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Temperature control strategy for a seal fatigue tester

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Analysis and modelling

ABSTRACT

Purpose: The aim of the paper is optimization of a control strategy used in a seal fatigue tester.

Design/methodology/approach: Analytical approach has been applied to get an understanding of a heat exchange process. It is required to optimize the control process algorithm.

Findings: The initial control algorithm has been improved regarding numerous tests under different operating conditions. The final version of the control program allows to maintain the temperature according to the on-off strategy minimizing the temperature oscillations and potential overshoots.

Research limitations/implications: It should be considered a new control strategy based on PID controller.

Practical implications: The major component of the tester is the heat exchanger. It consists of a tube and embedded pipe circuit feeding with the external heating or cooling medium. The tube is a cylindrical housing where the seals are assembled at both sides. Two main pumps circulate the medium at a specified flow rate and pressure. The temperature is maintained to hold it almost constant during heating and cooling phases. Two thermocouples are placed close to the seals, and the one in the middle of the heat exchanger tube. The tester is equipped with a control system consisting of a PLC controller and LabView data acquisition application. It is possible to control the device remotely through LAN/WAN networks. The LabView application communicates with the controller via software with the use of PPI (Point-To-Point Interface) protocol. A new control algorithm has allowed to perform tests according to testing specification without significant overshoots.

Originality/value: On-off control algorithm has been proposed for a combined heating-cooling installation rarely using in the industrial solutions.

Keywords: Numerical techniques; Rapid prototyping; Engineering design; Automation engineering processes

1. Background

A double-tube hydraulic damper consists of a few bypassed chambers and a piston moving up and down in a liquid-filled cylinder. The piston is kinematically forced to move within the cylinder, a pressure differential is built across the piston and which forces liquid to flow through restrictions (orifices) and valves located in the piston and the base-valve assembly (Fig. 1).

The presence of the piston divides the cylinder space in to two chambers: (i) the rebound chamber, that portion of the cylinder above the piston and (ii) the chamber, that portion below the piston.

The piston action transfers liquid to and from the reserve chamber, surrounding the cylinder, through the base-valve assembly located at the bottom of the compression chamber. There are two main leakage paths in a shock absorber which are sealed: leakage through the cylinder wall and the piston, and leakage between the rod and its guiding component. In the area of our interest is the former sealing system. It consists of a self-lubricated bearing, and the controlled bypass from the rebound chamber to the reserve chamber. This bypass is open when the rod moves inside the tube.

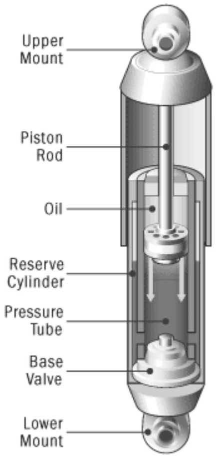

Fig. 1. Shock absorber cross-section

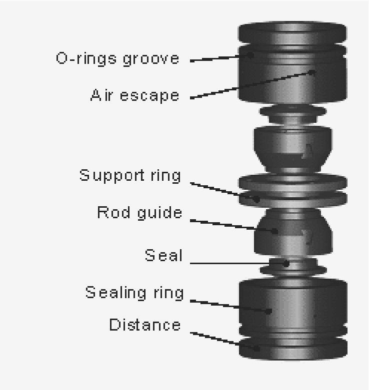

Fig. 2. Seals with rod-guide

The function of the bypass is dearation of the rebound chamber since the presence of entrapped air results in a large piston displacement during the oil compression stroke. The intended tester was designed to support the investigations on the rod-guide seals (Fig. 2). The main contributors of the seal durability are internal pressure, temperature and mechanical wear. The tester allows to perform tests under controlled exposure to temperature and mechanical friction resulted from a shock absorber side load. [1-8] [11-17]

2. Device description

The hydraulic scheme of the tester is presented in Fig. 3. It consists of heating and cooling laboratory circulation devices equipped with internal reservoirs (Fig. 4). The devices provide heating and cooling medium to the heat exchanger tube through a hydraulic circuit. The heating circulator provides precise temperature control from 5°C above ambient to 200°C and features time/temperature programming through a graphic LCD display menu. The cooling circulator provides precise temperature control from -50°C to 200°C. The temperature stability for these devices is in the range ± 0.01ºC (Fig. 3).

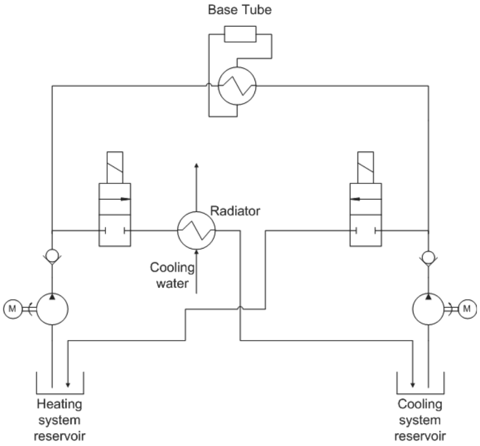

Fig. 3. Hydraulic scheme of the seal tester

Fig. 4. Heating and cooling laboratory devices

The hot and cold medium pumps provide the flow rate and pressure, which are required to achieve the demand heat exchange rate. Two gear pumps provide flow rate of Q=10 l/min, at pressure of p=5bar. Two on-off valves and two passive non-return valves control the flow through the heat exchanger. The additional plate cooler is used when the hot medium flowing to the cold tank. The basic component of the tester is the heat exchanger consisting of a reservoir (internal chamber) and the embedded pipe circuit feeding with the external hot/cold fluid medium. The reservoir is a cylindrical housing where the seals are assembled at both sides (Fig. 5). The control system passes the heating or cooling medium through the on-off valves and with the use of two main pumps. The heat exchanger is mounted on the hydraulic or mechanical testing machine which provides vertical movement of the rod inside the heat exchanger.

The oil leakage can be monitored from the top through the windows in the extended nut, and from the bottom through a transparent oil pan. The oil pan is mounted on the rod body, by a metal band clip. Therefore, the oil flowing from the inside, through the seal, is gathered in the chamber. The test is continued until the oil leakage occurs. The shock absorber seal condition is quantified based on the amount of leaked oil gathered in the oil pans.

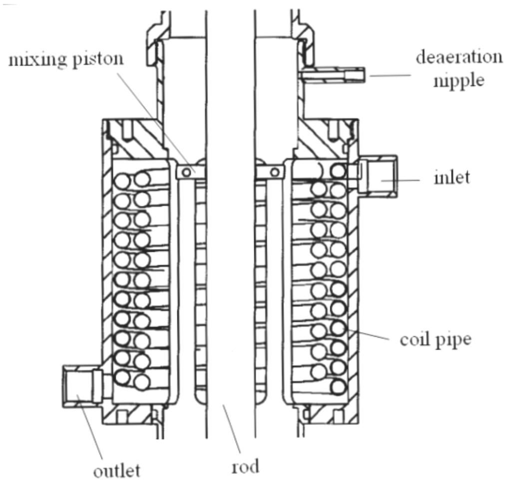

Fig. 5. Cross-section of heat exchanger tube

3. Control system

Powering and controlling functions are performed by the control box. The seal component life tester is activated by the "START", and deactivated by pressing the "STOP" button. If the "RESET" button is highlighted, the operator has to reset safety devices by pushing the "RESET" button. The PLC offers two control modes. In "AUTO" mode only the "START" and "STOP" buttons are functioning, so the operator is only able to start or stop the test. In "MANUAL" mode, the operator has full control over all the functions and can switch individual pumps or valves on or off. This mode is particularly useful for pumping oil between reservoirs or checking whether the valves and pumps are working properly. Another feature of the "MANUAL" mode is the fast cooling. The fast cooling process is activated by the "FAST COOLING" button and stopped by the "STOP" button or automatically, when the medium temperature reaches 25-40°C. The tester has a control system based on the Siemens S7-200 controller equipped with additional analog thermocouples module and the LabView data acquisition application. The temperature is maintained with the use of on-off control strategy. The valves and pumps are either on or off, with no middle state. [9] [10] The on-off control algorithm switches the output only when the temperature crosses the assumed high and low test setpoints. For heating control, the output is on when the temperature is below the setpoint, and off above setpoint. Since the temperature crosses the setpoint to change the output state, the process temperature is cycling continually, going from below setpoint to above, and back below. To prevent damage to valves, an on-off differential, or "hysteresis," is added to the controller operations. This differential requires that the temperature exceed setpoint by a certain amount before the output turns off or on again. On-off differential prevents the output from "chattering" or making fast, continual switches if the cycling above and below the setpoint occurs very rapidly.

4. Optimization

The control algorithm is foreseen to maintain the constant temperature around the seal locations. This process is disturbed by a variable stroke and velocity of the rod movement inside the heat exchanger tube affecting significantly the heat exchange processes. Moreover, the inlet and outlet of the external heat exchanger circuit are located at the opposite sides of the tube. Therefore, the temperatures are similar only when the mixing process is enough efficient. We decided to use an on-off control algorithm. The goal of this control strategy is to maintain the temperature T at the specified setpoints T_1 or T_2. To achieve this we define the control band of temperatures between $T_1+\Delta T_{1UP}$, $T_1–\Delta T_{1DOWN}$, and $T_2+\Delta T_{2UP}$, $T_2–\Delta T_{2DOWN}$, with ΔT significantly lower compared to T_1 and T_2. The ahead-time ΔT has different activation limits depending on the rise/drop thermal constants of the hot and cold circuits. For example, when the temperature is lower than the high end of the control band around the lower setpoint $T_1+\Delta T_{1UP}$, the cooling circuit is turned off. When the process temperature is lower than the low end of the control band around the lower setpoint $T_1–\Delta T_{1DOWN}$, the heating pump is turned on. The temperatures are gathered from three thermocouples. Two of them are located close to the seals and the controlled temperature is assumed as the average temperature of these two thermocouples. The temperature difference between sensors is less than 3°C during normal operation. The third thermocouple is assembled in the middle of the tube. It is used for safety reason to monitor the average oil temperature inside the tube. When the maximum temperature limit is violated the device is turned off. The electronic signals produced by the thermocouples are converted to a standard voltage signal in the thermocouple module of the controller. The sensor calibration is done in controller by means of a regression (either linear or non-linear) between the variable measured (temperature) and the voltage signal produced by the sensor. A typical test temperature band is defined by specifying the minimal T_1 and the maximal T_2 temperatures along with their durations in time, Δt_1 and Δt_2 respectively. A typical temperature range is T_1 = 90 to T_2 = 120°C. Considering typical test conditions, the maximal temperature T_2 is held constant during the time Δt_2 with the tolerance ±2°C, while the minimal temperature T_1 is held constant during the time Δt_1 with tolerance –2/+6°C. An increased error range for the minimal temperature is caused by significantly higher thermal inertia of the cooling process (hot tank capacity is half of the cold tank capacity). There an additional parameter defined for the test, namely the number N of periods of temperature changes. The temperature at the end of the test T_{end} is a predefined constant equal to 25-40°C for safety reasons. Upon the test completion (completion of all the N cycles) the control system starts the fast cooling automatically and it cools the tube to T_{end} and turns the circulators off. The algorithm settings have been optimized regarding identified rise and drop time constants of the heat exchange process. The recommended values depend on heat exchange efficiency (stroke and velocity of rod movement). The optimization has been performed by selection of the actual time when the cooling pump is turned off. The off command is sent at the specified ahead-time before the average temperature reaches the setpoint T_2. The same optimization has been done regarding the upper temperature setpoint T_1.

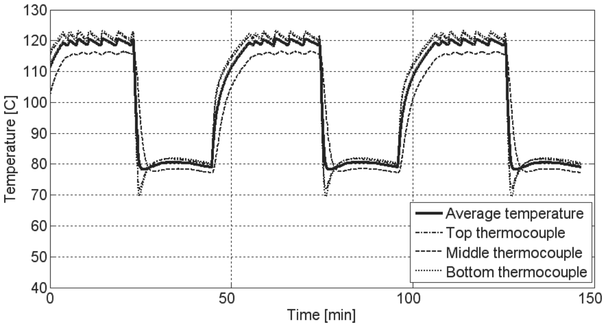

Fig. 6. The optimized overshoot of the lower temperature setpoint

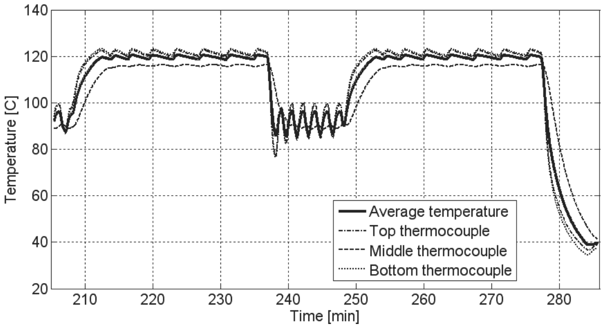

Fig. 7. The initial overshoot of the lower temperature setpoint

Fig. 6 and Fig. 7 present the temperature waveforms measured during the tests before and after optimization of the control band settings. In Fig. 6 the variation of the minimal temperature is small and thus the temperature itself approximately constant during the time interval. Fig. 7 shows a case with increased variation of the minimal temperature.

5. Conclusions

The seal component life tester is a device enabling a long-term durability test of damper seals. The purpose is to replace testing of a complete shock absorber by a component test which is more reliable and cost effective. The goal of the project is to design a test setup where durability test can be done only on the seal instead of on the complete shock absorber. The paper provides an overview concerning the optimization process of the controller settings for the PLC Siemens S7-200. The benefit of the improved control algorithm is robustness of the test at different operating conditions (different temperature setopints).

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