Engineering Failure Analysis 92 (2018) 50–60

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Diagnosis of EMD645 diesel engine connection rod failure through modal testing and finite element modeling

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ARTICLE INFO

Keywords:
Engine failures
Conrod failure
Experimental modal analysis
Stress analysis
Buckling

ABSTRACT

Connection rods are best known through their use in internal combustion piston engines. GM-GT26 locomotive uses a 3300 horse power V type engine with 16 cylinders that works at maximum crank speed of 900 RPM. The present study is concerned with the failure of a 645E3B engine connection rod with a reported catastrophic deformation due to unknown reasons. This rod has suffered from simultaneous bends in two surfaces with obvious marks of failure. A theoretical procedure, an experimental modal analysis technique and simulation by using finite element engineering softwares are used for this study. It includes finding the natural frequencies and the corresponding mode shapes for a new connection rod. This is then used to validate the FEM simulated model. The critical loads and the buckling forces on the connection rod are then calculated. The maximum loads are calculated by using the classical approaches and are verified by simulation in ADAMS-Engine software. The dynamic modeling includes rigid and flexible beam models and the torsional modes of vibrations are also considered. It is concluded that the connection rod failure is due to buckling at the presence of hydrolock phenomenon. The outcome of this research provides vital information for the proper operation and maintenance of heavy duty Diesel engines.

1. Introduction

Connection rods are best known through their use in internal combustion piston engines, such as automotive engines. In reciprocating engines, connection rod (Conrod) plays a vital role in conveying the power that is produced in the combustion chamber to the crankshaft and consequently moving the vehicle. The new design of connection rods are of a distinctly different design from the earlier ones that were used in steam engines and steam locomotives.

The role of Conrods in heavy duty Diesel engines of locomotives starts from turning the reciprocating motion of pistons into the rotation of the crankshaft. In Diesel-electric locomotives and through this mechanism, the produced kinetic energy rotates the coupled generator rotor and yields electrical power to be used in traction motors. Consequently, the wheels and axles rotate by the coupling between the pinion and the gear.

GM-GT26 locomotive uses a 3300 horse power V type engine with 16 cylinders that works at maximum crank speed of 900 RPM. The design of this engine goes back to 1967. The 645E3B engine uses two types of Conrods that have geometrical differences in their designs. In both of these designs the small end is attached to the piston pin, gudgeon pin or wrist pin, which is constrained with a half circular head. But the larger ends of the two types of Conrods are different. In this engine for minimizing the shear stresses on the crankpin journal, the blade Conrod is at the center of the crankpin journal. But, the fork Conrod surrounds the blade Conrod and both

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https://doi.org/10.1016/j.engfailanal.2018.05.005
Received 8 March 2017; Received in revised form 1 January 2018; Accepted 9 May 2018
1350-6307/

Nomenclature

A	Section area (m^2)	P_{cr}	Critical buckling load (kN)
BSF	Bucking safety factor	r_y	$=\sqrt{I_{yy}/A}$ radius of gyration for side buckling (m)
D	Cylinder diameter (m)	α	Angle between the crankpin journal and cylinder central line (degrees)
E	Young's modulus (MPa)	β	Ratio between the crankpin journal eccentricity and the Conrod length
F_{total}	Maximum compression load (N)	γ	Centripetal acceleration of the piston and Conrod (m/s^2)
I_{yy}	Area moment of inertia for front/rear buckling (mm^4)	${\sigma_{cr}}^e$	Elastic critical buckling stress (MPa)
K	Buckling factor	${\sigma_{cr}}^p$	Plastic critical buckling stress (MPa)
L	Effective length (mm)	σ_{cr}	Critical buckling stress (MPa)
M	Inertia mass (kg)	σ_y	Yield strength (MPa)
P_{max}	Maximum gas pressure (N/m^2)	σ_u	Ultimate Strength (MPa)
${P_{cr}}^e$	Elastic critical buckling load (kN)	ω	Density (gr/cm^3)
${P_{cr}}^p$	Plastic critical buckling load (kN)	υ	Poisson's ratio

of them are clamped with baskets to the crankpin journal of crankshaft. Fig. 1 shows the installation mechanisms of these two types of Conrods and, Table 1 presents the design parameters of a blade Conrod.

Connection rods are subjected to inertial forces that originate from the reciprocating mass and gas pressure forces that are due to the maximum ignition pressure. These forces result in the axial and bending stresses. Bending stresses in Conrods originate from the eccentricities of the crankpin journal within the main shaft of the crankshaft, and the rotational mass forces. Therefore, a connection rod must be capable of transmitting axial tension, axial compression, and bending stresses. Failures of connection rods are often caused by the bending loads that act perpendicular to the axes of the two bearings.

In 1996, Lu presented an approach for shaping a Conrod that is subjected to a load cycle consisting of the ignition force, inertia load, and the displacement. He calculated the stresses by a Finite Element Approach (FEA), and finally determined the fatigue life based on the fracture mechanism [2]. Phad and Burande analyzed a Conrod for extracting its static and dynamic properties. The results of this analysis showed that the tension stresses in the Conrod are higher than the compression stresses. The stresses decline from the pin end to the crank end. The maximum stresses occur on the fillets of the small and the large ends of the crankshaft [3].

Desai et al. carried out a numerical and experimental analysis to find the critical spots in the Conrod structure. In this study, the stresses on different areas of the Conrod were measured in the laboratory by applying different loads. On the other hand, the under investigation analysis was simulated for finding the tension and compression stresses on different parts of the Conrod. The results of this study showed that the maximum stress happens at the larger end of the Conrod [4]. Shenoy conducted a dynamic analysis of the loads and stresses in the connection rod component. They explained that the tensile load applied over 180° of the crank contact surface with cosine distribution, whereas the compressive load applied as a uniformly distributed load over 120° of the crank contact surface [5].

However, not many studies were carried out on the Conrod buckling. Shenoy and Fatemi performed an optimization including the simple linear buckling analysis [6]. Recently, Lee et al. studied the buckling sensitivity of a Conrod to present a buckling evaluation procedure via FEA. The study predicted the critical buckling stress through a classic analysis and FEA. This was followed by some experimental procedures with a Conrod test rig for validation purposes. The results of this investigation demonstrated that when a weight reduction of Conrod shank is attempted, buckling should be considered as an essential factor along with the other criteria such

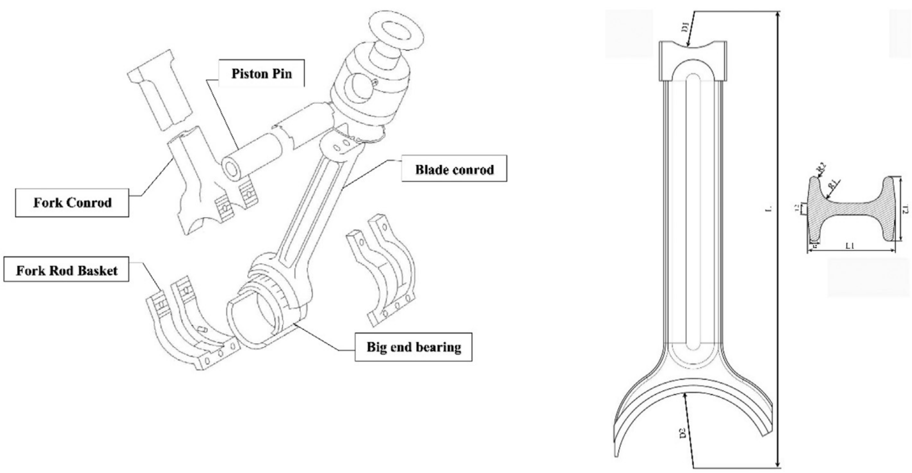

Fig. 1. Installation schematic of the blade Conrod on 645E3B Diesel engine [1].