Design and laboratory test of variable diameter casing centralizer

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Abstract. Casing centering tools widely used at home and abroad include conventional rigid casing centralizers and conventional elastic casing centralizers. These two kinds of casing centralizers have the same defect in the use of performance or scope of application, which is the large friction resistance in the process of casing pipe. Therefore, considering the existing problem of conventional casing centralizers and the use requirements of casing centralizers in cementing, a variable diameter centralizer which can better solve the problem of conventional casing centralizer and meet the requirements of service is designed. In addition, the key parts of the variable diameter centralizer are optimized by using finite element analysis, which achieve better economic performance on the basis of meeting the requirements.

1. Introduction
For horizontal Wells and extended Wells, extreme casing pipes eccentricity caused by own gravity has been the main reason that affects whether the casing can go down to the borehole smoothly or not. At last, it will affect seriously the cementing quality[1~4]. On the current situation, the effective solution is installing casing centralizer in the proper position to improve the cementing quality.

At present, there are mainly two types of casing centralizers at home and abroad: one is the rigid centralizer, and the rigidity of rigid centralizer is larger and has better diversion function, which can improve the displacement efficiency and improve the cementing quality, but it can hardly change the diameter, and it is difficult to make the rigid centralizer down to the specified position in the processing of casing pipe. The other is the elastic centralizer, which can be used in the well with variable diameter, but its reset ability is poor, and it is difficult to meet the requirements in many cases[5~7].

The variable diameter centralizer designed in this paper has the advantages of strong reset ability, easy down well and strong adaptability, which can make up the limitation of the conventional casing centralizer in the scope of application, and it is of great significance to keep the casing in the middle of borehole and improve the quality of the cementing.

2. Structure design and calculation main points of variable diameter casing centralizer

2.1 Working principle and overall design parameters of variable diameter centralizer
The variable diameter casing centralizer is based on the conventional elastic casing centralizer, which adds the activation locking mechanism, as shown in Fig. 1. When the casing string with variable diameter centralizers down to the specified position in the process of casing pipe, the steel band that is bound to the centralizer bows is released by using the hydraulic pump to pressurize the activation lock, activate the lock piston and cut the shear pin. So that the bows can be pulled open to achieve the purpose of centralizing the casing string.
The diameter of casing string which centralizing is 140mm, and the minimum reset force is 2758N when the deviation ratio is 67%.

2.2 Structure of activation lock, steel band and shear pin

The activation lock is the most important structure in the variable diameter centralizer, which is the key component of the variable diameter centralizer to realize the variable diameter.

The main function of the activation lock is to make the centralizer locked before the centralizer runs to the designed setting depth (the centralizer is bound to the casing), and does not affect the casing sting running to the borehole. When the casing string runs smoothly down to the designed setting position, the activation lock is operated by injecting pressure outside the well (Activate the lock piston to move downward under pressure, cut off the shear pin and release the locked steel band, then enable the centralizer to open smoothly, enter the working state and complete the centralizer work of casing string). The main parts of the activation lock are cylinder block, piston, upper cover, lower cover, shear pin and connecting screw. The whole structure is as shown in Fig. 2.

As shown in Fig. 3, the steel band is bound to the centralizer bows through the steel band buckle, and one end of the steel band is fixed on the cylinder block of the centralizer activating lock, and the other end is locked by the activating lock piston (also released by the activated lock piston). When the pressure makes the activation lock work, the lock piston is activated and the shear pin is cut down. The steel band is unlocked. The centralizer bow can pull the steel band open, and then achieve the purpose of centralizing the casing string.
Figure 3. Structure chart of steel band

The shear strength checking equation of steel band is as follows

$$\tau_{\text{max}} = \frac{2F_s}{A} \leq \tau$$  \hspace{1cm} (1)

Where, \(\tau_{\text{max}}\) is the maximum shear stress of the steel band (MPa), \(F_s\) is shear force acts on the steel band (N), \(A\) is section area of steel band (mm²), \(\tau\) is the allowable shear stress of steel band (MPa).

The reset force of casing centralizer is 2758 N, and the shear force of the steel band is provided by the reset force of the centralizer, so \(F_s=2758\) N. The expansion length of the steel band \(L\) is 486mm and the thickness of the steel band \(\delta\) is 0.5mm.

The section area of steel band \(A\) is as follows

$$A = L \cdot \delta$$  \hspace{1cm} (2)

The formula for calculating the allowable shear stress of steel \(\tau\) is as follows

$$\tau = n_s \cdot \sigma_b$$  \hspace{1cm} (3)

Where, \(n_s\) is safety factor of steel band (Because material of the steel band is 0Cr18Ni9, its safety factor \(n_s\) is 0.6), \(\sigma_b\) is tensile strength of steel band (\(\sigma_b\) is 520MPa), so \(\tau\) is 312 MPa.

According to the formula (1) and formula (3), \(\tau_{\text{max}}\) is 22.7 MPa. Because \(\tau_{\text{max}}\) is less than \(\tau\), the strength of the steel band meets the requirements.

The shear pin is one of the key parts in the activation lock, which is the key to release the steel band. The shear pin is inserted into the cylinder block, under the piston and blocking the piston. When the pressure of the piston is activated more than the cutting pressure of the shear pin, the shear pin can be cut down, the steel band which locked by the piston is released, the centralizer achieves the purpose of centralizing the casing string. Therefore, the material and structure of the shear pin have a decisive influence on the function of the activation lock. Its specific size is as shown in Fig. 4.

Figure 4. Structure chart of shear pin

2.3 Finite element analysis of the centralizer

The cylinder block is the main part of the activation lock. It is the carrier to activate the lock and other important parts, and it is also an important working part. Under the action of external pressure, it is necessary to ensure that its deformation will not affect its performance and the performance of other parts installed on it. By means of the finite element analysis, the force and deformation of the current...
structural form in the corresponding working environment (temperature and pressure etc.) can be obtained, and the unreasonable or not economical structural form is optimized.

Free meshing of cylinder block was performed using the Mesh option provided by ANSYS Workbench. As shown in Fig. 5, the mesh of the simplified model is divided into 2,961 nodes.

![Gridding division of simplified model](image)

Figure 5. Gridding division of simplified model

The load of the cylinder block is set according to the actual environmental pressure and external pressure, and the constraint conditions are analyzed and simplified according to the assembly relationship between the cylinder block and other contact parts. Pressure and constraints of cylinder is as shown in Fig. 6.

The result of finite element analysis is as shown in Fig. 7 and Fig. 8. According to the analysis results, under the design environment, the maximum deformation of the cylinder block is about 0.0024 mm, which does not affect the assembly and performance of the cylinder block. The material of cylinder block is 35CrMo, so safety factor is 2 and yield strength is 985 MPa. The maximum equivalent stress is 101.83 MPa, The product of its maximum equivalent stress and its safety factor is 203.66 MPa, which is far less than its yield stress, so the cylinder block will not have plastic deformation, which meets the requirements of use and strength.

The upper cover of the activated lock is thinner and has a steel band passing through it, so under the action of external pressure, it is necessary to ensure that its deformation amount is within the allowable range and cannot hinder the movement of the inner steel band. In addition, its pressure performance in the corresponding environment needs to be guaranteed.

The result of finite element analysis is as shown in Fig. 9 and Fig. 10.

![The force and constraint of the cylinder block](image)

Figure 6. The force and constraint of the cylinder block

![Total deformation of the cylinder block](image)

Figure 7. Total deformation of the cylinder block

![Equivalent stress of the cylinder block](image)

Figure 8. Equivalent stress of the cylinder block
According to the analysis results, the maximum deformation of the upper cover is 0.66332mm, and the maximum allowable deformation of the upper cover is 0.5mm according to the design requirements. The deformation of the upper cover exceeds the maximum allowable range and does not meet the requirements. The maximum equivalent stress of the upper cover is 3036.4Mpa, the product of its maximum equivalent stress and its safety factor is 6072.8 MPa. And the maximum yield strength of the upper cover is 985MPa, which is far less than the product of its maximum equivalent stress and the product of the safety factor, so the permanent plasticity will occur in the upper cover. The design of the upper cover does not meet its performance requirements and strength requirements, so it needs to be optimized.

Under the premise of meeting the requirements of installation, the depth of trough of belt is appropriately reduced and the thickness of the upper cover is increased, the strength of the upper cover is increased, and the pressure capacity will be greatly improved. On the basis of the original structure, the depth of trough of belt is reduced from original 2 mm to 1.5 mm (that is, the thickness is increased from original 0.5mm to 1mm).

3. Laboratory test of variable diameter casing centralizer
The variable diameter casing centralizer is as shown in Fig. 11 and Fig. 12.

The length of variable diameter casing centralizer is 515 mm, the maximum diameter is 210 mm before tensioned, the maximum diameter is 190mm after tensioned, the weight is 6.8 kg, and the middle part of the centralizer has activation lock and steel band. When the centralizer reaches the designated position in the underground, the pin is cut off, the piston moves down, the steel band is ejected from the activation lock, and the centralizer achieves the purpose of centralizing the casing.
string. The pin shearing strength is 21MPa, and the opening of the activation lock should be tested under the shear of the pin.

As shown in Fig. 13, the centralizer is placed in the sealing device, and pressed with the pressure pump. When the pressure reaches 17 MPa and keeps 15min, the pins are not cut off. When the pressure reaches to 22 MPa, the four pins in the centralizer are cut off, the piston descends, and the steel band is opened immediately.

Figure 13. Laboratory test of variable diameter casing centralizer

4. Conclusions

According to field requirements and overall parameters, a variable diameter centralizer is designed in this paper. The design and optimization of key parts parameters are accomplished by theoretical calculation and finite element analysis. The pressure value of the shear pin is verified by design of laboratory experiments, and the test results are consistent with the design goal. The experiment is ready for the subsequent construction of the field test.

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