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# FRANKLIN RODS – SHARP OR BLUNT?

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This paper gives the historical background of 250 year old question: should the Franklin rod tip be sharp or blunt ? The earlier works, the new field results from USA and own laboratory experiments are presented. The switching impulse tests were carried out with two different shapes of high voltage electrodes: rod or sphere and without additional dc bias voltage. In the arrangement with rod as high voltage electrode the smaller breakdown voltages were measured with sharp grounded electrode with negative impulse polarity. At the positive polarity the breakdown voltages do not depend on the shape of grounded electrode.

The tests with spherical high voltage electrode showed, that breakdown voltages under negative polarity are practically the same for three different grounded electrodes. In spite of that, the remarkable differences in time to breakdown were noted.

**Key words –** lightning rod, protection zone, breakdown voltage

## 1. INTRODUCTION

The classical lightning conductor was applied first in 1752 [1]. Franklin' discovery was inspired by the observation of corona discharges from a sharp grounded rod which was moved close to a charged ball. As a result of discharges a significant charge decrease on the solid state was found. Franklin proposed therefore the sharp tip of lightning rod in order to discharge the charge accumulated inside the storm clouds. The experts' opinions were shared on this point already in the 18th Century. The Royal Society became involved and a committee was appointed to study the problem and make recommendations. The committee of eminent electricians, including Franklin, met and rendered its report, proposing sharp rods. One of the five members of the committee, Benjamin Wilson, took exception to the decision for sharp rods, on the ground that these would unnecessarily "invite" strokes, whereas rounded ends would not. With the coming of the American Revolution the protagonists took on political colour and king George III ordered blunts on the rods protecting the royal palace [2]. The sharp Franklin rods are shown in the drawings from Osinski' handbook Sposób Ubezpieczający Życie i Majątek od Piorunów printed in 1784 in Warsaw (fig. 1).

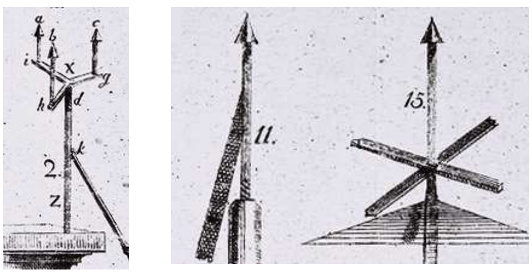


Fig. 1. Drawings of lightning rods from 18. Century [1]

It seems, the blunt rods were used not only in England but in continental Europe too. Many old, representative buildings in Germany have been equipped with spherically tipped lightning rods (fig. 2a). It is not clear wheather such balls were put to improve the lightning protection efficacy or for decorative purposes only. There are small balls on many lightning rods protecting TV antennas in Germany (fig. 2b).

**a** **b**

Fig. 2. Blunt rods. a) A house in Wrocław built in 1920s (when the town belonged to Germany) b) TV antenna protected by blunt rod, Stuttgart, Germany

Prof. Szpor patented the anti-corona tip of lightning rod in 1972. The tip in the form of a hemisphere, a basket or a toroidal ring shall decrease the electrical field to avoid corona discharges (fig. 3).

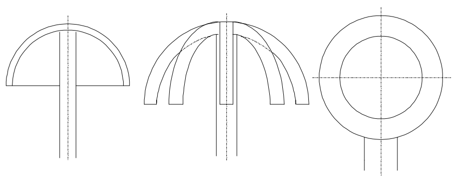


Fig. 3. Tips of lightning rods patented by Szpor [3]

## 2. THE TIP OF HIGH VOLTAGE ELECTRODES

The model lightning experiments carried out in the laboratory are conducted at about 100 times smaller distances and 10 times smaller voltages than the dimension and voltages of real lightning. Therefore the laboratory results have to be treated with a care because they cannot be automatically extrapolated to the field conditions.

During the tests carried out in 1930s with scale models it was observed that very long upper discharges develop from the grounded rod during tests with negative impulse voltages [4]. These discharges can reach even 40% of the gap distance. Therefore the tests carried out at the positive polarity are recognized as more representative than tests with the negative polarity.

The lowest electrical strength is measured in the air gap between rod and plate electrodes. A lot of experiments conducted in this arrangement show the influence of rise time of the impulse voltage and the radius of the rod. When the switching voltage is switched on to the rod electrode, the first corona burst appears. Then, this discharge extinguishes (dark period) and ignites again (subsequent coronas). Usually, the brighter leader discharge develops before the voltage reaches the maximum value. When the streamer discharge, moving before the leader, reaches the grounded plate, then during the subsequent 10 μs the leader bridges the whole gap (final jump).

It appears that at the early breakdown phases, the first or subsequent corona burst are not necessary. They depend on the electrode radius and on the rise time of the voltage. Even if these discharges totally disappear the breakdown voltage does not have to increase. The breakdown voltage of the rod – plate arrangement at the positive polarity and the critical rise time is given by the equation [5]:

$$U_{50\%} = \frac{3400}{1+\frac{8}{d}} \tag{2}$$

where: $U_{50\%}$ in (kV); d – gap distance in (m).

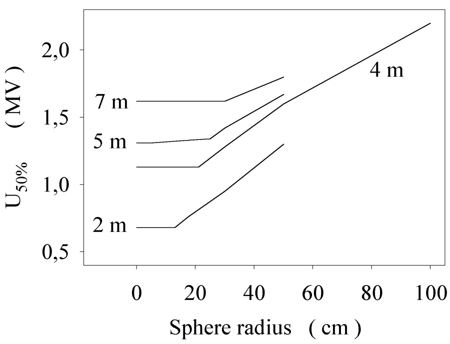



Fig. 4. Breakdown voltage of the sphere-plate air gap as a function of electrode distance. The **positive** switching impulses with the critical rise time [5]

At the first stage the increase in the rod tip does not cause the increase of the breakdown voltage. When the radius approaches a critical value, then the breakdown voltage increases. The critical radius is greater for longer air gap distances (fig. 4).

## 3. OBJECTS, EXPERIMENTAL PROCEDURE

The measurements at High Voltage Laboratory of Darmstadt University of Technology were carried out with the electrode arrangements shown in the fig. 5a. The high voltage electrode was in the form of a rod (diameter of 5 cm) with a conical tip (cone angle of 45°). Two types of grounded electrodes were chosen: the sharp electrode – the rod with a diameter of 2 cm and with a conical tip (cone angle of 15°, electrode E2 in fig. 6) and the sphere electrode with a diameter of 20 cm (E1). The breakdown voltages were measured at the lightning voltage 1.2/50 μs or switching surges 200/2500 μs for different polarities, distances and grounded electrodes.

In the test performed at High Voltage Laboratory of University of Stuttgart the electrode arrangement shown in fig. 5b was used. The diameter of high voltage electrode amounted to 0.7 m. Three grounded electrodes were chosen as shown in fig. 6 – E2, E3, E4. The tip of electrode number E3 was rounded with a radius of 2 mm, the hemisphere electrode radius amounted to 8 mm.

The breakdown voltages were measured at the negative polarity of switching surges 200/2500 μs for 1 m distance between the high voltage sphere and the grounded electrode.

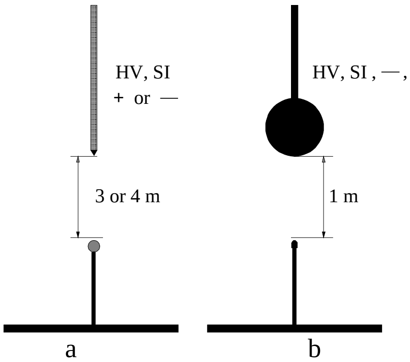



Fig. 5. Electrode arrangements and distances. Diameter of high voltage sphere 0.7 m

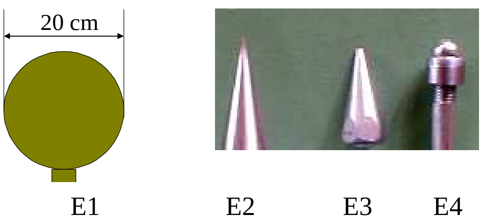



Fig. 6. Grounded electrodes used

## 4. RESULTS

The breakdown voltages of air gaps are practically the same for both grounded electrodes at the positive voltages. Note that at the negative switching voltage the electrical strength is lower about 5% –10% for sharp grounded electrode than for the grounded sphere. Those measurements suggest that the sharp Franklin rod could be better than the lightning conductor with a relatively big sphere (diameter of 20 cm) at its tip.

Table. 1. The comparison of breakdown voltages for the rod – point electrode and the rod – sphere electrode. Test arrangement from fig. 4a, grounded electrode E2 or E1

| Grounded electrode | Gap space m | Impulse shape, polarity | $U_{0\%}$ kV | $U_{100\%}$ kV |
|---|---|---|---|---|
| Sphere E1 | 3 | − SI | **2060** | **2340** |
| Point E2 | 3 | − SI | **1860** | **2220** |
| Sphere E1 | 3 | ⊕ SI | 1010 | 1330 |
| Point E2 | 3 | ⊕ SI | 1045 | 1285 |
| Sphere E1 | 4 | ⊕ LI | 2200 | 2270 |
| Point E2 | 4 | ⊕ LI | 2150 | 2240 |
| Sphere E1 | 4 | − LI | 2500 | 2590 |
| Point E2 | 4 | − LI | 2470 | 2550 |

$U_{0\%}$ - withstand voltage, $U_{100\%}$ - minimum voltage with the 100% breakdown probability, explanation in text,
SI –switching impulse, LI – lightning impulse

Szpor got the similar result. He used two vertical rods with a diameter of 1 cm, each 0,5 high. One electrode had a sharp point and the second rod had a hemispherical end. The high voltage electrode has been represented as a rod of 1 cm diameter and 3 m long. At the electrode distance of 1,5 m the grounded point electrode attracted significantly more negative discharges than did the blunt electrode [6]. The lightning surge 8/70 μs with the amplitude of -1,75 MV was applied. At the positive polarity (breakdown voltage of +1,2 MV) more discharges were attracted by blunt electrode.
The test results with switching impulses, especially with positive polarity have much greater spread that the results with lightning impulses. An example of breakdown distribution function under positive switching impulses shows fig. 7. The positive breakdown voltage of the arrangement rod-sphere at the distance of 3 m was estimated according to the series method. The voltage amplitude was increased 25 kV for each next series. The distribution function in fig. 7 suggests that the probability distribution is non-symmetrical. Note that the estimated breakdown probability for voltage greater than 1170 kV is lower than 1.

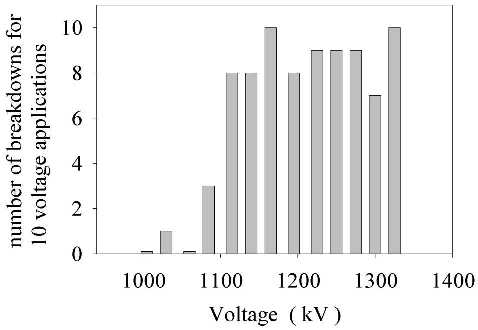
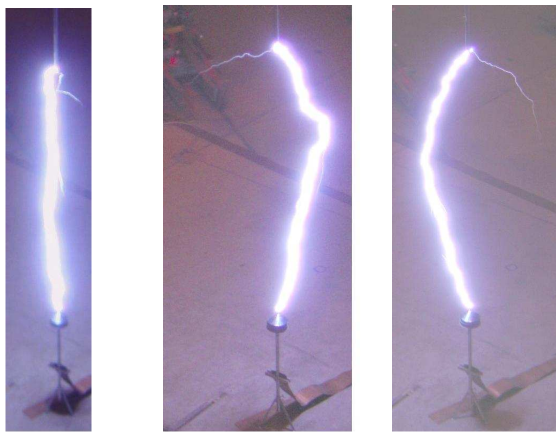



Fig. 7. Distribution function of breakdowns for the rod-grounded sphere arrangement at the distance of 3 m. Positive switching impulses

These is due to known unpredictable behavior of positive switching discharges. The path of positive discharge, as opposite to the negative discharge path, is non linear (fig. 8 ).



negative polarity positive polarity positive polarity

Fig. 8. Switching discharge pattern

The higher breakdown voltage measured for sphere electrode at negative switching impulse (tab 1) is not consistent with model simulations by Akyuz and Cooray [7]. Their analysis of conditions necessary for the initiation of upward leader from Franklin rod have shown that the optimum rod radius is 35 cm. They have shown that as the negative stepped lightning leader approaches the ground the Franklin rod with a larger radius launch a connecting leader first.

The breakdown voltages measured at the test arrangement from fig. 5b are listed in table 2. In spite of some differences in medium times to breakdown the negative breakdown voltages were practically the same. The shortest time to breakdown was observed with the blunt electrode E4. In this arrangement the discharge starts from bottom electrode only. Therefore it does not model appropriately the conditions occurring during a lightning stroke.

Table 2. Breakdown negative switching voltages at test arrangement from fig. 5b

| Grounded electrodes | $U_w$ (kV) | $U_{90\%}$ (kV) | $T_b$ (μs) |
|---|---|---|---|
| Very sharp E2 | 550 | 580 | 199 |
| Radius 3 mm E3 | 550 | ~ 580 | 194 |
| Blunt E4 | 550 | 580 | 175 |

## 5. INFLUENCE OF D.C. BIAS VOLTAGE

The above tests were carried out in the laboratory at the relatively small electrode distances, without the d.c. bias and therefore without the corona from the sharp electrode. Moore compared the number of strokes to sharp rods with that to blunt rods in the Magdalena Mountains of central New Mexico at the height of 3200 m [8]. The sharp or blunt tips were installed on 6 m high masts 6 m apart from each other. During 7 years 13 strokes were noted, all of them were attracted by blunt rods. According to Moore, this result can be explained by the influence of corona space charge. Sharp tips under the electrostatic field of a stormy cloud produce the corona.

The influence of corona from sharp rods on the impulse breakdown voltage at negative polarity was studied by Jakubowski [9] and Allen [10]. Jakubowski did not observe the influence of intensive corona on the impulse breakdown voltage at the electrode distance of 1 m. At the distance of 1,5 m Allen observed that the negative d.c. bias voltage increases the breakdown voltage at switching impulses about 4% (fig. 9).

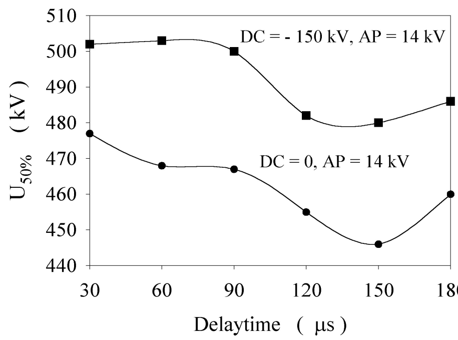



Fig. 9. 50% sparkover voltage as a function of delay time [10]

The small effect of corona noted by Allen was achieved at the very high d.c. bias voltage of 150 kV. The medium electrostatic field amounted about 100 kV/m. Under a real cloud the medium electric field is in the range of 20 kV/m only. Additionally, the electrode arrangement high voltage plate – grounded rod is not appropriate for modeling of lightning discharges because the breakdown develops here from bottom rod electrode only. For modeling of lightning discharge the rod-rod arrangement is better.

## 6. CONCLUSIONS

The electrical strength of an air gap consisting of a sphere and grounded plate increases if the sphere radius is greater than a critical value. This effect was noted for positive switching voltage.

Under negative switching impulse the breakdown voltage of the 3 m air gap rod – sharp grounded tip is smaller than the breakdown voltage of the gap rod – grounded sphere with a radius of 25 cm. Under positive switching voltage and under lightning impulses the sparkover voltage does not depend on the tip of grounded electrode.

Intensive corona discharges cause a small increase in negative sparkover voltage in the air gap consisted of HV plate and grounded rod with a sharp tip.

The above phenomenon could be responsible for the observed by Moore better behavior of blunt rods under field conditions in New Mexico.

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