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Structural integrity analyses of two gas turbines exhaust systems used for naval propulsion

António Soares[a], Rui F. Martins[b,*], António F. Rodrigues Mateus[c]

[a]*Faculty of Sciences and Technology, Universidade Nova de Lisboa, Department of Mechanical and Industrial Engineering, Campus de Caparica, 2829-516 Caparica, Portugal*

[b]*UNIDEMI, Faculty of Sciences and Technology, Universidade Nova de Lisboa, Department of Mechanical and Industrial Engineering, Campus de Caparica, 2829-516 Caparica, Portugal*

[c]*Arsenal do Alfeite, S.A., Base Naval de Lisboa, Alfeite, 2810-001 Almada, Portugal*

Abstract

Heating and cooling cycles, as well as accelerations and decelerations, to which naval gas turbine's exhaust systems under study are submitted to, could lead to the nucleation and propagation of cracks, and result in the reduction of its expected fatigue life. The paper herein presented refers to the numerical simulations of the mechanical and thermal behaviours of two different gas turbine's exhaust systems used in naval propulsion. In addition, some experimental values that were collected, namely temperature and pressure, served as input values for the finite element analyses carried out. The analyses made to the exhaust systems revealed the existence of high stresses near the lower support flanges, which are mainly caused by the non-uniform thermal expansion that the exhaust systems are subjected to. Additionally, redesigned exhaust systems were studied in order to enhance the thermal behaviour of the exhaust systems and, therefore, increasing its fatigue life. The modifications introduced in the exhaust systems resulted in the reduction of the induced stresses. However, frequent surveys should be performed to the critical welds of the exhaust systems, in order to prevent crack propagation from the weld toes. Moreover, high quality fabrication is required in order to avoid the presence of initial defects in the structure.

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Keywords:Structural integrity; Design and structural assessment; exhaust systems; gas turbine; naval propulsion; AISI 316L.

* Corresponding author. Tel.: +351-21-294 85 67; fax: +351-21-294 85 31.
E-mail address: rfspm@fct.unl.pt

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1. Introduction

Transient heating and cooling cycles (thermal shock) led to the nucleation and propagation of cracks at the weld toe of some fillet and butt-welded joints located near the lower support ring of a naval gas turbine exhaust system (Fig. 1a), resulting in a reduction of its expected fatigue life (Martins et al. 2009). In fact, the dissimilar thicknesses of the support ring and of the exhaust pipe's shells resulted in different deformation's values when under heating and cooling cycles, for the two structural parts referred, and the different thermal inertia of the parts originated thermal fatigue crack propagation. Additionally, the material used to fabricate the exhaust system – an AISI 316L austenitic stainless steel grade type - had a very low carbon content to diminish the probability of sensitization (ASM Handbook, 1994). Nevertheless, metallographic analyses carried out in some butt-welded joints revealed the presence of oxides in the material and also the presence of chromium carbide precipitates at the grain boundaries of the heat affected zones (HAZ), which most probably nucleated and grew during the post-weld cooling time (Cruz et al., 2010), (Martins et al. 2010) and (Martins et al. 2008). In addition, the medium surface finish of the material produced by the rolling process, as well as the welding defects introduced during the fabrication of the exhaust system (Fig. 1b), resulted in a reduction of the fatigue strength of the material and, consequently, on the fatigue life of the structure. The existence of numerous defects on the fracture surface obtained near the critical region (Fig. 1b) can also be explained by the fact that welding of austenitic stainless steels frequently generates micro-cracks (TWI Report, 2005).

The paper aims to compare the mechanical and thermal behaviour of the original exhaust system's design with the mechanical and thermal behaviour of some alternative designs, which includes either minor structural design modifications or the use of two alternative materials. An alternative exhaust system's design (Fig. 1c) was also assessed.

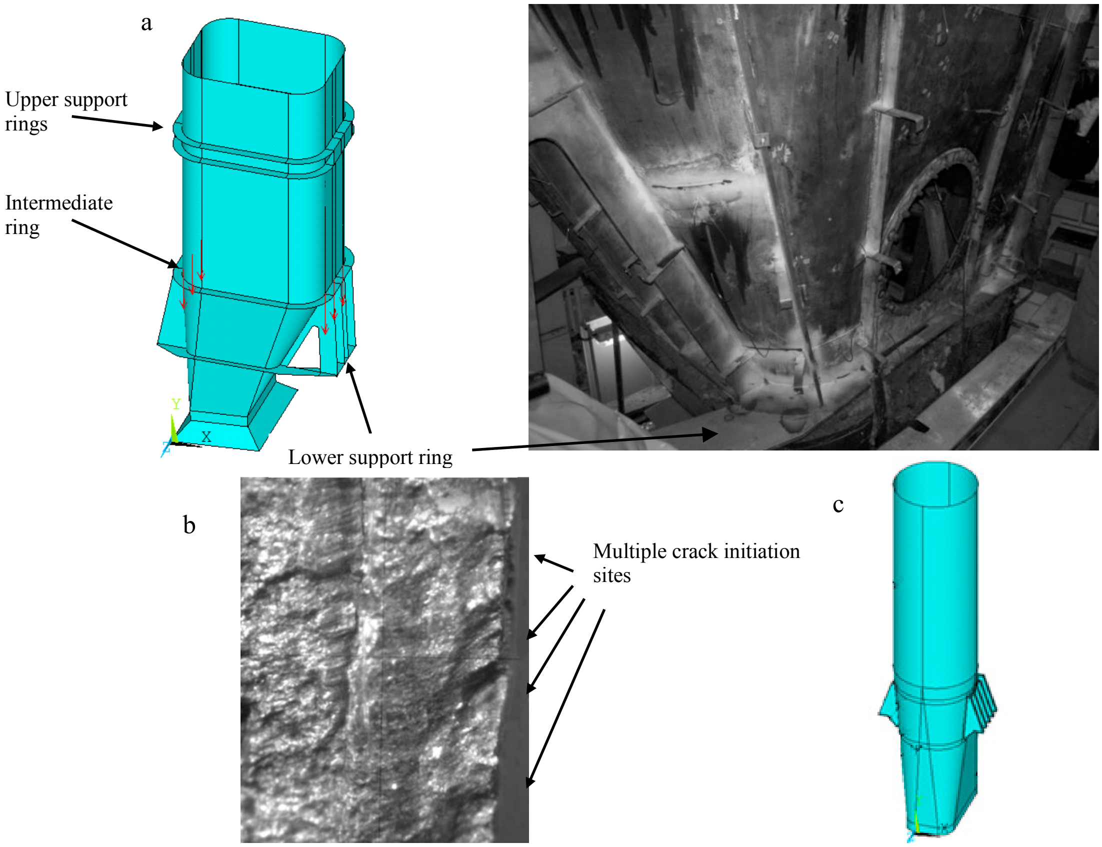

Fig. 1. (a) Overall view of the exhaust system under study and detail view of the lower support ring at the critical region of the structure; (b) Fracture surface taken out from the critical region of the exhaust system where multiple crack initiation occurred; (c) 2nd exhaust system design.