CIRCULAR-DISTRIBUTION OF CORONA CURRENT OF MULTIPLE-CONDUCTORS TRANSMISSION LINE (Ⅲ)

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(1) Introduction

The auther discussed the following points the papers titled "Circular-Distribution of Corona Current of the Multiple Conductors Transmission Line (Ⅰ) (Ⅱ)". (1) (2) Bulletin of Nagoya Institute of Technology, vol 15 (1963), 16(1964) : In the part (Ⅰ), the characteristics of circular distribution on the multiple-conductor transmission-line and the values of θm under the various conditions were discussed. In the part (Ⅱ), shielding effect of the corona current on the double conductor was simulated by combination of a brass wire and solid P.V.C. insulation or a string of solid insulator of the same diameter.

This report comprises

(1) the measurements of circular distribution of D.C. positive and negative corona current on double-conductor under various pressure (Several tens mm Hg to 760 mm Hg)

(2) distribution of the corona current on the multiple-conductor of transmission line was presumed by comparing D.C. component in A.C. corona current with the deduction of D.C. positive and negative corona current.

For this purpose, a special air-sealed coaxial cylindrical-electrode was used to provide from low to high pressure (1 to 10 kg/cm^2. abs.) conditions.

The series of measurements under high pressure (1~10kg/cm^2. abs.) of various gases such as N_2, Co_2, CCl_4, CCl_2F_2 and SF_6 will be made succeedingly.

(2) Apparatus and Method of Measurement

Fig. 1—A shows the outline of the air-sealed coaxial cylindrical-electrode and measuring circuit. This cylindrical-electrode consists of a brass cylinders havine outside-diameters of 15 and 20 cm and inlaid bushings at the both ends. The length of the apparatus is 120

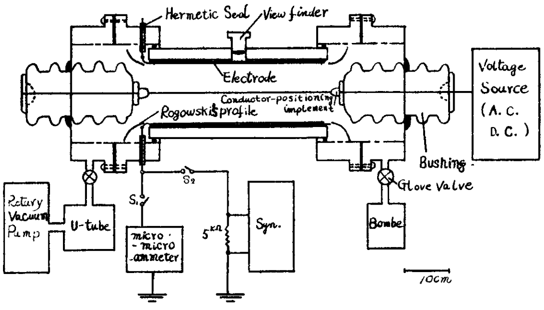

Fig 1—A　Schematic diagram of experimental Apparatus

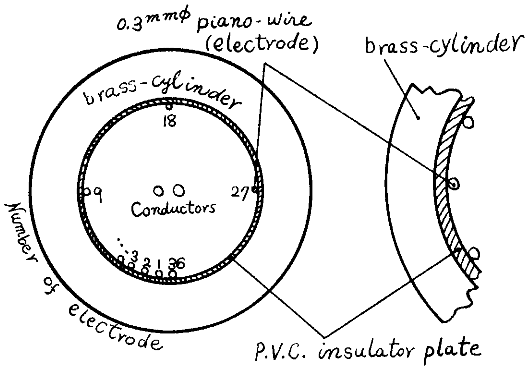

Fig 1—B　Disposition of electrodes and conductors

cm and the volume 4 litre. The inside of the center part of the cylinder (10 cm in diameter) is lined with P.V.C. sheet of 0.5mm thickness in the axial length of 30 cm as shown in Fig. 1—B. On this plate, 36 cuts of piano-wires of 0.3mm diameter and 28cm length are arranged on the equally spaced positions. They are used as segmental electrode. The terminal is lead out through hermetically sealed bushings.

The ends of the electrodes are shaped to Rogowski's profile to prevent distortion of field. The adjustable conductor-positioning implements are equipped at the end of the both bushings to provide conductor arrangement having various m/d. The valve in the left is connected to a U-manometer and a rotary vacuum pump, the valve in the right, to gas-bombes. At the center of the apparatus, a view-finder of 2cm diameter is equipped to make visual corona observation.

In this report, the measurements on the conditions $N=2$, m/d=10 and the varying pressure of 760mm Hg to several tens mm Hg.

where N : number of conductor,

m : distance between two conductors in cm,

d : diameter of conductor in cm.

Measurements of distribution of corona current were made in the same procedure for Report (I), (II).

(3) Circular-distribution of D.C. corona current on double conductors under various pressures.

3—1 : Characteristic of corona starting voltage under various pressures.

Fig. 2 shows the relation between pressure and corona starting voltage. Applying test voltage with the increasing rate of 400 volt/sec, the voltage between both ends of series resistance (5 kΩ) which represents whole corona current were measured by using an oscilloscope (Iwasaki-type SS-5156).

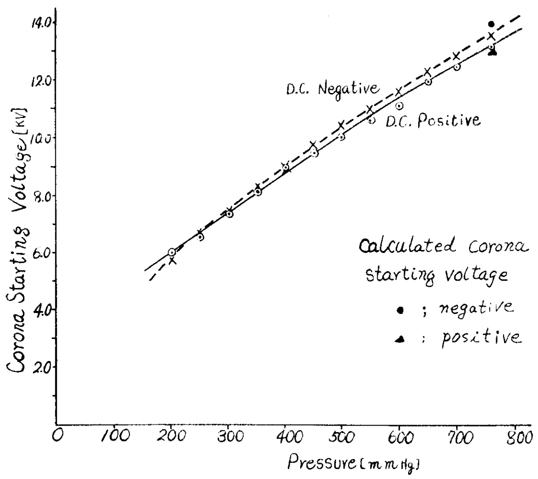

Fig 2 Characteristics of pressures—corona starting voatage.
$N=2$ m/d=10

The equation to calculate corona starting voltage of double conductors in transmission line given by Wagner(3), can be transformed into the following equation by applying the constants obtained by Watson and Whitehead(4) for coaxial cylindrical electrode.

For D.C. positive (applying the constant by Watson)

$$E_2\oplus=\frac{33.7m_0m_1\delta(1+\frac{0.214}{\sqrt{\delta r}})r\ \log e\frac{R^2}{r^2}}{1+2\frac{r}{m}\sin\frac{\pi}{2}}\quad (\mathrm{kV})$$

For D.C. negative (applying the constant by Whitehead)

$$E_2\ominus=\frac{31.0m_0m_1\delta(1+\frac{0.308}{\sqrt{r\delta}})r\ \log e\frac{R^2}{r^2}}{1+2\frac{r}{m}\sin\frac{\pi}{2}}\quad (\mathrm{kV})$$

where r : radius of conductor in cm

m : distance between conductors in cm

R : radius of coaxial cylindrical electrode in cm

m_0: coefficent for conductor surface condition

m_1: coefficent for weather,

δ : relative air density.

Applying the calculated condition to the above equation, corona starting voltage is obtained as follows :

$E_2\ominus=13.8\mathrm{kV}$ $\qquad E_2\oplus=13.1\mathrm{kV}$

These values almost agree with the values obtained through the measurements.

As seen in Fig.2, corona starting voltage with D.C. negative is higher than D.C. positive under the pressure above 250mm Hg while the relation is reversed below 250mm Hg. This phenomenon was also reported as the results of the measurements by F.W. Bandel[5], too.

3—2 : Circular-distribution of D.C. positive corona current on double conductors under various pressure.

Fig. 3—A shows circular distribution of D.C. positive corona current in which constant D.C. positive 14kV was applied

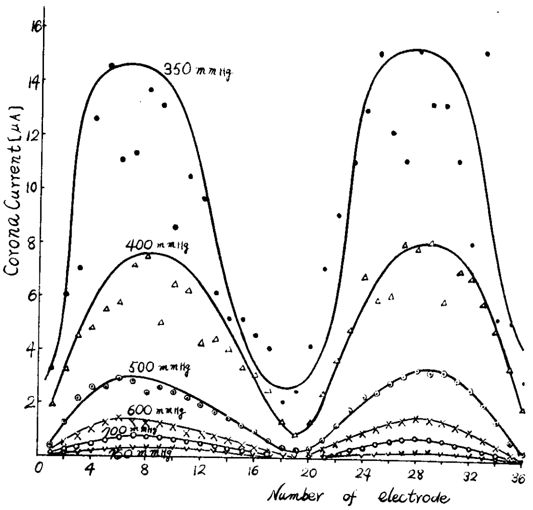

Fig 3—A Circular distribution curves of D.C. positive corona current from the double conductors.
D.C. positive 14KV constant
$N=2$ m/d=10

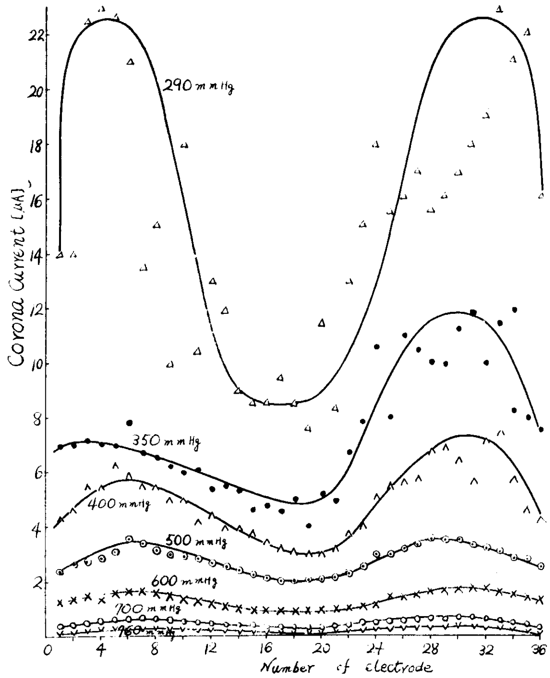

Fig 3—B Circular distribution curves of D.C. negative corona current from the double conductors.
D.C. negative 14KV constant,
$N=2$, m/d=10

to conductors and the pressure was varied from 760mm Hg to 350mm Hg.

In Fig 3—A, the abscissa gives numbers of electrodes on the cylinder and the ordinate gives corona current into each segmental electrodes.

Between 760mm Hg and 450mm Hg, corona current distribution has clear and sharp directionality and symetricity.

On the other hand, Fig. 4—A gives the directional circular distribution of D.C. positive corona current under varying pressure keeping total corona currtent at 20μA constant. The lower the pressure, the lower the maximum corona current (in electrode No. 8 and 27) and the higher the minimum corona current (in electrode No. 1 and 18) were obtained. The sharpnesses of the directional distribution becomes dull according to lowering the pressure, while still remains down to 70mm Hg as shown Fig. 4—A

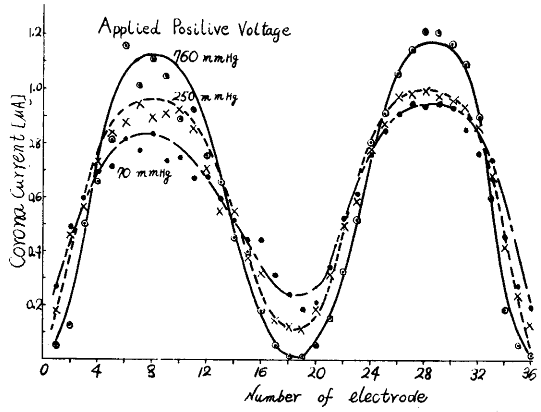

Fig 4—A Circular distribution curves of D.C. positive corona current from the double conductors.
total corona current=20μA constant
N=2, m/d=10

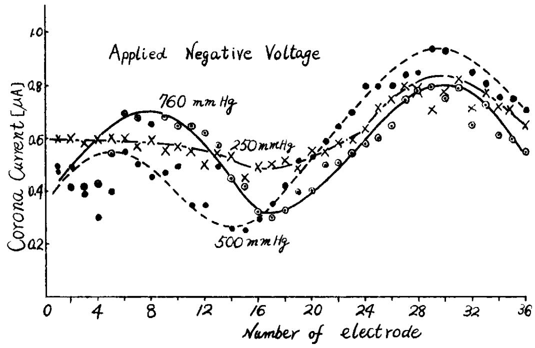

Fig 4—B Circular distribution curves of D.C. negative corona current from the double conductors.
total corona current=20μA constant
N=2, m/d=10

3—3 : Circular distribution of negative corona current on the double conductors under various pressure.

Fig. 3—B shows circular distribution of negative corona current on double conductors under the applied D.C. negative voltage of 14kV for the parameter of pressure. Near an atomospheric pressure, the distribution has directionality but it is not so remarkably as those of positive corona current. We consider this is because that an unstable Trichels, pulse corona are formed at the part of conductor surface having maximum gradient. The distribution has directionality near 290mm Hg, but considerable numbers of measured points are not in regularity. Thus, as shown in Fig. 3—B, in the case of negative, the sharpness and symmetricity of corona current are less remarkable than that of positive corona current in Fig. 3—A.

On the one hand, Fig 4—B gives circular distribution of D.C. negative corona current for the parameter of pressure at total corona current 20μA constant. As shown in this figure the directional distribution of corona current is not remarkable at low pressure (about 450 mm Hg) and these curves considerably differ from the curves of distribution of D.C. positive corona current shown in Fig. 4—A.

3—4 : Effective range of multiple conductors under various pressure.

It is interesting that in circular distribution of positive and negative corona current, maximum (I *max.*) and minimum (I *min.*) values of corona current were obtained for various pressure. In case that D. C. voltage of 14kV was applied, positive corona current increases keeping directional distribution according as the pressure decreases, but both I *max.* and I *m.n.* values suddenly increase at about 450mm Hg and the directionality was losen.

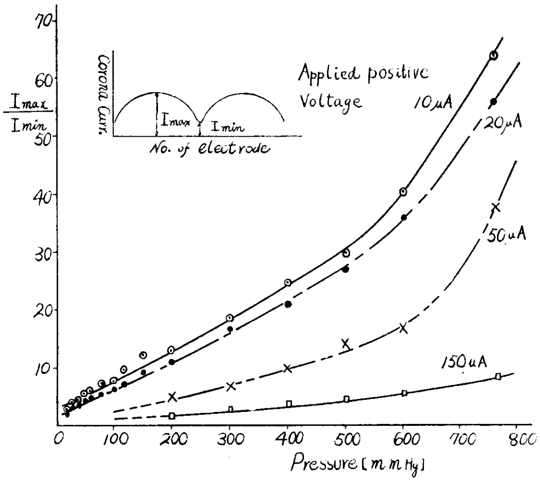

Fig 5—A Characteristics of I_{max}/I_{min}— Pressures.
$N=2$, m/d=10

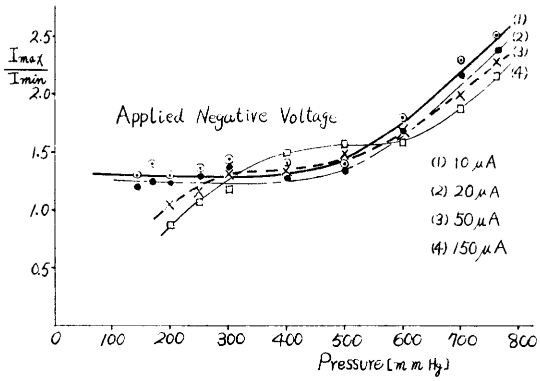

Fig 5—B Characteristics of I_{max}/I_{min}— Pressures.
$N=2$, m/d=10

On the otheo hand, Fig. 5—A, B give characteristic I *max.*/I *min.* of D.C positive and negative corona current under various pressure keeping the total corona current at 20μ A constant.

At positive corona current, Fig 5—A, the directionality is remarkable down to and effectiveness of multiple conductor arrangement is found to considerable low pressure, around 20mm Hg.

In negative corona current, Fig 5—B, effectiveness of multiple conductors is clear above 600mm Hg and somewhat noticed from 600mm Hg to 250mm Hg but cannot be expected below 250mm Hg.

3—5 : Relation between θm and pressure.

Since the gradient of electrical field on multiple conductor suface varies like a sinsoidal wave, the corona carrent differs at every point arround the conductor. Thus, effective gradient is used for approximate calaculation of total corona loss of conductor.

F. Cahen[6] gave the effective gradient by the following equation :

$$E_{eq}=\frac{E\ \max+E\ \text{mean}}{2}$$

$$E_{eq}=E_{\theta m=60^\circ}$$

Here E_{eq} is effective gradient, and $E_{\theta m}$ is field intensity at P of Fig 6

Sato[7] confirmed that corona loss of $\theta m=80^\circ\sim70^\circ$ agree with the mean value obtained through the experiments and the theoretical calaculation. Hirrano and Isobe[8] advacated $\theta m=65^\circ$ making a farther step on Sato's theory. One of the auther has already discussed in

Report (I)[9] that θ_m were obtained through the measurement of distribution of positive and negative corona current on double conductors, these differed depending on ratio m/d, and θ_m was arround 60° in case of m/d=10.

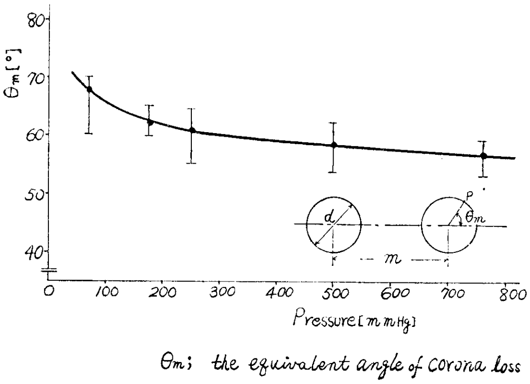

Fig 6 Characteristic of θ_m—Pressures.
D.C. Positive, N=2, m/d=10

Fig. 6 shows θ_m which were calaculated from the distribution of corona current for variable pressure. From the figure, it is clear that θ_m is the function of not only m/d but also pressure. θ_m is arround 60° at 760mm Hg, but come arround 70° at 70mm Hg, spreading wider according as pressure decreases.

(4) Circular-distribution of A.C. corona current (D.C. component) on double conductors under various pressures.

In case of A.C. corona, corona current corresponding to the polarity of every half cycle is produced and therefore circular-distribution of A.C. corona current (D.C. component) can be explained by surperpoisng the distribution of positive and negative corona current as mentioned above.

This time, A.C. corona current (D.C. component) is measured by inserting a condenser of 20 μ F parallel to micro-micro-ammeter.

The arrangements for measurements are same as in above (3).

4—1 : Characteristic of total corona current (D.C. component)-voltage for various pressures. Sato[10] and Imanishi[11] reported recitfied current resulting from D. C. component in corona currnent under application of A.C. voltage and the authers reported the same characteristics of corona current on double conductors under the atomosphere.[12] Fig. 7 shows characterstics of total corona current (D.C. componet)-voltage for various pressure (760mm Hg~80mm Hg). When increasing the voltage with a increment of 400 volt/sec, D.C. positive component of corona current starts by rectifier action, then it turns over negative component through maximum value according to increase of applied voltage. The maximum values of positive component of cnrona corrent vary with pressure and the maximum point is (0.6μ A) around 300mm Hg.

Same conclusion is obtained by deduction of D.C. positive and negative corona current at various pressure when D.C. test voltage is applied to conductors. This relation is not showed in the figure.

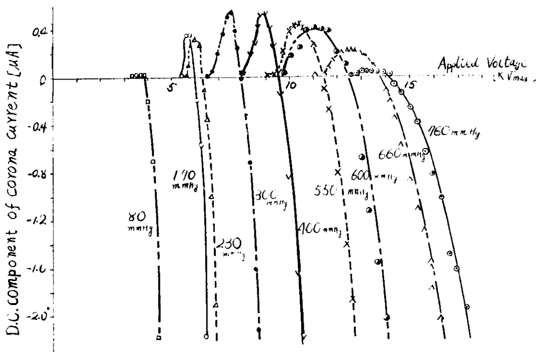

Fig 7 Characteristics of V—I (D.C. component).
Applied A.C. Voltage
$N=2$, m/d=10

4—2 : A comparison between A.C. corona current (D.C. component) and deduction of D.C. positive and negative corona current.

Fig. 8—A shows the distribution of A.C. corona current (D.C. component) when total corona current is constantly 5μ A at various pressure. For A.C. corona current (D.C. component) the directional distribution is clearly noticed as shown in Fig. 8—A. With decreasing of pressure, I_{max} decreases and I_{min} increased as same as in case of D.C. corona current, and these distributions becomes flat curve as in case of D.C. corona current.

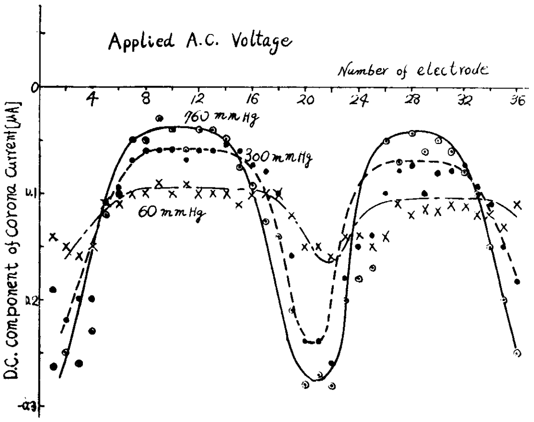

Fig 8—A Circular distribution curves of A.C. corona current (D.C. component) from the double conductors.
total corona current=5 μA constant
$N=2$, m/d=10

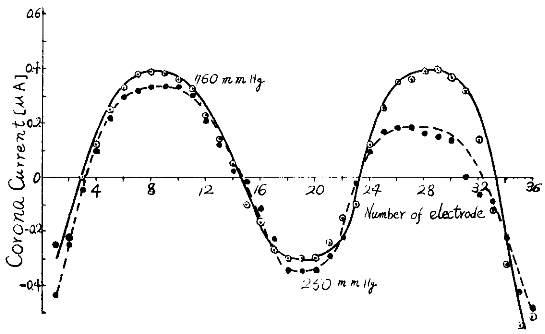

Fig 8—B Circular distribution curves of [D.C. positive corona current+D.C. negative corona current] from the double conductors.
total corona current=20μA constant
$N=2$, m/d=10

On the one hand, Fig.8—B shows deduction of D.C. positive and negative corona current. Comparing Fig. 8—A with Fig. 8—B, it is noticed that A.C. corona current and deduction of positive and negative corona current is not exactly same. However, identical tendency of the distributions is observed for both A.C. corona current (D.C. component) and deduction of positive and negative corona current, so that the distribution of A.C. corona current might be presumed by superposing distributions of D.C. positive and negative corona current as above.

Fig. 9 shows the values of A.C. corona current (I_{max}, I_{min}) at various pressure, the directional distributhion is not noticed at pressure below 200mm Hg, since I_{max} decreases and I_{min} increases, so that effectiveness of multiple conductors can't be expected below 200mm Hg.

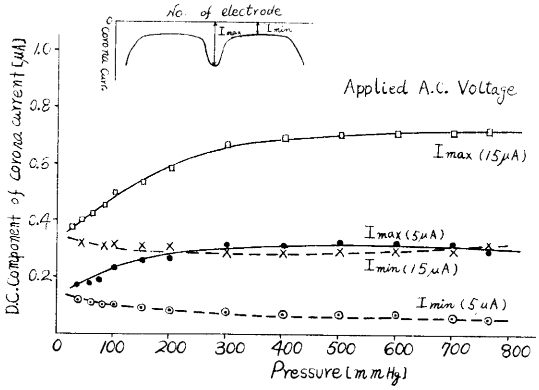

Fig 9 Characteristics of I_{max}, I_{min}—pressures.
$N=2$, m/d=10

(5) Discussion and Conclusion

In case of constant voltage of D.C. 14kV, circular distribution of positive corona current of the double conductors shows the regular directional distribution owing to stable glow corona formation at maximum gradient region on conductor and space charge effect at conductor circumference. Above experiments, at a pressure of about 400mm Hg, since total corona current exceeds 200μA and streamer corona is added to glow corona, the directional distribution is not noticed. In case of pressure of 70mm Hg at total corona current of constant 20μA, diffusion of gasous ions becomes active, and space charge effect is not so influential. Therefore, the distribution of positive corona current is presumed to approach to flat curve.

On the other hand, distribution of D. C. negative corona current at low pressure does not show directional distribution probably due to effect of negative ion,

(1) In the case of total corona current of constant 10, 20, 50, and 150μA effectiveness of double conductors is noticed at pressure below several tens mm Hg. for positive corona current.

(2) At negative corona current, effectiveness of double conductors is accurately observed at atomospheric pressure, but becomes indistinctily at pressure below 250mm Hg.

(3) θ_m is not only function of m/d, but also function of pressure, the lower pressure the larger θ_m extends to about 70° at 70mm Hg.

(4) A.C. corona current (D.C. component) has the directional distribution, too. Since these distribution corresponds to deduction of D.C. positive and negative corona current on the double conductors, distribution of the corna current on the double conductors transmission line might be presumed by superposing of D.C. positive and negative corona current.

R e f e r e n c e

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