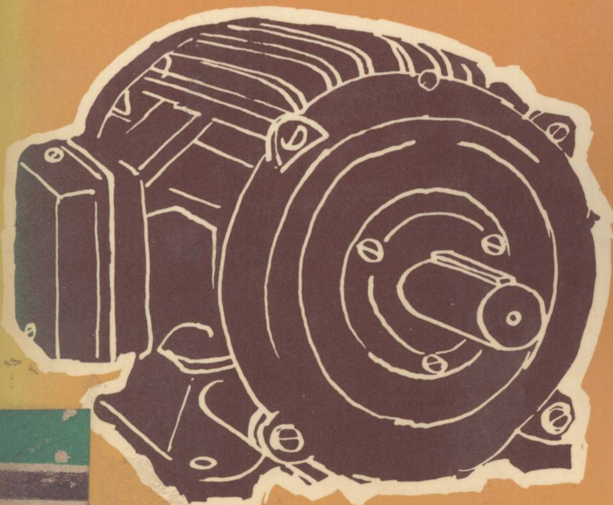
Electric Motors

Second Edition

A J Coker

Revised by P Chapman

QUESTIONS & ANSWERS



Electric Motors

Electric motors.

QUESTIONS & ANSWERS

Electric Motors

A. J. Coker
revised by
Philip Chapman

Newnes Technical Books

THE BUTTERWORTH GROUP

UNITED KINGDOM
Butterworth & Co. (Publishers) Ltd
London: 88 Kingsway, WC2B 6AB

AUSTRALIA
Butterworths Pty Ltd
Sydney: 586 Pacific Highway, Chatswood, NSW 2067
also at Melbourne, Brisbane, Adelaide and Perth

CANADA
Butterworth & Co. (Canada) Ltd
Toronto: 2265 Midland Avenue, Scarborough, Ontario M1P 4S1

NEW ZEALAND
Butterworths of New Zealand Ltd
Wellington: T & W Young Building, 77–85 Customhouse Quay, 1, CPO Box 472

SOUTH AFRICA
Butterworth & Co. (South Africa) (Pty) Ltd
Durban: 152–154 Gale Street

USA
Butterworths (Publishers) Inc
Boston: 19 Cummings Park, Woburn, Mass. 01801

First published 1965
Second edition 1976
Reprinted 1977, 1978
Published by Newnes Technical Books, a Butterworth imprint

ISBN 0 408 00200 X

Printed and bound in England by
Hazell Watson & Viney Ltd, Aylesbury, Bucks

CONTENTS

PREFACE

This book has been written for students, apprentices and technicians who need a basic introduction to electric motors. This edition maintains the philosophy of the previous one by providing information on the practical aspects of a.c. and d.c. motors and their associated control gear for all those concerned with the use, installation, operation and maintenance of motors in industry and elsewhere.

Several developments have taken place in the technology of electric motors since the appearance of the first edition of this book, and probably the most marked advance has been in the application of solid-state devices to the control of motors. The linear motor also has experienced a somewhat spectacular rise to prominence, mainly due to its potential for propulsion of mass transport systems. These two topics are dealt with in some detail. Other new features include the more recently developed types of motor-pole amplitude modulated motors, reluctance motors – and new standards relating to motor ratings.

This edition has been completely metricated and thus encourages the reader to think in metric terms rather than to go through the tedious process of conversion wherever motor power ratings, torques, etc. are quoted.

It is hoped that this new edition will be as well received as its forerunner by all those students, apprentices and technicians who need a basic grounding in the practical aspects of electric motors.

P.C.

1

INTRODUCTION

What is the standard a.c. supply voltage in Great Britain ?

Fifty-hertz, 240/415 volts, indicating 3-phase supply at 415 volts for 3-phase loads connected to the three phase lines, 3-phase 4-wire supply for connecting 240-volt single-phase loads between one or other of the phase lines and neutral, and single-phase 415-volt supply for single-phase loads connected between two phase lines.

What is phase voltage ?

The voltage between any phase wire of a 3-phase supply and the neutral wire.

What is the relationship between the phase voltage and the line voltage of a 3-phase 4-wire system ?

Line voltage = $1 \cdot 732 \times$ phase voltage.

What is a 3-wire d.c. supply system ?

A system consisting of positive and negative outers and a middle or neutral wire. The voltage between the outers is twice the voltage between either outer and neutral. For example, a 220/440-volt d.c. supply is one having 440 volts between outers and 220 volts between each outer and neutral.

What is meant by the torque of a motor ?

The turning effort developed by the motor, usually

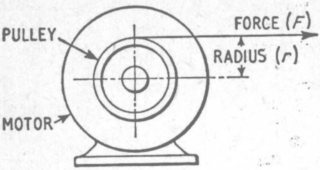


Fig. 1.—The torque of a motor

Torque is force (*F*) multiplied by the radius of action (*r*). If *F* is in newtons and *r* is in metres the torque will be given in newton metres (Nm).

expressed in so many newton metres (Nm). If the motor exerts a force of F N acting at right angles to a radius of r m from the centre of its pulley, the resulting torque is $F \times r$ Nm.

How is the torque of a motor produced ?

The production of torque requires the interaction of two sets of magnetic fields. The usual arrangement is for these fields to be produced by two sets of windings, both carrying current derived from the supply. One set of windings is situated on the stationary outer member (stator or field poles) and the other set on the rotating member (rotor or armature).

The principle is illustrated in the accompanying diagram. This shows a coil free to rotate about its axis in a magnetic field. If the coil is supplied with current, or a current is induced to flow in it, as indicated, the magnetic flux associated with this current will interact with the magnetic-field flux and produce a torque on each side of the coil. The coil consequently rotates, anti-clockwise in the case shown.

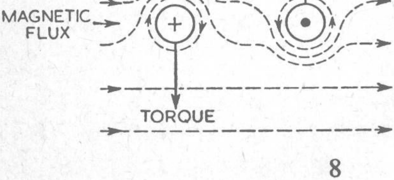


Fig. 2.—How the torque of a motor is produced

The magnetic-field flux interacts with the magnetic flux due to the current flowing in the conductors of the coil.

The principle is the same whether the currents producing the two fields originate from a.c. or d.c. supplies.

In the d.c. motor, the magnetic-field system is fixed and the current fed to the rotating armature coils is changed to alternating current in the coils by means of brushes and commutator.

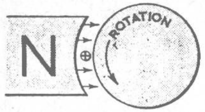


Fig. 3.—Conventional signs for magnetic polarity, direction of current and direction of rotation.

The magnetic lines of force are assumed to leave the face of a north pole.

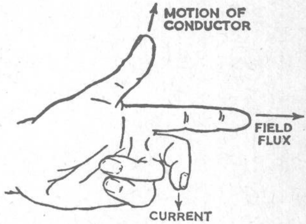


Fig. 4.—The direction of rotation of a motor is obtained by the use of Fleming's left-hand rule.

Direction of rotation depends on the direction of the main-field flux and the direction of the currents in the rotor or armature conductors.

In a.c. motors of the induction type, the stator windings are usually distributed in slots around the stator core. These windings are connected to the supply and the rotating field produced by them induces currents to flow in the rotor windings.

What torques must be considered when driving a machine ?

(1) The initial starting (breakaway) torque needed to overcome the static friction of the driven machine and thus start it away from standstill.

(2) The accelerating torque needed to run the driven machine up to full speed.

(3) The running torque when full speed is reached.

How can the initial starting torque needed for a driven machine be found ?

One method is to wrap a cord attached to a spring balance around the half-coupling or pulley of the driven machine and to give a steady pull, noting the force required to start the shaft rotating.

The starting torque required by the driven machine in newton metres is equal to

Pull (N) × radius of half-coupling or pulley (m)

An alternative method is to fix a bar along the horizontal diameter of the pulley and hang weights on the bar at a known distance from the centre of the pulley until the pulley begins to turn.

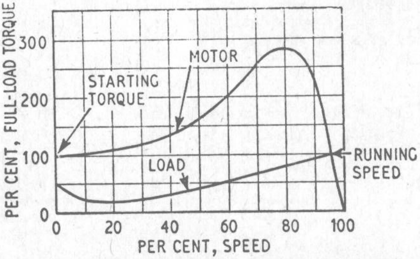


Fig. 5.—Torque/speed curves of a motor and its load

The motor curve is for a squirrel-cage induction motor. The area between the two curves indicates the torque available to accelerate the load.

How is the accelerating torque determined ?

From the torque/speed curves of the motor and the load. The point at which the torque/speed curves intersect will be where the final running speed occurs. The motor torque available for accelerating the driven machine at a particular speed corresponds to the difference between motor torque and load torque at that speed.

What is meant by the power of a motor ?

Its mechanical output or rate of doing work—the work it does per unit of time (per minute or per second). The power rating of a motor is measured in watts, or more usually, kilowatts. Motor power was formerly measured in horse-power. 1 h.p. = 746 watts.

How is the torque of a motor related to its power?

The motor exerts a force F acting at right-angles to the radius r of its shaft or pulley. Its torque is force multiplied by radius (torque $= F \times r$).

The work the motor does *in one revolution* of the motor pulley is equal to the force exerted (F) multiplied by the circumference of the pulley ($2\pi r$), that is, $F \times 2\pi r$.

The work done by the motor *in one minute* is its mechanical output or power and this is equal to work done per revolution × r.p.m., that is,

$$F \times 2\pi r \times \text{r.p.m.}$$

As we have already seen, $F \times r$ is the torque, so work done per minute =

$$\text{mechanical output} = 2\pi \times \text{r.p.m.} \times \text{torque}$$

If torque is in Nm, the power in watts is obtained by dividing by 60, which gives

$$\text{Power of motor} = \frac{2\pi \times \text{torque (Nm)} \times \text{r.p.m.}}{60}$$

Motors can be divided into two main classes in respect of their characteristic performance. What are these ?

Shunt characteristic and series characteristic.

What is a shunt characteristic ?

The characteristic of motors that have a fairly constant speed independent of load conditions within their working range from no-load to full-load. This type of characteristic is required for most industrial and many other applications and is largely met by the use of three-phase and single-phase induction motors.

What is a series characteristic ?

The characteristic of motors that have a high torque at starting and at low speed, as well as a tendency for speed to rise on light load. Such motors would not be used when a steady speed is necessary unless the load is constant. They are well suited to traction and crane applications. In fractional-kilowatt sizes, the universal motor, which has a series characteristic, is widely used.

What is meant by the time rating of a motor?

Some motors are required to carry full load all day, others to run only for a series of short periods on full load, say a few minutes at a time. The less time a motor is actually in operation over a period, the more time it has to cool down between spells of operation and the smaller its frame size needs to be. It is economical in practice therefore to classify motors as to their time rating. Various time ratings have become standardised: maximum continuous rating, short time rating or some special rating based on a particular duty cycle. The manufacturer guarantees that the motor will not exceed a certain temperature after being run on full load for a certain length of time.

What is maximum continuous rating?

This is a statement of the load and conditions assigned to the machine by the manufacturer at which the machine may be operated for an unlimited period.

What is short time rating?

This is again a statement of the load and conditions under which the machine may be operated but this time for a limited period only, starting at ambient temperature. There are several preferred periods for which short time rating may apply, these being 10, 30, 60 and 90 minutes.

For what type of application does a short time rating apply?

Applications with fairly intermittent periods of operation, such as cranes, hoists, lifts and certain machine tools that are operated only infrequently.

What is meant by the temperature rating of a motor?

The rated output of a motor is controlled by the temperature that the winding insulation is capable of withstanding. The maximum-permissible-operating temperature depends on the type of insulation and the classifications in more general use are:

Class A—cotton, silk, paper and similar organic materials when suitably impregnated.

Class E—materials or combinations of materials that are capable of operating at a higher temperature than Class A.

Class B—Mica, asbestos, glass fibre, and similar inorganic binding substances.

Class H—mica paper composites, e.g. three layers of glass cloth, mica paper and polyester film bonded with varnish to provide tough, flexible insulation.

How is the power required to drive an individual machine decided?

The power required is best obtained from the maker of the machine to be driven. In many applications the power required depends upon the efficiency of the driven machine and this can only be estimated by its manufacturer. This particularly applies to pumps, compressors, generators, centrifugal separators and fans.

For driving machine tools, the required power is increased for heavy duty and rapid production and reduced when only light work is the rule.

What calculation is commonly used to determine the minimum power required when the loads to be driven vary over a particular work cycle?

The minimum power required to avoid overheating is determined approximately by the root-mean-square method:

$$\text{Power} = \sqrt{\frac{(P_1)^2 t_1 + (P_2)^2 t_2 + (P_3)^2 t_3 + \ldots}{\text{Total time of one cycle of operation}}}$$

where P_1, P_2, P_3, etc are the powers required during the duty cycle and t_1, t_2, t_3, etc. are the periods of time in minutes corresponding to the above power demands.

How is power decided for driving a lineshaft belted to a group of machines?

If there is a sufficient number of machines, say six or more, and these are hand-controlled so that there are pauses during which no work is being done, such as for setting up, the motor power will seldom exceed half the sum of the requirements of the driven machines. A more powerful motor will be necessary when the driven machines are on full-capacity work all the time.

What is the power required for driving cranes, hoists and winches?

$$\text{Power} = \frac{\text{kg lifted} \times \text{lifting speed in m/s}}{9 \cdot 81 \times \text{efficiency of mechanical parts}}$$

An efficiency of about 0·70 may be assumed for worm and spur gearing or 0·65 if a stage of friction gearing is incorporated as in a friction hoist. These are average figures that may be exceeded in certain favourable cases. On the other hand, they may easily be less, requiring more power if the gear train consists of many stages or if badly cut or worn or if cast gears are employed.

How is the current required to supply a 3-phase motor at full-load calculated?

From details of power, efficiency and power factor. The current is equal to

$$\frac{\text{Power} \times 100}{1 \cdot 732 \times \text{line voltage} \times \%\ \text{efficiency} \times \text{power factor}}$$

How is the full-load current of a single-phase motor arrived at?

From the formula

$$\frac{\text{Power} \times 100}{\text{Voltage} \times \%\ \text{efficiency} \times \text{power factor}} = \text{current}$$

How is the full-load current of a d.c. motor calculated?

From the formula

$$\frac{\text{Power} \times 100}{\text{Voltage} \times \%\ \text{efficiency}} = \text{current}$$

What is power factor ?

The factor or percentage of the current in an a.c. circuit that is supplied in the form of energy, the remaining current being idle. This idle current is termed reactive current or wattless current.

The power factor of a circuit is calculated from $\frac{\text{kW}}{\text{kVA}}$

If an induction motor is described as having a power factor of 80 per cent or 0·8, what does this mean ?

That 80 per cent of the motor current at full load is power current, doing work, and 20 per cent is idle. A kVA demand meter or an ammeter will register the full 100 per cent of current but a wattmeter will take into account only the true energy component of the current, namely 80 per cent.

An additional point about an induction motor is that the idle or wattless current is lagging.

How does lagging wattless current arise ?

Every induction motor (or transformer or other electrical apparatus comprising coils of wire embedded in or surrounding an iron core) constitutes an inductive reactance.

If the motor is switched on to an a.c. supply, whether it does useful work or not, a current is taken from the system to excite it. This current is 90° lagging in phase on the voltage and is reactive current or so-called idle or wattless current. The only energy in this current is that required to overcome the losses and is but a small fraction of the total.

When the motor is put to work, it will take, in addition to its excitation current, a power or energy current according to the amount of work to be done and the efficiency loss in the motor. The proportion of the two currents varies according to the percentage load on the motor. Consequently, the nearer the motor runs to full power the greater will be the proportion of power current to idle current, i.e. the higher the power factor.

What is meant by power-factor correction?

Excitation current is an essential feature of a.c. induction motors (and other a.c. inductive apparatus). The demand for excitation current exists whether the motor runs loaded or light. If this current circulates back and forth in the supply system, the supply cables, alternators and other equipment have to be designed to carry it and the additional expense involved is passed on to the consumer in higher price per kW. A low power factor on the supply involves the locking up of capital by the supply authority in order to carry heavy idle current. However, the user can arrange to reduce the excitation currents carried by the supply by improving the power factor of his installation. To enable supply authorities to turn idle capital into revenue-producing capital, they offer a tariff that in effect gives a substantial bonus to those consumers who improve the power factor of their load.

How can power factor be improved?

By the installation of static capacitors, by the provision