Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 21: Electrical Machines

Unit Workbook 2

in a series of 3 for this unit

Learning Outcomes 2 and 3

Electric Motors and Generators

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.

Construction

The two basic components common to both motors and generators are;

- Rotor – the spinning part at the centre
- Stator – fixed part which surrounds the rotor

Other components of motors and generators are;

- Bearings – these provide physical support for the rotor
- Air gap – the space between the rotor and stator
- Windings – usually copper coil placed around both the stator and rotor
- Magnets – these can be found in either or both the stator and rotor
- Slip rings and brushes – present on some types

The overall construction principle for a generator and motor is shown in figure 2.

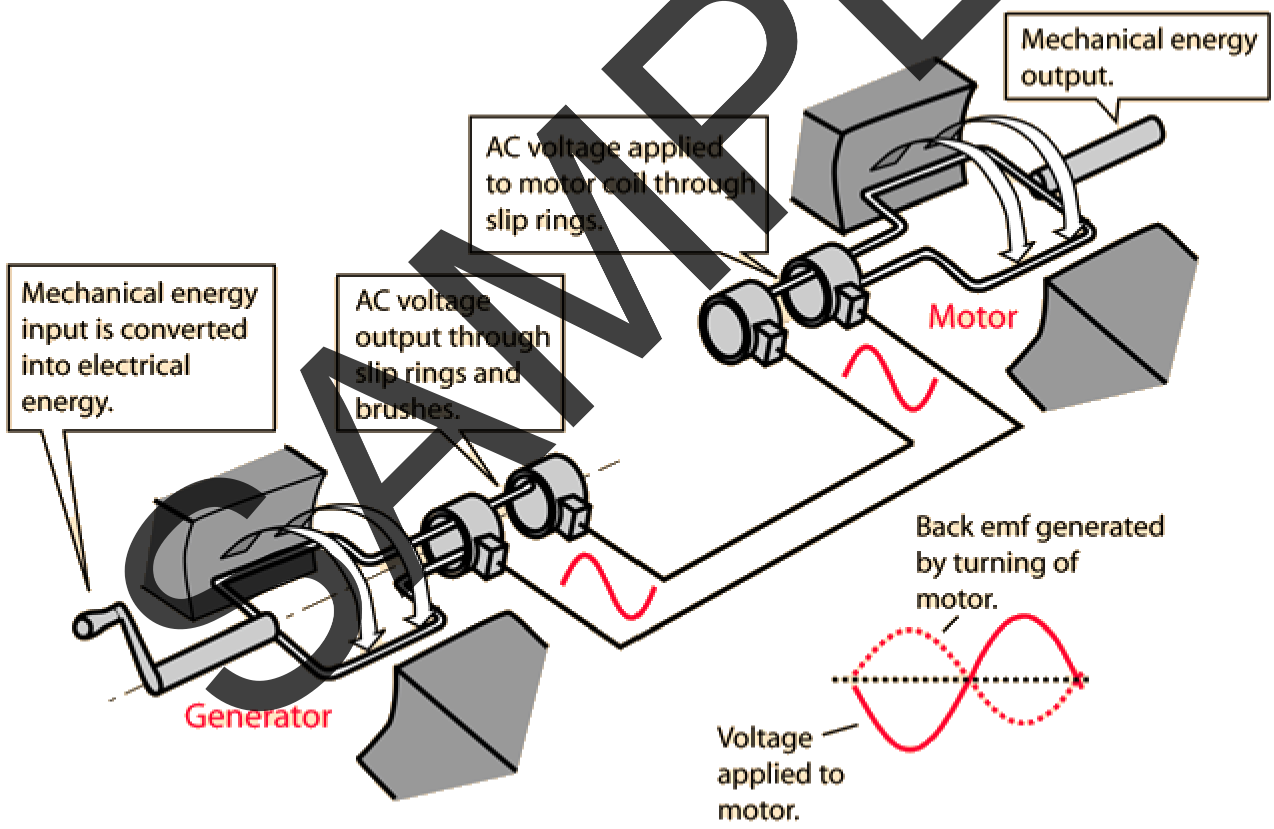

Figure 2 *An AC generator powering an AC motor*

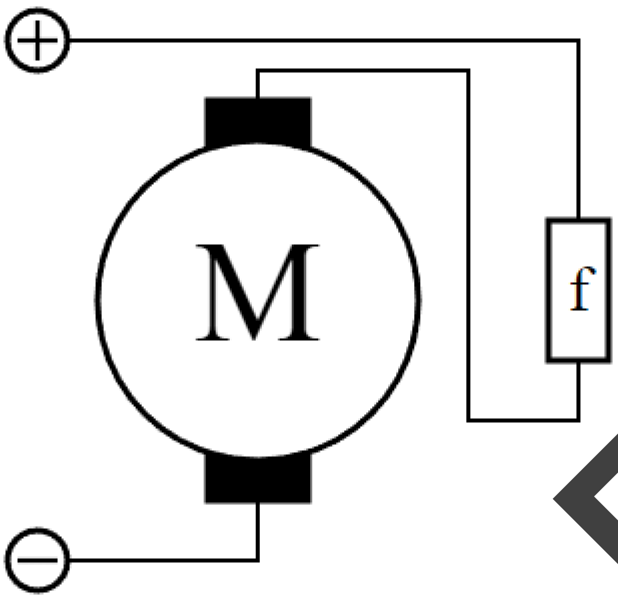

Figure 6 *Series wound brushed motor*

Shunt wound

This type has the field winding connected in parallel with the rotor winding. It can deliver increased torque, without a reduction in speed, by increasing the motor current. This type of motor is suitable for lathes, conveyers, grinders and vacuum cleaners.

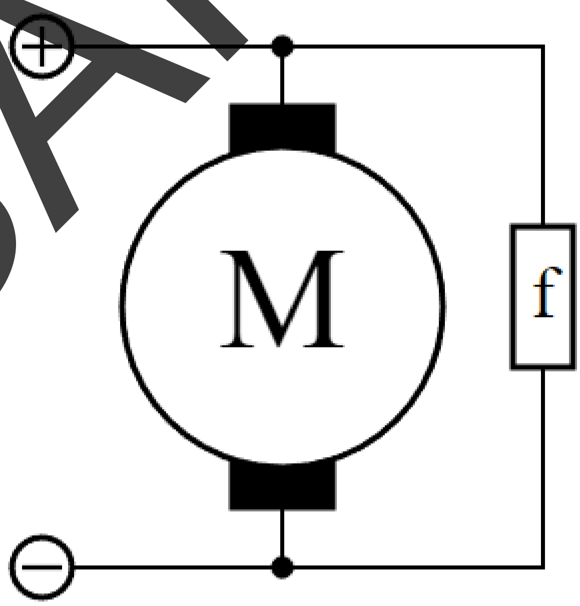

Figure 7 *Shunt wound brushed motor*

AC Motors

Synchronous

These motors have their speed of rotation synchronised with the frequency of the supply current, with the speed remaining constant with changing loads. Constant speed operation means that these motors find uses in robotics and process control.

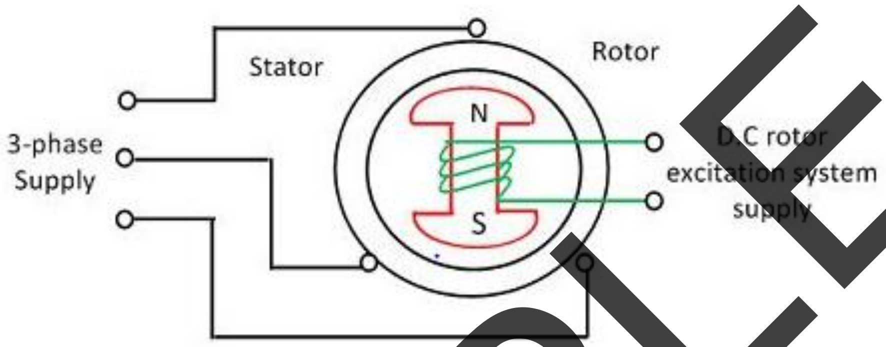

Figure 11 *Synchronous AC motor*

Asynchronous (Induction)

These are the most common types of AC motor. They use the electromagnetic field from the stator winding to induce an electric current in the rotor, and thereby torque.

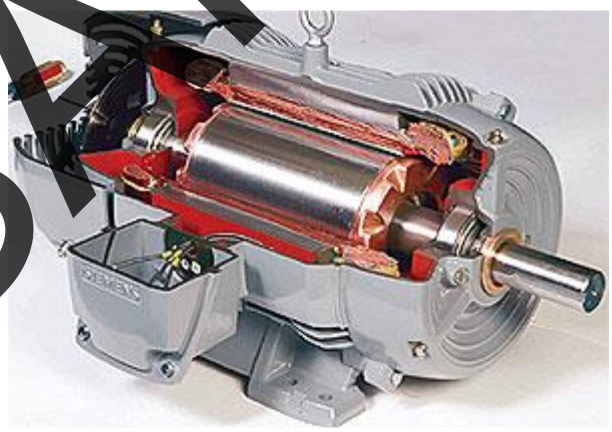

Figure 12 *Induction motor*

Single Phase

Single phase induction motors find uses in low-load applications such as household appliances.

Self-excited

The generator produces its own current to energise the field coils. As for motors, we may have series, shunt and compound arrangement for the field and armature windings.

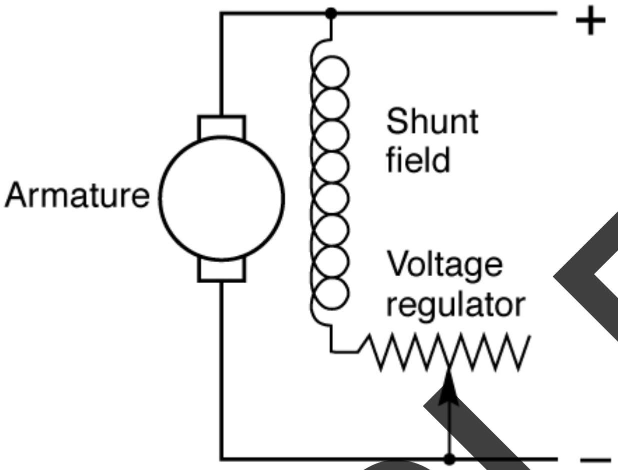

Figure 14 *Self-excited DC generator*

AC Generators

These can be categorised as either;

- Synchronous generator
- Induction generator

Synchronous generator

The coil is connected to slip rings, and the load is connected to brushes which rest on these slip rings. The slip rings are arranged in such a way that every 180 degrees of rotation sees the current direction reversed in the load; hence, an AC current is generated.

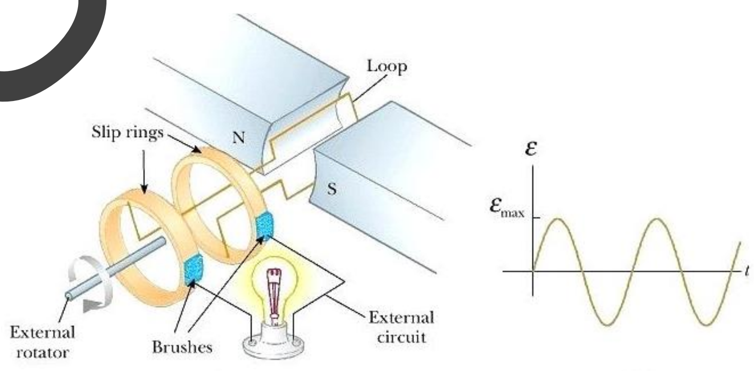

Figure 15 *Synchronous AC generator*

This is used when a star/delta starter will not provide enough starting torque. The autotransformer has just one winding per phase and one or more tapped points on each winding are used in succession, from lower voltage to higher voltage, until the motor reaches its rated speed.

Resistance or Reactance Starter

Placing three appropriately valued resistors or inductors in series with the motor, it is possible to reduce the starting current to any desired value. The downside here is that the starting torque is also reduced. Once the motor has reached full speed the resistors/inductors are shorted out with contactors.

Solid-State Soft Starter

This is a widely used starting method which allows for a smooth increase in both current and torque. The smoothness of starting prevents sudden jerks in the rotor and thereby protecting some sensitive loads. Semiconductor control circuitry and an arrangement of back-to-back thyristors is used to facilitate the smooth starting.

Quantification of Induction Motor Parameters

Rotor Voltage

Let us allocate some letters and subscripts to various quantities…

E_1 $\quad Stator\ e.m.f.(voltage)$

E_2 $\quad Rotor\ e.m.f.(voltage)$

N_1 $\quad Number\ of\ turns\ on\ stator\ winding$

N_2 $\quad Number\ of\ turns\ on\ rotor\ winding$

When the rotor is at a standstill…

$$E_2 = \left(\frac{N_2}{N_1}\right) E_1$$

The rotor e.m.f. when running (E_r) is proportional to the slip, s, therefore…

$$E_r = sE_2$$

$$\therefore \quad \boldsymbol{E_r = s\left(\frac{N_2}{N_1}\right)E_1}$$

Synchronous speed and rotor speed

Let…

$n_s = synchronous\ speed$

$n_r = rotor\ speed$

$$\therefore \quad \boldsymbol{n_r = n_s(1 - s)}$$

Efficiency and Power

Efficiency, η, can be quantified as…

$$\boldsymbol{\eta = \frac{output\ power}{input\ power} \times 100\%}$$

The main losses in an induction motor are;

- Stator losses
- Rotor copper losses
- Friction and winding losses

Torque

Let…

$R_2 = Rotor\ resistance$

$X_2 = Rotor\ reactance$

$m = number\ of\ phases$