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Experimental study on Fuel Heating of A Gas Turbine Engine

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Abstract. In order to mitigate the latent hazards caused by fuel retention in the gas turbine and ensure a higher ignition success rate, an investigation was conducted on the impact of fuel heating on the gas turbine. By incorporating a fuel heating device into the gas turbine, experiments were carried out to evaluate its heating performance at different positions within the fuel system. The objective was to elevate the temperature of the main fuel pipe prior to ignition, thereby reducing ignition success speed and guaranteeing successful combustion initiation. The findings revealed that placing the fuel heating device at the outlet of the fuel control device met all requirements; however, positioning it before this device failed to meet expectations. Furthermore, when subjected to heat, this particular heating device did not accurately reflect actual fuel temperature; additionally, relying solely on circulating heat within the existing fuel system proved inadequate. Consequently, based on these test results, an optimal solution involving supplementary heating devices was determined - a decision that holds immense significance for ensuring steady operation of gas turbines.

Keywords: Gas Turbine, Fuel System, Fuel Heating, Heating Performance, Experimental Stud.

1. Introduction

Gas turbines have advantages such as compact structure layout, good fuel economy index, high thermal efficiency, good reliability and long service life, which are widely used in aviation, navigation, land aviation and other military defense fields, and also widely used in joint power generation, energy supply, metallurgy and other fields, and have also achieved considerable development in the national economy [1,2,3]. Gas turbine start-up and operation is an important part of gas turbine operation management. The starting process of a gas turbine is divided into three stages, in which the second stage the combustion chamber starts to ignite and the unit starts to transition from a cold state to a hot state [4]. In the operation of gas turbine, the failure of any burner may cause combustion fluctuation and shutdown accident [5], and in serious cases, thermoacoustic shock will be triggered, resulting in damage to burner components [6]. When the intake temperature of a certain type of turbine is low, the fuel is in a low temperature state leading to ignition difficulties, and the fuel supplied to the combustion chamber between the fuel supply speed and the successful ignition speed remains in the gas turbine, which is easy to cause detonation and even local abnormal temperature failure.

In order to ensure the stable operation of gas turbines, the technical treatment of fuel oil retained inside gas turbines needs to be further improved. The combustion performance of the fuel main can be effectively improved by improving the internal device of the gas turbine [7]. This paper fully considers the feasibility of the test and the scientific research method, mainly studies the heating performance of the fuel heating device at different positions in the fuel system, provides technical support for the optimization of the heating scheme before ignition of the fuel system, and explores the feasibility of the fuel system's own circulating heating scheme.

2. Test principle

1) Except for the pipelines exported from the fuel control device to the fuel main pipe, other pipelines shall adopt tester pipelines; The inlet and outlet temperature sensor and wall temperature test of the fuel heating device were delivered with the gas turbine, and the other temperature tests were carried out with the tester equipment. The accessories were controlled by the tester universal control cabinet.

2) Parameters of gas turbine and other auxiliary systems could be simulated by signal simulators, such as gas turbine exhaust temperature.

Fig.1.showed the schematic diagram of the test.

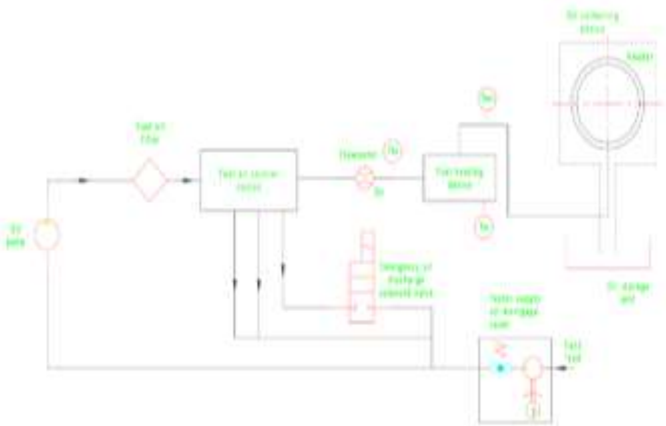

Fig. 1. Schematic diagram of the test

3. Test purpose

1) The fuel heating device was heated separately and the heating characteristics of the fuel heating device were explored.

2) The fuel heating device was installed at the PZ outlet of the main oil circuit of the fuel control device to test the fuel heating performance.

3) Before installing fuel filter, we tested fuel heating performance.

4) The fuel heating device was not powered on, and only cold operation was done to test the fuel heating performance.

4. Test verification

4.1 The fuel heating device was heated separately and the heating characteristics of the fuel heating device were explored

The test procedures were as follows:

1) We filled the fuel heating device with fuel.
2) Heating was performed according to the heating operation steps of the fuel heating device (target temperature Tout=80℃), and the heating time, inlet temperature Tin, outlet temperature Tout and wall temperature Twb of the fuel heating device were recorded.
3) The heater powered on for 2min, powered off (30 ~ 40) s, which was a heating cycle.
4) We repeated step a 3 to 4 times until the oil temperature reached (Tout-5℃) and stopped heating it.
5) Notes:
   a) Each continuous heating time should not exceed 2min.

b) The wall temperature reached 60℃ or the oil temperature reached 75℃ must stop heating.

The test results were shown in the following table:

We filled the fuel heating device with fuel, then restore the inlet and outlet pipes, and heated the fuel heating device separately, as shown in Table 1.

Note: The wall temperature could not enter the data acquisition system, and the FLUKE table was used to record the temperature.

Table 1. Individual heating test record of fuel heating device

Serial number	Heater condition	Tin(℃)	Tout(℃)	Twb(℃)
1	Power off (initial state)	16.82	26.55	26.51
2	Power on for 2 mins, power off for 30 s	19.43	31.49	66.82
3	Power on 2 mins	19.61	36.43	70.91
4	Power on 1 min	19.92	39.00	75.23

After about 5min of test, after on-site consultation, it was decided to insert the temperature sensor temperature probe at the outlet directly into the liquid at the outlet, and the measured temperature was 90.63℃.

From the above results, when the fuel heating device was heated, because the liquid did not flow, the temperature measured by the temperature sensor at the entrance and exit were low, and the wall temperature sensor was slow in response, and could not truly reflect the fuel temperature.

On site, all the fuel in the fuel heating device was emptied, the fuel was refilled, and the temperature sensor temperature probe at the outlet was directly inserted into the liquid at the outlet, and the heating was restarted. The results were shown in Table 2, Table 3, and Fig. 2.

Table 2. Individual heating test record of fuel heating device (first time)

Serial number	Heater condition	Tin(℃)	Tout(℃)	Twb(℃)
1	Power off (initial state)	7.86	12.43	12.33
2	Power on for 2 mins, power off for 30 s	7.83	28.12	20.63
3	Power on for 3 mins, power off for 30 s	8.42	81.12	41.52
4	Power off for 2 mins	12.17	96.27	50.01

Table 3. Separate heating test record of fuel heating device (second time)

Serial number	Heater condition	Tin(℃)	Tout(℃)	Twb(℃)
1	Power off (initial state)	6.51	16.45	16.46
2	Power on for 2 mins, power off for 30 s	6.82	30.12	24.10
3	Power on for 2 mins, power off for 30 s	7.11	63.22	34.82
4	Power on for 2 mins, power off for 30 s	7.71	75.22	40.10
5	Power off for 2 mins	11.30	93.12	49.22
6	Power off for 9 mins	20.08	80.75	56.11
7	Power off for 15 mins	22.80	69.11	55.22
8	Power off for 25 mins	21.26	43.23	50.60
9	Power off for30 mins	19.96	38.01	47.60

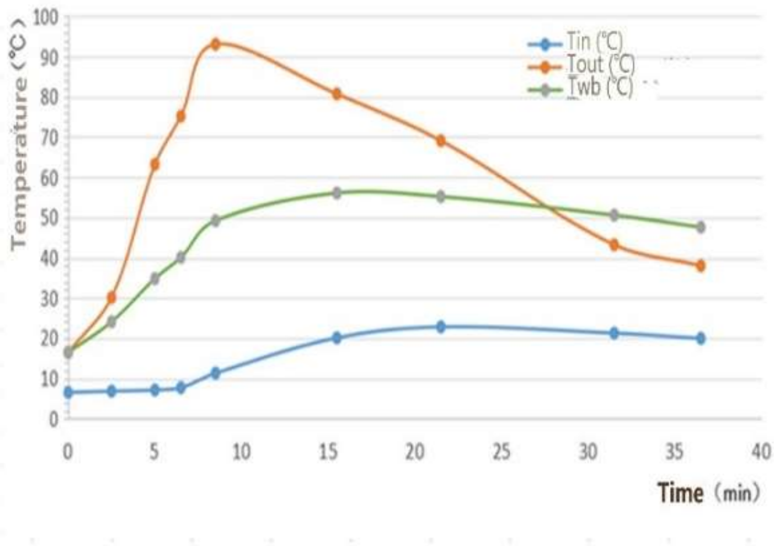

Fig. 2. Relation of inlet temperature, outlet temperature and wall temperature

It could be seen from the above tests:

a) It took about 5 mins to heat the fuel from below 10 ℃ to 80 ℃.

b) The temperature rose at the inlet was the slowest, the temperature rose at the outlet was the fastest, and the reaction of the wall temperature was slower than that at the outlet. After the power failure, the outlet temperature continued to rose and then decreased, while the wall temperature decreased slowly.

4.2 The fuel heating device was installed at the PZ outlet of the main oil circuit of the fuel control device to test the fuel heating performance

The performance of the gas turbine control system determines the variable operating condition performance, economy and safety of the corresponding power plant [8]. The fuel oil control device is composed of metering valve, differential pressure return valve, electro-hydraulic servo valve, constant pressure valve, air relief valve, emergency solenoid valve and oil discharge solenoid valve, etc., to control the fuel flow [9].

The test pipeline diagram was shown in Fig.3, in which port PO was led to barrel 1 with a hose; We filled the fuel from the temperature measuring point at the outlet of the fuel heating device until it was fully filled, and then connected the outlet of the fuel heating device to the fuel main; Gas turbine pipeline from the flowmeter to the fuel main pipe; The fuel manifold was open, wrapped in a plastic sheet with an opening at the bottom of the plastic sheet to facilitate the transfer of fuel to the oil drum 3.

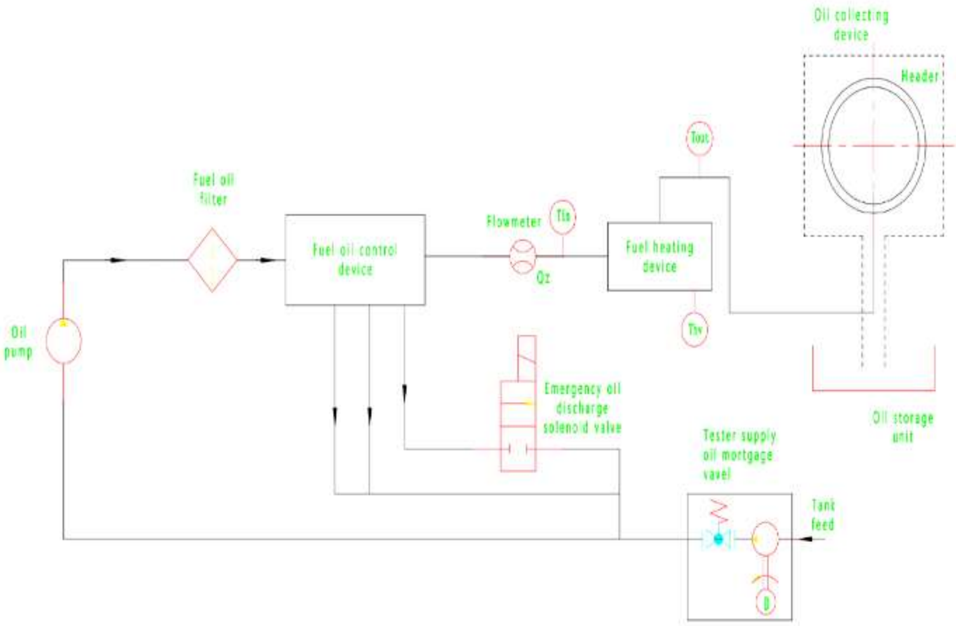

Fig. 3. Test pipeline diagram after the fuel heating device was installed in the fuel control device

The test procedures were as follows:

1) The low pressure pump oil supply Pin (0.18 ~ 0.4) MPa, the emergency valve and oil discharge valve were powered off, and the metering valve of the fuel control device was closed. Record the fuel temperature T1, Tin, Tout, Twb before the test.
2) We opened the fuel heating device to start heating, and start timing, until the fuel heating device outlet temperature Tout reached 80°C, recorded the fuel temperature T1, Tin, Tout, Twb at this time.
3) According to the starting procedure, the Ng speed was from 2900r/min to 4000r/min within 11s, the oil was supplied at a constant flow rate of 288.6L/h, and the data was recorded as T1, Tin, Tout, Twb, Ng, Wf, Wg, QZ.

The test results were shown in the following Table 4 and Table 5:

Table 4. Fuel heating device Installed in the fuel control device PZ outlet fuel heating performance record (first time)

Serial number	Heater condition	Tin(°C)	Tout(°C)	Twb(°C)
1	Power off (initial state)	12.54	8.26	33.20
2	Power on for 2 mins and power off for 30 s	15.54	7.38	40.60
3	Power on for 2.5 mins and power off for 30 s	26.05	72.10	56.70
4	Power off and start for 11 s	9.60	43.10	60.01

Table 5. Fuel heating device Installed in the fuel control device PZ outlet fuel heating performance record (second time)

Serial number	Heater condition	Tin(°C)	Tout(°C)	Twb(°C)
1	power off (initial state)	18.05	35.51	35.10
2	Power on for 2 mins and power off for 30 s	12.77	44.00	41.20
3	Power on for 2.5 mins and power off for 30 s	12.00	77.10	53.21
4	Power off and start for 11 s	12.98	41.10	53.11

It can be seen from the above test that after the heating device was heated, the fuel temperature was rapidly reduced by about 30 ° C (72.10-43.10=29 ° C for the first time, 77.10-41.10=36 ° C for the second time) after starting for 11s.

4.3 Before installing fuel filter, we tested fuel heating performance

The test pipeline diagram was shown in Fig.4, in which port PO was led to barrel 1 with a hose; The fuel heating device was installed before the fuel filter; The fuel manifold was open, wrapped in a plastic sheet with an opening at the bottom of the plastic sheet to facilitate the transfer of fuel to the oil drum 3.

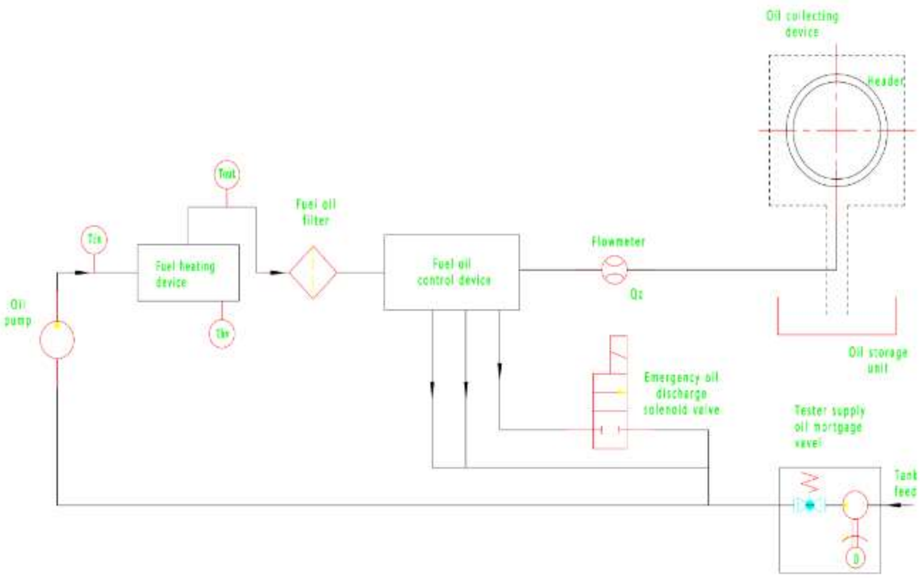

Fig. 4. Fuel heating device before filter test pipeline diagram

The test procedures were as follows:

1) Open the fuel heating device to start heating, and time until the fuel heating device outlet temperature Tout reaches 80℃, record the fuel temperature T1, T2, T3, Tin, Tout, Twb at this time.The low pressure pump of the tester provides oil (0.18 ~ 0.4) MPa, the emergency valve and the oil discharge valve were powered off, and the metering valve of the fuel control device was closed.
2) According to the cold operation program, drive for 3min, and record T1, T2, T3, Tin, Tout, Twb, Ng.
3) According to the starting procedure, the Ng speed was from 2900r/min to 4000r/min within 11s, the oil was supplied at a constant flow rate of 288.6L/h, and the data was recorded as T1, Tin, Tout, Twb, Ng, Wf, Wg, QZ.

The test results were shown in the following Table 6:

Table 6. Test record of fuel heating performance before fuel filter was installed in fuel heating device

Heater condition	Tin(℃)	Tout(℃)	Twb(℃)	Test parts imported fuel oilT1(℃)	Fuel temperature after measurement T2(℃)	Return oil temperature T3(℃)
Heater power off (initial state)	22.87	23.88	24.61	6.77	19.60	23.55
power on for 2 mins and power off for 30 s	20.9	33.27	32.60	6.81	19.40	22.05
power on for 2 mins and power off for 30 s	19.60	51.80	43.80	6.81	19.30	20.81
power on for 2 s and power off for 30 s	20.00	58.60	49.30	6.81	19.27	20.11
power on for 1 min and power off for 30 s	21.90	75.64	53.20	6.81	19.20	19.46
Heater power off, gear pump on	22.00	27.40	42.00	6.81	20.2	29.70
Power off,start for 11 s	26.7	27.40	40.00	6.81	23.3	27.12

As can be seen from Fig.5, after the fuel heating device was heated, the gear pump started to run, and the fuel temperature dropped rapidly (75 ° C to 27 ° C), which could not achieve the purpose of heating the fuel.

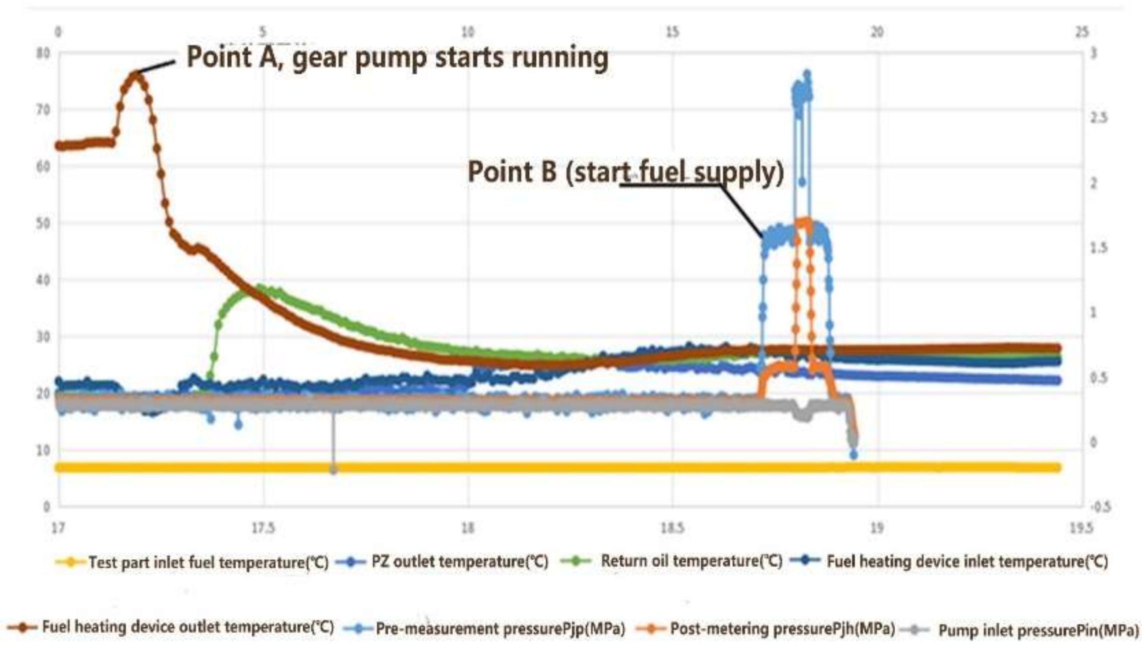

Fig. 5. Test curve of fuel heating performance before fuel filter was installed in fuel heating device

4.4 Fuel heating device was not electrified, only did cold operation, we tested fuel temperature rise performance

The test pipeline diagram was shown in Fig. 6, in which port PO was led to barrel 1 with a hose; The fuel heating device was installed before the filter (the whole process was not electrified); The fuel manifold was open, wrapped in a plastic sheet with an opening at the bottom of the plastic sheet to facilitate the transfer of fuel to the oil drum 3.

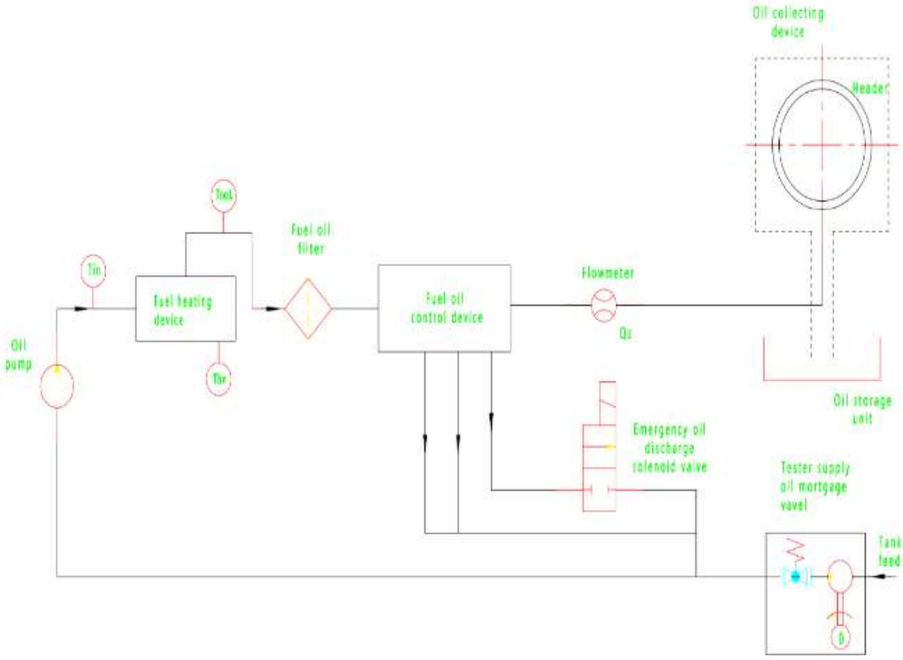

Fig. 6. The fuel heating device did not have power and only did cold operation to test the performance of fuel temperature rise

The test procedures were as follows:

1) The low pressure pump of the tester provided oil (0.18 ~ 0.4) MPa, the emergency valve and the oil discharge valve were powered off, and the metering valve of the fuel control device was closed. Record the fuel temperature T1, T2, T3, Tin, Tout, Twb before the test.
2) According to the cold operation program, we drove for 3min, and recorded T1, T2, T3, Tin, Tout, Twb, Ng.
3) After 5 mins of parking, repeated b).
4) After 5 mins of parking, repeated b).

The test results were shown in the following Table 7:

Table 7. Fuel heating device did not power, only did cold operation, the record table of fuel heating test

Serial number	Heater condition	Tin(℃)	Tout(℃)	Twb(℃)	Measured fuel temperature T2 (℃)	Oil return temperature T3 (℃)
1	Heater power off (initial state)	18.07	23.20	22.50	16.14	18.99
2	Cold run for 5 mins	18.88	24.89	23.88	15.81	25.97
3	Stop for 1 minute	-	-	-	-	-
4	Cold run for 5 mins	26.33	26.24	25.10	15.54	25.83
5	Stop for 1 min	-	-	-	-	-
6	Cold run for 5 mins	27.5	27.33	26.21	16.06	27.33

As can be seen from TABLE VII, only cold operation could not achieve the purpose of fuel heating.

5. Conclusion

The experimental conclusions were as follows:

1) When the fuel heating device was placed at the outlet of the fuel control device, the heated fuel entered the fuel main pipe, so that the fuel entering the combustion chamber was hot and met the requirements.
2) When the fuel heating device was placed after the fuel filter (in front of the fuel control device), although the fuel has been heated, the temperature dropped rapidly after cold operation and could not meet the requirements.
3) When heating the fuel heating device, because the liquid did not flow, the temperature measured by the temperature sensor at the inlet and outlet were low, the wall temperature sensor was slow, and could not truly reflect the fuel temperature, it was recommended that the fuel heating device was optimized to directly measure the fuel temperature.
4) The fuel system itself cycle heating scheme (direct use of cold operation to heat the fuel cycle), the fuel temperature rise was very slow, could not meet the requirements.

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