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344.—REPORT OF THE STUDY COMMITTEE No. 8 (Lightning and Surges)

by Prof. Dr. K. BERGER,
Chairman of Committee.

Committee No. 8 met in Paris during the 1956 Session of C.I.G.R.E. and in September 1957 in Montreux (Switzerland). The subject of Committee No. 8 not having been discussed at the 1956 session, the committee confined itself to one report, No. 326 (1), on the work of the Committee. Whereas in 1954 and 1952 the Committee had presented two reports on the statistics of faults due to surges as a result of lightning discharges (report No. 302 in 1952 and No. 306 in 1954), report No. 326 of 1956 (1) treats the problem of the accuracy of industrial measurement of surge voltages. It summarizes the results obtained in 14 European laboratories in the measurement of breakdown voltages of the following arrangements:

1. Sphere gap (diameter 250 mm, spacing 60 and 125 mm);
2. Rod gap (spacing 450 mm);
3. Rod-plate gap (spacing 450 mm).

According to a program which had been fixed in detail, the curve for the probabilité of breakdown was measured several times with the normal 1/50 wave. In the second part of the report, the breakdown characteristic was determined by applying waves with rising amplitude and front-steepness.

The results presented in report No. 326 of 1956 were discussed by the Committee in 1956. Whereas the conformance of results is sufficient in the case of breakdown voltage of sphere gaps, this is not so for rod gaps and still less for measurements within the wave-front.

The chairman takes this oppoturnity of again thanking the managements of the laboratories and the engineers who collaborated in these comparative measurements. This especially taking into account the pressure of technical work today and considering the zeal and the time demanded of each of the collaborators for carrying out these tests.

(1) Comparative measurements with gaps.

The following is a list of the collaborating laboratories:—

Allgemeine Elektrizitäts-Gesellschaft, Hochspannungsinstitut, Kassel-Bettenhausen ;

Allmänna Svenska Elektriska Aktiebolaget, Ludvika ;

A.-G. Brown, Boveri et Cie, Baden ;

Électricité de France, Paris ;

Eidg. Techn. Hochschule, Hochpannungslaboratorium, Zürich ;

Forschungskommission des S.E.V. und V.S.E. für Hochspannungsfragen, Zürich ;

Kabelwerke Brugg A.-C., Brugg ;

Neamloze Vennootschap tot Keuring van Electrotechnisches Materialen, Arnhem ;

Porzellanfabrik Langenthal A.-G., Langenthal ;

Micafil A.-G., Zurich ;

S.A. des Ateliers de Secheron, Geneva ;

Siemens-Schuckertwerke A.-.G., " Transformatorenwerk", Nürnberg ;

Studiengesellschaft für Höchstspannungslagen e.V., Ruit über Esslingen a.N. ;

Technische Hochschule, Graz.

The problem of the accuracy of technical measurement was pursued by the A.S.E.A. laboratory in Ludvika and a report was drawn up by N. Hylten-Cavallius and J. Fryxell entitled: "The variation of the 50 % flashover voltage of rod gaps and insulators". An extract of the report, written by the authors, is included as Annexe I in the present report of Committee No. 8. On the same comparative measurements a theoretical article by W. Baumann appeared in *Elektrotechnische Zeitschrift* (*E.T.Z.*), 1957, p. 369-377, entitled: "Statistischer Fehler bei der Bestimmung der 50 %-Ueberschlags-Stosspannung". Following a discussion of these measurement problems, the Committee confirmed, during its meeting in Montreux in 1957, its decision to concern itself in future with questions of the measurement of surge voltages and currents as well.

Committee No. 8 (Lightning and Surges) thus now deals with the following subjects:—

1. Lightning and its overvoltages ;
2. Internal overvoltages ;
3. Lightning arresters ;
4. Measurement of surge voltages and currents.

The problem of greatest present interest in the last mentioned subject is the voltage divider for measuring high voltage waves chopped in the front. Technical Committee No. 37 of the I.E.C., for example, demands that the breakdown voltage of lightning arresters be measured down to breakdown time of 0.5 μs. The verification of the accuracy of the voltage divider is therefore the primary problem. Of the two possible solutions, comparison with a standard divider, of checking each divider over a range of frequencies or under a very steep unit step, the second method would seem to be better for technical progress.

A very interesting report treating these questions by M. Romano was published in *Revue Générale d'Électricité*, May 1956, p. 289. Another contribution to this problem was presented by M. Özkaya, H. Baatz and H. Böcker: *Procedure for the determination of the errors of measuring-circuits for impulse voltages*. This work is included as Annexe II in this Committee's report.

Since the Committee deals with problems concerning the measurement of high voltages, a very valuable report on the accuracy of sphere gaps was discussed in the Committee. This is the work by H. E. Fiegel and W. A. Keen: "Factors influencing the sparkover voltage of asymmetrically connected sphere gaps", published in *A.I.E.E. Transactions*, Vol. 76, Pt I, 1957.

Fiegel and Keen especially concern themselves with the influence of the distance of the spheres from the ground, vertical walls and surge generator. In order to obtain a measuring accuracy of better than ± 3 %, the minimum distance from surrounding objects was found to be considerable. If one wishes to utilize the sphere gap with spacings appreciably greater than the radius of the spheres, this distance should be greater than what one had believed to be acceptable up to now. Further, the work shows that, in order to achieve the same goal, the height of the spheres above ground should be fixed between an upper and a lower limit.

This report is of special importance at present because the I.E.C. is in the course of revising its rules for measuring high voltages with sphere gaps.

A summary of this report, written by the authors, is included in the present Committee report as Annexe III.

In conclusion, the author wishes once again to draw attention to the fact that under the auspices of the Bristih Electrical Research Association, and especially of Dr. Golde, a lightning flash counter has been developed and is now commercially available. The Committee hopes that this lightning flash counter will furnish more accurate information on the severity of storms in different countries and regions than the "isoceraunic level" at present used.

ANNEXE I

THE VARIATION OF THE 50 % FLASHOVER VOLTAGE OF ROD GAPS AND INSULATORS

by N. HYLTEN-CAVALLIUS and J. FRYXELL,
(Sweden).

SUMMARY

In report No. 326 *C.I.G.R.E.*, 1956, BERGER [1] *gives an account of comparative tests on spark-gaps made by fourteen different European laboratories, wherein it is reported that the* 50 % *flashover voltage values have differed by more than* 20 %.

This report discusses briefly a continuation of these tests carried out by one of the participant laboratories [A.S.E.A.] in order to find the sources ot the discrepancies. The tests have been concentrated to full impulses on rod-gaps [dry test] but some comparative tests have also been made on insulators.

The results obtained have been much more stable than those compiled in C.I.G.R.E.-report 326-1956 *with the exception of impulses of negative polarity on rod-gaps where large unsystematic discrepancies have been observed.*

An explanation for these large discrepancies for negative polarity on rod-gap may be the uncertain range for rod-gap flashover, i.e. the range where the flashover may follow either of two different flashover mechanisms. For positive polarity this range, however, occurs at much lower voltages than those used here.

Neither influence of the surroundings, atmospheric condition, ionization level or the impulse circuit itself explains the discrepancies reported by BERGER *for positive polarity. These may therefore either be explained by errors in measurement of voltage or be left unexplained.*

INTRODUCTION

In Report No. 326 C.I.G.R.E., 1956 BERGER gives an account of flashover voltages of different sparkgaps, as measured by a number of different laboratories. The differences in the reported values for gaps, of the same design, were sometimes very large and the causes have not yet been explained. In order to investigate the reason for these discrepancies one of the participants, Asea High Voltage Laboratory Ludvika, Sweden, has undertaken systematic measurements on both rod-gaps and insulators using full impulses (these were not covered by BERGER).

Some factors, the surroundings and the impulse circuit, were varied systematically while others e.g. humidity, irradiation etc. changed arbitrarily as the duration of the tests covers a period of about one year.

MEASUREMENTS

One result given in C.I.G.R.E.-report 326/1956 is the 50 % flashover voltage of a 450 mm rod-gap, measured in dry state by 14 participant laboratories. The test procedure was one generally used by high voltage laboratories, i.e. 10 shots applied at each of several subsequent voltage levels. Each laboratory repeated the test a number of times (generally six) and reported the 50 % voltage levels (*Em*) as an average of all tests, usually by plotting on probability paper. The standard deviation (*s*) of the flashover voltage was also given.

TABLE I.

Horizontal rod-gap 450 mm. Values obtained from C.I.G.R.E.-report 326/1956.

Positive polarity		Negative polarity	
Em kV	s %	*Em* kV	s %
269	4	352	2
270	4	355	2
280	3	360	4
280	2	367	4
280	2	370	2
285	2	372	6
293	3	374	5
294	4	375	4
295	3	379	4
295	1	385	6
302	5	390	8
304	3	394	5
312	4	431	4
341	4	449	2

Table I groups the 50 % values from all participant laboratories and also the relevant standard deviation. These 50 % values are dealt with as a statistical variable and plotted on probability paper in *figure* 1.

A summary of table 1 and *figure* 1 is presented in table II giving the lowest and the highest 50 % value reported by any of the participant laboratories. Further, all 50 % values are averaged. The range of variation (D %) in the table indicates the relative difference between the maximum and the minimum value. The standard deviation s_+ and s_- is a rough estimation based on the values in table 1. It varied between 1-5 % for positive polarity and between 2-8 % for negative polarity, giving an average of say 3 % for positive and 4-5 % for negative polarity.

The present tests by A.S.E.A. were carried out on a 450 mm rod-gap of similar design to BERGER's and on an insulator dimensioned as in

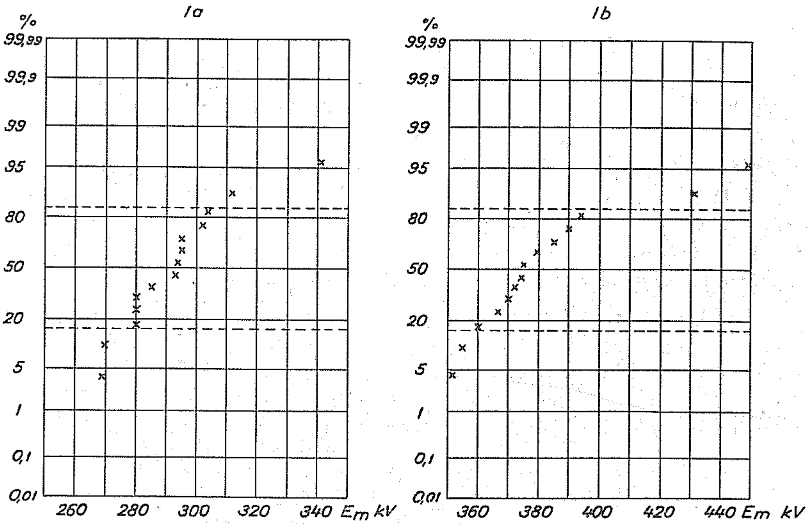

FIG. 1.—Horizontal rod-gap 450 mm, 50 % flashover voltage
Values obtained from C.I.G.R.E.-report 326/1956.
a) positive polarity *b)* negative polarity

figure 5. In order to study the influence of the surrounding, tests were performed, firstly with the test-object arranged "free" and then with two 1,400 × 1,400 mm earthed plates one placed on either side. The distance between the test object and plates was 675 mm for the insulator tests and 620 mm for the rod-gap tests.

Another factor examined was the dimensioning of the test circuit. This was studied by varying the front capacitor (C_B) and consequently the series resistance of the impulse generator, while keeping the nominal impulse front time and time to half value constant. The variation made in the front capacitor was from 0 (or actually the capacitance of the rod-gap plus leads) to 1,200 pF. The effect of this front capacitor was studied on 20 occasions. In each case 10 shots at each voltage level were given.

The influence of surroundings was examined on 9 occasions. In each case 10 tests of 10 shots at each of a number of subsequent voltage levels differing by about 5 % were given.

All tests were performed in the same laboratory over a period of about one year totally involving about 50,000 voltages applications.

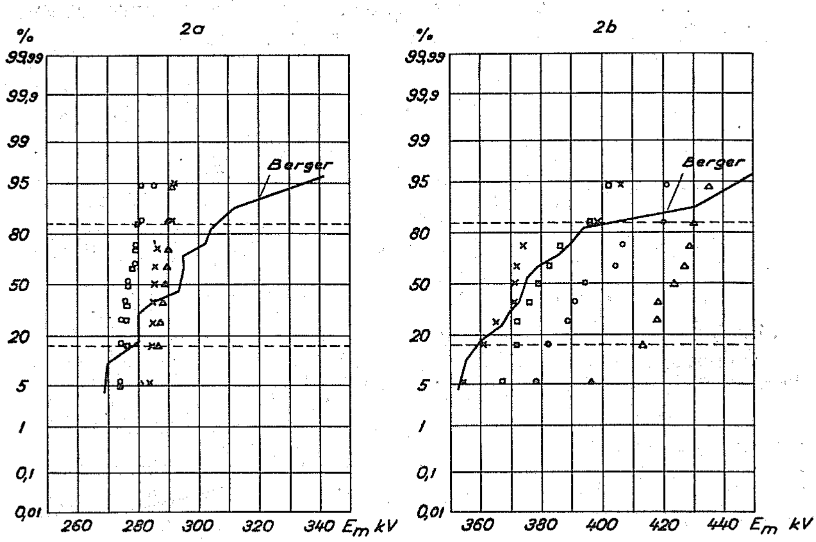

FIG. 2.—Horizontal rod-gap 450 mm, 50 % flashover voltage.
Values obtained from the present report.

x Free arrangement: $C_B = 800$ pF;
Δ Earthed plates: $C_B = 800$ pF;
□ Free arrangement: $C_B = 200$ pF;
V Eearthed plates: $C_B = 200$ pF.

a) positive polarity *b)* negative polarity

Results of all tests were corrected for humidity in accordance with A.S.A.-standards. The factor k used in the denominator of this correction formula varied between 0.94 and 1.00. No external irradiation was used but the testing plant was exposed to daylight of varying intensity via roof-windows, and to light from incandescent lamps.

Voltage measurements were constantly checked against results by an independent method. The differences observed were within ± 2 %.

Additional information on the testing conditions is given in [4] submitted to the C.I.G.R.E. Study Committee No. 8.

Results of the present tests are found in figures 2-4, a summary of which is presented in table II together with the results in C.I.G.R.E.-report 326/1956. *Figures* 2 and 3 show the influence from the surroundings (the earthed screens) at two different values of front capacitor e.g. 200 and 800 pF. *Figure* 4 gives the flashover voltage as a function of the front capacitor, varying within a relatively large range, 0-1,200 pF, while the test object was arranged free.

TABLE II.

50 % *flashover voltages.*

	Minimum value kV	Average value kV	Maximum value kV	Range of variation D %
C.I.G.R.E.-report 326-1956 :				
Rod-gap pos. $s_+ \simeq 3$ %	269	292	341	25
Rod-gap neg. $s_- \simeq 4\text{-}5$ %	352	376	449	26
Present report :				
Rod-gap pos. $s_+ \simeq 3$ %	274	282	292	6,5
Rod-gap neg. $s_- \simeq 8$ %	354	393	435	21
Insulator pos. $s_+ \simeq 3.5$ %	311	318	321	3.5
Insulator neg. $s_- \simeq 8$ %	503	530	545	8

DISCUSSION

If it is assumed that the standard deviation (s) of the flashover voltage of the test object itself is the only factor influencing the results, it can be shown [2, 3], that all 50 % values given by BERGER and the present report would fall within a range much less than 0.5 s. As s is 8 % or less this means that D in table II would never exceed some few percent. A reasonable addition of uncertainty owing to minor inaccuracies in the measurement of test voltage (some few

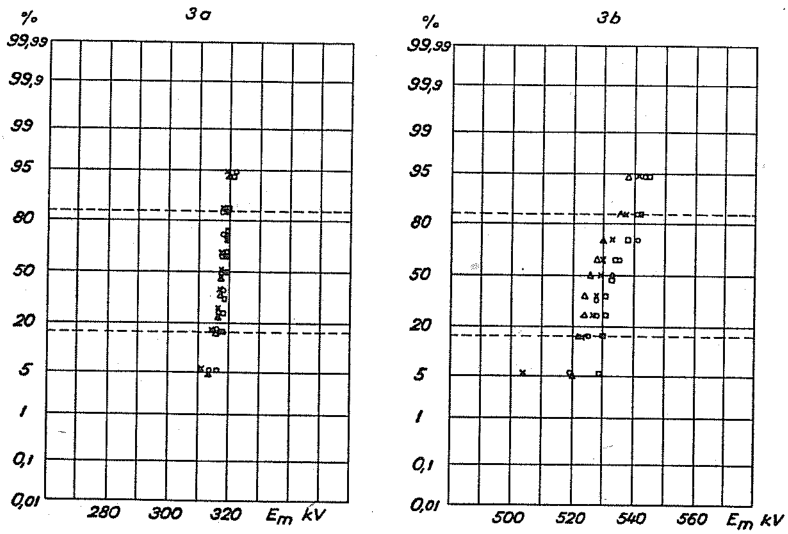

FIG. 3.—Vertical insulator, 50 % flashover voltage. Values obtained from the present report.

x Free arrangement: $C_B = 800$ pF;
o Earthed plates: $C_B = 800$ pF;
Δ Free arrangement: $C_B = 200$ pF.
□ Earthed plates: $C_B = 200$ pF.

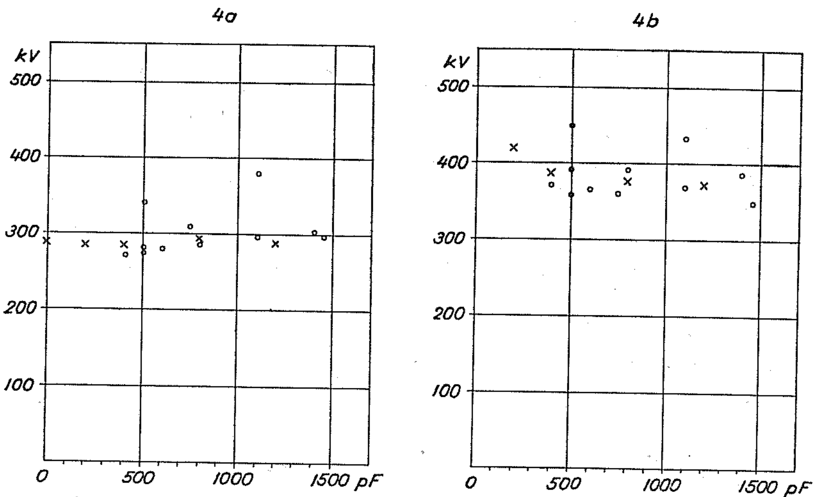

FIG. 4. — Horizontal rod-gap 450 mm, 50 % flashover voltage.

x Values obtained from this report;
o Values obtained from C.I.G.R.E.-report 326/1956.

percent) or inaccuracies due to the correction for humidity, etc., would extend D to say 5-6 %. This is still acceptable from an engineering point of view. However, when studying table II it is found that the results from C.I.G.R.E.-report 326/1956 both polarities and the present report for rod-gap negative polarity differ within a far larger range (i.e. $D = 20\text{-}25$ %).

The reasons for these large discrepancies could be due to one or more of the following factors:—

1. Errors in measurement of voltage far larger than assumed;
2. Excessive inaccuracy of excisting correction factors for air density and humidity;
3. Some mechanical feature of the gap (sharp edges, etc.);
4. Greater influence from the surroundings than expected;
5. Irradiation factors;
6. Excessive influence from dimensioning of the impulse circuit;
7. "Unknown" factors.

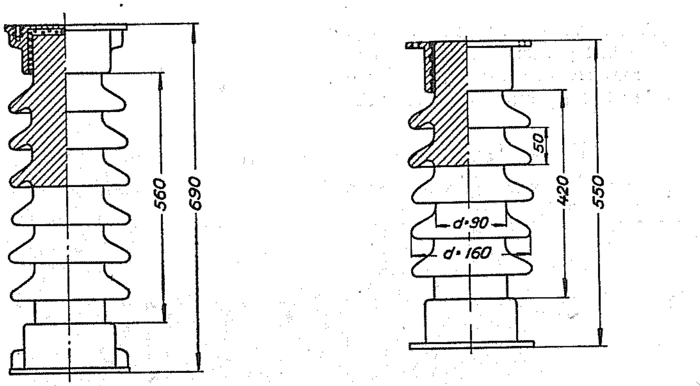

Fig. 5. — Insulator test objects.

Insulator used for negative impulse test. Insulator used for positive impulse test.

When considering these factors a reference is made to *figures* 2-4.

(a) *Rod-gap positive polarity.*

Figures 2 *a* shows a systematic influence from the surroundings reaching about 3 %. However, as the screens were placed very near the test object their influence was quite exaggerated and hence the uncertainty reported in C.I.G.R.E.-report 326/1956 cannot be due to this factor. (Results from C.I.G.R.E.-report 326-1956 are also reproduced in *figure* 2 *a*.) The influence from dimensioning of the impulse circuit is almost negligible as can be seen from both *figures* 2 and 4.

The conditions of the air and the natural irradiation have of course varied unsystematically during the period of testing but still the values have been quite stable. From these observations one is justified in eliminating a number of the above mentioned factors and consequently only factor 1, excessive inacccuracy in the measurement of voltage, 3, mechanical feature of the gap and 7 "unknown" factors remain.

Referring again to C.I.G.R.E.-report 326/1956 it can be seen that the highest observation could perhaps be regarded as "outlying". However, even if this is eliminated the resulting D-value of 16 % is still far too high to be tolerated.

(b) *Rod-gap negative polarity.*

The picture obtained from *figures* 2 *b* and 4 *b* in this report is quite confusing. The results could be stated as a peculiar yet systematic excessive influence from surroundings and from capacitor. It cannot be assumed to be excessive errors in the measurement of negative voltages as the insulators tested over the same voltage range gave much more stable results, *figure* 3 *b*.

When comparing with C.I.G.R.E.-report 326-1956 it could be argued that his two highest values are "outlying". However, two outlying observations in a series of 14 is highly improbable.

(c) *Insulator both polarities.*

The insulators for both polarities were very stable and showed very little influence from surroundings and dimensioning of impulse circuit, *figures* 3 *a-b*. It is interesting to note that the lowest value for negative polarity (considered outlying?) was the first in the series of tests.

CONCLUSIONS

In conclusion it may be said that the report for rod-gaps positive polarity (and insulators both polarities) shows much more stable results than the C.I.G.R.E.-report. It is difficult to discuss the reason for the larger discrepancies of the C.I.G.R.E.-report. Apparently the influence of the surroundings and dimensioning of impulse circuit can be eliminated from the discussion. Further, as the tests in the present report were carried out over a relatively long period of time, with varying conditions of air and irradiation, it is possible that these factors (if it is assumed that the conditions for the participant laboratories have not varied within a large range) could also be eliminated. BERGER made no correction for humidity as this did not improve the results.

It is unlikely that some mechanical feature of the rod-gap (edges etc). appreciably affects the results as the rod-gap in itself has a very distorted field.

Consequently if the above conclusions are correct the errors must be due either to the measurement of voltage, or to some factors yet unknown. It is difficult to vouch for the accuracy of impulse voltage measurements. However, through long experience of checking between the results form different measuring devices, a number of sources of inaccuracy, in the measurement (and also in the generation) of impulse voltages, have been revealed [5]. Examples of such sources of error are sensitivity to the surroundings of low capacitance dividers, temperature drift in sealed off oscillographs sometimes in the tube itself, *LC*-oscillations in the leads connecting the calibrating sphere gap to the test specimen, disturbances in the earth system, etc.

BERGER's measurements of the flashover voltage between spheres show good agreement. However, in this test the participant laboratories knew the I.E.C.-flashover values for sphere gaps. If a relatively large difference had been obtained between the I.E.C.-values and those measured, during a certain test series, the laboratory in question would probably have regarded the observation as outlying and after investigating the measuring circuit, repeated the test. On rod-gaps, however, the results were not known beforehand and such an elimination of "obvious" mistakes has not been done.

Unknown factors are for instance the uncertain range of flashover for a rod-gap, e.g. a range where the rod-gap flashover voltage can follow either of two different flashover mechanisms. Such distorsion areas have been reported in literature [6]. STRIGEL, for instance, has shown in a figure on page 265 [6] such distortion areas for both positive and negative polarity. For positive polarity this area occurs at a rod-gap distance less than 250 mm, whereas for negative polarity the distortion area occurs around 450 mm. The above mentioned uncertain range for a rod-gap may thus explain the discrepancies for negative polarity in BERGER's and the present report. The discrepancies for positive polarity in BERGER's report, however, still remain unexplained.

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[5] HYLTÉN-CAVALLIUS, N., Impulse tests and measuring errors. *A.S.E.A. Journal*, No. 5, 1957.

[6] STRIGEL, R., *Elektrische Stossfestigkeit*, 2nd edition, Berlin-Göttingen-Heidelberg, 1955.

ANNEXE II

PROCEDURE FOR THE DETERMINATION OF THE ERRORS OF MEASURING-CIRCUITS FOR IMPULSE VOLTAGES

by

Muzaffer ÖZKAYA, Dr. Herbert BAATZ, Prof. Dr. Helmuth BÖCKER

(Germany)

The comparative measurements of breakdown voltages of sphere gaps carried out by the C.I.G.R.E. study group No. 8 give a good agreement between the 50 % impulse sparkover voltages measured in different laboratories, but the impulse characteristics differ widely for sparkover times of less than 1 µs. This result prompted a search for a simple calibration procedure for voltage dividers. A theoretical examination of the possible errors of dividers with rectangular waveforms had already been carried out at the inception of impulse voltage techniques [1, 2]. Compensated resistance dividers had been developed [3]. However, it is only recently that methods of measuring the error have been specified. ROMANO [4] measures the frequency response characteristic of the divider, where as HYLTÉN-CAVALLIUS [5] uses a rectangular impulse method. Both these authors use low voltages and amplifiers. The method described here also employs rectangular impulses, but uses high voltages, so that no additoonal measuring equipment is required and the procedure is in line with the usual measuring technique using impulse voltages. Instead of the

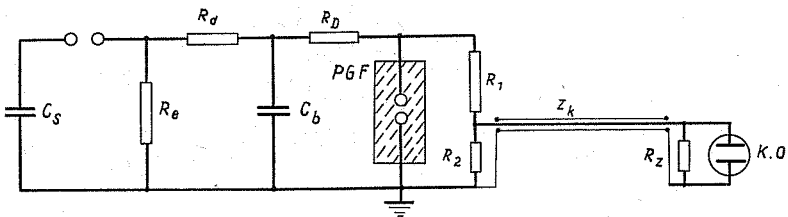

FIG. 1.—Circuit arrangement for calibration of voltage divider.

test object, however, a sphere gap is enclosed in a compressed gas atmosphere. The gap sparks over only when the peak value of the impulse voltage is reached. If the pressure is increased by a factor n, the sparkover voltage becomes n times greater and the duration of the chopping n times shorter. For a 1-cm gap at atmospheric pressure the sparkover voltage is 30 kV and the chopping duration is 30 ns, while at 15 atmospheres these figures become 450 kV and 2 ns respectively. Such a short duration of voltage collapse can be regarded as providing an adequately rectangular pulse for testing dividers. *Figure* 1 shows the impulse and measuring circuit with the pressurized spark gap. In general, a voltage divider with its capacities and with the inductance

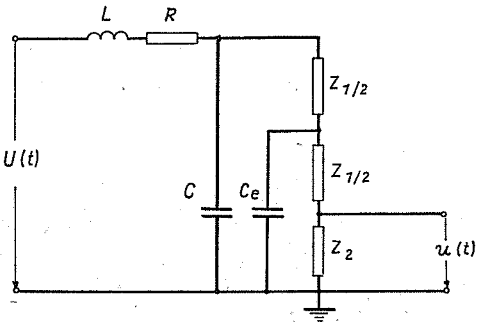

FIG. 2.—Fundamental circuit diagram of the total measuring arrangement.

and capacity of the leads to the point of measurement can be represented by the circuit diagram shown in *figure* 2. In this circuit the impedances Z_1 and Z_2 forming the divider can consist of resistances, capacities or a combination thereof. The measuring system consists of the divider proper with the impedances Z_1 and Z_2, together with the inductance and capacity of the leads and the input

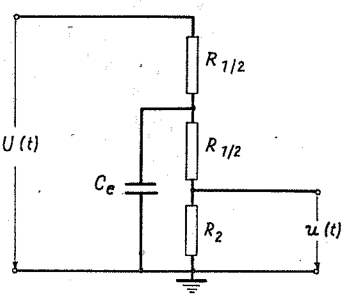

FIG. 3.—Fundamental circuit diagram of the resistive voltage divider.

capacity of the divider. This connection lead to the system being measured cannot always be avoided. Dividers comprising pure resistances should be correctly adjusted, so that they have no additional capacity C_e, which would give rise to errors in measurement. Such and accurate compensation of the divider will not always be possible, however.

The purely ohmic divider having the equivalent circuit shown in *figure* 3 will reproduce a rectangular impulse as an exponential

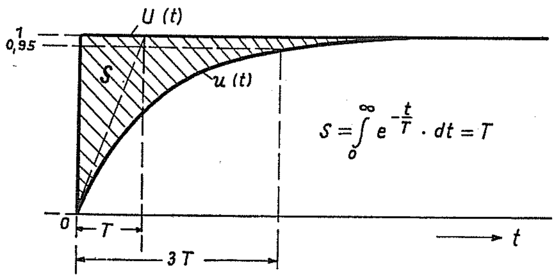

FIG. 4.—*RC*-response of a rectangular wave by resistive voltage divider.

waveform (*figure* 4) on account of the capacity C_e. That is to say:—

$$u(t) \approx uU_0\left(1 - e^{-\frac{t}{T}}\right),$$

where $T = \frac{R_1 C_e}{4}$ and u is the transformation ratio for D.C.

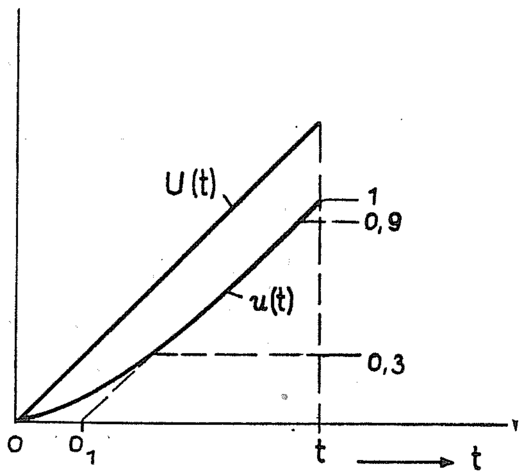

FIG. 5.—*RC*-response of a linear rising front wave by resistive voltage divider.

The error arising at time t is $F = 100\ e^{-\frac{t}{T}}$ in percentage. The time costant T can be determined from:—

1. The tangent at the starting point;
2. The shaded area S, which can be measured;

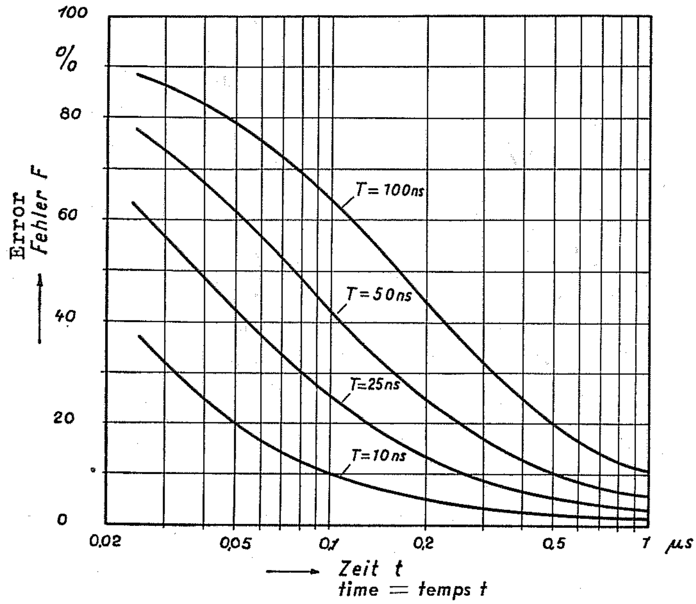

FIG. 6.—Error curves of linear rising front waves by *RC*-response. Time constant T of divider as parameter

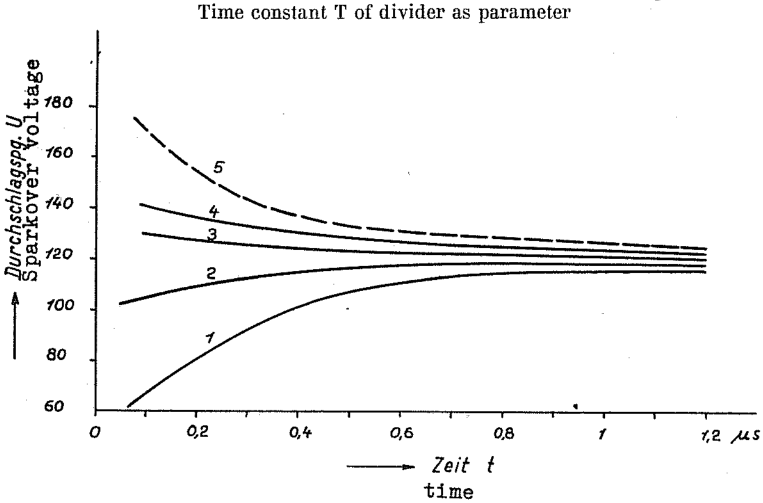

FIG. 7.—Sparkover voltage of a 15 cm-sphere gap with 4 cm distance. measurement by different resistive voltage dividers.

1. $R = 30$ kΩ $T = 100$ ns.
2. $R = 30$ kΩ $T = 50$ ns shielded.
3. $R = 13$ kΩ $T = 25$ ns.
4. $R = 5$ Ω $T = 14$ ns.
5. Corrected test results of the curves 1 to 4.

3. The time 3 T to the point where the exponential curve rises to 95 % of the final value.

It is suitable to take the area S according to 2, or simpler the time 3 T according to 3. In this way possible departures from the true RC form are compensated. The following time constants have been determined for purely ohmic voltage dividers:—

Resistance (kΩ)	Length (cm)	Time constant T (ns)	Capacity C_e (pF)
30	150	100	13.3
30	150	50	6.7 with a shielding ring on the head
13	65	25	7.7
5	50	14	11.2

In order to determine the impulse characteristics when sparkover occurs on the front of the impulse, triangular waveforms are generally used. For this the measured voltage waveform (*fig.* 5) is:—

$$u(t) = uSt\left[1 - \frac{T}{t}\left(1 - e^{-\frac{t}{T}}\right)\right],$$

where S is the slope of the triangular waveform.

The following value is obtained for the amplitude error at the time t

$$F = 100\,\frac{T}{t}\left(1 - e^{-\frac{t}{T}}\right), \text{ expressed in percentage.}$$

It is thus independent of the steepness of the front, and is represented in *figure* 6 for different values of the time constant T of the divider. The amplitude error depends on the time t. If t is measured, as laid down by the I.E.C., from the conventional zero 0_1 as shown in *figure* 6, an additional error arises. This error becomes larger as the time constant of the divider increases, and gives higher values of voltage, since the measured value of t is too small. For this reason the true starting point 0 of the voltage impulse must be determined, so that correct values will be obtained. With triangular waveforms the relative error in time is equal to the relative error in amplitude for values of time exceeding the time constant of the divider.

The lead connecting the object being mesured to the divider and its input capacity form an oscillatory circuit, as shown in *figure* 2, which also affects the results of the measurement. This error is dependent on the phase and amplitude of the oscillation. Care should therefore be taken that the natural frequency of this circuit is as high as possible. Within certan limits the oscillation can also be damped if it is troublesome.

The correction procedure described was used with the four dividers specified above to determine the impulse characteristic of a sphere gap shown in *figure* 7. Even in the case of the divider fitted with the 5-kΩ resistance a considerable correction was required for short sparkover times. For this reason a check and calibration should be made of every divider, if voltages are to be measured on the front of impulse waveforms.

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ANNEXE III

FACTORS INFLUENCING THE SPARKOVER VOLTAGE OF ASYMETRICALLY CONNECTED SPHERE GAPS

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Summary Report on *A.I.E.E. Transactions*, Vol. 76, pt. I, 1957 (July 1957 section of Communications and Electronics, paper 57-20, p. 307-316).

The sphere gap is widely used as a method of measuring high voltage. Its acceptances as a standard is based on extensive calibration of the breakdown of air as a dielectric between spheres of specific sizes and spacings. The A.I.E.E. Standards No. 4 [1] states that the accuracy of measurement for spheres used according to certain recommendations will be within $\pm 3\ \%$ of the tabulated values. These recommendations pertain to the sphere and sphere frame construction, gap irradiation, corrections for relative air density and precautions

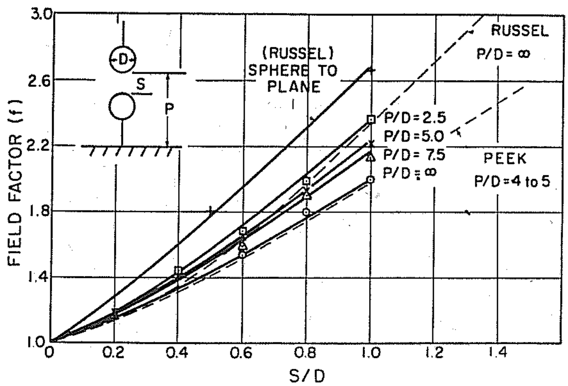

FIG. 1.—Field Factors.

concerning external fields and ground effects. These precautions in themselves, however, are not enough to hold the accuracy of the sphere to the limits stated.

To understand how individual influences contribute to the sparkover voltages of sphere gaps it is necessary to knwo how they affect the voltage distribution in the space between the spheres and particularly

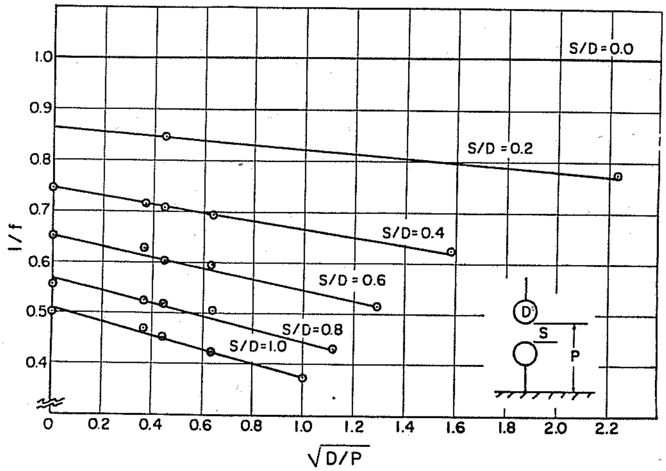

FIG. 2.—Linear relation between factor and sphere-gap geometry.

how they affect the regions which are stressed the highest. The field factor or ratio of the maximum stress to the average stress in the space

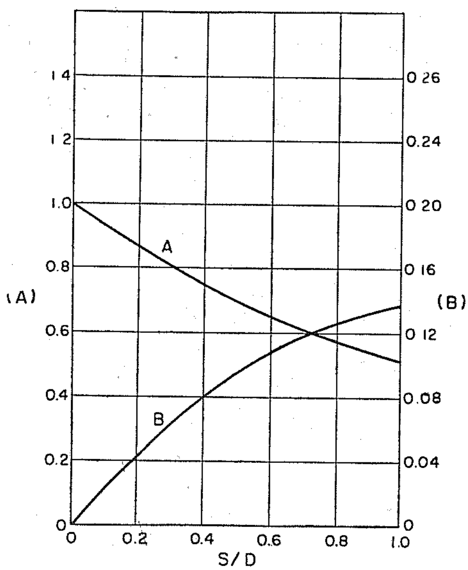

FIG. 3.—Variations of parameters in equation for the field factor:—

$$\frac{l}{f} = A - B \left(\frac{D}{P}\right)^{\frac{1}{2}}$$

between the spheres is a measure of this distortion. The field factor for isolated spheres can be calculated but the effects of leads and nearby grounded objects which are present during impulse and sixty-cycle tests cannot be calculated accurately. Because of this a two dimensional electrolytic field analyzer was employed to determine the field factor. Whit the analyzer the effect on the field factor of certain physical parameters such as shank size (d), sphere diameter (D), gap spacing (S) and distance from sparking point to horizontal

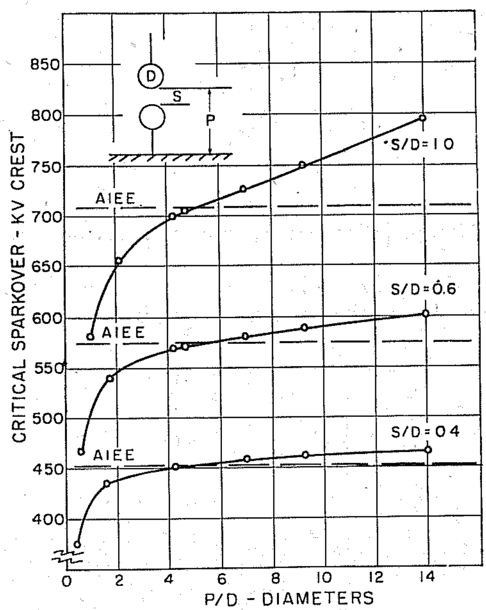

FIG. 4.—Sparkover voltages as function of distance to horizontal ground plane, 50 cm spheres.

ground plane (P) were determined for vertically-mounted asymmetrically-connected sphere gaps. In *figure* 1 the field factors (f) versus the ratios of gap spacing to the sphere diameter (S/D) are plotted, with P/D as a parameter.

It was noted that, when the reciprocal of the field factor versus $(D/P)^{1/2}$ was plotted, a family of straight lines were obtained with S/D as the parameter. From the family of lines, shown in *figure* 2, the equation:—

$$\frac{1}{f} = A - B\left(\frac{D}{P}\right)^{\frac{1}{2}}$$

was derived. The values of the parameters A and B for various gap spacings are plotted in *figure* 3.

To determine how well high voltage sparkover tests would correlate with analyzer results, negative 1.5 + 40 μs impulse critical sparkover tests were made on a set of 50 cm sphere gaps in a relatively large test area so as to minimize all influences except for the horizontal ground. The results of these tests are plotted in *figure* 4 with the various distances given in diameters. From the curves it will be noted that

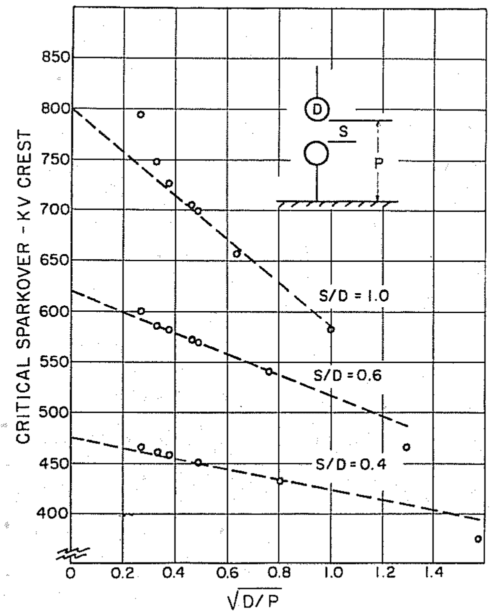

FIG. 5.—Comparison of variation of sparkover voltages and field factors for 50 cm spheres.

the sparkover voltage increases with increasing distances to the horizontal ground plane. The field factors obtained by the analyzer had indicated that an increase would be obtained; i.e., as the field factor for a particular spacing is decreased the sparkover voltage will increase. If this voltage increase is directly proportional to the reciprocal of the field factor, the critical sparkover gradient for a given sphere diameter and gap spacing must be constant and the sparkover curves for various values of $(D/P)^{1/2}$ should be straight lines. These lines should also have the same slopes as were obtained in *figure* 2. In *figure* 5 the various critical sparkover voltages are plotted versus $(D/P)^{1/2}$. The date follow fairly well the straight dashed lines which have been drawn with the same slope as the corresponding S/D lines of *figure* 2 indicating good agreement between the high voltage and analyzer measurements. As will be noted at the larger distances to the ground plane, sparkover voltages higher than the predicted ones resulted, which indicated additional influences. This variation was found to be caused by the influence of the impulse generator. *Figure* 6 presents data which shows the influence of the generator proximity on the sparkover voltages of 50 cm spheres for

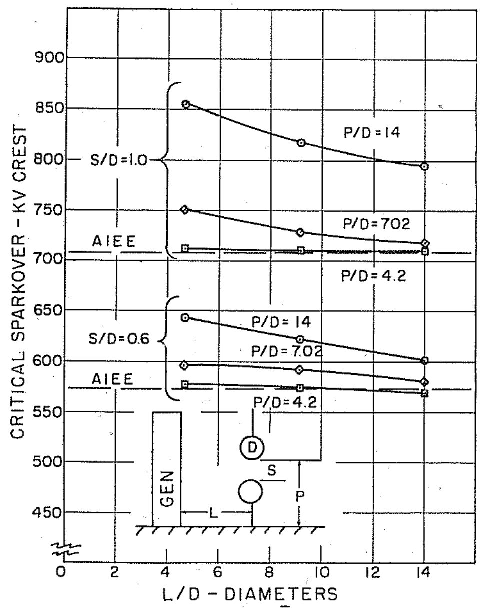

FIG. 6.—Sparkover voltages as function of distance from impulse generator, 50 cm spheres.

various distances to the horizontal ground at gap spacings of 1.0 and 0.6 diameters. The curves show that when the spheres are used at about the minimum distance to ground recommended in the standards the generator influence is slight, but as the spheres are used at greater distances from the horizontal ground the generator influence becomes more pronounced.

The influences of shank size, vertical ground plane, and vertical resistance divider are also discussed in the paper. Also the variation of the sparkover voltage of 100 cm spheres as influenced by the horizontal ground plane and impulse generator are presented.

Table I presents a summary of the ground and impulse generator influences showing the deviation of the sparkover voltages from the values listed in the standard table. The first column lists the sphere size under consideration, the second and third columns the distance in diameters to the horizontal ground and impulse generator respec-

TABLE I.

Summary of relative influences.

Sphere Size	P/D	L/D	Percent deviation in sparkover voltage from those given in the Standards' Table			
			$S/D = 1.0$	$S/D = 0.8$	$S/D = 0.6$	$S/D = 0.4$
50	5	14 (1)	0	»	0	0
50	10	14 (1)	+ 6.9	»	+ 2.6	+ 2.2
50	5	4.5 (1)	+ 2.1	»	+ 1.4	»
50	10	4.5 (1)	+ 12.4	»	+ 7.8	»
50	5	5 (2)	— 2.3	»	— 0.8	»
100	4.2	7 (1)	+ 2.0	+ 1.0	+ 0.7	— 0.8
100	10	9 (1)	+ 16.6	+ 15.9	+ 12.5	+ 5.5
100	3.7	2.25(1)	»	»	+ 2.9	»

A.I.E.E. Standard No. 4 precautionary remarks: distance to external electric high voltage fields, $L > 2$ diameters; distance to ground, 5 to 10 diameters for 50 cm and smaller spheres, down to 2.5 diameters for 200 cm spheres.

(1) L = distance to the generator.

(2) L = distance to vertical ground plane.

tively and the remaining columns the deviations from the values listed in the standards for various gap spacings. These deviations in sparkover voltages have resulted even though the spheres were used within the recommended limits of distances to surrounding objects

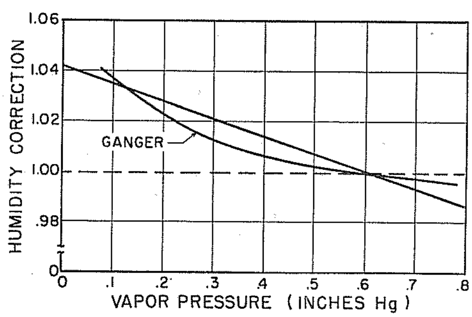

FIG. 7.—Humidity correction factors.

that affect the field of the gap. This is particularly true for spacings in excess of 0.6 diameters.

In general, it is indicated that the sparking point of the high voltage sphere should be in the range from 3 to 5 diameters above ground for 50 cm and larger spheres, and distances to other grounds should be of the same order or greater. The distance to high voltage carrying parts should be in excess of these distances to minimize the deviation in sparkover voltages from those given in the tables.

The sparkover data presented in the paper were obtained at two different periods, six months apart, when the humidity was quite different. It was noted that in some cases there was as much as a 3 % difference between sparkover voltages corrected for relative air density when the test conditions were identical except for rather large differences in vapor pressure. In *figure* 7 is a humidity correction curve arrived at from the data as well as data presented by Gänger [2] which he found applied as vapor pressure corrections for uniform field gap sparkovers.

The results of this investigation show that the sphere gap will not have accuracies within ± 3 % when used according to recommendations in the standards pertaining to grounds and external fields. However, if these influences are properly recognized and the spheres used wihin more closely defined limits the attainable accuracy could be even better than ± 3 %.

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