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Failure analysis of a carbon steel roller shaft of continuous pad steam machine

Santosh D. Dalvi*, Hariom, D. Chandrababu, Sunil Satav, Vijoykumar

Lokmanya Tilak College of Engineering, University of Mumbai, Navi Mumbai-400 709, India

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ABSTRACT

This paper presents the failure analysis of carbon steel roller shaft of continuous pad steam machine used in textile industry. The fracture position was located at a stepped diameter. The failed component was the shaft made of carbon steel AISI 1040. Standard procedure for failure analysis was employed in this investigation. Visual examination, chemical analysis, hardness and tensile strength measurements, microstructural characterization, fractography analysis by Scanning Electron Microscopy (SEM) and Finite Element Analysis (FEA) were used for the failure analysis. Using this failure analysis approach, we pinpointed the root cause of failure and developed a means of solving this type of failure in the future. Firstly, the chemical composition of the shaft is done by an Optical Emission Spectroscopy (OES) method, the found chemical composition was matching with required standard value. Mechanical testing consists of two test i.e. tensile test and hardness test and it was found out that the strength and hardness of specimens were within the required capacity. For metallurgical analysis, the microstructure of the shaft was developed by using an optical microstructure. Equal distribution of ferrite perlite shows that heat treatment was performed well and carbon percentage in a material is satisfying the standard values. Thus, it proves that the material used was of good quality and indicates that failure is not due to material property. Further for the fractography, the fractured surface was examined by SEM. The cross-section was taken in a quarter segments and divided into four regions i.e. A, B, C, and D. Fractography morphology mainly showed that the failure of roller shaft was caused due to fatigue. To examine the stress distribution at the fractured surface the Finite Element Method (FEM) was also carried out. Based on the shaft size, a precise ANSYS model was developed. The result of FEM shows that stress concentration was significant at roller shaft step which could reduce the material reliability to some extent. Based on the failure analysis it could be concluded that due to stress concentration a micro crack is initiated along the weak interface and further it converted into the major fatigue failure. Fractography morphology of failed roller shaft also confirms the fatigue failure.

1. Introduction

Failure, in general, is the inability of a component, structure, system, or program to function as intended (usually unexpectedly). From a designer point of view, failure analysis relies heavily on the ability to make accurate predictions of the strength and fracture of materials under complex loading conditions [1]. In this study, we will primarily focus on the process of analyzing and understanding material failure. Failure analysis of roller shafts was conducted by performing the conventional steps. The roller shaft of a continuous pad steam machine in 2016 suddenly appeared the abnormal phenomenon when it was running in condition. This paper describes the

* Corresponding author.

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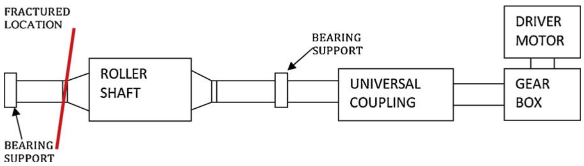

Fig. 1. Schematic illustration of the roller shaft showing the approximate fracture location.

failure analysis of a fractured roller shaft of a pad steam machine that led to catastrophic consequences in terms of damage to other equipment, loss of production, and risks to workers' health and safety. Hence the purpose of this research was to discover the answers through an application of scientific procedures. This failure investigation had been paid attention to the analysis of the cause of failure which ranged from chemical analysis of material, mechanical properties such as tensile test and hardness test, microstructural characterization, FEA, and thus the preventive measures were developed in order to avoid the recurrence of the similar failure. It was reported that the roller shaft has found fractured after the emergency shutdown and the fracture happened near the site of the shaft's variable diameter. The failed roller shaft was made of AISI 1040 carbon steel which had 2600 service hour before failure. The hardness of core material is specified as HB223-250. Some journals of roller shaft are specified to be induction-quenched to obtain the surface hardness of HRC 40-50. The roller shaft's smallest diameter was 90 mm and the chamfer of the shaft shoulder is less than 1 mm. Finally, the paper documents the results of initial examinations, detailed investigations and potential root causes of failure in the roller shaft.

2. Observation and background

For any investigation, the first and foremost step is to gather data. Data collection is the process of gathering information on targeted variables in a systematic way, which helps one to answer relevant questions and evaluate outcomes. A detail background investigation was important to identify probable factors for failure. Information related to the technical specification of the equipment, the service history of the component, and operating condition of the machine has to be gathered. The failed component in this case study was a Roller shaft and the entire transmission is illustrated in Fig. 1. The failed shaft is made of AISI 1040 stainless steel and was only in service for 2600 h, before experiencing the failure, which raised concerns at the manufacturing Process. The system is operated by 15 KW electric motor runs at 2900 rpm. The speed of the motor can be controlled by Variable Frequency Drive (VFD), according to the requirement. A gearbox of the reduction ratio of 6.2 and a universal coupling attached between the motor and gearbox. The figure shows that fracture was found in the stepped portion of the shaft and no external vibrations were observed prior to the shaft breaking. The temperature of the operational environment was considered to be ambient.

3. Experimental procedure

The failed roller shaft was collected from the plant for investigations. The sample was cleaned with acetone to remove dirt for visual examination prior to chemical and mechanical testing. OES of the samples was carried out to identify exact chemical composition present in the samples. The shaft samples were tested for two prime mechanical tests i.e. tensile test and hardness test. Tensile testing of the specimens was carried out on 500 KN Universal Testing Machine (UTM). Hardness measurements were conducted on the obtained specimen with help of Rockwell hardness tester towards the center to the periphery. An applied load of 981N was used during testing, and for determining the hardness of the failed component several indentations were made. Transverse specimens were made from the fractured end of the failed samples for conducting an optical microscopic metallographic examination. These samples were individually mounted in conductive mounting and polished by conventional metallographic techniques for the scratch-free surface. The polished samples were etched in 3% Nital solution (3 mL HNO_3 in 97 mL ethyl alcohol), and both unetched and etched samples were examined under an optical microscope [2]. Further for the fractography, the fractured surface was examined by SEM. The cross-section was taken in a quarter segments and divided into four zones i.e. A, B, C, and D. Finally, to examine the stress distribution at the fractured surface the simulation was done on ANSYS software by putting boundary conditions and material properties.

4. Results and discussion

4.1. Visual observation of failed shaft

In this primary stage of the investigation, close observation of the damaged parts and failure surfaces was done. The visual examination includes the determination of fracture location, photography, dimensional checks, finding the visual crack lines and crack initiation point. Once this on-site examination was complete, samples of material were extracted for detailed laboratory examination, chemical analysis, mechanical testing, and metallurgical analysis. The schematic Fig. 1 shows that fracture was found in the stepped portion of the shaft where the bearing is mounted. Fig. 2a and b shows the actual image of roller shaft of a continuous pad steam machine. In Fig. 2a shows the longitudinal view of actual shaft (kept in the workshop of industry) and Fig. 2b shows end section of shaft where failure has occurred.

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