RELIABILITY DESIGN OF HYDRAULIC DRIVE FOR MECHANICAL ARM OF LOGGING INSTRUMENT

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ABSTRACT: In order to solve the problems of the existing domestic logging driven equipment in deep well, under high temperature and high pressure resistant ability and single function, taking the reliability design proposed in this paper as a guide, the reliability prediction and analysis for the hydraulic drive system are carried out. The analysis experiment can solve the problems of the driven equipment, such as poor heat-resisting ability, poor pressure-resisting ability and single function. The weak link of the system is obtained, and the design emphasis is clarified. Under the guidance of this system, the structure design of the key components such as manifold block and hydraulic cylinder in the hydraulic system is carried out. The results show that under the environment of high temperature and pressure, the sealing ring in the hydraulic system of pressure balance can be selected by conventional design method.

Key words: Reliability, hydraulic drive, hydraulic cylinder

1. INTRODUCTION

Logging is an important method to identify and evaluate oil and gas reservoirs and solve a series of geological problems in the process of oil exploration. It can directly provide the information and data to petroleum geology and engineering technicians. The stability of logging instrument used in logging process is the precondition to ensure the correctness and validity of logging information and data. The measurement of formation parameters needs to attach the borehole wall by the logging instrument. The driven system of mechanical arm is the key element to decide the performance stability of this kind of logging instrument, which is also an important and difficult problem of logging depth [1].

Therefore, it is very important to develop a reliable logging instrument driven system in deep well work.

The work of logging driven instrument is not reliable under the condition of high temperature and high pressure in 8000m underground mine. The reliability analysis and design of hydraulic drive in the harsh environment is analysed, and the specific structure of the hydraulic system are designed.

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2. RELIABILITY PREDICTION AND ANALYSIS OF HYDRAULIC DRIVE SYSTEM

2.1 Reliability prediction

A reliability index must be specified clearly before the reliability prediction is carried out. The reliability of hydraulic drive system of logging instrument means that it can ensure that the mechanical driven arm can be pushed on the borehole wall to carry out the measurement task in the logging process under 8000m deep well. When the hydraulic cylinder is pressed back because of leakage, it cannot be reliably pushed, and the motor should be opened several times. This provides a large enough thrust for the mechanical arm. At this point, it is necessary to introduce the judgment link of displacement sensor [2]. This link will not only increase the loss of the high temperature motor and piston pump, but also increase the link of the reliability model and reduce the reliability of the whole system. The reliability that is now estimated is a reliability model based on a power-on. Logging instrument is a special testing equipment. After a logging, some maintenance will be done, and if a logging fails, the damage in the logging device will be completely scrapped. The prediction and analysis of the dynamic reliability is not applicable to the hydraulic system of the logging instrument, and the system is considered to be a unrepairable system [3]. The logging time is 8 hours, and the machine is repaired every three months. The total working time is 300h. The work time of logging instrument is: MTTF = 300h.

Because of the strict size limitation of logging tools, redundant design should not be adopted. The basic reliability model of the system is consistent with the mission reliability model, and all the logic relations of the components are series reliability model. Therefore, the following assumptions are adopted to simplify the reliability block diagram [4]:

There are only two states in the system or cell: normal and fault;

A box represents the function of a subsystem or unit, and the normal or unnormal operation of each unit is independent of each other;

The system or unit that is not included in the reliability diagram of the system is considered to be safe and reliable

The reliability model established in figure 1 is a series model. The numbers in the block diagram represent the failure rate of the components, which are obtained by the component manufacturer.

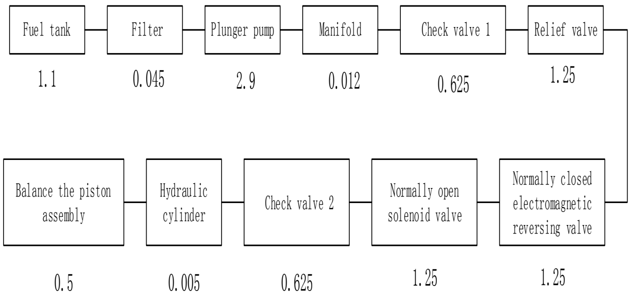

Fig 1 Toolbox hydraulic drive system reliability diagram

According to the reliability data of hydraulic system components, the failure rate of the system is calculated. The formula is as follows:

$$\sum_{i=1}^{N}\lambda_i t_i = \pi_E\pi_D\pi_C\sum_{j=1}^{2}\lambda_{0sj}t_{sj} \quad (1)$$

In the formula, π_E——environmental factor, π_E=100;

π_D——Derating factor, π_D=0.8;

π_C——Correction factors related to filtration accuracy, π_C=0.925;

λ_{0sj}——Total basic failure rate of circuit under J condition, j=1,2;

t_{sj}——The working time of the whole hydraulic system is 600h.

Since the reliability model of all hydraulic parts in the hydraulic system is the same during the process of pushing and recovering, the duty factor of the working time is not considered. The failure rate of the system is 0.21, and the average failure time of the system is: MTTF=1512h. The average failure-free time of the system fully meets the requirements

2.2 Influence and harmfulness analysis of hydraulic system failure mode

The function of the hydraulic drive system of the logging instrument is that the motor drives the plunger pump to suck the hydraulic oil in the integral fuel tank. Through the control of the hydraulic components in the system, the system will output amount of hydraulic oil with pressure and flow to the hydraulic cylinder. Finally, it will drive the manipulator to do the measurement work. The system function and structure diagram are shown in figure 2.

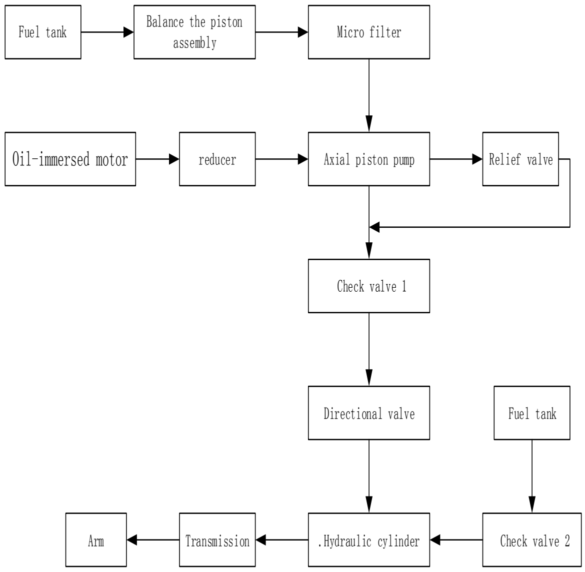

Fig. 2 System function and structure diagram

The hazard matrix can be used to compare the harm degree of various failure modes, so as to determine the priority of the improved design. Since there is no specific experimental data for new product development, the fuzzy grade standard can be used to represent the probability of failure mode [5]. In the hazard matrix, the harshness level is expressed by abscissa, and the failure mode probability level is expressed by ordinate. The coordinate location of each fault mode is carried out, and the position of the coordinate point at the intersection of the perpendicular lines of the diagonal line indicates the damage degree of the fault mode to the system. In figure 3, the order of hazard is a>b>c>d.

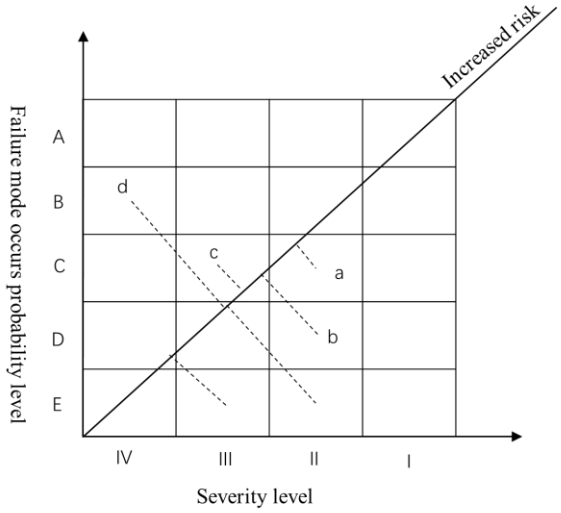

Fig. 3 Logging hydraulic drive system hazard matrix diagram

Through hazard matrix analysis, several kinds of failure modes with the highest degree of damage are as follows:

Filter failure (strainer wear). The reason is that the pressure difference is too large to cause the rupture after the blockage. The improvement measure is to Increase the capacity of the filter;

Overflow valve (loss the voltage regulating capacity and appear leakage). The reason is spring fatigue or steel ball wear. Improvement measure: regular replacement, oil pollution prevention, derating selection overflow valve [6];

Solenoid directional valve (without reversing). The reason is the push rod is jammed because of the particle entry or spring fracture. Improvement measure: oil pollution prevention, regular replacement;

Hydraulic cylinder (slowly retracted under load). It is caused by unqualified dynamic seal, static seal or oil pollution. The improvement measure is to select the sealing ring, piston rod, cylinder material and processing technology reasonably;

Balance piston assembly (leakage). It is caused by unqualified dynamic seal, static seal or oil pollution. The improvement measure is to design cylinder reasonably and select more suitable sealing ring to prevent oil pollution [7].

According to criticality analysis, it can be seen that the key components of the system are filters, overflow valves, solenoid directional valve hydraulic cylinder, and balanced piston assemblies. The following design suggestions are put forward.

The main design difficulty of the hydraulic system of the logging instrument is the harsh environment. Therefore, environmental design in reliability design must be carried out for this particular environment.

In the critical failure mode of strict control system pollution, 6 items are caused by pollutants. Contamination can rapidly accelerate the loss of internal precision hydraulic components. In the design process, we should increase the capacity of the filter. In the design of the structure, the key components of the hydraulic system should be kept away from the pollution source.

Derating design is adopted and the technical index of components is improved. The main factors affecting the system reliability are the hydraulic cylinder, solenoid valve, balance piston assembly and the fatigue life of components. In the selection and design of components, the technical indexes of purchased parts should be improved appropriately and the design elements should be studied and improved

3. STRUCTURE DESIGN OF HYDRAULIC DRIVE SYSTEM

3.1 Design of integrated block component

In order to save space, each hydraulic component is installed, and a special hydraulic manifold block is designed. The plunger pump assembly (including motor, reducer and plunger pump, etc.), filter, check valve, solenoid valve and overflow valve should be installed on the manifold block.

The installation of LEE hydraulic valve is very special compared with conventional valve. The sealing of the check valve and the overflow valve is produced by the expansion of the controlled valve body. As shown in figure 4, multiple independent seals and retaining rings enable the locking end of the LEE valve to lock and seal [8].

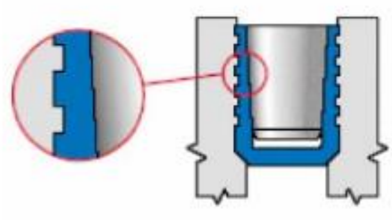

Fig. 4 Body expansion seal

The influence of the material and size of the valve periphery (the shell) on the valve holding capacity is critical. The influence of temperature, deformation and internal pressure on the expansion of integrated block must be considered. Therefore, in the selection and installation, these factors must be taken into account. According to the requirements of the sample, the wall thickness of the valve body is determined. Supposing that the diameter of the valve body is D, the minimum wall thickness is 0.65D when the wall thickness is uniform. When the wall thickness is non-uniform, the minimum wall thickness is 1.1D

The sealing of solenoid valve adopts MultiSeal technology, and the polyamide imide sealing material with controlled expansion amount is used. MultiSeal greatly simplifies the layout of through holes and greatly saves space. In addition, its use also reduces processing costs and improves reliability

3.2 Design of hydraulic cylinder

If the hydraulic cylinder and the integrated block are designed into a whole structure, then the internal links are reduced. The reduction of block diagram in reliability design can improve the reliability to a certain extent. However, considering that the hydraulic cylinder and the integrated block are designed as a whole, the machining is difficult and the manufacturing cost is high. Therefore, the integrated block and the hydraulic cylinder are separated and designed, and the O-ring end face sealing is adopted between them. An oil filled check valve is integrated inside the hydraulic cylinder, which is composed of cylinder, piston, piston rod, end cover and check valve.

Structural reliability of hydraulic cylinder

Structural reliability analysis of cylinder of hydraulic cylinder is calculated by stress strength interference model. The conventional design method only uses the safety factor method to estimate whether the structural components meet the performance requirements. It does not take into account the random variation of the same material itself and the random variation of the external force. The stress intensity interference model is a model for static strength reliability analysis. It is assumed that the strength of the material is δ, and the external stress is s. Both of them are random variable. The density functions are g (δ) and f (s), respectively. There is an intersection interference zone between the two density function curves, that is, the shadow area in figure 5. The larger the interference zone is, the greater the failure probability of components is.

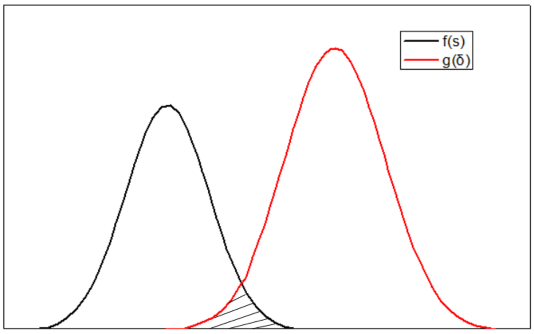

Fig.5 Stress-strength interference model

Under this condition, the expression of part reliability R is:

$$R = P(\delta > s) = P(\delta - s > 0) \qquad (2)$$

The formula can be obtained after the calculation:

$$R = 1 - \Phi(z) \qquad (3)$$

In the formula $z = \dfrac{y - \mu_y}{\sigma_y}$, the lower limit of integration is $z = \dfrac{0 - \mu_y}{\sigma_y} = \dfrac{\mu_\delta - \mu_s}{\sqrt{\sigma_\delta{}^2 + \sigma_s{}^2}}$.

According to the relevant literature, the strength distribution of the material is S~N (394.5, 20.3), and the probability distribution of the cylinder stress is X~N (309.51,0.618) [9]. The reliability of cylinder structure of hydraulic cylinder is as follows:

$$z = \frac{\mu_\delta - \mu_s}{\sqrt{\sigma_\delta{}^2 + \sigma_s{}^2}} = -\frac{309.51 - 394.5}{\sqrt{20.3^2 + 0.618^2}} = 4.18 \qquad (4)$$

The structural reliability is R=1-Φ(4.18)=1.

Dynamic seal analysis of hydraulic cylinder

The oil temperature of the hydraulic oil in the sealing ring will cause the rubber to expand. In addition to the change of expansion coefficient, the elastic mould of rubber should also change. Therefore, the choice of the material of the sealing ring must be selected according to the analysis of the actual working condition. When the maximum temperature reaches 175℃, fluorine rubber or silicone rubber must be chosen as the sealing ring material [10]. According to the use environment, fluorine rubber is suitable for petrochemical industry, oil resistance and aging resistance. It is the best choice for logging equipment to use sealing ring [9].

The coefficient of temperature expansion of fluorine rubber is $K=145\times10^{-6}/℃$. The maximum diameter of dynamic sealing ring is D_1=30mm, and the temperature deformation is 0.00435mm. The maximum diameter of the static sealing ring is D_2=80mm, and the temperature deformation is 0.0116mm. The basic thickness of the sealing ring is about 3mm. Therefore, the expansion induced variable is less than 1% of the compression of the seal ring, which is negligible.

At 8000 meters, the sealing ring is in no working condition, but it is also subject to the uniform pressure of 140MPa. Therefore, it is necessary to calculate the influence of uniform pressure on the sealing of the seal ring. By analyzing the whole compression of the sealing ring, it can be seen that it is influenced by the bulk modulus of the sealing material. After calculation, the volume change quantity is ΔV=-24.24mm, and the change of the sealing ring diameter is $V_0+\Delta V$=640.76mm, Δd=-0.06mm. It accounts for 2% of the diameter of the seal ring. Usually, the compression of sealing ring is 10%~15%. Therefore, this volume variable caused by environmental pressure can still be within the scope of tolerance. In order to ensure high reliability, the sealing clearance can be appropriately reduced.

Reliability prediction of hydraulic cylinder

The reliability of hydraulic cylinder is mainly composed of the structural reliability of the cylinder of the hydraulic cylinder and the reliability of the sealing ring. The reliability relationship between the two cylinders is connected in series. The reliability of the hydraulic cylinder is calculated to be 1, and the reliability of the hydraulic cylinder is determined by the reliability of the sealing ring. By analyzing the dynamic seal of the hydraulic cylinder, the sealing ring is affected by temperature and pressure, and it has 2% influence on the compression of the dynamic seal. Therefore, this structure has little influence on the sealing performance of the sealing ring. According to the information provided by the manufacturer, the sealing ring takes reciprocating movement 2×10^8 times. A downward movement represents a repeated movement, then the dynamic sealing life of the hydraulic cylinder is 1.6×10^9 hours. Similarly, the reliability of the dynamic seal is connected in series, and there are three sets of sealing rings at the hydraulic cylinder. The overall life is 5.3×10^9 hours. That is to say, the average failure-free time of the hydraulic cylinder is 5.3×10^9 hours, and the traditional experience value standard in the reliability prediction is reached.

4. CONCLUSION

According to the hydraulic system scheme of logging instrument, the reliability prediction is carried out. The hydraulic drive system of logging instrument is analyzed, and the weak links and key components in the system are found out. Then, the hydraulic system structure of the hydraulic actuator of logging instrument is designed. According to the selected key components, the reliability structure design of the hydraulic cylinder is carried out. In view of the high temperature and pressure environment of hydraulic cylinder, the dynamic seal of hydraulic cylinder is analyzed. The analysis results show that under the environment of high temperature and pressure, the sealing ring in the hydraulic system with pressure balance can be selected by conventional design method.

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