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A new methodology for the optimization of bolt tightening sequences for ring type joints

Ibai Coria[a], Mikel Abasolo[a,*], Imanol Olaskoaga[b], Arkaitz Etxezarreta[c], Josu Aguirrebeitia[a]

[a] Department of Mechanical Engineering, ETSI Bilbao, University of the Basque Country (UPV/EHU), Alameda Urquijo s/n, 48013 Bilbao, Spain
[b] Managing Director of Fastening Solutions Division, Matz-Erreka, S.Coop. San Juan Industrialdea, 99 pabiloia, 20.570 Bergara, Spain
[c] CTO of Fastening Solutions Division, Matz-Erreka, S.Coop. San Juan Industrialdea, 99 pabiloia, 20.570 Bergara, Spain

A R T I C L E I N F O

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Optimization methodology
Uniform bolt load
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A B S T R A C T

Achieving uniform bolt load distribution is critical to obtain leak-free service in pressure vessel gasketed joints used in offshore pipelines. This is a difficult task due to bolt load variations during the assembly process. In this sense, the Elastic Interaction Coefficients Method has been developed in previous works to define tightening sequences that provide the target load at the end of the sequence in one or two passes. The method is very costly because a complete sequence must be simulated and the load of every bolt must be measured after each tightening operation. The present work validates this method for Ring Type Joints and further develops a numerically and experimentally validated new methodology that provides highly satisfactory results with a significantly lower cost.

1. Introduction

In the assembly of pressure vessel gasketed joints, uniform bolt force is critical to achieve uniform distribution of gasket stress and therefore leak-free service of the joint. Nevertheless, whenever a fastener is tightened in a gasketed joint during the assembly, the joint gets compressed and consequently the load in previously tightened fasteners is reduced. This phenomenon is known as elastic interaction or bolt cross talk (Bickford and Nassar, 1998). The magnitude of these load variations depend on a large number of parameters whose influence is hard to predict, such as geometry and material of the joint components, load magnitude, bolt spacing, assembly pattern, amongst others (Nassar and Alkelani, 2005; Takaki and Fukuoka, 2002). Thus, obtaining a uniform load distribution at the end of the assembly is not straightforward.

Several standards contain different bolt assembly procedures which have shown good performance in terms of achieving final uniform load and therefore preventing gasket damage and reducing leakage incidents (API, 2011; ASME, 2013; Brown et al., 2010; NORSOK, 2013). In all of them, the tightening sequence is carried out in several passes gradually increasing the value of the torque applied to the bolts in each pass. The tightening sequence is generally following a star pattern or similar (circular patterns, if present, are only used for the latest passes), which ensures a better alignment of matching flanges and avoids local overloads in the gasket and rigid body motion in the joint (Bickford, 1995). However, standards point out that these sequences are indicative and generalist and they recommend that each assembler should develop his own sequences that suit their particular products and working conditions.

Significant effort in research has gone into developing faster assembly methods that provide a uniform load distribution in a single pass or in two pass sequences. This process is known as the *optimization of the tightening sequence*. The most popular method in the specialized literature is the *Elastic Interaction Coefficients Method* (EICM) (Bibel and Ezell, 1996, 1992; Fukuoka and Takaki, 2004; Van Campen, 1969), which has been validated in different gasketed joints (Bibel, 1994; Ezell, 1992), in a cylinder head of highly variable stiffness and contact geometry (Goddard and Bibel, 1994) or even in wind turbine generator flanges (Abasolo et al., 2014, 2011) among others. Analytical methods have also been developed for the optimization of the tightening sequence for joints with highly non-linear gaskets (Abid et al., 2016, 2015; Fukuoka and Takaki, 2003).

In the present work, the optimization of the tightening sequence for metallic gasketed Ring Type Joints (RTJ) (ASME, 2003) is studied. These joints are excel in offshore Oil & Gas applications because of their capacity to provide a high integrity seal at very high internal pressure (Currie, 2012). The benefit is that the gasket is confined in a groove and has two sealing surfaces. Besides it tends to be self-

* Corresponding author.
E-mail addresses: icoria001@ikasle.ehu.eus (I. Coria), mikel.abasolo@ehu.es (M. Abasolo), iolaskoaga@erreka.com (I. Olaskoaga), aetxezarreta@erreka.com (A. Etxezarreta), josu.aguirrebeitia@ehu.es (J. Aguirrebeitia).

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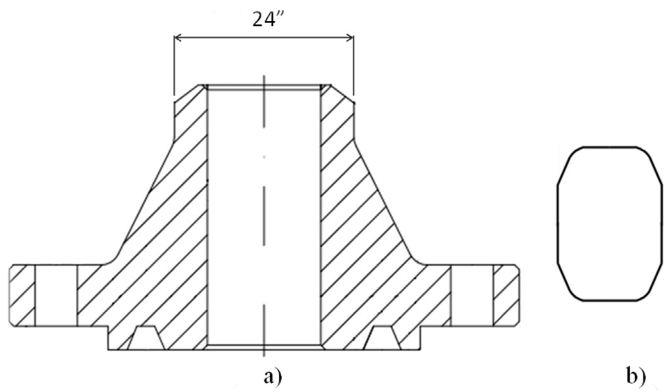

Fig. 1. Studied joint: a) 24″ NPS Class 150 RTJ SCHD 40 (ASME, 2003) b) R76 metallic ring gasket with octagonal profile (ASME, 2012).

actuating, i.e. the sealing pressure increases with the increase of the service pressure.

As a first step, the validity of the EICM for the optimization of the tightening sequence for RTJs has been studied (Sections 4 and 5 of the article). Then, as a major contribution of this work, a new methodology for the optimization of the tightening sequence for RTJs, called the *Tetraparametric Assembly Method* (TAM), has been developed, which is a further improvement of the EICM due to its significantly lower cost (Section 6 of the article). Prior to that, Sections 2 and 3 describe respectively the joint under study and the analysis tools used in this work (FE model and test bench).

2. Joint under study and operational variables

This work studies a Ring Type Joint (RTJ), composed by a pair of 24″ NPS Class 150 RTJ SCHD 40 flanges (ASME, 2003) and a R76 metallic ring gasket with octagonal profile (ASME, 2012) (Fig. 1). The materials are ASTM A105 steel (E=201 GPa, ν=0.3) for the flange and soft iron (E=198 GPa, ν=0.285) for the gasket. The bolts size is $1^{1/4}$–8 (UN Series) Class 10.9, with tensile stress area 1 in^2.

In order to observe the influence of the magnitude of tightening load in the joint behavior, two values were used, 200 kN and 300 kN (approximately 40% and 70% of the yield stress of the bolts). Besides, the two assembly patterns illustrated in Fig. 2 were analyzed. The friction coefficient in the flange-gasket contact depends on many factors and it is hardly predictable; for the calculations in this work, two representative values were chosen: μ=0.2 and μ=0.3.

3. FE model and test bench

The optimization of the tightening sequence with the EICM and the TAM was performed with a FE model. In parallel, a test bench was built to validate the FE model and the results obtained.

3.1. FE model

The FE model of the joint was built in Ansys Workbench® (Fig. 3). Taking advantage of the symmetry of the system, only one flange and one half of the gasket was modeled defining boundary conditions that simulate this symmetry. Furthermore, a rough (non sliding) contact was defined between each bolt and the flange, and a frictional contact between the flange and the gasket. The tightening load of the fasteners was applied via pretension sections. All of the components (flange, gasket and fasteners), were meshed with eight-node bricks and ten-node tetrahedrons, resulting in a model with 1,237,977 DOFs.

3.2. Test bench

Fig. 4 shows the test bench built for this work, composed by two pipes welded to the bolted flanges. The bolts are tightened by a hydraulic torque wrench. However, the bolt load cannot be accurately measured by measuring the torque because the torque-load relationship shows a large scatter (Bickford, 1995). To solve this important problem, the bolt load has been directly measured using i-bolt® ultrasonic measurement technology by Erreka Fastening Solutions, which provides a 3σ accuracy better than ± 3% (Bickford, 1995; Erreka, 2015).

3.3. Validation of the FE model

In order to verify that the FE model properly simulates the loss of load in the bolts during the assembly of the joint, two analyses were performed in the FE model and in the test bench. In the first analysis,

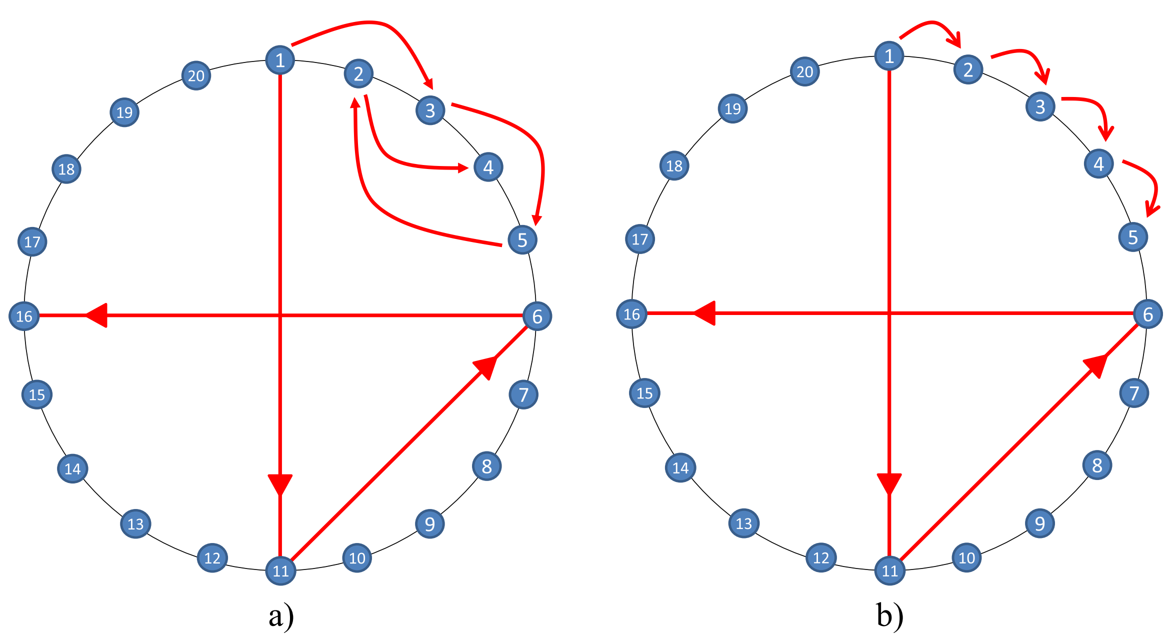

Fig. 2. Analyzed assembly patterns: a) Pattern 1: 1-11-6-16→3-13-8-18→5-15-10-20→2-12-7-17→4-14-9-19 b) Pattern 2: 1-11-6-16→2-12-7-17→3-13-8-18→4-14-9-19→5-15-10-20.