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STRESS OF MAKE-UP TORQUE ON THE GAS STORAGE WELL BORE AND COUPLING CONNECTING THREAD

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Abstract. The structure of wellbore and coupling is connected by thread, it is the position where fatigue failure accidents are happened in gas storage well, and the make-up torque of thread is the key factor that influences the mechanical properties of this structure. In this paper, a finite element method was established to discuss the calculation method of make-up torque and the influence law on the stress of coupling in the gas storage well. Results show that the make-up torque cannot be simply ignored due to its great impact on internal stress distribution of gas storage well. Experimental results showed the correctness of the model. Under the action of the make-up torque, the overall stress level inside the wellbore is higher than the external coupling. However the maximum stress exists in the external coupling. The overall stress gradually increases with the increase of interference rotation number (abbr. RN) between coupling and wellbore, but the overall distribution trend is almost the same. The first thread on the left of the connection part is the area where fatigue failure is most likely to occur. The make-up torque between threads increases linearly with the increase of RN between coupling and wellbore.
Key words: Gas storage well, make-up torque, finite element analysis, stress test, thread.

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1. Introduction

The underground gas storage well has those advantages as a new type of a high pressure gas storage facility, such as small floor area, easy operation and low maintenance cost. Now, it has been widely used in natural gas vehicle filling stations. However, in the event of failure accident, the gas station will directly endanger people's lives and properties, because it is usually set up in the traffic arteries and other densely populated places. Therefore, the gas storage well has been included in special equipments safety supervision system and managed as III pressure vessels [1] in our country.

Figure 1 shows the structure of the gas storage well. The prototype of the gas storage well comes from oil and gas well. It is composed of an upper head, a well tube, a coupling and a lower head [2]. The buried depth is between 50 m and 300 m and the corresponding number of well tube is 5 to 30. Each well tube is linked through coupling in series. So, the thread connection joint is the basic structural unit of the gas storage well. The well tube and coupling of gas storage well, as well as the wellbore and well bottom device, are connected by the long-thread processed according to the API SPEC 5B [3]. The axial shift, produced by tightening the thread when connecting the thread, can achieve the interference on the joint surface of the internal and external thread tooth, as well as the special cone seal of thread groove. However, it's an injury to the tube body when processing the thread groove on the tube body, which will result in the decrease of the tube wall thickness and cause local stress concentration in the structure. Thus, the thread groove is the weak link of the structure of

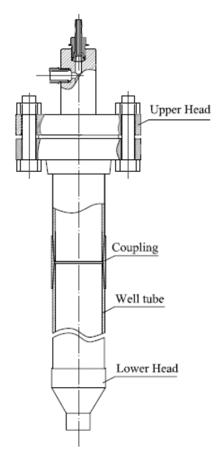

Fig. 1. Schematic diagram of structure for gas storage well

the gas storage well [4]. However, limited feasible studies and practical tests have been reported on studying the security of thread connection joint of gas storage well.

Numerical method is a useful way to research the thread structure, because it's difficult to measure [5]. For Example, literatures [6–8] established the calculation model of thread connection joint of gas storage well and analyzed the stress distribution of well tube and well head. Numerical model cited in the above literatures, however, only considered the internal pressure of well tube, without considering the affect of make-up torque of thread pre-tightening. The torque, as a load of this structure, will directly affect the deformation and stress distribution of internal thread of well tube and coupling in the gas storage well. The result is hardly convincing if the torque loads are not considered.

In this work, a finite element analysis model of gas storage well tube and coupling with a consideration of make-up torque was established, and the variation regularity of the stress of thread connection joints with the variation of make-up torque was also researched. This work provides a numerical analysis for the design, production and application of the well tube of the gas storage well and even oil well.

2. Establishment of the finite element model

2.1. The finite element model

There are some differences between the head and bottom sealing of gas storage well produced by various manufacturers. In order to make research results more general, only the well tube and coupling thread joint are analyzed in this paper. The problem is simplified to an axisymmetric problem because the stress direction on the threaded end is almost parallel to the centerline due to the very small helix angle of the connecting thread of the gas storage well [9]. So, only half of the geometrical model is taken to be calculated due to the symmetrical structure of the well tube on both sides of the coupling.

On the basis of the above simplification, the geometric model, as shown in Fig. 2, is established for stress analysis and calculations. The thread dimension is shown in Fig. 3 and the thread taper is 1:16. The 8-note isoparametric element is used for mesh generation to do thinning processing for the grid of thread connection. Mesh generation is shown in Fig. 4. The analysis is based on elastic finite element method [10]. The material is L-80. Elastic modulus is $E = 2.03 \times 10^5$ MPa and Poisson's ratio is $\mu = 0.3$. Contact element is used to analyze and calculate the threaded joints. Friction coefficient between the thread are related to sealing grease, generally to be 0.015–0.025 [11, 12]. In this calculation, the friction coefficient is 0.02.

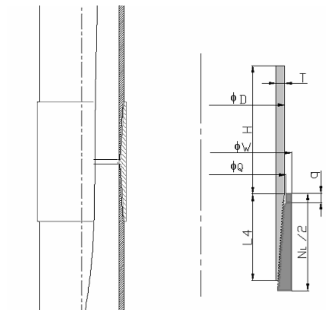

Fig. 2. Geometric model of finite element analysis

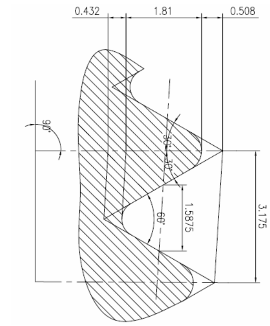

Fig. 3 Thread dimensions

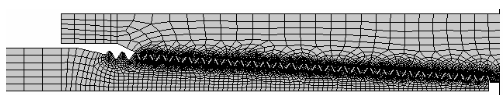

Fig. 4. Finite element analysis mesh of threaded joints

2.2. Validity check of numerical model

In order to test the correctness of the results of the calculation of the model of the gas storage wells, a stress-strain measurement of the gas storage wells is carried out and the arrangement of the measuring points is shown in Fig. 5. Extracting the results of the stress of the key points of the coupling and the shell, compared with the results of numerical analysis, and results are shown in Table 1. It can be seen that the numerical calculation and experimental results are basically consistent, and the error is less than 8%.

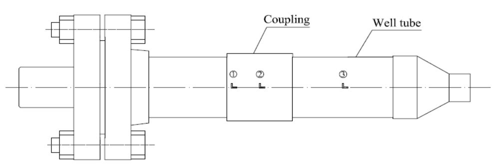

Fig. 5. The arrangement of measuring points

3. Results, analysis and discussion

3.1. Calculation method of make-up torque

The reverse deduction method is used in this work, because torque load cannot be directly applied into the axisymmetric model. Firstly, according

Table 1 Comparison of results

Position / Calculation method	Casing pipe, point 1	Top of coupling, point 2	Middle of coupling, point 3
	Circumferential stress/ MPa		
Experimental results	289.2	164.15	157.56
Analytical solution	295.7	None	None
Numerical simulation	267	160	146
Error of numerical simulation/%	7.7	2.6	7.4

the geometric dimension of the thread between internal and external thread, the value of interference fit under the different RN is determined. Secondly, the appropriate contact conditions are set and the contact pressure between the threads under different magnitude of interference simulated using finite element calculation method. Finally, by using the self-compiling program, contact pressure of different node is extracted, then multiplies by the action area and central moments, the corresponding make-up torque of thread of different magnitude of interference is obtained. Taking the upper face of single thread shown in Fig. 6 as an example, the make-up torque on this plane can be derived as follows

$$M = 0.5f \cdot [(R_{N1} + R_{N2}) \cdot S1 \cdot R1 + (R_{N2} + R_{N3}) \cdot S2 \cdot R2 + (R_{N3} + R_{N4}) \cdot S3 \cdot R3 + (R_{N4} + R_{N5}) \cdot S4 \cdot R4],$$

where M the make-up torque, f the friction coefficient, P the contact pressure, R the radius; Subscript: $N1$, $N2$ and so on, the node number.

Similarly, the corresponding make-up torque of different RN between well tube and coupling can be obtained.

3.2. Affect of make-up torque on coupling stress distribution

The gas storage well, whose diameter $D = 177.8$ mm and wall thickness $I = 10.36$ mm. Von-Mises stress distribution is shown in Fig. 7 for the stress distribution between coupling and well tube joints with RN is 2.

Figure 7 shows that when $RN = 2$, there is a larger stress on the well tube and coupling. The overall stress level of the well tube is higher than that of the coupling, but the overall maximum stress comes from the coupling. As for the well tube, the Von-Mises stress is generally more than 500 MPa. What's more, with the increase of the wall thickness, the overall stress level decreases gradually, but its internal maximum stress occurs in maximum wall thickness

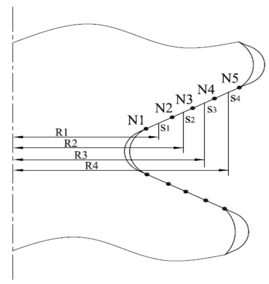

Fig. 6. Calculation schematic diagram of single-threaded torque

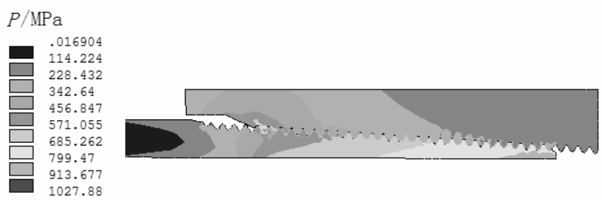

Fig. 7. Von-Mises stress distribution cloud of coupling

of the thread which connects with the coupling. That is the bottom of the first thread on the left side connected with the coupling. For coupling, when the wall thickness increases, the overall stress level decreases gradually, and its internal maximum stress occurs in the minimum wall thickness of the thread, which is connected with the well tube at the bottom of the first thread in the left side connected with the well tube. Since there is a larger stress both in the coupling and well tube, the make-up torque will definitely have a greater impact on the stress distribution of the gas storage well subjected to internal pressure load. Thus, make-up torque should not be ignored.

The contact pressure distribution at the junction between the coupling and the well tube is shown in Fig. 8. The maximum contact stress exists in the top of the first thread tooth on the left side of the coupling and well tube. It will cause the bending of the corresponding thread tooth and make the stress at the bottom of the thread tooth turn to be the largest one eventually. Therefore, the maximum stress of the coupling and the well tube occurs at the end of the first thread on the left side. The maximum stress whose main component is peak stress exits in limited regions, which causes fatigue failure instead of significant deformation.

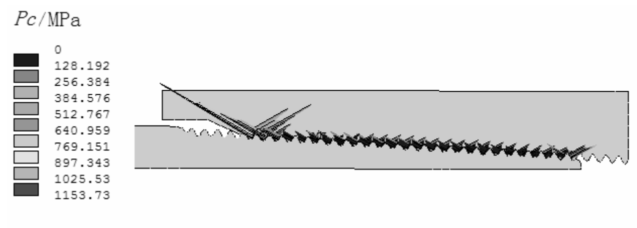

Fig. 8. Contact pressure distribution cloud of coupling

3.3. Method for determining the number of pre-tightening threads of coupling

The stress distribution cloud of coupling under different make-up torque is drawn on the basis of simulation on $RN = 0.5$, 1, 1.5, 2 and 2.5, as is shown in Fig. 9. It can be seen, that with the increase of RN between coupling and well

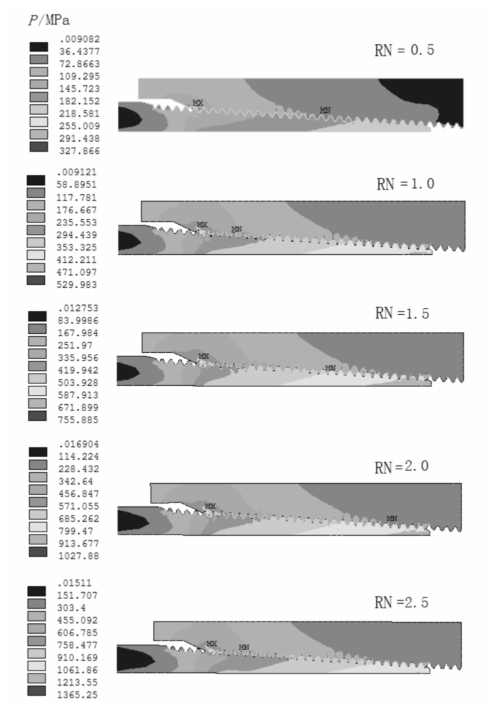

Fig. 9. Stress distribution cloud of coupling under different make-up torque

tube, both overall stress level and maximum stress are increasing gradually, but the overall distribution trend is almost the same. The maximum stress appears at the bottom of the first thread tooth of both contacts, where fatigue failure is easily to happen.

Extracting the stress of thread contact, the change relation between make-up torque of coupling and well tube and RN is calculated, as is shown in Fig. 10.

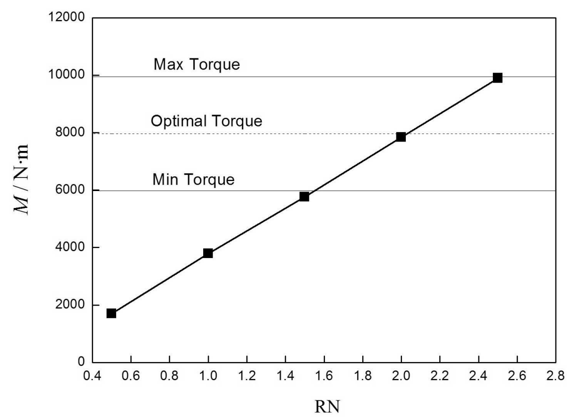

Fig. 10. Change relation between make-up torque and number of threads

Make-up torque increases with the increase of RN, they tend to be a linear relationship. Comparing the results with the make-up torque range specified in the SY/T5412-2005 standard [13], the reasonable RN between the coupling and the well tube of the gas storage well is in the range of 1.6–2.5, while the coupling is in the best make-up torque condition when RN is 2. Therefore, numerical results match exactly the RN and make-up torque suggested in the standard. This fact proves the correctness of the calculation model in this paper from another aspect. So, the established numerical model and the calculation method can be used to predict the pre-tightening of the coupling make-up torque of the gas storage well and determine the number of pre-tightening threads and guide the engineering operation.

4. Conclusion

Considering the impact of pre-tightening force, a finite element numerical model of the gas storage well is established in this paper. And the calculation method of the make-up torque and its impact on the stress of coupling are discussed in detail. The conclusions are as follows:

(1) The finite element model of the gas storage well which is established in this passage can obtain the stress distribution inside the vessel, the simulation results basically tallies with experimental results, and the error is less than 8%.

(2) The make-up torque cannot be simply ignored because it has a great impact on internal stress distribution of gas storage well. The numerical model and the calculation method in this work can be used to predict the number of pre-tightening threads of the gas storage well.

(3) Under the action of the pre-tightening force, the overall stress level of inside of the gas storage well tube is higher than the external coupling, but the maximum stress appears in the coupling.

(4) With the increase of RN between coupling and well tube, the overall stress levels are gradually increasing, but the overall distribution trend is almost unchanged. The first thread, contacting with each other, is the possible place of fatigue failure.

(5) With the increase of RN between coupling and well tube, the make-up torque between them increase gradually and linearly

REFERENCES

[1] Chen, Z. Z., K . Shi, B. X. Li.. Discussion of Design Issues of Gas Storage Well. *Pressure Vessel,* **29** (2012), No. 2, 49–56.

[2] Li, K. X. Drilling Manual (the First Party) Volume 1, Volume 2, Volume 3, BeiJing, Petroleum Industry Press, 1990.

[3] API SPEC 5B. Specification for Threading, Gauging and Thread Inspection of Casing, Tube, and Line Pipe Threads.

[4] SY/T 5322. Strength Design Method of Casing String.

[5] Tang, X., D. M. Luo. Stress Analysis and Fatigue Analysis of CNG underground gas Storage Well. *Natural Gas and Oil*, **28** (2010), No. 3, 49–52.

[6] Feng, X., J. C. Liu, M. Yang, S. P. Zeng, W. B. Liu. Finite Element Analysis of the Coupling of the CNG Filling Stations In Underground Gas Storage Wells. *Natural Gas Industry*, **28** (2008), No. 6, 118–119.

[7] Yang, L., Z. Liang, J. L. Tian, L. Zhang, Y. H. He. Threaded Calculation and Finite Element Analysis of the CNG Storage Wells. *Oil Field Equipment,* **37** (2008), No. 10, 59–63.

[8] Feng, X., Y. L. He, B. Li, T. J. Lin, X. Liu. Finite Element Analysis of Bottom Head of Filling Stations Underground Gas Storage Wells. *Surface Engineering of Oil and Gas Fields*, **27** (2008), No. 3, 5–7.

[9] TUREYEN, O. I. Effect of the Wellbore Conditions on the Performance of Underground Gas-storage Reservoirs. SPE/CERI Gas Technology Symposium, Calgary, Alberta: SPE, 2000.

[10] ZHAO, Q. C., Z. Q. WANG, Y. J. DU, B. ZHOU, Y. L. HAN. Finite Element Analysis and Test of the Stress and Strain Fields of Tubing's Thread. *Journal of Surveying*, **26** (2005), No. 3, 253–258.

[11] KWON, W. Y., E. F. KLEMENTICH, I. K. KO. An Efficient and Accurate Model for the Structural Analysis of Threaded Tubular Connections. *SPE Production Engineering,* (1990), No. 4, 261–264.

[12] MCHAEL, J., A. D. MANUEL. How to evaluate and select Premium Casing Connections. IADC/SPE 35037, 1996.

[13] SY/T5412-2005. People's Republic of China Oil and Natural Gas Industry Standard-Casing Running Operating Procedures.