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Broken Characteristic of Curved Thin Copper Wires due to Lightning High Impulse Current

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abstract

In the past research, after thin straight copper wires of 0.1 mm ϕ were exposure to the impulse current, their temperature rose and they were melted according to the specific pre-arcing Joule integral in an adiabatic state. However, in this research we confirmed the straight copper wires were broken in solid state before melted. And the test data suggest that ohmic heating is the main reason for breaking these thin copper wires, less than 0.6 mm ϕ in the experiments. Then the impulse current was impressed through curved copper wires from 0.3 mm ϕ to 0.6 mm ϕ. And the current-carrying capability of curved wires was experimentally compared with that of straight ones.

1 Introduction

The winter lightning frequently strikes in the Hokuriku district in Japan. And high voltage and large current give a serious damage. [1] So our research focuses on the properties of earthing wires under heavy current, which are used as lightning wires, and to find how the current conducting ability will be when a conductor is curved.

Here, we present the brief experimental results on copper wires from 0.3 mm ϕ to 0.6 mm ϕ as conducting heavy current. The research results showed that ohmic heating is the main reason for breaking thin copper wires, less than 0.6 mm ϕ in the experiments. Furthermore, the breaking impulse current peak values of curved copper wires are lower than that of straight ones.

2 Experimental conditions

Impulse current generator (maximum voltage 160 kV; maximum stored energy 80 kJ; 32 capacitors each 2.5 µF, 40 kV) is used, which is located in Technical University of Munich. The used copper wire type is Cu-OF1, whose purity is over 99.95 %. In Germany we ordered the conductors to the GUTMANN Kabel company.

The experimental circuit is depicted in Fig. 1. The copper wires were bare and had a round-section, shown in the vertical view of Fig. 2. The effective length along the wire was $L = 0.82$ m and the diameter was D = 0.3 ~ 0.6 mm. They were symmetrically fixed into copper plates electrodes. The shunt resistance is R_i = 2.7mΩ, and the magnification of a voltage divider is 1/1,000. The current wave shape $i(t)$ was recorded by an oscilloscope (OS). The experiment was conducted at room temperature Θ_0 of approximately 15 to 18°C. The test current was a ca. 8/20µs lightning impulse current which is

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shown in Fig.3. Here t_p is the time to reach the peak current value I_p and t_q is the time for the current to fall to $I_p/2$.

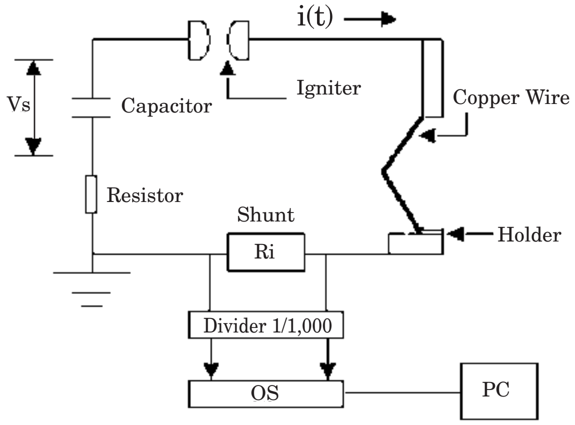

Fig. 1 Experimental circuit

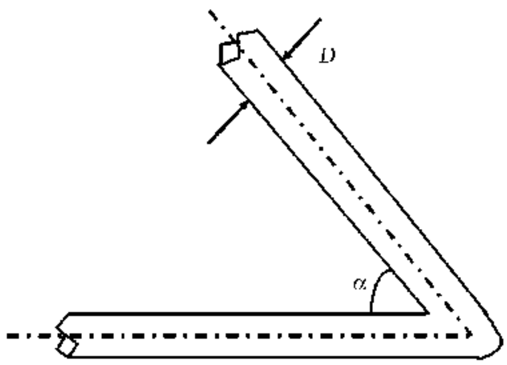

Fig. 2 Vertically curved copper wire

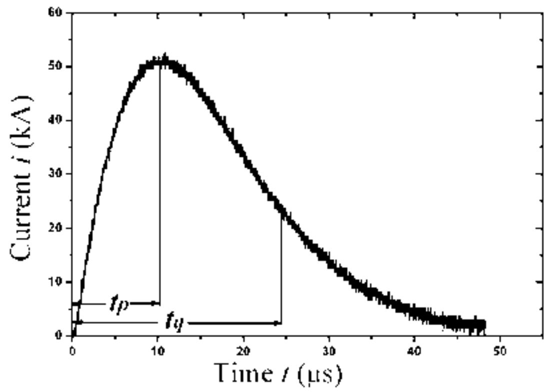

Fig. 3 Input impulse current (t_p=10μs, t_q=24μs)

3 Experimental results

3.1 Procedure of experiment

The photographs on the experimental setup conditions and broken copper wires are shown in the following Figs. As shown in Fig. 4 (A), the copper wire was fixed into electrodes. Both sides were fixed with a nut and washers. We designed the setup, making the electrode rod and copper wires on the straight line to avoid the magnetic force from the electrode rod. Then, we shorten the copper wires to half to do the same experiments. Next, we changed the wires shape into trapezoid shape to do the experiments which are shown in Fig. 4 (B).

For the copper wires of 0.3 mm ϕ to 0.6 mm ϕ, the experiments were done under the 200kV setup. With this setup, if a copper wire survived during exposure to an impulse current with the charge voltage X (kV), we would change it for a new copper wire and step up the charge voltage by 5kV to (X+5) kV. This process would continue n times until a newly changed copper wire is broken at (X+5n) kV, then U_p is (X+5n) kV. U_p is the capacitor charge voltage value under which the copper wire is broken. We repeated it two times and got the average value as final U_p. If the copper wire was broken at first time, we would reverse these processes, decreasing the charge voltage by 5kV to (X−5) kV. $I_p = U_{Shunt}/(2.7*10–3)$. The breaking current peak value in the following refers as the I_p.

(A) (curved angle 45°, diameter 0.6mm)

(B) Trapezoid shape

Fig. 4 A fix situation of a copper wire

3.2 In case of 0.3 mm ϕ

In case of the straight copper wires of 0.3 mm ϕ, after carrying the lightning impulse current, the copper wire was almost completely melted. As shown in Fig. 5 (a), melted gems were formed in equal intervals along the wire. So the thin wire of 0.3 mm ϕ is regarded to be almost completely melted. [4] However in case of the curved copper wires of 0.3 mm ϕ, after conducting the lightning impulse current of I_p=4.4kA, the breaking only happened at the middle curved part as shown in Fig. 5 (b) and broken tips became thinner at the top which are regarded as the result of a tension force and melting. And the total length of the wire was not changed after broken.

(a)

(b)

Fig. 5 Melted situation of a 0.3 mm ϕ

3.3 In case of 0.6mmϕ

In case of the curved copper wires of 0.6 mm ϕ, after carrying the lightning impulse current of I_p=9.8kA, the copper wires were almost broken at the middle curved part. An interesting phenomenon was observed. The broken copper wire became longer, which are shown in table 1 and Fig.6. However the weight was kept same about 2.06g.

Table 1 Extended lengths of broken wires of 0.6 mm ϕ (Original length is 0.82 m)

Diameter D (mm)	Angle α(°)	Average current peak value Ip(kA)	Extended length ΔL (m)
0.6	180(L=0.82m)	9.9	Not broken, L=1.04m and ΔL=0.22m
0.6	135(L=0.82m)	9.6	Curved point is broken, L=0.90m and ΔL=0.08m
0.6	90(L=0.82m)	9.5	Curved point is broken, L=over lm and ΔL=over 0.18m
0.6	45(L=0.82m)	9.5	Curved point is broken, L=1.15m and ΔL=0.33m

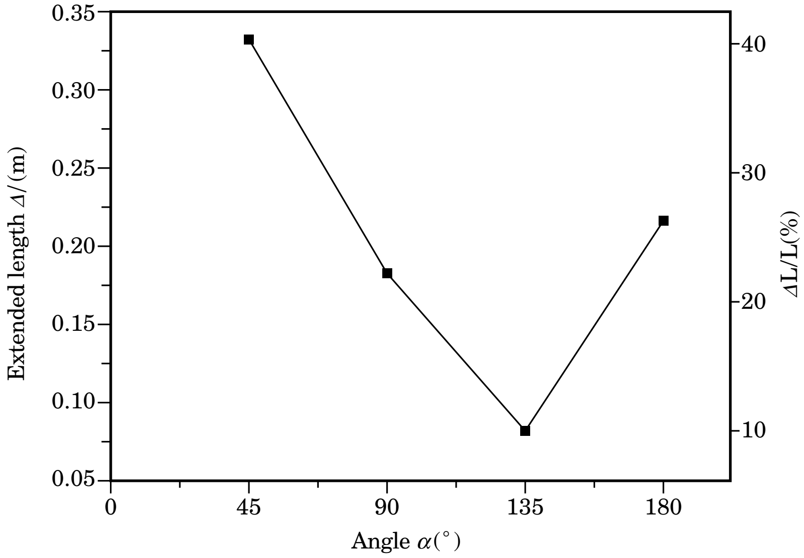

Fig. 6 Elongation of copper wire of 0.6 mm ϕ

The copper wires of 135° curved were almost extended to 0.90 m (the original length is 0.82 m) after broken. It seemed that the whole copper wire was extended longer and the diameter of the whole copper wire became into 0.52 mm ~ 0.56 mm.

Comparing with the copper wires of 135°, the length elongation phenomenon with curved angle α= 90° becomes very noticeable and the length is elongated to about 1m (the original length is 0.82m) 25% longer comparing with original length. Small round particles were formed at the broken part and the diameter of this broken part became the thinnest at about 0.38 mm ϕ. Far away from the broken part, the diameter became thicker at about 0.5 mm ϕ, the last part near the electrode kept the same diameter at 0.6 mm ϕ, which are shown in Fig.7. The extended length in the copper wires of 45° became about 1.15 m or 40% longer comparing with original length.

When the copper wires of 0.6 mm ϕ carried lightning impulse current slightly lower than the breaking impulse current Ip, the copper wires were also elongated although not broken. It suggests the length elongation phenomenon happened before breaking the copper wire. The copper wires were elongated longer and longer with decreasing bending angle. We consider resonance phenomenon induced by the pressure waves is the main reason.

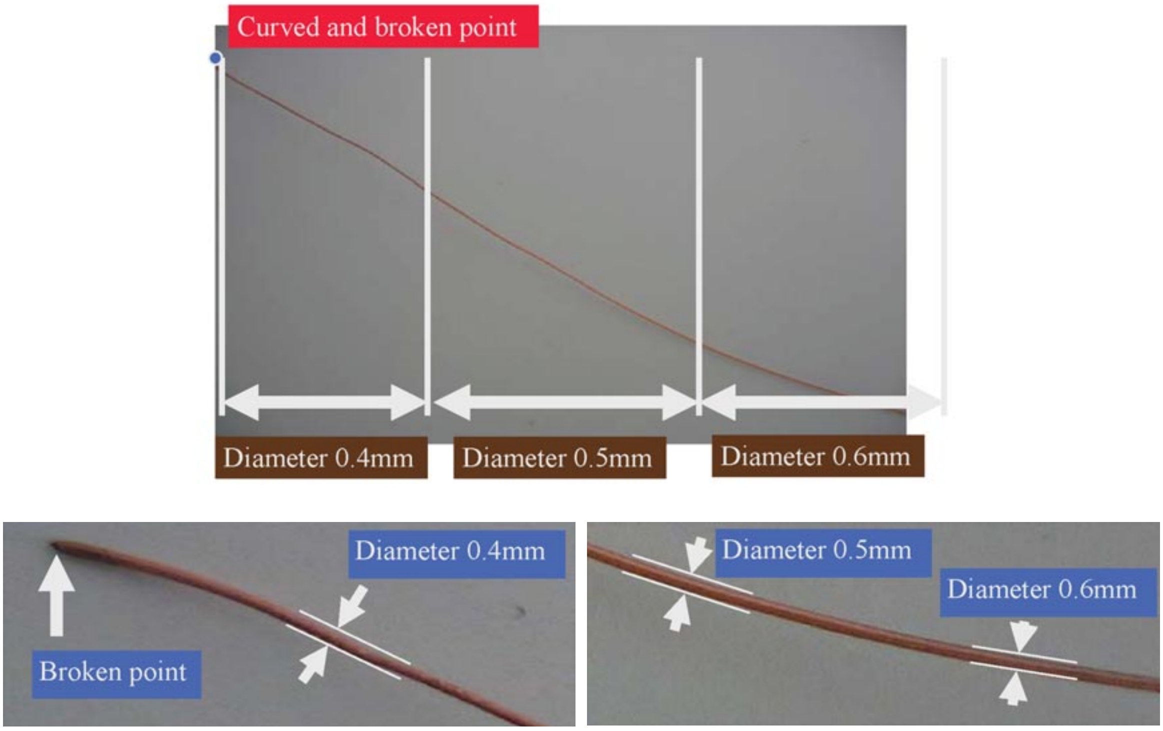

Fig. 7 Broken situation of a 0.6 mm diameter (curved angle is 90° and I_p is 9.8)

Because this length elongation phenomenon is very special and only observed in the copper wires of 0.6 mm ϕ, we carried out the second experiments to confirm it. The same phenomenon was again surely observed. The measured breaking current peak values I_p are shown in Fig.8. As shown, the difference between the first and second I_p is very little to be only in 3%. The curved angle has some influence to the breaking impulse current peak values. With the increase of the curved angle from the steeply curve to straight, the breaking current peak values become bigger.

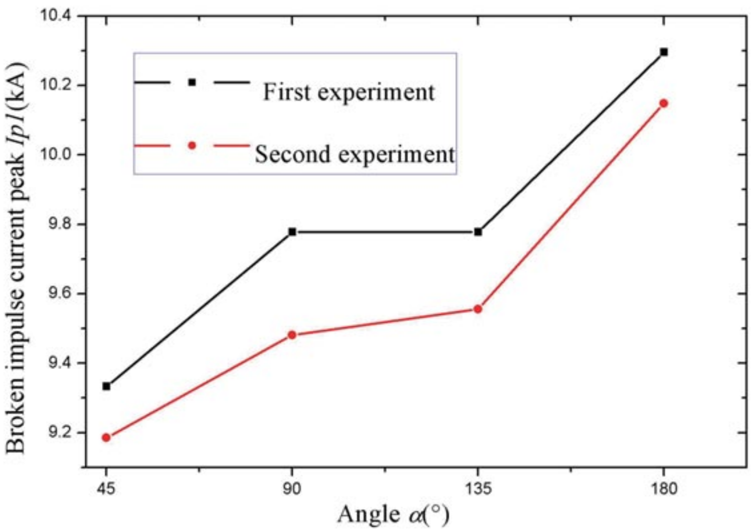

Fig. 8 Breaking current peak values of 0.6 mm ϕ in the first and second experiments

3.4 Experimental results

In Fig. 9 the measured breaking current peak values and theoretical adiabatic melting current peak values [2] of copper wires with diameter of 0.3 mm to 0.6 mm are shown. As shown in the figure, in case of 0.3 mm ϕ the difference between measured breaking current peak values and theoretical adiabatic melting current peak values is not so noticeable. They are broken mainly by the high temperature produced by the Joule heating. In case of the copper wires of 0.6 mm ϕ, the curve angle has some influence to the breaking current peak values. With the increase of the curved angle the breaking current peak values become a little bigger. The other way with the decrease of the angle from the straight to the steeply curved, the breaking current peak values become a little smaller. The electro–magnetic force is responsible for the decrease. All the breaking current peak values of the curved wires are less than those of the straight ones.

According to the experimental results, the wire length has almost no influence to the breaking impulse current peak values to all diameter conductors. However the curved shape has some influence to the breaking impulse current peak values for 0.6mm ϕ, as different wire shape influences the electro–magnetic force distribution along the curved conductors.

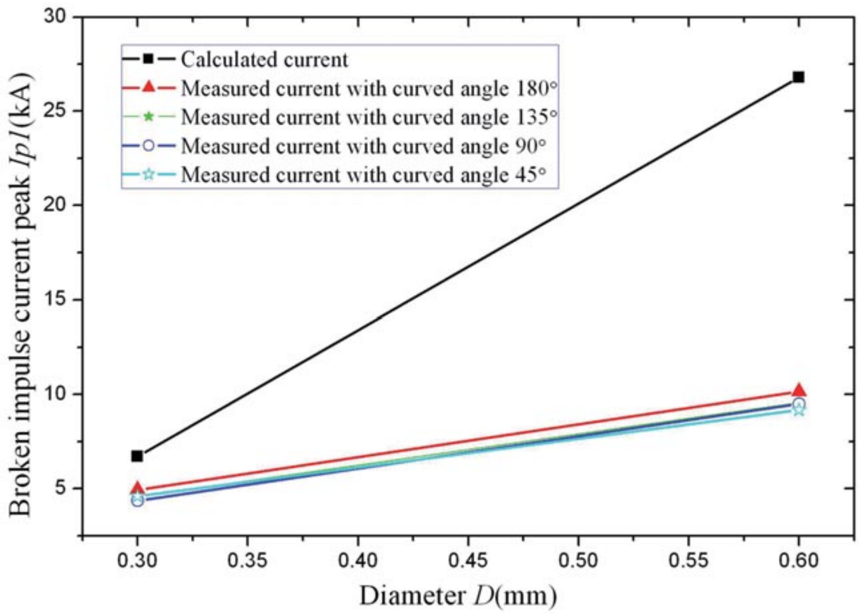

Fig. 9 Breaking characteristics of copper wires (impulse peak value versus diameter)

4 Conclusions

The following results are obtained according to above research:

1: In case of the thin copper wires of 0.3 mm ϕ and 0.6 mm ϕ, the test data suggest that the curve angle has no great influence to the breaking current peak values. Although the breaking current peak values of 0.6 mm ϕ begin to appear the influence of the curved angle but not so noticeable (the difference between max. value of 180° and min. value of 45° is less than 1kA or about 8%).

2: The ohmic heating is the main reason for breaking these thin copper wires.

3: The wire length of 0.3 mm ϕ was not changed after broken, but the length of 0.6 mm ϕ was elongated when broken.

4: In case of 0.3 mm ϕ all the breaking current peak values are almost equal, however in case of

0.6 mm ϕ the breaking current peak values of the curved wires are less than those of the straight ones.

5: The breaking current peak values increases with the diameter,

6: The wire length has almost no influence to the breaking impulse current peak values to all diameter wires.

7: The curved shape has some influence to the breaking impulse current peak values for 0.6mm ϕ, as different wire shape influences the electro–magnetic force distribution along the curved conductors.

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