Engineering Failure Analysis 56 (2015) 109–115

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Crankshaft failure analysis of a boxer diesel motor

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ARTICLE INFO

Article history:
Received 17 December 2014
Received in revised form 23 March 2015
Accepted 23 March 2015
Available online 1 April 2015

Keywords:
Failure mode analysis
Automotive crankshaft failures
Crankshaft failures
Failure mechanisms

ABSTRACT

This paper reports a failure mode analysis of a boxer diesel engine crankshaft. Crankshafts are components which experiment severe and complex dynamic loadings due to rotating bending combined with torsion on main journals and alternating bending on crankpins. High level stresses appear on critical areas like web fillets, as well as the effect of centrifugal forces and vibrations. Since the fatigue fracture near the crankpin-web fillet regions is one of the primary failure mechanisms of automotive crankshafts, designers and researchers have done the best for improving its fatigue strength. The present failure has occurred at approximately 2000 manufactured engines, and after about 95,000 km in service. The aim of this work is to investigate the damage root cause and understand the mechanism which led to the catastrophic failure. Recommendations for improving the engine design are also presented.

1. Introduction

Engines have gone through significant changes since that the automobile was first introduced in the 1880s, one of the most important inventions of the nineteen century which had also a significant impact on our industry and society. Automobile industries are always interested to develop new products that meet the market requirements.

Crankshafts are power shafts of engines with a complex geometry having crankwebs and crankpins which are additional bearing surfaces whose axis is offset from that of crank. This component is placed into the crankcase (on the bedplate) and is supported by journal shell bearings. Each offset part of the crankshaft has a bearing surface known as crankpin to which the connecting rod is attached. It converts the linear (reciprocating) motion of pistons into a rotary motion that can be transmitted through a drive line system. The power from the burnt gases in the combustion chamber is delivered to the crankpin through the pistons and connecting rods.

A crankshaft is subjected to several forces that vary in magnitude and direction (multiaxial loading). Bending stress and shear stress due to twisting are also common stresses acting on crankshafts. Torsional loadings appear as result of the power transmission known as torque or binary.

The crankshaft is drilled with a network of oil passages to deliver lubricating oil under pressure to the oil galleries and bearings. In general, they have also counterweights in order to prevent undesirable vibrations and are added to offset the weight of the piston and connecting rod assemblies. At the rear of the crankshaft, a flywheel is assembled for damping the power pulses from the engine. The crankshaft main journals rotate in a set of supporting bearings (main bearings),

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http://dx.doi.org/10.1016/j.engfailanal.2015.03.014
1350-6307/

causing the offset rod journals to rotate in a circular path (translation movement) around the main journal centres. The diameter of that path is the engine stroke when the piston moves up and down in its cylinder.

Many researchers have concluded that fatigue failures are largely due to cyclic bending loading combined with torsion at critical fillet regions. In order to avoid recurrence of failures, machining and final grinding has to be done carefully for preventing discontinuities or crack-like defects in the fillet region [1]. Other studies of broken power shafts by fatigue also show how important is this matter [2–8] when preventive design actions are not taken into account.

Fig. 1(a) and (b) shows a typical crankshaft of a boxer diesel engine with the main and usual nomenclature. Crankshafts normally have either integral or attachable counterweights which are used to balance dynamic forces that occur during the engine operation. These counterweights compensate the centrifugal forces created by each crankpin linked to crank webs during the crankshaft rotation about the main journal axis. In the absence of the counterweights, the crankpin mass tend to bend and distort the crankshaft causing excessive edge loading in the main bearings. Therefore, each half crankweb is generally extended in the opposite direction to that of crankpin, to counterbalance the radial mass effects.

Fatigue failures occur due to the application of fluctuating stresses that are much lower than the stress required to cause failure during a single application of stress. Fatigue failures generally start at critical points where metallurgical and structural defects exist and therefore high local stresses are favourable, such as zones of stress concentration present at sharp geometry, and changing of the cross-sectional area.

Being the fatigue process formed by an initiation zone and another one by propagation. The initiation is much localized and it has origin close to the crankpin-web or main journal fillets due to a high stress concentration frequently as result of a deficient fillet radius or wrong rectification of the crankpin and fillets. In addition, the crankshaft material is quite sensitive to local metallurgical defects [1].

Crankshafts are engine power shafts that run with harmonic torsion combined with cyclic bending stress due to radial loads of combustion chamber pressure [3]. Most of crankshafts that failed by fatigue are due to cyclic bending under opening mode I.

Bending causes tensile and compressive stresses at crankpin-web fillets and main journals. The torsion due to torque causes shear stress mainly on the main journals. Being the crankshafts one of the most highly stressed engine components, it is noted that the stress increases four times as the engine speed doubles. When a crack is eventually detected in a crankshaft it should be rejected, because is generally assumed that may sudden break if continues in service. Accurate stresses are critical input to fatigue analysis and optimization of crankshafts and the performance of any engine largely depend on its size and working in dynamic conditions [7]. The developing of robust fatigue design methods such the use of Finite Element Analysis (FEA) has significantly contributed to achieve this objective. Cracks in power shafts, such as crankshafts, generally start at surface of journals and growth under mixed-mode ($\Delta K_I + K_{III}$): cycle bending, mode I (ΔK_I), combined with steady torsion, mode III (K_{III}). This statement comes from the cyclic bending stresses due to the misalignment between main journals or the effect of the force on crankpin transmitted by the connecting road at top centre (TDC). The steady torsion arises from the power transmitted by the shaft. Therefore crankshafts are generally subjected to rotating bending combined with steady torsion on main journals, and alternating bending at crankpins [9].

Automobile manufacturers are always in competition to develop a new motor that responds quickly in power and reduced consumption. The motor of this case study is an example of innovative design and successful in the automotive industry. The pistons move towards each other like boxer's gloves at the beginning of a match. It works in a horizontal position instead of the vertical line position, i.e. cylinders and pistons are on a horizontal plane, see Fig. 1(b). These engines offer a low gravity centre and thereby may run with better stability and control. This layout of cylinders is generally known as boxer engine which name was adopted because each pair of pistons moves simultaneously like boxers fighting. These engines can run very smoothly and free of unbalanced forces with a four-stroke cycle and do not require counterweights

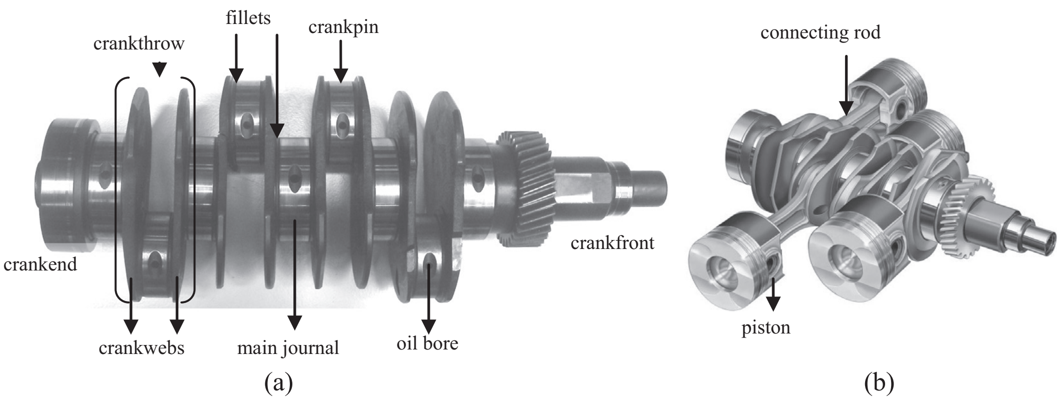

Fig. 1. (a) Typical crankshaft with the main and usual nomenclature, and (b) pistons at horizontal position.