Research on Evaluation Technology of Low Temperature Cold Start Performance of Hydraulic Oil

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Abstract. In order to comprehensively test the low temperature cold start performance of hydraulic oil and ensure their use effectiveness to the fullest, the idea of low temperature cold start performance index is proposed, so as to comprehensively evaluate the low temperature capability. Firstly, the cold start performance index system of hydraulic oil tested in low temperature environment is constructed, so as to describe its low temperature capability from multiple angles and in a comprehensive manner; secondly, for different index types, the corresponding data collection methods and data analysis methods are clarified, and the low temperature cold start performance of hydraulic fluid is evaluated. Finally, using the method as an example for three oils, the index types and assessment results are given to further illustrate the scientific nature of the research method. The research content can provide some technical support for the evaluation of the low temperature cold starting performance test of hydraulic winches.

Keywords: Hydraulic winch; Hydraulic oil; Low temperature; Cold start performance.

1. Introduction

The low temperature capability of military oil is mainly characterized by the low temperature performance of the oil, including the basic physical and chemical properties and low temperature cold start performance [1]. The low temperature cold start test can evaluate the efficiency of the oil under the real low temperature environment in the highland alpine region. The low temperature cold start performance is the key embodiment of the oil's low temperature capability [2]. Low temperature cold start performance as a manifestation of the actual use of each low temperature ability, can well reflect the low temperature ability of the oil, therefore, in the low temperature test how to objectively evaluate the cold startability, so as to grasp the oil low temperature level is particularly important.

In this paper, by studying the connotation of low temperature cold start test and combining the actual operating conditions of oil, we design our own hydraulic winch low temperature cold start test rig. On this basis, three evaluation performance indicators (pump outlet pressure, output power and average temperature rise) are proposed to establish the correspondence between cold startability indicators and low temperature capability, and to quantify the low temperature capability. Accordingly, the test data and evaluation methods corresponding to different cold startability indexes are given. The research idea can provide a strong theoretical support for the comprehensive evaluation of the low temperature capability of various types of oils.
2. Cold Start Test Connotation Study

2.1. Hydraulic Winch Working Principle
At present, the evaluation of hydraulic oil cold start test is mainly the mainstream of the hydraulic winch test, hydraulic winch has the advantages of high power density, strong load-bearing capacity and continuous working capacity, is widely used in the national defense equipment, construction machinery, vehicles, construction, ships, metallurgy and other heavy machinery and equipment winch and winding device. The basic working principle of the hydraulic winch is to use the hydraulic oil pump to generate high pressure hydraulic oil, which drives the hydraulic motor to rotate after going through the high pressure oil pipe and control valve system, and after decelerating and increasing the torque of the hydraulic motor through the reducer, the winch barrel rotates to tow the load [3].

2.2. Low Temperature Test Index Determination
Hydraulic winch required hydraulic oil in the flow process, there will be along-range pressure loss and local pressure loss, and the pressure loss and the viscosity of the hydraulic oil, the greater the viscosity, the greater the pressure loss. In the ultra-low temperature environment, such as in the winter -43 ℃ desert area, the viscosity of the hydraulic oil will increase significantly, and the hydraulic system will produce greater pressure loss at this time. If the pressure of the hydraulic oil in the hydraulic system is not enough to overcome the pressure loss, resulting in the control valve system is difficult to open or hydraulic motor is difficult to rotate, it will cause the hydraulic winch slow action or non-action phenomenon. It can be seen, in low temperature conditions, the smaller the viscosity of the hydraulic oil, the better the low temperature mobility, the smaller the pressure loss. However, if the hydraulic fluid has a small viscosity at low temperatures, the viscosity of the hydraulic fluid at high temperatures will be significantly lower [4]. The low viscosity of the hydraulic oil under high temperature conditions will lead to easy leakage of components in the hydraulic winch system, reduced system pressure, reducing the airtightness and towing capacity of the hydraulic winch system, while the low viscosity makes the oil film thinning will also exacerbate the wear of hydraulic components. Therefore, in the low temperature conditions to assess the performance of the hydraulic winch cold start, the analysis of the best range of low temperature viscosity of hydraulic oil, and then guide the design of hydraulic oil index, is one of the key means to improve the performance of the hydraulic winch system.

2.3. Progress of Domestic Cold Start Test Research
At present, the domestic hydraulic winch R & D and production units in the field of hydraulic oil low temperature cold start performance evaluation technology research is still blank, foreign countries have not proposed the corresponding evaluation device and evaluation standards. There is a method related to the hydraulic oil low temperature "aviation hydraulic oil low temperature stability test method"[5], the method outline for: a certain amount of specimen, under the specified temperature conditions, placed for a certain period of time, its oscillation, the turbidity and the turbidity of the reference solution, in order to observe the presence of gel, crystallization and solidification phenomenon to determine the stability of the sample is judged by observing whether there is gelation, crystallization and solidification. However, this method mainly determines the stability of hydraulic fluid in low temperature environment by turbidity, and does not determine the cold start performance of hydraulic fluid in low temperature environment.

Therefore, this paper analyzes the test data of three oils, L-HM46 hydraulic oil, 8H hydraulic transmission oil and #15 hydraulic oil, including pump outlet pressure, output power and average temperature rise, through the self-developed hydraulic winch low temperature cold start test rig to further explain the scientificity and feasibility of the test method. This is not only beneficial to guide the production process of hydraulic oil, but also beneficial to the use of hydraulic oil in alpine areas and even in the military widely used and popularized, providing technical support for the military leadership to make decisions on the selection of fuel for field combat.
3. Low Temperature Cold Start Test

3.1. Test Setup Construction

By analyzing the working principle and working process of the hydraulic winch system [6,7], combined with the influence of the low temperature viscosity of hydraulic oil on the cold start performance of the hydraulic winch, the overall scheme of the low temperature cold start performance evaluation device of the hydraulic winch system is designed as shown in Figure 1. Through the motor (1) simulates the engine driven oil pump (2) rotation, the generated high pressure hydraulic oil under the control of the hydraulic winch (5) through the high pressure oil pipe (7), driving hydraulic motor (17) rotates at high speed, and then the planetary reducer (16) is used to decelerate and increase the torque of the hydraulic motor (17), so that the torque is generated between the planetary reducer (16) and the brake hub (13) to simulate the towing capacity of the hydraulic winch system. The working process uses the data acquisition and manipulation platform (10) to obtain the torque, rotational speed, pressure, temperature, voltage and current values from the torque sensor (14), pressure sensor (11), temperature sensor (21) and power distribution cabinet (3). The hydraulic oil's ability to deliver power under ultra-low temperature conditions (ultra-low temperature freezing chamber (8)) is evaluated by comprehensive analysis of torque and speed magnitude, pressure drop, temperature rise, power loss and other parameters.

![Figure 1. Schematic diagram of low temperature cold start test device.](image)

3.2. Test Subject Selection

In order to reflect the universality of the test object selection, three test oil samples were selected for military, civilian, and fluid substitutes. And because there is no obvious difference in the performance test of the same aspect of the oil on this bench, #15 hydraulic oil [8], L-HM46 hydraulic oil, and 8H hydraulic transmission oil [9] were selected as the test oil, and their parameters are shown in Table 1.

| Indicator parameters | L-HM46 hydraulic oil | 8H hydraulic transmission oil | #15 hydraulic oil |
|----------------------|----------------------|-----------------------------|------------------|
| Volume               | 60 L                 | 60 L                        | 60 L             |
| Viscosity grade      | 46                   | 34                          | 22               |
| Brands               | Kunlun               | Kunlun                      | -                |
| Color                | Pale yellow          | Light brown                 | Red              |
| Condensation point   | -15°C                | -30°C                       | -65°C            |
3.3. Selection of Test Conditions
The towing force is mainly the power output of the hydraulic winch, which is the force that is generated by the hydraulic motor to generate a rotating torque, drive the planetary gear reducer to decelerate and increase the torque, and make the winch reel rotate to tow the heavy load. It can be seen that the hydraulic winch can produce the pre-set 98 KN pulling force, the key lies in the planetary gear reducer output shaft can produce the corresponding size of torque. It is calculated that the towing force should be set to 12000 according to the application scenario.

The temperature gradient is set mainly based on the temperature tolerance limits of different oils, which are about -45°C for military hydraulic fluids, -5°C for civilian hydraulic fluids, and -25°C for fluid substitutes. Therefore, in order to make the measured test data have good differentiation, the temperature gradient of the test is set to 25°C, 0°C, -20°C, -40°C.

3.4. Test Process Setup

3.4.1. Debugging equipment. ① Check the safety of the equipment, to exclude leakage, leakage of liquid, the valve is not tight and other safety hazards; ② Open the hydraulic winch test stand control program and PC computer; ③ Open the four way three position valve to adjust the valve position of the nitrogen gas cylinder, so that the pressure is 0.5MPa.

3.4.2. Cleaning oil circuit. ① Power on the test device, 20L test oil into the tank, set the three four-way valve to the middle position, not connected to the load, open the data collector, start the motor, so that the hydraulic oil in the oil circuit for 30s; then set the three four-way valve to the left and right position, each cycle for 10s; ② Check the client data collection, display, storage for abnormalities, the three The four-way valve is restored to the middle position and stopped. Note: Whether the adjustment of the left, middle and right positions of the three-way valve is in place depends on the horizontal relationship between the top of the presser column and the scale line of the base.

3.4.3. Replace the oil. ① Drain the oil to the waste oil drum, add 20L test oil to the tank, do not connect the load, adjust the four way three position valve to the left and right position, start the motor, after 3 min of each cycle, restore the four way three position valve to the middle position, stop the machine, drain the oil to the waste oil drum. Repeat the procedure twice; ② Add 20L test oil to the tank, ③Add the oil sample in the cold storage.

3.4.4. Temperature setting. Set the cold storage temperature in accordance with the "Cold Storage Instructions for Use", and constant temperature of not less than 4h.

3.4.5. Equipment operation. ① Turn on the data collector, start the motor and run for 10s; ② Set the four way three position valve to the right position, there will be two situations. Case one: no speed output within 3s, set the four way three position valve to the middle position, stop the machine and end the test; case two: if there is speed output, set the four way three position valve to the middle position after 10s, then set it to the left position to offset the torque, end the data collector and stop the machine to cool the oil circuit. ③ When the temperature difference between the temperature sensor value and that before the test is less than 1°C, start the air compressor to make the pressure in the air tank reach 0.85MPa and connect the load. Repeat step ①② and relieve the pressure. Note: Set the four way three position valve to the right position, and turn off the motor immediately after no speed output in 3s to stop the test to prevent damage to the motor and other hardware equipment.

3.5. Evaluation Indicators
In this test, there are 11 kinds of data that can be collected by the self-built Labview data acquisition system, including pump outlet pressure P1, valve group inlet pressure P2, valve group outlet pressure P3, reducer inlet pressure P4, pressurization station pressure P5, torque value J, rotational speed data v,
voltage U, current I, tank oil temperature T1, pipeline oil temperature T2. The data collection points are shown in Figure 2.

![Figure 2. Schematic diagram of data collection points.](image)

It can be seen that the data collected by this system are abundant from Figure 2. In this paper, the pump outlet pressure (P1), output power ($J \times \nu \times \pi / 30$) and average temperature rise (T2-T1) are selected as evaluation indexes, and the rest of the data are used as auxiliary evaluation basis.

### 3.6. Test Results

In order to exclude chance factors and ensure the repeatability and differentiation of the experiment, each oil was tested three times in the same temperature environment. Figure 3 shows the test results.

![Figure 3. Test results of low temperature cold start test device.](image)

Figure 3 shows that the pump outlet pressure, output power and average temperature rise of the same oil in different temperature environments are different, but the values of each evaluation index of the
same oil in the same temperature are almost similar. #15 hydraulic oil can be used normally in -40℃ environment, 8H general hydraulic transmission oil can only be used normally in -20℃ environment at the lowest, while L-HM46 The minimum working temperature of hydraulic oil is 0℃. Therefore, on the whole, #15 hydraulic fluid has the best low temperature cold start performance, 8H general hydraulic transmission fluid is the second best, and L-HM46 hydraulic fluid is the worst.

(1) Test result repeatability judgment.

The standard GB/T 6379.1-2004 [10] and GB/T 6379.2-2004 [11] give the repeatability judgment based on the fact that the number of relative deviations D not greater than the repeatability limit \( r = 5\% \) should be two-thirds of the total number of times. The formula for calculating the relative deviation is as follows Equation 1.

\[
D = \sqrt{\frac{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}{(n-1)\bar{Y}}} \times 100\% \leq r = 5\%
\]  

Where D is the relative deviation; \( Y_i \) is the value of the test result at the ith test; \( \bar{Y} \) is the arithmetic mean of the test value; \( n \) is the number of repeatability tests, the test n is always equal to 3; \( r \) is the repeatability limit of this test, the value of 5%.

(2) Test result differentiation judgment.

In this test, differentiation means that the performance of different oils can be distinguished and discriminated. GB/T 6379.1-2004 and GB/T 6379.2-2004 stipulate that the difference between the extreme difference of each experimental data of distinguishability and repeatability is greater than one order of magnitude, which can be considered to have good distinguishability.

In summary, this paper makes two types of judgments on the test data—repeatability judgment and differentiation judgment. The experimental data were processed using Equation 1, the total number of judgments is 39 times, of which the number of judgments with repeatability or differentiation is 37 times, accounting for 95% of the number of judgments, so it can be considered that the test results have good repeatability and scientific differentiation. That is to say, the hydraulic winch low temperature cold start test evaluation technology has good repeatability, differentiation, science and feasibility, can be a reasonable distinction and reproduction of the low temperature cold start performance of different oils.

4. Conclusion

In the self-developed hydraulic winch low temperature cold start performance evaluation test bench on three kinds of oil (L-HM46 hydraulic oil, 8H hydraulic transmission oil, #15 hydraulic oil) carried out a series of research tests, and the test results were analyzed and discussed, the conclusions obtained are as follows.

(1) There are three indicators for determining the low temperature cold start performance of the oil: pump outlet pressure, output power and average temperature rise.

(2) In order to ensure the reliability of the low temperature cold start performance of the oil, the three indicators should be collected at the locations shown in the device schematic, and the collection time should be 10 s.

(3) The three sets of data for the repeat test have good repeatability, which illustrates the reproducibility and feasibility of the test rig from the side. The three sets of data from the differentiation test have significant differentiation, which proves the differentiation and scientificity of the test rig from the side.

(4) The next step will be to investigate the relationship between oil viscosity-temperature characteristics and low temperature cold start performance based on the results obtained so far, and to conduct experimental verification.

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