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Automatic Test Facility for the Wellbore Cement Integrity

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Abstract

The cement integrity represents a critical issue in the well life, because cement has to provide formation isolation and support for the casing string. This paper presents the automation system for the ITE (Institute of Petroleum Engineering Clausthal) wellbore cement fatigue testing facility. The testing facility was designed to investigate the cement fatigue by applying controlled stress. The cyclical load is achieved by a PI controller tracking a specific reference. Because the system has to be precise in a narrow domain and the controller tuning parameters cannot be online identified, an analytical approach of the control system has been used.

Key words: *hydraulic control system, cement test facility, LabView®.*

Introduction

The cement integrity is of major importance for the well bore completion. The cement functions are to isolate the well casing from geological formations, to stabilize and sustain the casing string. The new applications for high pressure/high temperature (HP/HT), water injection wells and compressed air energy storage require an extended fatigue resistance of the cement. To solve this, ITE has developed a test facility to investigate the cement fatigue over the estimated life-time of the well. The test was accelerated in order to provide information about cement integrity in a practical time. The test facility simulates the pressure changes in the well bore with a predefined frequency and magnitude. The pressure value has to oscillate up to 80 bars and the cycle length should be 1 minute. The facility consists of a specimen, a hydraulic system, and a measurement and automation device. Because the cement is very sensitive to pressure peaks a prior analyses of the system stability is required along with a fine tuning of the control parameters. The calculations must be done analytically because a system online identification can be disastrous for the specimen.

The experimental setup

The specimen (fig.1) contains a 5 ½’’ inner casing and 10 ¾’’ outer casing. The annular volume is filled with cement. The length of the cement section in the annulus is about 4 meter, which is more than 10 times the outer diameter of the casing, according to the good engineering practice. Inside the inner casing a filler bar is used to reduce the volume of the working fluid. At the bottom of the annular zone CO_2 at a pressure of 0,6 MPa is injected. When cement fractures occur the gas migrates to the upper side building pressure which is instrumented by PT2. The pressure inside the inner casing is measured through PT1. The relative displacement between the two casings is measured using the displacement transducer DT1.

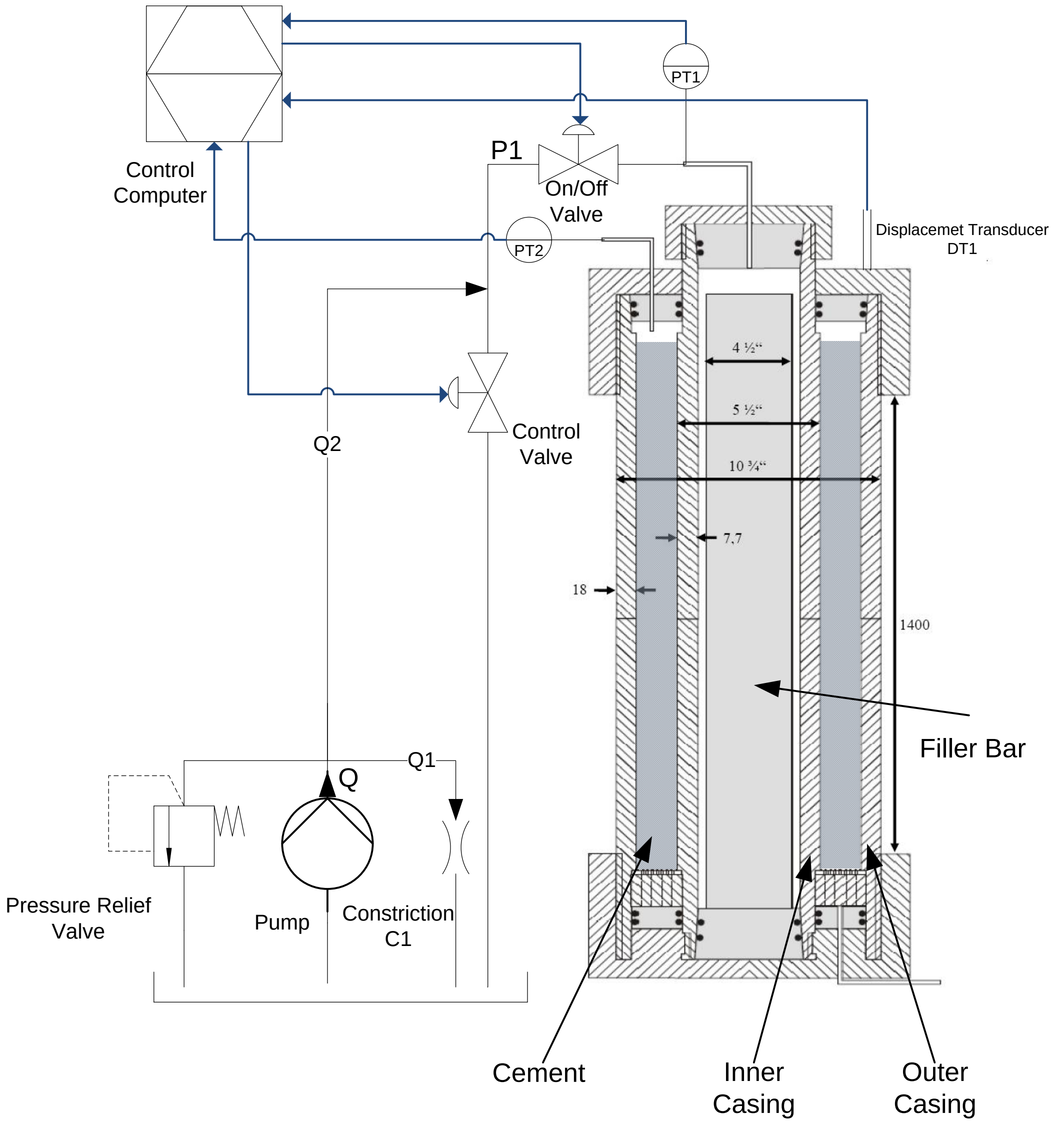

Fig 1. Test facility assembly (after Wehling 2008).

The hydraulic system contains a pump, a proportional valve, an on/off valve and a pressure relief valve. To generate the necessary pressure in the system a hydraulic pump with an electrical driven radial piston was chosen. The pump pressure (Pmax = 700 bar) is over dimensioned to avoid a continuous load at the upper limit and to allow future upgrades of the facility.

The flow supplied by the pump is partially directed to the valve, and another part is lost because of leakage (equation 1). The total pump and valve leakage (equation 2) is modeled as laminar flow through a constriction C_1. The flow through the valve is modeled using the orifice flow equation for turbulent regime (see equation 3).

$$Q = Q_1 + Q_2 \, , \tag{1}$$

$$Q_1 = C_1 P_1 \, , \tag{2}$$

$$Q_2 = C_d A \sqrt{\frac{2}{\rho}(P_1 - P_T)}\,, \tag{3}$$

where:

Q = pump flow [m^3/s];

Q_1= leakage flow [m^3/s];

Q_2 = valve flow [m^3/s];

C_1 = flow coefficient;

C_d = orifice discharge coefficient;

A = orifice area [m^2];

P_1 = specimen pressure [Pa];

P_T = tank pressure [Pa] (in this case 0 Pa).

The pressure accumulation in the specimen as represented in the equation 4, is derived from the definition of the effective bulk modulus of the oil. The ballooning effect of the specimen due to pressure is neglected.

$$\frac{dP_1}{dt} = \frac{\beta}{V} Q_2\,, \tag{4}$$

where:

V = Specimen internal volume [m^3];

β = hydraulic oil effective bulk modulus [Pa].

Figure 2 presents the schematic of the system using a PI controller, modeled with Simulink® [7]. The derived control system resembles to a system whose hydraulic force is controlled by a valve.

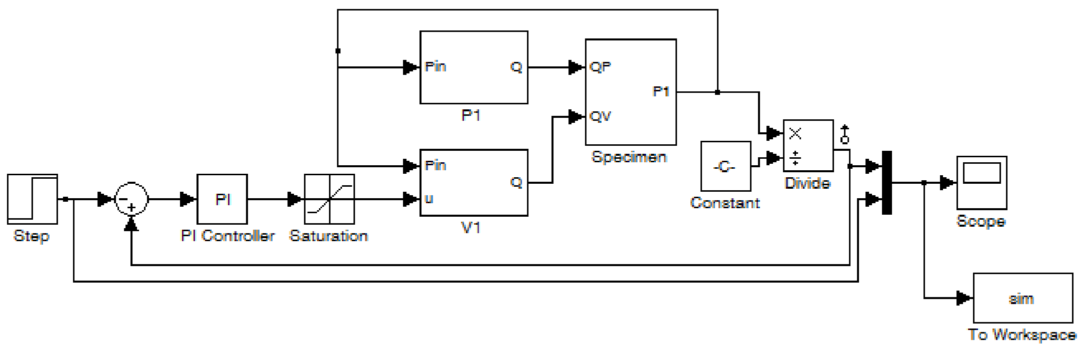

Fig. 2. The Simulink® model of the automation system.

The system is typically operated under slow pressure variations compared to the valve dynamic, and therefore the valve dynamic can be neglected. Using a standard Proportional-Integral (PI) Controller the command on the valve can be expressed as shown in equation 5:

$$u = K_e(P_{1d} - P_1) + K_i \int (P_{1d} - P_1)\, dt\,, \tag{5}$$

where:

K_e is the proportional gain;

K_i = the integral gain;

P_{1d} = the desired pressure in the specimen.

In the figure 3 the step response for the control system is presented. Initially the pressure exhibits an overshoot because the valve is normally closed and the pressure will increase inside the hydraulic circuit. This peak at the start of the facility is eliminated by an on/off valve V2, which is closed at the beginning and open after the control valve starts working. The minimal pressure of the system is above zero in order to keep an artificial load on the pump (for this case the minimum pressure is set to 20 bar). After 6 seconds a set point of 80 bars is applied and the control valve starts to close in order to increase pressure in the specimen. The trajectory exhibits a first order response with a low overshoot. This case simulates the worst situation because in reality, the system is stimulated with ramp signals.

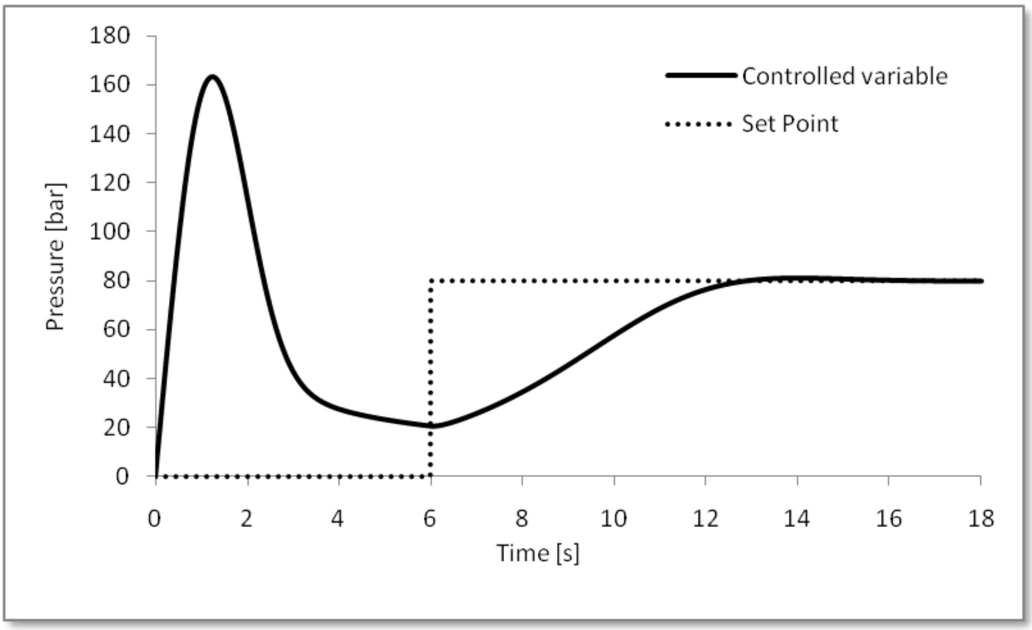

Fig. 3. Time response of the automation system.

The implementation of the control system

Center of the measurement and control system is a PC equipped with a measurement card and LabView® application software [5]. The system is based on the state machine sequences in order to initiate the system and to generate the required set points. The following values can be adjusted on the desktop (see fig. 4) and allows the control and change of the pressure cycles and respectively the loads acting on the cement.

Physical Values

- Maximal System Pressure
- Minimal System Pressure
- Correction Factor for the Strain Gages

Time limits

- Pressure Build-up Time
- Pressure Hold-up Time
- Pressure Draw-down time
- Pressure Hold-down time

Data Logging

- Data Logging Rate

The block diagram of the LabView® program is presented in figure 5. The machine state manager block coordinates the activity of the application component modules.

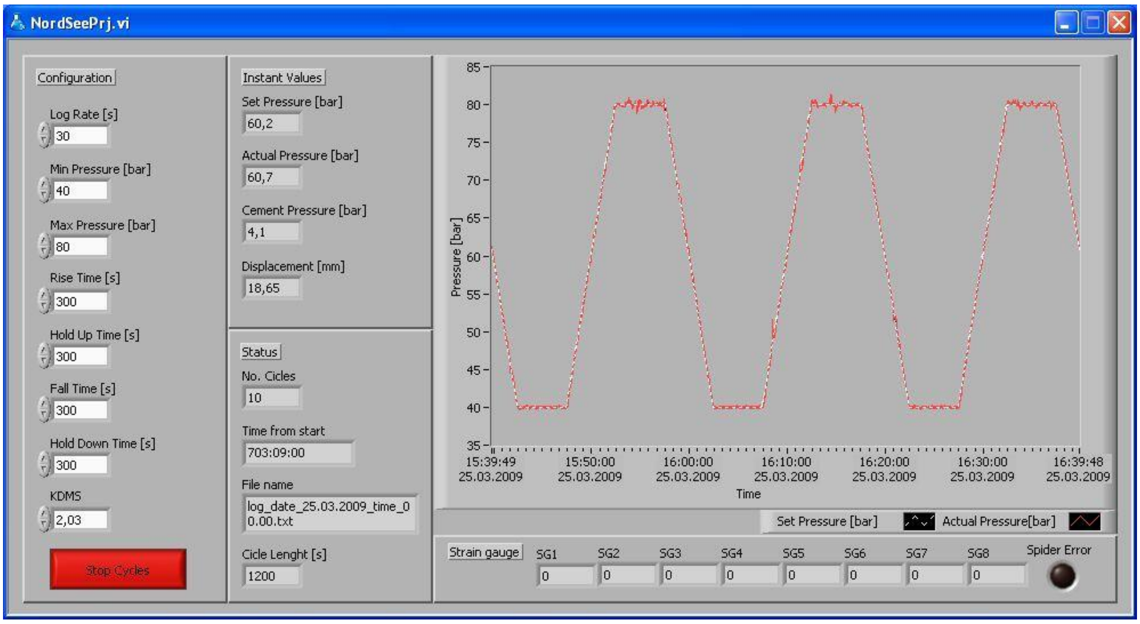

Fig. 4. The control application interface.

The application is able to log the values of 8 strain gages, two pressure transducers and a displacement transducer. The strain gages are applied on the external surface (cement contact) of the inner casing to identify the hoop stresses caused by internal pressure. The pressure sensors measure the pressures inside the inner casing and in the annular region. A significant variation of the pressure in the annulus shows a failure in the cement structure. The displacement sensor reads the relative displacement between inner and outer casing.

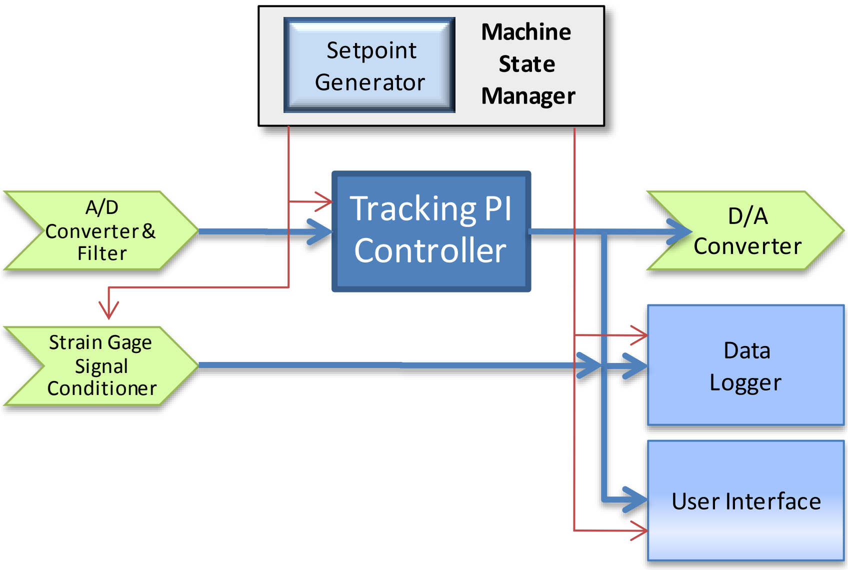

Fig. 5. Functional blocks of the LabView application.

The software logs data from the measurement devices and writes them into a file. Every day a new file is created, to keep the file size low for faster processing. The controller tracks the set point changes generated by a functional block. The initialization and the shut-off of the facility are designed to assure a slow transition of the pressure.

Results and discussions

As shown in figure 3, any uncontrolled peak may generate a system failure. The tuned controller has shown that such peaks can be modified by adding small delays in valve opening. Figure 4 shows that the controller is able to hold a constant pressure value with minimal fluctuations. To protect the system against peaks, several offline simulations have been performed to identify the maximum possible peaks induced by the system. Once those values have been identified, the PI controller gain values have been accordingly modified.

Conclusions

The ITE cement testing facility to investigate the fatigue life of the cement and the mathematical model to design the right controller of the system were presented. The use of an empirical procedure to tune the controller is dangerous for the cement integrity, considering that the safe pressure limits and pressure dynamic can be easily exceeded. The initial PI controller gains were determined using Simulink® control design toolbox furthermore a future fine tuning of the facility was performed to achieve more reliable results.

References

1. Jelali, M., Kroll, A. – *Hydraulic servo-systems; modeling, Identification and control*. Springer Verlag, London, 2003.
2. Manring, N., – *Hydraulic control systems*. WILEY-VCH, New Jersey, 2005.
3. Merritt, H. – *Hydraulic control systems*. John Wiley & Sons, 1967.
4. Poley, R. – *Using simulation software to simplify DSP-based Electro-Hydraulic Servo Actuator Designs*., Texas Instruments Inc, 2006.
5. Sumathi, S., Surecha, P. – *LabView based advanced instrumentation systems* . Springer Verlag, Berlin, 2007.
6. Wehling, P. – *Cement Integrity Testing Accelerated Life Test in a Large Scale, Annular Geometry Cement Test Center Prototype*. Master Thesis, 2008.
7. * * * – *Simulink Control Design 2.5*. MathWorks, 2008.

Instalaţie automată de testare a integrităţii cimentului de sondă

Rezumat

Această lucrare prezintă componentele şi sistemul de automatizare a unei instalaţii de testat cimenturi pentru sondele de foraj. Integritatea cimentului reprezintă un punct cheie pentru durata de viaţă a sondei asigurând protecţie contra formaţiunii geologice exterioare. Instalaţia a fost proiectată pentru a investiga oboseala cimentului de sondă prin aplicarea controlată de stres. Testele ciclice sunt controlate de un regulator PI ce urmăreşte un set de referinţe. Deoarece sistemul trebuie să fie foarte precis iar determinarea parametrilor regulatorului exclude o identificare online, se impune o abordare analitică a proiectării sistemului de control.