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Fatigue resonant tests on drill collar rotary shouldered connections and critical thread root identification

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A B S T R A C T

A fatigue test series on a drill collar rotary shouldered connection, thread type 5-1/2 FH MOD, was performed with a dedicated alternating bending resonant test rig. Compared to a quasi-static testing approach, the dynamic loading allowed high testing frequency and a relatively light supporting structure. Crack initiation was identified as the onset of a discrepancy between two strain gauge signals which were monitored throughout the test. A through-wall crack condition was assumed as the effective fatigue failure. The stress distribution in the connection was then analysed with a finite element plane harmonic axisymmetric model, taking into account both the initial make-up torque and the alternating bending load during the test. In these simulations, the most critical stress between the pin or box, in terms of fatigue, mainly depended on the preload. The modelled contact behaviour of the incomplete threads of the box played a significant role in predicting the position of the crack initiation thread root, which was then compared with the test results.

1. Introduction

Drill collars are usually placed at the lower part of drill strings and, similarly to drill pipes, can experience large lateral bending loads, induced by string vibration and/or rotation inside a bent path, leading to possible fatigue failures [1-7]. These loadings are exacerbated by the extreme operating conditions that can be found, for example, in deep-sea drilling for scientific explorations and geological surveys. Inoue et al. [8, 9] described the scientific drilling vessel Chikyu owned by the Japanese research institute JAMSTEC and reported the cumulative fatigue damage analysis performed for the Japan Trench Fast Drilling Project (JFAST) to reach the deep earthquake zone at 1000 m below the seafloor at water depths of around 7000 m. The drill pipe fatigue and the interaction with other kinds of load during the operation, such as the axial dynamic tension induced by the wave motion, were analysed with a probability approach [10]. The possible use of higher strength steels S155 and S160, instead of the more common S150, was therefore investigated by Inoue et al. [11, 12] for this harsh environment.

Resonant test rigs are based on the principle that the lowest natural mode of a mechanical system, for example the first bending mode in a beam-like structure, can be easily excited by a driven vibrating inertial device, and a dedicated control system can keep the stress amplitude steady during the entire fatigue test [13]. A resonant test rig is commonly used for large diameter pipe-like components, such as drill string elements [14-16], for two main reasons. Firstly, the working frequency can be driven in the range of 20–30 Hz, instead of a value lower than 10 Hz obtained with a quasi-static supporting structure [17, 18], which considerably reduces

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the testing time especially for long runouts. Secondly, the structure required to support the vibrating system can be relatively light. In fact, the inertial dynamic induces a load on the specimen itself, while it does not affect the supporting elements which, conversely, to bend large diameter pipes would be quite cumbersome [19].

Rotating resonant rigs, featuring a spinning eccentric mass attached to one side of the pipe specimen, are usually employed for long pipe structures, and they correctly simulate the rotating feature of the load [15, 16, 20, 21]. On the other hand, heavy drill collar specimens are more easily tested by following an *in-plane* scheme with two couples of eccentric masses at the ends of large bending arms, as reported by Bertini et al. [14]. We used this in-plane configuration to test drill collar connections whose external diameter was 7in. and thread connection size was 5-1/2in. The test rig is described, along with the setup procedure, and then a fatigue series test results are reported and analysed.

In this work, in order to identify the key factors which drive the fatigue strength of this threaded connection, we first describe the experimental testing and then propose a finite element analysis. The thread geometry naturally involves stress concentrations that need to be taken into account [22]. The load distribution on the threads can also be optimized [23] by introducing a double shoulder connection rather than the usual single shoulder [24-26]. In addition, the make-up torque needs to be carefully measured and monitored [27, 28]. The fatigue mean stress at the root of the first engaged thread of the pin is significantly affected by the preload, and an over make-up torque can be applied to introduce beneficial residual stresses [29]. We investigated the effect of the make-up torque, and then identified the thread root where the fatigue crack initiates by considering the modelled contact status of the incomplete threads of the box.

2. Experimental setup

2.1. Resonant test rig

The resonant test rig used for this activity, Fig. 1, was initially designed and manufactured at the Mechanical Department of the University of Pisa between 1995 and 2000. Its working principle and the mechanical design are detailed in [14] where recent results regarding drill collar connections are also described. These results were used as a comparison for the tests presented in the present paper.

The resonant principle of the test rig involves two couples of eccentric counter-rotating masses that produce an inertial effect, along the horizontal direction, while the transversal direction forces are neutralized, Fig. 2. The two mass couples can be phase shifted to moderate the applied cyclic bending intensity. Besides this phase tuning, the intensity of the alternating bending can also be controlled by changing the working frequency, as was the case for the tests reported in this paper.

A dynamic parametrization for the bending stress amplitude σ_a can be obtained as a single degree-of-freedom vibrating model with inertial excitation and viscous damping:

$$\sigma_a \propto \frac{m_e R_e \omega^2}{\sqrt{(1-(\omega/\omega_n)^2)^2 + (2\xi\omega/\omega_n)^2}} \tag{1}$$

where m_e, R_e are the eccentric mass and the eccentricity length respectively, ω is the working angular frequency and ω_n is the natural mode angular frequency, which is the result of the bending stiffness of the pipe specimen and the bending arm moments of inertia. Clearly, having introduced a source of (linear) damping in the model, i.e. a small damping ratio ξ, the stress amplitude is bounded even at the resonance condition ($\omega = \omega_n$), Fig. 3. By keeping the excitation subcritical ($\omega < \omega_n$), the bending load amplitude rapidly increases with the working frequency. This trend was exploited to closed-loop control the stress amplitude during the tests. When the working frequency is driven closer to the resonance, the bending amplitude is higher, and becomes lower when the frequency is not near the natural mode. After a fatigue crack initiation and propagation, the system's natural frequency becomes lower. Therefore, in

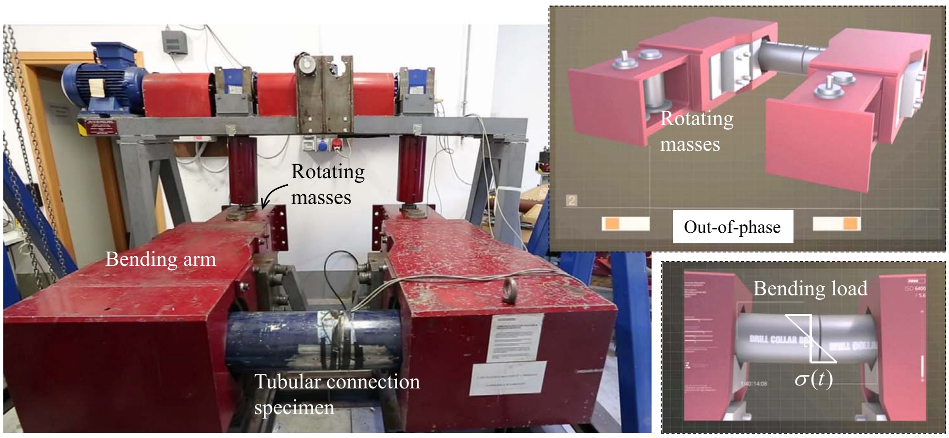

Fig. 1. Resonant test rig and drill collar connection specimen, and bending load induced by the out-of-phase eccentric masses.