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Failure and thermo-mechanical stress analysis of the exhaust valve of diesel engine

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ABSTRACT

In this work the failure analysis of the exhaust valve of diesel engine was performed. Visual examination of damaged engine parts showed that on the fracture of exhaust valve the beach marks, typical for fatigue failure were observed. Additional observations of the crack initiation zones indicated that the crack origins were not covered by material defects or corrosion products. In order to explain the reason of premature valve damage, the non-linear finite element analysis was utilized. The discrete model of simplified valve system composed of the valve guide, the poppet valve and the seat face was defined. In numerical analysis both the mechanical force arising from the valve spring and also the thermal load resulting from the non-uniform temperature field were defined. The results of nonlinear static analysis showed that in the engine without any disturbances, the maximum principal stresses in the critical zone of the valve have low values. The examination of another (non-defected) valve from damaged engine head indicated that irregular carbon deposit was located on the valve face. The results of stress analysis performed for the valve with the carbon deposit showed, that in the valve stem a high bending stresses were occurred.

1. Introduction

The piston engines are commonly used in automotive industry. Nowadays the tendency to increase the engine power is observed. Simultaneously the engine capacity is often decreased in order to reduce both the fuel consumption and also the emission of noxious compounds. The mentioned design assumptions cause achieving the high operational stresses in the parts of modern piston engines.

A valve system is one of the main components of a diesel engine. The poppet valve opens and closes the connection between the cylinder and the exhaust manifold during the work of the engine (Fig. 1). The exhaust valve is subjected to the complex thermo-mechanical load. The mechanical load is caused by the valve spring when the valve is closed.

The valve has a contact with hot exhaust gases which temperature can be higher than 700 °C [1]. The thermal load is concerned with the non-uniform temperature field which occurs in the exhaust valve during the work of the engine. A high working temperature decreases the fatigue and static properties of the valve material. Due to the above reasons, the exhaust valve belongs to the group of critical engine parts (from the fatigue point of view).

The stress and failure analysis of the valves of piston engines were described in several research works. In the work [2] the failure analysis of a two-stroke diesel engine damaged after nine months of operation was performed. As a result, the turbocharger, the piston crown, the cylinder head, the fuel injector and the exhaust valves from one cylinder were extremely damaged.

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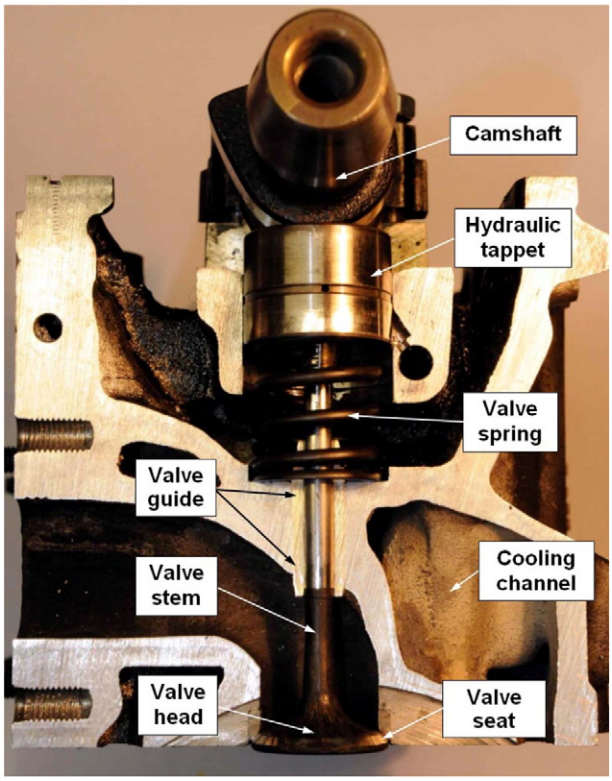

Fig. 1. Exhaust valve assembled in the head of a diesel engine (cross-section of engine head in which the fracture of valve occurred).

Examinations showed that various fracture mechanisms, such as thermal cracking, intergranular fracture and high-cycle fatigue were observed for damaged engine parts.

The results of experimental investigation of two-stroke diesel engine (with was lubricated by the oil with the use of two different kinds of oil additives) were presented in the work [3]. In this paper the author's attention was focused on erosion, corrosion and "guttering" problems of the exhaust valves. The paper [4] presents the failure analysis of a diesel engine exhaust valves which were damaged in operation. The formation of the lamellar structure in the material of the valve head was a main reason for the fatigue failures of investigated exhaust valves.

The failure problem of exhaust valve stem of the Waukesha P9390 GSI gasoline engine was presented in the work [5]. A significant loss of hardness showed that the valve failed as a result of overheating.

Results of the fatigue test of valves obtained by permanent-mould cast γ-TiAl alloy were presented in the work [6]. Titanium alloy is an alternative material used for production of engine valves because it has low density. As a result of smaller mass of the valve, the reduction of both the inertial loads and also the stress values are observed in the valve stem.

A study of complex analysis of the valve (considering head thermal deformation) is presented in the work [7]. The authors describe the problem of exhaust valve fracture of the gasoline engine. The critical fracture zone was the valve stem in which the highest temperature is observed. An additional result of this paper is also the stress distribution in the valve in which the mechanical, thermal and dynamic loads occur. Authors indicate that the non-uniform deformation of the engine head (common with the seats) is the reason of appearing the bending stresses in the valve stem. This phenomenon causes decrease of the fatigue life of the valves.

In the work [8] the stress and failure analysis of the engine head were presented. A non-uniform temperature field in the engine head was a main reason for both the stress concentrations and the cracks appearing on the seat faces of the head.

The review of the engine valves failures is presented in paper [9]. According to the authors, the main reasons of valve failure are: overheating, decrease the strength of material at high temperature, oxidation, fretting, galling and impact load. The authors of work [9] indicate that the most critical zones of the valve (from the fracture point of view) are the head and the stem.

In many papers only the static loads are considered. In the work [10] the dynamics of complex valve system was investigated. The authors performed a complex experiment in which the camshaft was powered by an electric engine. As a result of performed analysis the dynamic forces in the valve stem were measured using strain gauges. Moreover, the acceleration of the valve head was measured using the piezoelectric sensors. The results of another research works show that vibrations have a negative influence on the fatigue life of many parts used also in the aviation industry [11–13].

The main objective of presented investigations is the failure analysis of the exhaust valve of diesel engine. The additional research goal of this work is determination of the stress state in the exhaust valve of a piston engine, subjected to complex thermo-mechanical load.