneswar, 752014
[3]Asst Professor, Department of Mechanical Engineering, Nalanda Institute of Technology, Buddhist Villa, Chandaka, Bhubaneswar, 752014*

*Corresponding Author- sanjayakumarraj@thenalanda.com

Abstract - *This review paper gives the insights of various analysis carried out to find shaft failure. Roller Shaft failures can be optimized by preventive mechanical maintenance techniques & using safe design with proper manufacturing processes. The various literature has been systematically compared and reviewed to get a proper shaft failure analysis. Every method has its pros and cons and used by specific industrial segments. Shaft failure causes the unnecessary shutdowns and leads to heavy production loss. The objective of this paper is to study various shafts failure analysis and select the best method to find out the root cause failure of heavy nip roller shaft used in textile industry.*

Keywords: **shaft failure, maintenance techniques, heavy nip roller shaft, production loss, manufacturing etc.**

1. INTRODUCTION

The term shaft refers to a rotating machine element, circular in cross section which supports elements like rollers, gears, pulleys & it transmits power. The shaft is always stepped with maximum diameter in the middle and minimum at the ends, where Bearings are mounted. The steps provide shoulders for positioning of gears, pulleys & bearings. The fillet radius is provided to prevent stress concentration due to abrupt changes in the cross section.

Shafts have various names depending on the application such as Axle, Spindle, Countershaft, Jackshaft, Line Shaft etc. Ordinary transmission shafts are made of medium carbon steels with a carbon content from 0.15-0.40 percent such as 30C8 or 40C8, for greater strengths high carbon steels are used such 45C8 or 50C8. For applications where corrosion and high wear takes place, shaft material used is alloy steel. Common grades are 16Mn5Cr4, 40Cr4Mo6.

High cost of alloy steels is compromised due to the added advantages. Commercial shafts are made of low carbon

steels. They are produced by hot rolling & finished to size by either cold drawing or turning and grinding. They are further hardened by oil-quenching to achieve the required strength and hardness. For very large sizes the billets are forged into the bars and finished by usual turning and grinding. Design of shafts mainly depends on

1. Strength basis
2. Torsional rigidity basis

2. LITERATURE REVIEW

Gys Van Zyl, Abdulmohsin Al-Sahli

The case study is based on the analysis of Failure of Conveyor Drive Pulley Shafts. This paper investigates the failure root cause by visual examination, optical and scanning electron microscope analysis, chemical analysis of the material and mechanical tests. It uses finite element analysis to quantify the stress distribution.

The macroscopic analysis of the shaft showed that the failure is of fatigue however closer microscopic examination revealed a fracture appearance that was more brittle and inter-granular than normal for a fatigue failure. The unexpected appearance of the fatigue fracture surface may simply be the characteristic of material. Comparing the fracture with fatigue test samples concluded the failure mechanism was fatigue.

Finite Element Analysis showed the stress report for various levels developed in shaft and obtained a graph of stress rang(MPa) Vs. fillet radius at shaft corner(mm).It concludes that the pulley shaft has failed due to fatigue mechanism and was a result of improper overhaul. A sharp fillet at the shoulder of shaft where the diameter of changes drastically. Welding carried out during shutdown resulted hardness change at fillet shaft shoulder. The manufactured mechanical parameters stood at their ground and do not intervene in failure however improper service contributed majorly to shaft failure.

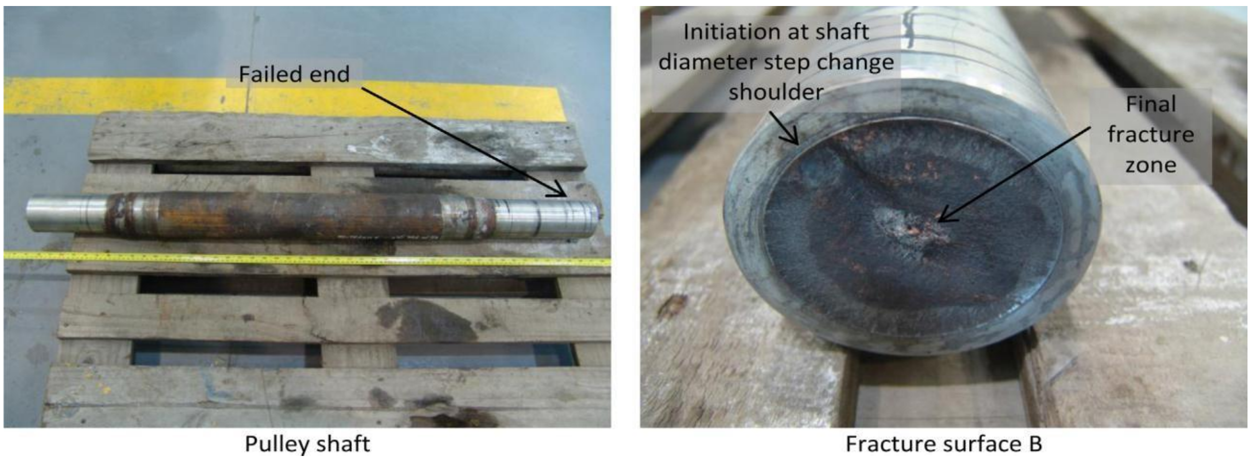


Fig-1: Failed pulley shaft [1]

2.2. Jinfeng du Jun Liang Lei zhang

This paper covers the failure analysis of the induced draft fan ... design and manufactured shaft and finds the chamfer less than prescribed in ... ion. It also states the improper balancing of the shaft gives the additive ef... her stress concentration. The vibrations and the alternating torsional loading ... enting the ratchet like profile. The entire analysis was carried in two steps

1. Analysis of failed shaft`s performance and fracture
2. Analysis of the stress, torsional resonance & shaft`s design.

The Material of content of shaft was found to be standard. Average micro hardness, yield strength & tensile strength were 157 HV, 349 MPa, 527 MPa hence the material quality was good and failure was not due to material property. FEA showed the remarkable stress concentration at the shoulder`s chamfer 5mm, but the actual radius was 2mm. The higher stress concentration and torsional vibration induced the micro crack's initiation along the chamfer and grew in size due to continuous stress and torsional vibration.

Fig-2: The three-dimensional model of induced draft fan's shaft. [2]

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 3, March : 2023

Xu Xiaolei *, Yu Zhiwei

This paper is an analysis of failure of main shaft of locomotive turbo charger. The fracture position is located at a groove between journals with different diameter. The rotating bending fatigue is the dominant failure mechanism of the shafts. Detailed metallurgical analysis indicates that fillet region of the groove had subjected to high temperature. This resulted from the intense friction between the bearing-sleeve and the assisted pushing Bearing, which made the fatigue strength of the fillet region of the groove decrease.

The stress concentration at fillet area initializes the fatigue. The chemical composition of the failed main- shaft material was determined by spectroscopy chemical Analysis method. The microstructure in various regions was observed by SEM. The fracture surfaces were analyzed

by visual and SEM observation to study the failure mechanism. By normal heat treatment process, surface hardness of journals are specified to be induction- quenched should not have greater difference. Bearing shaft showed the wear, then the main shaft was fractured. Failure mechanism of the main-shaft is by rotating bending fatigue fracture. A greater friction force caused high

Temperature induction in bearing due to friction between bearing sleeve. The fatigue strength at the fillet area would be affected due to change in temperature.

It was worth noting that too short fillet radius increased the stress concentration so high that it facilitated the fatigue cracks to initiate in the fillet region of the groove. It further facilitated the conditions responsible for the rotation-bending fatigue fracture of main-shaft.

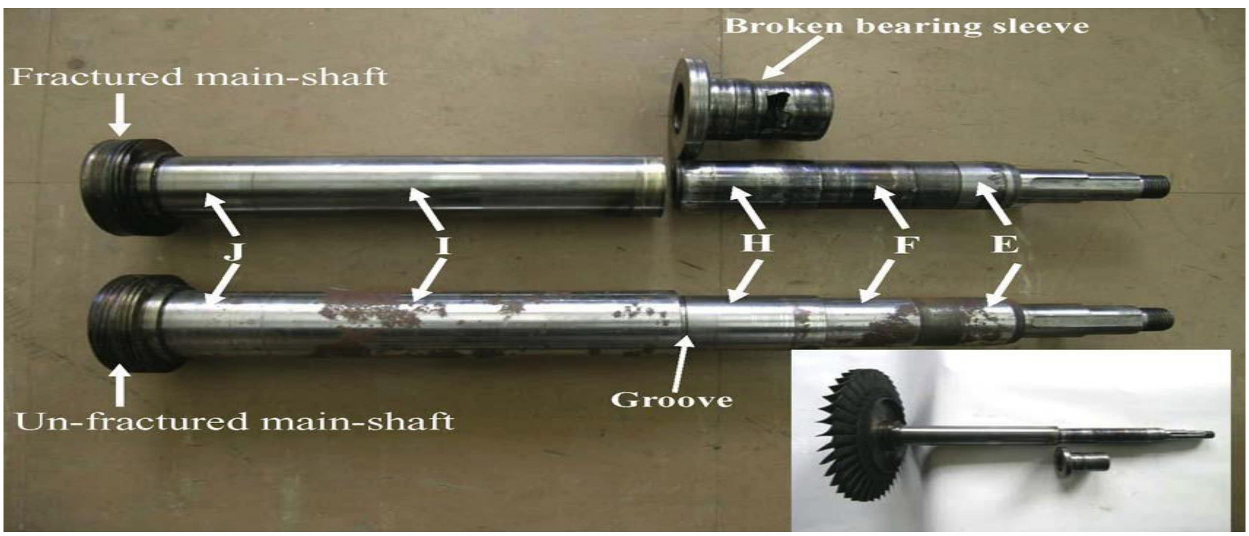


Fig-3: Fractured main-shaft and broke bearing sleeve. [3]

A.M. Lancha, M. Serrano, J. Lapena, D. Gomez Briceno

This paper analyses the failure of a river water circulating motor shaft. It includes Fractography, Metallography & Energy dispersive spectroscopy. It also focuses on the various mechanical tests to find out root cause of the failure. Location of the failure surface was not on any fillet, corner or keyway but at 600mm from of the ends of the shaft. Shaft failed after 80,000 operational hours. The characteristics of the fatigue are neatly mentioned. The Fractography was determined by the scanning electron microscopy. It stated that cracks are of inter granular morphology with grains.

Chemical Composition was found to be ok, but the Mechanical Tests taken did not give the satisfactory results. Carpy test was conducted and the shafts impact value did not meet the manufacturer's value.

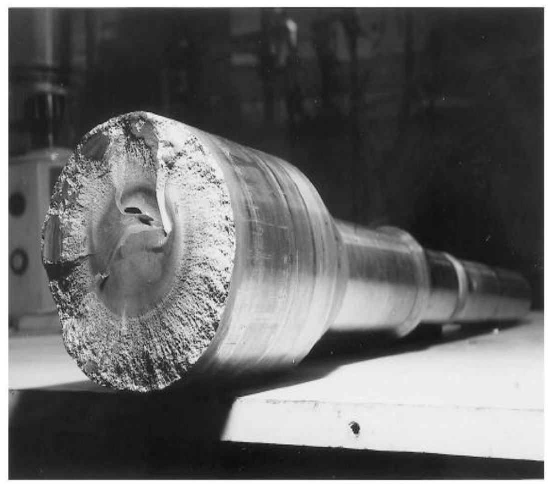


Fig- 4: Photographs of the failed shaft [4]

Tensile and Hardness tests were not up to the mark. The material of the shaft was Martensitic Steel, thermal analysis was conducted to analyze the root cause of failure. Martensitic steels are susceptible to two types of embrittlement, Temper and Hydrogen Embrittlement. The shaft showed cracks internally first and then on the surface. It was concluded that the shaft failed due to improper thermal treatment. It facilitated temper embrittlement process.

The paper emphasizes on the ways of a shaft may fail by fatigue, different fatigue cracks and its causes. The estimated life of shaft was 2, 00,000 hours however, it was operational for only 1, 63,411 hours. The visual examination showed that the crack initiations were from the critical radius. The cracked surface indicates the facture took place due to combination of twisting and bending. While the sample was cut for mechanical and metallographic test no of pours and gas holes were detected.

These may have occurred in the casting process. However holes and gas pours were not found around the crack initiation location. Chemical composition of the specimen matched with reference standard mechanical tests were also conducted to have the better understanding of failure. The standard used for tensile test was in resonance with the GOST1497-84 requirement. The average values of mechanical properties such as yield strength, tensile strength elongation brinell hardness were determined and compared with required GOST977. The results were unsatisfactory.

The finite element model of the shaft showed more stress concentration then at critical radius then the limiting values. It was concluded that shaft failed due to the combination of several factor:

- Improper corrosion protection in the region of critical radius.
- High stresses during beginning/end cycle.
- The critical radius could be increased show that stresses are distributed over larger area.

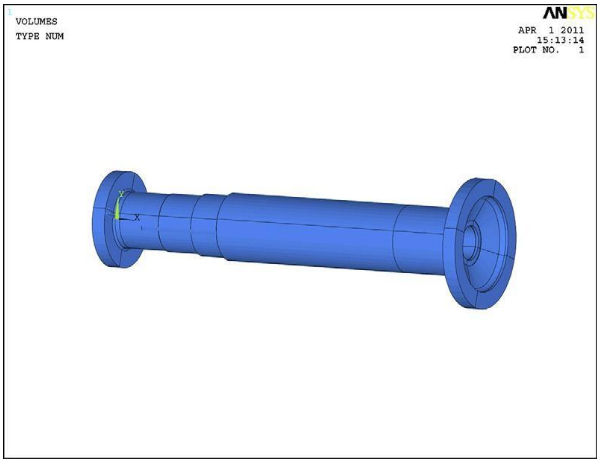


Fig- 5: 3D shaft model [5]

**R.W. Fuller a, J.Q. Ehrgott Jr. b, W.F. Heard b,
S.D. Robert b, R.D. Stinson b,K. Solanki c, M.F. Horstemeyer c**

This paper presents failure analysis of a structural component shaft. It follows a systematic conventional approach of finding root cause of failure. It follows an information gathering, initial observation, secondary visual examination, data interpretation, mechanical testing, non-destructive testing, microscopic analysis, metallography, chemical composition, failure mechanism determination and conclusion. The fractured shaft was a part of drive train. Its material was AISI304SS and was operational for three weeks.it was connected through a 15 HP mixture motor which operates constantly. However the voltage for the mixture motor should be constant.

The shaft was a loose fit hence it was installed using weld plugs of AISI304SS. In transmission system it was uncertain whether the gear box was pivoted, the gear box did not influence shaft failure. Also, the torque arm was not under any preload. The key way material was same as that of shaft and 12.7 mm^2. During chemical analysis spectrometer readings were taken and the material AISI304SS. This material is susceptible to sensitization during welding process.

Sensitization greatly reduces the shaft strength also this material if not formed properly, grain edges are depleted and thus lose their corrosion resistance. Various mechanical test are carried out to determine the ultimate tensile strength of the shaft. Hardness testing concluded that steel was annealed, however the effect of annealing was lost at the surface due to the heat affected zone from the welding. The material sample were cut from failed shaft for analyzing micro structure. The sample were polished to a mirror finished and edged with glycerin to revile the microstructure.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 3, March : 2023

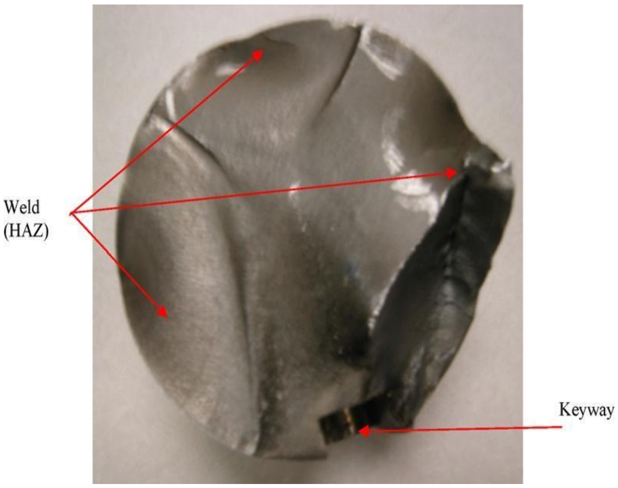


Fig-6**:** Failed shaft with heat affected zone (HAZ) and keyway. [6]

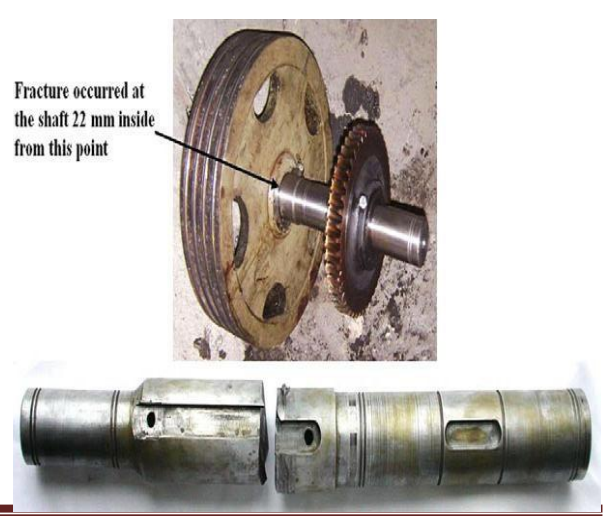
The microstructure shows that the grains were distributed unevenly along the entire austenite matrix, the face is referred to as delta ferrite stringers. This facilitates blocking of inter granular cracks. However, if temperature during welding reaches high value, it becomes sensitized and lose this properties. Electron microscope shows that inter granular cracks were centered at the weld location. Further calculation reveled that stress concentration at the weld plugs was higher than the standard design. The fillet corner was too sharp to withstand the stress concentration for longer duration. At percent speed 99 safety factor with stress concentration was 1.001.The failures causes were more allied to welds. Because of vibration issue of loosely fit shaft weld plugs were used which resulted in stress concentration**.**

A Gokesenli, I.B. Iryurek

This paper analyses the failure of an elevator drive shaft. Analysis of chemical, mechanical and structural properties has been discussed in thoroughly. Fatigue failure has initiated at the keyway edge of the shaft. The stresses at the position where crack initiated are calculated and compared to the Finite Element Method (FEM).The chemical composition of the shaft was found to be within the acceptable region. Mechanical properties of the shaft

such as Yield strength, Tensile strength, Rupture Elongation and Hardness are calculated.

During the stress analysis, minimum and maximum shear stresses are investigated at the fracture surface. Total shear stress was found to be 25.7 MPa. Visual examination concluded that the surface from the keyway ground to the keyway side surface was approximately perpendicular hence radius of curvature was negligible.



2.	Jinfeng du, Jun Liang, Lei zhang	Actual radius of chamfer less than the design radius caused more significant stress Concentration.	Fractography Using SEM, Spectroscop, Finite element analysis using ANSYS	2016
3.	Xu Xiaolei , Yu Zhiwei	wear of the bearing sleeve	Fractography,Spectroscopy	2009
4.	A.M. Lancha, M. Serrano, J. Lapena, D. Gomez Briceno	Improper thermal treatment of the material	Fractography using SEM, EDS, Charpy tests	2001
5.	Tomaz Vuherer, Zoran Odanovic, Ivana Atanasovska, Dejan Momcilovic , Radivoje Mitrovic	Inappropriate corrosion protection in the zone of critical radius	Spectroscop, Finite element analysis using ANSYS, , Charpy tests	2012
6.	R.W. Fuller , J.Q. Ehrgott Jr. , W.F. Heard , S.D. Robert, R.D. Stinson , K. Solanki , M.F. Horstemeyer	Failure of shaft occurred due to improper welding	Fractography using SEM, spectrometer	2008
7.	A Gokesenli, I.B. Iryurek	Low radius of the curvature of keyway	Spectroscop, Finite element analysis using ANSYS	2009

Fig- 7: Failed elevator drive shaft. [7]

By taking the shaft geometry into consideration notch effect is calculated. By determining the Endurance Limit and Equivalent stress, Fatigue Safety of Factor is achieved to be 1.05 which is quite low. It was concluded that by increasing the radius of the curvature of keyway the stress could be diminished at high value. By using the FEM stress intensity and concentration are shown.

3. SUMMARY OF LITERATURE REVIEW

Sr no.	Author	Failure reason	Research tool	Year
1.	Gys Van Zyl, Abdulmohsin Al-Sahli	Shaft failed as a result of fatigue.	chemical composition by means of XRF,SEM analysis, Finite element analysis using ANSYS	2013

4. CONCLUSION

The various failure analysis of shafts mentioned above do not follow any specific approach. To analysis the root cause of failure it essential to follow various examinations and comparing the results. A mechanical shaft may fail due to several reason such as improper engineering design, chemical composition, negligence in operations and maintenance, welding repairing works. To overcome the above disadvantages precautions should be taken

The heavy nip roller shaft failure analysis is to done by following methodology

1. Visual inspection of the failed component
2. Design standards of the shaft considering maximum bending and torsional theory.
3. Metallographic inspection of failed specimen.
4. Analyzing stress concentration at major step down.
5. Finite element analysis of roller shaft using ANSYS software.

BIBLIOGRAPHY

[1] Gys van Zyl *, Abdulmohsin Al-Sahli, "Failure analysis of conveyor pulley shaft," *Case Studies in Engineering Failure Analysis,* vol. 1, pp. 144-155, 2013.

[2] jinfeng Du , Jun Liang, Lei Zhang, "Research on the failure of the induced draft fan's shaft in a power boiler," *case studies in engineering failure analysis ,* Vols. 5-6, pp. 51-58, 2016.

[3] Xu Xiaolei *, Yu Zhiwei, "Failure analysis of a locomotive turbocharger main-shaft," *Engineering Failure Analysis,* vol. 16, pp. 495-502, 2009.

[4] A.M. Lancha*, M. Serrano, J. LapenÄ a, D. GoÂ mez- BricenÄ o, "Failure analysis of a river water circulating pump shaft," *Engineering Failure Analysis,* vol. 8, pp. 271-291, 2001.

[5] Dejan Momcˇilovic´ a, Zoran Odanovic´ a, Radivoje Mitrovic´ b, Ivana Atanasovska c,, "Failure analysis of hydraulic turbine shaft," *Engineering Failure Analysis,* vol. 20, pp. 54-66, 2012.

[6] R.W. Fuller a, *, J.Q. Ehrgott Jr. b, W.F. Heard b, S.D. Robert b, R.D. Stinson b,, "Failure analysis of AISI 304

stainless steel shaft," Engineering Failure Analysis, vol. 15, pp. 835-846, 2008.

[7] A. Göksenli *, I.B. Eryürek, "Failure analysis of an elevator drive shaft," Engineering Failure Analysis, vol. 16, pp. 1011-1019, 2009.