THE DISEASES OF ELECTRICAL MACHINERY

1906

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BY

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EDITED, WITH A PREFACE, BY

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PREFACE.

EVER since the year 1887, when a paper of mine on the Diseases of Dynamos appeared in *The Electrician*, the topic of the causes of failures and break-downs of electric machinery, and of their prevention and cure, has been a familiar one with me. As the subjects of pathology and morbid anatomy never lie far away from the attention of the physiologist, so the study of the ailments and defects to which dynamo-electric machines of all classes are liable comes continually within the purview of the student of dynamo design. Diseases, to borrow the language of the medical profession, may be either congenital—I had almost said hereditary—or acquired. Some diseases affect particular races, others are special to particular climates. Some are incident to youth; others are a prerogative of old age. Some are sporadic, some epidemic; some transient, some chronic, some curable, some incurable. And, to continue the metaphor, while some require a species of surgical treatment, others are better handled by careful attention to a strict regimen of daily exercise or by the administration of drugs.

The constitutional diseases of dynamos may arise either from defective design or from imperfect construction. A rickety constitution in a dynamo may be the result of inherent imperfection in the forms of those parts which should give strength to the structure, or it may be due to the employment of bad or faulty materials, or to bad workmanship. Diseases acquired as the result of overwork and of neglect, though classified as acquired rather than constitutional, are more likely to exhibit themselves in cases where there is a constitutional weakness than in those where the constitution is initially robust. Often, indeed, the consulting electrical engineer, when required to advise upon some electrical mishap, must have compared his task to that of the medical practitioner. The physician who is called in to see a patient must have the eye, and the training, to detect the constitutional taint as well as the more obviously present cause of mischief. When called into consultation upon the human subject, the physician's first inquiry is as to the symptoms that present themselves. Perhaps a clinical examination may be needed to ascertain the whole of the symptoms in a case. The diagnosis being completed, a course of treatment suggests itself. A wide experience is here invaluable. A surgical operation may be necessary, or perhaps bandages and poultices may accomplish all that is required. Simple rest and change of diet often accomplish wonderful cures; but in neglected cases, long and careful nursing may be the only hope. Every profession has its failures. Behind the physician—one speaks of it lightly—lies the grave-yard; behind the consulting electrical engineer—tell it not in Gath—lies the scrap-heap.

Happily, with the co-operation of designer and constructor, of electrician and engineer, the modern dynamo has developed into a strong, healthy creature. One hears little now-a-days of many of the troubles that beset his childhood. It is true that in the seventies he was a puny weakling; that in the early eighties he suffered from a sudden epidemic of the disease called "flats"; that owing to early mismanagement he used not only often to run away, but even to burst his binding wires. His limbs were racked by want of proper balance, and occasionally a sudden high fever caused him to shuffle off a mortal coil or two. But in all these things there has come, with the advent of manhood, an amazing robustness of constitution. Fifteen years ago, one could truthfully write that in those electroplating shops in London—and how few they were!—where dynamos are used, the practical men in charge of them "almost invariably hold the firm opinion that they are not getting the current from the machine unless they can see sparks at the commutator, and they therefore so adjust the brushes that they get a good blaze." Those good old days are gone, and with them many a species of dynamo which was unable to compete in the struggle for existence. The survival of the fittest, here as everywhere else, has eliminated the constitutionally unfit. Not all the skill of the cleverest consultant can keep in being the type doomed by inherent defects to disappear.

Nevertheless, the study of the diseases of electric machines has its importance in the industry of to-day. With the newer and larger machinery in use, new defects arise and old ones reappear in new forms. Only by study of the malady, when it appears, can the right treatment be discovered to prevent its reappearance. The experience of others is always useful to the novice. The knowledge of that which has happened in disease is the safest guide towards a cure. In short, by the proper study of dynamo-pathology we may arrive at a fuller command of dynamo-therapeutics.

The author of this book, Mr. ERNST SCHULZ, a German engineer of wide experience, is known to a few in England by his writings. His little treatise on the diseases of electric machines appears to fill a useful place. It has now been translated for English readers, for whose benefit the present writer has added a few notes and paragraphs, though without material alteration to the text. It is but fair to state that the actual work of translation has been borne by Mr. HUGH LEDWARD, whose double training at Finsbury and Carlsruhe has qualified him to deal with technical terms. To him I return, in my capacity as editor, a grateful acknowledgment.

SILVANUS P. THOMPSON.

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INTRODUCTION.

THIS little opusculum owes its existence to a wish expressed in several quarters that the author would put together in more complete form, as a book, some earlier scattered publications of his on the present topic. I should not have yielded forthwith to this demand had it not been actually for the absence of any such book in this subject. Neither in the excellent Pocket-books or Calendars such as those* of Pohl, Uppenborn, and Von Gaisberg, which have been before the public for a long series of years, nor yet in the more bulky technical treatises does one find an account of the faults and break-downs of electric machines in a convenient form for the use of engineers and fitters. Such a compilation ought, on the one hand, to be short, and to avoid theoretical expositions wherever these are not absolutely necessary; on the other hand, it ought to afford to the practical man

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* The Author here particularly refers to the pocket-book for electrical engineers and fitters by Chief-Engineer H. Pohl, entitled "The Erection of Electric Light and Power Stations," published in Hannover by the Messrs. Jänecke Brothers. A similar remark is more or less applicable to the various pocket-books for electrical engineers in the English language. Nevertheless, there exist in English several works which deal with the subject of Diseases of Dynamos, as may be seen in the final chapter of the Editor's book on *Dynamo-Electric Machinery* (Seventh Edition, 1904). There are also the works of Messrs. Crocker and Wheeler, and that of Mr. Lummis Paterson.

ready rules as compendiously as possible, so that the advice of the little book shall seldom or never leave him in the lurch.

My practice for twelve years as a constructor, and my present position as civil engineer, have caused thousands of machines to pass through my hands, so that I am well able to pass judgment upon the points which are to be treated within the compass of this theme. In the following pages I have generally given explanations of those faults and troubles only which occur in the operation of machines, yet without rigidly adhering to this rule; so that occasionally also faults of manufacture and defects that have their origin in calculation and design are described. Further, the expositions are not confined merely to the machines themselves, but include also those pieces of auxiliary apparatus, such as regulating rheostats and starters, which are inseparable from all operating plant.

The subject divides itself naturally into four principal sections, namely :—

I. Continuous-current Machines.
II. Single-phase and Polyphase Alternators.
III. Single-phase and Polyphase Motors.
IV. Transformers.

So, then, may the little work serve the desired use for those for whom it is written, and be to them a trusty adviser.

MÜNCHEN, 1903.

THE DISEASES
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CHAPTER I.

CONTINUOUS-CURRENT MACHINES.

FOR our purpose we may divide the different faults which occur with continuous-current machines into:

1. Breakdowns in the armature.
2. Faults in the field magnet winding.
3. Faults in the regulator and the starting resistance.

Breakdowns in the Armature.—We will commence with the faults which may occur in the armature. These may show themselves either by a more or less heavy, but at any rate an abnormal, sparking at the commutator, or by unusual heating of a part of the armature, or by the machine refusing to generate any current; or finally, in the case of motors, by the motor refusing to start. There are, however, some other faults which, although they come under the head of armature breakdowns, yet do not fall into any of the above categories. These we will consider by themselves.

Sparking.—By far the most usual cause of sparking is bad or unsuitable handling of the commutator or of the whole machine. In many cases where complaints have been made regarding continuous-current machines, it has turned out that there was no ground for complaint in the machine itself, but that the whole blame lay upon the dynamo attendant, through whose carelessness or ignorance the machine has been damaged. For example, by simply carelessly switching a dynamo into parallel with another dynamo, or with a battery, or through working the starter of a motor too suddenly, i.e. in general by suddenly putting in or taking out an unusually heavy current, a burn-spot will be caused on the commutator, which in spite of careful treatment with glass-paper, cannot quite be got rid of. This causes the brushes, when passing over the spot, to spark, which further increases the size of the spot, so that a burn which extended originally over one or two segments only, is so much extended that in a short time sparkless commutation is impossible, even if the commutator is rubbed down with glass-paper.

Often in such a case as this the fault will be attributed to other causes, as for example, the projection of the mica insulation between the segments, to the varying degrees of hardness of the single segments, or to the commutator being out of truth or having become slack; while all the time the dynamo attendant knows perfectly well the cause of the trouble. In all such cases, therefore, it is advisable carefully to turn down the commutator in order to again obtain a perfectly smooth surface before complaining to the builders of the machine.

The turning down of the commutator must be done by a specially trained man, either between the centres of an accurate screw-cutting lathe, or by means of a special apparatus for turning down commutators, such as has been designed by the author. The purchase of such an apparatus is to be recommended to all installation firms and engineers.

The following also comes under the heading of ruin of commutators by careless handling. The working surface of all properly designed commutators is longer than the width of all the brushes on one spindle. This is obviously in order that the brushes on one spindle may be so staggered in relation to those on the other spindle, that the surface of the commutator is equally used and worn away. In many cases one finds this rule not obeyed, and the brushes of all the spindles exactly in line one with another. Thereby parts of the commutator are not used, and in course of time noticeable ridges appear. These cause the brushes to lift on edge, so that they are lifted partially from the commutator, thus causing sparking, and in a short time destroying the commutator. In this case also the only remedy is to turn down the commutator.

Carborundum for Grinding Commutators.—It may here be mentioned that recently for the purpose of grinding down the commutator surface, carborundum is used instead of glass-paper. This can now be obtained in the form of carborundum-paper in different degrees of fineness. With this material it is possible to do something that one cannot do with glass-paper, that is, to grind down those commutators that have the insulation between the segments made of too hard material. This is rendered possible by the hardness of carborundum. The author now uses carborundum exclusively in his practices. On no account must emery be used.

Wrong Placing of the Brushes.—A cause of sparking is often the wrong position of the brushes, since the segments are so burnt by the sparks that afterwards, when the brushes are correctly adjusted, sparkless working is still impossible. Since in different modern types of machines various types of armature winding are employed, it is of no use giving a general rule for the position of the brushes, and it could lead very easily to the wrong result. While one could formerly say that at no-load the brushes might stand exactly in the middle between two pole shoes, and must be rocked forward with increasing loads, this is nowadays not the case. Modern machines are more and more so wound that with a two-pole drum armature the two sides of a winding are not at an angle of 180° to one another (fig. 1), but are wound with a shortened pitch, so that the angle which the two sides

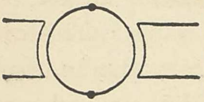

FIG. 1.

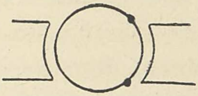

FIG. 2.

of a coil build one with another is only a little larger than the angle subtended by the pole piece (fig. 2). With this type of armature the brushes must not be placed in the middle between two poles, but must be moved a considerable distance closer to one pole tip. It is therefore necessary, since the type of winding can but rarely be seen from the finished armature, to place the brushes according to the mark which is placed by the maker on the brush gear of almost every machine Most modern machines are provided with one mark only. This is because the same position is correct for both no load and full load. It is usually necessary, at any rate for motors, to specify that this should be the case. Machines of earlier date, however, were provided with two marks—one for no load and the other for full load. It should be noticed that for dynamos the brush-holder must be shifted in the direction of rotation with increased load to give them a forward lead, while for motors the brushes must be moved in the opposite direction, giving them a backward lead.

If the brushes are kept for a long time in the wrong position, in addition to the bad effects of the sparking on the surface of the commutator and the brushes, a not inconsiderable heating of the commutator may result. The wrong placing of the brushes may also be the cause of unusual armature heating.

Wrong Speed.—Sparking may also be caused by the machine being run at too high a speed, although the machine itself is all right. It is by no means unimportant whether the prescribed speed be adhered to or not. If we considerably increase the number of revolutions per minute, we must, if the voltage remains constant, diminish the flux in the magnets by weakening the exciting current. If this be carried too far, the action of the currents in the armature finally becomes too great, and the machine commences to spark, as otherwise at normal speed it would only do under a heavy over-load. This may be caused, in the case of dynamos, by a wrong ratio in the gearing. With motors, also, we have the same fault sometimes in cases where the speed is to be regulated by a resistance in the shunt circuit. It must therefore be insisted that such increases of speed must only be allowed when agreed to by the makers of the machine. The regulator above mentioned should, if possible, be without a zero-contact, so that it is impossible to switch off unwittingly the shunt current while the armature is still in circuit. The result of this would be destruction of the motor, either by heating or running away.

Such motors with variable speed must always be specially calculated and designed with regard to sparking, so that they can withstand the weakening of the field. The author has published—in the *Elektrotechnischen Anzeiger* 1902, in the *Handbuch der Elektrotechnik*, vol. ix. part 2, and in other places—some articles on the speed regulation of continuous-current motors. We may here draw attention to the connection of motors (in three wire systems) to circuits that work at 110 volts and 220 volts, and also to the use of motors with two windings and two commutators, which may be connected as desired either in series or in parallel. Both methods allow of 100 per cent. variation in speed.

Booster.—In this respect the working of boosters, such as are used with accumulator batteries, is very unsatisfactory. Boosters are built to generate about 50 volts in order to be able, in series with an ordinary 110 or 220 volt generator, to charge a battery of 60 cells. When commencing charging, when the battery is half discharged, the booster should not generate more than 20 volts. The charging is therefore commenced with a total pressure of 130 volts. One may consider how very difficult it is to build a dynamo which with constant speed will stand a regulation of the voltage to less than 50 per cent. of its normal value, while generating the full load current all the time. These machines, therefore, must be specially calculated with the greatest care in respect of the necessary suppression of the sparking with the unusually weak fields. If we regulate these machines still lower, down to about 10 volts, as the author many times has had to do, it is impossible to prevent heavy sparking, due to the influence of the armature currents upon the weak magnetic field. It may be here remarked that the care of these machines should be given only to experienced and conscientious hands. In many cases it will also be well to render unnecessary any considerable weakening of the field by providing the booster with a two-speed pulley, so that with low voltages one can also work at a slow speed and with a stronger magnetic field. This course might often be pursued, and above all in those cases where the booster is driven by a belt from the main machine.

Excitation of Booster Fields.—It should here be remarked that a booster should always be provided with separate excitation of the field magnet. Separate excitation makes the magnetism of the machine more stable, and is in any case much to be preferred for machines where the voltage must be regulated down to a very low value. As is well known to practical men (and explained by the theory) a shunt machine can only be regulated down to about one-third of the normal voltage. From this point downwards the voltage becomes unstable, i.e. the machine is inclined to lose its voltage altogether. With separate excitation this is completely prevented. For this reason it is best to excite the field magnets of the booster either from the main machine, or from the battery itself.

Commutator Lubrication.—To the numerous causes of sparking, although there is really no fault in the armature, belong the materials so much abhorred by every dynamo maker which are sold for lubricating commutators. Whatever they may be called, it is only in the rarest cases that they are of any use, and in an exceedingly large number of cases they do considerable damage. One may take it for granted that the maker has calculated the machine so that it works sparklessly with the brushes supplied. If however, in spite of this, the machine sparks, the use of some graphitic compound will not alter the state of affairs. The undesirable increase in the brush resistance may cause an otherwise good machine to spark. If one, however, thinks it necessary to give the collector a polish, which is in general only possible with carbon brushes, it should be done with a drop of pure mineral oil, which must be carefully rubbed over the whole surface.

[The editor prefers a touch of vaseline, applied on a bit of clean cotton cloth; cotton waste should not be used.]

Spare Brushes.—When inserting new brushes, it is to be very carefully seen that the surface of the new brushes fits exactly to the surface of the commutator. It is scarcely to be feared that any one will imitate the mistake (which the author has met with several times) of inserting carbon brushes in the holder without any grinding of the surface whatever. One cannot sufficiently strongly point out that a badly ground brush has been the destruction of many a commutator. This work, therefore, must not be carelessly done; but a fair amount of time should be devoted to it, and the machine only set again in full working when one is convinced that there is a good and perfect contact at the sliding surface. It is for this reason advisable to run a machine with new brushes for several hours without load, so that the brushes may become thoroughly bedded to the outline of the commutator.

Brushes are ground to shape by bending a piece of glass-paper (rough side uppermost) round the commutator, placing the brushes in the brush-holder, and screwing them up tight against the glass-paper. The brush rocker is then moved backwards and forwards until the brushes, by rubbing upon the glass-paper, have taken the same curvature as the commutator surface, and bed properly against it.

Unsuitable Commutator Material.—We now come to the actual faults which may lead to sparking. We must in the first place mention the purely mechanical cause of unsuitable material. For modern commutators with carbon brushes, the segments are made of hard-drawn or drop-forged copper, with layers of mica insulation between the segments. With these commutators unsuitable material and improper construction may both lead to sparking. In the former case this shows itself only after some weeks' working, so that it is not found out in the test room.

Too Hard Mica Insulation.—The varying degrees of hardness of mica must be here noticed. Mica which, as is well known, is an exceedingly good insulator, is very variable in regard to its hardness. If we are to use mica in building commutators, we must see that it is about as hard as the copper, in order that the brushes should wear away the copper and the mica at the same rate. As it is certainly not easy always to fulfil this condition, we have become accustomed to using mica which is softer than the copper. Since it is impossible to examine each mica slip in the workshop, it may happen that some piece of mica is used which is harder than the copper. It is then clear that the copper will be worn away sooner than the mica, so that, after some weeks' working, the mica stands out a little above the copper. This cannot be satisfactorily determined either by the eye or by touch, since a piece that may project less than the hundredth of an inch is sufficient to start the brushes chattering, and thus may cause sparking. This sparking is very dangerous, since it damages the copper in a remarkably short time. Grinding with glass-paper is no use, since such hard mica is not touched by glass-paper. The application of glass-paper only increases the fault, since the copper alone is rubbed away. In such cases a light cut must be taken from the commutator surface with a sharp pointed tool, after which the surface should be polished with fine glass-paper.*

If the process has proceeded still further, it may so happen that the machine will not work, i.e. gives no voltage, since the contact between the brushes and the commutator is broken by the protruding mica insulation.

Turning down of Commutators.—It may be here advisable to say a few words regarding the turning down of commutators. When turning down the commutator, the author recommends that the peripheral speed should not be greater than 20 to 25 feet per minute. A sharp pointed tool should be used for the first cut, so that the mica and copper are turned down together, and that no mica segments should remain sticking out. For the finishing cut a similar tool should be used, and it should not traverse at a greater rate than $\frac{1}{250}$th inch per revolution. The cutting speed may, however, be raised to 35 feet per minute. The commutator must then be carefully examined on the lathe, to see whether any of the segments are joined by tags or burrs of copper. These must be carefully removed. The surface must then be smoothed with glass-paper, and as good a polish given as possible, for which purpose the use of a few drops of oil

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* [A less drastic remedy than taking a cut off the commutator, is to file the surface while it is gently turned round, using a glass-hard file, itself of fine cut. Or instead of a file, a fine carborundum hone may be applied.—Ed.]

with the glass-paper may be recommended. *In no form whatever may emery be used.* From the above it can be seen that the turning down of a commutator should be entrusted to an experienced hand, since an inexperienced man could totally destroy the commutator. There is a great difference between turning iron and turning other metals, and a man skilled only in turning iron might do much harm.

Artificial Mica Segments.—It may be mentioned that recently a kind of artificial mica—called megohmite—has been used as a substitute for natural flaked mica. Megohmite has the advantage of a smaller degree of hardness, while at the same time it does not suffer from the fault of other artificial kinds of mica—namely, the melting out, when heated, of the lac used to cement the mica flakes together.

Press-spahn and vulcanised fibre are very unsuitable materials for the insulation of commutators, above all, when carbon brushes are used. These materials shrink with heating and swell when damp. Machines with such commutators cannot be described as of modern design. With old machines having metal brushes, press-spahn was permissible.

Loosening of the Commutator Segments.—An error in design is shown by the not uncommon loosening of the commutator. This fault can be easily tested by striking with a hammer (with a piece of wood in between) upon the individual segments, and seeing whether they move back. The loosening of commutators may be caused by the shrinking of the insulation between the commutator segments and the clamping rings. If vulcanized fibre has been used for insulation, in the course of time this will always happen. On the other hand, the clamping rings which hold the segments in place may be responsible. In any case, it will hardly be the duty of the engineer who erects the machinery to correct this. Commutators which have become loose on their shaft naturally cause sparking, at any rate with carbon brushes, since they become untrue, and cause the brushes to jog up and down. With metal brushes, owing to their greater flexibility, sparking from this or other of the above causes is much less to be feared.

Commutator out of Truth.—A commutator may also become untrue in consequence of the varying hardness of the segments. This fault is indeed less to be feared when using hard-drawn or drop-forged copper ; but it often appears when the segments used are of cast metal, such as simple brass, or (better) bronze, such as silicium-bronze or phosphor-bronze. The use of such bronzes for commutators is therefore not quite satisfactory, although it is not to be condemned absolutely.

Brushes and Brush-Holders.—The brushes have an important influence upon sparking. Errors may arise, of a disastrous kind, both in form, number and material. In modern machines, having two or more rows of collecting brushes, it is the invariable practice to have at least two, and frequently more than two, brushes in each row. A row of narrow brushes will make better contact than one wide brush. In the case of carbon brushes, as many narrow brushes as possible should be used side by side in each row. A single wide brush would be far too stiff and immovable, and the brush holder would be too heavy to follow small inequalities in the commutator. In general, a brush-width * of 1 inch should not be exceeded ; carbon brushes of above $1\frac{1}{5}$th inch in width, should be allowed in exceptional cases only. It is not only the width, but also the breadth † of the brushes which is of importance. In this respect the breadth, as used originally by the builder, should be followed. He alone is in a position to prescribe the most suitable breadth for the brushes, since this dimension is of great influence upon the commutation. It is therefore a mistake to order carbon brushes later from another maker, who might supply brushes of a wrong breadth.

Carbon Brushes.—The quality of the brushes also plays an important part. The resistance of the different qualities is very different. It is not desirable for every continuous-current machine that the brushes should have an especially high or low resistance.

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* The term "width" means here the width in a direction parallel to the axis of the machine.

† The term "breadth" is here used for the breadth in the direction around the commutator. The breadth of a carbon brush is usually at least twice the breadth of one of the segments of the commutator, and frequently as great as that of three segments.

Nor does it follow that a machine which runs well with copper brushes will run well with carbon brushes, or *vice versâ*. It depends upon the build of the machine, upon the dimensions of the pole shoes, and upon the number of segments, whether high or low resistance brushes are needed. It must also be pointed out that although a brush may have very good mechanical properties, yet it may not work satisfactorily.

From the question of resistance we now pass to the mechanical properties. Many carbon brushes are too hard to be used; they break off at the corners, and thereby lead to sparking. Other brushes, again, are too soft; they dirty the commutator, and wear away very rapidly. The various kinds of carbon brushes which are on the market very rarely fulfil all the requirements which must be expected. Here, again, one firm—the company "Le Carbone"—has made itself prominent by the production of really good carbon brushes. Brushes of the finest quality are indeed fully six times as dear as those of other makes. They are, however, extremely satisfactory in working, and will stand a high current density, so that from a brush of 1 square inch of working surface one may take, in continued working, a current of 30–40 amperes; and, at times of momentary overload, easily twice as much.

The commutator material for use with carbon brushes must be without exception either hard-drawn or drop-forged copper. The use of bronze or cast-copper is to be deprecated. As insulation between the segments, mica alone comes into consideration.

Metal Brushes.—The subject of metal brushes is an endless one. For while the fabrication of carbon brushes lies in the hands of a few good firms, the production of metal brushes has been taken up by a number of makers whose ignorance of the subject is only exceeded by the pushing way in which they advertise their wares. The requirements of a good metal brush are the following: It must possess a low resistance, must be very flexible, must in a short time accommodate itself to the surface of the commutator; and, finally, it should be made of some material that does not wear away the commutator, since it is better that the brushes should be worn away rather than the commutator.

A brush which is at present much used, and has been found by the author, by long experiments and in the last few years by almost exclusive use, to be suitable for all purposes, is the laminated brush made under the patents of Boudreaux.* This brush consists of extraordinarily fine leaves of metal, the composition of which is kept secret. It is, however, certain that additions are made to the metal which have the effect that the brush keeps the commutator

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* These *Boudreaux* brushes are made by several firms, including the following: L. Boudreaux, 8 Rue Hautefeuille, Paris; Louis Patz, in Dresden; Le Carbone, 36 Lime Street, London, E.C.

Brushes of a somewhat similar sort, but not lubricating, are made by several makers, including the firm of P. Ringdorff, of Essen.

somewhat greasy. This has the advantage of causing a very small wear of the commutator. In addition, owing to the exceeding fineness of the metal leaves, the brush sticks very close to the commutator and produces a good contact surface. The single disadvantage of this brush is that it wears away very quickly. This could, however, only be helped if one gave up some of the previously mentioned advantages. This brush cannot be used for low-voltage machines, such as electroplating machines. It is therefore to be remarked by the way that low-voltage machines of less than 10 volts do not work well with Boudreaux brushes, since the lubricating action of the brushes causes a small resistance under the brushes. This resistance is of no importance in the case of machines of higher voltage, where it may be entirely neglected, since owing to the current being comparatively small there is no noticeable drop of voltage. On the other hand, in the case of low-voltage machines the current is comparatively large, and as the heating at the brushes may consequently be considerable, an excessive heating of the commutator may result; and the voltage-drop, due to the contact-resistance, would be too great.

Uncertain Contact between the Armature Wires and the Commutator.—A by no means unusual fault, which causes considerable commutator sparking, consists in uncertainty of contact between the armature conductors and the commutator lugs

Old machines may often be met with where the method of connection is by screws. This method has, indeed, certain peculiar advantages ; for example, that a spare commutator can be put in by an unpractised hand, and quickly too. This advantage is, however, entirely overweighed by the danger of some of the screws of the lugs getting loose after the machine has been running for a long time. Then all the coils of the armature have no longer the same resistance, since under certain conditions, a very considerable resistance may be produced through the loosening of the screws. This results in sparking occurring at particular segments of the commutator, by examination of which it can easily be seen whereabouts the faulty connection exists. With connections that have been well sweated in with solder the fault is of extremely rare occurence, and, as a matter of fact, can only occur when many wires are soldered into one segment, for then it may happen that some of the wires have not been sufficiently covered with the solder.

Break in a Winding.—A breakdown due to the complete break of an armature turn by fracture of the wire appears oftener than the preceding. It often happens, especially with thin wires (i.e. with machines of low output, high voltage, or low speed), that a bad spot in the wire, which is not noticed during winding, breaks after the machine has been running a short time. This naturally occurs more often at those places on the armature where the wires are in tension, namely, at the place where they enter into the slots, or close to where they are joined to the commutator lugs. It is therefore advisable not to carry the armature wire too stiff or too straight from the slot to the commutator, but to give it a slight bend, through the elasticity of which bend a break due to undue strain is averted. While in the case of dynamos this break usually shows itself by the machine refusing to give its voltage (that is, refusing to excite itself), in the case of motors (which are, so to speak, separately excited) we have a slight increase in the speed, and also very heavy sparking often running right round the commutator. When the motor has come to rest, the insulation between those segments between which the defective coil is connected will be seen to be badly burnt. There is, perhaps, no fault of electric machines which can be so easily diagnosed as the above. If, in the case of a dynamo, we suspect this particular fault, we can obtain the same effect by running the machine without load, but with separate excitation of the magnets, as can always be done where there is a battery of accumulators. The machine, though driven as a dynamo, will then spark in exactly the same way it would do if running as a motor. The cause of the breaking of the armature wires in a motor is often due to an incorrect proportioning of the starter. When motors are to start without load, the starter must not be designed for starting at full load, for otherwise, in consequence of the low resistance of the starter, the motor starts too quickly. This is to be especially noticed with those motors which are continually starting and stopping.

Broken armature wires should, if possible, be soldered with silver solder. In urgent cases the two segments, between which the broken coil lies, may be short-circuited by driving in temporarily a small spike between the commutator segments at the lugs, or by dropping a small drop of solder between them. This is, however, only permissible when the commutator has a large number of segments, and at best it is only a temporary remedy.

Bad Centering of the Armature.—While in the case of two-pole machines bad centering of the armature between the poles (so that it is nearer to one pole than the other) has no effect on the sparking, yet this can cause much trouble with multipolar machines. For example, most four-pole machines (except tramway motors and small motors) are connected so that in the armature winding there exist four parallel circuits. Incorrect centering will, in this case, cause the voltages in the four parallel circuits to be unequal. This generates a flow of internal balancing currents, and causes uneven loading of the four different circuits, resulting in sparking; and, in certain cases, resulting also in a rapid and strong heating of the armature, even at times when the external circuit is open.

In the case of those bipolar machines that have the poles of the magnets one above the other, it is customary to decentre the armature by making the air-gap between the upper pole and the armature smaller than that between the armature and the under pole, in order, by the attraction of the upper pole, to relieve the bearings of a part of the weight of the armature. This must not be done with multipolar machines having more than two paths through the armature winding. It is done in some railway motors.

The heating of the commutators of low-voltage machines is often caused by there being too heavy masses of copper, too massive segments, in which, owing to the heavy currents, eddy-currents ensue. The heating roughens the commutator surface, and so leads to sparking.

Having now dealt sufficiently with those faults which show themselves by heavy sparking, we pass on to other phenomena.

The Different Kinds of Armature Short-Circuits.—One often hears the cause of a break-down referred to as a short-circuit or, as workmen call it, a "short" in the armature. Very few of those who use these words picture to themselves the various and differing faults which are included in this name. First, the insulation, between the armature winding and the iron core of the armature, may have broken down at some point. Secondly, the insulation of one coil may have given way in two places, so that the armature coil is short-circuited on itself. The same effect may be caused by copper dust or dirt between two segments of the commutator. Or, thirdly and finally, a coil may have formed a direct short-circuit with another coil, as may easily occur with those drum armatures in which many wires cross one another at the front and back, either by reason of an unsuitable method of winding, or in consequence of a knock which the armature has received. In addition to these three quite different kinds of faults, which all take the name of short-circuits in the armature, there exists a series of defects of a similar character.

Contact between the Winding and the Frame. A chance connection of any point of the armature winding with the iron of the armature is of no importance so long as no other live part of the machine is likewise connected with the iron of the machine. A precisely similar state of things exists continually in the case of all those machines of which one pole is put to earth. In the case of such machines, for the sake of security, the frame is also always earthed. The result of this is that any small fault in the winding immediately develops into a short-circuit. In most cases this will result in the burning out of the armature winding. This same fault will also occur (i) with railway motors; (ii) with motors which are connected to a tramway circuit; (iii) with motors with earthed frame working on a three-wire system, having the middle wire earthed. Often, too, in ordinary plants, where the machines are not insulated from earth, the occurrence of a break in the insulation in one of the loads, if there is at the same time a short-circuit between armature winding and armature iron, may result in the destruction of the winding. Fig. 3 explains this diagrammatically.

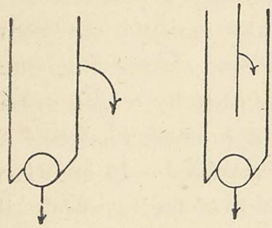


FIG. 3.

A casual connection between the brush-holder spindle and the rocker is in itself of no account until another short-circuit takes place at some second spot. To follow up the direct bearing of these remarks, let it be remembered that a breakdown cannot occur unless or until a wrong path is opened to the current along which it can pass. There must be an entrance and an exit for the current. If there is only one place where the winding and the iron are in contact, the current has an entrance but no exit. So nothing occurs until there is a second contact somewhere else between some live part of the circuit of the machine, or of the leads and the iron of the machine, or something that is connected to the iron.

It is not difficult to locate the short-circuit in a machine by means of a galvanoscope or simple galvanometer, such as a common linesman's detector and a single Leclanché cell, or a "dry" cell. If no galvanometer is available, an ordinary electric bell may serve. If heavier currents are on hand from some supply system, an incandescent lamp or, better, a voltmeter may be used.

The following is then the process for finding the position of the short-circuit. The machine is disconnected completely from the leads. The main leads and the shunt leads are therefore removed from the terminal board. The brushes are lifted off, and the customary connection on the terminal board between one pole of the armature and the field winding is removed. One wire from the galvanoscope is pressed upon the frame, that is on the iron, taking care that the end of the wire really makes a metallic contact, the other is applied to—

1. Each of the brush spindles.
2. The field terminals.
3. The commutator.

If in any one of these cases the galvanoscope needle is markedly deflected, then there is a short-circuit in the part under test. If a bell is being used, the ringing of the bell indicates that there is a short-circuit.

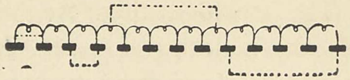
The fault can sometimes be repaired by carefully examining the machine ; for example, in the first case, where the insulation between the spindle and the rocker is defective, or in the second, where one of the field terminals has become connected to the iron. A break in the armature cannot often be repaired on the spot ; repair in the factory is usually necessary.

Short-Circuit in the Winding.—While the above mentioned single armature short-circuit only causes breakdowns when a second contact has occurred or is already present, a short-circuit in a winding, that is to say a contact between two points of an armature coil, is at once destructive and causes a serious breakdown. In a dynamo the usual result, unless the fault has short-circuited only a very small part of the winding, is that the machine refuses to excite itself. If the field-magnet is now separately excited, and the machine is run, it still does not reach its full voltage ; and one can also clearly observe that the machine uses up a great deal of power, even when the external circuit is open. In quite a short time, $\frac{1}{4}$ to $\frac{1}{2}$ a minute, a smell of burning will be noticed. If the machine is at once stopped, and one then touches the coils to ascertain their heating, one can find, by the unequal heating of the coils, that one coil in which the short-circuit exists—it will be much hotter than the others. This heating results from the heavy current which is produced in the short-circuited turn of the armature. To this also is due the great absorption of power, in spite of the circumstances that the external circuit is opened and that no current is being generated for the purpose of excitation. If this kind of fault occurs in a continuous-current motor the effect is that the motor runs very slowly backwards. In certain circumstances the motor may not run at all. One can then, however, if the field-magnet is excited, clearly prove the existence of the short-circuit by turning the armature of the motor, when the motor will begin to run backwards. In these cases rewinding of the armature is usually necessary. At the very least a new coil must be inserted in place of the defective one.

Short-Circuit between Two Armature Coils.—The occurrence of a short-circuit between two different coils is still worse, since in such cases a great part of the armature winding will become carbonised, unless the fault is immediately noticed and the machine immediately stopped.

Short-Circuit in the Commutator.—All that has been said above regarding the winding, applies similarly to the commutator. If everything else on the machine is all right, a direct short-circuit of one segment with the commutator shell or spider is, in itself, of no account so long as no other short-circuit occurs. If two adjacent segments touch one another, or if both are in contact with the shell or spider, the result is the same as if a coil was internally short-circuited. The coil will burn, and the same effects, the large amount of power taken, the heating and (if a motor) the backward running of the machine, will be the same. If two segments at a greater distance from one another are in contact, the result is the same as if two points of two different armature coils were in contact. The burning of the whole intervening winding will be the result. In this last case a dynamo, even with separate excitation, will give no voltage, and a motor will not start.

In order to explain this fault, we will represent the state of affairs diagrammatically in the following way :



Figs. 4-7.

In all these figures the dotted lines represent the points where a short-circuit is present. In Figs. 4-7, we see a commutator diagrammatically represented with all its segments and the armature winding (twelve segments—one segment represented twice over). In one coil there is a short-circuit. We then see from Fig. 4 that this coil will take no part in the work of the machine, since it constitutes, in itself, a closed circuit. Since in this coil, however (if the machine is separately excited, or is run as a motor), an E.M.F. will be generated, and since the coil is short-circuited, a very heavy current will result, and this coil will become heated.

In Fig. 5 we have represented two adjacent segments joined together. This will obviously have the same result as the above. The coil which is connected to the two segments is short-circuited, and therefore, when rotated in a magnetic field, a strong current will be induced in it.

If the two faults do not occur in one coil but in two separated coils or commutator segments (this last can occur only through the two segments being in contact with the shell or spider), we see clearly from Figs. 6 and 7 that the short-circuited path for the current extends over all the coils lying between the two faults. The machine, therefore, will work no longer, and in the majority of cases will burn out. With drum-armatures, in such an event, the complete rewinding of the armature is usually necessary; while with ring-armatures, the renewal of the two coils only is necessary, unless the other short-circuited coils have been carbonised by the heavy current passing for a considerable time.

From Figs. 4–7 (which have been put together in one diagram) one can further see what has been previously stated, viz. that a single contact is in itself of no account, but that it only becomes dangerous when a second point of contact comes into existence.

When repairing continuous-current machines, it may happen that the commutator is removed and incorrectly replaced, so that the wires leading to the segments are wrongly connected. The replacing of a commutator, and the connection of it with the winding, must not therefore be left to an inexperienced hand.

FIG. 8.

If, for example, the correct method of connection is that represented in Fig. 8, it would be quite possible, even for a trained man, unless he had noticed the correct method of connection before removing the commutator, to reconnect the winding with the ends of the sections reversed, as shown in Fig. 9. Nothing can be said against this method of connection. It is quite correct in itself; but still the machine will not generate any current unless either the direction of

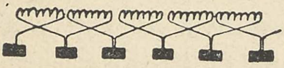


FIG. 9.

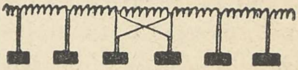


FIG. 10.

rotation of the machine is altered, or else the two ends of the magnet-winding are reversed. This case is not bad; but it might happen, for example, that only one coil was incorrectly connected, as shown in Fig. 10. This coil will now generate a reversed electromotive-force and lower the voltage of the machine.

Faults in the Magnets.—We now pass over to those faults in continuous-current machines which are principally caused by faults in the winding of the magnets. Here a wrong connection is by no means too rare. Everyone knows that in the case of a bipolar machine, one pole should be a north-pole and the other a south-pole. Which of the poles should be north and which south depends upon the method of connection of the armature with the commutator, and upon the direction of rotation of the machine.

Wrong Connection.—When, therefore, a continuous-current machine does not give its voltage (at any rate when starting up for the first time), this fault is the most probable one, namely, that the two poles are wrongly connected. It is in this event only necessary to change the leads to the coils; that is, to reverse the direction of the current in the exciting winding. There is also always a possibility that when the exciting coils have been removed from the poles during repairs, and have been afterwards replaced, an incorrect connection may have been made, so that the two poles, instead of being one north and the other south, are both alike, perhaps both north or both south. This fault may not be at once perceived. It is generally necessary to know the direction of winding of the magnet coils. This can usually be ascertained by examining the upper layer of the winding.

Polarity.—That pole is a north-pole around which the current in the exciting coil flows in a counter clockwise direction, as viewed from a point opposite the pole face. This rule is correct only when looking towards the bored-out pole-surface. *Vice versâ*, that pole is a south-pole where the circulation of the current is in the clockwise direction. Here, also, one is supposed to be viewing the pole-face from a point opposite it. Figs. 11 and 12 explain these rules.

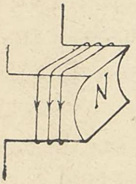


FIG. 11.

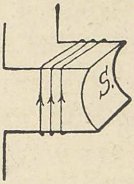


FIG. 12.

The Order of the Poles in Multipolar Machines.—In four-pole machines the poles that are opposite one another must be of the same name, so that a north-pole always shall follow a south-pole. Whatever be the number of poles, adjacent poles must always be of different polarity. A fault in this respect affects the working of the machine, the more the greater the number of wrongly connected poles, and the less the total number of poles. The results of wrongly connected poles are (1) too low armature voltage, (2) heavy sparking, (3) internal currents in the armature winding, resulting in heating.

Fault in the Magnet Winding.—A further fault may lie in a complete break in the field-magnet winding, so that no current can flow in the coils, and then no voltage can be produced. In early machines one often found that, though the coils in themselves were properly wound, the ends of the wires were very carelessly brought out. Good mechanical ways of bringing out the ends of the winding were neglected until the last few years. The usual part to break is the beginning of the winding of a coil. Any break occurring at this point is most troublesome, since one must then usually unwind the whole coil to get at the broken part. Because of this, it is worth while to use for the commencement of a magnet coil a piece of thin flexible cable made of stranded copper wires, and to wind this several times round the coil before soldering it on to the wire with which the coil is to be wound. Above all, both the beginning part and the end part of every coil ought to be completely free from any drag or strain. This is practically carried out in many different ways, as may be found described in treatises on the construction of dynamos.

A break in the winding of the field in the case of a continuous-current dynamo is not in itself dangerous, since the machine (even with separate excitation) will not work. But in the case of motors this fault is an exceedingly dangerous one, since the motor, if running without load, will immediately race. The fault is also a dangerous one in the case of dynamos that are being operated in parallel on the 'bus-bars of a station ; for if one machine thus loses its excitation, the other machines in parallel with it will at once pour their currents into its armature. The presence of such a fault can easily be ascertained by the absence of a spark when opening or closing the field regulating switch. Also the amperemeter in the exciting circuit will show no current.

The Different Kinds of Short-Circuits.—Short-circuits can be caused in very different ways. First, in the case of a shunt machine, a coil may be short-circuited in itself in consequence of rough treatment during winding, the insulation being broken through at several places. The current will then pass directly across between different layers, and a number of turns are completely short-circuited and thereby bridged over, so that they are excluded from having any influence upon the production of the magnetic flux.

Short-Circuit in a Coil.—This fault is better recognised by an increase of the shunt current, and by a decrease in the resistance of the defective coil, than by the heating, which is probably always present to a certain extent. The resistance is decreased by the bridging over of several of the layers, and therefore the number of turns in the coil which are effectively at work is less than the actual number in the coil. Both these causes tend to increase the shunt current (at the same voltage), and therefore raise the heating of the coils that are at work. A direct short-circuit in a coil may produce so great a bridging-over of the turns that the whole coil no longer has any magnetizing effect; as, for example, if the end and beginning of the winding have become electrically connected together. With modern machines this will not often occur; but formerly, where the bobbins were made of zinc, which is not a mechanically satisfactory material, this fault has often happened. Such a completely short-circuited coil will naturally not become heated in working, since no current flows through it. With a bipolar machine this cutting out of one coil will have no further influence on the working of the machine; since, as is well known, when there are two opposite poles, one only need be wound, while the other will be a resultant pole without any winding. In spite of this, the strength of both poles (not taking into account the magnetic dispersion) will be the same as if both coils were at work; and since by the shortcircuiting of one coil the total resistance has been reduced to half of the previous value, a short current of double strength will now, at the same voltage, pass through the one remaining coil. This will naturally result in great heating of the still good coil, but there will be no sparking.

Damp often causes a gradual complete carbonisation of a coil.

Contact between the Magnet-Winding and the Iron.—In the case of shunt machines, the existence of a short-circuit between the winding and the iron, that is to say, of a contact between the copper winding (or more usually one of the coil ends) and the iron of the frame, though in itself of no account, may become dangerous. For when two such faults are present, either both in the winding of the magnets, or one in the magnet and the other in the commutator or in the armature-winding, there will be a breakdown. Further, with machines in a three-wire system, with earthed middle wire, when the frame is earthed, or in the case of railway motors working with an earthed return, any single fault of the kind under consideration will result in complete breakdown, just as has already been shown when treating of the armature breakdowns. Fig. 13 shows the following example: A contact is sup-

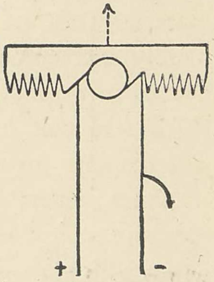


FIG. 13.

posed to occur between the iron frame of a bipolar machine and the copper cable or link connecting together the two magnet-coils. The frame is assumed to be earthed, and the negative conductor also earthed. In this case, the right-hand magnet-coil is completely cut out of circuit. The effect of such a short-circuit will be different according to the point in the winding where contact occurs.

Contact between the Thin Wire and the Thick Wire Winding.—In the case of compound-wound machines, short-circuits between the two windings may occur. With regard to the result of these, it depends entirely upon the position where they occur. The general scheme of a compound machine is given in Fig. 14. The thick line represents the series (thick wire) winding, and the thin line the shunt (thin wire) winding. The connections can also be made as in Fig. 15 where the shunt winding is connected directly across to the armature. The only difference lies in the fact that in the first case the shunt current flows

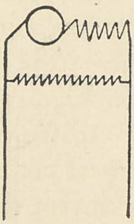


FIG. 14.

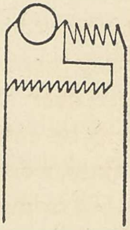


FIG. 15.

also through the series coils, and that in the second case it does not. Let us first keep to Fig. 14. Here a short-circuit or point of contact between the two wires may occur in different places. Fig. 16 shows a case where the middle of the shunt winding is in contact with one point of the series winding. The result is that half of the shunt current conveys no current. This fault shows itself in action in the same way as the previously mentioned fault, where some of the coils were bridged over. In the case of multipolar machines, working will be entirely stopped. In the case of bipolar machines, working will in general not be entirely prevented, but owing to the heavy current one coil will become very hot while the other remains cool.

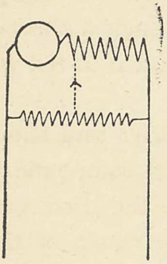


FIG. 16.

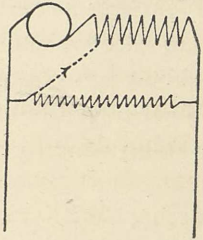


FIG. 17.

Fig. 17 shows a short-circuit between the commencement of the shunt winding and the beginning of the series winding. In this case the entire shunt winding is thus put in parallel with the series winding Since the resistance of the shunt winding will be about

1000 times as great as that of the series winding, one may say that the shunt winding is completely short-circuited. Practically no current will flow through it, and the machine will not excite itself, since the two poles of the armature are short-circuited. Such a short-circuit entirely prevents the working of a dynamo. With an electric motor it is equivalent to a direct short-circuit across the mains.

A further possibility is a contact between the end of the shunt winding and the beginning of the series winding, as in Fig. 18. This has obviously the same effect as a short-circuit between the negative lead and the negative brush spindle. The result, when the short-circuit path is itself of very small resistance indeed, is only that the series coil is short-circuited. The machine will then work as a shunt machine without affecting the working any further.

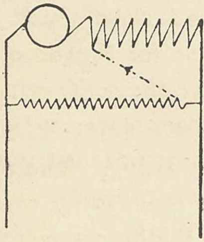


FIG. 18.

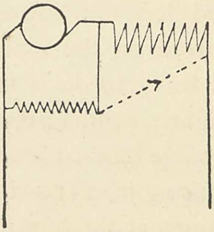


FIG. 19.

A harmless short-circuit is one between the two coils, between the end of the shunt and the end of the series winding. It is evident that such a short-circuit has no effect on the action of the machine, at any rate when the connections are made as in Fig. 14. If the connections are made as in Fig. 15 the effect is again that the series coil is short-circuited, and that the machine works as a single shunt machine (Fig. 19).

Wrong Connection of Compound-Wound Machines.—The wrong relative connection of the series and shunt windings of both dynamos and motors may, as is well known, lead to trouble. If a new or repaired compound-wound machine with the field regulator kept in one place drops in its voltage, although the speed has not varied, then if no short-circuit has occurred on the mains to account for the drop, the first thing to do is to see whether the series winding is rightly connected. If it has been reversed, it will of course tend to lower the voltage at full load, instead of raising it. The simple remedy is to reverse its connections at the terminal board. While with dynamos such a wrong connection can hardly cause a breakdown, yet with motors it is almost dangerous. In a correctly connected compound motor, that is to say, in a shunt motor with a series winding to increase the torque at full load, the current in the series winding must flow in the same way as in the shunt winding. This increases the magnetisation at full load. The result is, that with increased load the speed drops more than with a shunt motor ; it will usually drop about 25 per cent. This is no disadvantage for the purpose for which compound motors are usually used, namely, for cranes, hoists, lifts, etc. Now consider what will happen if the series winding is wrongly connected. The current will now flow in opposing directions in the two coils. The result is that the series coil, instead of strengthening the magnetic field, will weaken it. With a weakened field, however, the speed will increase, and this may lead to a catastrophe. When starting compound motors for the first time, one must for this reason be more careful than with ordinary shunt motors.

Faults in Starting and Regulating Resistances. We will now pass on to those faults which may occur in the accessories of the machine, namely, in the starters and the regulating resistances. There are naturally not many such faults, and when they do occur they are, owing to their great accessibility, easy to find out and to repair. The most usual fault is a break in one spiral or element of the resistance. Then no more current will flow through the apparatus. The result is that a dynamo will not give any voltage, and that a motor will not run: the former because the exciting current cannot flow, and the latter because the path of the armature current has disappeared. In both cases it is possible, in spite of this, to run the machines as long as the particular coil is near the end (i.e. the "off") point of the resistance. For then in the case of a dynamo we may certainly, and in the case of a motor we may usually, move the switch over without danger to the next "point" in the circuit, or we may short-circuit the defective coil. While in the above cases the breakdown is not in itself dangerous, even in the case of a motor with a regulating resistance in the magnet circuit, since it will be at once noticed, nevertheless the fault may lead to trouble. A break in the regulating, if it were to occur while the motor was running, would cause the motor either to race or to burn out. A continuous-current motor, the excitation of which is suddenly removed, will either run up to an enormous speed, or else stop and be burnt out, according to the load and the position of the brushes.

The Connections of Starters for Shunt Motors. Although it may appear superfluous to speak here about the correct connection of a starting resistance, yet numerous unpleasant experiences of the author's make it appear necessary to him to say something about this question. The rule for a shunt motor is that the starter must be connected so that it lies before the armature, see Fig. 20, while the shunt winding is connected parallel to the armature and the starter. In that case we fulfil the condition that when switching in, the shunt stands under the full pressure, i. e that the magnets are strongly magnetised, while the armature current is weakened by the resistance con-

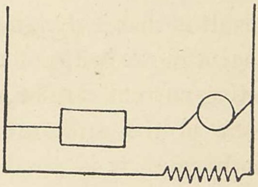


FIG. 20.

nected in series with it. In no circumstances should the connections be made as in Fig. 21, where the shunt is now parallel to the armature alone. In that case when switching in, only a weak current will flow through the shunt, and the motor will not exert any torque, i.e. will not start.

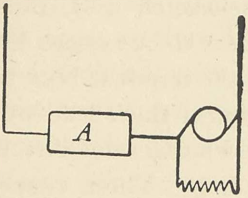


FIG. 21.

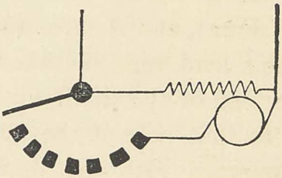


FIG. 22.

Until recently the arrangement shown in Fig. 22 was often used in order to prevent sparking when switching off the motor. The shunt winding is connected directly to the leads and remains in circuit at the end of the run, until opened by means of a special switch when the motor is stopped. A very simple

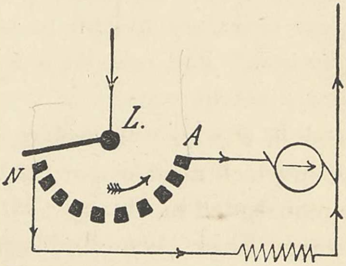


FIG. 23.

and suitable method of connecting up the starter is shown in Fig. 23. Any sparking is prevented by this arrangement. The starters are usually constructed with three terminals, which are usually distinguished by three letters such as in the sketch, as L (line), N (shunt), and A (armature). It is to be noticed that a thin lead must be taken from the terminal N to the free end of the shunt winding, and a thick lead from A to that pole of the machine which is not directly connected with the shunt winding. These connections are shown in Fig. 24. There are, however, two common ways in which mistakes are made. The more usual case is represented in Fig. 25. Here the marks on the resistance have been used correctly. The terminal L is connected to a lead, the free end of the shunt is connected to N, and to the terminal A one pole, but the wrong pole, is connected. The connection has been made namely to the pole which is connected to the shunt winding, and the return lead is taken from the free pole. If one now considers what

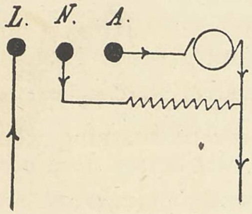


FIG. 24.

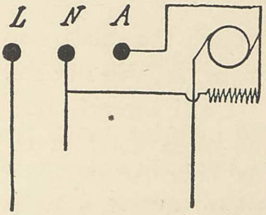


FIG. 25.

will happen in this case, one will find that the motor may start without load, but not with load. The further the starting lever is turned the more the shunt current is diminished, until finally no current at all flows through the magnet. The motor will then either run away, sparking furiously, or else stop dead and burn out.

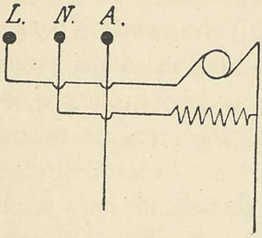


FIG. 26.

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A further false method of connection is shown in Fig. 26. Here the terminals A and L have been interchanged. The result is that the shunt current is much weakened at starting, wherefore in most cases the motor will not start. If it does run, however, it will then run better from contact to contact, until finally the end contact is reached, when it is then correctly connected. In this case the fault occurs which is represented in Fig. 21.

Various other Faults.—We have now said enough on this subject, and turn to the last division of our catalogue of the faults of continuous-current machines. We will here consider different causes of trouble which do not fall under any of the above headings. A fault which often occurs is the loss of the remanent magnetism of a machine. This may be caused in two ways; first, owing to the machine not having been used for a long time, and secondly, through false magnetisation of the poles.

Loss of Magnetism.—The first phenomenon is due to the fact that cast-iron or cast-steel of a dynamo may gradually lose its remanent magnetism until the remaining field is no longer powerful enough to generate a high enough voltage to produce a sufficient current in the field coils. The second fault is more important, since it occurs oftener. Here various occurrences may lead to the demagnetisation of the poles. It may be caused by an extraordinary armature reaction, or by the occurrence of the currents in the magnet coils in the wrong direction. In the first case, with shunt machines, a heavy short-circuit may result in an armature current heavy enough to overcome the field induced by the magnet winding. Such cases have often occurred in practice. The possibility has also been proved that a shunt machine can be depolarised during accumulator charging. Currents in the wrong direction in the magnet winding occur principally with compound machines working with accumulator plants.

Reversed Poles.—The by no means uncommon sudden reversal of the polarity of a continuous-current dynamo follows immediately after the above. As has been there remarked this can be easily caused, in the case of a shunt machine, by a heavy short-circuit, when the current in the armature overpowers the magnetic action of the polar windings, and not only destroys it but even reverses the field. The author has met several cases, which were formerly considered impossible of belief, which can be explained only on these grounds. That the reversal of compound machines may easily be caused by the back flow of current from accumulators is well known to everyone.

Since the reversal of polarity only occurs in accumulator stations, or in plants where several generators work in parallel, all that is necessary to do is to lift the brushes from the armature and to send a current through the field from the 'bus-bars.

Heating of Magnet Coils by a too Heavy Shunt Current.—Every dynamo is built for a certain voltage and for a certain speed. It follows, hence, that it is not allowable to run a dynamo either at normal voltage and higher or lower speed, or at normal speed with too high or too low pressure. We have already considered, in the part dealing with sparking, the faults caused by a machine running at normal pressure and too high speed, or at normal speed and low pressure, and have seen that in these circumstances the weakening of the field is the cause of the trouble. The other fault, namely, the running of the machine at normal speed and too high voltage, or at normal voltage and low speed, we have not yet considered. This fault is shown by abnormal heating of the armature iron and of the field coils. It occurs oftener than one would think in plants with accumulator batteries. Dynamos for charging accumulators are, at their normal highest voltage (165 volt for 60 cells), already very heavily loaded. This in itself is of no harm, since this high voltage is only required for a comparatively short time. One should on no account try to get any more out of the machine. A reduction of the current has not much effect, since with such heavy excitation the influence of the load on the shunt current is very small, so that the heating of the coils and armature iron does not depend upon the load but upon the voltage.

The Bearings.—Modern bearings are always fitted with ring lubrication. Several firms employ self-aligning bearings with spherical seatings, even with motors of 1 horse-power only. If the motors are carefully put in order when starting up for the first time, the bearings will very rarely run hot, in spite of the high journal speed. When a hot bearing does occur, it is always due to neglect.

The bearings of new machines must always be washed out with paraffin oil until the oil flowing away remains clear. In many cases small and medium machines are kept a good time in stock, so that it is impossible to prevent some little oil finding its way into the oil chamber. If a machine be started up without this cleaning out, the bearing may run hot, and the journal may bind in the bearing or the babbit-metal bushing be melted out.

The use of a good and not too heavy oil for filling the oil box goes without saying. If the oil is too thick, the oil rings will not run round. The oil box should not be filled too full, as then the oil ring is hindered from moving, and may not convey up enough oil to the journal.

The oil rings should be of brass (cut off from drawn brass tube, carefully cleaned from grit). Iron is objectionable, because of magnetic effects, and zinc is also bad, since it is so easily rubbed away.

A fault which often occurs with new plant is the belt being stretched too tight. This cannot be sufficiently strongly impressed, since a too tight belt may melt out a bearing in next to no time.

This occurrence may be prevented by gradual tightening of the belt. Since, however, mishaps often occur from this cause, it is obvious that sufficient attention is not always paid thereto.

Cutting-off of the Air Supply.—When working continuously, a motor requires a good supply of air, and a common cause of abnormal heating of a motor is the hindering of the supply by covering the motor with a case. Only when motors are intermittently at work is such a covering allowable. For continuous working it is dangerous for the motor. Any casing over the motor should have sides and top of perforated metal ; except in the case of motors in mines, or in places where the atmosphere is explosive, totally-enclosed motors should not be tolerated.

We must now refer to a fault which is caused directly by the neglect or forgetfulness of an employé. When stopping a motor, even if only for a short time, the starter handle *must* always be brought back to the starting point, so that the total starting resistance is in series with armature, and so that when the current is turned on again, the armature is not short-circuited. When a breakdown occurs in the current supply, the starters of every motor connected to the system must be brought back to the first step.

Short-Circuit in the Supply Leads.—If a short-circuit in the supply cables occurs while the dynamo is stopped, the dynamo will not generate any current when started up, since the shunt field cannot be produced owing to the short circuit. This cause may be found out in the following manner. Disconnect the leads from the machine, and run up the machine with a voltmeter across its terminals. If a short-circuit is in the leads, the only remedy is naturally its removal.

Short-Circuit in the Leads due to Motors not being Switched Off, or to a number of arc lamps being connected in parallel. If, when the plant is shut down, the switching out of the motors is forgotten, then this may, under certain circumstances, have the same effect as a short-circuit in the mains. It follows, hence, that under all circumstances, when shutting down, all motors and arc lamps must be switched off. By using starters with automatic release this may be ensured, as far as motors are concerned, since these starters, when the current is cut off automatically, return to the starting point.

Determination of the Temperature.—Dynamos and electric motors naturally become heated when running, since the losses in the machine disappear as heat. The rise of temperature under normal circumstances must, however, not exceed a certain amount, and it has been fixed, from long experience, that the heating of any part of the machine in continual work should not exceed 40° Centigrade, or 70° Fahrenheit, above the temperature of the surrounding air.

In order to see whether the temperature-rise, after several hours' running, exceeds the above limit, it is not sufficient to feel the machine with the hand. Special thermometers must be placed on the armature winding immediately the machine is stopped, and prevented from cooling by cotton wool or wadding.

The readings must be taken at short intervals, and continued until no further rise of the thermometer can be observed, i.e. until the thermometer begins to fall.

CHAPTER II.

SINGLE-PHASE AND POLYPHASE GENERATORS.

Generators with Rotating Armatures.—Until recently it was not unusual for single-phase and polyphase generators to be built with rotating armatures, with two or three slip-rings for the delivery of the current. For low pressures (up to about 500 volts) such machines are still to be found. They are but little different in design from continuous-current machines. An advantage is that the most delicate part of the continuous-current machine, i.e. the commutator, is absent, consequently faults and breakdowns are much rarer with these machines. The slip-rings are naturally much more easily insulated from the spider or the shaft than the commutator.

Faults in the Armature.—Faults do not often occur with the slip-rings. The armature winding of such single-phase machines differs from that of a continuous-current machine, in that while in the latter at least two, and with multipolar machines usually more than two, parallel armature paths are present, in the case of single-phase generators with rotating armature there is almost invariably one path only. This is a reason why the number of armature turns is less than that of a continuous-current machine under conditions that are otherwise similar. As is well known, polyphase generators have several windings meeting at one point; a two-phase machine two, or sometimes four, windings ; and a three-phase machine three windings, which are connected together at the so-called neutral-point. Faults occurring in these windings may be either short-circuits to iron, or short-circuits between the copper of one coil or two coils. They show themselves not by sparking, since the continuous sliding surface almost entirely prevents sparking, but by the unusual heating of the winding.

Modern Alternators with Fixed Armature.—Since in practice alternators with rotating armatures are daily becoming rarer, we will consider at once the modern single-phase and polyphase generators with fixed armature and rotating field-magnets. This procedure is rational since the same faults occur in both kinds of machine.

Calling the fixed armature the stator, we can consider the breakdowns in alternators under three heads, viz. (1) the faults which occur in the stator; (2) the faults occurring in the magnets; (3) the faults of the exciter.

Faults Occurring in the Stator.—The stator of a modern single-phase alternator has one immoveable winding laid in slots or tunnels on the internal periphery, and the windings are brought out to two fixed terminals. Unless special circumstances, e.g. heavy current output, call for a departure from the usual practice, all the armature coils are connected in series; although, naturally, for machines of low voltage and large output, it is easily possible, in order to obtain a manageable section for the copper, to arrange for several parallel circuits.

Break in the Winding.—If the turns are all in series, on the occurrence of a break the machine will naturally give no current. Such a fault can easily be found, but will rarely occur, since a cause for the breaking of the fixed armature winding is very unusual.

Short-Circuits in the Windings.—If a short-circuit between the windings of a machine is present (by which we mean an undesired electrical connection of two points of the winding), the seriousness of the fault depends greatly upon the position of the short-circuit. If the short-circuit occurs in one coil only, it naturally affects that coil only. It is as if the coil were short-circuited, and then the internally-generated voltage produces an immense current. Such a fault is therefore soon noticed, by reason of the dangerous heating of the damaged coil. In addition to this, the voltage of the whole machine will be lowered, (1) because the voltage of the defective coil is no longer available, and (2) because the heavy current in the faulty coil demagnetises the magnet system. A temporary repair can be made without immediately inserting a new coil (that is, of course, if the point of breakdown cannot be made good again by inserting mica as insulation), by cutting out the defective coil and connecting the two neighbouring coils (of the same phase) together. The circuit in the defective coil must, of course, be opened. Since single-phase generators also usually possess a fairly large number of coils, the absence of a single coil can be made up for without unduly loading the armature iron and the magnet coils too much by increasing the magnetising current. With modern types of generators, the winding is so arranged that it is impossible for two coils separated from one another any distance to come into contact with one another. This cause of breakdown need therefore not be considered.

Short-Circuit between the Stator Winding and Iron.—A short-circuit to iron, in the case of an alternator, may be not only dangerous for the winding, but also for human beings. Modern alternators are built for very high pressures. A voltage of only 200 volts can, under certain circumstances, cause a fatal shock. Such generators have, therefore, earthed frames.

The Earthing of Generators.—This earthing has the following effect. In an alternating-current system of distribution with many branches, a fault in one cable is by no means an unusual occurrence. If such occur, then everybody who is not insulated from earth is under the influence of this short-circuit to the earth. If it were now possible for the alternating current to flow through the fault, and then through anybody back to the other pole, it would usually result in a fatal shock. Consider now in what manner most accidents have arisen. It is owing to someone having touched the frame of the alternators. This is a sufficient reason for earthing the frame. If the alternating current were to come into contact with the iron, then, if the machine were not earthed, anyone touching the frame would be the connecting link between the machine and earth. If, therefore, there occur at one and the same time a short-circuit in the cable and one to the iron of the machine, a pressure would act upon the man, the exact value of which would depend upon the ratio of the resistance of the connection to earth and the resistance of the man. This voltage could, under certain circumstances, be fatal. If, however, the machine is not insulated from earth, but is connected by a low resistance path, the man will be protected, since he has a much higher resistance.

With an insulated machine it is possible for the simultaneous appearance of a fault in the cable and the winding to pass unnoticed. With an earthed frame, however, a current would flow through earth between the two faults, and, according to the extent of the faults, the coils of the armature will be more or less over-loaded.

If two short-circuits to iron occur in the winding it has the same effect as a short-circuit between the copper of the winding, which has already been considered above.

Two-Phase Winding.—Two-phase armatures have two independent windings, displaced one from another by a half of the pole-pitch and connected together at the neutral point. Three-phase alternators have three windings, displaced by two-thirds of a pole-pitch. While, practically, two-phase generators are always connected, as above mentioned, in one point—the neutral point—three phase-windings are connected in two different ways.

Three Phase Star Connection.—Fig. 27 represents the more usual star method of connection. Here the three ends of the windings are united at the neutral point. The voltage between 1 and 2 is equal to the voltage between 2 and 3, and also between 1 and 3. This fact must be noticed as differing from

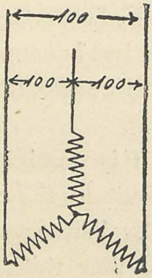

FIG. 27.

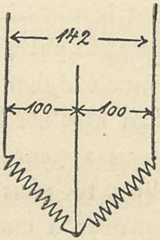

FIG. 28.

the conditions with two-phase systems and three-wire continuous-current systems (Figs. 28 and 29).

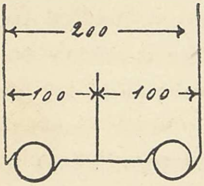

FIG. 29.

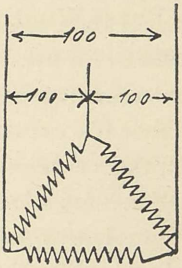

FIG. 30.

Mesh Connection.—Fig. 30 represents another method of connection, which is called the mesh or Δ (delta) connection. With the mesh connection, as can be seen from the figure, the end of every phase is connected with the beginning of the following phase. There is no neutral point. The current is taken from the three junction-points of the phases. Mesh connection is now practically never used in any machines working at over 100 volts.

In order fully to understand that which follows, it were perhaps necessary to treat the above a little more in detail than is permissible within the compass of this little volume.

Break in the Winding.—We will now consider what will happen in the case of two-phase and three-phase generators with a break in the winding. We come to the following result. In the case of a two-phase machine, a break affects only that phase in which the break occurs. As a result, as can be seen from Fig. 28, under such circumstances a two-phase generator will then only work single-phase.

The effect of a break upon the running of a three-phase generator depends upon the method of connection, whether Δ or star. If the machine is star-connected, then a break in phase 3 (Fig. 27) has the result that the machine will only work single-phase. Namely, the lamps between the terminals 1 and 2 will only burn while the lamps between 2 and 3 and 1 and 3 go out. Is the machine, on the other hand, Δ-connected, then if a break occur in phase 3 it appears as if the machine would only run two-phase. In reality, however, the machine still runs three-phase. There are really still three voltages generated in the machine. The pressure between 1 and 3 is, however, not produced in the defective phase 3, but is the resultant of the phases 1 and 2. As a result of the break, the remaining phases will obviously be much more heavily loaded.

Contact of Different Phases.—Short-circuits to copper and iron have naturally the same effects with polyphase machines as were above described in the case of single-phase machines. Short-circuits between two different phases are, however, especially dangerous, whether due to a direct contact between the copper, or whether both coils are short-circuited to the iron. This fault will be at once noticed—leaving out of consideration the unusual heating—by the voltages being no longer equal. The position of the fault can easily be found by means of a galvanoscope or incandescent lamp, or by an electric bell.

Wrong Connection in the Stator Winding.—It does not often happen that the stator coils are wrongly connected, still it will do no harm to refer here to one or two points connected therewith. If a single coil is wrongly connected, it can only be that the beginning and end of the coil have been changed one with another. The coils are always connected one after another, the end of the first with the beginning of the second, and the end of the second with the beginning of the third, and so on. If, therefore, one of the coils is wrongly joined up, it will act against the others, and so tend to reduce the total voltage of the separate phase by twice the voltage of the particular coil. It is, however, also quite possible that a complete phase is wrongly connected with the others. It may happen that the beginning and end of one phase of a three-phase machine have got mixed, so that instead of the beginning being connected to the terminal and the end to the neutral point, the reverse has taken place (Fig. 31). A machine connected in such a way certainly gives three-phase currents. The currents, however, are not relatively displaced 120°, but only 60°. [The author has described this fault previously in connection with the winding of three-phase motors, in his *Handbuch der Elektrotechnik*, vol. 9, 2nd part, pp. 60, 91, 92.]

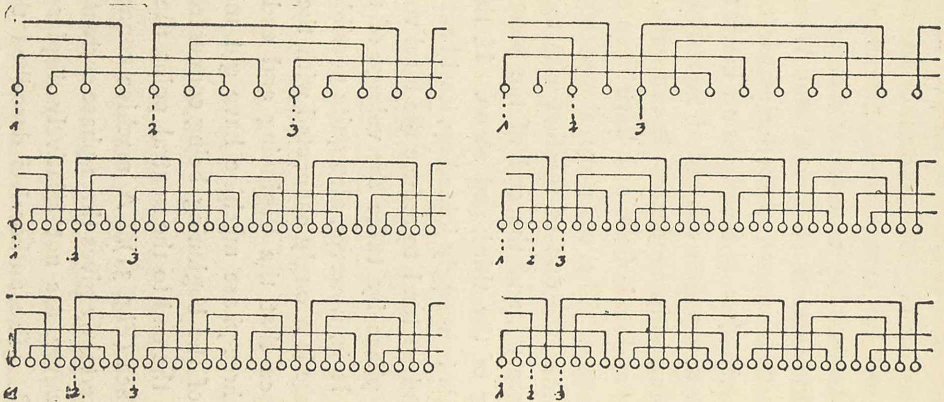

FIG. 31.

EXAMPLES OF CORRECT AND INCORRECT METHODS OF CONNECTING THREE-PHASE WINDINGS.

Field Winding.—If we now pass on to the faults in the field system of modern alternators, it is obvious that they are the same as those in continuous-current machines. Almost all modern alternators have a stationary and external armature which surrounds a revolving magnet-wheel. The latter consists of a number of outwardly-pointing poles fixed upon the periphery of a massive wheel. The field-magnet winding of an alternator differs from that of a continuous-current machine in three points : (1) the magnets are rotating; (2) as a result of this, the current must be supplied to the magnetising coils by means of slip-rings ; (3) the alternator is not self-exciting, but is excited by current from a special continuous-current machine called the *exciter*.

Considering these points, one after another, it is clear that by reason of the first the magnet winding is subjected to a mechanical strain, which does not occur with continuous-current machines. Under similar conditions, therefore, breakdowns in the insulation would happen oftener were it not that the danger is lessened by another cause. If there were the same heavy mass of copper on each pole, as there is in the case of a continuous-current machine, the above would be correct. Alternators have, however, always more numerous poles, and therefore a smaller weight of copper per pole, for machines of the same output.

The necessity of using two slip-rings, and the brush gear belonging thereto, brings into the field system a feature which may give rise to faults of insulation as well as to other faults. Slip-rings can indeed be easily insulated from one another, and from the shaft. A fault is, however, more likely to appear there than on the fixed terminals of the continuous-current machine. Sparking at the slip-rings may be due to two causes. It may either be due to a periodically occurring break in the magnet-winding; or, more usually, it results from bad material for the brushes or slip-rings, careless handling, untruth or dirtiness of the rings.

At any rate, all faults occurring in the exciting winding of an alternator are easily found. Moreover, the large number of the poles presents the advantage that in the case of a breakdown of one pole, one may without fear cut out one pole, connecting together the preceding and following poles. Then, by increasing somewhat the magnetising current, the correct voltage can be still maintained. This results in an irregularity in the strength of the various poles, which is however of no importance, because sparking, such as would occur with a continuous-current machine under the same circumstances, is impossible.

Exciter.—The continuous current for the field is usually supplied by a direct-coupled exciter, which usually possesses a single shunt winding, but sometimes a series winding also. With this machine the same faults may occur that we considered at the beginning, so that it appears useless to add anything more here.

Synchronizing.—Where two or more alternators are to be operated in parallel on the same 'bus-bars, it is necessary to provide synchronizing arrangements, so that the attendant on the switch board may not throw into circuit an alternator that is not already in step with those that are already on the circuit. Accidents of a serious nature have arisen from generators being switched in when not in step. To avoid accidents, the generator that is to be thrown in should be brought up to the proper voltage and to the proper speed, but must not be switched in until, by gentle adjustment of the speed up or down, the electromotive force has been brought into precise phase with that of the circuit. The synchronizing apparatus for indicating this usually consists of a lamp, fed through a small differential transformer, which lamp does not shine with a steady brilliance unless synchronism has been attained.

Cleaning Alternators. — Alternators must be cleaned from time to time from dust or dirt. A blast of high-pressure air is very convenient for this purpose ; or, for small stations, a hand air-pump, *made of wood,* having a barrel 2 feet long and 4 inches wide, is useful. In foundries and factories, where iron scale or iron dust is in the air, the magnet-wheels of alternators are sometimes found to collect fringes of dust on their poles, which ought to be cleaned off every day.

CHAPTER III.

SINGLE-PHASE AND POLYPHASE INDUCTION MOTORS.

THE *rotor*, i.e. the rotating part of the motor, which is often, but incorrectly, termed the armature, is the only part of an induction motor of which the construction is different from that of the above described single-phase and polyphase generators. The external part, the fixed *stator*, which is really the stationary armature of the motor, is exactly the same as the stationary armatures of modern alternators. This similarity is in the case of the larger sizes so exact that the same patterns are used for the stators of generators and induction-motors.

It is therefore useless to say anything extended here concerning the faults which may occur in the stator winding, since we have already noticed most of them. We will therefore only consider some points which are at any rate different in their external effect, and which differ from those previously mentioned.

We must specially mention the single-phase motor, which, as is unfortunately well known, is under certain conditions particularly liable to faults. Single-phase motors of the sorts now in use possess, in addition to the stator winding for normal running, another or second stator winding, which is only in circuit when starting up. By various means an artificial phase difference is created between the currents into the two windings, so that the motor starts as a two-phase motor. There are two usual methods of obtaining the required phase difference, either by inserting a capacity in the main circuit, or by inserting a reactance coil in the auxiliary circuit. The best results are obtained by applying both at once. Good results are, however, obtained by inserting a choking coil in the auxiliary winding, and an inductionless resistance in the main circuit. The above applies particularly to motors with short-circuited rotor. Motors with slip-rings are much better for starting, and require, in addition to the starting resistance between the slip-rings only, either a choker in the auxiliary circuit, or a capacity in the main winding of the stator, in order to start with full torque.

The cause of the faults to which single-phase motors are liable lies, as is well known, much more rarely in breakdowns in the winding, than in the auxiliary apparatus, the capacity being the weak part. These capacities consist of insulating pots in which a series of iron plates are placed, side by side, insulated one from another. The pot is then filled with potash, or soda solution, to the top of the iron plates. The current flows through this capacity, passing from plate to plate through the liquid. The action of the capacity depends entirely upon the concentration and the quantity of the liquid in the pots. If the solution evaporates in summer, or freezes partly in winter, the value of the capacity is altered, and the motor will no longer start satisfactorily. It may, indeed, refuse to start at all. If, therefore, motors having starting apparatus—that is, motors fitted with capacities—refuse for no apparent reason to start, in 99 cases out of a 100 it is due to the capacity. Choking coils are naturally not liable to such changes, and are therefore much to be preferred. Auto-transformers are also sometimes employed in starting apparatus. They are unlikely to give trouble.

Polyphase Motors. Stator Faults.—Two-phase and three-phase motors require no such auxiliary apparatus for starting. They can, however, be troubled with the faults which we have already learnt in connection with generators. If, for example, a three-phase motor heats abnormally, so that parts of the stator winding are hot while the rest is normal, it is at once clear that a short-circuit is present, either in one phase or between two different phases. The motor will then work with small torque but large current, which will be unequally divided amongst the three phases. A polyphase motor with star connection will not start with a break in one phase. Should the break occur while running, it then continues as a single-phase motor so long as the load is not too heavy. A fully loaded three-phase motor will almost always stop if a break occur in one phase. If half-loaded, it will continue to run, but the current in the remaining phases will be doubled. A three-phase motor will also often not start if the three phases are wrongly connected, so that, as already mentioned, in the case of the generators, a phase difference of 60° is caused by changing the beginning and the end of one phase in a star-connected winding. And if it starts, it will start backwards. In fact this is one way of reversing the rotation.

I might also mention a wrong connection which could make a motor of no use under certain circumstances. Although most firms build their three-phase motors with star-connected stator windings, it happens, principally for 110-volt motors, that the stator winding is designed as a mesh-connected winding, for the reason that then the same winding, if re-connected with a star-grouping, can be used for 190 volts. If a motor, which should be mesh-connected, is wrongly connected in star, it will start so long as it be not too heavily loaded, but will show a heavy drop in volts; and with an only average load, drop out of step and stop.

Wrong Frequency or Wrong Voltage.—An induction motor, designed to run at some particular speed on mains that work at a particular voltage with a particular frequency, cannot, in general, be worked from mains supplied at either a different voltage or a different frequency. Thus, suppose a four-pole induction motor, the no-load speed of which is 1500 revolutions per minute, at a frequency of 50 periods per second at 110 volts between lines. If put on a different circuit, where the frequency is 40 periods per second, the voltage must likewise be reduced to 88, and then it will run at 1200 only, and will give only $\frac{4}{5}$th its previous output with the same current as before. As a rule induction motors cannot be used for higher frequencies, or higher voltages, than those for which they are designed, but may be used for lower frequencies, provided the voltage is proportionately lowered.

Rotor.—That which principally distinguishes induction motors from alternators is the rotating part of the machine, the *rotor*. While the generators here possess a complete magnet-wheel or system with a number of separate poles excited by a continuous current, in all the induction motors we have a simpler piece of machinery which is built either as a short-circuited (or squirrel-cage) rotor, or as a slip-ring rotor with starting resistance. In the latter case we find principally the same faults as with continuous-current machines, while in the first case faults are altogether rare.

Short-Circuited Rotor.—The great mechanical simplicity of the rotor ensures almost entire freedom from faults. With early types, in which the single bars were sweated into or on to rings, it may occur, if the motor is heavily loaded, that the solder at some of the joints will melt, and the bars work themselves loose. The high resistance at the joint may then cause the motor to stop. With later types, the bars are not only sweated but riveted, or, in some cases, screwed on to the end rings, or else by the use of suitably stamped coils all joints are avoided. Some makers wind the rotors with many turns of bare wire, but with one joint only in each phase. In any case, such faults as arise at joints are easily recognised and repaired.

Slip-Ring Rotor.—Since the winding of the slip-ring rotor is considerably more complicated, there is more cause for faults. First, a break can occur in one phase, either in the starting resistance or the rotor winding itself. The motor will not then start so well, and will run up only to about half the normal speed. A short-circuit in one phase, or between separate phases, may be recognised from the loud humming noise caused, as well as by the heating of the rotor.

It may here be pointed out that all firms without exception build the slip-ring rotors, not only of their three-phase motors, but also those of their single-phase and two-phase motors, with three slip-rings and a three-phase winding; and, consequently, a triple starting resistance in the rotor circuit is always used, no matter how many phases the motor may have. We have said above that a three-phase motor will still start with a break in one phase; a break in two phases will, however, cause it to stop, since it is obvious that no current can flow in the third phase.

From the above it follows that faults with polyphase motors are much rarer than with continuous-current motors, as may be confirmed at any time from actual practice. The only part of them that requires attention is the lubrication of the bearings, and as this is usually automatic, with oil-rings, inspection is necessary only at long intervals. It need hardly be added that where motors are used in a dusty workshop, they should be protected with gauze or perforated metal over the openings in their frames; and may occasionally need to be opened to remove dust. Beyond this, induction motors rarely need any attention whatever. We therefore close this chapter, and turn to the consideration of the troubles met with in transformer work.

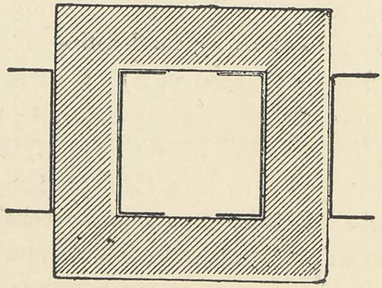

FIG. 32.

CHAPTER IV.

SINGLE-PHASE AND POLYPHASE TRANSFORMERS.

TRANSFORMERS may be divided into two types, core transformers and shell transformers. The classification is imperfect, because all shell transformers have a core, and all modern core transformers have yokes, if not a shell. A single-phase core-type transformer is represented in Fig. 32, a shell-type transformer in Fig. 33. It can easily be shown that the iron core of

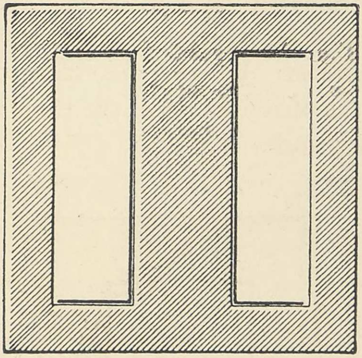

FIG. 33.

a single-phase transformer can be developed from the iron part of two dynamos. The core transformer

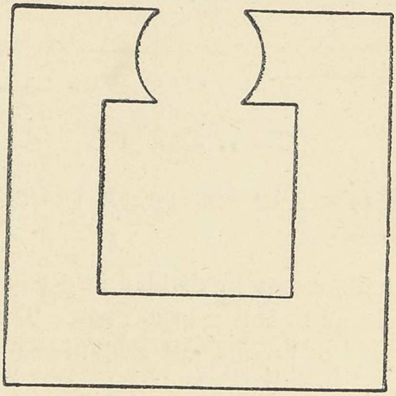

FIG. 34.

Fig. 32 can then be regarded as springing from the horseshoe-type of field-magnet (Fig. 34), and the

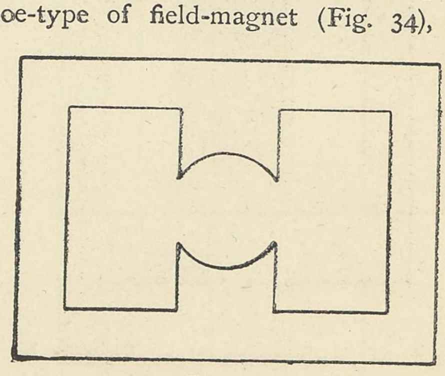

FIG. 35.

shell transformer from the iron-clad or semi-enclosed bipolar-type of field-magnet (Fig. 35).

Two-phase and three-phase transformers are obtained in the simplest way by connecting two or three separate transformers according to either Fig. 36 (two-phase) or Fig. 37 (three-phase; star connection).

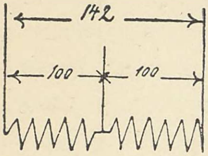

FIG. 36.

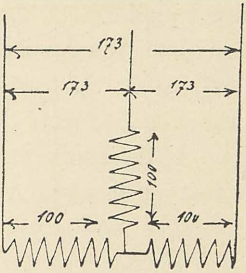

FIG. 37.

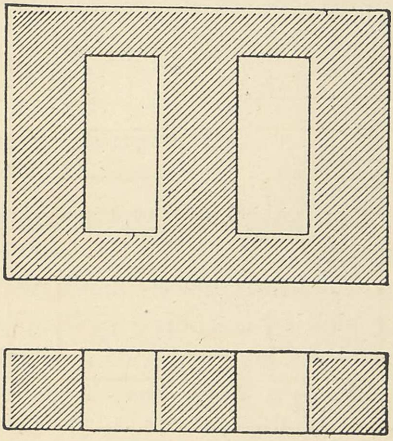

FIG. 38.

Three transformers are also often connected in mesh, as in Fig. 30. If the two-phase voltage between lines is 142 volts, the two single-phase transformers must be built for 100 volts. With star-connected three-phase transformers, with a voltage of 173 volts between lines, the separate transformers must be built for 100 volts. If the line voltage is 1000 volts, each of the star-connected transformers must be of 577 volts. If the transformers are connected in mesh, the line voltage is equal to the voltage of a single transformer. In Figs. 30, 36 and 37, the various voltages have been inserted.

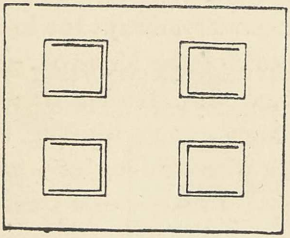

FIG. 39.

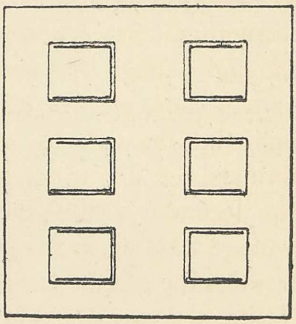

FIG. 40.

Two-phase and three-phase transformers can, however, also be built by combining mechanically in one system a corresponding number of single-phase transformers. Numerous firms have built three-phase transformers as in Fig. 38. These are three-leg core transformers. The difference between them and the single-phase shell-type (Fig. 33) is, that the section of the three legs is the same, and that all the three are wound, while in the single-phase transformer the middle leg, which is the core, has twice the section of the outside legs, which here serve as shell. Shell transformers for polyphase currents have also been built as in Fig. 39 (two-phase) and Fig. 40 (three-phase).

There are two windings on each core, a primary and a secondary winding, since a transformer is built to transform an alternating current from one voltage to another. Since, however, the primary is not always the high voltage side, or the secondary always the low voltage side, we will here speak of the high-voltage and the low-voltage windings. In step-up transformers, the fine winding, or high-voltage winding, is the secondary, while the thick wire winding, or low-voltage winding, is the primary. In step-down transformers the reverse is the case. There are two different ways of arranging these windings. In one arrangement, one winding lies around the other, over the whole length of the core. The two are separated by an insulating layer. In the second arrangement, the winding is laid in a row of coils on the core, alternately primary and secondary. The former method is represented in Figs. 32 and 33, and the latter in Fig. 41. It is hardly possible

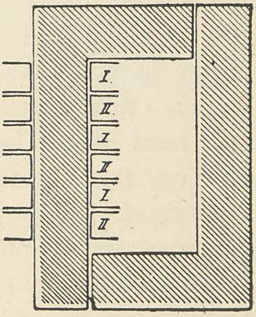

FIG. 41.

to single out any special advantages of one method over the other. It is, however, an advantage that the arrangement with sandwiched coils lends itself to a quicker repair than the other arrangement. With regard to voltage-drop there is nothing to choose, both arrangements being equal with correctly dimensioned gap between the primary and secondary windings, and a sufficient number of separate coils.

Faults. Bridge-over in the Winding.—Faults occur relatively much more rarely with transformers than with dynamos. The most usual fault is a short-circuit in the high-voltage winding, which causes it to carbonize in layers, resulting in a more or less serious bridging over of part of the high-voltage winding. It is at once seen that such a carbonisation will extend less with transformers having sandwiched coils than with the other type. The windings short-circuited by this carbonisation are then subject to a heavy short-circuit current. Beyond this, they have further no magnetic action upon the low-voltage winding. The result will usually be that the secondary voltage will increase, since the ratio of transformation (i.e. the number of primary turns divided by the number of secondary turns) is altered.

In addition, the heating of part of the transformer and the high no-load current will point out this fault. The conditions will be much the same if the fault appears in the other winding, as will usually happen if the high-voltage winding is not the primary but the secondary winding, as is the case in transformers for stepping-up. In this case the secondary voltage will be lowered, not increased.

It can easily be seen, from what has gone before, that the same effect will be caused by a double short-circuit to iron.

Lightning.—Lightning is considerably feared in transformer stations, and many faults are laid to the credit of lightning which can be otherwise explained in the most simple manner. If lightning strike the primary or secondary transformer leads, owing to the high self-induction of the windings, it is not to be expected that it will pass through either coil; it will, more likely, seek the quickest way to earth, and, owing to the high voltage of such a discharge, it will certainly find one. It thereby destroys the insulation of the particular winding, and damages, by the heat evolved, both a part of that winding and also usually a part of the other winding as well. There are, however, many possibilities for lightning to find its way to earth through a transformer without in any way affecting its action, so long as there is no second short-circuit in the transformer. In many cases an earthed sheet or wire is provided between primary and secondary to prevent disaster.

Great danger can be produced with badly insulated transformers, by the high-voltage winding coming into contact with low-voltage winding in two places, since the high-voltage alternating current then enters the low-voltage circuit, and may do great damage with great danger to property and to life. Such occurrences are fortunately rare—how they may occur can be seen from Fig. 42. Here one lead, carrying high-voltage current, may have a short-circuit to earth while at the same time the low-voltage side is also earthed. If the lightning then travels in the direction of the arrow, and a short-circuit between the primary and secondary winding is caused by the action of the arc, the high-voltage current enters directly into the low-voltage circuits, and destroys lamps, motors and everything taking current, and may, possibly, end with fatal results.

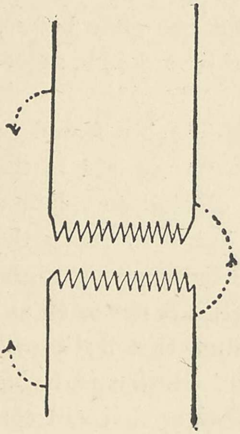

FIG. 42.

Transformation of Three-Phase Current by Two Single-Phase Transformers.—If one of two transformers connected together for transforming two-phase current should break down, the plant can only be driven single-phase until the break-down is repaired. On the other hand, if one transformer of three connected in mesh should break down, the plant can still be worked three-phase. The two remaining transformers will naturally be very heavily loaded.

CHAPTER V.

EFFICIENCY.

MANY purchasers of dynamos, motors or transformers, stipulate for a certain *efficiency* of the machine, and sometimes demand a test to show that the stipulated value has not been exceeded. Here is perhaps, therefore, a suitable place to describe the simplest and most easily comprehended method of measuring the efficiency. By this term we understand the ratio of the energy given out to the energy put in to the machine. In the case of a dynamo, it is the ratio of the electrical energy given out to the mechanical energy supplied to the shaft. For an electric motor, it is the ratio of the mechanical energy given out to the electrical energy put in. And in the case of a transformer, the ratio of the electrical energy given out to that supplied. Both values which form the numerator and denominator of a fraction must be expressed in terms of the same kind, and for this purpose it is preferable to express power, whether electrical or mechanical, either in *watts* or else in *kilowatts.* Now 1 horse-power of mechanical power is equal to 746 watts of electrical power. If a dynamo supply 10,000 watts, and in doing that takes 15 horse-power, the efficiency is $\frac{10{,}000}{15 \times 746} = 0 \cdot 91 = 91$ per cent. If a motor takes 10,000 watts and gives out 12 horse-power on the shaft, its efficiency is $\frac{12 \times 746}{10{,}000} = 0 \cdot 89 = 89$ per cent. If a transformer takes in 20 kilowatts and gives out 19 kilowatts, its efficiency is $\frac{19}{20} = 0 \cdot 95 = 95$ per cent.

It is clear that in this process of transformation which takes place in an electric machine, being either from mechanical energy into electrical energy (dynamo), or electrical energy into mechanical energy (motor), or finally, from electrical energy at one voltage into electrical energy at another voltage (transformer), losses in energy must occur inside the machine. Otherwise the energy put in and taken out in a given time would be equal; we would have 100 per cent. efficiency, and the problem of perpetual motion would be solved. We know the various losses within our electric machines very accurately, and will only mention the loss in the coils of the armature and of the field-magnets; the losses in the laminated iron cores; losses through eddy-currents; friction in bearings, air-friction, brush friction and resistance, etc. etc. In the following method it is unnecessary to separate out all the above losses. We must, however, understand how we may classify these different losses in groups.

It can be seen that the loss in the armature winding, in the thick wire winding of compound-wound machines, in the stator winding and rotor winding of induction motors, and finally, in the windings of transformers, can be calculated by measuring the electric resistance in ohms, and by finding out the full load current. This loss is then equal to the resistance multiplied by the square of the current, $R \times C^2$.

It is equally clear that the loss in the field-magnet winding of a shunt machine is known, if one knows correctly the voltage and the current flowing through the windings when the armature is at full load. The loss is equal to the voltage multiplied by the shunt current.

Although the above losses in the copper conductors can be very simply measured as soon as the resistance is known (as can be at any time found out by sending a sufficiently heavy current through the circuit, and measuring the current and the volts between the ends of that resistance, the resistance being equal to the volts divided by the amperes), the calculation of the losses in the iron and of the friction losses is very difficult. It becomes, however, easy to get at these losses experimentally by running the machine (whether dynamo or motor) light, as a motor, at full voltage and full speed. When so running, one measures the amperes in the armature circuit. It is advisable to run the machine at least two hours before taking the final amperemeter reading; because as the machine warms up a little, the copper resistances are increased, while the bearing friction diminishes slightly. The armature current, multiplied by the voltage, gives the value of the magnet and friction losses very accurately.

Example 1.

Continuous-current shunt dynamo, 40 kilowatts, 600 revolutions per minute, 110 volts. Armature resistance (measured) = 0·0055 ohms. With full load (364 amperes) at 110 volts, and 60 revolutions per minute, the machine had a shunt current of 6 amperes.

The machine was connected as a motor, and an accurate amperemeter was connected in the armature circuit; the reading on this, after running several hours, was 15 amperes.

Loss in the armature winding . . = $364 \times 364 \times 0{\cdot}0055$ = 725 watts.
Loss in the magnet winding . . = 6×110 = 660 watts.
No-load loss . . = 15×110 = 1650 watts.
Total losses 3035 watts.

Efficiency of the machine:

$$\frac{40{,}000}{40{,}000 + 725 + 660 + 1650} = \frac{40{,}000}{43{,}035} = 0{\cdot}93, \text{ i.e. } 93\%.$$

Example 2.

Continuous-current shunt motor, 50 horse-power, 110 volts, the same machine as was tested above as dynamo. The values of the resistances are the same, and also the current at full load. The magnet current is, however, only 4 amperes. The no-load current is still 15 amperes. We have the following losses :—

Armature winding . .	725 watts.
Magnet winding . .	440 watts.
No-load	1650 watts.

so that the efficiency at 50 horse-power is

$$= \frac{50 \times 746}{(50 \times 746) + 725 + 1440 + 1650} = 0{\cdot}91, \text{ i.e. } 91\ \%.$$

Example 3.

Three-phase induction motor with short-circuited rotor for 220 volts, 2 horse-power, 50 periods per second, 1500 revolutions per minute.

By measurement the current was found at no-load, and at full-load, and also the electrical resistance of one stator phase, i.e. of one third of the stator windings.

The no-load current was 2·22 amperes, the power taken at no-load was 59 watts per phase ; therefore, for all three-phases 177 watts. With 5·5 amperes full-load current per phase, the power consumption was 600 watts per phase, i.e. 1800 watts altogether. The electric resistance of one stator phase was 0·73 ohms. There occur, therefore, the following losses :—

1. No-load (mechanical and magnetic losses, losses in the stator winding due to the no-load current) = 177 watts, as per test.

2. Additional copper loss at full load (in the stator) $= (5{\cdot}5 \times 5{\cdot}5 - 2{\cdot}22 \times 2{\cdot}22) \times 0{\cdot}73 \times 3 = 55$ watts.

3. Copper losses in the rotor. These are proportional to the slip. The motor made 1500 revolutions per minute at no-load, and 1420 revolutions per minute at full-load. The rotor losses are therefore—

$$1800\left(1 - \frac{1420}{1500}\right) = 99 \text{ watts.}$$

The efficiency is therefore—

$$\frac{1800}{1800 + 177 + 55 + 99} = \text{about } 0{\cdot}845, \text{ i.e. } 84\tfrac{1}{2}\,\%.$$

We may also deduce from the above experiment the value of the power-factor—

$$\cos\phi = \frac{1800}{220 \times 5{\cdot}5 \times \sqrt{3}} = 0{\cdot}86.$$

An example about the efficiency of transformers we consider superfluous, since now the value of the efficiency should be clear after considering the above, namely, equal to the ratio of the watts given out by the secondary to the watts put in to the primary.

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