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A methodology for the fatigue design of notched castings in gray cast iron

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Abstract

Fatigue failures of machine components remain a topic of relevant importance in the industrial world. They usually occur from geometrical features such as holes, notches, corners and grooves, whose actual influence is not well estimated in the design phase. Cast parts made in gray cast iron are typical examples of components difficult to design in fatigue because they are simultaneously characterized by complex geometries and microstructure. In this contribution the issue is discussed starting from the failure analysis of a cyclically pressurized hydraulic component. The work consists of an experimental procedure, i.e. the fatigue characterization of the material on specimens extracted from cast parts, and of a numerical design activity, i.e. the prediction of life time according to the critical distance method [Taylor D. Crack modelling: a technique for the fatigue design of components. Engng Fail Anal 1996;3(2):129–36]. The implication is that cracks and localized damage begin to appear in the microstructure of gray cast iron at sharp notches from the first cycles of loading. In order to obtain a correct prediction, the fatigue design should adopt fracture mechanics arguments to determine non-propagating conditions.

Keywords: Fatigue in notched members; Gray cast iron; Critical distance method; Structural durability

1. Introduction

It is widely established that fatigue failures are still the most critical and often not well understood causes of in-service decease of mechanical components. Fatigue failures generally originate starting from favourite sites where stress concentrates, as holes, notches or severe geometric changes, whose effects are often underestimated in the design. Both surface roughness, which can depend on the manufacturing process, and environmental conditions play a crucial role in the process of fatigue crack initiation and propagation.

According to Berger et al. [2] the (cost-controlled) parameters that influence the structural durability of a machine part can be summarized in four terms: material, manufacturing, loadings and design. As shown

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further, this work mainly concerns the aspects related to material and part design, which are linked by the manufacturing technology.

Fluid power components are typical examples that combine both aspects of complex geometry and complex material microstructure and are therefore difficult to design in fatigue. Gray cast iron is often selected to produce parts of complex geometry due to its excellent castability and adequate mechanical properties. On the other hand, gray cast iron is quite poor in terms of fatigue resistance due to its typical microstructure of distributed graphite lamellae in a pearlite matrix.

Because most components are designed to operate for very long lives, a method for predicting the fatigue limit of a component of arbitrary shape is highly desirable. The classical design approaches adopted to predict the fatigue life consider the maximum stress (or strain) acting in some critical points (“hot-spots”) of the component [3,4]. These values, calculated via analytical or numerical methods, are then compared with the fatigue or cyclic strength of the material to assure the structural durability of the part. The weak point of the stress or strain-based approaches is the possibility to dramatically underestimate the fatigue endurance of the component, when the case of sharp notches in which stress concentrates in a relatively small area. This contribution is aimed at presenting a fatigue design approach under development specifically for fluid power components made of gray cast iron. As mentioned, any fatigue design method has to deal with loading, geometry, material and fabrication aspects. Here loading and geometry aspects are treated using the elastic finite element analysis (FEA) method to identify locations of stress concentrations at which high local stresses and high stress gradients exist.

For this study, material and fabrication aspects have been investigated using specimens extracted from actual cast parts. The specific object of the study is a directional valve body, which is characterized by a system of internal channels distributing pressurized oil to different outlets. The part is shown in Fig. 1; a typical application of the valves group is also illustrated. The valve body is produced by casting in a sand mold with an internal sand core to realize the channels system. During the product development, the internal core was modified by the designers and the material changed from vermicular to gray cast iron to reduce the producing cost. Fatigue tests of the redesigned casting were performed on a hydraulic test bench under a pulsating pressure from 1 to 35 MPa. A premature failure of the component was detected, therefore the need of a fatigue design criteria.

To determine the crack initiation location, the liquid penetrant method was applied to a cross-section of the component after some thousands of cycles. Some results are illustrated in Fig. 2a and b. In Fig. 2a two large cracks are visible: the first originates from the vertical channel denoted “P” in correspondence of a sharp notch, and runs into the horizontal cylindrical channel “H”. Crack indicated with number 1 was responsible of loss of functionality of the valve body. A second internal crack, indicated with number 2, is found in the bottom of “H” channel and follows the core longitudinal section plane.

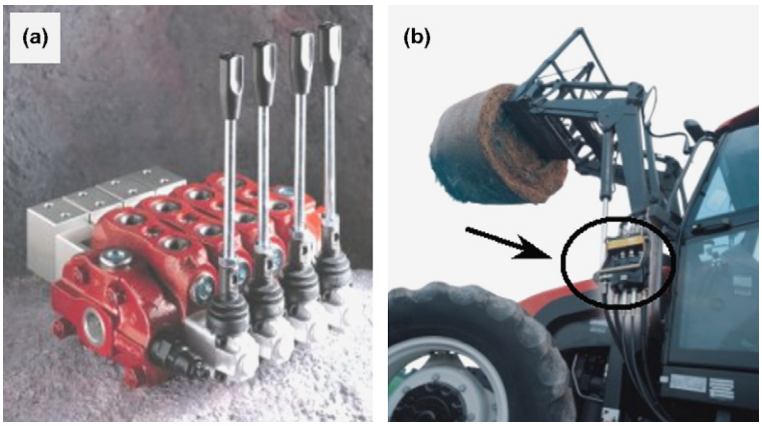

Fig. 1. (a) Modular set of high pressure directional valves; (b) typical application of the valve on a tractor lifter.