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Case study

Failure analysis of a bridge crane shaft

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ABSTRACT

Failure analysis of a shaft used in a bridge crane has been carried out. The shaft fractured in the keyway with evidence of fatigue. Chemical analysis, micro-structural characterization, fractography, hardness measurements, and finite element simulation were used for the analysis. The microstructure was predominantly tempered martensite; large amounts of oxides, micropores, and manganese sulfide inclusions were found. The geometry of the keyway also promoted the initiation crack because the width and height were erroneously designed. It was concluded that all these factors produced fatigue failure. It is recommended to first guarantee the chemical composition and microstructure of the material. Secondly, use magnesium or calcium additions in the steel casting process to obtain better shape control of inclusions and, finally, accomplish the geometric parameters recommended by the standard to avoid high stress concentration factors.

1. Introduction

Shafts are used to transmit power to other mechanical elements and are generally subjected to torsional and bending loads. One of the most common failure mechanisms in shafts is fatigue. Fatigue failures start at vulnerable points where metallurgical and structural defects exist that favor high localized stresses [1]. Normally, the points of stress concentration in shafts are present in sharp changes of the cross-sectional area or at the keyways [2]. Additionally, when defects appear in these sensitive sites, the fatigue life is severely compromised.

Other failure analyses have been performed on shafts, especially related to the corners of the keyway, where the predominant causes of the onset of fatigue failure were due to low radius of keyway curvature [3], inclusions [4,5], incorrect repair welding [6], brittle microstructures [7], and machining marks [8]. All of these failures were present across the entire cross section of the shafts and started at the corners of the keyway. In this failure analysis, only one side of the keyway was completely fractured by fatigue, not the entire transversal section. Besides, this type of failure has been recurrent in this mechanical element for years.

The shaft analyzed (replacement part) belongs to a bridge crane fractured after one year of operation. Fundamentally, the bridge crane system consists of an electric motor that transmits power to the shaft and this shaft transmits power to a reducer gearbox; a representation of the system is shown in Fig. 1. The keyway connects the system's brake. According to the material specification provided by the manufacturer, the material is an AISI 4340 steel normalized and tempered. Engine power is 3.73 kW and operates from 600 to 1800 rpm.

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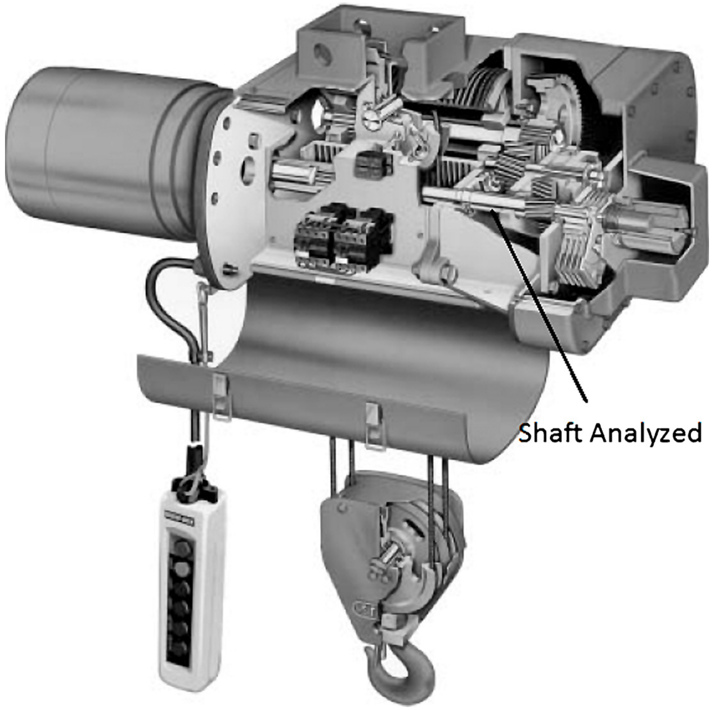

Fig. 1. Bridge crane and shaft analyzed, adapted from [9].

The scope of this investigation was to determine the cause of failure occurring in this shaft, an element commonly used in almost all industries, to prevent similar failures that could be the cause of damage of the complete equipment and, not less important, to guarantee industrial security for workers.

2. Experimental procedure

Chemical analysis, visual inspection, fractography, metallographic analysis, hardness measurements, and finite element simulation were used for the analysis. The shaft's chemical analysis was carried out via optical emission spectroscopy (ARL 3460 Advantage spectrometer); fractography was performed by using a stereoscope (Nikon SMZ1000) and scanning electron microscopy (Jeol jsm-6490LV); for the metallography, the samples were polished and etched (2% Nital reagent during 40 s), micro indentation Vickers was used with 10 g during 15 s and 10 indentations for hardness determination.

3. Results and discussion

3.1. Visual and stereography examination

One edge of the keyway was fractured, a general view is shown in Fig. 2(a) and (b), some important features of the fracture are shown: machined marks on the keyway, crack origin, fatigue propagation zone, plastic deformation in the final fracture zone. Also, a longitudinal mark can be noted in the keyway, with characteristics of plastic deformation near the fracture zone.

Machining marks influenced in the nucleation of fatigue cracks. Besides, a longitudinal mark in the keyway, possibly caused when the key was put in the keyway, produced additional damage in the corner of the keyway. Additionally, Fig. 3 shows a beach pattern and ratchet marks, evidence of high local stress [8–11].

Fig. 4 reveals growth of a secondary crack on the other side of the keyway because of the reversibility of the torque the shaft must withstand. This torque alternation promoted change of the stress in each corner of the keyway and, finally, induced fatigue failure.

The keyway radius was measured at 0.6 mm and the shaft diameter is 25.4 mm; therefore, the r/d ratio is 0.024. Using this ratio, for a standardized keyway, it was found that the stress concentration factor for a torsion shaft (K_{ts}) is 2.52 [12]. The USA standard recommends maximum stress concentration factors up to 2.6 when the torque is transmitted without the key. However, the keyway width recommended for the same standard is 6.3 mm, but the shaft had a keyway width value of 9.1 mm. Likewise, the keyway height must be 3.2 mm, but the shaft had a keyway height value of 3.3 mm.