Design of High-temperature and High-pressure Environment Simulation Device

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Abstract—This paper designed a high-temperature and high-pressure environment simulation device, and simulated the temperature and pressure environment for downhole instrument performance testing and calibration on the ground. The device can meet the low energy consumption, small control precision, easy removal requirements. The depth of oil wells is generally between hundreds to thousands of meters due to the geological characteristics. With the increasing depth, temperature and pressure are gradually increasing, and high temperature and high pressure environment is the key to the instrument performance stability test. Therefore, testing and experiment for the downhole instrument performance plays an important role in ensuring the instrument's safety and stability during the process of operation.

Keywords- High-temperature; high-pressure; simulation; instrument; calibration

I. INTRODUCTION

With increasing depth of the well, due to the geothermal gradient and the liquid column pressure, downhole temperature and pressure also increased. The corresponding instruments and equipment must be down into the wellbore, the requirements for downhole tools and instrumentation also will improve, and the high temperature and high pressure increases the risk of underground work[1]. Oil and gas exploration and development are high-cost and high-risk jobs, especially failures in downhole equipment effectiveness may lead to a variety of downhole complex conditions and accidents, causing huge economic losses. Therefore, researchers need to simulate downhole environments, provide similar downhole pressure and temperature conditions, and carry out the experiments and calibration of underground work tools and associated instrumentation before descending to the wells.

II. DESIGN IDEAS AND PARAMETERS

A. Design Ideas

This paper designs a high-temperature and high-pressure environment simulation device for downhole instrument's High temperature and pressure resistant performance, which can simulate the temperature and pressure environment conditions under the oil and gas well. The device is mainly designed from the following aspects:

1) High temperature and pressure vessel fully simulates the wellbore shape;

2) Raise and lower the temperature and pressure automatically and control remotely;

3) Design automatic pressure relief device and pipes to ensure the security of experiment.

B. The system design specifications

1) Operating temperature range: room temperature - 150 ℃;

2) Temperature control accuracy: ± 1 ℃;

3) Working pressure range: 0-90MPa;

4) Pressure control accuracy: ± 0.1Mpa.

C. High temperature and high pressure vessel structure diagram

The structure of high temperature and high pressure vessel is shown in Fig. 1

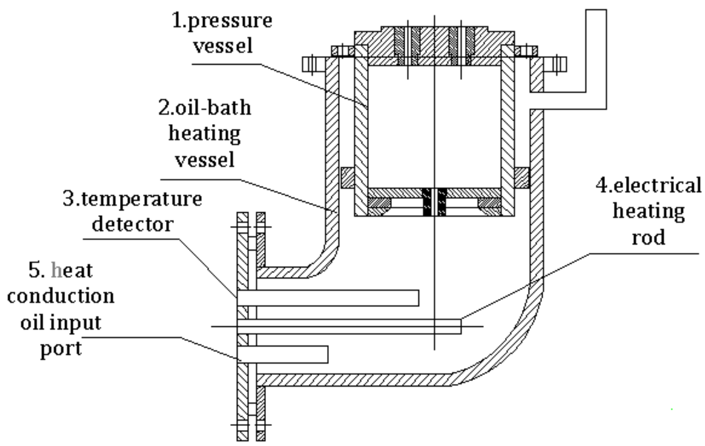

Figure 1. High temperature and high pressure vessel structure figure

III. HIGH-PRESSURE ENVIRONMENT SIMULATION VESSEL

A. Structure of high pressure vessel

High pressure vessel is the principal part of high-pressure environment simulation system, its main role is to provide sufficient high-pressure environment space, and achieve testing and test simulation for a variety of different structures and sizes of downhole oil instrument. To simulate the downhole conditions more realistically, the high pressure vessel is designed to be cylinder structure, safety coefficient design is high according to reference [2], finally choose the material 12Cr2Mo. In order to prevent the damage arising from excessive internal pressure, there is a certain thickness. According to the downhole tools and instruments dimensions, the pressure vessel has a length of 5m and internal diameter of 1m. The bottom is sealed with disposable sealing head (first take the sealed and screwed fastening, finally soldering process) [3]. The top of the container is used as the work piece handling port, since repeated handling, use removable sealing head (take screw fastening first, and then sealed, and finally rotate with wedge gripping to mechanical clamping). The structure is particularly special and it's easy to operate, the sealing is safe and reliable, its overall structure is shown in Fig. 2.

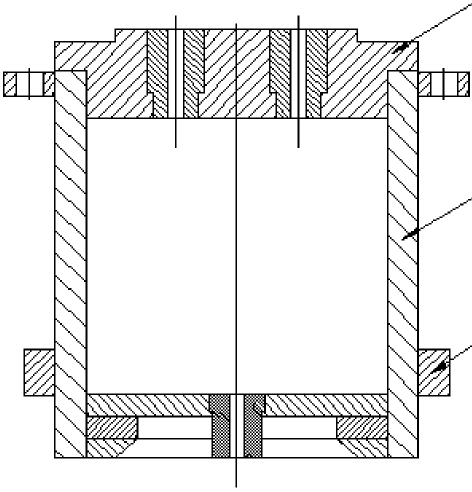

Figure 2. High pressure vessel

The main components and their role of the pressure control system are as shown:

TABLE I. MAIN COMPONENTS AND THEIR ROLES

Main components	*Role*
Water tank	Supply Water
High pressure pump	Provide high voltage power
Pressure accumulator	Voltage regulator
Air compressor	Offer pressurized air
Water suction pump	Pressure relief
High voltage relief valve	Constant pressure overflow
Water switch valve	Adjust the water flow
line	Provide the pressure medium circulation channel

B. Determination of the pressure vessel wall thickness

Because of the pressure vessel is to bear hundreds of MPa pressure, the wall thickness is a key issue, according to the reference [4], wall thickness is calculated as follows:

(1) The thickness δ is the minimum theoretical wall thickness to withstand the calculate pressure Pc to safely required, as in

$$\delta=\frac{P_c D_1}{2[\sigma]\cdot\varphi-P_c} \tag{1}$$

In the formula: P_c- calculated pressure, MPa;
D_1- vessel inside diameter, mm;
[σ] -allowable stress of material, MPa;
φ - seam coefficient, 0.85;

(2) Calculate the thickness δd- the sum of calculate thickness δ and corrosion allowance C2, as in

$$\delta_d=\delta+C_2 \tag{2}$$

(3)Nominal thickness δn-calculated thickness plus steel negative deviation and round up, as in

$$\delta_n=\delta+C_2+C_1+\triangle \tag{3}$$

In the formula: Δ-roundness value
C_2- steel negative deviation, 1.6mm

Because the choice of material is low-alloy steel, it should be multiplied by the factor 170 / [σ], assuming a pressure of 90Mpa, the calculation results of the pressure vessel wall thickness is 152mm.

C. Determination of the pressure control scheme

Pressure control is the core of the system, and the pressurized scheme is to use the high-pressure pump to inject water into the container. Throughout the process, constant volume of the inner container, with continuous injection of the liquid, the internal pressure of the vessel rising, only to open the valve connected to the atmosphere to discharge the water can reduced pressure.

To achieve voltage regulation, it was decided to add pressure accumulator between the high pressure pump and pressure vessel[5], the pressure has been maintained at a precise setting. At the same time, the console is provided with manually operated pressurization and pressure relief button to achieve the system's manual pressurization and pressure relief. The main configuration of the pressure control system is shown in Fig. 3

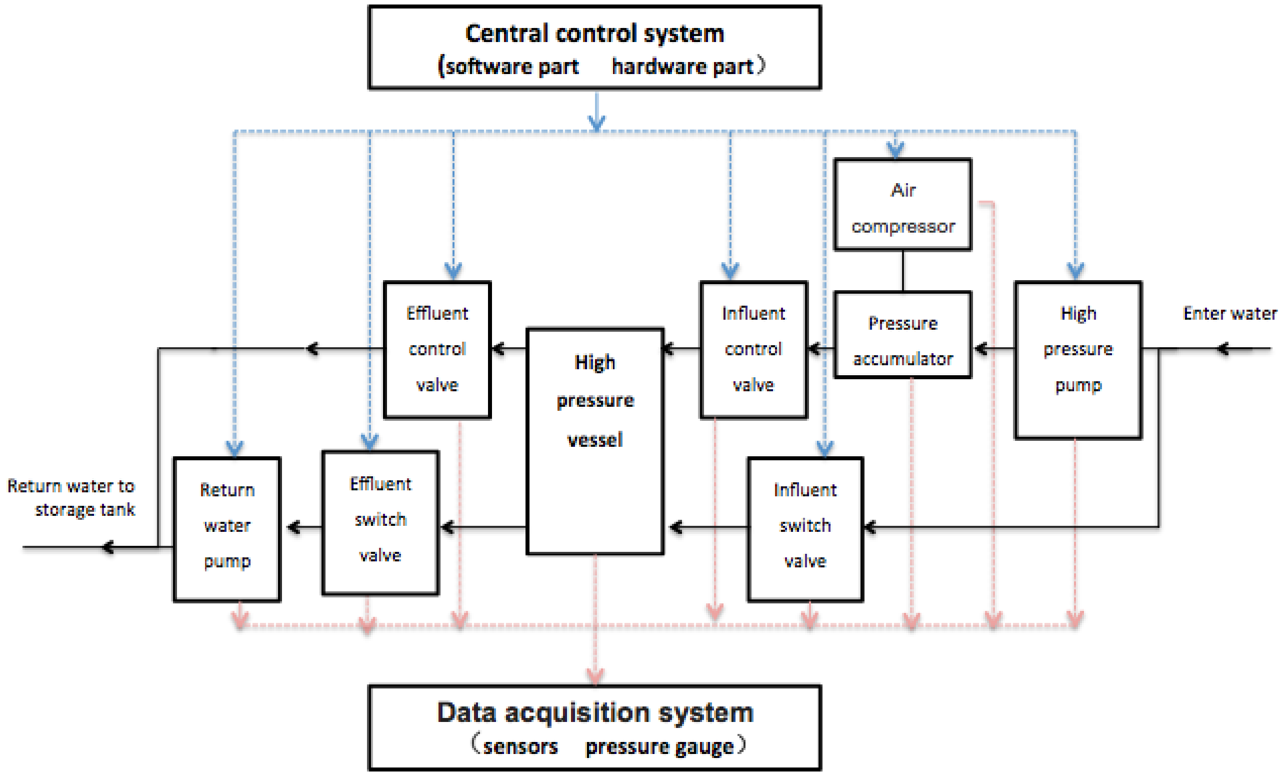

Figure 3. Pressure control system

D. Pressure Control and related calculations

It needs to pressurize to the high pressure vessel during the experiment and larger water flow is required, so it is reasonable to choose high pressure reciprocating pump according to the flow. Use a high-pressure pump to ascend and descend pressure directly, install high-precision digital pressure indicator on the pump and the input port, and control the pressure directly to achieve pressure automatic control.

Inject the liquid to the sealed pressure vessel , with the injection of the liquid, the liquid volume V is varying, the corresponding point of a closed container in the pressure value P is also varying, the relationship between the variation of pressure ΔP and the variation of liquid volume ΔV [6]:

$$\triangle P=\beta_e \frac{\triangle V}{V} \tag{4}$$

In the formula, β_e is the elastic modulus of the liquid (pure water), ideally have a value of 2400MPa, but the ideal state does not exist. According to experimental experience and relevant data, because the water usually contains gases (such as water soluble gases and gases do not dissolve in water but in airtight container, including water vapor), so the elastic modulus of water is lower than the theoretical value a lot. The elastic modulus of water is only 1000MPa in the natural state.

IV. AUTOMATIC TEMPERATURE HEATING AND COOLING CONTROL SYSTEM DESIGN

A. The calculation of heating power

The creation of the automatic oil-bath heating and cooling vessel filled with conducting oil (figure), heating and cooling to the vessel automatically [7]. According to actual needs of the current depth of 8000m (highest well temperature 240° C), 400 ° C heat transfer oil is designed as a conductor by using a bar-type electrical heating rod heating [8]. According to the theoretical formula [9], as in

$$P=\frac{(m_1\times C_1+m_2\times C_2)\times\triangle T}{864t} \tag{5}$$

In the formula: P -power, kW;
m1-weight of the heating medium, kg;
C1-specific heat of the heating medium, kcal / (kg·° C);
m2-weight of the vessel, kg;
C2-specific heat of container medium, kcal / (kg·° C);
Δ-the temperature difference between medium and environment,° C
t - media heating time, h.

Using temperature sensors for remote control and testing to ensure that the temperature can accurately reach the set temperature value[10]. Its overall structure is shown in Fig. 4

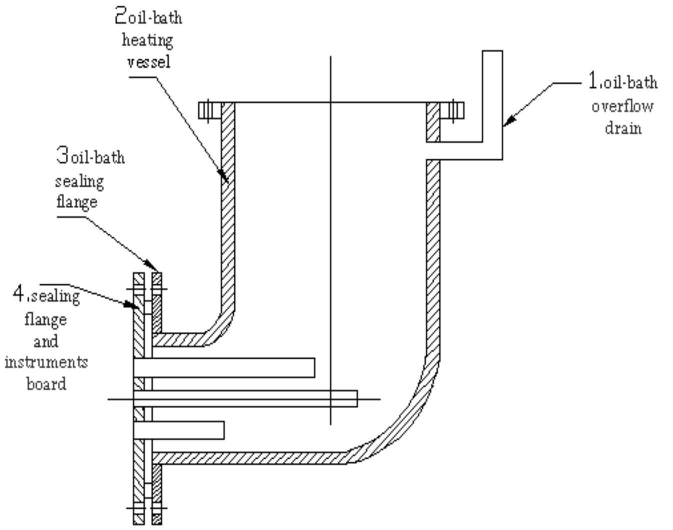

Figure 4. Oil-bath heating vessel

In the process of heating, the temperature is timely monitored by the temperature sensor. If the temperature is too low, PLC controls the electric heater automatically shift to increase the heating power, when the temperature is higher than the set temperature, the electric heater is shut down automatically.

B. The design of thermal insulation layer

Heat preservation of the primary purpose is to ensure that the fluid inside the equipment is able to work in the experimental stages under the required temperature.

According to the comprehensive analysis of the performance characteristics of all kinds of insulation materials, combined with the specific requirements of the simulation test, according to the characteristics of the simulator, heat preservation, the application for the specific requirements and economy analysis, heat preservation material performance and so on into consideration, and finally choose foam asbestos as the insulation material. The ultra light foam asbestos is asbestos fiber elaborated by chemical refining, and make it become the slurry structure, repass shaped by high temperature [11]. Therefore, it is suitable for the simulation device heat preservation. Its performance is as follows:

（1） Bulk density Kg/m3:20-30

（2） Tensile strength Kg/m3:0.8 1

（3） Porosity % : 75-80

（4） Coefficient of thermal conductivity W/m.k: 0.028 to 0.040

（5） Using temperature℃: 500 or less

（6） Combustibility: non-combustible

（7） Ignition loss % : 4.5-6

（8） Elastic recovery rate is 100 ℃ 50 g/cm2:98%

（9） Tide content % : 1.2 to 2.5

（10） Moisture absorption rate % : waterproof type 1.6 to 2%

（11） Product specifications: board, length: 1000 ± 10 mm, width: 500 ±5 mm, thickness: 30-70 ±5 mm

This device uses foam asbestos as insulation materials, both in terms of economy, service life, heat preservation effect can meet the requirements of the simulator. There is no need to do further calculation any more. Its biggest heat preservation temperature can reach 500 ℃, the thickness also can choose between 30-75 mm. In order to ensure that the heat preservation effect best, heat dissipating capacity to reduce to a minimum, the final thickness is 75 mm.

V. TEMPERATURE AND PRESSURE CONTROL PROCESS

Downhole environment simulation system simulates downhole temperature and pressure in different depth, executes instrument calibration under the ground. The main function of temperature and pressure control system include: simulate downhole temperature and pressure conditions in different depth, each performance index for downhole oil instrument testing or calibration.

Based on the above requirements, this paper designed underground oil instrument testing system controlled by PLC. PLC is introduced on the basis of the traditional sequence controller microelectronics technology, computer technology, automatic control technology and communication technology and form a new generation of industrial control device, the purpose is to replace relay, perform the logical, sequential control functions such as time, counting, and establish a flexible SPC system.

Technical requirements of test system are simulation of the downhole instrument by using constant temperature and constant pressure; booster and warming according to the set curve.

A. The flow chart of the system

The flow chart of the system is as shown in Fig. 5

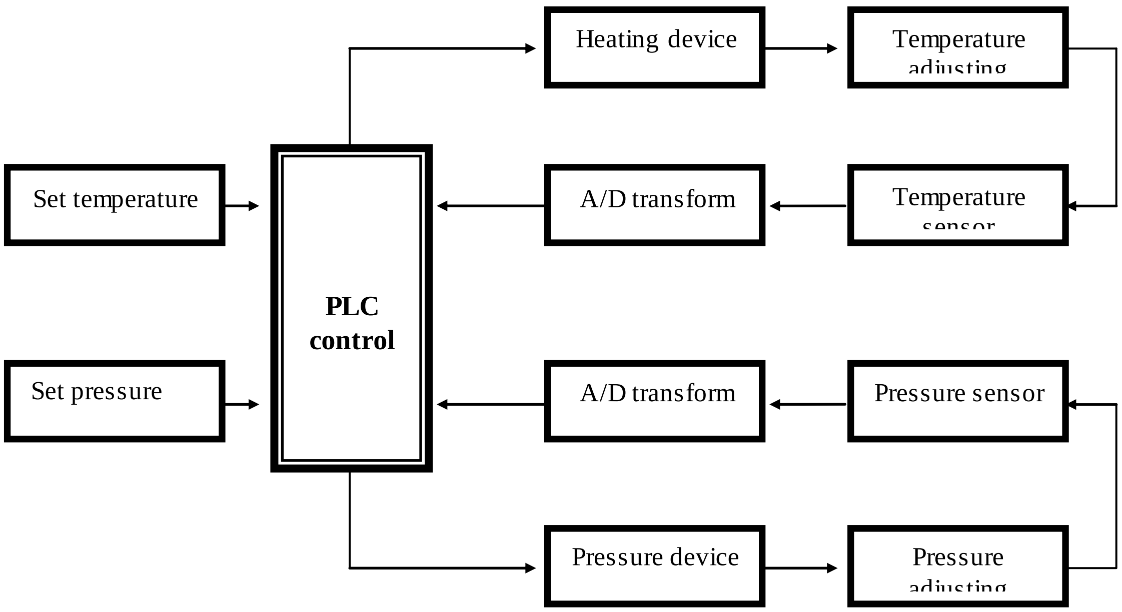

Figure 5. Flow chart of the high-temperature and high-pressure control system

B. Pressure control process

Pressure control is to use high pressure pump to inject oil to the high pressure vessel, the pressure of the pressure sensor parameters as controlled object return parameter passed to the computer, when the pressure in the container after reaching a given value, control high voltage electromagnetic flow capacity of overflow valve, in order to control the system pressure reached to the set value, so as to achieve the aim of pressure control.

C. Temperature control process

Temperature is the most difficult parameters to control in the system, the goal of this system adopts the heating speed controllable temperature setting control mode, the control part adopts intelligent temperature control instrument, the instrument is controlled by PLC, can effectively control the temperature of the test system, provide reliable high temperature environment for instrument testing [12].

Oil-bath heating vessel is wrapped in external thermal insulation material, so the heating and cooling time has a big time difference. It requires that the temperature control overshoot, otherwise it would extend the time of check. For the temperature control system, this system adopts the sequence logic control algorithm. According to the actual temperature and the set point, adjust the heat of the heating rod to achieve the temperature control.

VI. SUMMARY

High-temperature and high-pressure environment simulation device for downhole instrument calibration can simulate the temperature and pressure environment that the instruments use under the downhole ,in order to do the all true simulation testing for the downhole instrument temperature resistance and pressure resistance performance based on production and testing requirements. It provides more effective safety and accuracy for the use of the instrument, in order to eliminate downhole unstable temperature and pressure mutagenic hazard, greatly increasing the production and operation success rate and reliability.

This simulation test device is designed for high temperature and high pressure due to time, technology and other reasons. The device controls the pressure and temperature of the detailed operation steps, controls the element selection, and the related control system software development only made a simple introduction, so the physical simulation test device still needs further perfection to carry on the processing after assembly. However, in this paper, a simulation test device for other innovation is of simple structure, convenient operation, easy disassembly and assembly.

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