THE APPLICATION OF ALTERNATING CURRENT ELECTRIC MOTORS AND CONTROL GEAR

By N. J. A. BONFA

Introduction

At the present time electric motors and their associated control gear are in such universal use and perform so satisfactorily that there is the risk of their importance being overlooked in the general scheme of electrical engineering. In this age of mass production we are all only too easily led to consider things in a general way so that particular characteristics are often grouped loosely together in the need for haste which is pressed upon us by our modern way of life. Thus, one particular item of plant may be classed generally with another, even though the detailed characteristics of each may be different, and in this way we can be led into errors of application which can cause loss of time, production and money. In presenting this paper an attempt will be made to cover some of the many interesting points concerning the application of alternating current electric motors and control gear and to show where the leading variations in the characteristics of the plant are of importance.

There are three main factors to be considered when applying electric motors and control gear. The first is the specification of the motor, the second is the specification of the control gear and the third is a knowledge of the driven machinery. The importance of the characteristics of the driven machinery is of some account and it is here that many of the errors of application are made. Other factors are the regulations of the electricity supply authorities and abnormal conditions of supply, such as low voltage. The regulations of the supply authorities are a safeguard against misuse of their supply and very necessary to protect the interests of other consumers. However, they are sometimes framed on a basis which makes them difficult to apply, as the limiting starting currents are graded and not necessarily correlated with the types of motors and control gear, which are normally available. Also, account is sometimes not taken of the limitations imposed by the driven machinery and this leads to various anomalies. It is fortunate that in the case of larger installations the size of the power supply is such as to permit considerable relaxation of the limiting starting currents and greater freedom may be exercised.

Electric Motor Specification

When specifying an electric motor, we need to consider the following system, output and rating particulars, together with the basic types which are available and the various mechanical features desirable to meet the requirements of the driven machinery and the situation where the motor will be employed.

System:	Single or three phase, frequency, low or high voltage.	
Type:	*Single Phase*	*Three Phase*
	Split phase.	Standard squirrel cage.
	Capacitor.	High torque squirrel cage.
	Repulsion induction.	Slipring.
		Commutator type.
		Compensated induction.
		Synchronous.
		Auto-synchronous.
Output:	Horsepower and speed.	
Rating:	Continuous, short time, continuous light running, overload capacity, temperature rise, ambient air temperature, altitude.	
Enclosure:	Screen protected, drip-proof, single-pipe ventilated, double pipe ventilated, filter ventilated inlet, totally enclosed, totally enclosed fan-cooled, weatherproof, hose-proof, closed air circuit with heat exchanger, flame-proof, pressurised explosion-proof.	
Mechanical Features:	Constant speed, variable speed, multi-speed. Shaft: horizontal, vertical, inclined. Foot mounting on floor, wall or ceiling. Flange: horizontal or vertical with or without skirt. Resilient mounting with or without automatic belt tensioning device. Carcass mounting.	
Bearings:	Ball and roller or sleeve endshield bearings. Ball and roller or sleeve pedestal bearings. Third outboard bearing.	
Mechanical Coupling:	Belt drive, chain drive, gear drive, direct solidly coupled, direct flexibly coupled, single outboard bearing direct solidly coupled, flywheel mounted.	
Noise Level:	Industrial or special.	
Windings:	Special connection arrangements when required, Class A insulation, Class B insulation.	
Cable Entries:	As required.	
Other Features:	Continuously rated sliprings and brushgear, electrical interlock on rotor short circuiting gear.	

Control Gear Specification

Similarly, with control gear, we need to consider the following particulars:

System:	Single or three phase, frequency, low or high voltage.
Rating:	To suit motor output and rating.
Mounting:	Wall, floor, switchboard, cubicle.
Enclosure:	Enclosed, totally enclosed, dust-proof, weather-proof, hose-proof, flame-proof.
Operation:	Manual, automatic, local or remote.
Contacts:	Air-break or oil-immersed.

Type:	*Squirrel Cage*	*Slipring*
	Direct-on.	Combined stator-rotor.
	Direct-on reversing.	Stator C.B. and rotor starter.
	Direct-on multi-speed.	Stator C.B. and drum controller.
	Star-delta.	Stator C.B. and speed controller.
Protection	Under-voltage release, under-voltage no-close device, over-current releases.	
Fault Capacity:	To suit system if required.	
Cable Entries:	As required.	
Other Features:	Ammeter, floor stands, isolating switch, sequence interlocks, auxiliary contacts.	

Electro-Mechanical Characteristics

The choice of a suitable motor and its control gear depends on a knowledge of the features which are available with makers' standard design ranges in relation to the electro-mechanical characteristics of the motor with its control gear and the nature and characteristics of the driven machine. The most important electro-mechanical and duty characteristics are the starting torque of the motor, the frequency of starting and the starting time. The first is dependent on the driven machine and influences the choice of the type of motor and control gear. The second and third decide the design of the control gear and may have a bearing on the design of the motor if either the frequency of starting is high or the starting time is prolonged.

The typical average electro-mechanical characteristics of motors with their control gear are given below:

Single Phase Motors

Type of Motor	*Method of Starting*	*Starting Torque Per cent. of F.L.T.*	*Starting Current Per cent. of F.L.C.*
Split phase ...	Direct-on ...	200/220	650/700
Capacitor	Direct-on ...	300/400	450/600
Repulsion induction	Direct-on ...	300/400	300/400

Three Phase Motors

Type of Motor	*Method of Starting*	*Starting Torque Per cent. of F.L.T.*	*Starting Current Per cent. of F.L.C.*
Standard squirrel cage	Direct-on ...	100/175	450/750
	Star-delta ...	33/ 55	150/250
	Auto-transformer	20/ 80	100/400
High torque squirrel cage	Direct-on ...	225	325/600
	Star-delta ...	66	100/175
	Auto-transformer	30/110	110/300
Slipring	Rotor resistance	Up to 200	Up to 250

Driven Machine Starting Characteristics

It is in connection with the starting characteristics of the driven machine that difficulty is most often met in choosing a suitable electric motor and control gear combination. There are so many factors to be considered that it can be difficult to predetermine the starting characteristics to be expected and we often have to rely on experience to guide us. Some makers of mechanical equipment have given attention to the problems and are able to give accurate information, from tests and practical experience, which is of great help to the electric motor and control gear application engineer. With this information available, the engineer is better able to predetermine with sound judgment what equipment to apply. Otherwise, he must rely on his own experience of the characteristics inherent to the basic types of driven machinery and in this respect he is wise to employ a conservative view in order to apply equipment which he can be confident will meet the duty required.

Where the required starting torque to cause sufficient acceleration is moderate, no difficulty is likely to be experienced, but the more onerous and special starting characteristics need more careful consideration. Typical of the duties which can be difficult are those met with machinery having high static or break-away torques, equipment starting loaded and those cases where the torque increases with the speed during acceleration. Then there are machines with high inertia where the starting time may be of long duration.

The table below gives a useful guide to the starting torque commonly met with various basic classes of driven machinery.

Type of Driven Machinery	*Starting Torque Per cent. of F.L.T.*
Line shafting	33/ 50
Pumps, centrifugal, against closed valve	33/ 50
Pumps, centrifugal, against open valve	33/100
Pumps, reciprocating	100/200
Fans	33/100
Compressors, centrifugal	33/100
Compressors, reciprocating, unloaded	60/100
Compressors, reciprocating, loaded	150/200
Machine tools	100
Textile machinery	100/200
Conveyors, loaded	125/150
Haulages, loaded	125/150
Crushers...	100/200
Tube mills	200

Choice of Motor Rating

When deciding what rating of motor should be applied to a drive, due allowance has to be made for the contingencies which are likely to be met in practice. Low voltages and the possible variations in the estimation of the actual load lead us to allow a reasonable margin over the estimated actual load. Often an arbitrary margin of 15 per cent. is used when deciding the motor rating. This is a safe figure with medium-sized motors, but it is on the high side for large machines and it is hardly sufficient with many drives requiring small or fractional h.p. motors. Fortunately, with the latter, the grading of the ratings normally manufactured is such that it is difficult to apply an unsatisfactory rating if the matter is handled along engineering lines. Nevertheless, poor application is common in this field.

Overload is one of the keys to reasonable motor application. With electrical plant, excluding switchgear, the weight of the constituent materials governs the thermal capacity of the plant and so its ability to safely absorb the extra heat generated under overload conditions. Thus, generally speaking, the overload capacity of motors is dependent on their size and the smaller the machine the lower is its overload capacity. Conversely, with the driven machinery, the likelihood of overloads occurring is usually much greater with small machines than with the larger units. This will make it clear why greater care should be exercised when applying small and fractional H.P. motors.

High Starting Torque Squirrel Cage Motors

These motors have been developed to bridge the gap between the starting characteristics of standard squirrel cage motors and slipring machines. They can be applied in a number of cases where standard squirrel cage motors are not entirely suitable and where it is desired to economise on the higher cost of slipring motors with their control gear and at the same time enjoy the advantages of the greater simplicity and easier maintenance which the squirrel cage type of machine affords. It is of interest that, notwithstanding the better starting characteristics of the high starting torque motor, the acceleration is inherently more smooth than with a standard squirrel cage motor and less shock is transmitted through the drive during starting. This characteristic enables specially designed high starting torque motors to be successfully applied to wire drawing machines and certain classes of textile machinery, such as ring spinning frames.

There is a case for the greater employment of high starting torque squirrel cage motors and many borderline cases would be better handled by them, particularly where the starting characteristics of the driven machinery are known to be in the difficult bracket and where high inertia starting loads are present.

Multi-Speed and Variable-Speed Drives

Squirrel cage motors of the change pole or multi-winding type may be used where constant speed operation at two or more of the normal A.C. speeds is required. Up to four separate constant speeds in one machine are usually available with two separate change pole windings. The change pole windings are of the consequent pole type and the higher speed is twice the lower speed for each winding.

The control gear for multi-speed motors has to be designed for the switching arrangement required by the motor windings and over-current protection has to be provided for the output rating corresponding to each speed. Contactor gear is therefore, of necessity, more complicated than that required for single speed machines.

Continuously variable speed drives necessitate the use of either slipring motors with rotor resistance control or commutator type machines. With the former there are the losses in the rotor circuit to be considered and it is important to know the torque/speed characteristics of the driven machine to design the rotor resistor. A faceplate type rotor controller or drum controller having balanced notches may be used, but very fine adjustment of the speed is difficult to achieve without special equipment and the commutator motor with speed control by brush rocker movement is generally more suitable where the speed has to be set to close limits. Typical of cases where speed control within fine limits is required are rotary-printing presses and sugar mills with electric motor drive. With sugar mills the associated group of motors may be connected to an alternator running separately from the remainder of the generating plant and the speed of the group of motors is varied by alteration of the speed of the prime mover driving the alternator.

Short Time Rated Continuous Light Running Motors

Many machine tool operations require varying outputs from the driving motor over a cycle which is repeated. Automatic turret machines carry out operations where the full output is required for only a short period of the total operating time. Economies in capital and operating costs may be effected by using short time rated motors designed to run continuously at light load and these motors are termed continuous light running motors. Apart from their lower capital cost they keep down the maximum kVA demand and improve the power factor, which are important points where power is purchased on a kVA demand basis.

Flywheel Drives

Presses, punches and similar machines which incorporate a flywheel to deliver a large amount of power over a relatively short period during each operating cycle are successfully driven by motors having a higher than normal slip. This enables the machine to slow down during the power stroke and draw power from the energy available in the flywheel rather than from the motor. The basically constant speed characteristic of standard induction motors causes them to draw high peaks of power from the supply during the power stroke and the motors have to be rated to deal with the heating effects of the current peaks which flow so that larger motors than actually necessary have to be used. In addition, the heavy peaks of power transmitted by the motors cause greater belt wear than is normally expected.

With large machines, slipring motors having a fixed slip resistor in the rotor circuit are used and the resulting performance shows such a marked improvement over that possible without the slip resistor that high slip high torque motors have been developed for the small and medium sizes. The slip at full load with these machines is about 10 per cent. and this enables the flywheel to drop about $12\frac{1}{2}$ per cent in speed during the power stroke without motor current peaks of a high order. Some surprising economies have been achieved in practice and, in addition to the reduction in the capital cost of the motors and control gear, belt wear is considerably reduced and a much better overall power factor may be expected with an installation consisting of a large number of machines.

Winding Insulation and Impregnation

Class A insulating materials, consisting of cotton, silk, paper and similar organic materials suitably impregnated and also enamelled wire are in general use and lend themselves to easy and economical manufacture. Special cases where the ambient air temperature may be high, necessitates Class B insulating materials which comprise mica, asbestos and similar inorganic materials in built up form combined with binding cement and the motors cost more to manufacture.

It is sometimes thought that Class B insulation is better than Class A, but this is not necessarily the case and in fact there is some justification for the reverse opinion. Asbestos is difficult to handle, lacks mechanical strength and is very hygroscopic. Glass is in itself a poor insulator, because of its low resistance to surface creepage. Both materials are difficult to impregnate. Mica is undoubtedly the best Class B insulation material, but it is expensive to apply and can only be used effectively with heavy section conductors.

Impregnation of Class A insulating materials has reached a very satisfactory stage with the use of polymerising synthetic resin varnishes of the thermosetting type. Such varnishes are easy to apply and are readily absorbed by cotton covered wires. The finished product gives a winding which is thoroughly impregnated, mechanically strong, with excellent insulation and a high degree of resistance to moisture and acid.

The tendency today is strongly towards the use of synthetic covered wires of which there are well-known brands. These coverings are tough and pliable, have excellent electrical properties and their use enables the slot size to be reduced because of their better space factor when compared with cotton covered wires. Modern designs make extensive use of these synthetic covered wires and this is generally to the satisfaction of operating engineers.

Sliprings, Commutators and Brushes

It is fair comment to point out that sliprings, commutators and brushes are the weakest link in any electrical machine. Sliding contact such as is necessary in electrical machines has always been a problem to electrical designers and a great deal of thought and ingenuity has been put into the design and application of equipment which will give very satisfactory performance within the limits of its ability.

This whole subject is now the sphere of the expert and we can always avail ourselves of his help, which is so readily available, when problems arise. The important points to be borne in mind are that the life of brushes is limited, as wear must take place, and that the performance is dependent to a very high degree on regular and careful maintenance. Also, variations in performance are to be expected with variations in operating speeds and atmospheric conditions.

Noise

All industrial class motors make noise, especially during starting, and the degree of sound emitted varies with the electrical design, output and speed. It is particularly dependent on the use of ventilating fans to assist the inherent ventilation characteristics of the machine. The fact that a cylindrical rotor with its winding has sufficient fan action enables many ratings to be constructed without the inclusion of a separate internal fan to pump air through the motor. Such machines are relatively quieter than those with separate internal ventilating fans.

An important point is that the actual sound emitted is not normally taken as a measure of the noise. What is commonly used is the apparent sound which is the difference between the actual sound emitted and the threshold of sound of the surroundings. This is what is heard by the ears, because of their unique type of sensitivity to sound, and whereas a motor can be noisy where the threshold of sound is low, exactly the same motor would be considered quiet in different surroundings with a higher threshold level.

It is unreasonable to expect quietness of operation from industrial class machines and all makes of motors have probably received adverse criticism at some time or other in this respect. Also, if one rating of a particular make appears to be quiet, it does not follow that another rating of the same make will give equal performance.

Special motors are made which are designed to operate with a low level of sound emission. Various classes are available and lower than normal sound levels are achieved by electrical design modifications and the omission of ventilating fans. Where very low sound levels are desired, sleeve bearings are essential.

Over-Current Protection

It is standard practice to include over-current protection with the control gear and its function is to automatically disconnect the motor from the supply in the event of abnormal operating conditions. The over-current releases may be operated either magnetically or thermally and both types are in general use. The magnetically operated type are more costly to produce, but have a greater inherent ability to carry high over-currents of fault current magnitude and can be relied upon to maintain their calibration indefinitely.

In addition to giving protection against abnormal conditions of operation the over-current releases must, at the same time, be capable of carrying the starting currents without giving rise to inadvertent operation. An inverse time lag characteristic with a definite minimum time characteristic during starting and an over-riding instantaneous characteristic for heavy fault currents is probably the ideal, but this can only be obtained with special equipment. Standard types of over-current releases either include devices which achieve the desired characteristics to a sufficient degree for normal applications or are of a type where the characteristic is partially inherent, as is the case with thermal over-current releases.

Magnetically operated over-current releases incorporte time lag devices which may be of the oil dashpot type or of a mechanical pattern. With the oil dashpot type the special characteristic required during starting is achieved either by restrainers, which are simple flap valves designed to close the normal overload time lag orifice in the piston of the dashpot device by movement of the oil through the orifice, or compound spring loaded dashpot pistons giving progressive restriction.

The adjustment of the time lag with oil dashpots is achieved very simply by providing a selection of orifices of different diameter in the piston assembly and an oil with a reasonably constant viscosity over the range of temperatures normally to be expected is usually provided with the control gear for use in the dashpots. Further adjustment of the time lag may be achieved by the use of oils of higher viscosity and long time lags to meet awkward starting conditions are possible. The adjustment which is possible to the time lag characteristic of oil dashpot time lags is a useful feature as it can be achieved without altering the over-current settings.

On control gear with magnetic over-current releases, settings are usually provided for currents about 20 to 25 per cent. in excess of the normal F.L.C. of the motor although lower settings are available if necessary. These settings will provide protection against abnormal operating conditions.

Where motors operate under borderline conditions of overload it may not be possible to get low enough settings with the over-current releases supplied with the control gear and it may be necessary to install over-current releases with lower settings. However, it is unreasonable to expect the control gear to provide over-load protection for motors which have been incorrectly applied. Such cases are only too common and require an alteration in the motor rating to correct an unsatisfactory position.

Fault Protection

Where control gear is used on systems having a high fault capacity, either equipment designed for the fault rating may have to be used or special steps may have to be taken to protect standard control gear types. On high voltage systems the use of circuit breakers of adequate fault rating does not present any real difficulty as suitable equipment is readily available. With low voltage systems, however, the need for providing control gear of high inherent fault rating is fortunately not so necessary from an engineering point of view, although the importance of this matter should not be underestimated and special cases may require more detailed consideration.

The factors which assist with low voltage equipment are the relatively small size of the vast majority of the circuits and the attenuation of the fault by the impedance of the cables and the fault arc. Where the cable runs are short or the equipment is of relatively large capacity, greater care should be taken. With large motors, circuit breakers of suitable fault rating may be employed, but with small motors H.R.C. fuses are usually used to give back up protection. Where H.R.C. fuses are used they should always be chosen in relation to the starting currents which are likely to flow and it is good practice to allow a reasonable margin in their rating.

Single Phasing

What is termed single phasing, that is, the inadvertent single phase running of three phase motors is a common fault and very often it is due to a misunderstanding of the performance of fuses during starting. It has been and will probably continue to be the cause of many motor failures. The matter is aggravated by the fact that it is most difficult to provide protection against single phasing for delta connected motors developing about 50 to 66 per cent. of their normal load without special equipment. In fact, even where specially manufactured motor protective relays operated by over-current are used, protection can only be ensured if the motors are star connected. Relays incorporating a resistance-reactance network are used and there are also other types of relays operating on current differential which are claimed to be effective.

With single phase running a number of factors come into the case and it has been suggested by some investigators that the line current increases by about 65 per cent. For a star-connected machine the increase in the current carried by the two windings in series across the single phase supply is the same as the increase in the line current and the over-current protection normally included with the control gear is equally as effective as for three-phase running. However, with a delta connected motor the position is quite different. The line current will still increase by about 65 per cent. but, according to the same investigators, the current in the winding directly across the single phase supply increases by about 90 per cent. and that in the two windings in series across the single phase supply decreases by about 5 per cent. Thus, in the case of a motor carrying a medium load of about 55 per cent. of normal, such that the line current increases to the 100 per cent. figure under single phase running, the winding directly across the single phase supply will carry an overload in current of about 15 per cent. This overload in the winding across the supply can increase to about 45 per cent. before over-current releases set at 125 per cent. of the normal full load current can detect the condition and this will make it clear why standard control gear cannot be expected to cater for the contingency.

Star-Delta and Auto-Transformer Starting

With squirrel cage motors, star-delta and auto-transformer starting may be used where the starting torque is within the limits of the motor characteristics and where it is desired to limit the starting current. This type of starting should be avoided with borderline cases and instances are met where the motor is incapable of accelerating the load satisfactorily in the start position of the control gear. With some of these cases the motor may fail to accelerate beyond a fairly low speed and the position is most unsatisfactory from the point of view of the motor in particular and, in addition, difficulty can be experienced with the control gear which is expected to be able to switch the motor from the start to the run position under the most onerous conditions. The performance is aggravated by low voltage where the motor torque falls off in proportion to the square of the voltage. Also, such simple things as tight glands in pumps and the running in which is often a feature of certain types of mechanical equipment can give rise to difficulties. Very often the difficulties which are experienced may justifiably be put down to poor application of the equipment and a great deal of unnecessary trouble is caused to all the parties concerned.

The transient currents which can occur with these methods of starting are of importance. These transients are indeterminate and depend on the size of the motor, the fault capacity of the system, the impedance of the motor with its connections and the instant of time when the final switching is made. With large motors, transients of a very severe character may be met and it is usually impracticable to use star-delta and auto-transformer starters of the conventional type with high voltage motors. Before this problem was fully appreciated and understood, many high voltage motors had their windings damaged by high transient currents. The explanation of the phenomena is that the magnetic field system of the motor tends to persist during the period when switching from the start to the run position and the motor generates a voltage which is decaying in value and frequency during the transition period. At the instant when the final switching is made, the supply is connected to a system of differing voltage, frequency and phase relationship being generated by the motor and transient currents of about thirty times normal have been recorded during investigations of this problem.

The difficulty may be overcome either by directly switching the motors or, in the event of current limitation being necessary, by using continuous torque starters of the Wauchope resistor switching or Korndorfer auto-transformer type which are arranged to keep the motor connected to the supply during the transition period. These starters also have the advantage that they considerably reduce the transmission of shock to the drive during the changeover from the start to the run positions and there are many cases where they can be applied to advantage with large motors for use on both high voltage and low voltage systems.

Direct-On Starting

Direct-on starting is the simplest way of controlling squirrel cage motors and very large motors can be handled in this manner. Low voltage motors have windings which are suitable for carrying the relatively higher starting and transient currents, except in some special cases such as two pole motors, where the coil pitch is long in relation to the diameter of the machine and special means are not used to support the overhang. With large high voltage machines the support of the overhang of the windings is relatively more important and attention is given to this point by the designers.

Apart from the lower cost of the control gear, direct-on starting offers the advantage that the maximum torque is available from squirrel cage motors and considerable economy is possible, because they can be used where slipring motors were once considered essential. Due allowance should be made for the relatively rapid acceleration which can occur, together with the rising torque characteristic during acceleration, and the transmission devices between the motor and the driven machine should have sufficient margin in their design.

An interesting modern development connected with direct-on starting is the use of special couplings, such as the fluid or centrifugally operated type, which enable the peak starting torque of the motor to be utilised to start difficult drives with a worthwhile saving in the cost of the motor and with much lower transmission of shock to the driven equipment. A typical application is the starting of long conveyors of the endless belt type and it is claimed that the maintenance of the mechanical equipment is considerably reduced. Also, these coupling devices enable squirrel cage motors to be used where previously slipring machines or motors with similar starting characteristics had to be applied.

Starting Slipring Motors

The highest starting torque/starting current ratio is that obtainable with slipring machines started by the rotor resistance method. Starting torques of at least twice full load torque are available with standard machines and higher torques are possible with special designs. The fact that the starting torque may be varied to suit the requirements of the driven machine make it a relatively simple matter to apply the correct equipment provided the characteristics of the driven machine are known. With manually-operated control gear, notching up the starter will usually cater for an awkward case, but this is not necessarily so with automatic equipment, where greater care in the design of the rotor resistor is necessary.

With control gear incorporating resistors, the rating of the resistor is chosen to suit the starting duty and it is important to specify this in detail, indicating in particular the frequency of starting which is required. Without this information, the control gear application engineer must work to conservative margins which he knows will give satisfactory performance under the worst conditions likely to be met.

Power Factor Correction

Power factor correction may be applied with auto-synchronous machines and, when new motors of medium size are to be installed, consideration can be given to the advantages of this type of machine. They start with a slipring motor characteristic and synchronise automatically with a minimum of shock to the supply system. The degree of power factor correction is easily controlable within the rated limits and they are free from any possibility of troubles which can be caused by resonance, harmonics in the supply system and voltage increases which are commonly met during off-peak load conditions. They can be applied equally well to constant or variable loads and, in the case of the latter, there is no risk of swinging the overall power factor to leading values except under exceptional circumstances. Furthermore, it is not necessary that they should be running continuously where kVA demand limitations have to be met as shutting down the auto-synchronous motor will, in most cases, drop off sufficient load to keep the kVA demand within the prescribed limit.

Conclusion

In this paper a summary has been made of some of the points which are of interest in the application of alternating current electric motors and control gear. This is a large field and many applications have interesting features which it has not been possible to include in this brief survey, but which are the special sphere of the electric motor and control gear application engineer. If this paper has succeeded in stimulating interest and also drawing attention to some of the lesser-known features of this fascinating branch of electrical engineering, the author's small contribution will be amply rewarded.

The President stated that he was grateful for the paper and for the remarks made by the author in thanking the operating engineers for their assistance in the past. As an operative engineer himself he wished in turn to express his thanks generally to the commercial engineers for their assistance and advice. As was mentioned in the paper, he also had experience of conveyors which were driven by squirrel cage motors. They had proved difficult to start and had to be started by throwing the starter over immediately on to full current.

Mr. Bonfa said that Star Delta Starters could only be successfully applied where the starting was reasonably light and difficulty would always be experienced when using this type of starter on big machines starting heavy loads.

Mr. Scott considered that an important point missed in the paper was the ventilation of motors. He considered that not enough attention was paid to ventilation and warned that this was one cause of over-heating.

Mr. Bonfa replied that this was an interesting point and on the Reef he had experienced the necessity of actually removing fans because of vibration problems with certain types of machinery. However, if the fans and the air circulation system were properly designed, no trouble should be experienced on this score.

Mr. Lindemann enquired why it should be that motors developing, say, 100 h.p. at the coast would not give more than about 90 per cent at higher altitudes.

Mr. Bonfa replied that the reason for this was the lower density of air at the higher altitudes, and, therefore, less heat was removed by the lighter air at higher altitudes.

Mr. Gunn said he had recently discovered a motor, manufactured in England, which is a uni-directional motor.

Mr. Bonfa said there are many motors made with very efficient fans, which, however, would only function in the one direction.

Dr. van der Pol said that on numerous occasions squirrel cage motors on centrifugals had failed. Could this be due to work-hardening of the copper strips owing to the high frequency of starts and stops, causing increases and decreases in temperature, resulting in continuous expansion and contraction of the metal?

Mr. Bonfa pointed out that with the squirrel cage motor the losses occurred inside the machine and where one got repeated starts, as with centrifugals, the motor must be designed to cater for the frequency of starting.

Mr. Farquharson enquired if Mr. Bonfa had had any experience in starting up squirrel cage motors with resistors. It has often been said that in the sugar industry a totally enclosed motor was the answer to all our troubles, but the fact remained that a totally enclosed machine had little overload capacity and this meant employing a very big motor.

As far as ventilation was concerned, this often depended upon the situation in which the motor was placed and another factor was the large amount of dirt which was drawn into the motor.

As to Mr. Gunn's point, Mr. Farquharson said that if the manufacturer knew beforehand the direction of rotation of the motor, he could design a much more efficient fan and one which would function in either direction.

As far as the failure of squirrel cage motors driving centrifugals was concerned, Mr. Farquharson considered the big factor was vibration rather than heating and cooling.

This 50 Cycle vibration plus the heating when starting and regenerating made the windings loose so that they rattled and eventually broke down mechanically.

Mr. Bonfa said that the method of starting squirrel cage motors by resistors had definite applications in specific cases, particularly where the starting torque was low.

He mentioned there was a new British Standard for motors and that previous overload specifications were no longer being employed. This at present affected motors above 50 h.p. per 1,000 r.p.m.

Ventilating electric motors was a specialist's job and, as far as small machines were concerned, the simplest types of fans were used.

As far as centrifugals were concerned, he thought that both explanations put forward, namely, overheating and fatigue due to vibration, came into the picture. Losses would be experienced whichever type of drive was employed and losses in the fluid coupling drive could be very high.