Fatigue Reliability of Large Catamaran Considering Inspection Updating

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ABSTRACT

This paper presents a method for simplified fatigue stress analysis for large catamaran based on implied cumulative fatigue criterion. A probabilistic fracture mechanics model for fatigue life prediction is introduced. Probabilistic fracture mechanics approach is calibrated to an SN approach to better account for crack initiation and initial crack size. The fatigue reliability of the considered structural details is modeled as a system considering the fact that fatigue cracks may occur at many locations. Subsequently, the effect of inspection on the system fatigue reliability is exemplified with the aim at probabilistic inspection planning.

KEY WORDS: fast ships; catamaran; fatigue, reliability, inspection planning, aluminum alloys

INTRODUCTION

Fast ships like large catamarans are of increasing commercial importance in the areas of passenger and cargo transportation and other marine operations. Fast sea transportation could be used for archipelago or coastal services in competition with short distance airplane services. For this reason, more and more attention and efforts are being paid to this field throughout the world.

In order to efficiently keep high speed, minimal structural weight is crucial. For this reason aluminum is a much-preferred material. Moreover, it implies a high utilization of the structure. Due to the high frequency of repetitive loads and the relatively low crack propagation resistance of aluminum, fatigue becomes an important design criterion.

Catamarans are composed of two demi hulls with a connecting bridge serving as car deck and passengers deck. As an important part of catamarans, the box structure between the two demi hulls is critical to overall structural integrity. There is a great possibility that multiple cracks or crack-like defects exist along welds. Each existing crack may lead to fatigue failure. The structure and loading of catamarans are among the most complex with significant uncertainties, most of which are still difficult to quantify. It is therefore desirable to carry out the analysis based on probabilistic concepts.

In-service inspections of catamaran structural details are carried out during its lifetime in order to ensure its integrity. Many efforts have been done on reliability updating through inspection and repair mainly applied for the components inspected or repaired at a component level, survey e.g. by Moan (1997).

In this paper, the reliability of welded sites that are designed to fulfill relevant fatigue design criteria (allowable cumulative damage) is studied. The probabilistic model for fatigue life prediction introduced includes correlation between the properties at different locations. The component reliability is based on a probabilistic fracture mechanics (FM) approach and aluminum alloy material properties are determined based on codes and experimental work. Uncertainties in wave-induced cyclic stress (load effects) and resistance against crack propagation (initial crack size, crack propagation parameters, crack propagation) as well as inspection reliability are taken into account and specified in probabilistic measures. In order to achieve a consistent fatigue life based on SN and FM approaches, the initial crack size used in FM model is calibrated by applying SN approach. The fact that fatigue cracks may occur at many locations is accounted for by a series system concept. Hence, a system fatigue reliability model is developed considering the correlation between safety margins in the different components. Subsequently, fatigue reliability is updated through inspection results based on the system concept with the aim at probabilistic inspection planning. Finally, a numerical example is presented to demonstrate its application to a large catamaran.

SIMPLIFIED FATIGUE STRESS ANALYSIS

Long Term Stress Distribution

Catamarans are subjected to oscillatory stresses mainly due to the action of waves. Studies of wave loading acting on ships have shown that long term distribution of stress range is modeled by a two parameter Weibull distribution,

\[ F_S(S) = 1 - \exp \left[ -\frac{S}{A} \right]^B \]  

(1)

where A, B are the scale and shape parameters respectively.