doi:10.3772/j.issn.1006-6748.2018.02.012

Analysis on performance and test of a new type of ultra-high pressure pipe joint①

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Abstract

Analysis as well as application of ultra-high pressure hydraulic system and elements has become a trend. The structure and operation principle of a new type of ultra-high pressure pipe joint is introduced. The structure of the new type of ultra-high pressure pipe joint is simple and is easy to be produced. The finite element model on two working conditions (preload condition with 30N · m torque and static-loading condition with 70MPa pressure) is built and computed. The width of contact area, the equivalent stress status, as well as the contact pressure status are plotted and analyzed. According to the national standard, test on air-tightness, blasting, and cyclic endurance is conducted and the results show that the new type of ultra-high pressure pipe joint has the sealability for ultra-high pressure up to 70MPa, and the DN6 ultra-high pressure pipe joint can provide effective seal under 70MPa fluid pressure. The research can provide a thinking and method on designing ultra-high pressure pipe joint and push forward the development of ultra-high pressure hydraulic system.

Key words: pipe joint, ultra-high pressure, sealing performance, hydraulic system

0 Introduction

Pressure of hydraulic system is within 35MPa pressure level, in which hydraulic components have been highly developed. In the past few years, 70MPa pressure level was applied more and more on some low-flow-need fields like hydraulic tools, pressure vessel, powder metallurgy and pressure tester, which is proved to be more economic benefit[1-3]. With the growing need on lightweight and energy conservation of devices, application of ultra-high pressure system and components have become a trend[4,5]. In 2012, referring to the 12th Five-Year Plan, high pressure hydraulic components were listed in the 20 kinds of basic mechanical parts, which shows a national strategic demand of China[6].

As a basic accessory, hydraulic pipe joint has great influence on the safety and reliability of hydraulic system[7]. Hydraulic joint varies on the type of pipe, in which hard pipe joint is more common, considering the lack in pressure rating and difficulty on layout of hose joint. Among all kinds of hard pipe joints, welded, bite fitting and flared fitting hard pipe joints are widely used in engineering field.

So far, no national standard is built on ultra-high pressure pipe joints. To meet the need of industrial development, common high pressure pipe joints are usually modified to bear ultra-high pressure[8]. In Ref. [9], 3 kinds of ultra-high pressure pipe joints are introduced: cone flared fitting with copper washer pipe joint, metal flat washer pipe joint and O ring pipe joint, the pressure rating of which can reach 80MPa ~ 100MPa. However, since the attachments like cone washer and the O ring, these pipe joints have too many parts and are difficult to be reused. Ref. [10] mentioned the marine bite type pipe joint, the working pressure of which is 63MPa in maximum. But structure and assembly process of the pipe joint are too complicated. After all, ultra-high pressure fluid brings great difficulty to pipeline connection, and all the pipe joints in the system need to form reliable sealing to ensure the system efficiency. Now it has become a necessity to research and develop on the ultra-high pressure pipe joints.

① Supported by the 2015 Industrial Transformation and Upgrading of Strong Base Project (TC150B5C0-29) and the National Key Basic Research Program of China (2014CB046400).
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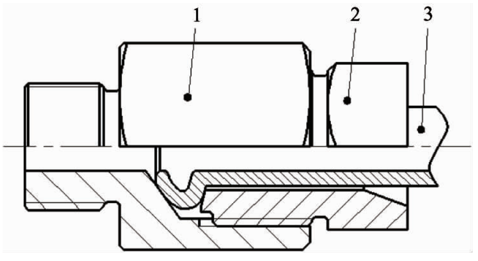
Received on Mar. 10, 2017

1 Structure of a new type of ultra-high pressure hydraulic pipe joint

Based on fully investigation, a new type of ultra-high pressure hydraulic pipe joints is conducted. The structure is shown in Fig. 1.



1. fitting body; 2. nut; 3. ball-end pipe

Fig. 1 Structure of ultra-high pressure pipe joint

The new type of ultra-high pressure hydraulic pipe joint is made of three parts: a fitting body, a ball-end pipe, and a nut. Like other kinds of pipe joints, the ultra-high pressure pipe joint is connected to blocks and hydraulic components by the thread on fitting body. On the other hand, the ball-end pipe acts on the conical surface in fitting body and forms steady face seal.

The ball-end pipe is processed with plain steel pipe by cold pressing directly. Firstly, a nut should be placed through a raw pipe, and then the raw pipe is processed into ball-end pipe in a special forming equipment. The combination of ball-end pipe and nut can benefit pipeline layout and reuse of the pipe joint itself.

The nut is machined in traditional way. And it is designed to apply preload on the ball-end.

Compared with the existing high pressure pipe joints, the new type of ultra-high pressure pipe joint is more compact in structure and simple in process. With the simplification of pipe joint, the number of leakage points in system decreases, which is an advantage at improving the reliability of ultra-high pressure system.

Conical surface is the important seal surface for the new type of ultra-high pressure pipe joint. This kind of seal form has already been used for long time. Back to 2006, conical sealing surface pipe joint was applied in the rocket propulsion system, and a theoretical study was conducted on it[11-13]. What makes it different is that the pipe joint for rocket propulsion system is machined by cutting, causing a series problem like low productivity, low material utilization, and high cost. Furthermore the new type of ultra-high pressure pipe joint is produced by cold pressing, and the procedure is simple, the productivity is higher, the ball-end shaped is smooth and round, and the cold hardening helps to strengthen the pipe joint. What's more, the cold pressing shaped ball-end like a disc spring, shown in Fig. 2. This helps the ball-end to store elastic energy, and benefits to self-preload and self-locking.

Fig. 2 Picture of ball-end pipe

In order to check the capacity of the new type of ultra-high pressure pipe joint, numerical simulation as well as test were conducted.

2 Modeling and simulation

As stated above, the bulb surface and the conical surface forms a seal area of new type of ultra-high pressure pipe joint. Considering the axial symmetry of pipe joint, two-dimensional axisymmetric element PLANE82 is used for the finite element modeling and the mesh generation of DN6 pipe joint.

Boundary conditions are set as follows:

1) Contact pair of ball-end and conical surface is created with contact element TARGE169 and CONTA172.

2) Constraint of position is set on fitting body. UX = 0, UY = 0.

3) Preload element PRETS179 is built on the thread of nut. The preload force is set to 6420N to simulate torque of 30N · m.

4) 70MPa pressure is applied to the wall of pipe to simulate the working condition.

The material of ball-end is steel 20, and the material of fitting body and nut is steel 45. And all the materials in this paper are isotropic and bilinear strain-hardening materials.

The basic parameters of steel 20 and steel 45 are shown in Table 1.

The model is built as Fig. 3, with 20696 nodes and 6664 elements in total.

Table 1 Material parameters of steel 20 and steel 45

	Density (g/cm^3)	Yield strength (MPa)	Elasticity modulus (GPa)	Poisson's ratio
C20	7.5	245	206	0.3
C45	7.85	355	209	0.26

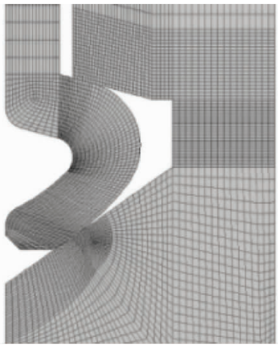
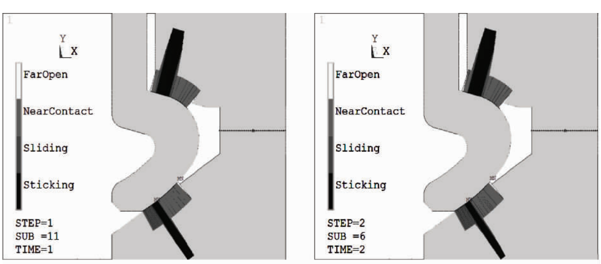


Fig. 3 Finite element model of pipe joint

2.1 Contact status of ball-end and conical surface

The contact status of preload condition and working condition of pipe joint is shown in Fig. 4, in which the black indicates contact area, the grey indicates sliding area, the white indicates near contact area, and the rest indicates far open area. It can be seen that a large contact area is generated on ball-end and conical surface, and forms surface seal. Simulation data says that in preload condition, the width of contact area is 0.458mm, and in working condition, the width is 0.400mm. The reason of width decrease of contact area is that the fluid pressure applied on ball-end works in axial direction, which is opposite to preload force, and it offsets the preload force. As the result shows, the maximal working pressure of the pipe joint is limited.



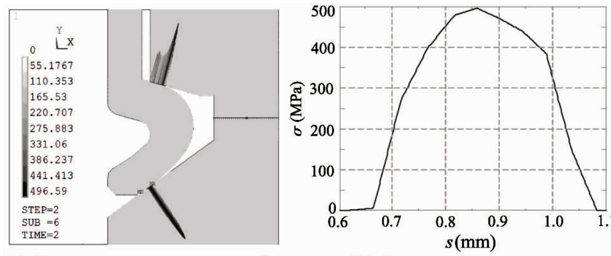
(a) Preload condition (b) Working condition

Fig. 4 Contour plot of contact status

2.2 Contact pressure of ball-end and conical surface

It is necessary for contact pressure to judge the reliability of seal[14]. According to Ref. [15], for metal to metal contact, the seal is reliable only when the contact pressure is enough to cause permanent deformation. When plastic flow occurs, the flaws on contact surface are filled with metal and form tight seal. To form contact area, the contact pressure to seal the gas is at least two times the yield strength of the metal (the softer one)[15].

With 70MPa fluid pressure, contour plot and curve of contact pressure is shown in Fig. 5. It shows that contact pressure σ of ball-end and conical surface reaches 496MPa, more than two times the yield strength.

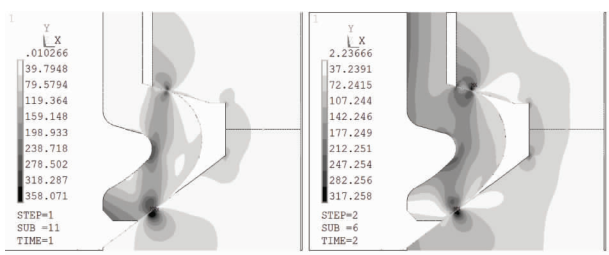


(a) Contact pressure contour plot (b) Contact pressure curve

Fig. 5 Contour plot and curve in working condition

2.3 Equivalent stress of ball-end and conical surface

The equivalent stress contour plot of preload condition and working condition of pipe joint is shown in Fig. 6. It can be seen that stress concentration occurs between ball-end and conical surface. The maximal equivalent stress on ball-end is 275MPa, and the maximal equivalent stress on conical surface is 360MPa. The result shows that there is plastic deformation on ball-end and conical surface. When the part of pipe joint is machined, all the peaks, troughs as well as leak paths on ball-end and conical surface are filled by plastic flow forming the sealing area.



(a) Preload condition (b) Working condition

Fig. 6 Equivalent stress contour plot

3 Test

So far, no test standard of hydraulic ultra-high pressure pipe joint is released. The hydraulic pipe joint test method GB/T26143-2010 is applied in this paper to perform test on DN6 pipe joint.

Four parts are performed in the test:

1) Air-tight test: according to the standard, the pipe joint is filled with 6.3MPa air beneath water, and no bubble is in sight. The pipe joint passes the test.

2) Pressure test: according to the standard, pressure test should be carried out in air. Pipe joint is filled with HM-46 hydraulic oil and pressurized with increase of 10MPa/s up to the test pressure of 140MPa, two times of the maximal working pressure. After 120s, there is no visible leakage and the test pressure maintains. The pipe joint passes the test.

3) Bursting test: according to the standard, test pressure should increase in 16% of maximal working pressure per second until the pipe joint fails or test pressure is 4 times of maximal working pressure. In this test, the test pressure increases in 10MPa/s to 280MPa, and then hold for 60s. The pipe joint works on and there is no visible leakage. The pipe joint passes the test.

4) Cycle endurance test: the test is carried on in the machinery industrial engineering and hydraulic parts quality supervision center. The test bed is shown in Fig. 7.

The cycle endurance test is shown as Fig. 8. Four pipe joints are connected to pulse valve block. And joints connect to each other with U-pipe and form components.

Fig. 7 Picture of cycle endurance testbed

Fig. 8 Picture of cycle endurance test

According to the standard, the components are cyclically loaded for one million times. The peak pressure is 133% of the maximal working pressure, which is 93MPa. And the impulse frequency is 1.25Hz. Curve of the test is shown in Fig. 9. Neither components fail nor leak occurs during the test. The pipe joint passes the test.

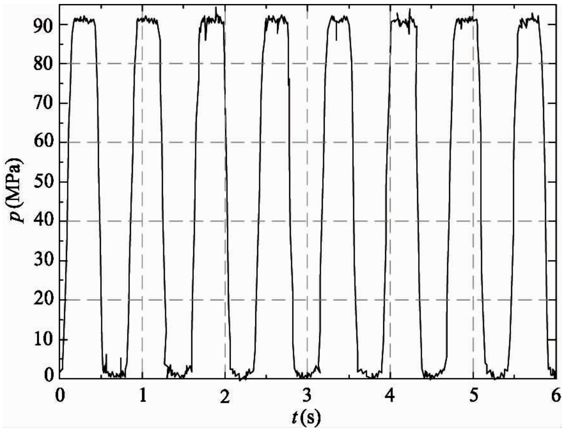


Fig. 9 Curve of cycle endurance test

4 Conclusions

(1) A new type of ultra-high pressure pipe joint is conducted and developed. The pipe joint has the advantages of fewer parts, leak points, and simple process.

(2) Results of numerical simulation show that, in all aspects the new type of ultra-high pressure pipe joint has the potential for ultra-high pressure seal.

(3) The test shows that DN6 ultra-high pressure pipe joint is capable of sustaining 70MPa ultra-high pressure, and effective and reliable seal is formed.

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