Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 21: Electrical Machines

Unit Workbook 3

in a series of 3 for this unit

Learning Outcomes 4

Electromagnetic Transducers and Actuators

Contents

INTRODUCTION

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose

Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory

Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example

The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question

Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge

You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

Sensors and Transducers

Transducers

Transducers are the name given to components that converts variations in a physical quantity (pressure, brightness, temperature) into an electrical signal, or vice versa. They are used in data acquisition to produce the electrical signal and feed it to a microcontroller, the microcontroller will analyse the signal and decide if the system needs appropriate adjustment.

Theory

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 $4 - 20$ mA DC or $0 - 5$ 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 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.1.1, where H is the transfer function.

$$Output\ Quantity = H \cdot Input\ Quantity \qquad \text{(Eq.1.1)}$$

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.

Types of Transducer

There are a large number of different types of transducer 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 properties that vary with temperature. Many of these components could potentially be used as temperature transducers if their transfer functions were well behaved and insensitive to other variables. Examples include; Thermocouples, Thermistors, Resistance Temperature Detectors, and Monolithic Temperature Transducers.
- **Optical Sensors** – Used for detecting light intensity. Typically, they respond only to particular wavelengths or spectral bands. Examples include; Vacuum Tube Photo Sensors, Photoconductive Cells, Photovoltaic (Solar) Cells, Semiconductor Light Sensors, and Thermoelectric Optical Sensors.
- **Position Displacement Sensors** – Used to measure mechanical displacement or position of an object. Some require physical connection to the object, others do not. Examples include; Potentiometers, Capacitive and Inductive Sensors, Linear Voltage Differential Transformers (LVDT), Optical Encoders, and Ultrasonic Range Finders.
- **Force and Pressure Transducers** – Used for measuring force and pressure. Most pressure transducers rely on the movement of a diaphragm mounted across a pressure differential and the transducer measures minute movements in the diaphragm. Capacitive and inductive pressure sensors operate in a similar way to capacitive and inductive displacement sensors. Examples include; Strain Gauges, and Piezoelectric Transducers.
- **Magnetic Field Sensors** – Measure either varying or fixed magnetic fields.
- **Ionising Radiation Sensors** – Ionizing radiation can be particle produced by radioactive decay, such as alpha or beta rays, or high-energy electromagnetic radiation, such as gamma rays or X-rays. In many of these detectors, a radiation particle or photon collides with an active surface material which as a result produces charged particles which are measured as an electric current. Examples include Geiger Counters, Semiconductor Radiation Detectors, and Scintillation Counters.

- **Humidity Sensors** – Relative humidity is the moisture content of the air which can cause pressure variations in the air or can cause variation in the electrical properties of materials. Examples include; Resistive Hygrometer Sensors and Capacitive Hygrometer Sensors.
- **Fluid Flow Sensors** – Many Industrial processes involve fluids and so there is a need to measure and control their flow. A wide range of transducers and techniques are commonly used to measure fluid flow rates. Examples include; Head meters, Rotational Flowmeters, and Ultrasonic Flowmeters.
- **Fibre Optic Sensors** – A new class of sensor which tend to be immune from Electro-Magnetic Interference (EMI) and measure amplitude, phase or polarization of light. The transducer is constructed so that one or more of these parameters varies with the physical quantity of interest.
- **Micro-Electro-Mechanical Systems (MEMS)** – Small electromechanical devices made using semiconductor integrated circuits.
- **Smart Sensors** – Cover a wide variety of devices which could range from a traditional transducer that simply contains its own signal conditioning circuitry to a device that can calibrate itself, acquire data, analyse it, and transmit the results over a network to a remote computer. An emerging class of smart sensors is defined by the family of IEEE 1451 standards, which are designed to simplify the task of establishing communications between transducers and networks.
- **Rotational Motion** – Tachometers are used to measure the rotational speed of the shaft, by attaching a small magnet to a shaft, another magnet is used to generate a magnetic field, which will generate a voltage pulse in the system. By counting the number of pulses, it is possible to count the revolutions for a given time frame.

Terminology

Purpose

People make measurements for many reasons: to make sure an item will fit, to determine the correct price to pay for something, or to check that a manufactured item is within specification. In all cases, a measurement is only useful if it is suitable for the intended purpose.

Consider the following questions:

- Do you know how accurate your measurement result is?
- Is this accurate enough?
- How strongly do you trust the result?

These questions relate to the quality of a measurement. When talking about measurement quality, it is important to understand the following concepts:

Precision, Accuracy and Uncertainty

Theory

Precision is about how close measurements are to one another. Accuracy is about how close measurements are to the 'true value'. In reality, it is not possible to know the 'true value' and so we introduce the concept of uncertainty to help quantify how wrong our value might be. The difference between accuracy and precision is illustrated in Fig.1.1 below. The idea is that firing an arrow at a target is like making a measurement. Accuracy is a qualitative term that describes how close a set of measurements are to the actual (true) value (the bullseye). Precision describes the spread of these measurements when repeated. A measurement that has high precision has good repeatability.