Engineering Failure Analysis 94 (2018) 13–23

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Short Communication

Fatigue failure of an intermediate transition block in fuel-injection pump fork assembly of a truck diesel engine

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ARTICLE INFO

Keywords:
Intermediate transition block
Fatigue fracture
Electro-discharge machining
Surface imperfection
Finite element analysis

ABSTRACT

A truck diesel engine fuel-injection pump fork assembly failed after service of 50703 km. Fuel-injection pump fork assembly was constituted of the fork at the side of air-compressor pump, the intermediate transition block and the fork at the side of high-pressure oil-pump. General inspection in site indicated that the intermediate transition block fractured into four pieces. Fractographic analysis indicated that the block cracked due to fatigue. Four cracks occurred at respective U-shaped groove on the block and originated from the electro-discharge machined (EDMed) fillet root of U-shaped groove, where high stress concentration was caused by the geometry design. A remelted layer of about 5–20 μm was observed on the EDMed U-shaped groove surface. A lot of micro-cracks were presented within the remelted layer, which acted as stress raisers and led to a considerable reduction in fatigue strength of material. The cracks and surface imperfections associated with the remelted layer provided sites for fatigue crack initiation and subsequence propagation into the substrate material, which ultimately caused fatigue fracture of block. A finite element model of the block predicted that the highest stress concentration areas coincided with the first fracture zones and the maximum stress gradient direction was in agreement with the crack initiating direction.

1. Introduction

Fuel-injection pump is one of the important components of truck diesel engine. The fuel-injection pump fork assembly is a transmission device, which connects the fuel-injection pump with the speed controller. The fuel-injection pump fork assembly is constituted of the fork at the side of the air-compressor oil-pump, the intermediate transition block and the fork at the side of the high-pressure oil-pump, seen in Fig. 1. The fork at the side of the air-compressor oil-pump is the drive end of the assembly, but the fork at the side of the high-pressure oil-pump is the outlet end, and the intermediate transition block is the joint link between the two forks. The fork at the side of the air-compressor oil-pump drives the intermediate transition block turn, and then the intermediate transition block drives the fork at the side of the high-pressure oil-pump turn.

A set of fork assembly failed after service of 50,703 km. Inspection in site found that the fork assembly failed due to the breakage of the intermediate transition block (Fig. 2). According to the information provided by manufacturer, the expected design life of fork assembly is about 300,000 km. The block is made of 40CrA steel, quenched and tempered (toughening treatment). The core hardness is specified as 321–375 HBW. In this paper, the fractured block was investigated using various material analysis techniques to

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https://doi.org/10.1016/j.engfailanal.2018.07.019
Received 11 March 2018; Received in revised form 19 July 2018; Accepted 20 July 2018
Available online 23 July 2018
1350-6307/

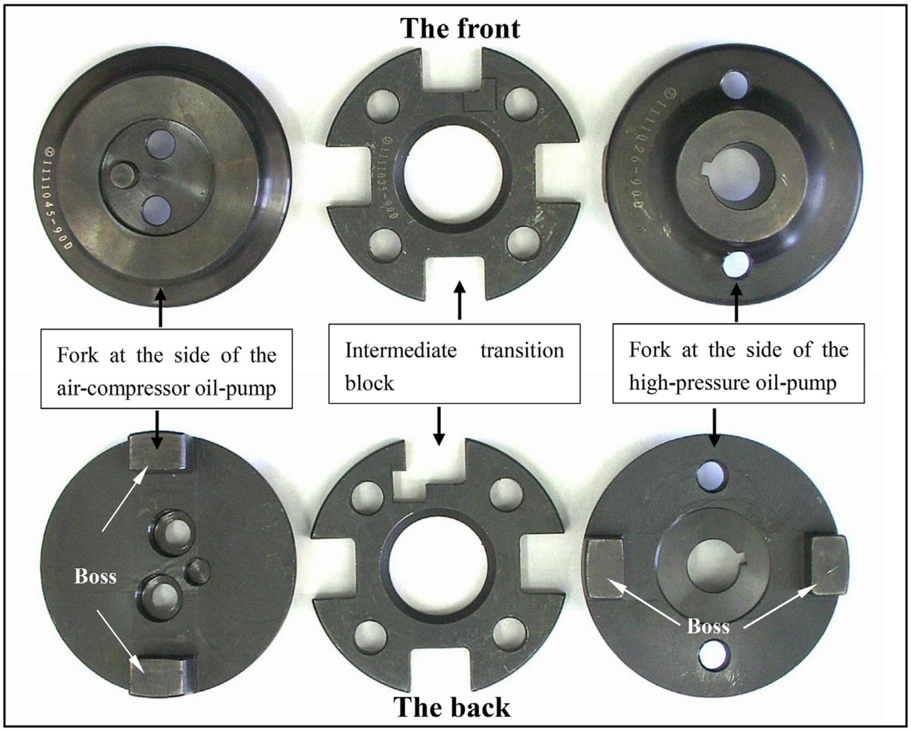

Fig. 1. Fuel-injection pump fork assembly.

determine the failure mode and the root causes and recommend possible measures for preventing such kind of failure in future.

2. Investigation methods

The chemical composition of the fractured intermediate transition block was determined by optical emission spectroscopy (OES). The microstructure was observed by optical microscopy (OPM) and scanning electron microscopy (SEM). Microhardness measurements in various regions were conducted using a Vickers system with a load of 25 g. The crack surfaces were observed visually and using SEM.

3. Observation results

3.1. Observation on fracture surfaces

The fractured intermediate transition block in as-received condition is shown in Fig. 2. It can be seen that the block fractured into four pieces and the corresponding cracks were identified as C1, C2, C3 and C4. The cracks C1 and C3 were situated on the U-shaped grooves in contact with the bosses of the fork at the side of air-compressor oil-pump and the cracks C2 and C4 at the U-shaped grooves in contact with the bosses of the fork at the side of high-pressure oil-pump (indicated in Fig. 2). All the cracks (C1, C2, C3 and C4) were nucleated at the fillet root of respective U-shape groove. The joined block in the front view and the back view did not exhibit any severe material protrusion and obvious macro-plastic deformation [1], suggesting that the load on the block was low before fracture. The cracks C1 and C3 propagated initially from the fillet root of U-shaped groove at an angle of 60° to the edge of the groove and the further propagation of the cracks toward the internal hole along the radial of the block resulted in the final fracture (indicated by dotted arrows in Fig. 2). The cracks C2 and C4 propagated from the fillet root toward the internal hole in arc shape (indicated by dotted arrows in Fig. 2).

Macroscopic observation on all the crack surfaces (C1, C2, C3 and C4) revealed in general similar fractographic characteristics (Fig. 3). Fatigue fracture patterns were identified on each fracture surface, which universally showed a propagation zone and a final fracture area. Beach marks indicative of fatigue propagation were found on the fracture surfaces. Following the orientation of beach marks, the fatigue crack origins were confirmed to be situated at the fillet root of U-shape groove, marked in Fig. 3. The crack origins of cracks C1 and C3 were point-sources, but the crack origins of cracks C2 and C4 were line-sources, suggesting that higher stress concentrations occurred on the cracks C1 and C3, compared with the cracks C2 and C4. The final fracture areas of four cracks were all smaller, suggesting that the block was not heavily stressed at the time of final failure, but there were high stress concentrations [2]. It was noted that the fracture surfaces of cracks C1 and C3 were smooth, but the fracture surfaces of cracks C2 and C4 were rough. Compared with the cracks C1 and C3, the final fracture areas of cracks C2 and C4 and the plastic deformation zones on them were