# Fatigue Behaviour of Threaded Pipe Connections

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*Abstract*− **Threaded pipe connections are used in different applications in the oil and gas industry. These tubular structural elements are often subjected to fatigue loads. Due to stress concentrations, resulting from the thread geometry, the connections are the weakest points in the pipeline. The stress concentrations depend on pipe dimensions, thread type and friction between the threads. To quantify these stress concentrations, finite element analyses are carried out for different connection types using the software ABAQUS$^{TM}$. Based on calculated stress concentration factors the fatigue lives of the connections can be estimated. To validate the models, small- and full-scale experiments will be carried out. A torque machine has been refurbished to assemble the connections with a certain make-up torque. These tests will be performed to study the coefficient of friction between the threads. Fatigue tests will be performed using a universal tensile test machine. Final objective is an optimized fatigue model considering the different connection parameters.**

*Keywords*− **threaded connection, pipeline, fatigue, FEA**

## I. Introduction

Threaded pipe connections are commonly used components in the oil and gas industry, both in onshore and offshore applications. They are used to connect drill pipes, transportation pipelines and pipe segments of tension legs of offshore platforms. The connections consist of a male and female part, called respectively pin and box. To ensure a good connection without fluid leakage, the pin and box are tightened with a specified torque, called 'make-up' torque. The 'made-up' couplings must be able to withstand a variety of service loading conditions. In deep-sea applications, the weight of the pipeline causes a considerable axial load on the pipeline. An additional fatigue load is caused by the environmental conditions in offshore applications or internal pressure changes in the pipeline.

The connections are often the weakest points in the pipeline. This is due to stress concentrations, resulting from the thread geometry. The stress concentration factors depend on different parameters as pipe dimensions (diameter, wall thickness), thread geometry and coefficient of friction between the threads.

For drill pipe connections, standardized design modifications exist to increase joint fatigue strength, but their practice is largely based on service experience [1].

Goal of this research is to gain insight into the influence of the different parameters on the stress concentrations and fatigue life of the connections. The results of a parametric study will be translated into a detailed fatigue model from which more simple design rules can be formulated.

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## II. Modelling of Threaded Connections

Finite element modelling is used to calculate local stresses in the connections. Instead of time-consuming and complicated 3D models, 2D axisymmetric models are used. 2D axisymmetric models do not take into account the thread helix nor the runout regions. However, this is a widespread approach of modelling threaded connections [2], [3] and results are in good agreement with the 3D models [4].

The 2D model is a longitudinal section of the connection (see Figure 1). The pin and box mesh is finer near the thread surface because the stress distribution is more complex in this region. Finite element analyses (FEA) were performed on different connection types using ABAQUS$^{TM}$.

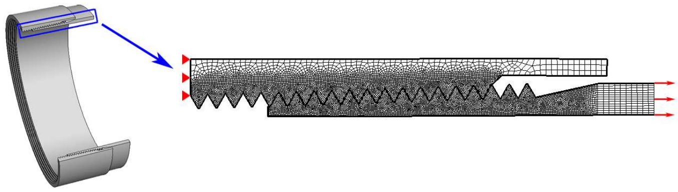

Figure 1: 2D axisymmetric finite element model of a 10" API Line Pipe connection.

The first step of the analysis is the modelling of the make-up. This is done by giving the pin and box an initial overlap corresponding with the number of turns for the make-up. Hereafter the thread surfaces are brought into contact with each other.

In the second step, an external axial load is applied additional to the load resulting from make-up. In Figure 2 the results of an analysis of a so called 10" (273 mm) API Line Pipe connection is shown. The calculated stress distribution is the result of make-up and an axial load of 200 MPa. As can be expected from [2], the highest stress concentration is located at the root of the last engaged thread of the pin. Even though the load is only 200 MPa, the highest appearing stress is approximately 800 MPa, which is the yield strength of the material used in this model. Thus localized plastic deformation will occur even at low service load.

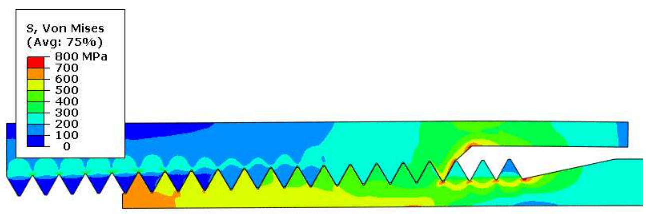


Figure 2: FEA results of 10" API Line Pipe connection with an external axial load of 200 MPa.

Using the stress concentration factors resulting from the FEA, the expected fatigue life of the connection can be calculated.

FEA are performed for different (with respect to thread geometry) standardized API connections. More analyses will be carried out to study the influence of pipe dimensions on the stress distribution in the connections.

## III. Experimental validation

Experimental tests will be carried out to verify the FEA. Like the modelling, the experiments will consist of two parts. First the pin and box will be made-up and afterwards the tightened coupling will be subjected to an additional axial load.

### *A. Make-up tests*

During the make-up it is necessary to accurately control the rotation and to measure the resulting torque. For this purpose a torque machine with a counterweight is being converted. The new design of the torque machine can be seen in Figure 3. To measure the torque accurately, the counterweight is replaced by a loadcell (4). The test specimen (1) is mounted in the torque machine. By rotating the drive wheel (2), the gear (3) is put into motion. This causes the box of the test specimen (1) to rotate over the pin. The resulting torque caused by the tapered geometry of the connection and the friction in the threads is transmitted to the lever arm (5) which is connected to the loadcell (4). The measured load multiplied by the length of the lever arm equals the acting torque. To allow an axial motion, a linear guiding system (6) is present.

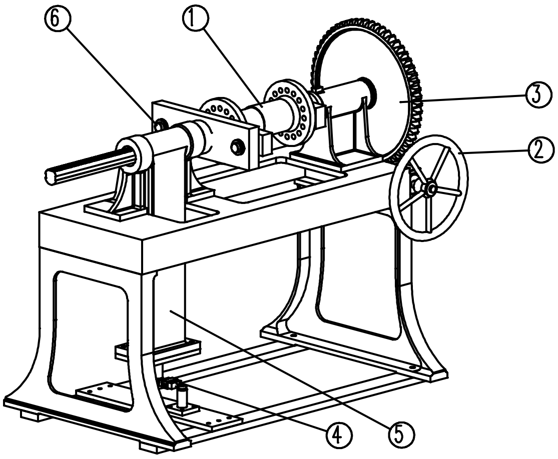


Figure 3: Torque machine 3000 Nm
1)test specimen, 2)drive wheel, 3)gear, 4)loadcell, 5)lever arm, 6)axial guiding.

The torque machine has a capacity of 3000 Nm, and the maximum test specimen length is 400 mm.

Strain gauges will be attached to both pin and box of the test specimen. The measured strains will be compared with the results of the FEA. From the measured torque vs. rotation, the coefficient of friction in the threads can be derived. The global deformation of the connection will also be monitored by means of an optical deformation measurement technique.

So called make-and-break tests will be performed during which the coupling is subsequently made-up and loosened. These tests are important because under certain circumstances galling takes place between the contact surfaces of the threads [5]. Surface conditions which will be altered due to galling, play an important role in fatigue life, since fatigue fractures initiate generally at the thread surface. The effect of lubricants on coefficient of friction and galling can also be investigated with this setup.

### *B. Fatigue and tensile tests*

Once the coupling is made-up, it will be mounted in a universal tensile test machine with a capacity of 1000 kN. The test specimens are designed in such a way that they fit in both the torque machine and the universal tensile test bench without additional changes. Both tensile tests and fatigue tests will be performed.

Applied load and elongation of the test specimen are registered by the universal tensile test machine. Strain at the surface of pin and box will be measured, as during the make-and-break tests, using strain gauges. The results from the tensile tests will be compared with the FEA. The model's material behaviour and contact conditions will be adjusted to meet the test results (inverse modelling).

The performed fatigue tests will be used to verify the fatigue calculations and to set up a fatigue model. Fatigue crack initiation and propagation will be considered as two separate parts of the fatigue mechanism.

In a later phase of the research a resonant bending fatigue test setup will be used to perform fatigue tests on full-scale connected pipe sections. This machine will be able to test pipes with a diameter up to 20" (508 mm) and length up to 6 m. This machine is currently being developed and will not be further discussed in this paper.

## IV. Conclusions

A finite element fatigue model of threaded pipe connections will be developed, and validated by experimental tests on a converted torque machine and universal tensile test machine. The results will be used to optimize thread designs and to formulate design rules for the studied connection types.

## Acknowledgements

The author would like to acknowledge the financial support of the BOF fund (B/04939) of the Ghent University-UGent and of the FWO Vlaanderen (3G022806). The support of Edip Özer Arman and prof. Guido De Roeck of the K.U. Leuven is gratefully acknowledged.

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