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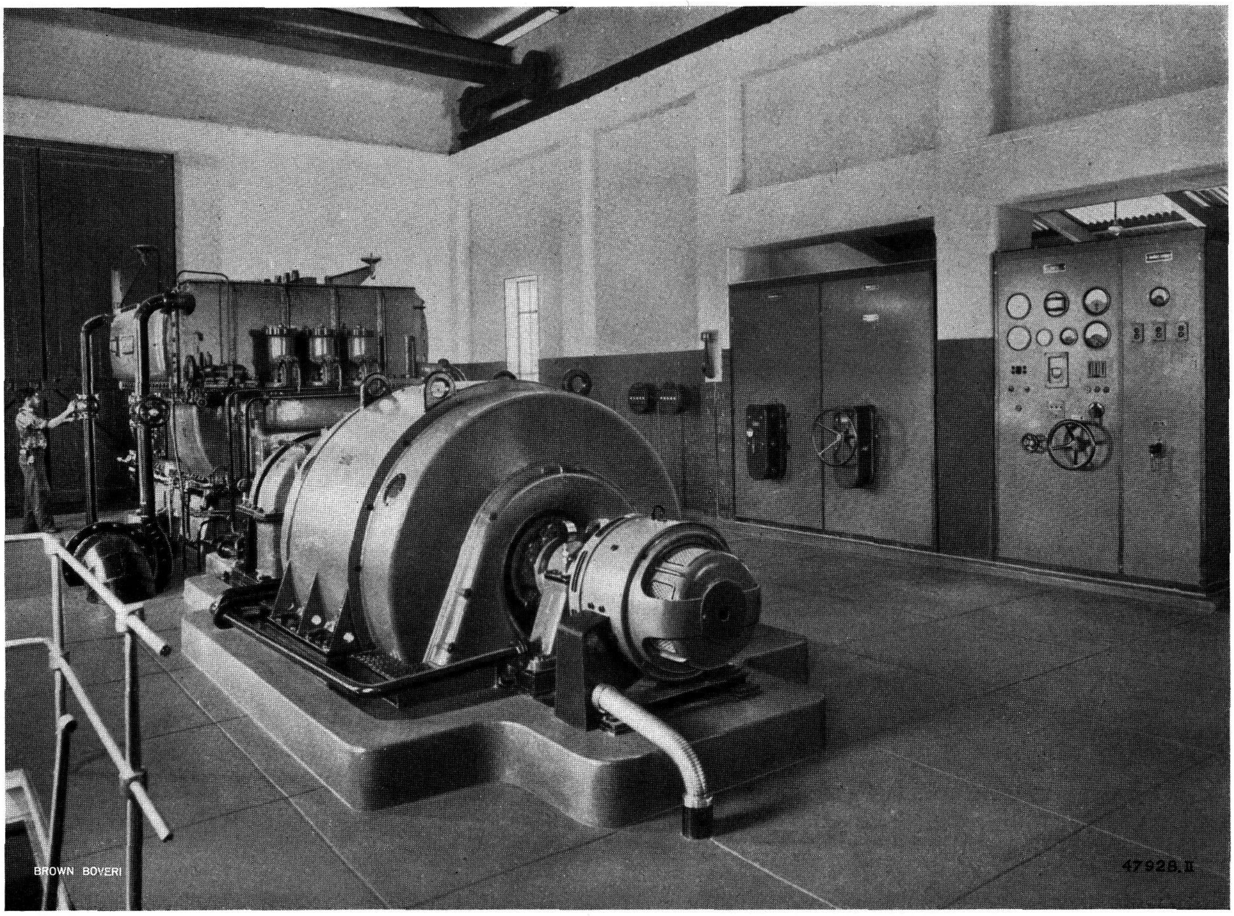

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FLASHOVER VOLTAGE OF INSULATORS AND SPARK GAPS IN THE INTERMEDIATE RANGE BETWEEN IMPULSE-VOLTAGE TESTING AND VOLTAGE TESTING AT OPERATING FREQUENCY.

COMMUNICATED BY THE RESEARCH LABORATORY OF BROWN, BOVERI & COMPANY, LIMITED, BADEN, SWITZERLAND.

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In conjunction with an article published earlier on the subject of the impulse flashover voltage of insulators when soiled, under rain and covered with dew, measurements were carried out on various insulators and on some typical arrangements of electrodes under impulse-voltages of long and of very long duration and under operating-frequency voltages of short duration, that is to say in that range of stress duration in which certain over-voltages are frequently encountered in service. The flashover voltages measured are given here in the form of a number of curves and in function of the duration of the stressing. The points set out below are especially interesting.

1. *The time lag of the flashover can attain as much as 1 s on many insulators. The flashover voltage, therefore, gets lower as the duration of stressing is increased, this even in a range between 0·01 and 1 s.*
2. *If an insulator has a flashover voltage which is considerably higher under negative than under positive impulse wave, the effect of polarity disappears under wave-trains of alternating polarity. Nevertheless, in some cases the flashover voltages measured under 50-cycle wave-trains of a duration of 0·02 .... 0·1 s are dependent, markedly, on the polarity of the first half cycle.*
3. *The flashover voltage in the case of single-pole impulse voltage waves, is frequently dependent on the steepness of the voltage rise (i. e. duration of wave front) apart from the duration of the stress. Thus, horn gaps and certain insulators show a considerably lower flashover voltage, in the case of a single-pole impulse voltage wave of about the same length of front and tail, than in the case of a steep-fronted wave with a tail flattened out, even when the duration of the stress (duration of half-amplitude) is the same in both cases.*
4. *Contrarily, there are other insulators for which the flashover voltage under impulse waves with a flat front is higher than under steep-fronted waves, this especially for insulator designs favouring surface discharges. The result of this may be that the flashover voltage — against all expectations — is higher for long waves than for short ones, in so far as the former have a long duration of front.*
5. *The soiling of an insulator can result in a marked reduction of the flashover voltages even in the case of quite short impulse waves. Apart from this, the character of the discharges is often entirely changed by the conductive layer of dirt, so that the curve of the flashover voltage in function of the stress duration is not only lower but presents a quite different character to that which is inherent to clean insulators.*
6. *The flashover voltage of some electrode arrangements for corona discharges (arrangements with sharp edges) is very high, as is well known, for industrial frequency voltages. These high values can only be attained by gradual increase of the testing voltage. Under impulse waves these high values are not reached, and the same applies to industrial frequency if the voltage is increased suddenly.*

I. DEFINITION OF THE PURPOSE OF THE TESTS.

Some time ago, we reported in this publication on tests which had been carried out to determine the flashover voltage of insulators which were soiled and also, particularly, subjected to rain and dew.[1]) The behaviour of a large number of insulators under these conditions was closely investigated under impulse waves and under operating frequency voltages. This allowed of refuting a very wide-spread and erroneous conception, namely that the flashover voltage of insulators was practically unaffected by soiling, by rain or dew on their surface. It is true that it was found that the flashover voltage was much less reduced by these influences in the case of impulse waves than in the case of operating-frequency voltages, but, nevertheless, the drop in flashover voltage under impulse waves is of a magnitude which cannot be disregarded.

In order to be able to judge of the behaviour of insulators under atmospheric over-voltages, tests with impulse waves of 50 μs duration and less would suffice. With regard to over-voltages due to earth faults and those due to breaking surges, tests were carried out with an impulse-wave duration of 1000 μs. If the flashover voltages measured are plotted in function of the duration of stressing to a logarithmic scale (Figs. 20—25 of the publication referred to) curves are obtained, the character of which is fairly simple, in fact which are nearly straight lines.

However, there is a very wide intermediary range between the impulse wave tests with a duration of half-amplitude of 1000 μs and the usual flashover measurements at operating frequency, and there was no data available for this range of duration. It appeared interesting to us to explore this unknown range, all the more so as these intermediate values have considerable practical significance. For example, breaking surges frequently have a duration of more than 1000 μs. On the other hand, in regulating processes, especially in automatic voltage regulation after some disturbance,

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[1]) Dr. W. Wanger: La tension de contournement sous ondes de choc de différentes durées, des isolateurs salis et sous pluie. Rapport 209 de la Conférence Internationale des Grands Réseaux, 1939.

there occur voltage rises at operating frequency which last often only for fractions of seconds, which, therefore, are far shorter than the duration of the stressing under ordinary operating frequency flashover tests. In both cases, the voltage stress to which the insulator is subjected, is in the above-mentioned intermediate range.

The results obtained have confirmed our supposition that it is not admissible to draw the curves of flashover voltage in function of the stress duration simply as straight lines in the intermediate range. In certain cases the character of the curve is considerably more complicated. We also made some surprising discoveries in this intermediate range. It was shown that the flashover voltages, here, are determined by influences which play no part either in ordinary impulse-wave tests or in ordinary operating-frequency tests.

Apart from the impulse voltages of 50 and 1000 μs duration of half-amplitude with a front duration of 1 μs which have already been used in the above-mentioned report, a longer impulse wave was now used of a duration of half amplitude of 5000-5500 μs. It was obtained by cutting out a single half-cycle from the operating-frequency voltage (50 cycles).[1]

We desire to state here that all through this article we give to the expression "duration of half amplitude" the same meaning as the definition given by the V. D. E. ("Halbwertdauer":— time during which the voltage exceeds the half peak value) and we are, therefore, not alluding to the "time to half peak value on tail" of the I. E. C., that is to say the time measured from the *origin* of the wave up to the half amplitude on tail. The "duration of half amplitude" seems to us a much better measure for the duration of stress than the time from origin of wave to half amplitude on tail, this especially when waves of different shapes are being compared.

Fig. 1 shows a cathode-ray oscillogram of the wave used of 1000 μs duration of half amplitude. Fig. 2 shows the wave of 5500 μs duration of half amplitude. This wave shows a second one in the contrary sense of a magnitude of about 30 %, which follows the half-cycle proper which it is intended to produce. Unfortunately, it was impossible to prevent this wave in the contrary sense, and it has no practical significance as regards the result of the tests. If the object under test does not flash over under a wave such as shown in Fig. 2, the ideal half cycle alone (without the second, smaller wave) would certainly not have caused a flashover. If, however, a flashover occurs on the object being tested during the first half cycle, the following wave in contrary sense will be cut off in any case and does not influence the process. Care must only be given to observing if no flashover takes place during the second smaller half cycle, with the help of a cathode-ray oscillograph. In our tests this, indeed, never happened, the peak value of the second half cycle is too small to cause trouble.

For still longer durations of stress, two and more half waves of operating frequency (50 cycles) were used. As is seen from Fig. 3, an oscillation in contrary sense following the two half waves could not be suppressed; but it is still smaller here than in Fig. 2, and only amounts to about 20 % of the first and second peak value. Fig. 4 shows a train of waves such as we used for longer durations of stressing; measurements were chiefly made with trains of 10 and 90 half waves. It is interesting to note how suddenly the voltage makes itself felt. Even the first wave shows the full value. There are no over-voltages of any kind in the whole wave train.

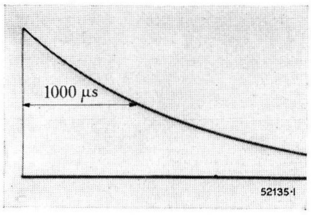

Fig. 1. — Wave of 1000 μs duration of half amplitude and 1 μs duration of front.

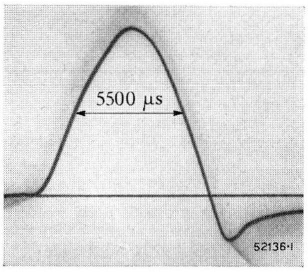

Fig. 2. — Wave of 5500 μs duration of half amplitude = single half cycle cut out of a voltage curve of 50 cycles.

The duration of stressing was chosen equal to the total duration of the train of waves. Thus, for example, for 10 half waves, 100,000 μs, for two half waves 20,000 μs, etc. There is, in this way, a certain contradiction to the definition of the duration in the single-pole impulses in which only the time is measured during which the half of the amplitude is exceeded. Despite this contradiction, it did not seem right to us to define the total duration of stress of a wave train as being the sum of durations of half amplitude of the individual half waves.

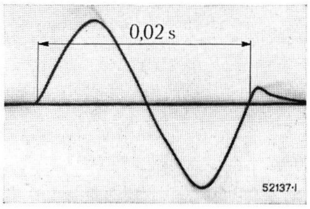

Fig. 3. — Two half cycles cut out of a voltage curve of 50 cycles.

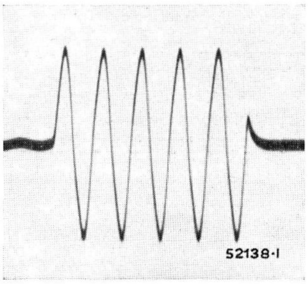

Fig. 4. — Train of waves taken from a voltage curve of 50 cycles.

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[1] The duration of half amplitude of half a cycle of frequency 50 is 6667 μs. By cutting out a single half cycle, the latter was so influenced that it now only had a duration of half amplitude of 5000—5500 μs.

Finally, the operating-frequency flashover voltage proper was measured by the usual testing method with a slow rise in voltage. In inserting these measurement results in the curves, we assumed that this test corresponded to a duration of stressing of about 10 s or 10^7 µs.

It might be objected that in the whole range covered by our investigation, and which extends from 50 to 10^7 µs, voltage curves of very different characters were used in the tests. We did this quite intentionally, because we considered that the shape of the voltage curves chosen by us for the different durations reproduced as closely as was possible the kind of stresses encountered in practice. For stress duration of 0·01 s and more, over-voltages at operating frequencies are those mostly encountered. Below this duration of stressing, over-voltages at operating frequencies are never encountered; here there can be no doubt that single-pole impulse waves are the most important form of over-voltage met with. It will be remembered that the single-pole form is that of atmospheric disturbances and also very closely that of breaking surges. These have, firstly, a direct-current voltage component and, secondly, a damped super-imposed alternating-current voltage component[1], so that a test carried out with a single-pole impulse wave to simulate the first voltage rise of the breaking surge certainly reproduces real conditions more faithfully than does a test with high-frequency voltage.

At the most it might be queried if the voltage surges with very steep front (Fig. 1) reproduce properly the over-voltages encountered in service. As, however, the I. E. C. and the most important national bodies have standardized wave shapes for impulse testing having much shorter fronts than tails, we ourselves carried out these impulse tests with waves of this kind. However, we wanted to find out in what measure the steepness of the wave front influenced the magnitude of the 50 per cent impulse-test flashover voltage[2], and in some tests we used apart from the wave 1 / 1000 µs (Fig. 1) the wave 250 / 1000 µs (Fig. 5). (Here the first figure represents the duration of wave front and the second the duration of half amplitude.) Both waves have the same duration of half amplitude and differ only in steepness of front. Further, apart from the half cycle of 5500 µs duration of half amplitude and flat front (Fig. 2) we also used, in many cases, a wave of identical length and with very steep front (Fig. 6).

Another variation of wave used in some cases consisted in one or several half cycles of a voltage at an operating frequency with a "preliminary stage" (compare oscillogram Fig. 7 which represents two half cycles with a preliminary stage composed of two half cycles of about 40% amplitude). Originally these first stages had to be used in order to avoid over-voltages occurring during the brief switching-in of the operating voltage. Later, the testing apparatus was improved in such a way that it became possible to switch in the full value of the operating-frequency voltage without incurring the danger of over-voltages being set up. Here, it was shown that the preliminary stage, with certain layouts of electrodes, influenced the magnitude of the flashover voltage. In some tests, the influence of a different number of half cycles in the preliminary stage was investigated.

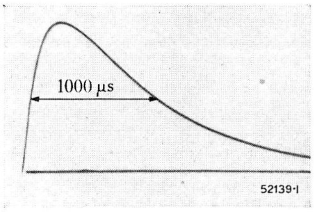

Fig. 5. — Wave of a 1000 µs duration of half amplitude with very flat front (250 µs duration of front).

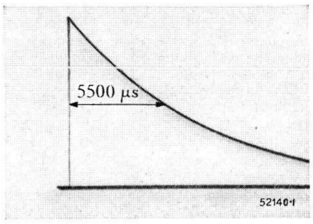

Fig. 6. — Wave of 5500 µs duration of half amplitude with very steep front (1 µs duration of front).

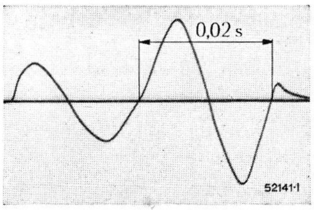

Fig. 7. — Two half cycles of a frequency of 50 cycles with a "preliminary stage" also comprising two half cycles.

II. THE TESTING DEVICES.

The impulse-voltage test measurements proper (see Fig. 1) were carried out in the ordinary way by means of an impulse generator. Further, the impulse waves of 1000 µs with flat front (Fig. 5) as well as those with steep front having very long duration of half amplitude (Fig. 6) were also generated in an impulse generator. It is true that these tests are not in the class of ordinary impulse tests, but they did not present any fundamental difficulties.

However, it was necessary to

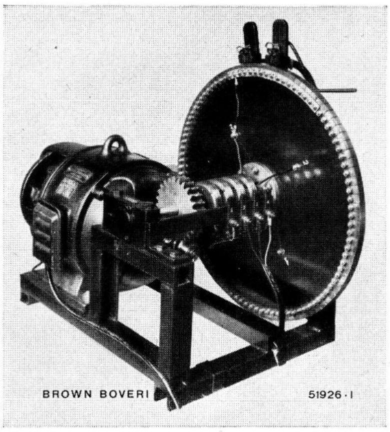

Fig. 8. — Device for the generation of single half cycles and of trains of waves of a frequency of 50 cycles.

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[1] Compare, for example, to Fig. 1 in the article "Over-voltage protection and insulation coordination" in The Brown Boveri Review of August 1939, page 180.

[2] Value formerly called "Minimum flashover voltage".

develop new testing apparatus to produce the voltages according to Figs. 2, 3 and 4, in which a determined number of half waves are cut out of an operating-frequency voltage. Fig. 8 gives a photograph and Fig. 9 the fundamental wiring diagram of this device. A synchronous motor, which is connected to the same source of current as the testing transformer, drives a big disc made of insulating material through a worm wheel. This disc makes exactly one revolution per second (at 50 cycles). There are 100 contact segments mounted and evenly distributed on the rim of the disc, these are separated and insulated from one another by small gaps. Therefore, the rim of the disc carrying the segments rotates by exactly one segment in a half cycle of the operating frequency. Two fixed contact brushes are arranged in such a way that whenever the voltage curve is passing through zero, a segment is running on to one of the brushes while another segment is running off the second brush. It is then only necessary to connect a number of neighbouring segments in order that a conductive connection be established between the two contact brushes during the desired number of half waves, this connection being exactly established at the passage through one zero value of the voltage and interrupted at the passage through another zero value.

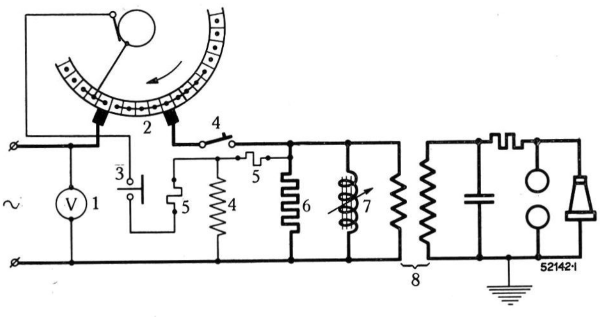

Fig. 9. — Fundamental wiring diagram of the apparatus for the generation of the waves according to Figs. 2, 3, 4, 7.

1. Voltmeter.
2. Segment disc with brushes.
3. Push-button switch.
4. Contactor.
5. Resistance.
6. Damping resistance.
7. Coil of adjustable inductance.
8. High-voltage testing transformer.

The segment disc with the two contact brushes is inserted in the low-voltage circuit of the testing transformer as shown in Fig. 9. There are four slip rings mounted on the segment-disc shaft which permit of connecting certain of the segments to a fixed point. Thus, several further segments are combined and connected to a push-button switch (3, Fig. 9). If at any moment the push-button switch is depressed, the contactor (4, Fig. 9) in the main circuit is closed a little before the conductive connection between the contact brushes is made. If the push-button is held down, the voltage wave set for is repeated regularly once every second. If the push button is released before the disc has accomplished one complete revolution, the desired voltage wave appears just once on the terminals of the testing transformer.

In order that no transient phenomena should be set up when the voltage is suddenly switched in, the operating value of the switched current, as well as that of the voltage, must be zero at the moment of closing the circuit, in other words voltage and current must be in phase coincidence. This can be attained, for example, by connecting a coil with adjustable inductance (7, Fig. 9) in parallel with the low-voltage winding; this permits of bringing the entire circuit into the state of resonance[1]. As, after interrupting the main current circuit by means of the segment disc, the transformer with the inductor and the condenser connected to it, goes on oscillating, a damping resistor is connected in parallel to the adjustable coil in order to damp down the free oscillations as quickly as possible.

III. THE INSULATORS TESTED.

To begin with, the flashover voltages in the intermediate range of stress duration between impulse voltage proper and operating-frequency voltage were investigated on some insulators which had already been the subject of tests described in the CIGRE report[2] already mentioned (Figs. 10 and 11). These insulators were tested when clean and then after an artificial coating of soot had been applied to them. The latter coating was applied in exactly the same way as in the earlier tests (compare to CIGRE report). The similarity of the soiling in both series of tests was proved by checking the flashover voltages under operating frequency and under impulse waves.

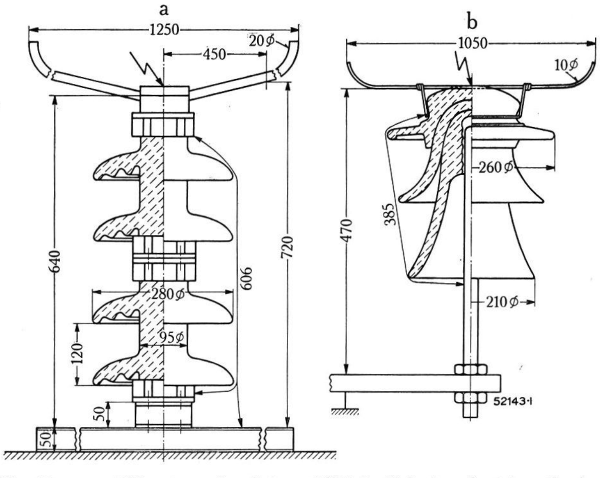

Fig. 10. — a. Pillar-type insulator of "Motor" design (put together). b. Pin-type insulator.

Two further insulators which were also mentioned in the CIGRE report are shown in Fig. 12. These insulators were mounted for 18 months in a boiler house and had gradually got covered with soot, just

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[1] There are also other connections which have given good results. Also other combinations than those described have been applied with the segment disc, contact brushes and slip rings; we are, however, unable to go into details on the subject here.

[2] See footnote on page 231.

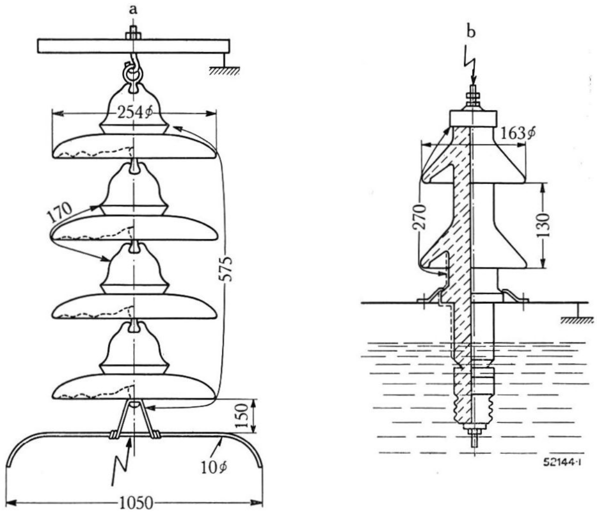

Fig. 11. — a. **Chain of four cap-and-pin insulators.**
b. **Bushing insulator.**

as happens to insulators in industrial areas. After finishing the measurements on the insulators covered with soot, the latter were thoroughly cleaned and the measurements repeated.

Some further naturally soiled insulators were kindly lent to us for testing purposes by the Swiss Federal Railways. The suspension insulators of cap-and-pin type (Fig. 13 b) and of rod type (Fig. 13 c) were taken from railway service on a line for both electrical and steam traction. When delivered to us, these insulators had a crust of soot over them. The pin-type of insulator (Fig. 13 a) and another chain of suspension insulators composed of quite similar cap-and-pin units as those shown in Fig. 13 b had done service near a cement mill and had a hard cement crust over their surface. All the insulators shown in Fig. 13 were then tested in clean stage.

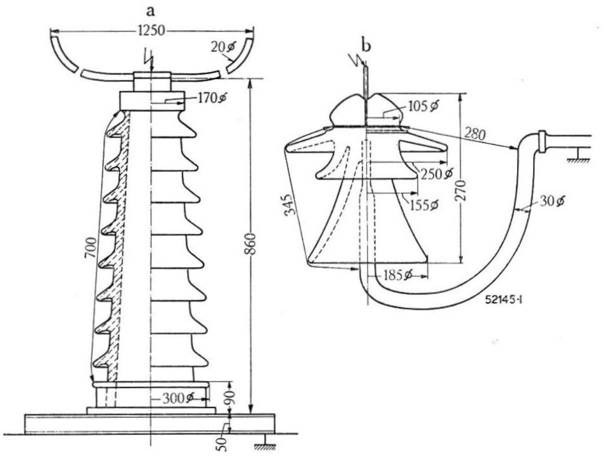

Fig. 12. — a. **Hollow pillar-type insulator.**
b. **Pin-type insulator.**

Unfortunately, want of space prevents us reporting on a large number of other insulators which were tested.

IV. THE FLASHOVER VOLTAGE OF THE INSULATORS IN FUNCTION OF DURATION OF STRESS.

The measured values of the flashover voltages plotted against the duration of stress are given in Figs. 14 to 22. As duration of stress, the duration of half amplitude is used for the single-pole impulse waves (that is below 10^4 μs) and the total duration of the voltage for the alternating voltages (above 10^4 μs). The time scale is logarithmic and, apart from the powers of ten, the intermediate values 2 and 5 are also indicated (thin lines).

The different values of flashover voltage are all given in per cent of the operating-frequency flashover voltage of the clean, dry insulator. Table I gives the absolute values of these measurements.

TABLE I

Operating-frequency flashover voltages on clean and dry insulators.

Insulator	Fig.	Flash-over voltage kV Rms	Flash-over distance mm
Pillar-type insulator of "Motor" design	10 a	224	606
Pin type insulator	10 b	162	385
Chain of four cap-and-pin insulators	11 a	227	575
Bushing insulator	11 b	102	270
Pillar-type insulator with hollow body	12 a	262	700
Pin-type insulator	12 b	127	280
Pin-type insulator	13 a	168	390
Chain of two cap-and-pin insulators	13 b	150	340
Rod-type suspension insulator	13 c	158	322

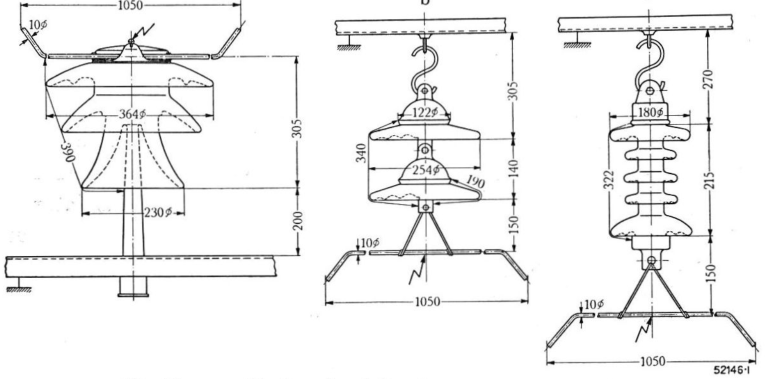

Fig. 13. — a. **Pin-type insulator.**
b. **Chain formed of two cap-and-pin insulators.**
c. **Suspension insulator of rod type.**

The measured values given in this chapter are those obtained with what we will term "normal waves" (according to Figs. 1, 2, 3, 4).[1] Everywhere the 50 % impulse-test flashover voltage is the criterium chosen, that is to say that voltage for which the insulator under test flashover in 50 % of cases. The measurements at 1 and 2 half cycles of a frequency of 50 cycles were carried out in the way usual in impulse tests. For longer series of waves, the voltage was slowly raised from wave train to wave train until a flashover was produced. After several repetitions of this process the arithmetical average of the different measurements was taken as is done in ordinary operating-frequency measurements.

All the values of the flashover voltage are corrected in the usual way for standard atmospheric conditions (760 mm Hg at 20^0 C). The humidity of the air varied during the tests between 8 and 13 g/m^3 and no correction was made to normal humidity conditions of 11 g/m^3, because there seems to be no clear law in existence allowing of so doing, and because the correction in question is not of any importance in the range in which these tests were made. In the tests under artificial rain, an angle of incidence of 45°, an amount of rain of 3 mm/min and a specific resistance between 9000 and 11,000 Ωcm were adhered to, according to I. C. E. rules. Also the water used for the coating of dew was of this specific resistance. It was applied by means of a vaporisor.

A part of the curves recorded show a regular character over the whole time range, while others show irregularities in the "intermediate range" which is investigated here for the first time; in part these irregularities consist of more or less abrupt steps and in part of small humps. These irregularities nearly all occur between 10^3 and $2 \cdot 10^4$ μs and seldom extend to 10^5 μs. It is very understandable that the curves should show irregularities in this region because here the character of the waves used changes. While, up to 10^3 μs, impulse waves with a steep front are applied, the operating-frequency half cycle, at about 5500 μs takes the shape of an impulse wave with very flat front. Then, between 5500 and 20,000 μs the character of the curve changes completely because, up to 5500 μs single-pole impulses are used while from 20,000 μs upwards the tests are made with waves of alternating polarity. A more exhaustive explanation of the irregularities, especially of the humps, is given in the last chapter.

The indication of polarity in the case of wave trains of alternating polarity refers to the first half cycle. Certain insulators, the "positive" flashover of which is much lower than the "negative" one, only flashover under the positive half waves whatever the polarity of the first half wave of the train may be. In this case the "negative" curves are considerably higher than the "positive" ones, up to 5500 μs and identify themselves with the latter from 20,000 μs upwards (see Fig. 14a). In the case of two half waves, the flashover takes place during the first one, on condition that it be positive and only during the second one if the first half wave happens to be negative.

In other cases, the negative flashover voltage drops gradually as the duration of stress is increased, until it reaches the value corresponding to the positive flashover (for example, see Fig. 19). In a case like this, the flashover occurring in a train of waves may take place on a positive or on a negative half wave. The character of the curve in Fig. 19a is worthy of note, especially in the case of the dry insulator and the one covered with dew. Here, the "negative" flashover voltage under two half cycles, 20,000 μs, is considerably above the positive one. If, notably, the first half wave is positive, the flashover occurs here; if it is negative, the flashover occurs in the second and positive half wave. The flashover voltage is then considerably higher, probably because certain charges built up during the preceding negative half wave, which affect the distribution of the field in a favourable sense.

The absence of any influence of polarity such as has been described is an interesting feature of certain insulators in a condition of high surface conductivity, this for the whole range of duration of stress. The complete identification of the positive and negative curves is shown chiefly in the case of wet insulators and especially if they are also soiled (see Figs. 15b, 16a and b, 17, 18b, 21).

As regards the influence of soiling on the flashover voltage, we would refer to the CIGRE report[2], in first place. To complete the latter we would mention that the insulators which got covered with soot in service on a railway line behaved similarly to those which were artificially covered with soot. On the other hand, the coating of coal dust on the insulators taken from the boiler house brought the flashover voltage still lower. Insulators in service in such exceptionally unfavourable conditions should be cleaned from time to time.

The sharp drop in the flashover voltage of the insulators soiled by cement and also covered with dew or under rain is worthy of note, this except for very short voltage-impulse tests. The porous cement deposit takes up water like a sponge, the result being a very big drop in the flashover voltage even for relatively short duration of stress (compare Fig. 21c).

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[1] A wave with preliminary stages similar to those of Fig. 7 was only used for the measurements at 5500 μs in the case of the insulators of Fig. 13.

[2] See footnote on page 231.

V. TESTS WITH SOME TYPICAL ARRANGEMENTS OF ELECTRODES.

It appeared interesting to us to carry out tests on some spark gaps and typical arrangements of electrodes, because we also expected to discover here certain irregularities in the intermediate range and also because these typical electrode arrangements are very favourable for determining the fundamental factors involved.

An ordinary horn gap (Fig. 23) was first tested, then an arrangement of two rings with round edges placed opposite one another (Fig. 24), and then a similar layout with two rings with sharp edges (Fig. 25). We have termed the latter "corona discharge rings". The rings were first so mounted that they were only separated by an air gap; then an insulating cylinder of transformer board was inserted between them and resulted in a construction which looked like a pillar insulator. Finally, a typical surface-discharge design was tested. It consisted of an oil-filled plain porcelain tube with a flange and through bolt (Fig. 26).

In all cases the spark gap was set at 360 mm in order to allow of comparing the flashover voltages of the different layouts. In Figs. 23 to 26 all values are given in per cent of the flashover voltage under operating frequency measured on point gaps of the same flashover distance (133 kV Rms).

Firstly, the measurements were carried out with the normal waves according to Figs. 1, 2, 3 and 4, the resultant data are given in the curves 1, 2 and 5, 6 of Figs. 23 to 26. Further, waves were used with a "preliminary stage" consisting of two small half cycles such as were used in Fig. 7. This preliminary stage was used for all the durations of stress from 5500 to $90 \cdot 10^4$ μs. The values measured are given in the curves 3, 4 and 7, 8 of Figs. 23 to 26. We will give details on the dotted and dot-dash curves in the next chapter.

Let us consider first the curves recorded with "normal" waves, without preliminary stage. A marked hump is the chief characteristic on the surface-discharge arrangement of Fig. 26, and it is

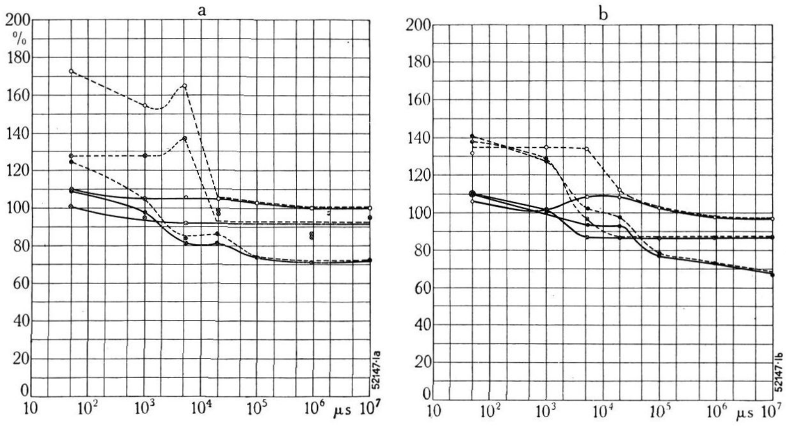

Fig. 14. — **Flashover voltage of a "Motor"-design pillar insulator (Fig. 10 a) in function of duration of stress.**

——— = positive. ○ = dry.
--------- = negative. ● = under rain.
⊗ = covered with dew.

a. Insulator clean.
b. Insulator with artificially applied soot coating.

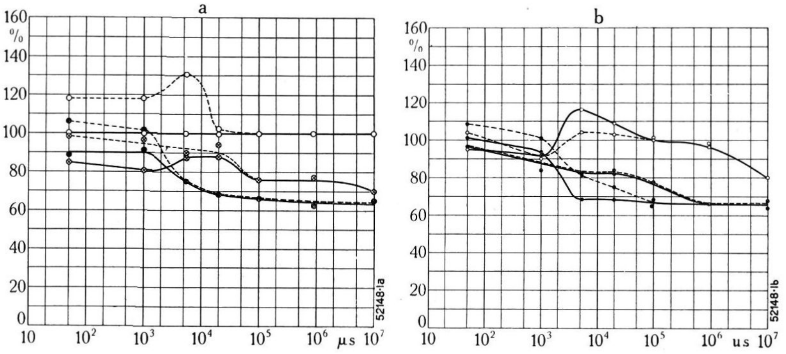

Fig. 15. — **Flashover voltage of a pin-type insulator (Fig. 10 b) in function of duration of stress.**

——— = positive. ○ = dry.
--------- = negative. ● = under rain.
⊗ = covered with dew.

a. Insulator clean.
b. Insulator with artificially applied soot coating.

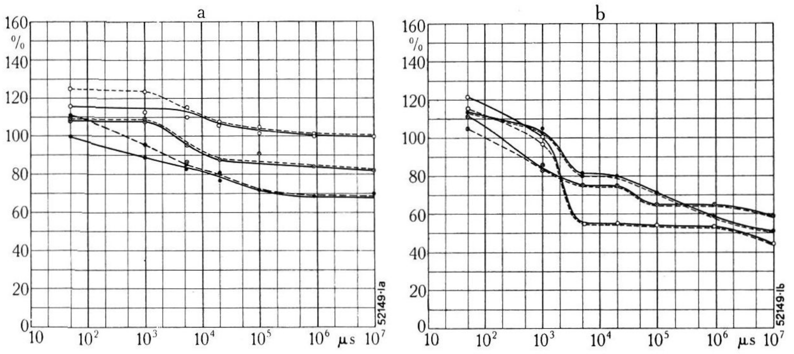

Fig. 16. — **Flashover voltage of a chain of insulators (Fig. 11a) in function of duration of stress.**

——— = positive. ○ = dry.
--------- = negative. ● = under rain.
⊗ = covered with dew.

a. Insulator clean.
b. Insulator with artificially applied soot coating.

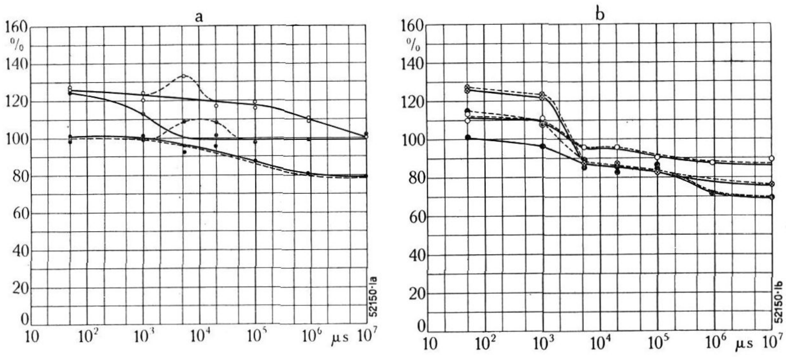

Fig. 17. — **Flashover voltage of a bushing insulator (Fig. 11b) in function of the duration of stress.**

——— = positive.
--------- = negative.
○ = dry.
● = under rain.
⊗ = covered with dew.

a. Insulator clean.
b. Insulator with artificially applied soot coating.

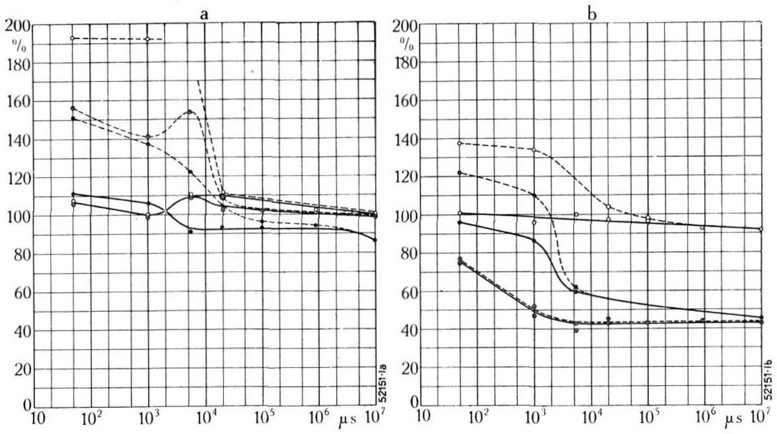

Fig. 18. — **Flashover voltage of a pillar-type insulator (Fig. 12a) in function of the duration of stress.**

——— = positive.
--------- = negative.
○ = dry.
● = under rain.
⊗ = covered with dew.

a. Insulator clean.
b. Insulator with a soot coating which formed during 18 months in a boiler house.

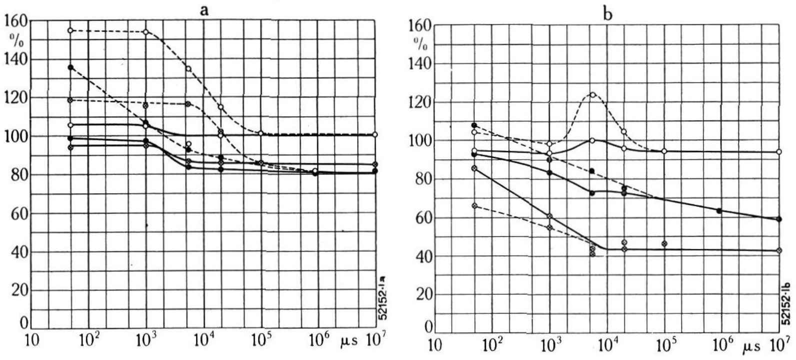

Fig. 19. — **Flashover voltage of a pin type insulator (Fig. 12b) in function of the duration of stress.**

——— = positive.
--------- = negative.
○ = dry.
● = under rain.
⊗ = covered with dew.

a. Insulator clean.
b. Insulator with a soot coating which formed during 18 months in a boiler house.

situated in the 10^3 to 10^5 μs region. This coincides with the measurement results recorded on insulators. It is true that with the insulators the surface-discharge feature is nowhere so absolute as in Fig. 26, but nevertheless a very marked hump is noticed there as well, for certain insulators favouring surface discharge (see, for example, Figs. 15a and 17a). We will endeavour to explain this phenomenon in the next chapter.

By using a preliminary stage, the effect of a gradual closing on the voltage is more or less perfectly reproduced. The positive flashover curves on the horn gap and on the sparking rings with rounded edges were, practically, unaffected thereby. The negative curves were slightly modified in the range of one to two half cycles. The behaviour of the horn gap when stressed with two half cycles, the first of which is negative, is especially interesting. If the two half cycles are suddenly switched in, that is without preliminary stage, the flashover occurs on the first half cycle. The flashover voltage is, therefore, exactly the same as in the case of a single half cycle. If, however, a preliminary stage precedes the two half cycles, the flashover only occurs on the second full half cycle and this at a markedly lower voltage, namely at the same voltage as for a single positive half cycle.

In the layout for surface discharges, the humps on the curves are considerably altered when waves with a preliminary stage are used. But, above all, the "corona discharge rings" are the most influenced by the preliminary stage. The positive flashover voltage for waves, or trains of waves, with a preliminary stage, is considerably higher for corona discharge rings without insulating body than for the same arrangement without preliminary stage. As is known, the operating-frequency flashover voltage of these rings with sharp edges, measured with gradual rise of the voltage, is very high, which may be explained by the fact that after a certain voltage magnitude the corona effect makes the field more homogeneous. Now the preliminary stage before a train of waves acts in similar manner to the gradual rise in voltage. On the other hand, a homogeneous corona effect and the better field it produces cannot take effect when waves or trains of waves are suddenly impressed on the object under test with their full value. Thus, the flashover voltage of "corona discharge rings" is not only, in the case of short impulse waves, considerably lower than under operating frequency but also is lower for very prolonged impulse waves with very flat front and even under wave-trains of long duration, a fact, we believe, was unknown up till to-day.

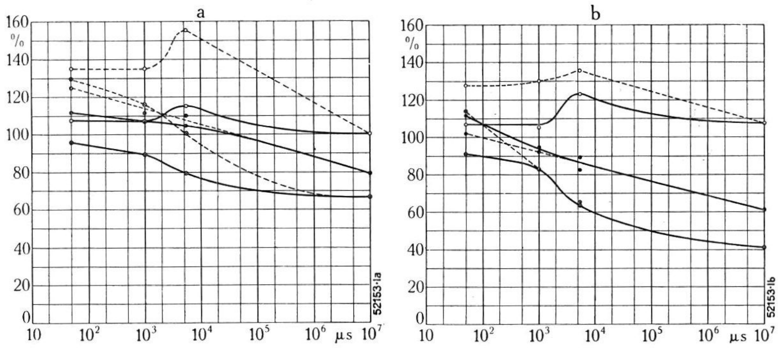

Fig. 20. — **Flashover voltage of a pin-type insulator (Fig. 13a) in function of the duration of stress.**

———— = positive.
---------- = negative.
○ = dry.
● = under rain.
⊗ = covered with dew.

a. Insulator clean.
b. Insulator taken from service near a cement mill and covered by a layer of cement.

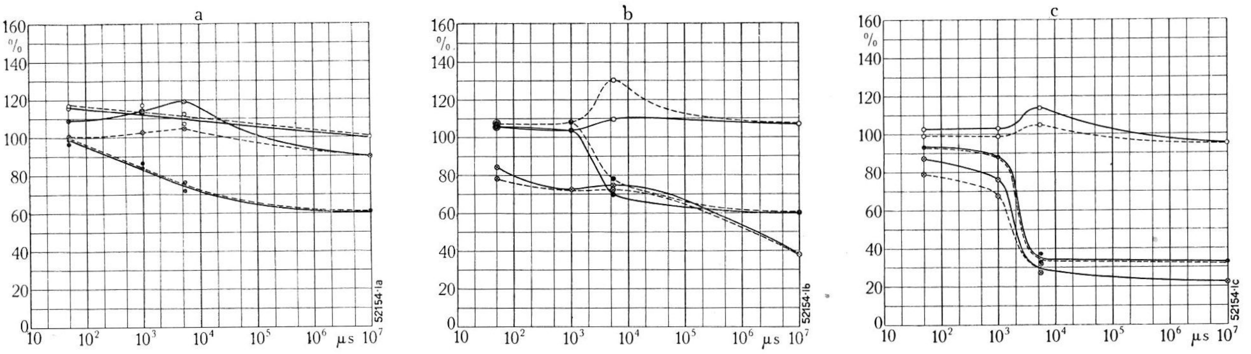

Fig. 21. — **Flashover voltage of a chain of insulators (Fig. 13b) in function of the duration of stress.**

———— = positive.
---------- = negative.
○ = dry.
● = under rain.
⊗ = covered with dew.

a. Insulator clean.
b. Insulator taken from railway service and covered with soot.
c. Insulator (similar to 13b) taken from service near a cement mill.

In the case of the "corona discharge rings" with insulating body inserted, the flashover voltage for a positive half cycle is also considerably higher when there is a preliminary stage than if there be no preliminary stage; but, even with a preliminary stage, the flashover voltage drops back again to a much lower value already under two half cycles. This is because the flashover occurs on the second and negative half cycle and is as low as in a wave beginning with a negative half cycle.

The influence of the preliminary stage is clearly shown in Fig. 27. The "corona discharge rings" were stressed by a half cycle of 5500 μs duration of half amplitude with a preliminary stage of the same relative height as in Fig. 7, the duration of the preliminary stage being varied between 0 and 5 half cycles. It will be seen that the flashover voltage is the lowest when the wave is applied

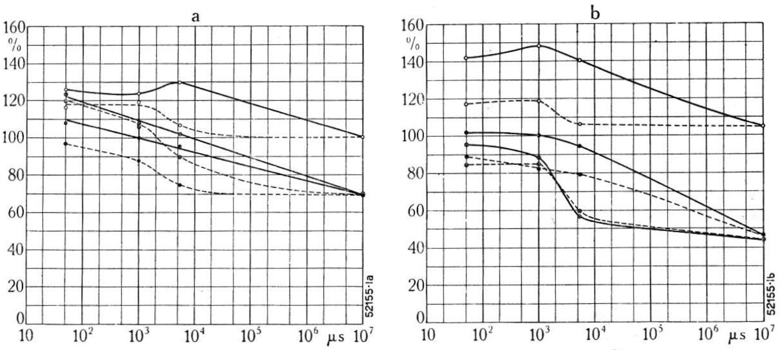

Fig. 22. — **Flashover voltage of a rod-type insulator (Fig. 13c) in function of the duration of stress.**

———— = positive.
---------- = negative.
○ = dry.
● = under rain.
⊗ = covered with dew.

a. Insulator clean.
b. Insulator taken from railway service and covered with soot.

directly at its full value (no preliminary stage). The preliminary stage increases the flashover voltage the more, the longer it lasts. Here the increase is considerably greater for the positive than for the negative wave. For purposes of comparison, the value of the operating-frequency flashover voltage is given, as it is measured when a gradual increase in voltage is applied.

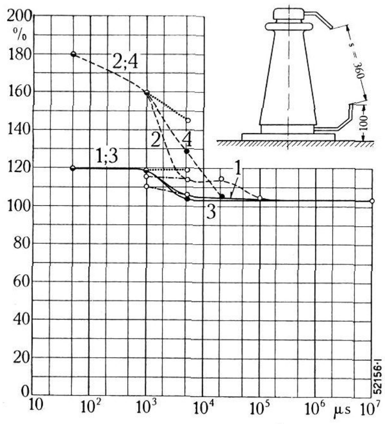

Fig. 23. — Flashover voltage of a horn-type sparking gap in function of the duration of stress.

1. Positive flashover voltage for waves without preliminary stage.
2. Negative flashover voltage for waves without preliminary stage.
3. Positive flashover voltage for waves with preliminary stage.
4. Negative flashover voltage for waves with preliminary stage.

.... = single-pole waves of short front duration.
-·-·-·-·- = single-pole waves of long front duration.

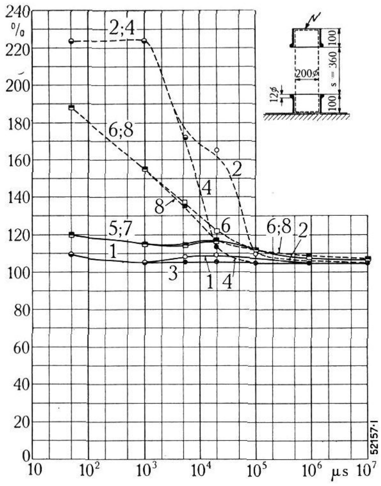

Fig. 24. — Flashover voltage between two rings with rounded edges in function of the duration of stress.

1—4. Electrodes without intermediate insulating body.
5—8. Electrodes with intermediate insulating body.
1, 5. Positive flashover voltage for waves without preliminary stage.
2, 6. Negative flashover voltage for waves without preliminary stage.
3, 7. Positive flashover voltage for waves with preliminary stage.
4, 8. Negative flashover voltage for waves with preliminary stage.

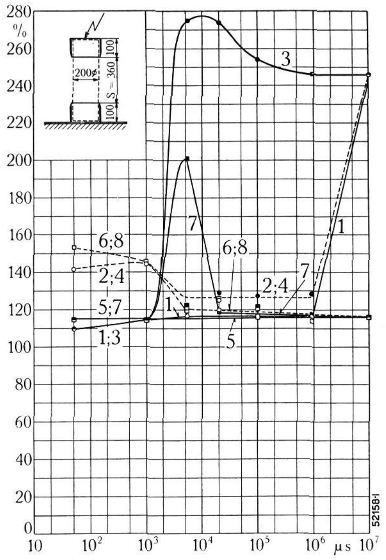

Fig. 25. — Flashover voltage between two "corona discharge" rings in function of the duration of stress.

1—4. Electrodes without intermediate insulating body.
5—8. Electrodes with intermediate insulating body.
1, 5. Positive flashover voltage for two waves without preliminary stage.
2, 6. Negative flashover voltage for two waves without preliminary stage.
3, 7. Positive flashover voltage for waves with preliminary stage.
4, 8. Negative flashover voltage for waves with preliminary stage.

In this respect we would refer to certain luminous discharges which form in the course of the duration of stress. With waves of 5500 μs and of longer duration the glow is easily perceived in the dark. If the wave begins by being of positive polarity, only the edges of the rings glow, if it begins by being of *negative polarity* a luminous cylinder is also perceived, reaching from one electrode to the other. This difference alone shows that the way the voltage wave begins is a matter of great importance.

If the voltage wave train which has begun with a negative half cycle, is applied for a longer time than 0·1 s on the corona discharge rings, the luminous cylinder retires in a series of sudden movements downwards and then disappears altogether. It is, of course, impossible to detect with the eye whether this luminous cylinder remains exactly unchanged for 0·1 s, but it is absolutely certain that the time it takes to disappear completely is about 1 s. This relatively slow process in the electric field between the two electrodes make it understandable that the magnitude of the flashover voltage depends very much on whether the voltage is suddenly applied or is gradually increased until a flashover occurs, or if the voltage is applied through the agency of a preliminary step.

The oscillogram of Fig. 28 in which a flashover only takes place after 0·32 s, although the voltage (apart from the preliminary stage) had its full value from the beginning, makes it clear that changes in the field must last for several tenths of seconds. In these measurements carried out on corona discharge rings with positive values of the first full half cycle, flashover time lags up to 0·5 s were observed. This surprising phenomenon explains why the flashover characteristic (curve 3 of Fig. 25) still falls in the range of 10^4 to 10^6 μs, because if the flashover were always to occur in the first half cycles, the flashover voltage at 0·5 or 1 s would have to be of the same magnitude as at 0·02 or 0·1 s. Further, all the *insulators,* the characteristics of which drop in the range of 0·01 to 1 s (10^4 to 10^6 μs) — see, for example, Figs. 16, 17, etc. — show flashover time lags of some tenths of seconds.

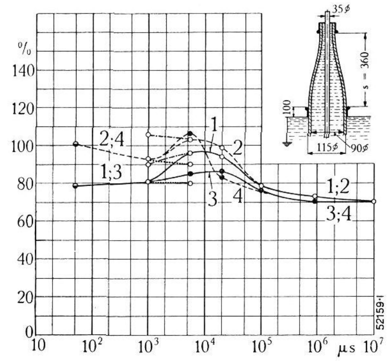

Fig. 26. — Flashover voltage of a typical surface-discharge layout in function of the duration of stress.

1. Positive flashover voltage for waves without preliminary stage.
2. Negative flashover voltage for waves without preliminary stage.
3. Positive flashover voltage for waves with preliminary stage.
4. Negative flashover voltage for waves with preliminary stage.

.... = single-pole waves of short duration of front.

-·-·-·-·- = single-pole waves of long duration of front.

The behaviour of the corona discharge rings is quite different when subjected to wave trains which begin with a negative half cycle. When this wave leads to a flashover at all, this will always be in the first full half cycle. It is not all clear why the flashover occurs before the first peak value is reached (up to 25 %) even when the voltage is so adjusted that it just suffices to cause the flashover. It is a remarkable fact that a wave can, in certain cases, cause a flashover to be produced on its front, while another identical wave may rise to its peak value, that is to 25 % above the flashover voltage without provoking a flashover (see the oscillograms of Fig. 29 [1]). This phenomenon is not observed on insulators, the flashover on which always occurs near the peak of the wave.

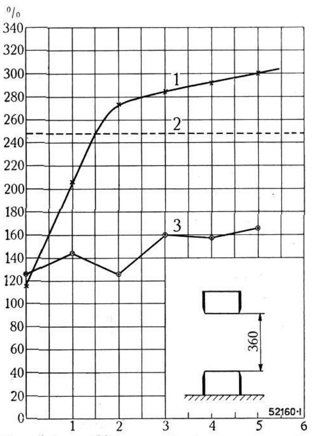

Fig. 27. — Flashover voltage of the same rings with sharp edges as in Fig. 25 when stressed by a half cycle with preliminary stage of about 40 % of peak value. Influence of the duration of this preliminary stage.

1. Characteristic of flashover voltage when the full half cycle is positive.
2. Characteristic of flashover voltage when the full half cycle is negative.
3. Operating-frequency flashover with gradual rise of testing voltage.

VI. THE INFLUENCE OF THE WAVE SHAPE ON THE MAGNITUDE OF THE FLASHOVER VOLTAGE.

In the preceding chapter we investigated the influence exercised by the preliminary stage, in other words, the way in which a wave or a train of waves is switched on to the object being tested. But the shape of the wave itself often plays an important part. The shape of the waves we usually worked with is very different from 1000 to 5500 μs duration of half amplitude (Figs. 1 and 2), and we expressed a

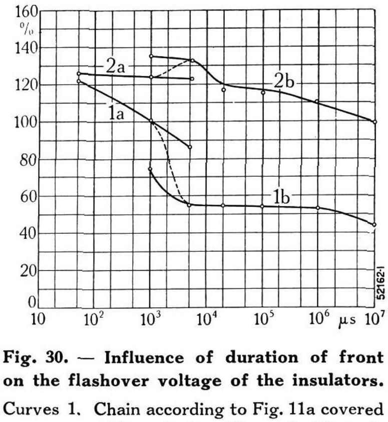

Fig. 30. — Influence of duration of front on the flashover voltage of the insulators.

Curves 1. Chain according to Fig. 11a covered with soot, dry. Stressed with positive waves.

Curves 2. Bushing-type insulator according to Fig. 11b, clean, dry. Stressed with negative waves.

a. Flashover voltage for waves with steep front.

b. Flashover voltage for waves with flat front.

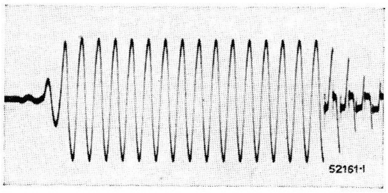

Fig. 28. — Oscillogram of flashover between "corona discharge rings" according to Fig. 25 when stressed by a long train of waves, the first half cycle of which is positive.

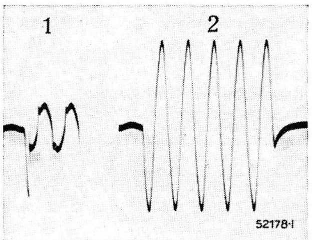

Fig. 29. — Oscillogram of train of waves with negative first half cycle applied to the rings, Fig. 25.

1. Flashover considerably below peak value of first full half cycle.
2. No flashover.

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[1] This remark is valid for waves with a preliminary stage as well as for those without one.

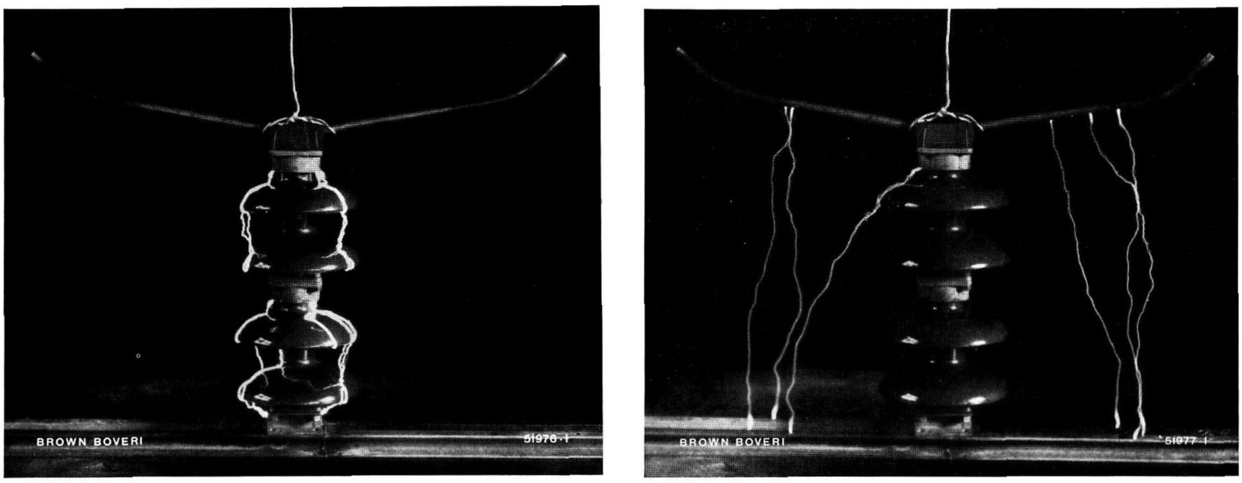

Fig. 31. — Repeated flashovers on pillar-type insulator of Fig. 10a, clean, dry, stressed by negative impulse waves.
Left: Impulse wave of 1/50 μs. Right: Half cycle of operating frequency voltage (according to Fig. 2).

conjecture, earlier, that certain anomalous phenomena inherent to flashover characteristics were probably due to this change in the shape of the wave. The dotted and dash-dot line curves of Figs. 23 and 26 furnish data on this subject.

The measurement points at 50 and 1000 μs duration of half amplitude are recorded, as is already known, by means of waves with very short duration of front (1 μs). The dotted parts of the curves represent a prolongation of those parts of curves 1 and 2 which lie on the left-hand side, that is towards points measured under a wave of 5500 μs duration of half amplitude and of very steep front (according to Fig. 6). Contrarily, the dash-dot lines are the prolongations of the right branches of the curves 1 and 2 towards points measured under waves of 1000 μs and with very flat front (according to Fig. 5).

Figs. 23 and 26 show very strikingly that the anomalies of the curves disappear for the greater part when the comparison is made only between waves either having short fronts or long fronts. The "steps" as well as the "humps" on the principal curves 1 and 2 (Fig. 23) are the result of the change in the shape of the wave between 1000 and 5500 μs, which is the region of transition from short- to long-fronted waves.

In the same way the anomalies observed in the insulator curves (Figs. 14 to 22) are chiefly due to the change in the shape of the wave. Two typical cases are very clearly represented in Fig. 30. Here we have drawn in in full line the curves recorded under waves of the same character and have indicated in dash lines the passages between waves of different shapes. It will now be clear that each of the curves of Figs. 14 to 22 is really composed of two partial and different curves, the transition taking place between 1000 and 5500 μs.

Many insulator curves present neither steps nor humps, which means that the two partial curves form a single one. Several measurements carried out under waves according to Fig. 5 and according to Fig. 6 gave points which lie exactly on this curve. The duration of the front has, therefore, no influence in these cases, on the magnitude of the flashover voltage.

In investigating more carefully the behaviour of typical electrodes, it was found that the flashover voltage of the horn gap is lower under waves with a long front than under those with a short front, which obviously results in a step on the curve of this apparatus (see Fig. 23). The arrangement for surface discharges, on the contrary, shows a higher flashover voltage for long-fronted waves than for short-fronted waves (see Fig. 26). This is understandable because the surface discharges which lower the flashover voltage of an insulating space, do not occur if the variations of voltage are sufficiently slow; therefore, these discharges are less pronounced for a very flat front than for a very steep one. This phenomenon explains the hump revealed on the curves of the apparatus for surface discharges.

The behaviour of insulators follows more or less that of one or other of the typical electrodes; it differs by there being sheds on the insulators. Fundamental tests, into the details of which we cannot go here, have shown, as a matter of fact, that a shed near the positive electrode raises the flashover voltage higher under waves with flat front than under waves with steep fronts.[1] Thus, the sheds cause a

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[1] This behaviour is explained by the appearance of surface discharges forming on the sheds when the insulator is subjected to steep-fronted waves. These discharges are clearly seen in the photograph on the left of Fig. 31 in the shape of streamers on the sheds of the pillar insulator.

hump on the curves of insulators similar to the one on the surface discharge arrangement. As, now, the sheds of outdoor insulators are generally so designed that they give better cover to the earthed electrode than to the one under voltage, it will be better understood why the humps generally appear in the negative flashover characteristics (see Fig. 14 a).

Further, it must be noted that a layer of semiconductive dirt on the surface of an insulator may modify its flashover characteristic entirely. For example, the bushing insulator with coating of soot entirely lost the character of a surface discharge device (Fig. 17 b). The flashover characteristic now shows a step instead of a hump, and this step is particularly pronounced if the insulator is covered with dew. The tests show that the flashover on soiled insulators is no longer caused by surface discharges, which justifies the modification to which the curve has been subjected.

To conclude, we will show with the help of an example that the flashover on an insulator can be caused in several different ways, according to the duration and shape of the wave (see Fig. 31). The flashover voltage of the insulator subjected to a wave with a very long front is very high, while that of the spark gap formed by the horn under voltage and the earthed armature is very low. This is why the flashovers under a flat-fronted wave (figure on right) occur the most frequently, not along the insulator, but directly between horn and earthed armature, this although the spark gap is longer here than over the insulator. The form of the flashover curves of insulators can only be explained, in several cases, by the different tracks taken by the flashover arc.

(MS 734) *Dr. W. Wanger and W. Huber. (Mo.)*

THE IMPORTANCE OF THE VARIABLE RESISTANCE FOR MODERN EXCESS VOLTAGE AND LIGHTNING PROTECTION.

Decimal index 621.316.933

The progress made in recent times in the domain of resistances which vary in function of the voltage, as regards absorption capacity, characteristic curves and stability is a guarantee of the absolute reliability of lightning arresters under all conditions.

I. INTRODUCTION.

NOT more than ten years ago opinions on the efficacy of lightning arresters were still divided. This fact is not astonishing as the experiences then available were of a very restricted nature and moreover surge arresters at that time were not such as to guarantee satisfactory workmanship and performance. Since then, however, careful studies of atmospheric discharge phenomena and the development of suitable measuring instruments, above all of the cathode-ray oscillograph, have enabled the surge arresters to be very greatly perfected. Tens of thousands of these apparatus are now in service and the experiences gathered on them lead to certain conclusions. While the first arresters were based on very different principles and constructed in various ways, nearly all modern lightning arresters now rely on the same principle: the variable resistance. This uniformity is, as in all technical branches, a sign that the surge arrester has passed the experimental stage and has found its final form.

During the long and patient researches for the development of the resorbit surge arrester Brown Boveri always bore in mind the two following principles:—

(a) A lightning arrester was to be constructed which would stand the actual service conditions imposed by the nature of atmospheric discharges (accordingly a surge arrester was aimed at which would lead all — even the heaviest — atmospheric discharges to earth, without any risk of damage).

(b) The lightning arrester must be adapted to the conditions met with in practice, the wishes and experiences of the clients being taken into consideration as far as possible.

The way in which this two-fold problem was solved will be shown in the following chapters which will deal chiefly with the part played by the resistances. Before entering upon details, however, it will be useful to explain the principle of the lightning arrester with variable resistances.

II. THE LIGHTNING ARRESTER WITH RESISTANCES WHICH VARY IN FUNCTION OF THE VOLTAGE.

This apparatus consists essentially of the spark gaps A and B and the resistance C all connected in series (see Fig. 1).

In order to enable dangerous surges to be led away to earth immediately, the resistance C must have a very low value. On the other hand the follow current (i. e. the current with service frequency which follows the path opened by the surge discharge and continues to flow even when the surge has disappeared) must be as low as possible, i. e. the value of the resistance C must be high. These conditions, though opposed to each other, can both be fulfilled by using variable resistances the value of which depends on the applied voltage. Fig. 2 shows the resistance of a resorbit resistance block at various voltages. At a service voltage of 1360 volts crest value its resistance is 453 ohms. This decreases, however, to much lower values as soon as the voltage rises. It is, for instance, 20 ohms at 5000 volts crest value and not more than 1 ohm at 9000 volts crest value. These few remarks, simple as they are, show the great importance of the resistance among the components of a surge arrester. The following chapters will show that in fact the resistance determines the principal characteristics of an arrester, the performance of which is highly dependent on the properties of the resistance used.

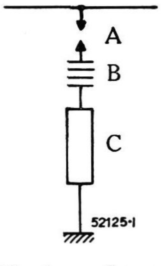

Fig. 1. — **Surge arrester with variable resistance (shown diagrammatically).**
A : Sparking gap;
B : Extinction gap;
C : Variable resistance.

III. THE ABSORPTION CAPACITY OF THE RESISTANCES.

An ideal surge arrester ought to be capable of absorbing and leading to earth all atmospheric discharges which may occur, without any danger of its being damaged. Recent investigations[1] have shown that 80 % of the discharge currents to be absorbed by surge arresters vary between 0 and 2500 A, 10 % between 2500 and 5000 A, 9 % between 5000 and 20,000 A, and 1 % above 20,000 A. Only a few years ago, the manufacture of resistances which would stand such currents would have seemed almost impossible. Since then, however, intensive research work has enabled great progress to be made in this respect and it can now be affirmed that the problem is solved and that modern surge arrester resistances can stand currents of the values mentioned without any risk of their being damaged. This is proved by Figs. 3 and 4, showing discharge currents of 19,800 A with a duration of half amplitude of 27 μs and of 68,500 A with a duration of half amplitude of 10 μs resp. These oscillograms show official tests performed at the test station of the A. S. E. (Association Suisse des Electriciens, Swiss Electric Association) at Zurich. Every resistance tested stood fifteen consecutive discharges of the one or the other type without being damaged in any way.

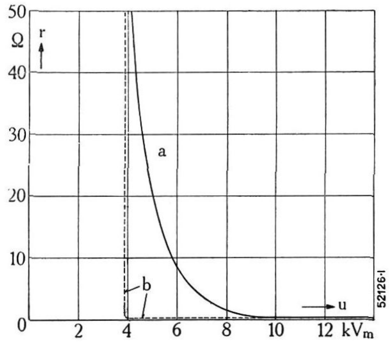

Fig. 2. — **Variation of the resistance r with the applied voltage u.**
a. Actual curve.
b. Ideal valve characteristic.

Only the limited output of the impulse generator of the A. S. E. prevented tests being performed with still higher currents up to the limit of the absorption capacity of the resistances. Judging by the test results, however, the limit of the absorption capacity for one single impulse will be considerably higher than 68,500 A and will probably reach several hundred thousand A.

IV. INFLUENCE OF THE RESISTANCES ON THE EXTINCTION OF THE FOLLOW CURRENT.

In chapter II the pecularity of the resistances, i. e. the variability of the resistance value within wide limits, according to the voltage applied, was mentioned, which makes it possible to limit the follow current to a low value. Naturally, the lower this current, the easier will be its extinction. Accordingly, the nearer the characteristic of a resistance approaches the ideal curve b in Fig. 2 the better the resistance will be. The variable resistances help to cut off the follow current yet in another way. If a sine wave voltage is applied to such a resistance, the current passing through

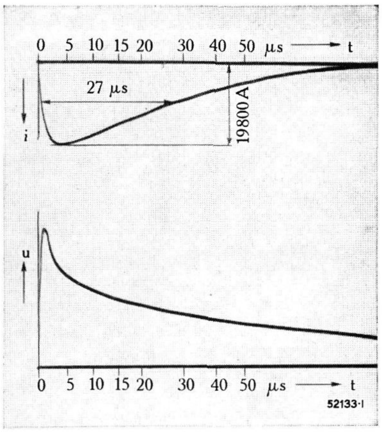

Fig. 3. — **Oscillographic record of the passing of 19,800 A (27 μs duration of half amplitude) through an arrester resistance (this record was taken by the A.S.E. when testing the Resorbit resistances).**

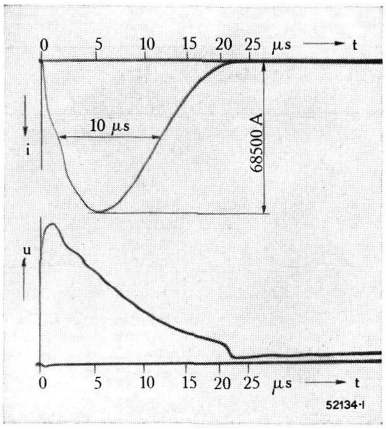

Fig. 4. — **Oscillographic record of the passing of 68,500 A (10 μs duration of half amplitude) through an arrester resistance (this record was taken by the A. S. E. when testing the Resorbit resistances).**

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[1] McEachron and McMorris, Electr. Eng. 1938 Transactions p. 307.

will not follow a sine wave at all, instead it will be distorted as is shown by the oscillogram in Fig. 5. This distortion prolongs the time during which the current passes through zero or is at any rate very low, thereby favouring the deionisation of the extinction spark gaps.

In connection with this, it may be worth while to mention that in order to function satisfactorily, an arrester resistance must possess a sufficiently high thermal capacity in order to be able to stand several consecutive discharges. The duration of the follow current depends on the phase angle of the instant at which the discharge starts with regard to the alternating system voltage, but as the current is always cut off at the first passage through zero, it will last at the most one half cycle (see Fig. 6). Nevertheless, the arrester may be subjected to several consecutive discharges at very short intervals. (Multiple lightning stroke.) This is provided for by the official rules specifying that an arrester be subjected to a considerable number of extinction tests following each other at short time intervals, i. e. the resistances must be capable of withstanding such stresses. The behaviour of a resistance in this respect can be controlled by making extinction tests at voltages above the normally admissible values. The oscillographic record in Fig. 5 shows, for instance, such a test at a voltage which is 45 % above the rated service voltage. In this exceptional case the current is only cut off after 12 half cycles. Nevertheless the resistances of that arrester were not in any way impaired by the test, a proof for the good quality of the material used.

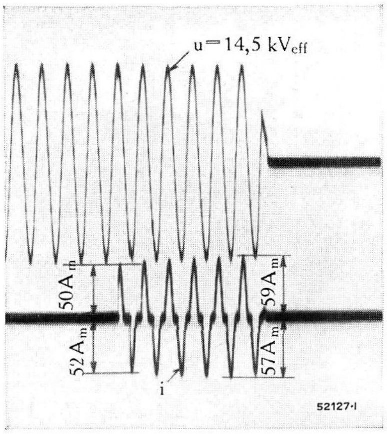

Fig. 5. — Extinction test with a surge arrester Type HF 10 q at a voltage of 14·5 kV i. e. 1·45 × nominal voltage.

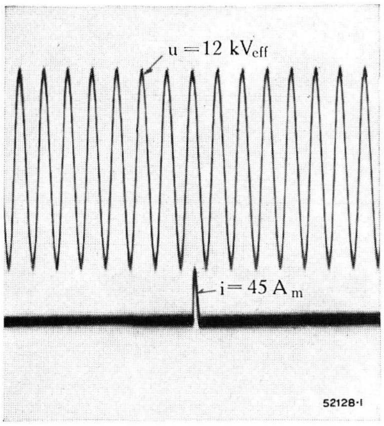

Fig. 6. — Extinction test with a surge arrester Type HF 10 q at a voltage of 12 kV i. e. 1·2 × nominal voltage.

V. THE RESIDUAL VOLTAGE.

The instantaneous value of the residual voltage, i. e. the voltage to which the incident wave is reduced, is given by the equation $u_p = i \times r$; i and r being the instantaneous values of the discharge current and the resistance respectively, in other words the residual voltage depends directly on the resistance characteristic.

The residual voltage of a surge arrester or of an individual resistance block is generally measured by recording the voltage-current characteristic by means of a cathode-ray oscillograph (Fig. 7). Fig. 8 shows such a record from which it will be gathered that the residual voltage of the surge arrester tested amounts to 5·9 kV crest value at the nominal discharge current of 2500 A. The nearer the voltage-resistance characteristic approaches the ideal valve characteristic b in Fig. 2 the lower the residual voltage for a given follow current will be, i. e. we are led to the same conclusion as in chapter IV. The absolute value of the residual voltage must not, however, be regarded as a decisive factor for the performance of an arrester. It is, in fact, sufficient if the residual voltage at the nominal discharge current is lower than or at the most equal to the breakdown voltage of the arrester. Fig. 9, a graph showing the breakdown and residual voltages of Brown Boveri Resorbit arresters Type HFp, will serve to illustrate this statement.

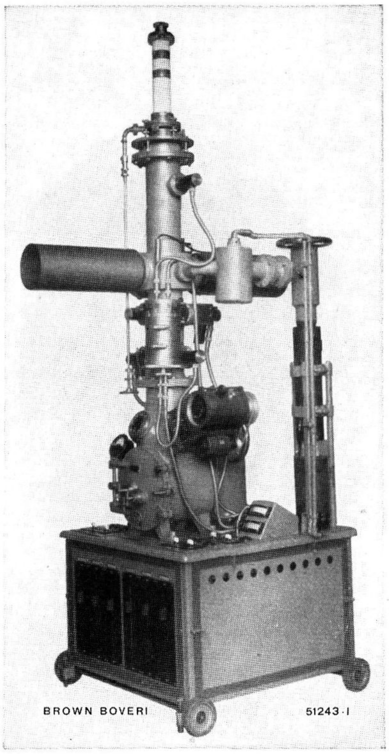

Fig. 7. — Cathode-ray oscillograph for controlling and recording the characteristics of Resorbit resistances.

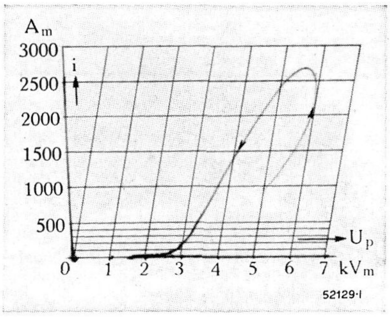

Fig. 8. — Voltage-current characteristics ($i = f(U_p)$) of a surge arrester element.

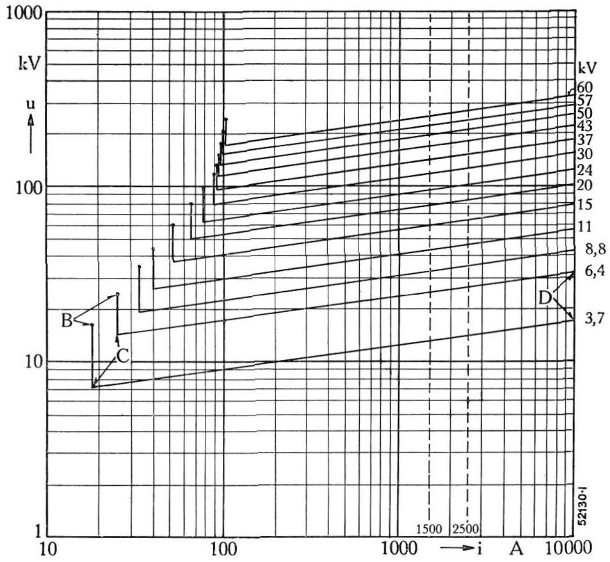

Fig. 9. — **Characteristics of surge arresters HF 3.7 to HF 64 for medium and high voltages.**
B. Breakdown voltage.
C-D. Behaviour of residual voltage.

VI. STABILITY OF THE RESISTANCE CHARACTERISTIC.

The purchaser of a surge arrester wants an apparatus which — apart from complying with the conditions of service — will not in any way be impaired as to its performance and properties even when being frequently called upon to function. A continuous test of the resistances helps to ascertain whether this condition is really fulfilled. In this test the resistance blocks are subjected to an uninterrupted series of discharges with a crest value adjusted to the nominal discharge current (i. e. 2500 A for Type p) and a duration of half amplitude of 30 micro seconds according to official rules. In the course of this test the voltage-current characteristic is recorded regularly, e. g. at the 10 th, 20 th, 30 th, etc. discharge. Fig. 10 shows an oscillographic record of the 60 th to the 160 th discharge on one resistance block. Taking into account the displacement of the volts-axis (this displacement cannot be avoided if a series of events at different times has to be recorded on the same film) it will be seen that the resistance is astonishingly stable in spite of the stresses it is subjected to. This test is thus not only a control of the practically unlimited durability, but also of the absolute stability of resorbit resistances.

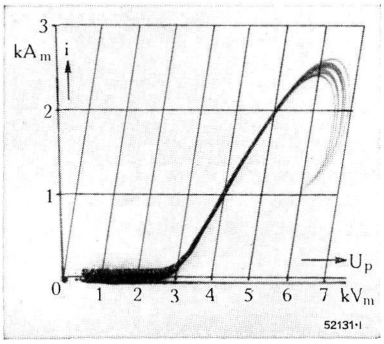

Fig. 10. — **Voltage-current characteristics of one resistance at the 60th, 70th, 80th, 90th, 100th, 120th, 140th and 160th consecutive discharge.**

Apart from this it is important to ascertain the regularity of the properties of the resistances. The result of such a test is reproduced in Fig. 11 which shows on one oscillogram the voltage-current characteristics of 15 resistance blocks chosen at haphazard. It will be noticed that the residual voltage of the different resistances varies by about ± 6·5 per cent referred to the average values. As generally one surge arrester contains several resistance blocks, these differences tend to compensate each other, so that the characteristics of complete arresters will differ still less than the figures given above.

VII. SUMMARY.

The foregoing chapters have dealt briefly with the properties of the principal component of a modern lightning arrester: the variable resistance. The great progress made in the construction of surge arresters is chiefly due to the continuous improvement of the resistances. Most of the characteristic data of an arrester, such as absorption and extinction capacity and the residual voltage depend directly on this component part. It may, therefore, well be affirmed that the quality of an arrester corresponds to that of the resistance material it contains. Well aware of this, Brown Boveri pay the greatest attention to the manufacture and testing of the variable resistances. Differing from inferior products, a high-class apparatus meets the clients' requirements not only as a whole, but its component parts by themselves will fulfil all reasonable expectations as to good workmanship, durability and regularity. In the domain of lightning protection the purchaser of a protection apparatus must have complete confidence in its constructor and the more the former is convinced that the material supplied to him is conscientiously studied and tested, the easier this confidence will be to establish.

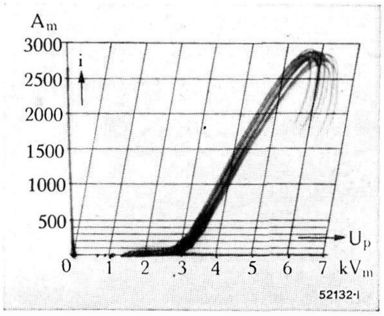

Fig. 11. — **Voltage-current characteristics of 15 resistances chosen haphazard from a lot of several hundreds.**

(MS 729) *Ch. Degoumois. (A. B.)*

THE DIESEL-ELECTRIC 1950 H. P. FIVE-COACH TRAINS OF THE DUTCH RAILWAYS.

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In addition to the 40 Diesel-electric 3-coach trains, 820 H. P., with a total seating and standing room for 8300 passengers, put into service in 1934, the Dutch Railways have now acquired 18 Diesel-electric 5-coach trains, 1950 H. P., with a total seating and standing room for nearly 7000 passengers. The following article is a summary description of these new 5-coach trains.

I. GENERAL NOTES.

AT the beginning of 1933, the Dutch Railways (henceforth termed D. R.) inaugurated the largest-scale motor-coach programme ever ventured upon in Europe, up till that time, by ordering simultaneously 40 Diesel-electric, 3-coach, 820 H. P. trains which were put into service in the year 1934[1]. The same railways placed a second remarkable order at the end of 1938, namely for *18 Diesel-electric 5-coach trains of 1950 H. P.*, which, according to programme, had to be running when the summer time-table of 1940 came into force. As a result of the difficult working conditions in the manufacturing plants due to the political situation which had developed since September 1939, it was found impossible to carry out this programme.

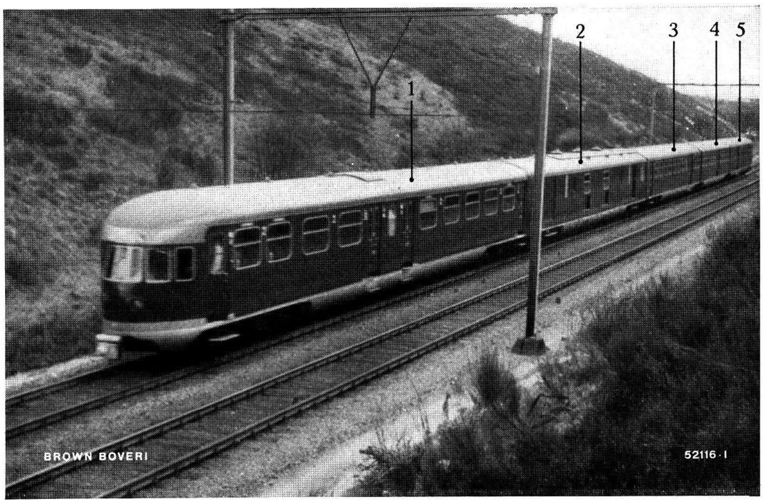

Fig. 1. — Diesel-electric 5-coach train, 1950 H. P. belonging to the Dutch Railways.
1, 3, 4 and 5 = passenger coaches. 2. = engine coach.

The new 5-coach trains of the D. R. (Fig. 1) constitute an innovation as regards capacity, power, comfort and speed and they place Holland in the forefront of those European countries which have developed Diesel motor-coach train services. The external lines of the 5-coach train are very similar to those of the earlier 3-coach unit (Fig. 2), but the degree of comfort afforded by the interior equipment is much superior. At the same time, a series of technical improvements and innovations have been incorporated in the new trains, a description of which will be given here. The 5-coach trains are designed for a maximum speed of 160 km/h, but the maximum schedule speed is limited to 120 km/h, for the time being. The overall length of the 5-coach train is 109 m which makes it the longest train unit in Europe. The weight of the train including 4800 l of fuel but without passengers or luggage is about 240 t (passengers and luggage about 30 t). The radius of action (about 2000 km) would allow of trips to Berlin, Paris or Basle and back without refuelling. When all the 5-coach trains have been put into service, the many regular express railway connections in Holland (in 1938, already 4.55 $^0/_0$ of all train-km were run at an average speed of over 100 km/h), will be considerably improved. One of the chief aims is to shorten considerably the across-Holland trip between Maastricht and Groningen. The new 5-coach trains can be coupled to the earlier 3-coach trains (built for a maximum speed of 140 km/h) and be run under multiple-unit control.

The new motor-coach trains were built by the Dutch firm Werkspoor (parts of the coaches and the Diesel engines built under licence agreement with Maybach); Beynes and Allan (parts of coaches) and Heemaf (electrical equipments). The latter build under Brown Boveri licences. Brown Boveri themselves also delivered a part of the electrical equipment as well as the charging blower sets for the Diesel engines and, therefore, participate to considerable extent in the machinery equipment of these trains.

II. COMPOSITION OF THE TRAIN AND LAYOUT OF THE COACHES.

The 5-coach train (Fig. 3) is made up of three third-class coaches, an engine coach and a second-class coach. The three third-class coaches are mounted on four two-axle bogies and form, in service, an undividable unit. The weight of the engine coach in service is about 93 t; it is mounted on two three-axle bogies; in case of necessity it can be changed from one train to another. The second-class coach

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[1] Hupkes: Die dreiteiligen Triebwagenzüge mit elektrischer Kraftübertragung der Niederländischen Eisenbahnen; Organ Fortschr. Eisenbahnw. 1937, No. 14.

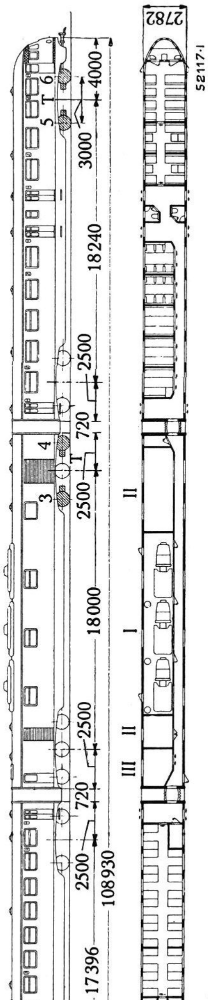

Fig. 3. — **General arrangement of a 5-coach train.**
From left to right:— 3 third-class coaches, 1 engine coach, 1 second-class coach. I. Engine room. II. Luggage compartment. III. Kitchen. T. Driving motor.

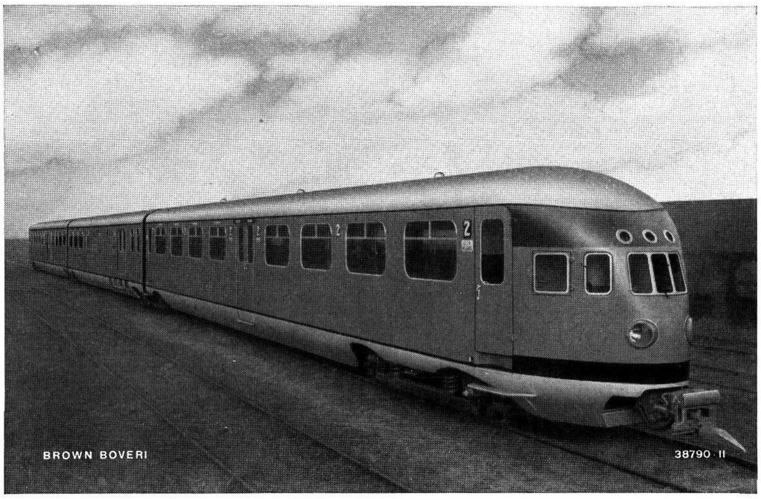

Fig. 2. — Diesel-electric 3-coach train, 820 H. P. belonging to the Dutch Railways.

at one end of the train is mounted on two two-axle bogies. All the coaches are connected by bellows and there is a driver's cab at each end of the train. Of the 6 driving motors, two are in each of the end bogies and two in one of the engine-coach bogies. The skeleton of the coach body is formed of light tubing electrically welded, while the doors, luggage racks and ducts for hot air and ventilation are made of light metal. The bogies are made of electrically-welded steel. The axles are fitted with axle boxes with SKF roller bearings and solid wheels.

There is an automatic Scharfenberg coupling at each end of the train. The coupling up of the electric connections and compressed-air pipes is carried out simultaneously with the mechanical coupling. Uncoupling is effected from the driver's cab by compressed air through the agency of a pedal. Hot air is used for heating the coaches and driver's cabs; this air is supplied by an air-heater heated by the Diesel-engine cooling water. The end third-class coach has an additional electric air-heating device. In summer, fresh air is blown into the coaches through the heating system. The Knorr-type of compressed-air brake acts on brake shoes applied to both sides of the wheels. For experimental purposes, five trains have also been equipped with an electro-magnetic rail brake composed of 12 brake electro-magnets each of 11,000 kg vertical pull. By combined action of compressed-air brake and electro-magnetic rail brake, the braked distance is reduced to about one half.

The engine plant is lodged in the engine coach as was the case for the earlier three-coach trains. The D. R. have found a very practical solution indeed in mounting the Diesel-generator sets on the coach frames and not in the bogies. The way the engine room is laid out allows of easy supervision and makes the machinery accessible which, of course, facilitates upkeep and repairs and makes running more economical. If the engine plant is built into the bogie instead of into the coach frame, the moment of inertia due to the masses of the bogie is increased and the running properties of the bogie adversely affected; further the Diesel engine absorbs soiled air which makes necessary frequent cleaning of the filter and regrinding of the valves. According to the publication "Traction Moderne", 1938, No. 16, it appears that experience gained in France shows that the life of a Diesel engine carried by the bogie is only $^2/_3$ of that of an engine built into the engine room of the coach.

Apart from the engine room, there is an electrical kitchen and two luggage compartments in the engine coach (Fig. 3).

III. DIESEL-ENGINE PLANT.

Each engine coach is equipped with three Maybach Diesel engines for charging by Brown Boveri charging set, to the Büchi process. These are the same type of Diesel engine, having the same dimensions as those of which the railway purchased 80 for epuipping their

3-coach trains[1]. Due to charging, the new engines deliver 650 H. P. at 1400 r. p. m.; the weight per unit of power of the engine including charging set only amounts to about 3·6 kg per H. P. The vertical-shaft charging set is placed between the two rows of cylinders of this 12-cylinder V-type engine (Fig. 4). The speed of the charging set is 11,000 r. p. m. The exhaust gas turbine (housing of cast steel without water jacket) works to the impulse process. The exhaust-gas pipes from each pair of cylinders are combined in one and led by the shortest track to the exhaust-gas turbine which is subdivided into six sections.

Each Diesel engine is coupled to its generator set through a double, fabric disc coupling and is carried on an auxiliary frame supported on the lower frame of the engine coach, being supported on rubber cushions. The three Diesel engine plants are quite independent of one another. Each Diesel engine has its own water cooler and oil-fired boiler for preheating the cooling water at starting. The closed-circuit cooling-water systems of all three Diesel engines are connected to the common cubicle for the air heating necessary for the heating of the coaches, this cubicle is supplied with air from two motor-fan sets. The preheating of the cooling water is carried out before each starting of the Diesel engines, whatever the season may be; the water is brought up to about 60^0 C; thanks to this the starting torques necessary are very low. Starting is effected with the help of the main generator running as a motor and supplied from a 300 A-hour storage battery of the Nife type. Coils are used to adjust the starting filling and to cut out the fuel feed. The adjustment to the Diesel-engine working speed desired is made by varying the spring tension of the speed governor by means of a speed adjuster of electro-motor type developed by Brown Boveri (Fig. 5). The output steps correspond to the following table and are in accordance with the load diagram of the Maybach Diesel engine and the steps of the speed adjuster depending on the positions of the controller handle (compare with chapter IV.).

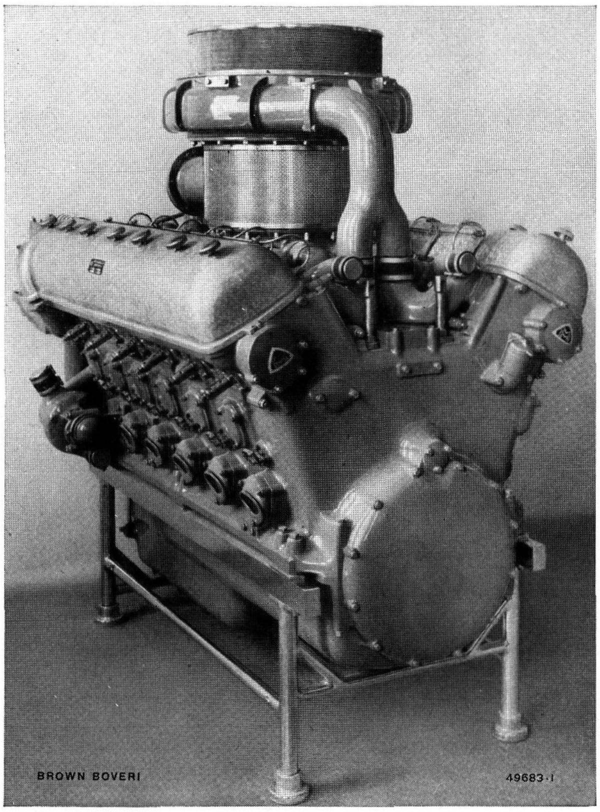

Fig. 4. — Maybach Diesel engine with Büchi charging by means of a Brown Boveri exhaust-gas driven turbo blower; 650 H. P. continuous rating at 1400 r. p. m.

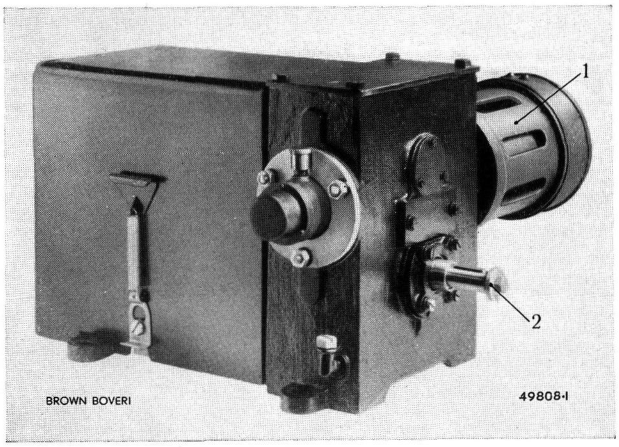

Fig. 5. — Electro-motor actuated speed-adjuster.
1. Control motor. 2. Driving shaft.

Step of controller	Speed r. p. m.	Output on Diesel engine shaft in H. P.	Torque of Diesel-engine		Load caused by
			in mkg	in %	
0	800	50	45	14	Auxiliary services
1	1000	162	116	35	Main load circuit and auxiliary services
2	1100	233	152	46	
3	1200	308	183	55	
4	1270	400	225	68	
5	1320	487	263	79	
6	1400	650	332	100	

The average power taken by the auxiliary services is about 40 H. P.

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[1] Compare with "Hupkes": Die dreiteiligen Triebwagenzüge der Niederländischen Eisenbahnen; Org. Fortschr. Eisenbahnw. 1937, No. 14.

IV. ELECTRICAL EQUIPMENT.

The diagram of connections and general layout of the apparatus was worked out by Heemaf Hengelo and Brown Boveri. Of the electrical equipment for 18 motor-coach trains ordered by the Dutch Railways from Heemaf, Brown Boveri built 12 generator sets, 6 converter sets and all the servo field-regulators, electro-motor speed adjusters, voltage regulators, relays for the motor coaches and a number of coil-controlled contactors.

Fig. 6 shows the fundamental diagram of connections of the main load (traction) circuit and of the auxiliary services. The six *driving motors* are distributed among the 5 coaches, as follows: — a pair of motors on each end bogie of the end coaches, the other two on one of the bogies of the engine coach. Each pair of motors is supplied, in parallel, from a main generator. In order that the bogie at the head of the train, whatever the direction of travel should be, should always work as a driving unit even when one of the Diesel-generator sets is out of commission, the diagram of connections is so made that the two driving motors 1 and 5 are supplied from the main generator I and the two driving motors 2 and 6 from generator III (see Fig. 3). There are two-pole coil-controlled contactors for switching in and cutting out the driving motors and for reversing direction of rotation. The driving motors have a one-hour output of 225 H. P. at 1000 r. p. m., 435 A, 425 V and a continuous output of 225 H. P. at 1280 r. p. m., 370 A, 508 V.

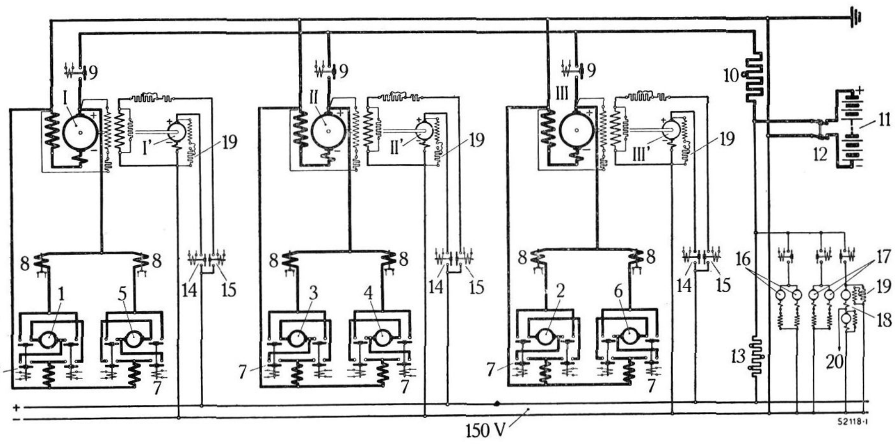

Fig. 6. — Fundamental diagram of connections of the load circuit and of the auxiliary services.

I, II, III. Main generator with auto-excitation and separate excitation as well as counter-compounding.
I', II', III'. Auxiliary generator.
1, 2 . . . 6. Driving motor.
7. Contactor for cutting out and reversing motor.
8. Over-current relay.
9. Starting contactor.
10. Current-limiting resistance in starting circuit.
11. Starting battery.
12. Two-pole battery switch.
13. Resistance for battery charging.
14. Contactor for putting in parallel.
15. Contactor for separate excitation.
16. Motor compressor set.
17. Motor fan set.
18. Converter set.
19. Voltage regulator.
20. Control and lighting circuit, 100 V constant.

The maximum speed of 1940 r. p. m. corresponds to 160 km/h, with a driving wheel diameter of 950 mm and gear-wheel ratio of 1 : 2·16.

Fig. 7 shows one of the three *generator sets.* The main and the auxiliary generators form a two-bearing set, the auxiliary generator being partly built into the main generator. The flexible coupling between the set and the Diesel engine is on the main generator side. The set is self-ventilated; the cooling air being drawn in from the engine room on the auxiliary-generator side and being expelled on the main-generator side below the engine-room flooring.

The one-hour rating of the *main generator* is 370 kW at 1400 r. p. m., 870 A, 425 V and the continuous rating 375 kW at 1400 r. p. m., 740 A, 508 V. The maximum voltage at 160 km/h is about 670 V. The *auxiliary generator* is dimensioned for a continuous output of 25 kW at 1000 to 1400 r. p. m., 166 A, 150 V.

The three auxiliary generators work in parallel on the auxiliary-service busbars of 150 V normal voltage. The automatic connecting in parallel is carried out by relays combined with coil-controlled contactors. Each auxiliary generator has its own automatic voltage regulator which compensates the deviations from the bus-bar voltage due to load and speed variations. The three voltage regulators are made mutually dependent by means of a stabilizing connection in such a way that the generator delivering the most power is influenced in the sense of a drop in voltage and the other generators in the sense of a rise in voltage until a point of balanced load delivery is reached again.

Contrary to the Diesel-electric 3-coach trains of the D. R. where characteristic control[1] is used, the 5-coach trains are all equipped with the Brown Boveri servo field-regulator control, which was called for in the specification. The control is so designed that satisfactory working of 3-coach and 5-coach trains in multiple unit control is attained. Fig. 8 shows the working

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[1] The Brown Boveri Review 1940, No. 8.

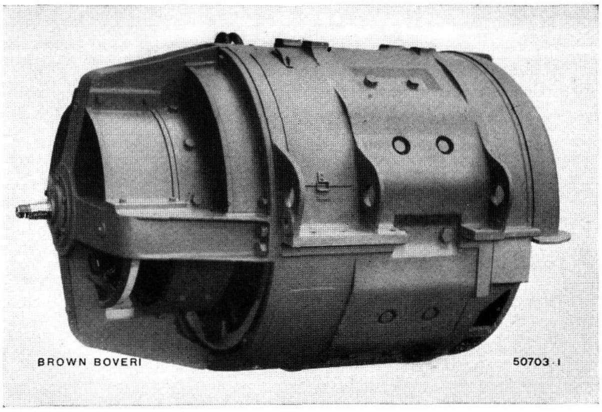

Fig. 7. — Main and auxiliary generator set for flexible coupling to the Diesel engine.

Coupling is made on the main-generator side, while the shaft end on the auxiliary generator side is used to drive the fan for the Diesel-engine cooler.

diagram of a Diesel-generator set in conjunction with the servo field-regulator control. The application of different torques by the servo field-regulator, in accordance with the data of the Table on page 249, is carried out mechanically from the speed adjuster, by rotating a cam shaft.

The *Brown Boveri speed adjuster* (Fig. 5) comprises a control motor combined with a worm and spur-wheel drive, two control relays and a position switch. The rotary movement of the speed adjuster is transmitted by chain-wheel drive, on the one hand, to the spindle of the Diesel-engine governor (adjustment of operating speed of the Diesel-engine) and, on the other hand, to the cam shaft on the servo field-regulator (adjustment of the torque). The electrically transmitted switching impulses are received by the speed adjuster by remote control from the drum of the controller. As soon as the desired step is attained, the control motor is stopped by short-circuit braking. The speed adjuster is designed for seven switching positions (including a switched-out position), it allows of speed adjustment which is both uniform and free of shocks and allows of setting any speed separately.

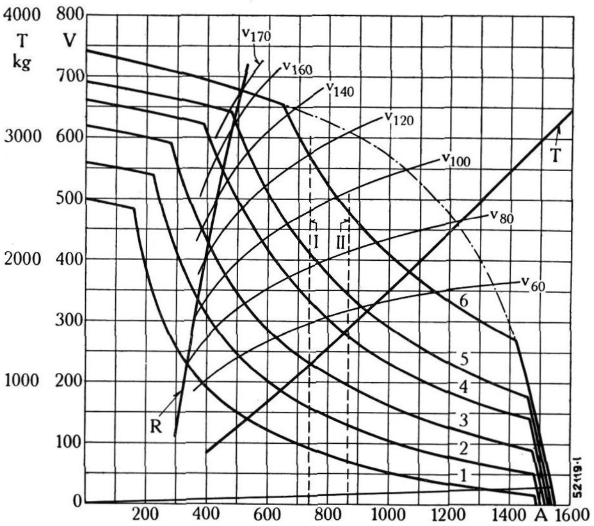

Fig. 8. — Working diagram of the Diesel-generator set in conjunction with servo field-regulator control.

1—6. Regulated voltage curves of the main generator for the output steps according to the Table on page 249. (For the auxiliary services, an average power output of 40 H. P. on the Diesel-engine shaft is assumed.)

V_{60}, V_{80}, V_{170}. Train speed in km/h.

T. Tractive effort of train at wheel tread (2 driving motors).

R. Travel resistance referred to 1/3 train weight (= 90 t).

I. Continuous output rating.

II. One-hour output rating.

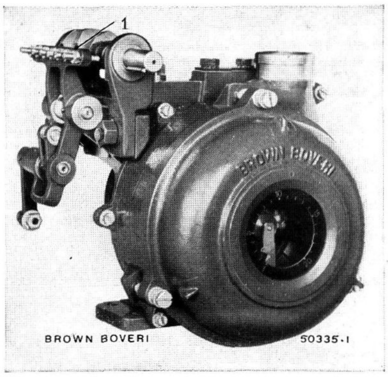

Fig. 9. — Servo field-regulator with mechanical torque adjustment in 7 steps.

1. Mechanical setting of torque.

Fig. 9 shows the *oil-pressure servo field-regulator* for mechanical torque setting.

Auxiliary services.

When the Diesel-generator sets are not running, the following auxiliary-service circuits are supplied from the starting battery: — driving motors of the air compressors for the brakes, the fans for hot-air heating, the pumps for the preheating of the cooling water of the Diesel engines, the converter set, the hot-water boiler, the cooling cubicle, the electro-magnetic rail brake. When the Diesel-generator sets are running,

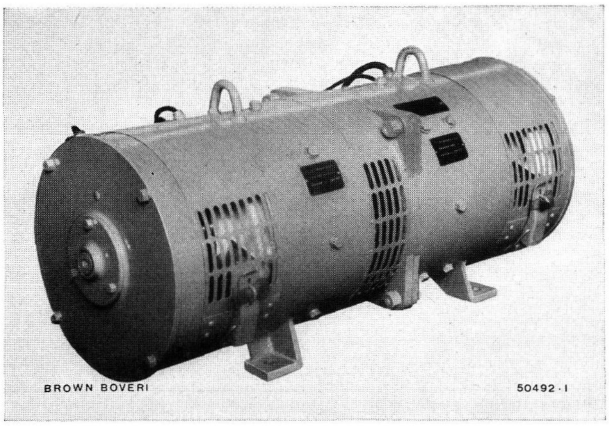

Fig. 10. — Converter set (motor generator set) of 8·5 kW continuous output rating.

the starting battery and consumer circuits it supplies are connected to the 150-V bus-bars, which also supply with current the separate excitation circuits of the main generators, the electric kitchen and the electric heating in the end coach No. 1 (about 30 kW).

To supply the lighting and control circuits a *converter set* is used (motor-generator set), according to Fig. 10, of 8·5 kW secondary output at a constant voltage of 100 V. The motor and the generator are in differential connection in accordance with a Brown Boveri patented arrangement[1] and are connected to the primary voltage varying between 110 V and 150 V (starting battery, auxiliary-service bus-bars). The current flowing in the secondary circuit is equal to the sum of the generator and motor current. The maintenance of constant voltage in the 100 V secondary network is looked after by a quick-acting regulator which influences the excitation of the motor. The generator has two slip-rings for tapping the alternating current at about 75 V, about 60 to 75 cycles which is then stepped down to 12 V for supplying the search light, signal lamps and remote heating, because the d. c. voltage of 100 V is not suitable for these purposes.

V. FIRST RESULTS OF SERVICE.

Trial runs were made with the first four Diesel-electric 5-coach trains, during April 1940 with most satisfactory results. All conditions laid down were entirely fulfilled. Thus, this important delivery was a success in every way. A maximum speed of 178 km/h was attained with motor-coach train No. 51 (first train delivered of this series) on the 24th of April 1940, on the Utrecht-Groningen line section. (The maximum schedule speed is fixed at 120 km/h for the time being).

After an interruption due to the belligerant activities in Holland, at the beginning of May 1940, the erection work and trial runs were proceded with according to programme, so that, by the middle of September, 15 complete trains had been delivered. The remaining 3 trains will probably be delivered at the end of this year. However, the new motor-coach material will not be put into regular traffic service for the time being.

(MS 730) *A. E. Müller. (Mo.)*

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[1] See the Brown Boveri Review 1938, No. 12, page 265.

THE INFLUENCE OF THE DEFLECTION VOLTAGE ON THE FOCUSSING AND SENSITIVITY OF THE CATHODE-RAY OSCILLOGRAPH, ESPECIALLY WHEN HIGH-VOLTAGE DEFLECTION PLATES ARE USED.

Decimal index 621.317.755

Cathode-ray oscillographs with direct high-voltage deflection generally produce oscillograms of poor quality. The close investigation of the field distribution in the deflection chamber shows that if an asymmetrical deflection arrangement is adopted, in which the plate which is under constant potential is located as near the axis of the beam as possible, as opposed to the usual symmetrical arrangement of the plates, oscillograms can be obtained which are fully equal in quality to those produced with low-voltage deflection.

THE part played by the cathode-ray oscillograph as a recorder of rapidly changing processes has been one of increasing importance as it is the only one known as being devoid of inertia. Industry, as well as science can no longer do without the cathode-ray oscillograph for research work and the supervision of manufacturing processes. It may be recalled, here, that modern investigations in the field of excess-voltage technology embracing the manifold problems of coordination, lightning arrestors, travelling waves and oscillations encountered on transmission lines and in windings, etc. would have presented insurmountable difficulties if the cathode-ray oscillograph had not been available. It is, therefore, obvious that efforts are being constantly directed towards the improvement of this most useful instrument. The object of the present article is to provide some information on the special problem of high-voltage deflection.

While, usually, cathode-ray oscillographs are only built for the direct recording of relatively low voltages, such, for example, as a max. of 3 to 5 kV peak value, the high-voltage deflection oscillograph allows the direct measurement of voltage of a higher range such, for example, as 50 or 100 kV peak value. However the results obtained with the latter apparatus are not of satisfactory quality, even when the practical difficulties inherent to using high-voltage deflecting plates have been overcome. To understand the reason for this, it is necessary to examine more closely the deflection process proper. This process can be represented in the following manner:—

The cathode beam, the electrons of which are accelerated in the discharge tube, through the agency of the beam voltage U_0, up to a velocity V_0, is subjected to a homogeneous transversal electric field of strength $\mathcal{E}$, extending to an axial length a and being produced by the voltage E between the deflecting plates P_1, P_2. This field deflects the beam and its point of image B on the writing plane of the oscillograph is, thus, displaced by the length b (compare to Fig. 1). Under this assumption, the equation valid for the deflection is

1. $b = \mathcal{E}\,\frac{a}{2\,U_0}\left(d + \frac{a}{2}\right) \approx \mathcal{E}\,\frac{ad}{2\,U_0}$, because, usually, $\frac{a}{2} \ll d$.

However, a deflection field of this kind isolated and independent in space is physically impossible; further, for certain practical reasons, the deflecting plate P_2 is usually earthed that is to say is brought to the same voltage as anode A or is connected to a constant bias voltage. Further, it is customary to place the plates symmetrically to the axis of the beam. We will, now, go more closely into the conditions pertaining to the deflection chamber.

Fig. 2 shows the distribution of the field more exactly, such as it exists in the high-voltage deflecting chamber of a cathode-ray oscillograph. Plate P_2 is assumed earthed, here, and plate P_1, subjected to the variable voltage E to be recorded. $N\left(\frac{1}{n}\right)$ is, generally speaking, the equipotential surface of the potential $\frac{E}{n}$, while $N\left(\frac{1}{2}\right)$ is that of potential $\frac{E}{2}$. As the figure shows, the electrons forming the beam have a different speed at every point of their track (which is approximately in the axis of the beam Str), corresponding to the potential N of the point under consideration and they are subjected to different deflections according to the strength of the field $\mathcal{E}$ at that point. Further, it will be seen that the equipotential surfaces cut by the axis of the beam extend nearly to the surface $N\left(\frac{1}{2}\right)$, corresponding to the potential $\left(\frac{E}{2}\right)$ under a deflecting voltage of magnitude E.

Therefore, the electrons of the beam are subjected to accelerations or decelerations in function of the deflecting voltage as would correspond to an increase or reduction of the beam voltage U_0 by the amount $\frac{E}{2}$. As the result thereof:—

1. The deflection sensitivity (according to equation 1) depends on the deflection voltage and there is, therefore, assymmetry of the coordinate system as regards the zero axis.
2. The focussing of the anode opening on the writing plane of the oscillograph, which is usually produced magnetically by a focussing coil, being also dependent on the velocity of the beam, can only be adjusted exactly for a single constant value of E.
3. The zero axis depends on the potential of the plates because the influence of the earth field also depends on the velocity of the beam.

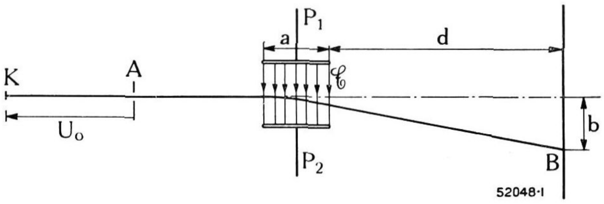


Fig. 1. — Principle of cathode-ray deflection.

K. Cathode.
A. Anode.
P_1, P_2. Deflecting plates.
$\mathcal{E}$. Strength of deflection field.
B. Point of image.
a. Axial length of deflection field.
b. Deflection.
d. Distance between deflection field and writing plane.
U_0. Beam voltage.

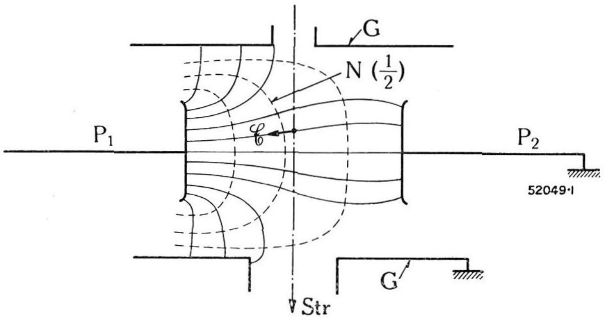


Fig. 2. — Distribution of the field in the deflection chamber, in the case of symmetrically placed deflection plates.

Str. Axis of beam (rotated through 90° as compared to Fig. 1).
P_1, P_2. Deflection plates.
G. Earthed housing.
$\mathcal{E}$. Strength of deflection field.
$N\left(\frac{1}{2}\right)$ Equipotential surface of potential $\frac{1}{2}$ E.
E. Difference of potential between P_1 and P_2.

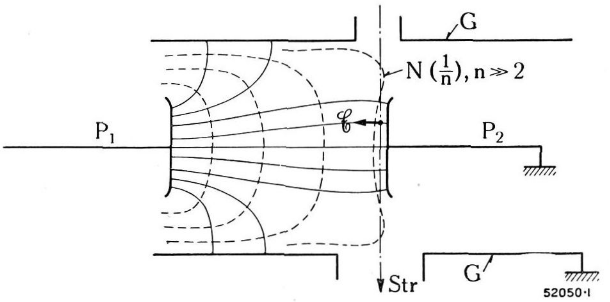


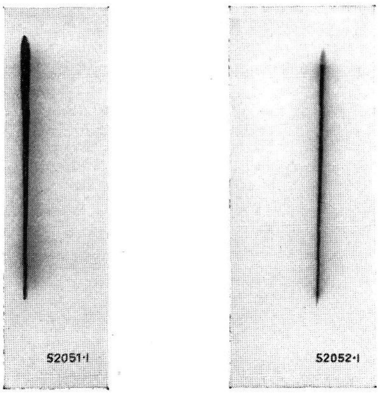
Fig. 3. — Distribution of the field in the deflection chamber in the case of asymmetrically placed deflection plates.

Str. Axis of beam.
P_1, P_2. Deflection plates.
G. Earthed housing.
$\mathcal{E}$. Strength of deflection field.
$N\left(\frac{1}{n}\right)$ · Equipotential surface of potential $\frac{1}{n}$ E.
E. Difference of potential between P_1 and P_2.

4. There is astigmatism of the focussing that is to say a writing spot which is deformed because the different component rays of the cathode beam do not pass through the same part of the field.

The first-mentioned conclusion leads to a trapezoidal coordinate system under the combined effect of two deflecting systems perpendicular to one another. This fact was well known in the case of hot-cathode oscillographs, because it is the more noticeable the smaller the beam voltage U_0 as compared to the deflection voltage E. The first and the second conclusions enumerated above have consequences which make themselves disadvantageously felt, however, in cold-cathode oscillographs as well when a high-voltage deflection system is used; here, the second conclusion is the more disturbing the closer the high-voltage deflection chamber is to the focussing coil and the further away it is from the writing plane.

As, now, as regards the deflection process, which depends solely on the strength of the field, it is quite immaterial under what potential it is produced, it can be affirmed that the *ordinary symmetrical arrangement* of the deflecting plates is *very disadvantageous.* If we chose an unsymmetrical arrangement of the plates, according to Fig. 3, in which the plate remaining at constant potential is brought as close to the axis of the beam as the extent of the beam allows, while the plate under variable potential is located as far away from the beam axis as is possible with regard to the deflection sensitivity to be maintained, all the undesirable disturbances mentioned are eliminated. As will be seen, the beam only reaches surface $N\left(\frac{1}{n}\right)$ ($n \gg 2$, for example 20) and *only 1/n of the deflection voltage is effective to influence the velocity of the beam* instead of about the half when a symmetrical plate arrangement is used. It will, therefore, be clear that the disturbances 1 to 3 (varying sensitivity, focussing and zero line) which are a direct consequence of the dependence of the velocity of the beam on the deflection voltage, are eliminated to a great extent. As, further, the field to be passed through tends to be more homogeneous, the astigmatic error which is already of little importance will be yet smaller. The considerations laid down here are also correct in principle when the high-voltage deflection plates are provided with earthed diaphragms to reduce the sensitivity of the high-voltage deflection plates. With the arrangement proposed here, high-voltage deflection gives the most satisfactory results and the oscillograms produced therewith are of as good quality as those usually obtained with low-voltage deflection.



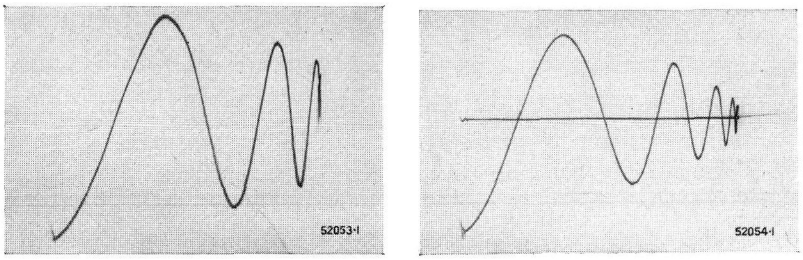
a b

Fig. 4. — Deflection recorded with a cathode-ray oscillograph with high-voltage deflection.

a. With symmetrical deflection system according to Fig. 2.

b. With asymmetrical deflection system according to Fig. 3.

The oscillograms of Figs. 4a and 4b show the recorded deflection obtained with a cathode-ray oscillograph with a cathode voltage of 50 kV peak value, when a 50-cycle voltage of about 10 kV peak value is applied to the high-voltage deflection plates in the one case with the usual symmetrical arrangement of the deflection plates in the other with the asymmetrical arrangement proposed here. Figs. 5a and 5b show the corresponding oscillograms of damped oscillations of about 10,000 cycles and about 15 kV peak value amplitude. Our conclusions are confirmed by these photos.



a b

Fig. 5. — Cathode-ray oscillogram of a damped oscillation.

a. Recorded with symmetrical high-voltage deflection system, according to Fig. 2.

b. Recorded with asymmetrical high-voltage deflection system, according to Fig. 3.

(MS 719) *Dr. H. Meyer. (Mo.)*

NOTES.

Three-phase shunt commutator motors for the drive of gas blowers.

Decimal index 621.313.36

To meet the very wide fluctuations in consumption on gas-distribution systems blowers are used, with which the volume delivered and the pressure can be varied by simple means. The adaptation to these requirements is best carried out by varying the speed of the blower, whether the latter be of the rotary or the centrifugal type.

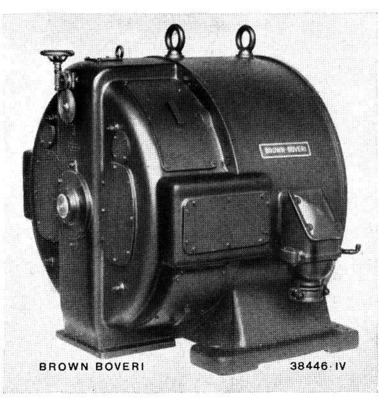


Fig. 1. — Three-phase shunt commutator motor of totally-enclosed pipe-ventilated design. 155 H. P. continuous rating, 580/380 r. p. m., 380 V, 50 cycles.

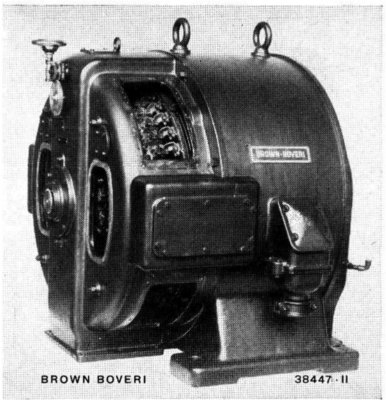
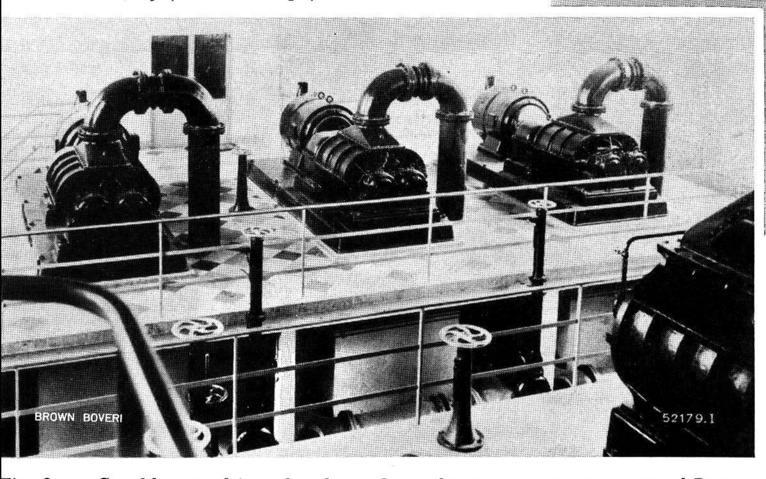


Fig. 2. — Three-phase shunt commutator motor, 155 H. P. continuous rating, 580/380 r. p. m., 380 V, 50 cycles, with covers raised to allow of inspection of brushes and commutator.

Thanks to the ease with which the shunt commutator motor can be operated and its wide range of speed variation, without losses, this motor is very suitable indeed for the drive of gas blowers. Attendance is of the simplest; just as in the case of a squirrel-cage induction motor, it is set to work by closing an ordinary circuit breaker. On displacing the brushes by means of a handwheel, any speed within the desired regulating range can be obtained, perfectly smoothly (without steps). The elimination of any other starting gear allows of adapting the plant very easily to the special working conditions met with in gas works, as regards safety against explosions. This explains why the three-phase shunt commutator motor has been rapidly gaining ground in this special field.



ig. 3. — Gas blowers driven by three-phase shunt commutator motors of Brown Boveri design. Continuous rating 82 H. P., 560/275 r. p. m.

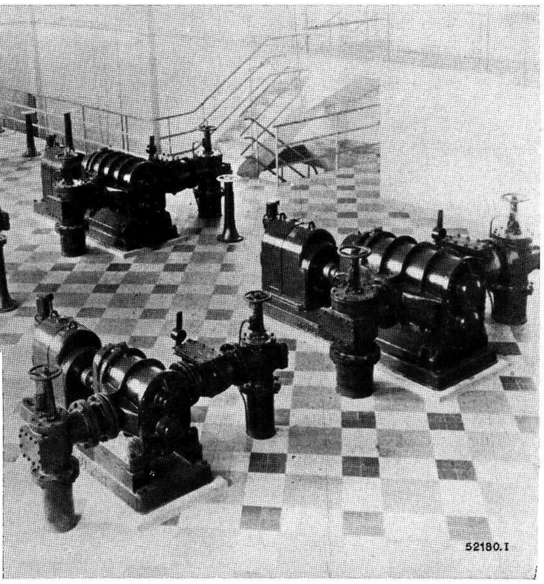


Fig. 4. — Four gas blowers driven by three-phase shunt commutator motors of Brown Boveri design, two of which are each of 7 H. P. continuous rating, 625/350 r. p. m. and two each of 3 H. P. continuous rating, 920/500 r. p. m.

Figs. 1 and 2 show a motor of this type supplied for the direct drive of a rotary gas blower. It is located in a machine room in which there are occasionally traces of town gas. To eliminate any danger of an explosion, the motor is chosen of the totally enclosed, pipe-ventilated design, the cooling air being led in and expelled through ducts. In order to allow of supervision when stopped, the commutator and brushes are easily accessible by raising covers. Ventilation is carried out by a fan set which draws in fresh air from outside the room. This separate ventilation is interlocked electrically with the main circuit breaker of the commutator motor through a contact gauge so that the motor can be only switched in after it has been scavenged with fresh air and the pressure inside the housing exceeds that of the surrounding air. If the ventilation ceases, the main circuit breaker trips automatically. The motor is started up by being connected directly to the electric supply system, but this can only be done when the brushes are in the position corresponding to the lowest speed; the momentary starting current peak is about twice the rated current.

The two motors delivered for the plant in question have been now in constant service for seven years without any trouble, which is a marked proof of the suitability of this motor design for gas-work plants. Figs. 3 and 4 show other applications of three-phase shunt commutator motors for the drive of gas blowers. These are also of totally-enclosed and separately-ventilated design. Starting and adjusting the speed are through remote control from a main switchboard. There is, therefore, a small control motor with reduction gear for displacing the brushes, built on to the main motor. Seven commutator motors were supplied to this plant in the year 1936 and they have been running perfectly since they were put into commission.

(MS 738) *A. Wick. (Mo.)*

GENERAL INDEX TO VOL. XXVII, JANUARY-DECEMBER 1940.

General.

Page

Apparatus.

Compressors and blowers.

Electric machinery and transformers.

Mutators.

Power stations.

Page

Steam generators and electric boilers.

Steam and gas turbines and accessories.

Traction.

Various applications of electric power.

FRONTISPIECES AND SEPARATE ILLUSTRATIONS.

General.

Page

Apparatus.

Compressors and blowers.

Electric Machinery and transformers.

Mutators.

Page

Steam generators and electric boilers.

Traction.

Various applications of electric power.

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