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Optimized bolt tightening strategies for gasketed flanged pipe joints of different sizes

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ABSTRACT

Achieving a proper preload in the bolts of a gasketed bolted flanged pipe joint during joint assembly is considered important for its optimized performance. This paper presents results of detailed non-linear finite element analysis of an optimized bolt tightening strategy of different joint sizes for achieving proper preload close to the target stress values. Industrial guidelines are considered for applying recommended target stress values with TCM (torque control method) and SCM (stretch control method) using a customized optimization algorithm. Different joint components performance is observed and discussed in detail.

1. Introduction

Gasketed bolted flange joints are extensively used in process industrial applications. Performance of a gasketed bolted flanged pipe joint is related to the proper joint assembly with all bolts tightened to the recommended target bolt stress values by ASME or industrial guidelines. However based on factors including target stress values available, tools, fitters training, gasket materials, bolts quality and others, sealing and strength of a joint cannot be ensured experimentally. Keeping in view these practical limitations, based on the availability of the computational power in the last decade, modeling and simulation has made it possible to visualize the behavior of individual components and as assembly as a whole for its safe operation. Researchers including Cao and Xu [1], Takkaki and Fukuoka [2–5], Abid [6], Nagata et al. [7], Tsuji and Nakano [8], Sawa et al. [9], Fukuoka and Sawa [10], Zhang et al. [11], Bouzid and Nechache [12], Shoji [13], Takkaki [14] and Brown and Warren [15] have performed detailed finite element studies keeping in view the limitations of experimental work. They used flange displacement at the bottom of the bolt by hit and trial methods target stresses in the bolts is achieved. Abid et al. [6] have highlighted yielding at flange and crushing of the gasket during experimental work for one size only as it is impossible to test all sizes which again practically are impossible in field applications. Therefore Abid et al. [6,16–32] have performed detailed 2D and 3D numerical studies, but limitations are observed in terms of semi-automatic applications of algorithm and results recording at required locations using manual picking at different joint components concluding hectic and time consuming. Keeping in view the above limitations, a generalized algorithm is developed for accurate results for the required target stress, times saving for solution and result recording as required compared to the manual inputs and can be implemented to all different flange sizes and classes using both the TCM and SCM for recommended bolt stress values by industrial guidelines. In this paper results of different flange sizes for Class 900# [33] (1, 4, 5, 6, 8, 10, 20 inch) are presented.

2. Finite element modeling, meshing, material selection, boundary conditions and solution

Three dimensional models of different flange sizes are developed. Due to the rotational symmetry, a part of the flange, pipe, bolt

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Nomenclature

TCM	torque control method
SCM	stretch control method
2D	two dimensional
3D	three dimensional
SC	stretching of bolts at one time during bolt tightening
DIFF	differential rate in target stress variables
DR	displacement rate for bolt up
UY	axial displacement of bolts
CURS	current stress during each iteration
ASME	American Society for Mechanical Engineers
B	bolt number
G	bolt group used during SCM
P	pass number
M	semi-automated algorithm
O	fully automated algorithm
HF	hub flange fillet location

for flange and pipe are as per ASTM A350 LF2 and bolts are as per ASTM SA193 B7 taken from Ref. [34] and are used in the industry. Gasket material properties and dimensions are used from Garlock [35]. Flange, pipe and bolts are modeled using Solid45elements. Interface elements (INTER195) and TARGET170 and CONTA174 elements are used for gasket and contacts generation. In order to have flange rotation gasket and flange are free to move in the radial and axial direction, with symmetry conditions applied at the lower portion of the gasket. To observe bolt bending, bolts are constrained at mid-section in the tangential and radial direction. To apply preload, an axial displacement is applied in the downward direction at bolt bottom areas. ANSYS software is used for analysis [36]. Industrial guidelines [35] are used for torque control method (one bolt is tightened at one time) for flange sizes 1, 4, 5, 6, 8 inch. For stretch control method (a group of bolts is tightened at one time) for flange sizes 10 and 20 inch using SKF strategy [37]. Meshed model of gasketed joint with applied boundary conditions is shown in Fig. 1.

TCM uses torque wrenches to apply torque on bolts due to which nut or bolt is turned against the surface of the flange and bolt is stretched and bolt preload is calculated using Bickford and Nassar

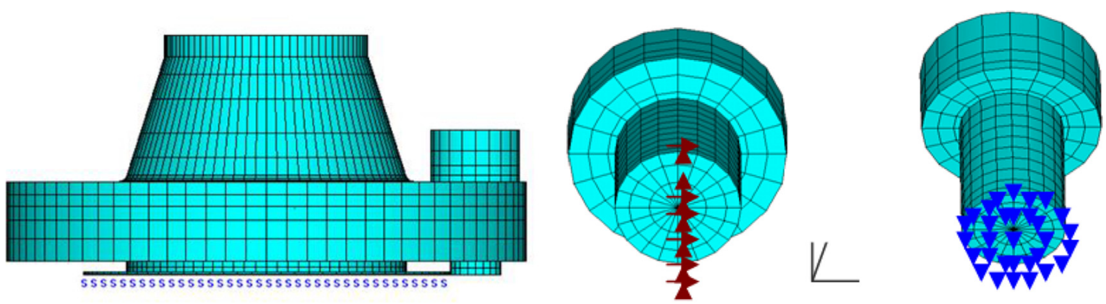

Fig. 1. Meshed model of gasketed joint assembly and applied boundary conditions.

and spiral wound gasket is modeled first and is then revolved to form full model. One bolt is modeled first while all others are generated using rotational symmetry. In this study elasto-plastic material model is used for all the flange sizes. Allowable stresses

Table 1
Pre stress values for 1, 4, 5, 6, and 8 inch flange size using TCM(Garlock [35]).

NS	Bolt dia(m)	Target Torque (Nm)	Pre-stress value for each pass (MPa)				
			P1	P2	P3	P4	P5
1	0.0222	198	35	75	115	115	–
4	0.0280	780	68	147	226	226	–
5	0.0320	1091	64	138	212	212	–
6	0.0285	896	74	160	246	246	–
8	0.0350	1359	61	132	203	203	–

[38]. In SCM stud is stretched by applying hydraulic pressure to the tensioner; nut is coiled against joint face and then pressure is released after which tool is removed. As the pressure is released bolts act as spring and tension is created in the bolt and the bolt are elongated. In TCM, bolts are tightened in cross pattern (sequence-1) for first four passes and in clockwise pattern (sequence-2) in 5th pass. In SCM, bolts are tightened by stretching 100% (SC100), 50% (SC50) and 33% (SC33) of the bolts at a time. Details of tightening sequence, number of passes and percentage increment of target torque for TCM and tensioning for SCM are summarized in Table 1 and Table 2 respectively.

3. Optimization algorithms

A generalized optimization algorithm to achieve bolt up stress values within range defined by ASME and industry is presented in

Table 2
Torque Increments for 10 and 20 inch flange sizes using SCM(SKF [37]).

No. of bolts	Bolt tightening sequence	Group	Bolts tensioning
16 (10 inch)	(1,5,9,13), (2,6,10,14), (3,7,11,15), (4,8,12,16)	G1~4	25 or 33%
20 (20 inch)	(1,5,9,13,17), (2,6,10,14,18), (3,7,11,15,19), (4,8,12,16,20)		
16 (10 inch)	1,3,5,7,9,11,13,15	G1	50%
	2,4,6,8,10,12,14,16	G2	
20 (20 inch)	1,3,5,7,9,11,13,15,17,19	G1	
	2,4,6,8,10,12,14,16,18,20	G2	
16 (10 inch)	1 to 16	One	100%
20 (20 inch)	1 to 20		

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