Chapter 2

Description of the Experimental Setup
2.1 Introduction

In this chapter a description of an experimental setup for an electrohydraulic actuation system is presented. It has been installed in the Hydraulics Laboratory of the Mechanical Engineering Department of Jadavpur University. All its principle components are discussed in the context of characterization experiments carried out for designing a sliding-mode controller.

2.2 Description of the Experimental Setup

Figure 2.1 schematically depicts the components in the experimental setup of a simple electrohydraulic actuation system. The principle components of the system are a hydraulic power pack, control valves, hydraulic cylinders, loading arrangements, sensors and a data acquisition system with controller. The hydraulic power source consists of a pump providing pressurised oil to the actuator, an electrical motor driving the pump, a relief valve RV that protects the system from over pressurization, a high pressure filter HPF for removing unwanted particles from the oil, a check valve CV to prevent reverse flow of oil to the cylinder, an oil cooler, a level indicator and a pressure gauge.

The control valves include a proportional valve PV with a voltage control card VCC for directing the pressurised oil in the left or right chamber of the hydraulic cylinder, four shutoff valves SV1 to SV4 that are essential to make either of the two hydraulic cylinders D or S operational. While S is a single rod cylinder, D is a double rod cylinder. The sensors include a Linear Variable Displacement Transformer LVDT for measuring piston displacement and two pressure transducers for measuring cylinder chamber pressures. All these sensors and a loading compression spring are shown as connected with the cylinder pistons. The real time system RTS is a combination of the data acquisition system DAQS and the controller. While the DAQS acquires the system data, the controller controls the PV with voltage signal to either of its solenoids through the VCC. The control is developed and embedded in the RTS from the host PC (connected to the RTS) which also stores all the sensor data.
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Fig. 2.1: The Experimental Setup for the Electrohydraulic Actuation System

The pump used is an axial piston pump of BRUENINGHAUS HYDROMATIK – make, having a rated flow of 60 lpm with pressure range of 0 to 140 bar and rotational speed of 1450 rpm. It is driven by a KIRLOSKAR – make, 3 Phase Induction type motor having a rated output power of 22 kW, with rated input of 415V±10% and 38 A, running at a specified speed of 1470 rpm.
The relief valve RV used in the setup is a direct operated pressure relief valve of Mannesmann Rexroth – make with pressure setting adjustments up to 315 bar with a permissible fluid temperature range of -30 to 80°C and viscosity range of 10 to 800 mm²/s.

The 4WRE 10E1 – 50 – 21/G24K/V proportional valve PV from REXROTH BOSCH GROUP has internal electrical position feedback. It weighs 6.3 kg and has specified nominal flow of 50 lpm, maximum flow of 80 lpm and input voltage of ±10V DC. The principle parts of the valve include a control spool with compression springs sliding inside a sleeve having port cuts, two solenoids, a housing with mounting face, a position transducer and the mechanical zero point adjustment. With the solenoids de-energised, the control spool is held in the central position by the compression springs. Direct operation of the control spool is possible by energising any one of the two proportional solenoids. The mounting face consists of four ports P, T, A and B – to be connected to the pump line, tank line and the two ports of a hydraulic cylinder – respectively. Depending on which one of the solenoids is energised with a control voltage from the Rexroth make amplifier card VCC with serial no. VT-VRPA2-1X/V0/T, the spool moves either to the left or right from the central position. Correspondingly port P is connected to either A or B and port T to B or A. This causes the piston within the cylinder to move to left or right from its initial position.

One of the two hydraulic cylinders used consist of a symmetric, double-acting actuator, with specified stroke of 200 mm, operating pressure of 140 bar, piston diameter of 50 mm and rod diameter of 30 mm. The other one is an asymmetric double-acting actuator of make REXROTH with specified stroke of 200 mm and operating pressure 140 bar. It has a piston diameter of 40 mm, rod diameter of 20 mm.

The setup also includes a Polyhydron check valve, a HYDAC standard high pressure filter that is capable of handling pressure up to 420 bar, a HYDAC INTERNATIONAL oil cooler handling 100 lpm of oil flow at a maximum pressure of 16 bar and temperature of 130°C.

The spring used is a compression spring. It is of medium-carbon steel with 0.31m free length, outer diameter of 0.09m, wire diameter of 0.012m and number of turns equal to 9 with material shear modulus value of 65GPa. The stiffness of 39500N/m has been found out experimentally by Das (2011).
The **LVDT** is from GEFRAN with a range of 0 to 200mm, repeatability of 0.01 mm, 0.05% linearity and resolution of 0.1mm. The two digital pressure transducers used from ASEC are piezo-resistive in nature, with a range of 0-100 bar and output of 0-10 V.

The data acquisition system used in the setup is a compact-reconfigurable-input-output real-time system, or **cRIO RTS**, from National Instruments. It consists of the NI cRIO-9004 which is an embedded real-time controller that features an industrial 195 MHz Pentium-class processor for deterministic and reliable real-time applications. It contains 64 MB of DRAM memory and 512 MB of non-volatile Compact Flash storage for file storage. The real-time processor comes along with DA and AD signal converters, 0-10V 4 channel simultaneous analog input module NI-cRIO 9215 and ±10V 4 channel simultaneous analog output module NI-cRIO 9263.

### 2.3 Operation of the Experimental Setup

Figure 2.2 depicts the **PV** to have four ports **P, T, A and B** for the discharges $Q_s, Q_r, Q_1$ and $Q_2$ respectively supplied by the pump, returning to the tank, feeding one of the Cylinders **S or D** and receiving from the corresponding other end. In Fig. 2.2, two pressure transducers **PT1** and **PT2**, a pressure gauge **G** together with the **CV** and the **RV** are shown along with the pump by their usual symbol.

In the actuation circuit shown in Fig. 2.2, Ports **A and B** of the valve is seen as connected to Ports **a1 and a2** of either **S or D**. The motion of a piston inside either of the cylinders can be achieved by the appropriate open and closed settings of **SV1 to SV4**. The flows are metered by command voltage input $e$ to the valve-control card, labelled in the figure as **VCC**. In turn, the **VCC** excites the push-type Solenoid **a or b** depending on whether $e$ is negative or positive respectively.

In Fig. 2.2, the **PV** has been shown symbolically in terms of four flow ports, two solenoid ports and three sets of valve positions by three blocks. The central block shows the flow port connectivity at the null and within the range of threshold voltage excitation. The left and right blocks correspond to beyond-threshold positive and negative voltage excitations respectively.
As long as the pressure $P_p$ is below the cracking pressure of $RV$, the entire pump flow $Q_p$ is directed to the $PV$ as discharge $Q_s$ through Ports $P$. This, along with the discharge $Q_r$ from $T$ are called unmetered, since the ports always remain open, whereas the discharges $Q_1$ and $Q_2$ at Ports $A$ and $B$ respectively are called metered and takes place as inclined jets. These orifice openings depend on the displacement of the respective spool lands controlled by the setting of $e$. Relatively wider spool lands than the corresponding axial cuts at Ports $A$ and $B$ that is referred as deadband is a feature of a proportional valve. Hence, there exists threshold voltage range of $\pm e_0$ within which all the discharges would take place as axial leakage flows.

Both the cylinders shown in Fig. 2.2 are horizontally mounted and externally loaded by a compression spring. In the figure, the input and output modules of the RTS have been shown as $IM$ and $OM$ respectively. The LVDT feeds a voltage signal equivalent of $y_{LVDT}$ to the $host$ $PC$ through the $IM$. From the $host$ $PC$, the $OM$ routs a command voltage $e$ in the range of $\pm 10V$ to the $PV$.

The present setup has been used to obtain simplified friction models for the two actuators which are used in control formulation. The simple friction model has been characterized in the set up shown in Fig. 2.2 with the springs dismantled. The LVDT and pressure transducers $PT1$ and $PT2$ have been used to obtain the necessary velocity and force. Using the built-in

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differentiator in Labview to process the acquired **LVDT** data of piston position received by
the **RTS** through the **IM**, the piston velocity in the simple model has been determined.

### 2.4 Summary

The description of an experimental setup for an electrohydraulic actuation system is
presented in this chapter. All its principle components as well as the operation of the
experimental set up are discussed in the context of characterization experiments carried out
for designing a sliding-mode controller.