Design of Variable Diameter Slip

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Abstract. The fixed clamp should be installed inside the BOP stack for sectional blockage and tubing pulling job. When there is combined string in downhole, it causes inconvenience in replacing slips of different specifications because of pressure in BOP stack. To solve the problems mentioned above, variable diameter slip was invented. Different arc's central angle model of slip was set by ANSYS, the oil tube was divided by sweep while the slip was divided randomly. The analysis shows the arc's central angle for clamping ø73 oil tube is 106° and the clamping force meets operation needs and the design requirements.

Introduction

Snubbing service is performing well service without killing operation. Snubbing unit is key equipment to control annulus pressure and oil tube pressure while performing snubbing service. When starting well pulling job, casing hook can be used to pick up the oil tube directly since the gravity is greater than the pressure imposed on the oil tube. As the oil tube getting less and gravity getting smaller, the pressure will get close to the gravity of the oil tube, then the tubing clamp of snubbing units should be used, and by reciprocating action of hydro-cylinder, the pulling job can be finished. That is a way to guarantee operation safety[1-2].

Snubbing service has been widely performed in many countries[3-5]. The most common development scheme is single-well and single-layer, the downhole string composition of which is usually simple .Both the travelling clamp device and the fixed clamp device of snubbing unit are installed outside the BOP stack. In that case, by replacing corresponding slips the combined string can be pulled.

The disadvantages of such slips are listed as follows: 1. Slips should be replaced when the diameter of oil tube changes, which brings inconvenient operations. 2. The storage of different slips increases processing and storage cost.

As a comparison, the most widely used snubbing technology of China is single-well and multi-layer. The downhole strings are usually staged with complex structure. The fixed clamp should be installed inside the BOP stack for sectional blockage and tubing pulling job. Then slips cannot be changed because of pressure in BOP. Production Engineering Department of Shengli Oilfield Company invented variable diameter slip to solve the problem mentioned above.

Optimization Analysis

Design analysis. Currently, two kinds of oil tubing are widely used in China, which are ø73mm oil tube and ø89mm oil tube. ø89mm oil tube should be pulled out before running ø73mm oil tube in sealing condition for production after fracturing. During this process, two kinds of oil tube are used, which requires the tubing clamp catching two kinds of strings. Schematic drawing of slip used on snubbing unit is shown in figure 1. The primary designed arc's central angle for clamping ø73 oil tube is 91° while the other part of the arc are used to clamp ø89 oil tube, which determines the string cannot be surrounded entirely when clamped by slips and the string deformation is not axial symmetry. Constant deformation brings fatigue breakdown and shorten the lifespan of oil tube. Therefore, the arc angle of slip should be distributed appropriately to minimize string deformation and meet strength requirements.

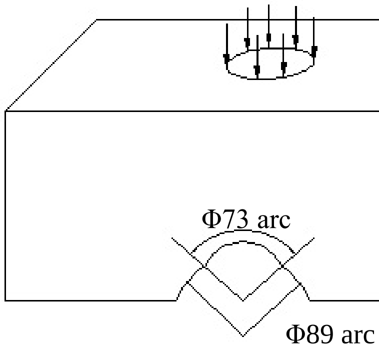

Fig. 1 Schematic drawing of slip on snubbing unit

Finite element model. The force on slip is shown in figure 2, which shows working status of slip in different working situations.

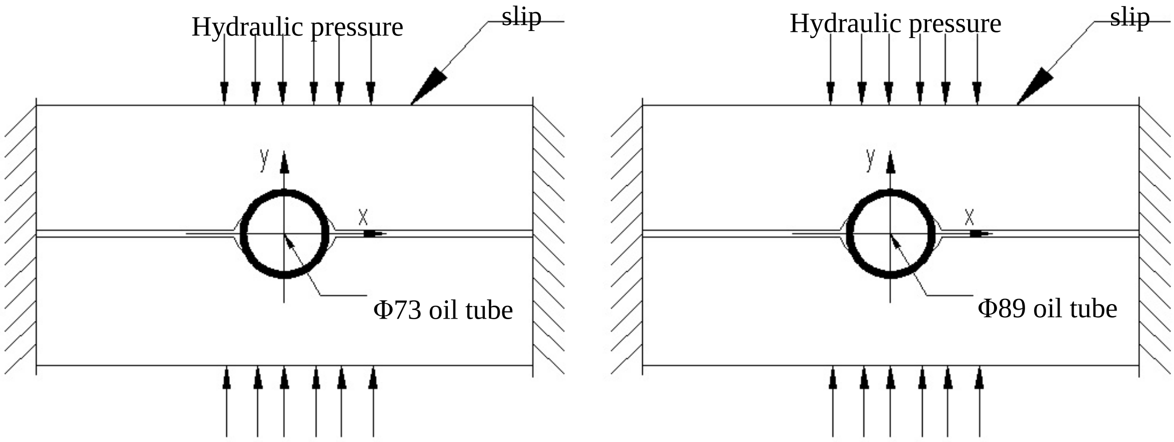

Fig. 2 Schematic drawing of force on slip

The hydraulic pressure exerted on the slip was 16MPa. Flank displacement along the direction of length and the direction of width were constrained. To simplify analysis, the length of oil tube was 3 times of the thickness of slip and the gravity of oil tube was omitted. There were two symmetry planes in the slip, so a quarter of the slip was taken to analyze. The central angle for clamping ø73mm oil tube was set from 91° to 109° and every angle was calculated in order to optimize the shape of the slip . Solid 185 unit was chosen because of its large deformation effect. And the shape of slip was simplified in the modeling procedure. Figure 3 shows the finite element model of the slip.

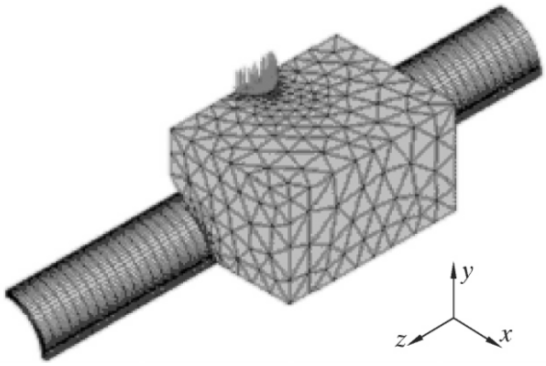

Fig. 3 Finite element model of slip

Because oil tube is more easier deformed than slip, so the oil tube was divided by sweep while the slip was divided randomly. The elastic modulus was 210Gpa, and the Poisson ratio was 0.3.

The displacement in z direction of the underside of slip was restricted, and displacement in x direction of the underside of slip was restricted symmetrically. The displacement of the front side in x direction was restricted. Oil tube was restricted symmetrically in axial direction. Calculating every 1° from 91° to 109° .

Displacement analysis. According to the result: for ø73 oil tube, the maximum displacement was the same with the displacement in x direction; for ø89 oil tube, the maximum displacement from 94° to 109° is equal to the displacement in y direction, the maximum displacement from 91° to 94° is slightly larger than the displacement in y direction.

Because the displacement in y direction was mainly reflected by the deformation of oil tube, besides, the maximum displacement of oil tube and the maximum displacement in y direction were similar, so the maximum displacement in y direction was reckoned as the maximum displacement of oil tube for simplified calculation. When analyzing the results, the displacement of ø73 oil tube was in x direction while the displacement ø89 oil tube was in y direction. Table 1 shows the maximum displacement u_{xmax} in x direction of ø73 oil tube and the maximum displacement u_{ymax} in y direction of ø89 oil tube of different angles, u_{max} represented the larger value of u_{ymax} and u_{xmax}.

$$u_{max}=\max \{ u_{xmax} , u_{ymax} \}. \quad (1)$$

Table 1 Maximum displacement of each angle

Angle [°]	u_{xmax} [10^{-5}m]	u_{ymax} [10^{-5}m]	u_{max} [10^{-5}m]
91	1.710	0.628	1.710
92	1.660	0.650	1.660
93	1.610	0.670	1.610
94	1.560	0.695	1.560
95	1.510	0.721	1.510
96	1.460	0.742	1.460
97	1.420	0.770	1.420
98	1.360	0.790	1.360
99	1.330	0.813	1.330
100	1.280	0.835	1.280
101	1.210	0.857	1.210
102	1.170	0.878	1.170
103	1.130	0.900	1.130
104	1.040	0.919	1.040
105	1.000	0.942	1.000
106	0.944	0.967	0.967
107	0.908	0.985	0.985
108	0.872	1.000	1.000
109	0.840	1.020	1.020

As the table shows, the maximum displacement of ø73 oil tube got smaller as the angle became larger, while the maximum displacement of ø89 oil tube became larger. When the angle was smaller than 106°, $u_{xmax} > u_{ymax}$; when the angle was no less than 106°, $u_{ymax} > u_{xmax}$. And when the angle was 106°, u_{max} got its minimum. Therefore, the arc's central angle for ø73 oil tube of the slip should be 106° to get minimum deformation.

Stress analysis. There are two kinds of working states for each design angle, one is ø73 oil tube, the other is ø89 oil tube. Each design angle of each working state corresponds to a maximum stress. Table 2 shows the maximum stress of each angle.

Table 2 Maximum stress of each angle

Angle [°]	σ_{73} [MPa]	σ_{73} [MPa]	σ_{73} [MPa]
91	51.3	35.5	51.3
92	50.7	36.2	50.7
93	50.0	36.2	50.0
94	49.2	36.1	49.2
95	48.7	36.9	48.7
96	48.8	37.0	48.8
97	48.3	37.7	48.3
98	47.3	37.8	47.3
99	46.5	38.3	46.5
100	45.9	38.7	45.9

101	45.1	39.1	45.1
102	44.6	39.7	44.6
103	44.1	40.0	44.1
104	42.6	40.2	42.6
105	41.8	40.6	41.8
106	40.9	41.1	41.1
107	40.2	41.6	41.6
108	39.7	41.9	41.9
109	39.3	42.2	42.2

As the table shows, maximum stress decreases as the design angle increases, when design angle reaches 106°, maximum stress starts to increase. When design angle is 106°, stress gets minimum.

Best allocation of angle. Considering displacement and stress, set the arc's central angle for ø73 oil tube 106°, this kind of structure can minimize stress and deformation of pipe string.

Laboratory Test and Field Test

Slips were trial produced according to the results of finite element analysis. Installed the slip on snubbing unit and set hydraulic pressure to 16MPa, clamped ø73 pipe string and ø89 pipe string with plug separately. The pressure of wellhead was 20MPa and no tube slide. Then relieved pressure, unclamped slip, no deformation of oil tube occurred, which showed that the design of slip is reasonable and slip plays a role of preventing slide.

A field application was conducted in 148-6 well to further test the performance of variable diameter slip. This well is double injection wells with high pressure, and the wellhead pressure after stopping injection is 14MPa, and the upper 2100m of string is ø89 oil tube, and lower 100m is ø73 oil tube. Variable diameter slip was used to prevent slide of string. No slide or deformation of ø73 string and ø89 string occurred during operation. The results showed that variable diameter slip meets operation needs and the design requirements.

Summary

(1) The best allocation angle of arc of slip was determined by finite element analysis, the arc's central angle for clamping ø73 oil tube is 106°.

(2) Field application showed that variable diameter slip can clamp combined strings and the clamping force meets operation needs and the design requirements.

Acknowledgement

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