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Optimizing loading path and die linetype of large length-to-diameter ratio metal stator screw lining hydroforming

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Abstract: In order to meet the high temperature environment requirement of deep and superdeep well exploitation, a technology of large length-to-diameter ratio metal stator screw lining meshing with rotor is presented. Based on the elastic-plasticity theory, and under the consideration of the effect of tube size, material mechanical parameters, friction coefficient and loading paths, the external pressure plastic forming mechanical model of metal stator screw lining is established, to study the optimal loading path of metal stator lining tube hydroforming process. The results show that wall thickness reduction of the external pressure tube hydroforming (THF) is about 4%, and three evaluation criteria of metal stator screw lining forming quality are presented: fillet stick mold coefficient, thickness relative error and forming quality coefficient. The smaller the three criteria are, the better the forming quality is. Each indicator has a trend of increase with the loading rate reducing, and the adjustment laws of die arc transition zone equidistance profile curve are acquired for improving tube forming quality. Hence, the research results prove the feasibility of external pressure THF used for processing high-accuracy large length-to-diameter ratio metal stator screw lining, and provide theoretical basis for designing new kind of stator structure which has better performance and longer service life.

Key words: tube hydroforming; loading path; large length-to-diameter ratio; metal stator lining; simulation

1 Introduction

With the rapid development of the world economy, crude oil will have a huge increase in demand in next ten years. Consequently, deep or superdeep well exploitation will become dominant to meet the demand of energy. However, the work environment of drilling tools will be more and more severe with the increase of drilling depth (with temperature and pressure higher than 175 °C and 100 MPa, respectively) [1]. Currently, as one of the most widely used downhole tools, the year sales of positive displacement motor (PDM) can reach hundreds of millions of dollars. The core component stator and rotor possess about 30% of the total cost. However, existing PDM stator relies on rubber lining whose rate of heat dissipation is slow greatly to contact with drilling medium and rotor, leading to rubber lining thermal fatigue failure prematurely. Therefore, improving existing stator structure and studying screw metal lining to mesh with rotor is the key and difficult problem to increase the drilling technique of deep and superdeep well exploitation [2−3].

Tube hydroforming is presented to process metal stator lining which is a large length-to-diameter ratio screw curved iso-wall thickness tube. THF process is an integral plastic processing method including internal pressure THF and external pressure THF. There are many influence factors on the forming quality, and now the main research methods include numerical simulation and test. Some scholars have considered the wall thickness uniformity of tee-shaped tube hydroforming process dependent on a number of variables such as friction lubrication conditions, axial material feed versus time and internal pressure versus time, and then obtained the optimal loading paths [4−7]. In order to get the optimal loading paths, a great deal of research has been conducted to study the failure phenomenon of necking and fracture which may happen in tube internal high-pressure forming process, and to analyse the effect of tube size and loading pressure on forming quality [8−9]. Now, this technology has been used in automotive and aerospace manufacturing widely [10−13]. SIEGERTK [14] did research on external pressure THF through the numerical simulation and test, giving the conclusion that the loading pressure of external pressure THF is lower than that of internal pressure THF, and the wall thickness reduction can be avoided.

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However, the research of external pressure THF isn't involved with large length-to-diameter ratio metal stator screw lining now. In allusion to the research gap, the effect of tube size, material mechanical parameters, friction coefficient and loading paths is comprehensively considered, and the external pressure plastic forming numerical model of large length-to-diameter ratio metal stator screw lining is established, in order to research the feasibility of external pressure THF used for iso-wall thickness metal stator lining and optimum forming technology.

2 Key factor in external pressure THF

External pressure THF is influenced by many factors such as lubricated friction, tube size, material mechanical parameters, loading pressure and loading paths. In this work, the numerical simulation technology is used to research the forming quality of metal stator lining.

2.1 Friction coefficient and tube size

The technical principle of large length-to-diameter ratio metal stator screw lining is shown as Fig. 1. The friction coefficient between tube and die can be controlled between 0.025 and 0.05 using glass lubricant [15−16]. For researching the forming quality in the large friction coefficient, friction coefficient of 0.05 is chosen in this work. Metal stator lining and stator casing bond together by forming the iso-wall thickness metal lining stator, as shown in Fig. 2.

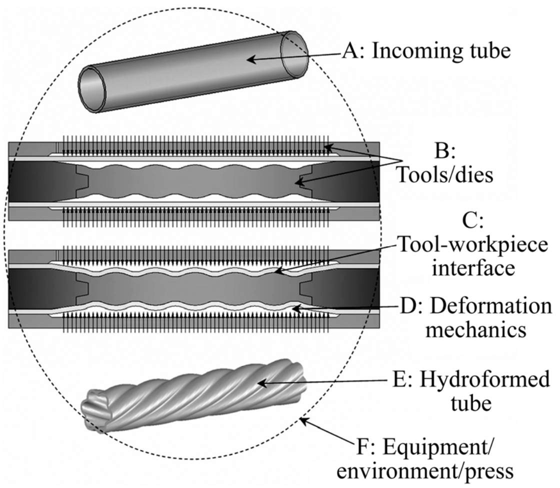

Fig. 1 Technology principle of metal stator screw lining

Because of the limited inside dimension of stator casing, tube thickness of metal stator lining is selected to be 5 mm. The tube critical buckling pressure is split into long cylinder critical buckling pressure and short cylinder critical buckling pressure according to the length. Large length-to-diameter ratio metal stator lining

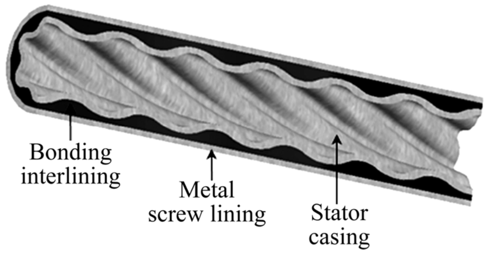

Fig. 2 Structure of metal lining stator

belongs to long cylinder, and tube critical length formula can be given as

$$L_{cr} = 1.17 D_0 \sqrt{D_0/t} \tag{1}$$

where L_{cr} is critical tube length; D_0 is tube outer diameter; t is tube thickness.

Critical tube length calculated according to the stator outer diameter is 1088 mm. The length of numerical model should be greater than this size. Therefore, tube length in this work is 1200 mm.

2.2 Mechanical parameters of tube material

The mechanical parameters of tube material are greatly important during numerical simulation, therefore, plastic properties of tube material should be considered, including yield criterion, material flowing law and strain hardening law.

The tube material selected is stainless steel 304, which has large plastic deformation and high forming strength. Several parameters, such as yield strength σ_s, tensile strength σ_b, elongation and strain hardening index are measured according to the test. Tensile test specimens are shown in Fig. 3.

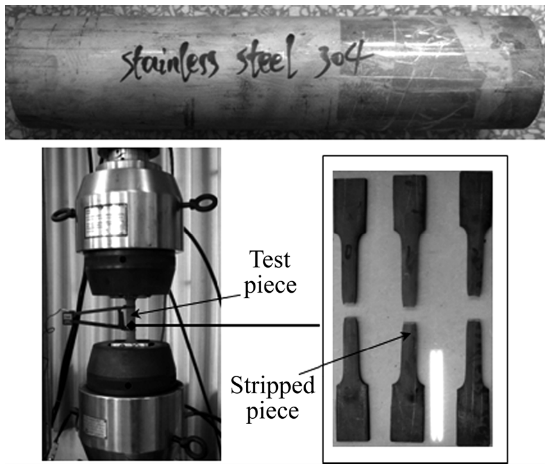

Fig. 3 Stripped pieces of stainless steel 304

Table 1 lists the mechanical parameters of stainless steel 304 under different loading rates. With the loading rate increasing, it can be shown that yield strength and tensile strength show a trend of increase, however,

Table 1 Tensile properties of tube under different loading rates

Material	Loading rate/ ($mm\cdot min^{-1}$)	Elongation/ %	Yield strength/ MPa	Tensile strength/ MPa
Stainless steel 304	5	71.11	277.477	694.106
	18	60.09	285.331	631.864
	50	60.00	298.968	653.825
	100	56.67	324.674	659.829
	150	51.11	325.627	652.206

elongation is significantly reduced [17].

Tensile test data with loading rate of 10 mm/min are suited to THF, and main mechanical parameters of tube can be gained, as given in Table 2.

Table 2 Mechanical parameters of tube

Material	Density/ ($g\cdot cm^{-3}$)	Elastic modulus/ GPa	Yield strength/ MPa	Tensile strength/ MPa
Stainless steel 304	7.93	195	281.552	653.972

Hardening law of stainless steel 304 conforms to the following model:

$$\sigma = K\varepsilon^n \tag{2}$$

where σ is true stress; ε is true strain; n is strain hardening index; K is coefficient. According to the true stress and true strain, K=1427.6 and n=0.42 can be acquired based on the power function hardening model.

2.3 Metal stator lining forming process

Figure 4 shows a cylinder with inside radius r_i and outside radius r_o. Under the external pressure effects, stress is the largest on the inner cylinder, and when the critical pressure is obtained, the inner wall will yield, forming the plastic zone. With the external pressure increasing, the plastic zone expands, then there are two zones formed which are plastic zone inside and elastic zone outside. It is assumed external pressure is p, the separatrix radius of plastic zone and elastic zone is r_j, k ($=r_o/r_i$) is radius ratio, and k_j ($=r_j/r_i$) is the depth of plastic zone.

If a tube material conforms to Tresca yield criterion, then

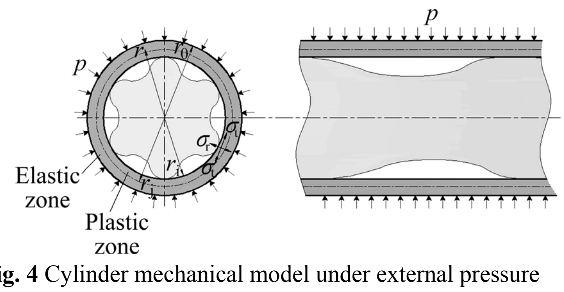

Fig. 4 Cylinder mechanical model under external pressure

$$\sigma_r - \sigma_t = \sigma_s \tag{3}$$

where σ_r is radial stress and σ_t is circumferential stress.

Equilibrium equation of tube cell can be expressed as $\mathrm{d}\sigma_r/\mathrm{d}r + (\sigma_r - \sigma_t)/r = 0$.

Boundary conditions are shown as follows: 1) If $r=r_i$, then σ_r=0; 2) if $r = r_j$, then $\sigma_r=-p_j$.

Therefore, radial stress, circumferential stress and axial stress can be expressed as

$$\sigma_r = -\sigma_s \ln r/r_i \tag{4}$$

$$\sigma_t = -\sigma_s(1 + \ln r/r_i) \tag{5}$$

$$\sigma_z = (\sigma_t + \sigma_r)/2 = -\sigma_s(0.5 + \ln r/r_i) \tag{6}$$

According to Condition 2), critical surface pressure of elastic and plastic zone is

$$p_j = \sigma_s \ln k_j \tag{7}$$

The relationship between external pressure and corresponding radius can be expressed as

$$p/\sigma_s = \ln k_j + (k^2 - k_j^2)/(2k^2) \tag{8}$$

If k_j=1 and $k_j = k$, then initial yield load and complete yield load can be expressed as

$$p_e = \sigma_s (k^2 - 1)/(2k^2) \tag{9}$$

$$p = \sigma_s \ln k \tag{10}$$

Moreover, tube maximum load can be expressed as

$$p_{max} = \sigma_b (r_o - r_i)/\beta \tag{11}$$

where σ_b is ultimate tensile strength; r_o is outside radius of tube; r_i is inner radius of tube and β is corner radius of die.

3 Building finite element analysis (FEA) model and optimizing loading path

The stress and strain state of metal stator screw lining THF is very complicated, therefore, in order to obtain high quality forming tube, the optimal loading pressure and loading paths should be ensured.

3.1 FEA model

The study object in this work has outside diameter of stator as 120 mm, lead as 960 mm, and drive ratio as 5:6. The FEA model of large length-to-diameter ratio metal stator screw lining THF is shown in Fig. 5, whose tube uses shell cell and die uses rigid cell.

Other variables of stainless steel 304 are shown as follows: tube thickness is 5 mm, length is 1200 mm and friction coefficient between tube and die is 0.05. The bore radius of tube is selected from 45 mm to 48 mm on the basis of die perimeter, so as to confirm optimal forming, and corner radius of die is 10 mm. Then maximum load of stainless steel 304 is 329 MPa.

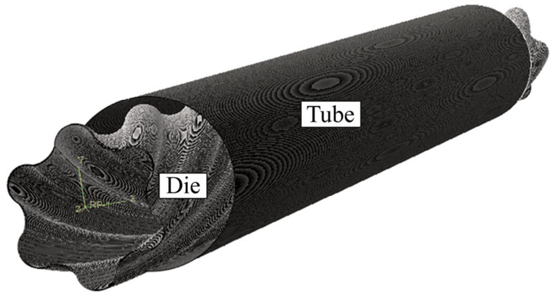

Fig. 5 THF finite element model

3.2 THF result analysis of different tube sizes with linear loading paths

The loading paths of external pressure THF for stainless steel 304 are shown in Fig. 6, whose loading time is 1 s, 2 s and 3 s, respectively, and the maximum load is 300 MPa.

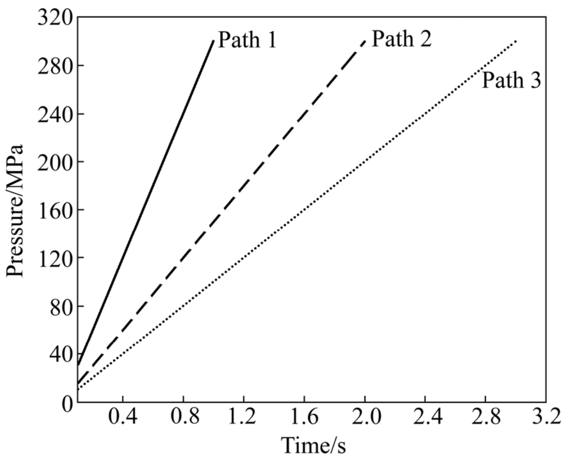

Fig. 6 Loading paths

Wrinkles of forming tube should be avoided during external pressure THF. Table 3 presents the metal stator screw lining forming results using different tube sizes with three loading paths. The geometric dimension of metal stator screw lining forming using each tube bore radius is unqualified with Path 1 and Path 3. The results show that, the inner bore perimeter of subsize tube is decreased after plastic deformation, causing the formation of tube inwall and incomplete plying-up of die. However, with jumbo size, the inner bore perimeter will be oversized, wrinkles occur after plastic deformation, and the formation of tube inwall and incomplete plying-up of die are caused too. The reasons are as follows. Because yield strength and tensile strength show a trend of increase with the loading rate increasing, then elongation is significantly reduced. Therefore, tube elongation reduces as loading time decreases, leading to the formation of tube inwall and poor quality of die, and it will cause wrinkles and incomplete plying-up of die.

Furthermore, when tube bore radius is 45 mm with Path 2, the tube inwall and incomplete plying-up of die are formed. When tube bore radius is 47 mm or 48 mm, wrinkles, tube inwall and incomplete plying-up of die are formed. Metal stator screw lining forming quality at tube bore radius of 47 mm with Path 2 is shown in Fig. 7. However, metal stator screw lining forming quality at tube bore radius of 46 mm with Path 2 could meet the requirement. Figure 8 shows the tube shape and central section thickness distribution, from which it can be acquired that the wall thickness reduction is not serious while incrassation is more obvious, and thickness variation amplitude reaches 1.5 mm with the maximum thickness of 6.1 mm located at the arc top and the minimum thickness of 4.55 mm located at the transition place of arc top and arc bottom of metal stator screw lining, respectively. Due to forming difficulty in transition place and serious plastic deformation of tube, metal flows to two sides under the hydraulic action.

The analysis according to metal stator screw lining forming quality shows that using external pressure THF can avoid the wall thickness reduction because it demands little material compensation, and in order to avoid causing death wrinkle and enhance forming quality, die perimeter and tube internal bore perimeter need to be fitted.

3.3 Optimizing loading paths and evaluating forming quality

External pressure THF is mainly for processing hollow complex component. And wall thickness distribution and forming dimension are important indicators for evaluating the forming quality. Thereinto, dimensional accuracy and surface quality can be measured by forming dimension, and wall thickness distribution can be used to evaluate the security of forming tube.

Because of the forming difficulty in transition place,

Table 3 Results of simulation

Loading path	Quality				Maximum displacement/mm				Failure mode			
	45 mm	46 mm	47 mm	48 mm	45 mm	46 mm	47 mm	48 mm	45 mm	46 mm	47 mm	48 mm
1	−	−	−	−	21.8	30	31.3	32.6	Gap	Gap	Gap	Fold; Gap
2	−	+	−	−	25.4	30.2	27.9	28.9	Gap	Qualified	Fold; Gap	Fold; Gap
3	−	−	−	−	24.8	25.6	27.2	28.9	Fold; Gap	Fold; Gap	Fold; Gap	Fold

"+" successfully formed; "−" failed formed.

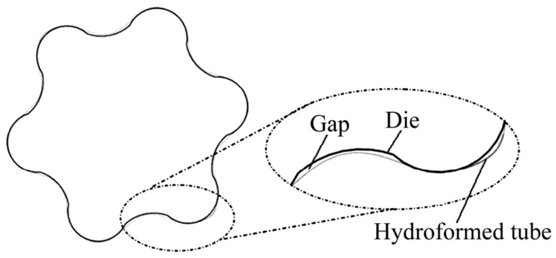

Fig. 7 Metal stator screw lining forming quality

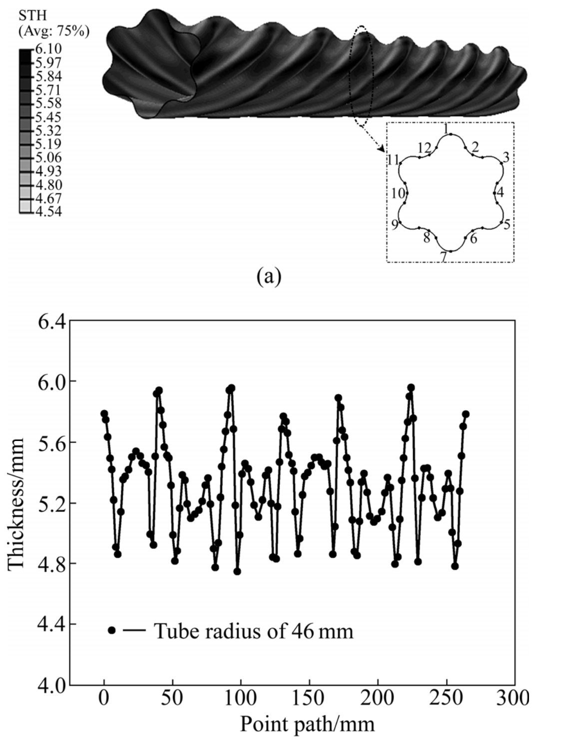

Fig. 8 Forming tube (a) and central section thickness distribution (b)

thickness is reduced there. Therefore, qualified forming tube can be evaluated by the forming quality of transition place. As shown in Fig. 9, the initial normal distance and formed normal distance from tube inwall to die arc transition place are denoted as l_0 and l, respectively, and the ratio of formed normal distance to initial normal distance is defined as fillet stick mold coefficient x to measure plying-up quality. The maximum thickness and minimum thickness of metal stator screw lining are denoted as $t_{\max}$ and $t_{\min}$, respectively, and the ratio of thickness difference to initial thickness is denoted as thickness relative error t'. Considering the fillet stick mold coefficient x and thickness relative error t' under the premise of guaranteeing eligible dimensions, the product of fillet stick mold coefficient x and thickness relative error t' is defined as forming quality coefficient r, and the smaller the forming quality coefficient r is, the better the forming quality is.

When the initial diameter of tube bore is 92 mm, and die opposite-angle arc transition place diameter is 66.245 mm, then the initial normal distance l_0=12.578 mm, and fillet stick mold coefficient x=l/12.578. When the initial thickness is 5 mm, then thickness relative error t'=($t_{\max}$−$t_{\min}$)/5 and forming quality coefficient r can be expressed as r=x·t'.

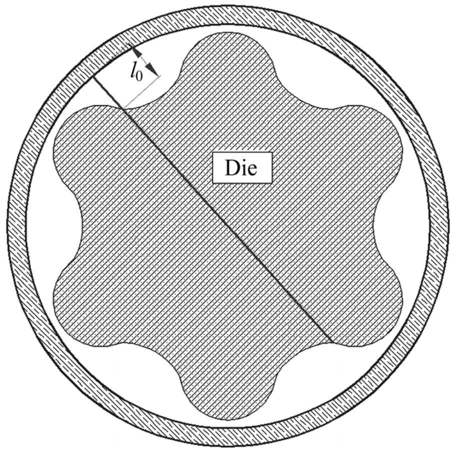

Fig. 9 Initial normal distance

Figure 10 shows multiple loading path of metal stator screw lining external pressure THF whose loading time is 2 s and maximum load is 300 MPa, including linear loading Path 2 and non-linear loading Path 4−Path 9. The time of reaching maximum load of each loading paths is 2, 0.5, 0.8, 1, 1.3, 1.5 and 1.8 s.

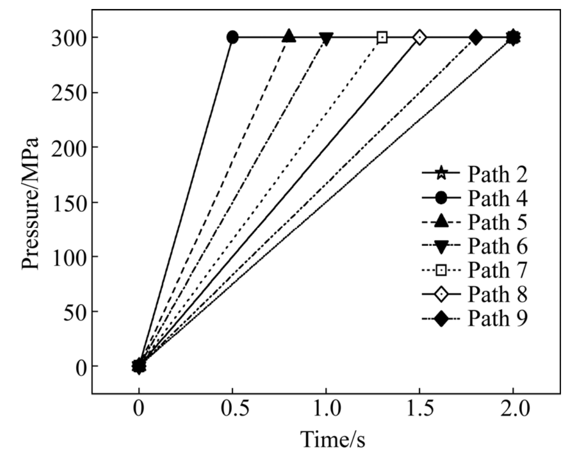

Fig. 10 Optimizing loading path

Figure 11 shows the variation trend of thickness relative error, fillet stick mold coefficient and forming quality coefficient with different loading paths. The results show that with the loading rate reducing, each indicator has a trend of increase, due to tensile strength reducing and elongation increasing, and then tube is easier to form buckling deformation and plastic deformation, leading to the increase of thickness relative error and wrinkling. However, plastic deformation in forming tube can occur easily to get qualified metal stator screw lining when loading rate is reduced to a

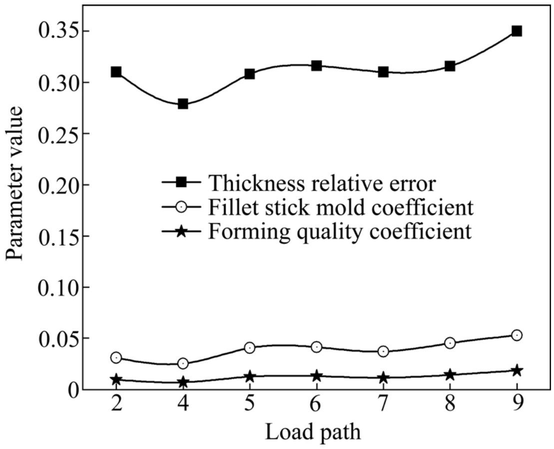

Fig. 11 Tube forming different of each loading paths

certain degree such as loading Path 2 and matches with the increase of loading pressure.

The loading path which has small value of evaluation indicators should be selected. Path 2 and Path 4 will be selected as the external pressure forming loading paths of metal stator screw lining and their forming quality is compared.

Figures 12−14 show central section displacement, thickness and stress distribution with Path 2 and Path 4, respectively. The results show that the displacement distributions of both loading paths are almost the same, proving the similar plying-up quality of forming tube and die. Compared with Path 2, thickness distribution of Path 4 is more symmetrical, moreover, thickness reduction and incrassation are both smaller. Because of the faster loading rate of Path 4, metal stator screw lining THF exhibits a few characteristics of less metal flow, more symmetrical stress distribution and higher strength limit.

Therefore, using Path 4 can get better forming quality of metal stator screw lining. The central section thickness with Path 4 is shown in Fig. 15, from which it can be found that wall thickness is between 4.8 mm and

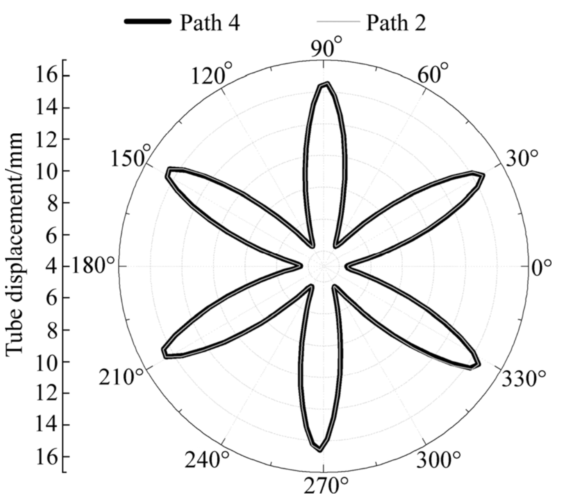

Fig. 12 Central section displacement distribution of Path 2 and Path 4

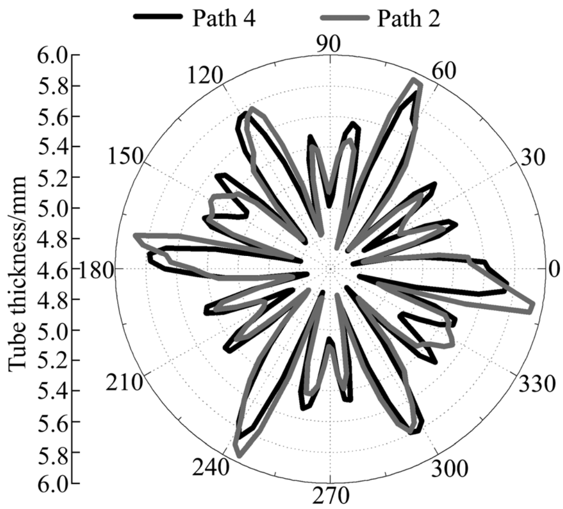

Fig. 13 Central section thickness distribution of Path 2 and Path 4

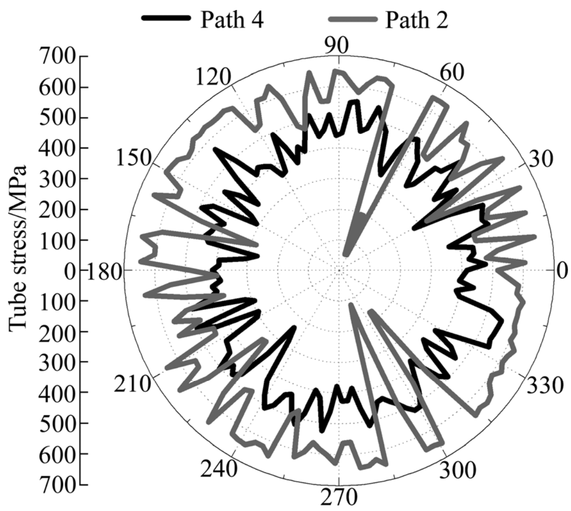

Fig. 14 Central section stress distribution of Path 2 and Path 4

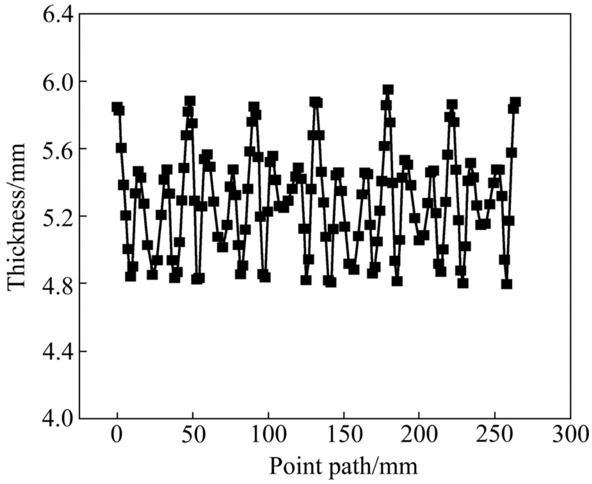

Fig. 15 Central section thickness value with Path 4

5.8 mm, thickness variation amplitude is about 1 mm and thickness reduction is not serious, about 4%. Moreover, the wall thickness would mainly be thickened, ensuring the security of metal stator screw lining in service.

The central section contour of metal stator screw lining mainly overlaps with die section contour, but fillet stick mold coefficient is only 0.024 and there is about 0.3 mm gap at die arc transition zone, as shown in Fig. 16.

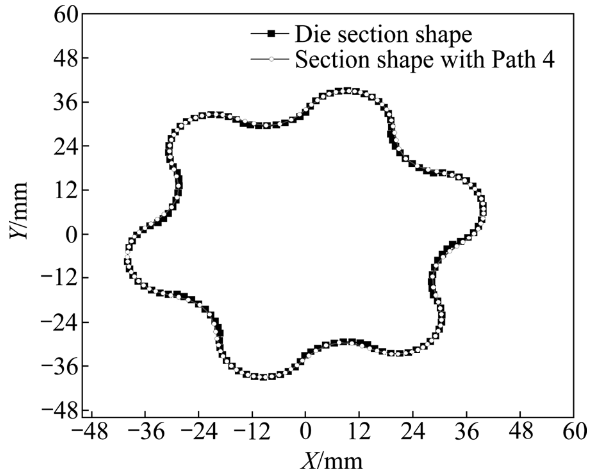

Fig. 16 Forming tube section contour compared with die contour with Path 4

Equidistance profile curve equation of stator die can be expressed as

$$\boldsymbol{R}_r^0(\theta, r^0)=\begin{cases}(n\mathrm{e}^{\mathrm{j}\theta}+\mathrm{e}^{-\mathrm{j}n\theta})+r^0\mathrm{e}^{\mathrm{j}\left[(-1)\frac{T\pi}{2}-\frac{n-1}{2}\theta\right]}(\text{arc top})\\ N\mathrm{e}^{\mathrm{j}\frac{2T\pi}{N}}+r^0\mathrm{e}^{\mathrm{j}\alpha'}(\text{arc bottom})\end{cases} \tag{12}$$

where $\boldsymbol{R}_r^0(\theta, r^0)$ is equidistance profile curve vector; N is stator lobe; n is rotor lobe; θ is guide round rotational angle; T is from 0 to n; r^0 is equidistance radius coefficient.

Then, equidistance radius coefficient of die arc transition place is given as

$$r^0=\frac{N\mathrm{e}^{\mathrm{j}\frac{2T\pi}{N}}-(n\mathrm{e}^{\mathrm{j}\theta}+\mathrm{e}^{-\mathrm{j}n\theta})}{\mathrm{e}^{\mathrm{j}\left[(-1)\frac{T\pi}{2}-\frac{n-1}{2}\theta\right]}-\mathrm{e}^{\mathrm{j}\alpha'}}$$

According to the analysis of metal stator screw lining, equidistance radius coefficient of die arc transition zone should be adjusted to r^0-l. Therefore, the linetype and surface treatment process of die arc transition place should be adjusted, so as to design high-performance and long-life PDM stator.

Figure 17 shows the result of central section contour of metal stator screw lining using adjusted die compared with initial die section contour. It can be found that the central section contour of metal stator screw lining overlaps with die section contour almost completely. Therefore, it is effective for getting qualified metal stator screw lining according to the analysis by adjusting die linetype.

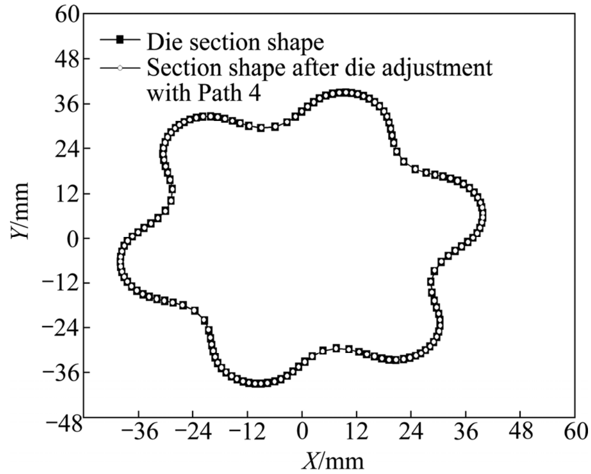

Fig. 17 Adjusted forming tube section contour compared with initial die contour

4 Conclusions

1) The external pressure THF can be used for processing high-accuracy large length-to-diameter ratio metal stator screw lining, thereby PDM stator will have better performance and long service life.

2) Three evaluation criteria for the forming quality of metal stator screw lining are fillet stick mold coefficient, thickness relative error and forming quality coefficient, and the smaller the three criteria are, the better the forming quality of metal stator screw lining is. By contrasting the results of all loading paths, it can be found that each indicator has a trend of increase with the loading rate reducing. Hence, reducing loading rate is helpful to decreasing the metal flow, in order to obtain the metal stator screw lining with more symmetrical stress distribution and higher limit strength.

3) External pressure THF used for metal stator screw lining demands little material compensation, and thickness reduction is not serious, about 4%, effectively avoiding thickness reduction of metal stator screw lining wall and ensuring the security in service.

4) According to stator die equidistance profile curve equation and fillet stick mold coefficient of die arc transition zone, equidistance radius coefficient of die arc transition place should be adjust to r^0-l, so as to design high-performance and long-life PDM stator.

References

[1] HU Jian-yi, WU Yin-ye, ZHANG Jing. Discussion on petroleum geology theory for high-elevation and ultra-deep formations [J]. Acta Petrolei Sinica, 2009, 30(2): 159−167. (in Chinese)

[2] ZHU Xiao-hua, SHI Chang-shuai, TONG Hua. Influence of static press, pressure difference and Poisson's ratio on deformation of stator lining [J]. Journal of Southwest Petroleum University, 2010, 32(6): 175−179. (in Chinese)

[3] ZHU Xiao-hua, JIA Yan-jie, TONG Hua. Critical weight on bit of

double-driven bottom hole assembly during vertical and fast drilling [J]. Journal of Central South University, 2012, 19(2): 572−577.

[4] LI Shu-hui, YANG Bing, ZHANG Wei-gang, LIN Zhong-qin. Loading path prediction for tube hydroforming process using a fuzzy control strategy [J]. Materials and Design, 2008, 29: 1110−1116.

[5] CRAPPS J, MARIN E B, HORSTEMEYER M F, YASSAR R, WANG P T. Internal state variable plasticity-damage modeling of the copper tee-shaped tube hydroforming process [J]. Journal of Materials Processing Technology, 2010, 210: 1726−1737.

[6] FIORENTINO A, CERETTI E, BRAGA D, MARZI R. Friction in asymmetric feeding tube hydroforming [J]. International Journal of Material Forming, 2010, 3(1): 275−278.

[7] LI Shu-hui, CHEN Xian-feng, KONG Qing-shuai, YU Zhong-qi, LIN Zhong-qin. Study on formability of tube hydroforming through elliptial die inserts [J]. Journal of Materials Processing Technology, 2012, 212: 1916−1924.

[8] PAUNOIU V, CIOCANIOCAN O, NICOARA D. Numerical study of tube hydroforming technology [J]. International Journal of Modern Manufacturing Technologies, 2010, 2(1): 67−72.

[9] LIU Xiao-jing, YAN Wei, DAI Hong-qing. Effect of hydraulic pressure loading paths on forming of automobile panels based on numerical simulation [J]. Journal of Central South University (Science and Technology), 2008, 39(3): 543−548. (in Chinese)

[10] PRASAD VARMA N S, NARASIMHAN R, LUO A A, SACHDEV A K. An analysis of localized necking in aluminium alloy tubes during hydroforming using a continuum damage model [J]. International Journal of Mechanical Sciences, 2007, 49: 200−209.

[11] SADAKATSU F. Recent development in tube hydroforming technology in Japan [J]. Journal of Plasticity Engineering, 2007, 14(5): 171−179.

[12] CHEBBAH M S, NACEUR H, GAKWAYA A. A fast algorithm for strain prediction in tube hydroforming based on one-step inverse approach [J]. Journal of Materials Processing Technology, 2011, 211: 1898−1906.

[13] SEYEDKASHI S M H, NAEINI H M, LIAGHAT G H, MASHADI M M, MIRZAALI M, SHOJAEE K, MOON Y H. The effect of tube dimension on optimized pressure and force loading paths in tube hydroforming process [J]. Journal of Mechanical Science and Technology, 2012, 26: 1817−1822.

[14] SIEGERTK. Research in hydroforming at the institute of metal forming technology of the University of Stuttgart [J]. Hydroforming of Tubes, Extrusions and Sheet Metals, 2003, 3: 245−258.

[15] DAI Jun-tao. Determining of contact friction and friction coefficient of metal pressure processing [J]. Forging & Stamping Technology, 1984(5): 48−54. (in Chinese)

[16] MARIELA L, BIBIANA M L. Numerical simulation of the lubricant performance in tube hydroforming [J]. Journal of Materials Processing Technology, 2008, 198(1/2/3): 372−380.

[17] SUN Yan-yan. Research on variable cross section tube hydroforming process [D]. Shenyang: Shenyang University, 2008. (in Chinese)

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