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Failure mode analysis of two crankshafts of a single cylinder diesel engine

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ABSTRACT

This paper reports an investigation carried out on two damaged crankshafts of single cylinder diesel engines used in agricultural services for several purposes. Recurrent damages of these crankshafts type have happened after approximately 100 h in service. The root cause never was imputed to the manufacturer. The fatigue design and an accurate prediction of fatigue life are of primordial importance to insure the safety of these components and its reliability. This study firstly presents a short review on fatigue power shafts for supporting the failure mode analysis, which can lead to determine the root cause of failure. The material of these damaged crankshafts has the same chemical composition to others found where the same type of fracture occurred at least ten years ago. A finite element analysis was also carried out in order to find the critical zones where high stress concentrations are present. Results showed a clear failure by fatigue under low stress and high cyclic fatigue on crankpins.

1. Introduction

Fatigue life prediction in metallic materials has been largely investigated since the middle of the nineteen century when were detected cracks in metallic bridges and railway axles. Catastrophic failures arose suddenly without anyone to understand why. This strange phenomenon has encouraged scientists and engineers to find the root cause of failures and also accurate and reliable methods to prevent such faults. Endurance curves, well-known as Wöhler curves, or *S–N* curves, mainly obtained under rotating or reversed bending, or, more recently, by ultrasonic fatigue, has significantly contributed for the knowledge of materials fatigue behaviour leading to a significant improving of the fatigue life of structures and components based on a reliable design against fatigue failure.

Engine shafts and crankshafts are subjected to a significant number of cyclic loadings during the service. Failures can arise from several root causes, namely sudden overloads, improper engine operating and maintenance, or by fatigue, a phenomenon which results from the cyclic loadings with stress levels lower than yield or ultimate strength of material. Power shafts are the most highly stressed engine components and those of more common failures by fatigue. Large research done on the fatigue domain clearly indicates that the problem is not completely overcome [1].

Failure analysis is a process for determining the causes or factors that leads an undesired loss of functionality. Understanding the root cause for failures is required to avoid recurrence and prevent failure in similar components. The failure analysis and laboratory testing can avoid many future failures as well as the design improving, the materials selection,

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the manufacturing process, and also the low cost maintenance. Therefore the study of failure and the knowledge of its operating history are of prime importance for any accurate and reliable analysis. It is well-known that the worst of all is to learn with catastrophic failures which can lead to the loss of lives and also high economic costs. Shafts and crankshafts are mechanical components of circular section which are common used to transmit power being widely used in many engines. However, a crankshaft is also a shaft with a complex geometry in order to convert the reciprocating displacement of piston to a rotary motion. Since a crankshaft experiences a large number of load cycles during its service life, fatigue performance and durability have deserved the attention and effort of researchers and designers. Concerning the crankshafts and its catastrophic failures, the failure mode analysis has been widely studied so far and some case study results can be found in recent literature [2–7]. The crack initiation in crankshafts is well localized and its origin is generally close to the crankpin–web fillets, or on main journal fillets, both frequently under bending loading, mode I. An incorrect fillet radius or a wrong rectification of crankpin and main journal fillets can originate a crack initiation.

Most of shafts and crankshaft failures are due to multiaxial fatigue, complex loading conditions and different failure modes, namely: rotating bending combined with torsion ($\Delta K_I + K_{III}$) on main journals; reversed bending on crankpin and crankwebs (ΔK_I) [8]. The fatigue failure of a component may be presented in three stages or distinct regions: crack initiation, crack propagation and fast final fracture. The crack initiation may be caused by high stress concentration at micro notches, defects or inclusions on the material surface, pitting, scratches, inadequate machining or heat-treatment, slip bands or dislocations intersecting the surface as a result of previous cyclic loading or work hardening. The crack propagation is the crack growth before the final fracture being the appearance smooth and brilliant. The fast final fracture is the event when the material no longer can bear the applied stress, and occurs quickly. The morphology of the fatigue surface cracks can also show beachmarks and striations: the first ones can be observed with the naked eye and the second ones by optical microscope or by scanning electron microscope (SEM). The beachmarks, which may contain thousands of striations, can also tell the history of the fatigue process. Each striation represents the advance of the crack front during one cycle of stress, where the distance among them depends on the applied stress range. Because of microplasticity at crack tip and the crack extension mechanism in a cycle, it should be expected that profile of striations depends on the type of material, and the visibility of striations also depends on the severity of load cycles [9].

Crankshafts present particular differences regarded to normal shafts because they need crankwebs to transmit the linear movement of pistons. They have distinct geometrical zones with different functions, namely crankwebs, crankthrow, crankpins, counterweights, main journals, as is shown in Fig. 1. Each pair of crankwebs connects together the two main journals. The main journal bearings support the whole crankshaft on the bedplate. The crankthrow (1 pin + 2 webs + 2 counterweights) is an offset of shaft which receives the force of piston through the connecting rod to rotate the shaft.

Counterweights balance the off-centre weight of both crankpin and webs and therefore compensate the centrifugal force generated by the crankshaft rotation speed. Without such balance, the crank action will create severe vibrations, particularly at higher speeds, leading to the crankshaft to become damaged if such vibrations are not controlled. Due to such abnormal vibrations the loosening of bolts frequently also happens. Counterweights use the inertia to reduce the pulsating effect of power impulses with the same manner as the flywheel which is also used to store rotational energy. The flywheel absorbs the energy during the motor cycle impulse and returns to the crankshaft at the dead points of two-stroke or four-stroke engines. There are dynamic forces that exist in a running engine that probably exceed the fatigue strength. For example, an off-center mass of 40 g at 50 mm of distance from the crankshaft's axis and 2000 rpm produces a centrifugal force of 88 N; but at 4000 rpm increases to 350 N. Hence the stress level increases four times as the shaft speed doubles.

The major crankshaft material competitors currently used in industry are forged steel, nodular cast iron, and austempered ductile iron. These materials should be readily shaped, machined and heat-treated. They need adequate strength, toughness, hardness, and high fatigue strength. The effects of manufacturing process on fatigue design and optimization of automotive components using experimental, numerical and analytical tools has been investigated [10]. This study was concerned with fatigue performance evaluation of forged versus competing manufacturing process technologies. The influence of the residual stresses induced by the fillet rolling process on the fatigue process of a ductile cast iron crankshaft section under bending was also investigated [11] under bending for two-dimensional plane strain finite element analysis. Due to rolling process the

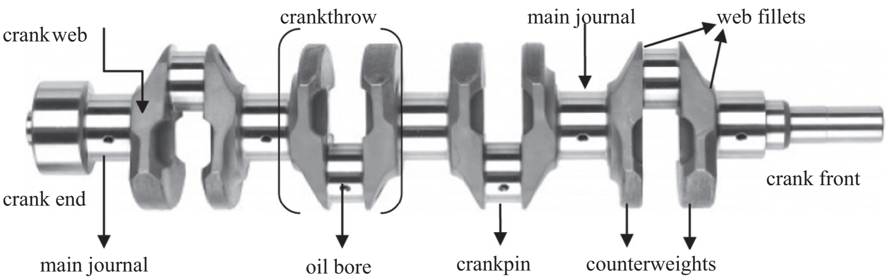

Fig. 1. Typical crankshaft with the technical and usual nomenclature.