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Research on Fracture Mechanism and Improvement Methods of Electric Submersible Pump Unit's Joint Screw

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Abstract: According to the problem of screw fracture of electric submersible pump unit in Shengtuo oilfield, the reasons for the screw fracture have been analyzed from three aspects: material, strength and pre-tightening force. The preliminary result shows that the imbalanced pre-tightening force of screw is the main reason of screw fracture. By means of Ansys software, the static and modal analyses for the electric submersible pump adapter have been conducted respectively under consistent and inconsistent pre-tightening forces. The numerical simulation results show that when the pre-tightening force is inconsistent, sharp increase in maximum stress of the screw accelerates the screw fracture, and the dynamic performance of screw in the vicinity of 3809.7Hz is the worst. Based on this, the special torque wrench is developed and then the pre-tightening quality of screw is improved greatly by using this wrench.

Keywords: Electric submersible pump, modal analysis, pre-tightening force, screw fracture, torque wrench.

1. INTRODUCTION

Electric submersible pump has the advantages of large displacement, high power, and simple energy transmission way and so on, and it has become the second largest equipment for artificial lift petroleum production at home and abroad [1, 2]. However, with its complex structure, poor working conditions and high failure rate, the falling accidents of the electric submersible pump caused by joint screw fracture occur occasionally, which results in greater economic loss.

Shengtuo Oilfield is the first discovered oilfield which was put to the development of oilfield in Bohai Bay basin, and it is also the first monoblock oilfield with ultra-high watercut period in China. As Shengtuo Oilfield entered the later period of high watercut stage, the conditions of wellbore and stratum have changed, and the scaling, corrosion, erosion, and casing leakage have also increased year by year. Among them, the submersible pump falling accidents caused by screw fracture, not only affect the normal oil production seriously, but also increase the operation difficulty. In the production process, any one of the component failure causes the oil well downtime repair. In most cases, due to work disorder of oil reservoir caused by shutdown of the pump unit, the oil well needs several days to recover its best state for oil production [3, 4]. Usually, the summation of the downhole operation cost and electric pump repair cost is about equal to the price of a set of new electric pump. Thus, falling accidents caused by screw fracture would cost a lot for repair.

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2. MATERIALS AND METHODS

2.1. The Fracture Status of Electric Submersible Pump Unit's Screw in Shengtuo Oilfield

The statistical results of electric pump falling accidents from 2005 year to 2010 year are shown in Table **1**. It can be seen from Table **1** that the falling accidents caused by screw fracture account for as high as 45% between 2005 year and 2007 year; the total falling accidents are 330 times more from the year 2005 to 2010; falling accidents caused by screw fracture are 117 times more, accounting for 35.5%. As shown in Fig. (**1**), the location of screw fracture is flanged end face, and the feature of screw fracture is the transverse shear fracture without longitudinal tension.

2.2. The Reason Analysis for Screw Fracture

From the view of the material of screw, electric pump flanges are connected by high strength M10×1.25 screws made of 35CrMoA. The test results of broken screws show that all element contents of material of screw reached the set standard, and the material quality of screw met the requirements of the engineering drawing. Thus, the possibility could be ruled out that the material quality of screw leads to the falling accidents of the unit.

From the view of the strength of screw, M10×1.25 screw is high strength screw, and its minimum tensile load is 8 tons. With 8 screws, the flange connection could bear loads of 64 tons, and the actual weight of the unit is only 1.8 tons, so the tensile strength of the flange connection is enough, and the screw cannot be broken because of insufficient strength.

From the view of the pre-tightening force of screw, when the screw is tightened by ordinary wrench, it is uneasy to control the torque value of every screw. The uncontrollable pre-tightening torgue would lead to an inconsistent

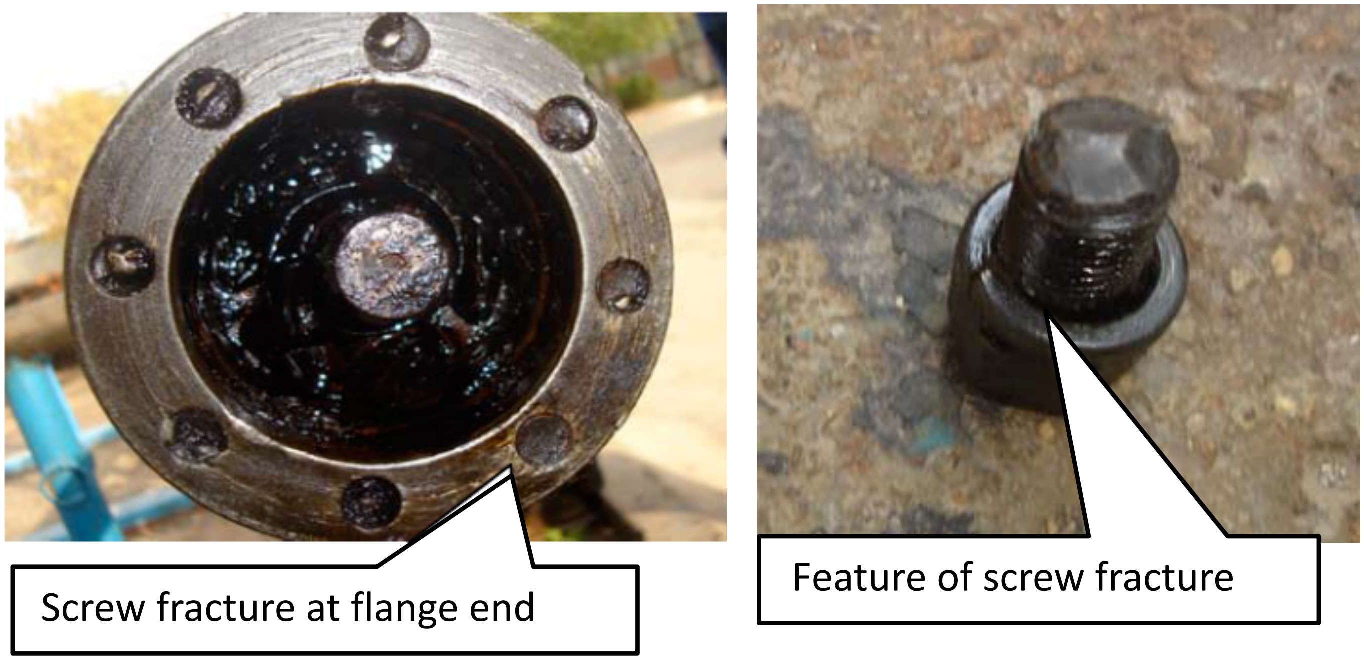


Fig. (1). Feature of screw fracture.

pre-tightening force of screw, and then the inconsistent pre-tightening force would result in excessive stress in some or other screws. Under the condition of fatigue vibration, some screws would get loose, and then the screws would be broken because of the radial force [5, 6]. Thus, it is the possible main reason of screw fracture that the pre-tightening force of screw is out of control.

Table 1. The statistical results of electric pump falling accidents from 2005 to 2010.

	Year#						
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**Total**
Falling accidents	90	64	58	47	38	33	330
Screw fracture	40	29	26	11	6	5	117
Rate (%)	44.4	45.3	44.8	23.4	15.8	15.2	35.5

2.3. Finite Element Analysis of Screw Fracture

2.3.1. Three Dimension Mechanics Model of Joint Screw

The joint screws of electric submersible pump unit are mainly used for connecting components. When the unit works, the model of joint screw is mainly affected by four forces: axial pre-tightening force Q caused by torque resulted from the initial pre-tightening; reactive torque T of motor shaft through connectors; pulling force F caused by weight of the parts below pump head; its own weight G.

The torque T is equivalent from pump seat to pump head, and the pump head is affected by the torque T, so that the top surface of pump seat needs to be fixed. Based on above analysis, the three dimension mechanics model of connection screw is established as shown in Fig. (**2**).

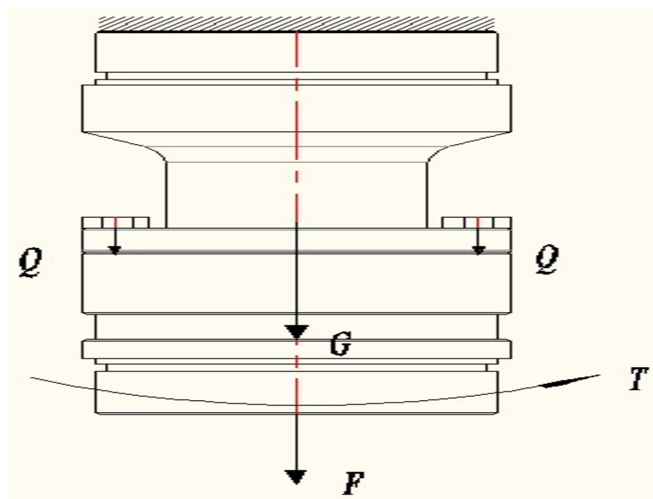


Fig. (2). The three dimension mechanics model of joint screw.

2.3.2. Static Analysis of Screw Under Consistent Pre-tightening Force

The tetrahedral element Solid187 is adopted, and the automatic mesh generation method is applied to get the model mesh. The element has 10 nodes, each node having 3 degrees of freedom. The element is suitable for complex and irregular models in CAD/CAM [7-9]. The whole model is divided into 783218 units and 1135983 nodes as shown in Fig. (**3**).

A local coordinate system is added in each screw, and the pre-tightening force 18kN is applied on the cylindrical surface of each screw [10, 11]. A fixed constraint is applied on the top surface of the pump seat, and then gravity load and tensile load are applied as shown in Fig. (**4**).

The stress distributions of screws are shown in Fig. (**5**). It is shown that the stress is mainly concentrated in the flanged

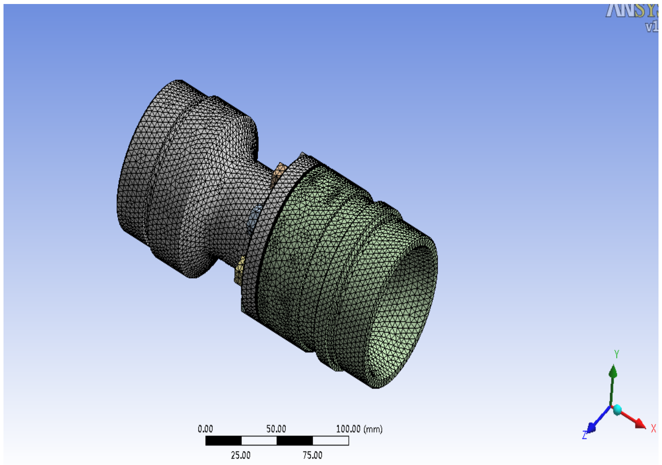


Fig. (3). The finite element model.

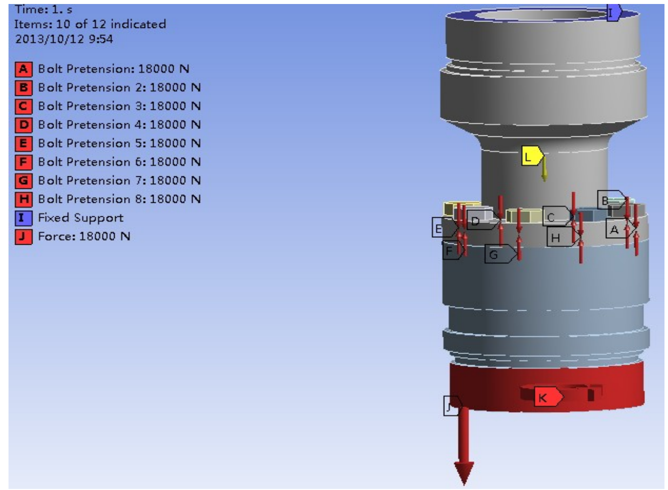


Fig. (4). Boundary conditions and loads.

connection, which explains the position of screw fracture. The maximum stress is 489.61MPa, and the yield limit of the material of screw is 835MPa, so the margin of safety is equal or greater than 1.71. It is clearly shown that the screw is not easy to fail, when the pre-tightening forces of 8 screws are consistent.

2.3.3. Static Analysis of Screw Under Inconsistent Pre-tightening Force

Based on this, the same model is imported and meshed, and the boundary same conditions are set as shown in Fig. (**4**), but the pre-tightening forces of 8 screws are respectively set for 10kN, 14kN, 16kN, 18kN, 20kN, 22kN, 24kN and 26kN. The stress distributions of screws are shown in Fig. (**6**). It is shown that the maximum stress occurring at the flanged connection, is about 692.79MPa. Compared to the maximum stress under consistent pre-tightening force, the maximum stress under inconsistent pre-tightening force increases by 41.5%, and nearly reaches the yield limit of the material.

Although screws can work under the condition, the speed of screw fracture is accelerated working in the close range of the yield limit and the fatigue load.

2.3.4. Modal Analysis of Screw with Pre-tightening Force

The pre-tightening force 18kN is applied on each screw, a fixed constraint is applied on the top surface of pump seat, and the order of frequency analysis is 6. Then the model is solved, and the initial six order natural frequencies and the descriptions of vibration type are shown in Table **2**, and the vibration mode diagrams are shown in Fig. (**7**).

As shown in Fig. (**7**) and Table **2**, it can be seen that the screw vibration is weak in the first and second modes, the screw is in strong vibration in the third and sixth modes, and the screw vibration is strongest in the fourth and fifth modes. The screw has the worst dynamic performance in the vicinity of 3809.7 Hz. The vibration of the connection position makes the pre-tightening force of screw decline or

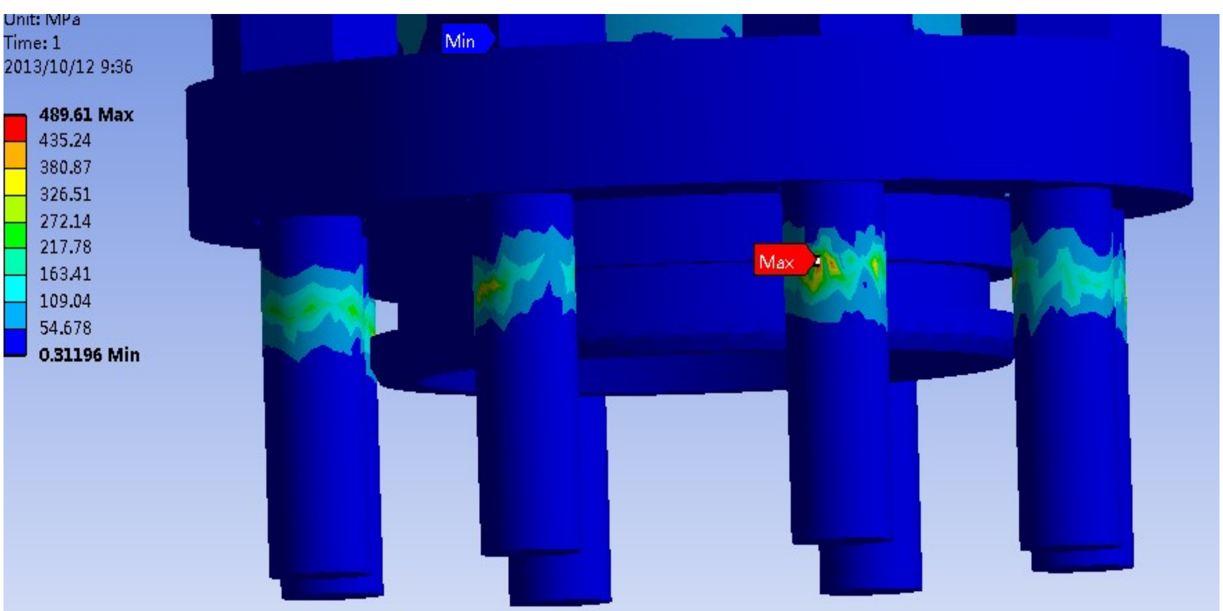


Fig. (5). The stress pattern of screw under consistent pre-tightening force.

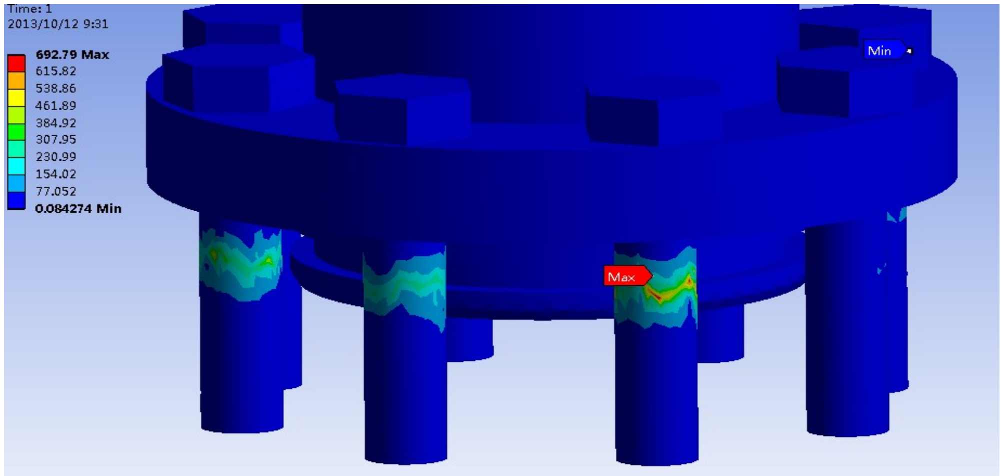
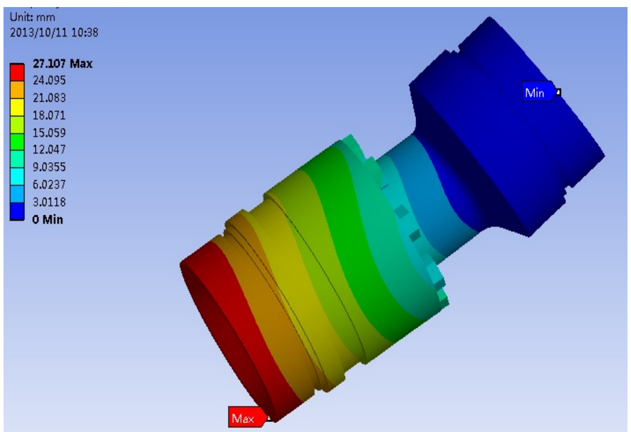
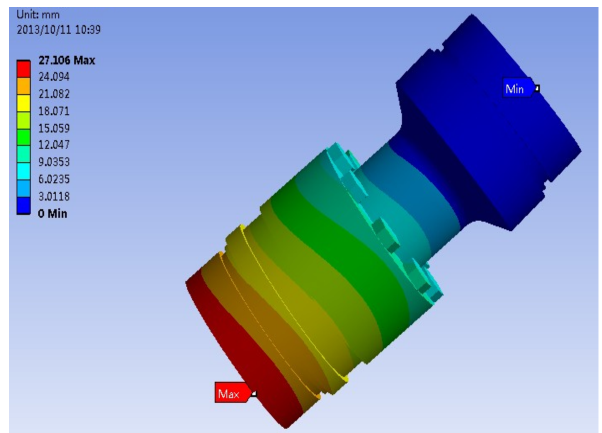


Fig. (6). The stress pattern of screw under inconsistent pretightening force.



(a)



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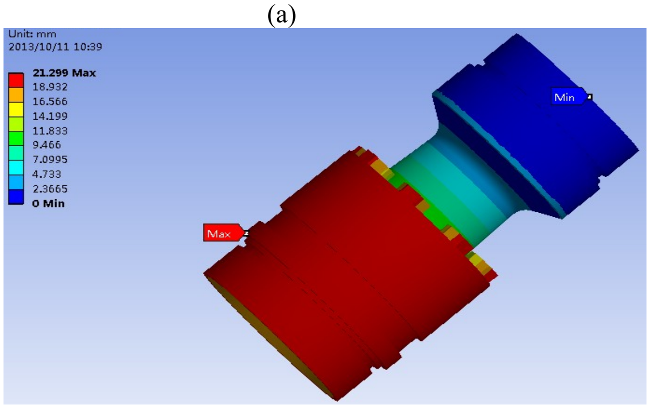

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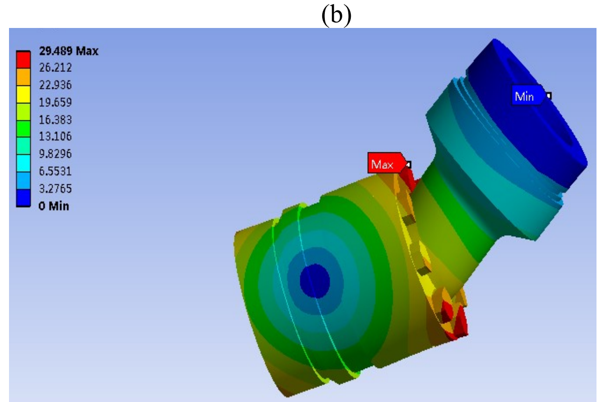

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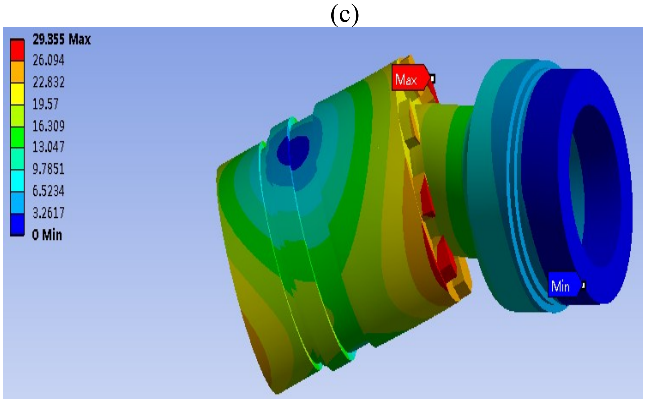

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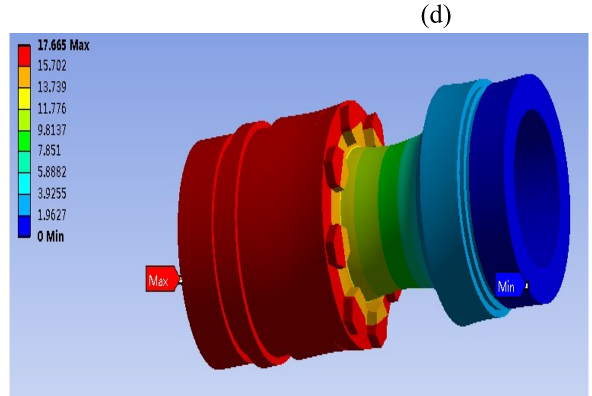

(f)

Fig. (7). The initial sixth order vibration mode diagrams of screw with pretightening force.

Table 2. The initial sixth order natural frequency and vibration type of connection screw.

Order	Natural Frequency/Hz	Vibration Type (Coordinate Axis Refer to Fig. 3)
1	978.68	The bottom of pump head vibrates drastically along the Y axis.
2	978.74	The bottom of pump head vibrates drastically along the Z axis.
3	2112.3	The bottom of pump seat, pump head, and screws vibrate along the radial direction with expanding trend
4	3809.7	Screws vibrate drastically along the Y axis.
5	3810.2	Screws vibrate drastically along the Z axis.
6	4110.4	The bottom of pump seat, pump head, and screws vibrate along the axial with tensile trend.

loose, the upper and lower connecting pieces are subjected to shear abrasion, and the fracture failure is prone to occur under the action of repeated dynamic torque.

3. RESULTS AND DISCUSSION

Based on this, a special torque wrench is developed to solve the problem that the pre-tightening force is inconsistent when electric submersible pump unit works. The special torque wrench is shown in Fig. (**8**). Torque value can be set accurately with graduated scale on the special torque wrench. When the torque reaches the set value, the wrench sends out clear alarm sound, and a slight shock could be felt on the handle. Therefore, the pre-tightening force of the screw could be determined accurately by the special torque wrench, and the pre-tightening quality of screw is improved greatly.

Fig. (8). The special torque wrench.

The field experiment results show that the application of special torque wrench improves the pre-tightening quality of every screw greatly, and eliminates screw fracture caused by inconsistent or excessive pre-tightening force. Due to the application of special torque wrench, the accident caused by screw fracture declined sharply, as screw fracture rate fell to zero in the beginning of 2011.

CONCLUSION

(1) When the electric submersible pump is assembled, inconsistent pre-tightening force of screw is the main cause of screw fracture.

(2) The initial six modal analyses show that the screw has the worst dynamic performance in the vicinity of 3809.7Hz, and then the screw is prone to failing.

(3) Special torque wrench is developed and can determine the pre-tightening force of screw accurately. Its application improves the pre-tightening quality greatly, and eliminates the screw fracture phenomenon caused by the inconsistent or excessive pre-tightening force.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

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