Maxmimum Bending Load Estimation for a Hydraulic Flanged Tube and Adapter Connection

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Abstract:

In this paper, a 1½ inch four-bolts split flange hydraulic connection (SAE Code 62) under a hydraulic pressure and bending loads was evaluated. To protect any potential leakage or other failure, the maximum acceptable bending forces and pre-load on the bolts were estimated through examining the contact pressure and gap distances at each interface of the connection. Compared with other method to evaluate this fastener, the finite element method analysis gave more accurate result in the complex contact problem.

Introduction:

Hydraulic connections of flanged tube, split flange and adapter devices are often used in plastic injection molding systems. These connections are intended for application in hydraulic systems, on industrial and commercial products, where it is desired to avoid the use of threaded port connection. Because this connection works under high pressure and high frequency alternative loads, it is very important to understand its load levels and deformation distributions. Based on that, the acceptable load range can be evaluated. In this analysis, a flanged tube with 1.5 inch four-bolts split flanges hydraulic connection (SAE Code 62) under a system hydraulic pressure and a bending force was evaluated against three different pre-tension load level on its bolts. To protect the separation of the connection, the pre-loads on the bolts play a significant role. If the pre-load is too low, it cannot maintain the necessary contact pressure at each interface. If the pre-load is too high, it will cause possible damage on the split flanges and fatigue problem on its bolts. To look at different pre-load effect at the connection, three pre-load levels were examined with external bending force and hydraulic pressure force. At the interfaces between the adapter and tube, adapter and filter o-ring, split flange and tube, the contact pressures and gap opening distances were checked under above load conditions. The purpose of this analysis is to give a simple approach to establish a relationship between the external forces and internal forces by ANSYS 5.7.1 new feature for this kind of complex connection.

Hydraulic connection model for SAE Code 62:

The hydraulic connection is comprised of six parts: a manifold, filter/o-ring, adapter housing, two split flange clamps, four M16 bolts and a flanged tube; all components may require a pre-load from four bolts to keep the system from separations. A typical 1-½ inch SAE Code 62 flanged tube hydraulic connection is shown in Figure 0-1 and Figures 0-2. The space gaps between split flanges and adapter, adapter and manifold are typically 0.5 mm, which would increase or decrease by external bending forces and internal pre-tension loads. All dimensions shown in following figures are in metric units.
Figure 0-1 - Overall Model Plot of the hydraulic connection

Figure 0-2 - 1/2 Model Plot of the hydraulic connection
Theoretical calculation of opening force:

Basically, the stiffness of the hydraulic connection can be simply evaluated through its geometry, all forces on it and the material properties. Assume in this calculation, the total pre-loads from bolts is $F_p \times 4$; the total force from the hydraulic pressure is $F_h$; the total force from contact pressure is $F_c$ and the bending force is $F_b$. Because the hydraulic pressure is an axial symmetric distribution load about the internal cavity, the total force of the pressure is also an axial load and it will not significantly effect the separation like external bending force. In symmetric axial direction, the total forces equivalent equation is:

$$F_p \times 4 + F_h + F_c = 0 \quad (1)$$

The total moment equivalent equation against outside bottom point of the o-ring/filter is:

$$(d + OD_{o-ring}) \times F_p \times 2 + d \times F_p \times 2 - (OR_{o-ring} \times (F_h + F_c) + L \times F_b) = 0 \quad (2)$$

where $L$ is the distance from bottom face of filter/o-ring to top of the tube; $d$ is the distance from bottom bolts to the bottom point of o-ring/filter. Assume 85 kN pre-load used for each bolt. The total resistant moment from four bolts will be 10,722 kN-mm. Assume the bending force is located at 4 inch from the end of flanged tube, then theoretically, the possible opening force will be 43 kN. From later FEA results, we can see that this force is far lower than the theoretical one.

FEA Model:

Because this connection is comprised by a group of solid blocks through the interfaces and pre-tension parts, it is easy to model and analysis by ANSYS by its contact and pre-tension element features.

Analysis method:

This is a static state stress analysis with nonlinear contact elements at each interface and pre-tension elements at four bolts. Because this connection has a symmetric plane about its geometry and loads, only a half model was modeled. Element types of SOLID92, CONTACT174, TARGET170 and PRETS179 of ANSYS 5.7.1 are used in this analysis.

During external bending force application, the parts potentially sliding against each other will significantly affect the friction between each part. The friction coefficients used at all interfaces of the connection are assumed as 0.15.

Material properties:

The SAE standard recommends that bolts for use with their connections shall be of the size and lengths indicated in Table 1 [1]. They shall be of SAE Grade 5 material or better as specified in SAE J429. Socket head cap screws of SAE Grade 5 material or better are acceptable. The properties of carbon steel SAE 4140 - 13Rc used in this analysis are Elasticity modulus $E = 207$ GPa, Poisson ratio $\nu = 0.29$, (minimum yield stress $\sigma_y = 415$ MPa, $\sigma_u = 655$ MPa, $\sigma_e = 327$ MPa).

Load cases:

To fully understand the connection under various possible loads conditions, three different load cases - three different pre-tension levels were used. These load cases were specified as following:

1) Case1-1: 25 % of full pre-load only.
2) Case1-2: 25 % of full pre-load plus a system hydraulic pressure.
3) Case1-3: 25 % of full pre-load plus a system hydraulic pressure and plus 10 kN bending load.
4) Case2-1: 50 % of full pre-load only.
5) Case2-2: 50 % of full pre-load plus a system hydraulic pressure.
6) Case2-3: 50 % of full pre-load plus a system hydraulic pressure and plus 10 kN bending load.
7) Case3-1: 100 % of full pre-load only.
8) Case3-2: 100 % of full pre-load plus a system hydraulic pressure.
9) Case3-3: 100 % of full pre-load plus a system hydraulic pressure and plus 10 kN bending load.

100 % of full pre-load means 50% pre-load/proof-load ratio is used for a M16 bolt.

Analysis Results & Discussion:
A total 9 load cases analyses were done by ANSYS 5.7.1, and a refined mesh was used at some stress sensitive location, to get more accurate results.

Analysis results:
In figures 1-1 to figure 1-4, .25 % pre-load only results are given by its stress, contact pressure and contact gap distributions.

Figure 1-1 - S1 distribution of whole connection under load case1
Figure 1-2 - S1 distribution of bolts connection under load case 1

Figure 1-3 - Contact pressure distribution under load case 1
In figures 2-1 to figure 2-4, .25 % pre-load, a system hydraulic pressure and 10 kN bending force results are given by its stresses contact pressures and contact gap distributions.
Figure 2-2. S1 distribution of bolts connection under load case 2

Figure 2-3. Contact pressure distribution under load case 2
Figure 2-4 - Gap distance distribution under load case 2

In figures 3-1 to figure 4-4, .50% pre-load results are given by its stress, contact pressure and contact gap distributions.
Figure 3-1 - S1 distribution of whole connection under load case 1

Figure 3-2 - S1 distribution of bolts connection under load case 1
Figure 3-3 - Contact pressure distribution under load case 1

Figure 3-4 - Gap distance distribution under load case 1
Figure 4-1 - S1 distribution of whole connection under load case 2

Figure 4-2 - S1 distribution of bolts connection under load case 2
Figure 4-3 - Contact pressure distribution under load case 2

Figure 4-4 - Gap distance distribution under load case 2
In figures 5-1 to 6-4, 100% pre-load results are given by its stress, contact pressure and contact gap distributions.

Figure 5-1 - S1 distribution of whole connection under load case 1

Figure 5-2 - S1 distribution of bolts connection under load case 1
Figure 5-3 - Contact pressure distribution under load case 1

Figure 5-4 - Gap distance distribution under load case 1
Figure 6-1 - S1 distribution of whole connection under load case 2

Figure 6-2 - S1 distribution of bolts connection under load case 2
Figure 6-3 - Contact pressure distribution under load case 2

Figure 6-4 - Gap distance distribution under load case 2
**Discussion:**

From 25% pre-load results we can see, although the stress order is acceptable for both split flange clamps and four bolts, 10 kN external bending force will cause a 0.08 mm opening gap at the interface between the adapter and the O-ring filter. The opening gap reduced to 0.001 mm at 50% pre-load. The stress order on the split flange and bolts are also acceptable. There is no gap at 100% pre-load. But the stress order on the split flanges and the top two bolts are quite high. Some plastic deformation will happen on the top surface of the split flanges under pre-load from the bolts. The alternating bending force may cause high-cycle fatigue failures on the top two bolts.

**Conclusion**

This analysis gave an easy approach to evaluate the relationship among internal load – pre-load from bolts, external load – hydraulic pressure and bending force through ANSYS 5.7.1 new function enhancement. Based on the stress, contact pressure and gap distance, the maximum acceptable bending forces and pre-load on the bolts were discussed. The analyses result also indicates the importance of using pre-tension elements for the bolts, contact elements for the interface of connection and refined mesh around stress concentration area.

**Reference:**
