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Preliminary Design of Wellhead Spacer Spool Based on the API Acceptance Criteria

Budi Baharudin[a#], Rahman Hakim[a], Rahmat Hidayat[a], M. Anas Fikri[b], Auliana Diah Wilujeng[b*]
[a] Polytechnics of Batam
Mechanical Engineering Study Program
Parkway Street, Batam Centre, Batam 29461, Indonesia

[b] Polytechnics of Madura
Heavy Equipment Mechanical Engineering Studi Program
Camplong Street Km.4, Taddan, Sampang 69281, Indonesia
e-mail: budi@polibatam.ac.id[#*]

Abstract

In the case of assembly wellhead, a spacer spools was used to provide space and connect between parts of the wellhead. In order to design spacer spool with specified material should comply the standards and procedures of the oil and gas industry. The purpose of this research is to choose the best material strength from three type of AISI 4130 materials based on the yield stress. The results of the material calculation were using the ASME BPVC guidelines. Based on acceptance criteria on API 6A 21st Edition, these ANSI 4130 materials were categorized as acceptable to be used as a body spacer spool for this specification, also calculated the stress of the flange and flange rigidity criteria. Based on the acceptance criteria on ASME BPVC guidelines, the results showed that these materials can be used for flange because it had stress value under yield strength of material which was flange rigidity criteria for operating condition has 0.59 and 0.66 for testing condition because had value of rigidity that met with acceptance criteria.

***Keywords**: design, wellhead, spacer-spool*

1. INTRODUCTION

In an offshore-oil mining system, a subsea wellhead system is a tubular system with cement casting method into soil. The loading of a subsea wellhead generated from MODU and drilling riser interactions with wave and current as indicated in Figure 1. The dynamic loads from the riser are transferred to the wellhead and distributed further to the conductor and into the soil and template structure if present [1].

To design is either to formulate a plan for the satisfaction of a specified need or to solve a problem [1], [2]. If the plan results in the creation of something having a physical reality, then the product must be functional, safe, reliable, competitive, usable, manufacture-able, and market-able [3]–[5]. Design is an innovative and highly iterative process. It is also a decision-making process. Decisions sometimes have to be made with too little information, occasionally with just the right amount of information, or with an excess of partially contradictory information [6]. Decisions are sometimes made tentatively, with the right reserved to adjust as more becomes known. The point is that the designer has to be personally comfortable with a decision-making, problem-solving role. In case of subsea drilling process, wellhead is the important component [7].

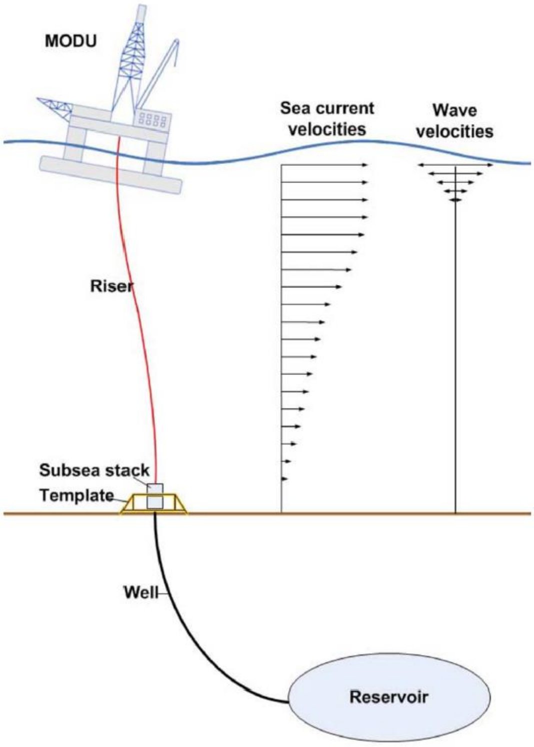

Figure 1. Offshore oil-mining system overview [1]

Wellhead has function to control and isolate pressure outcomes by isolating it in the annular. The pressure of drilling process can be varying depends on depth of drilling. Considering all those risks a calculation becomes the critical part of every wellhead Parts [8]. Calculation helps the Engineers to select the acceptable material to handle the pressure [9]. If the calculation is not made, the pressure outcomes are uncontrollable and dangerous. It will cause more serious risk [10]. If the material fails against the outcome pressure, it could be a blowout and resulting serious danger [7]. Those are the importance of calculation that will be discussed in this research.

2. METHODS

In this research, we use ASME BPVC (American Society of Mechanical Engineers – Boiler and Pressure Vessel Code). These standards are the regulation to calculate the mechanical properties of boiler and pressure vessel products. Wellhead system are work on pressure vessel area that one of the section parts is spacer spool. Furthermore, we generate ASME BPVC – Section VIII (Rules for construction of pressure vessel) – Division 2 – Alternative Rules to make the detail drawing [11].

For validation, we take API 6A 21st Edition standard which is to identifies requirements and gives recommendations for the dimensional, performance and functional interchangeability of design, qualification, materials, quality and organization of wellhead systems in the petroleum and natural gas industries [12]. Design are to determine standard functional requirements, Method to vent pressure, method of securing to body, Use of thread sealants/tape, Pressure ratings. Qualification of method for FAT Testing, and methods to qualify design. Materials, about how the transition method from CRA to Alloy for HH Trim. Minimum material properties for strength, and minimum material properties for corrosion resistance. Quality of production testing requirements, dimensional Inspection Requirements, NDE, hardness testing, PSLs, application of Monogram, marking requirements. Organization, describes the specific place where do we put it. For details about our workflow, we have already illustrated in Figure 2.

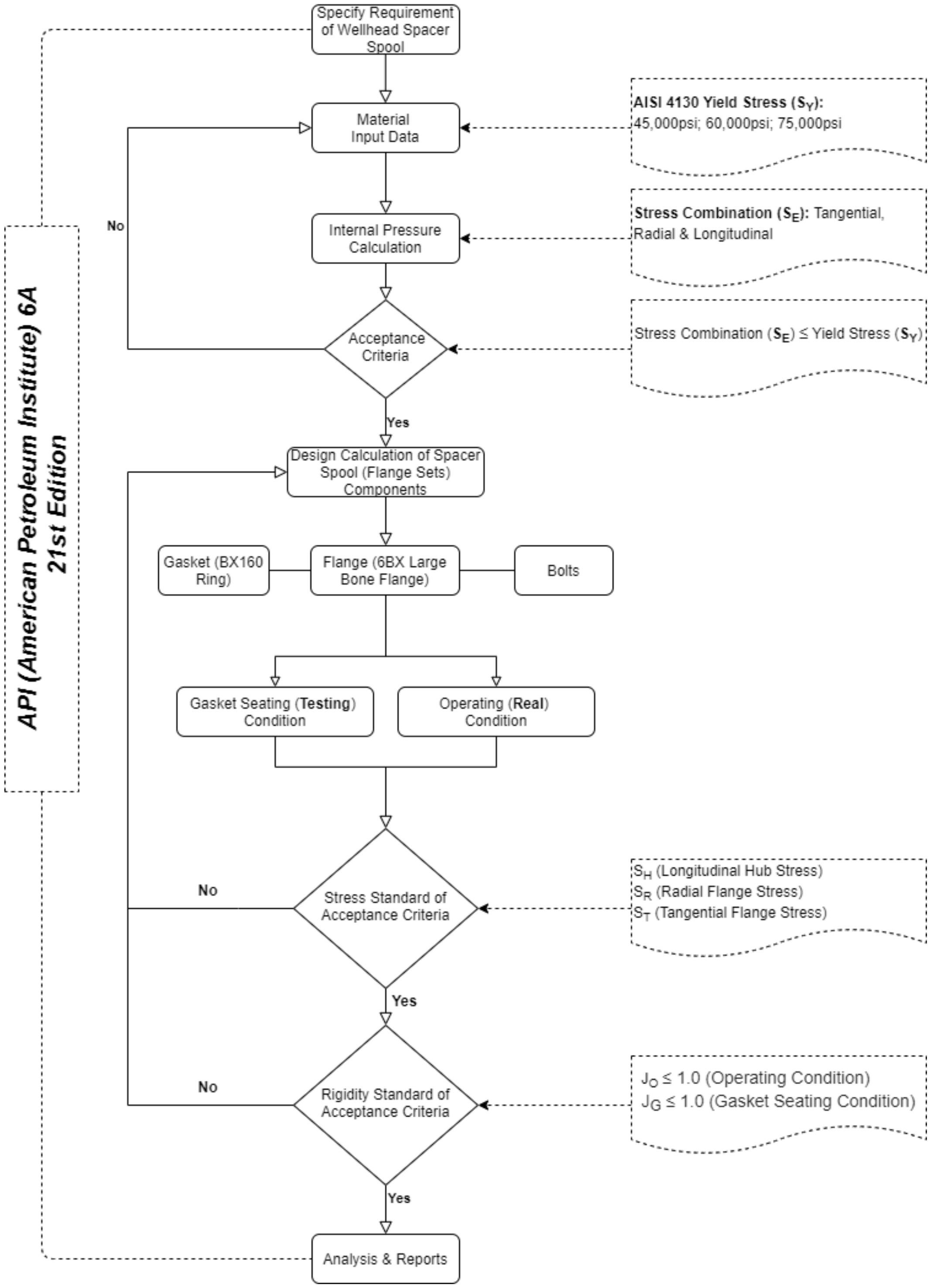

Figure 2. Research method of wellhead spacer spool

2.1 Specify requirements

The first thing to make the spacer spool design is to specify the requirements by giving the dimensions. The engineering drawing was designed by using Solidworks and for further research will compare on static pressure simulation data [13] with this basic calculation data. This section will determine all the dimensions before calculate it as the following:

a. Step 1: Specify the general design condition

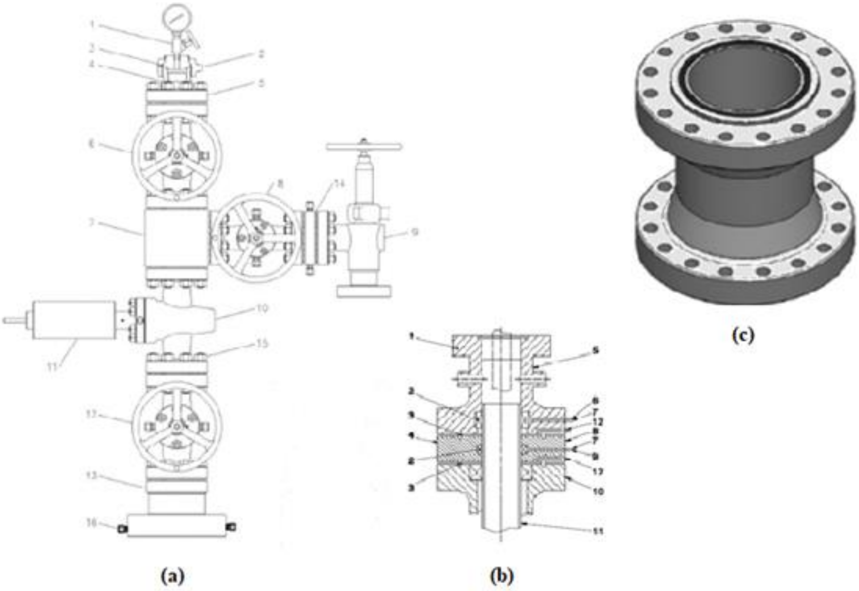

Figure 3. An Engineering drawing of a Christmas-tree Oil Wellhead, (a) Oil Well Head, (b) Cross Section of 5000-psi wellhead pressure rating [12], (c) 3D Model of Spacer Spool [14]

Table 1. Wellhead Spacer Spool Design Conditions [11]

Engineering Data	**Value**	**Units**
Pressure Inside (P_i)	5,000	Psi
Bolting Material	105,000	Psi
External Force (Fe)	0	Lbf
External Moment (Me)	0	Lbf-In
Flange Design Temperature	120	^{o}C
Modulus Elasticity	28,250,000	Psi
Bolting Design Temperature	120	^{o}C
Bolt Seating Stress (Sb_g)	63,000	Psi
Bolt Operating Stress (Sb_o)	63,000	Psi

Figure 3 describes the overview of the wellhead system and the following parts. The design of a bolted flange connection, calculations shall be made for the following two design conditions, and the most severe condition shall govern the design of the flanged joint. Operating Conditions, the conditions required to resist the hydrostatic end force of the design pressure and any applied external forces and moments tending to part the joint at the design temperature. Gasket Seating Condition is the conditions existing when the gasket or joint-contact surface is seated by applying an initial load with the bolts during assembly of the joint, at atmospheric temperature and pressure. For further data, describes on Table 1.

b. Step 2: Specify the Flange Design

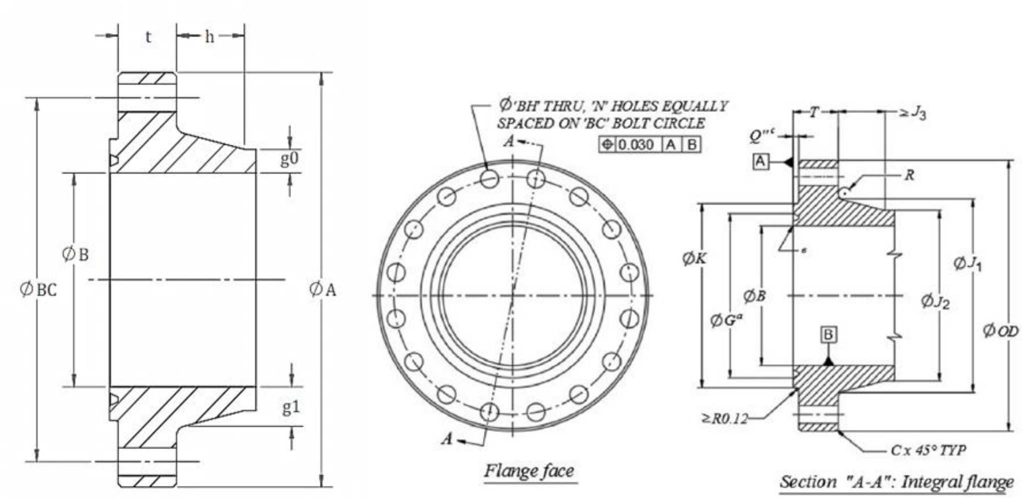

Figure 4. 3D Model of 6BX Large-bore Flange for 34.5MPa (5000 Psi) [12]

Table 2. Flange's Dimension Details

Remarks	Value	Unit
Bore Diameter *(B)*	13.66	Inch
Small Hub Thickness *(g_0)*	1.51	Inch
Large Hub Thickness *(g_1)*	2.64	Inch
Bolt Circle Diameter *(C)*	23.25	Inch
Flange OD *(A)*	20.5	Inch

In this step, determination of technical specifications and making detailed drawing in the flange section must adjust it to the Figure 4. As well as the technical reference for flange must adjust to type 6BX Large Bore Flange [9]. Table 2 shows that all dimension is based on standard. The dimensions acquired by API 6A 21st for pressure rating is 5000 Psi. Table 2 shows the dimensions of flange.

c. Step 3: Determine the Gasket Details

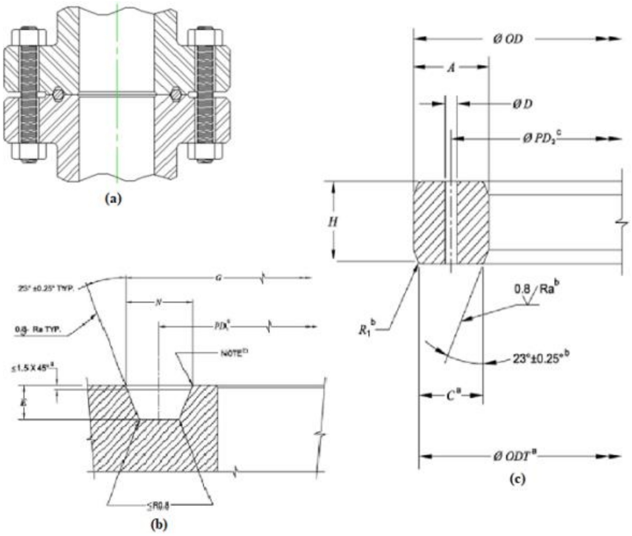

Figure 5. Type BX 160 Ring, (a) Construction of Flange Joint, (b) Cross-section of type BX ring groove, (c) Cross-section of type BX ring gasket [12]

Figure 5 described type BX 160 Ring Grooves. A section drawing of flange joint construction. Fig.5 (a-c) shows a cross section of type BX ring groove and ring gasket. A complete dimensions of gasket detail explained from this table 3 below.

Table 3. Detail of Type BX 160 Ring Grooves

Details	**Value**	**Unit**
Groove Width (*N*)	0.785	Inch
Basic Gasket Width (b_0) = N/4	0.196	Inch
Eff. Gasket Width (*b*) = b_0	0.196	Inch
Dia. Of Gasket Reaction (*G*)	15.302	Inch
Design Seating Stress (*y*)	26000	Psi
Gasket Factor (*m*)	6.50	

From the table above, if effective gasket width (b_0) ≤ 0.25 in, then G is the mean diameter or gasket contact face [12]. Design seating stress is amount of stress that will be applied to the gasket when tighten the bolt. The gasket factor is use for determining bolt load, for this condition we select the type ring joint, stainless steel and nickel base alloys.

2.2 Material Input Data

Several types of material that used as the design input. The consideration of every material is belonging to yield strength, where the yield strength is the limit of material deformation. Further deformation will not be acceptable. This research will examine material that applied in spacer spool. There are three type of materials examined in this research as following on Table 4.

Table 4. Material Data Input Variant [15]

Material	**Type**	**Size**	**Yield Strength [MPa] (Psi)**	**S_{fo} [Psi]**	**S_{fg} [Psi]**
Flange & Gasket (AISI 4130)	3rd grade	13-5/8 (6BX Large-bore)	310 (45,000)	27,000	27,000
	2nd grade		414 (60,000)	36,000	36,000
	1st grade	BX 160 Ring	517 (75,000)	45,000	45,000
Bolts (307A)	8th grade	1-5/8 UN	724 (105,000)	-	-

2.3 Standard Calculation of Internal Pressure and Acceptance Criteria

There are three type of stress as the pressure applied: longitudinal stress (σ_l), tangential stress (σ_t) and radial stress (σ_r). In determining the radial stress and the tangential stress, we make use of the assumption that the longitudinal elongation is constant around the circumference of the cylinder. In other words, a right section of the cylinder remains plane after stressing [10]. To control the material from failure we need to calculate the value of von misses to verify not exceed the material yield strength (S_Y). The calculation of maximum bending moment for spacer spool should be applied to verify maximum external load. Combining the moment inertia with maximum bending moment, is resulting the value of maximum load can be applied. In the literature, calculate multi axial stress as the first step (S_E), stated by the equation of stress (Tangential, Radial and Longitudinal) [15]. To verify the bolting has the minimum requirements of internal pressure calculation, refer to acceptance criteria as stated below:

$$S_E = \sqrt{\sigma_t^2 + \sigma_r^2 + \sigma_l^2 - \sigma_t\sigma_r - \sigma_t\sigma_l - \sigma_r\sigma_l} \tag{1}$$

$$S_E \leq S_Y \tag{2}$$

2.4 Standard of Design Calculation on Wellhead Spacer Spool and Acceptance Criteria

Spacer spool (Flange set) is commonly used in wellhead part to provide a means as connector or adapter to other part of assembly. Flanges set use bolts to tighten the flange connection, also to compress a gasket to give provision of sealing pressure. These calculations as follow:

a. Calculation of Required Bolt Loads

$$\frac{W_g}{A_b} \leq 0.83S_Y \tag{3}$$

$$\frac{W_o}{A_b} \leq 0.83S_Y \tag{4}$$

The bolt load is required to calculate the applied load when tighten the bolt. The calculations are divided into two result, for operating condition (W_o), Eq. 4, and gasket seating or testing condition (W_g), Eq. 3. Actual total bolt area (A_b) is the sum of actual bolt area times by number of bolts. Based on the acceptance criteria on stress-based bolts calculation, the equation for the applied load has to less than 0.83 times from the bolts yield strength, that already describe on Table 4.

b. Calculate the Flange Loads

The flange stress factors are some of variable in calculation of flange. Each of factor has function in the calculation of radial stress, tangential stress and longitudinal stress. To obtain the flange stress factor, make sure the calculation of flange factors obtained, then proceed to the calculation of flange moments. The calculation as stated on Table 5.

Table 5. Acceptance Criteria of Flange for Operating Condition and Gasket Seating Condition

Stress Variable	**Acceptance Criteria**	
	Real (Operating) Condition	**Testing (Gasket Seating) Condition**
Longitudinal Hub Stress (S_H)	$S_H \leq \min\,[1.5S_{fo}, 2.5S_{no}]$ $S_H \leq 1.5S_{fo}$	$S_H \leq \min\,[1.5S_{fg}, 2.5S_{ng}]$ $S_H \leq 1.5S_{fg}$
Radial Flange Stress (S_R)	$S_R \leq S_{fo}$	$S_R \leq S_{fg}$
Tangential Flange Stress (S_T)	$S_T \leq S_{fo}$	$S_T \leq S_{fg}$
Stress-based Combination Load	$(S_H+S_R)/2 \leq S_{fo}$ $(S_H+S_T)/2 \leq S_{fo}$	$(S_H+S_R)/2 \leq S_{fg}$ $(S_H+S_T)/2 \leq S_{fg}$

S_{fo} mean allowable stress on the flange evaluated at the operating temperature, S_{fg} mean allowable stress on the flange evaluated at the gasket seating temperature. If the flange type is an integral flange, it has to use S_{no} mean allowable stress on the integrated flange at the operating temperature, S_{ng} mean allowable stress on the integrated flange at the gasket seating temperature.

2.5 Standard Calculation of Wellhead Spacer Spool Rigidity and Acceptance Criteria

The equation of criteria acceptance of flanges rigidity for operating condition is shown in Eq. 4. For testing (gasket seating) condition is shown in Eq. 5 below.

$$J = \frac{52.14VM_o}{LE_{yo}{g_0}^2K_Rh_o} \leq 1.0 \tag{5}$$

$$J = \frac{52.14VM_g}{LE_{yg}{g_0}^2K_Rh_o} \leq 1.0 \tag{6}$$

To generate the rigidity acceptance criteria, we have to calculate: V, flange stress factor for integral type flanges; M_g flange design moment for the gasket seating condition; M_o, flange design moment for operating condition.

3. RESULT AND DISCUSSION

3.1 Internal Pressure Calculation Data and Acceptance Criteria

Based on the calculation on Table 6, the obtained stress combination, 27,638psi still less than material yield stress 45,000psi, 60,000psi and 75,000psi. In other word, this material is capable if we applied as the body of spacer spool because material strength is still on the safe condition. If the stress combination less or equal than the material yield stress, then accepted. If the stress combination greater than the material yield stress, then it called reject.

Table 6. Internal Pressure Calculation Data

AISI 4130 Material Type	Stress Combination (S_E)	Yield Stress (S_Y)	Factor of Safety (FoS)	Result
Grade 3rd	27,638 Psi	45,000 Psi	1.63	Acceptable
Grade 2nd	27,638 Psi	60,000 Psi	2.17	Acceptable
Grade 1st	27,638 Psi	75,000 Psi	2.71	Acceptable

3.2 Design Calculation of Wellhead Spacer Spool

a. Bolt Loads

Table 7. Acceptance Criteria for Bolts

Bolts Material	Yield Strength (S_Y) of Material (Psi)	Stress-Based Acceptance Criteria					
		Gasket Seating [Testing] Condition $(S_A)_g$ (Psi)		Result $(S_A)_g \leq 0.83S_Y$	Operating [Real] Condition $(S_A)_o$ (Psi)		Result $(S_A)_o \leq 0.83S_Y$
307A 8th Grade	105,000	$(S_A)_g = W_g/A_b$	59,787	Safe	$(S_A)_o = W_g/A_b$	56,575	Safe

From the result above, the bolt load at gasket seating condition (S_A) is 87,150psi, compared to the maximum load $(S_A)_g$ is 59,787psi, and for operating condition the maximum load $(S_A)_o$ is 56,575psi. It means that the bolt load is still acceptable which still not exceed the maximum bolt load. Then design qualified as accepted.

b. Flange Set (Flange 6BX Large-bore & Gasket BX 160 Ring) Loads

Table 8. Stress-Based Calculation

Applied Loads	Gasket Seating [Testing] Condition (Psi)	Operating [Real] Operation (Psi)
Longitudinal Hub Stress (S_H)	6,120	5,597
Radial Stress (S_R)	4,571	4,120
Tangential Stress (S_T)	2,222	2,003

From the result above, the applied stress on Hub based on the loads direction were calculated. Longitudinal Hub Stress (S_H), Radial Stress (S_R) and Tangential Stress (S_T) are have done calculate on gasket seating and on an operating condition.

3.3 Stress-Based Acceptance Criteria

Table 9. Calculation Data for Flange

Wellhead Spacer Spool Material	**Yield Strength (S_Y) of Material (Psi)**	**Stress-Based Acceptance Criteria (*Psi*)**					
		Gasket Seating [Testing] Condition (C_g) (Psi)		**Result** $C_g \le S_Y$	**Operating [Real] Condition (C_o) (Psi)**		**Result** $C_o \le S_Y$
AISI 4130	45,000	$S_H \le 1.5S_{fg}$	40,500	Safe	$S_H \le 1.5S_{fo}$	40,500	Safe
		$S_R \le S_{fg}$	27,000	Safe	$S_R \le S_{fo}$	27,000	Safe
		$S_T \le S_{fg}$	27,000	Safe	$S_T \le S_{fo}$	27,000	Safe
	60,000	$S_H \le 1.5S_{fg}$	54,000	Safe	$S_H \le 1.5S_{fo}$	54,000	Safe
		$S_R \le S_{fg}$	36,000	Safe	$S_R \le S_{fo}$	36,000	Safe
		$S_T \le S_{fg}$	36,000	Safe	$S_T \le S_{fo}$	36,000	Safe
	75,000	$S_H \le 1.5S_{fg}$	67,500	Safe	$S_H \le 1.5S_{fo}$	67,500	Safe
		$S_R \le S_{fg}$	45,000	Safe	$S_R \le S_{fo}$	45,000	Safe
		$S_T \le S_{fg}$	45,000	Safe	$S_T \le S_{fo}$	45,000	Safe
Stress-based Combination Load		$S_{fg} \ge (S_H+S_R/2)$	5,390	Safe	$S_{fo} \ge (S_H+S_R/2)$	4,859	Safe
		$S_{fg} \ge (S_H+S_T/2)$	14,216	Safe	$S_{fo} \ge (S_H+S_T/2)$	12,814	Safe

Table 9 shows the flange stress at gasket seating and in an operating condition were calculated. The amounts of stress at each condition are obtained. There are three kind of stress that calculated in this section. Based on table 8, the stress data on gasket seating condition, the hub stress (S_H) obtained is 6,120psi, radial stress (S_R) is 4,571psi and tangential stress (S_T) 2,222psi. Furthermore, on an operating condition, the hub stress (S_H) obtained is 5,597psi, radial stress (S_R) is 4,120psi and tangential stress (S_T) 2,003psi. Refer to the acceptance criteria, stress on flange must meet with the minimum requirements as stated above. Therefore, the selected material will be qualified as acceptable or reject. Combining with data on table 4, we meet all the minimum criteria (Acceptable) based on gasket seating condition (C_g) and in an operating condition (C_o) compared with S_Y.

3.4 Rigidity-Based Acceptance Criteria

The wellhead spacer spool examined in two conditions, operating condition and gasket seating (testing) condition. The index has a function to limit the maximum value that a material categorized as rigid. Both operating condition and gasket seating condition, have the same criteria, where the flange rigidity index (J) is less or equal than 1. It means if the value is close to 1, then the object is closes not rigid. And from the table above, both condition indexes are less than 1, then flange categorized as rigid.

Table 10. Calculation Data of Wellhead Spacer Spool Rigidity

Condition	**Criteria**	**Calculation Data (J)**	**Result**
Operating	$J \le 1$	0.59	Safe
Gasket seating (Testing)	$J \le 1$	0.66	Safe

4. CONCLUSION

Refer to the data result and discussion in the previous section, the conclusion obtained as stated below:

a. Considering the yield strength of material with designation 45,000 Psi is the minimum required material if applied to spacer spool body, top flange connection 13-5/8-inch, bottom flange connection 13-5/8 inch with pressure ratings 5,000 Psi based on the API 6A 21st edition acceptance criteria.

b. Although the material designation 45,000 perform well for body wellhead, it has a limitation that only handle lower range of capacity, as already described in previous section.

c. For economical consideration, indeed by choosing a 45,000 Psi material is the best decision to applied on spacer spool with specified dimensions. For a better performance better use a higher material strength, either 60,000 Psi or 75,000 Psi to have a better performance for spacer spool.

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