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Pearson BTEC Level 5 Higher Nationals in Engineering (RQF)

Unit 45: Industrial Systems

Unit Workbook 2

in a series of 4 for this unit

Learning Outcome 2

Transducers and Controllers

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2.1 Measurement Systems and Terms

2.1.1 Measurement Systems

Measurement systems inevitably collect some form of information from the real world and increasingly the information collected will be processed and stored in a computer. We will deal with the process of making the information compatible with computers later, but it is sufficient to say at this point that most real-world events and their measurements are in an analogue form. That is, the measurements can take a wide and continuous range of values. The physical quantity of interest could be temperature, pressure, velocity, position or any other aspect of the system under consideration. In order that the measurement of interest can be processed by our measuring system, these physical quantities need to be converted to some form that can be recognised by the measuring system. These will usually be electrical quantities such as voltage, current, or impedance and the device which undertakes this conversion is a transducer. The analogue voltage or current is then converted into a digital signal which can be interpreted and processed by a Digital Control System (DCS) or computer system. Thus, the general arrangement of a measuring system is as shown Fig.2.1 below.

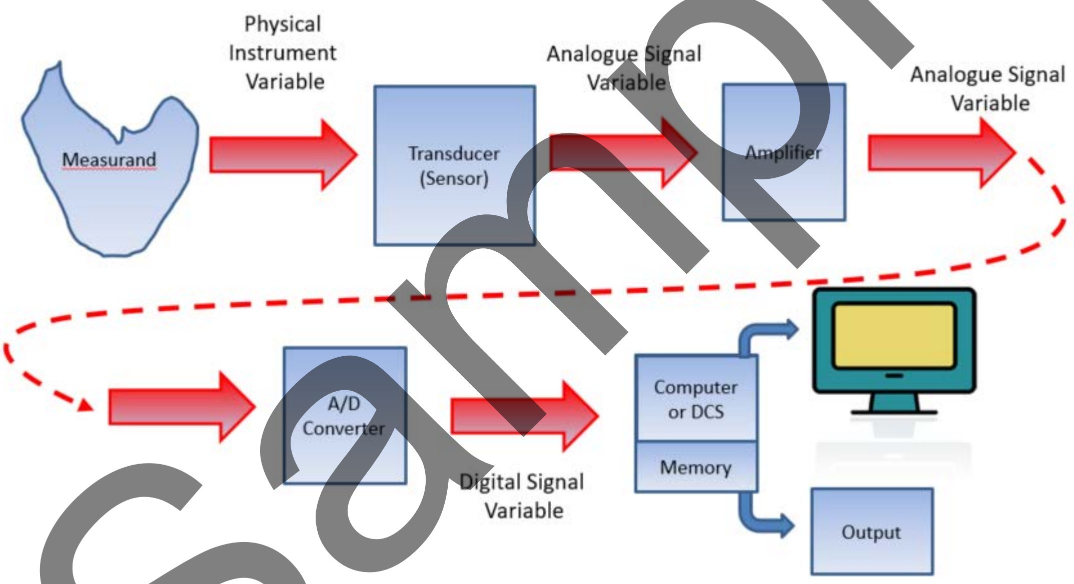

Fig.2.1: General arrangement of a measuring system

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2.1.2 Transducers

Most data acquisition signals can be described as analogue, digital, or pulse. While analogue signals typically vary smoothly and continuously over time, digital signals are present at discrete points in time. In most control applications, analogue signals range continuously over a specified current or voltage range, such as $4 - 20\text{ mA}$ DC or $0 - 5\text{ V}$ DC. While digital signals are essentially on or off, analogue signals represent continuously variable entities such as temperatures, pressures, or flow rates. Because computer-based controllers and systems understand only discrete on/off information, conversion of analogue signals to digital representations is necessary.

Transduction is the process of changing energy from one form into another. Hence, a transducer is a device that converts physical energy into an electrical voltage or current signal for transmission. There are many

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different forms of analogue electrical transducers. Common transducers include load cells for measuring strain via resistance, and thermocouples and resistance temperature detectors (RTDs) for measuring temperature via voltage and resistance measurement, respectively. Transmission channels are many and varied and we will discuss these later in this workbook.

The operation of a transducer can be described by Eq.2.1, where H is the transfer function.

$$Output\ Quantity = H \cdot Input\ Quantity \qquad \text{(Eq.2.1)}$$

For the purposes of this course, all transducers convert physical quantities into electrical ones; in other words, they convert one form of energy into another. Given that the transducer is at the front end of measurement operations, its properties and performance are critical to the performance of the measurement system as a whole. Some of these properties are as follows;

- **Dynamic Response** – The change in the output y caused by a change in the input x, where x and y are functions of time t.
- **Impulse Response** – Output when presented with a brief input signal, called an impulse.
- **Frequency Response** – The quantitative measure of the output spectrum of a system or device in response to a stimulus and is used to characterize the dynamics of the system. It is a measure of magnitude and phase of the output as a function of frequency, in comparison to the input.
- **Resolution** – The smallest unit of measurement that can be indicated by the measuring system.
- **Sensitivity** – The efficiency of the conversion process. It is the smallest amount of difference in quantity that will change an instrument's reading. A measuring tape for example will have a resolution, but not sensitivity.
- **Transfer Function** – The ratio of the output quantity to the input quantity of a system
- **Stability** - A measure of how the accuracy and precision of the measurement system perform over time. In other words, it is a measure of how much the output drifts in the face of a constant input. Stability will determine the required interval between calibration of the measurement system.
- **Noise** – There are many sources of noise in electronic systems, but all electronic systems are subject to it and exhibit random fluctuations of output for no discernible input.
- **Signal to Noise Ratio (SNR)** – Simply the ratio between the wanted signal and the unwanted background noise. Obviously, it is desirable that the SNR is as high as possible.
- **Dynamic Range** – Dynamic range is a term used to describe the ratio between the smallest and largest signals that can be measured by a system. The dynamic range of a data acquisition system is defined as the ratio between the minimum and maximum amplitudes that a data acquisition system can capture.
- **Linearity** - Describes how accurate measurements are across the complete expected range of the measurements. It answers the question about how accurate the system is across the dynamic range of the system.

2.1.3 Types of Transducers

There are a large number of different types of transducers available, the idea behind most of them are to convert the physical attributes they detect into an electrical signal which is then processed by the controller.

- **Temperature Sensors** – Used to measure variations with transfer with temperature, following well-characterised transfer functions. This should be no surprise since nearly all electronic components have

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2.2 Automation

The goal for an industrial system is to reduce the amount of human intervention required, and so automating as many processes as possible is desired. For this we need to choose the right component for the job.

2.2.1 Relays

Relays are used as a switch to activate a high current circuit, but to save energy they can be used on a low circuit current on the side. Once the low circuit current is complete, the relay uses a small coil to generate a magnetic field. The magnetic field will pull the switch in the high current circuit, which will complete the circuit. Once the low circuit is disconnected, the magnetic field disappears, and the high circuit switch will also disconnect by using a spring to pull it away.

2.2.2 Solenoids

Solenoids are used to convert an electrical signal into a linear displacement, the can be used to push and pull an object or can be used to "pinch" something into place. Solenoids use the electrical signal to create a magnetic field through a coil, the metal casing completes the magnetic circuit, which will, in turn begin to move the pole.

2.2.3 Motors

Motors convert the electrical signal into a rotational displacement and have already been discussed in more than enough detail in Workbook 1.

2.2.4 Pneumatics

Pneumatics is the principle of using air pressure to push a piston in a hollow cylinder to create a linear displacement. By using an external compressor, the more air that is pumped into the cylinder, the piston will move up. When the piston needs to drop down the cylinder, the air is bled off slowly to provide a controlled descent. However, due to the compressibility of gases, a substantial pressure difference is required to produce the necessary force.

2.2.5 Hydraulics

Hydraulics also use fluids to move a piston through a cylinder, but in this case the fluid is incompressible. Hydraulics operate with two classes of piston, the "Master" and the "Slave" piston, the master piston is the dictator in the system and controlled by the operator, while the slave piston is the one that will move as a result. One of the most common hydraulic systems in day-to-day life are the brakes in cars. Fig.2.2 shows a basic schematic of a hydraulic system in place, the master piston is shown as the one receiving the operator's "effort force" F_1, and the slave piston is applying the "load force" F_2.

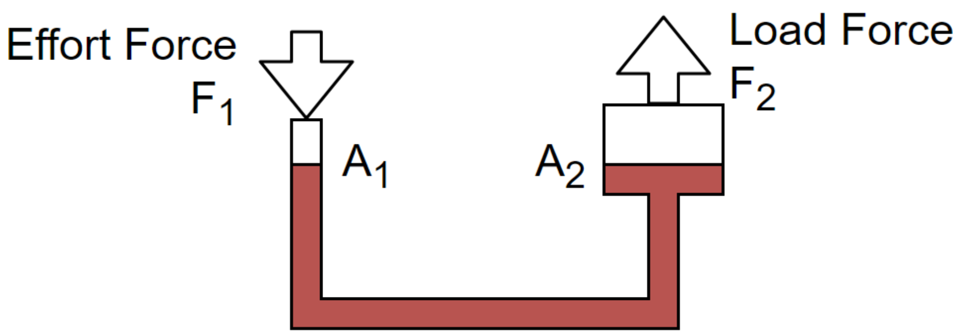

Fig.2.2: Hydraulic diagram

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The force on each piston F can be given as Eq.2.2, where P is the pressure and A is the area of the piston.

$$F = P \cdot A \qquad \text{(Eq.2.2)}$$

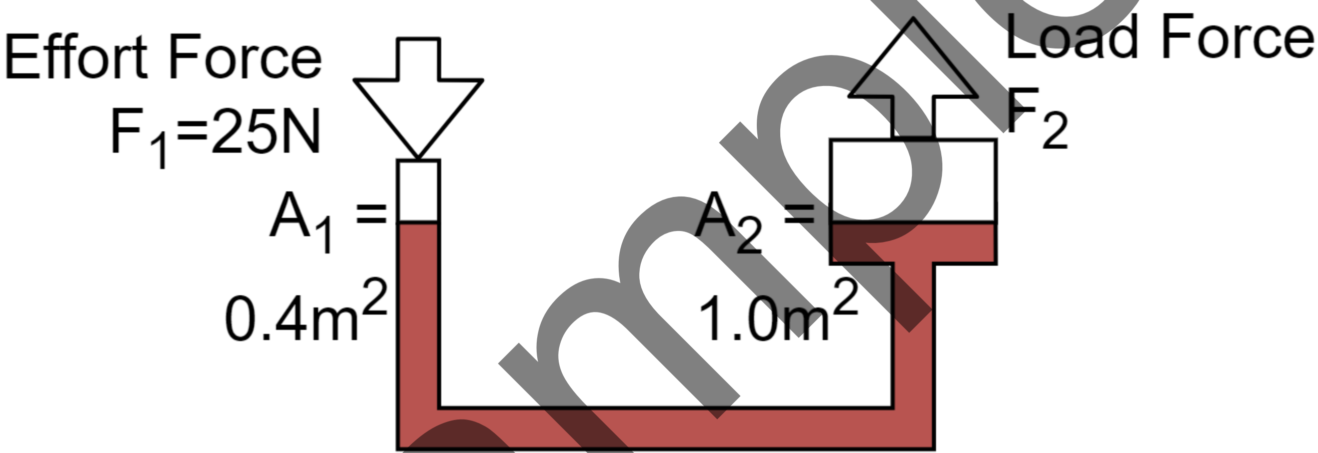
Since hydraulics are closed systems then the energy and work transmitted out of the system is zero, which means that the pressures on each piston is the same, which means that the load force generated can be calculated using Eq.2.3.

$$F_2 = F_1 \cdot \frac{A_2}{A_1} \qquad \text{(Eq.2.3)}$$

Example

A master piston, which has a cross sectional area of 0.4m^2 receives an effort force of 25N to push a slave piston with a cross-sectional area of 1.0m^2. Calculate:

1. The pressure created on the fluid by the effort force.
2. The load force exerted.



1. The pressure is given as:

$$P = \frac{F_1}{A_1} = \frac{25}{0.4} = 62.5\text{Nm}^{-2}$$

2. Since this is a closed system, the resultant load force can be calculated as:

$$F_2 = P \cdot A_2 = 62.5 \cdot 1.0 = 62.5\text{N}$$

Hydraulics can be found in a lot of heavy equipment, such as cranes, diggers, etc. However, one of the most common uses is found in the brakes of a car. As the driver pushes the pedal, the small master cylinder pushes down on the hydraulic fluid, which will then push the slave pistons and clamp down on the brake discs, which will slow the turning speed of the wheels. A basic schematic of a car's brakes can be seen in Fig.2.3.

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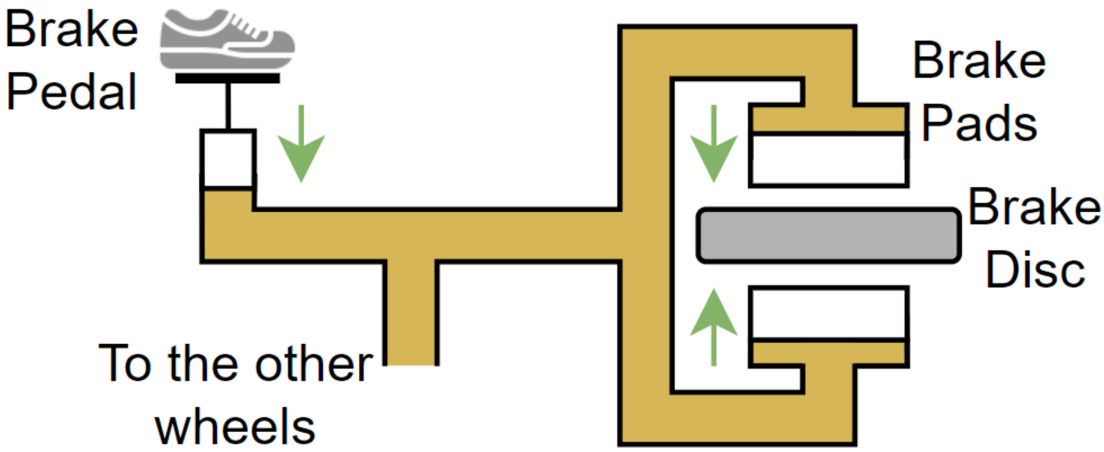

Fig.2.3: A schematic of a vehicle's braking system

This is a basic system, and one that is prone to "locking", in which the brake disc does not rotate, and the wheel will slip. The solution for this is anti-lock brakes, which will incorporate a tachometer and several "bleed" valves in the hydraulics. Once the system detects that the brakes are locking (the tachometer will sense zero rotation), the bleed valves will open and reduce the pressure on the brake pads will release the disc and allow it to rotate once again. With the disc rotating once again, the valves close and the brake pads are again pushed against the brake disc. Essentially creating a rapid clapping motion to optimise braking performance.

2.2.6 Electronic Actuators

An electronic actuator converts electrical energy into torque by using a motor. The motor turns a lead screw which, in turn, will start to twist a nut that is not allowed to just rotate with the screw. Instead, as the screw rotates, the nut begins to move up (or down the thread, depending on the direction the screw is turning).

Video The URL below gives a visual explanation of an electronic actuator.
https://www.youtube.com/watch?v=fdY5gVvozEo

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