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Failure investigation of the crankshaft of diesel engine

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Abstract

In this work the failure, stress and modal analysis of the crankshaft of diesel engine was performed. Visual examination of damaged part showed that the fatigue beach marks were observed on the fracture. Results of additional investigation using the scanning electron microscope revealed the presence of micro-cracks in crack origin area. In next part of experimental investigations the specimens were cut from damaged shaft. Results of tension test showed that mechanical properties of the steel used for the crankshaft manufacturing is in the range defined by the standard. In order to explain the reason of premature crankshaft damage, the finite element method was utilized. In first step the numerical model of crankshaft with the connecting rods was prepared. The boundary conditions were next defined on bearing journal surfaces. The complex load cases were also defined in order to model the real engine loadings. Results of nonlinear stress analysis performed for the crankshaft model showed that during work of engine with a maximum power the high stress area was located in another zone than the crack origin. This result was a reason for extension of investigation on the dynamic problems. In last part of the study the numerical modal analysis was performed for the crankshaft. In this analysis both the frequencies and modes of free vibration were obtained. Results of modal analysis showed that during second mode of free vibration the high stress area was located in the crack origin zone. Based on results of performed investigations it was concluded that the main reasons of premature failure are resonant vibrations of the crankshaft.

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Keywords: Crankshaft, failure analysis, finite element method, modal analysis, diesel engine.

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1. Introduction

The crankshaft belongs to the group of critical components of the piston engine. The crankshaft transfers the loads from the connecting-rods on the clutch. In diesel engines the large torsional moment at low rotational speed causes that high stresses are observed in assembly of crankshaft, piston and connecting rods. The high stress amplitude common with bad design or production defects can cause decrease the fatigue life of engine components.

The results of failure analysis of the piston engines crankshafts were described in several research works. An interesting fracture study of boxer engine crankshaft was described by Fonte at al. (2015). According to authors the catastrophic failure of crankshaft was caused by poor design of steel support shells and bedplate bridges. The failure investigations of the crankshaft of diesel engines were performed by Pandey (2003). The crankshafts were damaged at time between 30 h and about 700 h of engine operation. Performed analysis showed that cracks were initiated from the crankpin-web fillet region where high stress level was observed. The failure investigation of the crankshaft of diesel engine was performed in study of Zhiwei at al. (2005). The fracture was occurred in the zone between the 2nd crankpin and 2nd journal. Fractographic analysis showed that fatigue is the main mechanism of the crankshaft failure. The partial absence of the nitrided layer may result from over-grinding after nitriding. The failure analysis of two crankshafts of diesel engines was performed by Silva (2006). Both investigated crankshafts were damaged in short time after repair of the engine. The main reason of early failure was wrong grinding process. Majority failure cases of the crankshafts are related to the fracture in crank pin zone. This region is indicated as critical. The research, in which the crack was initiated in different region is described in work of Heyes (1998). The fatigue crack origin was in this case the oil hole. In mentioned above cases the authors analyzed mainly the static loads. During work of engine, the components are subjected to high rotational speed. As a result of rotation of an unbalanced shaft, a dynamic loads act on all engine components. In combustion engines these loads can be reason for pre-early fatigue damage of the structure as was reported by Witek (2014, 2016).

Main objective of presented investigations is explanation of failure reasons of the crankshaft of diesel engine. An additional aim of this work is determination the stress distributions in crankshaft during the work of the engine. In this study the modes, frequencies and stress states were also obtained for the crankshaft subjected to resonant vibrations.

2. Visual examination of damaged crankshaft

The crankshaft of S-4003 engine was ruptured in region of the crank pin no. 4 (Figs 1 and 2a) after about 5500 hours of engine operation. S-4003 is naturally aspirated diesel engine used for power of the tractor. The engine displacement is 3120 cm^3. The maximum power equals 33.12 kW at rotational speed of 2000 RPM.

Performed visual examination indicated that on crankshaft fracture the beach marks typical for fatigue failure were observed (Figs 2b and 3a). Observation of crack initiation zone showed that the crack origin was not covered by corrosion products. The local surface corrosion (brown color in Fig. 2b) on the fracture occurred because the crankshaft after failure was stored for a long time in a humid air.

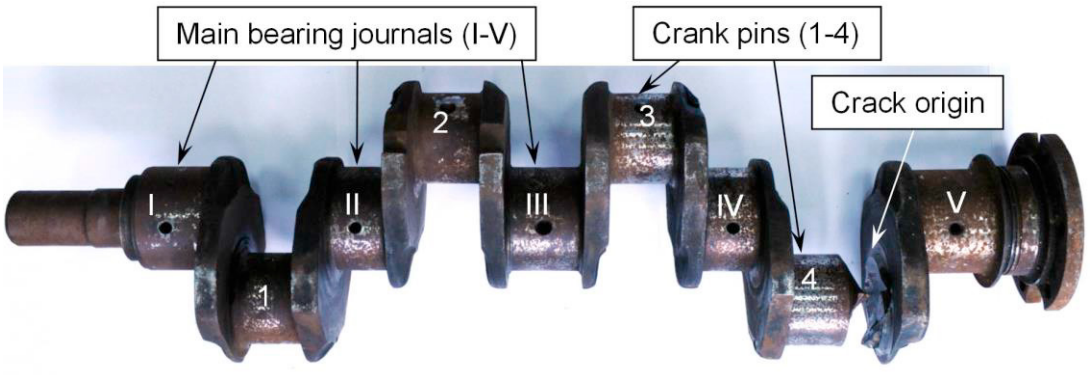

Fig. 1. Crankshaft of S-4003 engine after failure.