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On the assessment of fatigue life of marine diesel engine crankshafts

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ABSTRACT

The fatigue strength and its correct assessment play an important role in design and maintenance of marine crankshafts to obtain operational safety and reliability. Crankshafts are under alternating bending on crankpins and rotating bending combined with torsion on main journals, which mostly are responsible for fatigue failure. The commercial management success substantially depends on the main engine in service and of its design crankshaft, in particular. The crankshaft design strictly follows the rules of classification societies. The present study provides an overview on the assessment of fatigue life of marine engine crankshafts and its maintenance taking into account the design improving in the last decades, considering that accurate estimation of fatigue life is very important to ensure safety of components and its reliability. An example of a semi-built crankshaft failure is also presented and the probable root case of damage, and at the end some final remarks are presented.

1. Introduction

Marine main engines are largely used in ship propulsion and are required to have higher power outputs with smaller sizes. The engines power is raising from year to year with the increasing of deadweight in new ships construction. The engines commonly are of two-strokes and have low speeds (90–120 rpm) with considerable height. The increasing size of ships has resulted in a demand requirement for high powers, but at the same time a low engine speed results into a low consumption and thus also a low cost of fuel. The vital and main component of a marine diesel engine is the crankshaft, which transforms reciprocating motion of pistons into rotary motion, and experiences a large number of loading cycles during its service life. As it is well known, a mechanical component subjected to a repetitive stress probably will fail with a stress much lower than that required to cause fracture on a single load application. Therefore fatigue failures occur and generally after a long period of service conditions. It is estimated that the fatigue failure accounts for at least 85% of all service failures due to mechanical causes.

Crankshafts are power shafts subjected to multiaxial fatigue under complex loading conditions and are also one of most critically loaded components of internal combustion engines. The main source of loading comes from the gas pressure due to combustion process, which can reach hundreds of tons transmitted to each crankpin by the connecting rods. These forces vary according to angle of thrust applied by the connecting rod and the cylinder firing pressure but are greatest at about

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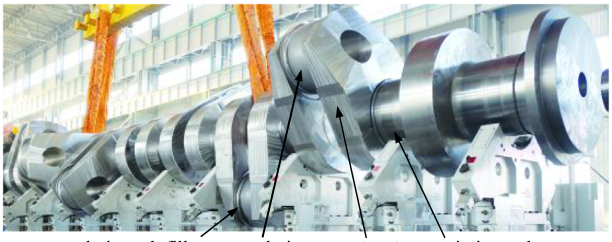

Fig. 1. Crankshaft type 90 half built-up crankshaft of low-speed 2-stroke marine diesel engine [2].

10° either side of top dead center (TDC). Crankshafts are subjected to, during one revolution, both maximum and minimum bending stresses combined with torsion. If the main bearings are in misalignment the bending is increased. Any rotating power shaft will be also subject to torsional vibrations at the natural frequency of the shaft resulting from the compression and firing forces applied to the crankpin through the piston and connecting rods. To absorb these types of vibrations some main engines has a damper.

Crankshafts normally have either integral or attachable counterweights. These counterweights counteract the centrifugal force created by each individual crankpin and crankwebs when whole crankshaft is rotated about the main journal axis. In absence of counterweights, the crankpin masses tend to bend and distort the crankshaft causing excessive edge-loading in the main bearings. Therefore, each half crankweb is generally extended in the opposite direction of the crankpin, to counterbalance the effect of crankpins.

A crankshaft has three main components as is shown in Fig. 1: the crankpin journal, which receives the force from the connecting rod; the main journals, which are supported by the main journal bearings on the bedplate; the crankwebs, which connect two main journals to the crankpin.

What is the root cause of main diesel engine failures? Some factors influencing the fatigue life of marine crankshafts are [1]: loss of effective lubrication; over speeding of engines or eventually an operation in critical or forbidden revolution range; faulty crankshaft damper designed to eliminate excessive vibration from the crankshaft; engine power imbalance, as result of deficient maintenance or wrong power monitoring; misalignment of journal bearings; improper design and manufacture of crankshaft; overloading of main engine; grounding of the vessel and damage or fouling of propeller; bearing shells suffering considerable metal loss due to sudden or gradual wear.

Most of crankshaft failures occur due to high stress concentration originated by the changing of cross-section at the crankpin-web or main journal fillets, or yet at the lips of lubrication bores. Another important root cause is the engine running with heavy vibration especially torsional vibrations. The abnormal wear of main journals or shell bearings can originate a significant misalignment of crankshaft and will cause a higher oil clearance. Regular inspections to the damper and screws tightening, measurement of crankthrow deflections, can also prevent future damages.

For estimating fatigue life there is several methods which are used nowadays such as stress life (S–N), strain life (ε–N) and Linear Elastic Fracture Mechanics (LEFM). The S–N method is based on nominal stress life using a rain flow cycle counting and an accumulation damage rule, generally Miner's rule. The LEFM assumes that crack is already present in the component and can be detected, being the crack growth analysis based on the stress intensity factor (SIF) K. The classical calculation method has limitations to be used for the strength analysis whereby the Finite Element Method (FEM) is a numerical calculation method that is largely used for the fatigue failure analysis of components and structures. However the Finite Element Method (FEM) and testing laboratories have contribute significantly to anticipate and avoid catastrophic failures, being that the probability of a catastrophic failure of marine crankshafts to occur is very low due to rigorous rules of design and periodic surveys [3]. For assessment of a crankshaft fatigue life is mainly necessary to determine the stress levels at the geometrical critical zones. Nowadays, with the increasing of computer efficiency, Finite Element Analysis (FEA) is largely used for stress state determination in crankshafts and is an advanced modelling technique that can help to predict the magnitude of stress on individual components within complex assemblies and under complex loading service conditions. The aim of this work is point out the main issues regarding fatigue life assessment of marine diesel engine crankshafts, design improving and manufacturing, presenting also an example of a semi-built crankshaft failure.

2. Design and manufacturing considerations

New crankshafts manufacturing has been developed in the last decades. Crankshafts can be manufactured by assembly parts or by forging. Nowadays, the more common marine crankshafts manufacturing are: (i) assembled crankshafts, where the crankpin journal, main journal and crankwebs are manufactured separately and then fitted together using a shrink fitting method; (ii) semi-built crankshaft where webs and main journals and/or crankwebs and crankpin journals are forged as one piece and shrink fitted together, being the most common for large marine main engines, as is shown in Fig. 2(a) and (b); (iii) fully forged crankshaft that is built from an entire forged. However crankshafts are generally classified into two categories: