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Characterisation of Dispersive Systems using a Coherer

P. M. Nikolić[1]*, **S. Đurić[1]**, **K. Radulović[2]**,
D. Vasiljević-Radović[2], **M. V. Nikolić[2]**, **M. M. Ristić[1]**

[1] Institute of Technical Sciences of the Serbian Academy of Sciences and Arts, Belgrade, Yugoslavia

[2] Center for Multidisciplinary Studies, University of Belgrade, Belgrade, Yugoslavia

(Dedicated to Professor Dr. Drago Kolar in memory of a great scientist and a great man)

Abstract: The possibility of characterization of aluminium powders using a horizontal coherer has been considered. Al powders of known dimension were treated with a high frequency electromagnetic field or with a DC electric field, which were increased until a dielectric breakdown occurred. Using a multifunctional card PC-428 Electronic Design and a suitable interface between the coherer and PC, the activation time of the coherer was measured as a function of powder dimension and the distance between the coherer electrodes. It was also shown that the average dimension of powders of unknown size could be determined using the coherer.

Keywords: Coherer; Dimension of Powders; Dielectric Breakdown.

Резюме: В данной работе исследована возможность определения порошка Al при помощи горозинтального когерера. Порошки алюминия известного размера обработаны помощью высокочастотного электромагнитного поля или постоянного электрического поля, которое увеличивалось до диэлектического пробоя. Время активации когерера измеряли в зависимости от размера частиц порошков и расстояния между электродами когерера, с использованием многофункциональной карточки PC-428 Electronic Design. Также показали, что средние размеры частиц порошков неизвестного размера можно опреелить при помощи когерера.

Ключевые слова: Когерер; размеры частиц; диэлектрический пробой.

Садржај: У раду је разматрана могућност карактеризације Al праха помоћу хоризонталног кохерера. Al прахови познатих димензија третирани су високофреквентним магнетним пољем или једносмерним електричним пољем, које је повећавано све док није дошло до електричног пробоја. Време активације кохерера мерено је у функцији димензија честица прахова и одстојања између електрода кохерера, коришћењем вишефункционалне картице PC-428 Electronic Design. Поред тога, показано је да се средње димензије честица прахова непознатих димензија могу одредити применом кохерера.

Кључне речи: Кохерер; величине прахова; електрични пробој.

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* Corresponding author (nikolic@bib.sanu.ac.yu).

Introduction

A long time ago (1835), Mark Rosenschoeld observed that the electrical conductivity of a mixture of graphite and other conductive materials increases during an electrical spark. Varliy (1852) also noticed that the electrical resistivity of some powder mixture decreases during thunderstorms with lightning [1]. He even made a patent about the protection of some instruments during lightning flashes. At the beginning of the XX century Marconi and Tesla [2] "crossed" the Atlantic for the first time with a type of radio communication using a coherer.

During the Second World War some armies successfully employed a coherer to light mines at a distance. This century Yoshihiro Hirokawa advertised a coherer device for protection against lightning.

The coherer consists of a glass tube partly filled with metal chips or powder lying loosely between brass plugs, which are fitted at its ends. A schematic survey is given in Fig. 1a and the horizontal coherer used in all our experiments is shown in Fig. 1b.
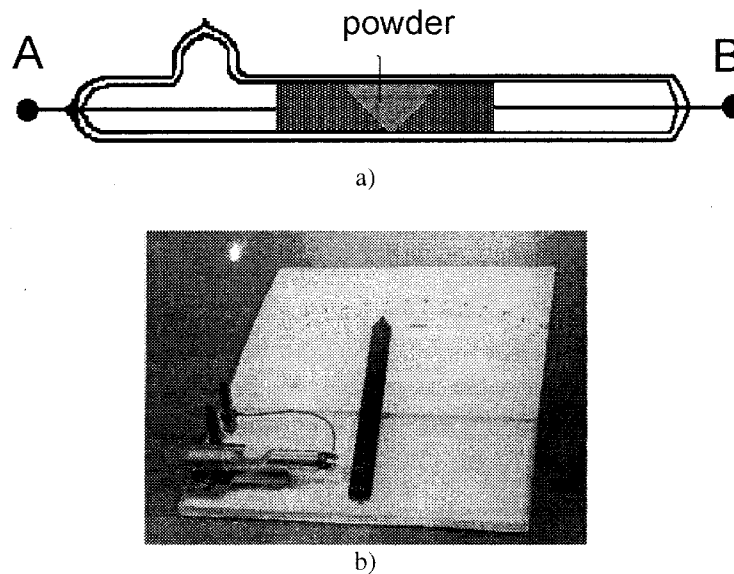

a)

b)

Fig. 1 (a) A schematic surway of a coherer; (b) A picture of a horizontal coherer.

When an electric potential difference is brought between the brass plugs and gradually increased above a certain value, the electric resistance between them suddenly falls from 100 kΩ or more to a much lower value, often less than 10 Ω. The reason for this behaviour is still not fully known. Some scientists explain this behaviour as ordinary electrostatic attraction. Others argue that small sparks occur between powder particles and break down the very thin metallic oxide, which is formed at the surface of each particle thus decreasing the resistivity. Nobody has measured the time taken for this sudden breakdown to occur. Therefore we intended to measure the breakdown time, to analyse it and also to determine if a coherer could be used to measure the particle size of a powder lying loose between the brass electrodes.

The coherer has not been in practical use since the Second World War because receivers and transmitters provided a better solution for telecommunications. That is probably the main reason why nobody has properly explained how the coherer really works. However, a Japanese producer makes and uses the coherer as a protector against lightning [3].

At present there is a growing interest in the coherer mainly from the historical point of view and also because Tesla used it frequently in his experimental communication systems.

Experimental

We first made a transmitter with an oscillator frequency of about 60 MHz and output power of almost 100 W, which could be changed i.e. decreased. When the key on the transmitter was pressed it was active only for a very short time - less than one second [4]. The receiver, the circuit diagram of which is given in Fig. 2, had an antenna, shaped like a telescope stick, which was connected to an oscillator circuit and coherer "K". The high frequency part was separated from the ohmmeter using a damping coil, Pr1. A parallel line to the coherer, which consisted of a diode, d, capacitor, C_4, and voltmeter, V, was used for tuning the receiver to resonate with the transmitter.
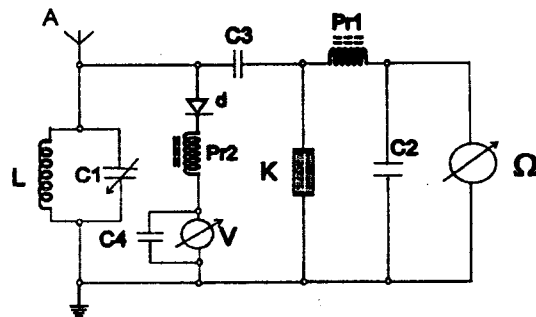

Fig. 2 Circuit diagram of a receiver with an antenna shaped like a telescope stick.

At the beginning we used copper powder of known particle sizes. In Fig. 3 the resistivity between the coherer electrode is given as a function of copper powder size. Black circles show the resistivity of copper powders before the high frequency generator was switched on. The values of the resistivity are given with open circles after the transmitter was switched on.
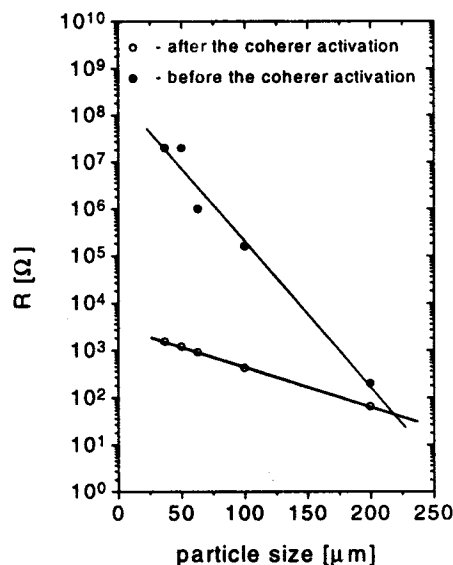

Fig. 3 Electrical resistivity, R, versus copper powder size. Black circles show the resistivity of copper powder before high frequency generator was switched on. With the open circles R is given after the transmitter was switched on.

The resistivity, decreased by almost four orders of magnitude for the smallest copper particle size. This decrease was smaller when the diameter of the particles increased and for powder of about 200 μm diameter it was only about 400 Ω. When there was no high frequency electromagnetic field present, the resistivity values were rather scattered. They became less scattered when the electric field was brought to the ends of the coherer during experiments. The intensity of this field depended on several factors: the position of each antenna, the position of the cables connecting the coherer and transmitter, etc. We considered that the working condition would be the most stable if DC voltages and fields were used. A very stable DC generator and measuring device was made in our laboratory the scheme of which is given in Fig. 4.
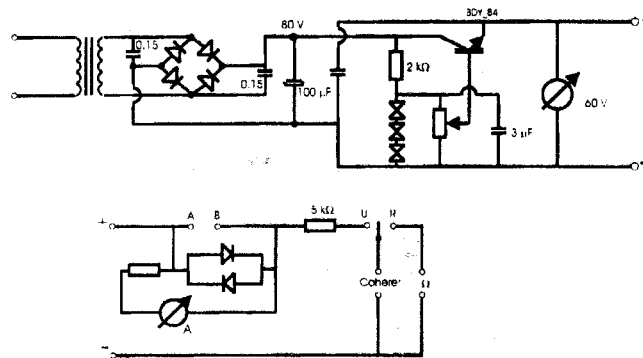

Fig. 4 A measuring device with a very stable DC generator which could measure the resistivity of the coherer and also the breakdown voltage.

This stable DC voltage could be increased until a sudden change of measured voltage happened, at the moment when the oxide films broke down. Then the resistance of the coherer was measured and also the breakdown voltage. The measurements with both VF transmitter and DC generator gave nearly identical results, so later we used only the DC generator to study the coherer and metallic powders. In Fig. 5 is given the experimental arrangement where a multifunctional card PC 428 was used as the interface between the coherer and a computer. The change of voltage in the coherer as a function of time for Al powder of 10 μm diameter is given in Fig. 6. The distance between the electrodes was 0.25 mm. There was a sudden decrease of voltage, from 96 V to nearly zero in an interval of less than 15 ms. This measurement was repeated when the multifunctional card frequency was increased to 100 kHz and the time distance between two measuring points was 10 μs. The results for three Al powders with different diameters are given in Fig. 7. The breakdown time was about 110 μs for the finest Al powder, because eleven points were registered during the breakdown time. For the sample with intermediate particle diameter (A14) six points were registered during the breakdown and for the largest particle size (A15) only three measuring points were observed. Therefore, the breakdown in these two cases took 60 and only 30 μs, respectively. However, the breakdown time also depends on the number (N) of powder particles present between the electrodes in the coherer. For Al powder it is easy to calculate the particle size in each case because it is known that the thickness of Al_2O_3 is 25 Å for every particle. Then for Fig. 6 N = 25 for the distance of 0.25 mm between the brass electrodes and the dielectric strength (DS) is

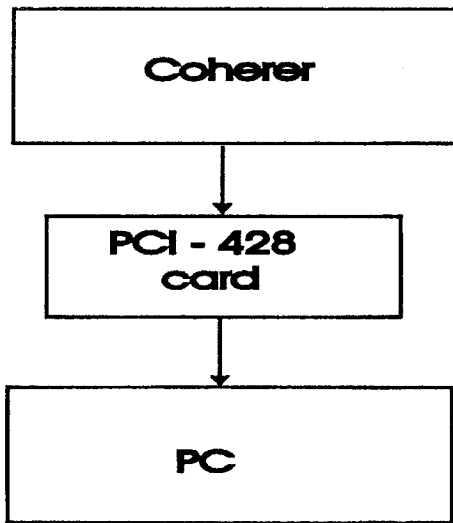$$DS= (96/25)/(25 \times 2 \times 10^7) = 768 \text{ kV/mm}.$$

Fig. 5 The experimental arrangement where a multifunctional card (PC428) was used as an interface between the coherer and a computer.
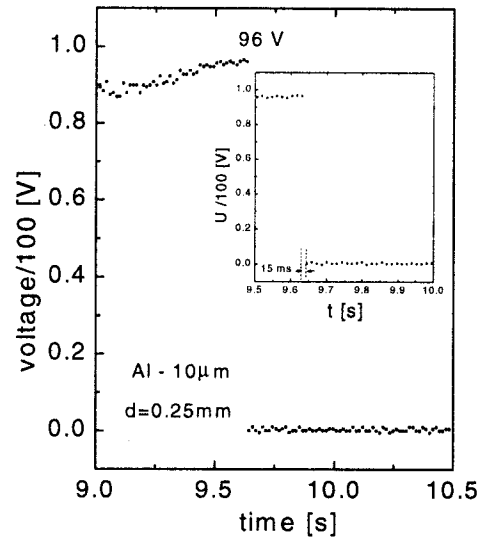
Fig. 6 Change of voltage in the coherer as a function of time for Al powder of 10 μm diameter.

Now when DS is known for each particle size of Al (Fig. 7) one can easily calculate first N, and then the average diameter of the particles. The calculated values are given in the same figure, together with the resistivity between the brass electrodes after the breakdown.
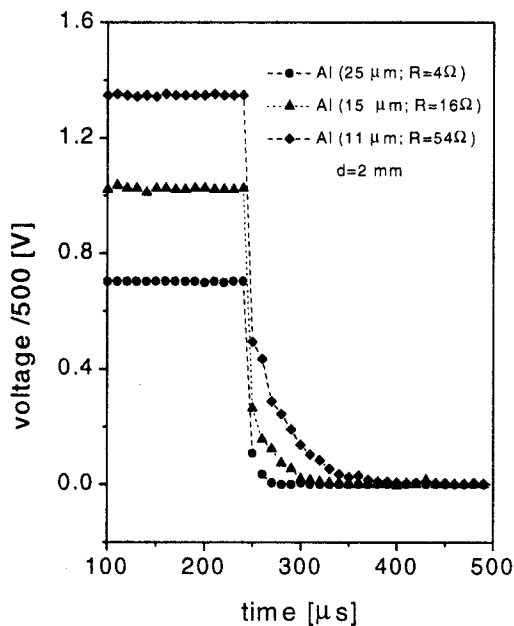

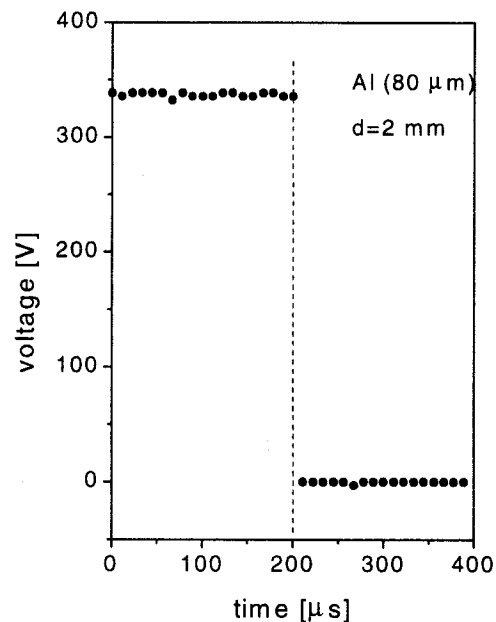**Fig. 7** Change of voltage as a function of time for three Al powders with different diameters.

Fig. 8 Change of voltage on the coherer electrode versus time during the breakdown procedure for Al powder with average particle diameter of about 80 μm.

We used also Al powder with average particle diameter of about 80 μm. The change of voltage on the coherer electrode versus time is given during the breakdown procedure in Fig. 8. It is obvious that in this case the breakdown time was less than 10 μs. Some copper

powders were also examined with the coherer. In Fig. 9 three voltage/time diagrams for copper powders of average diameter 37, 50 and 63 μm, are given. There one can see that the breakdown time was also the largest for the smaller particle size and vice versa. In this case the time was much longer than for Al powder. Thus, for Cu powder of diameter 37 μm it was about 120 ms, while for the particle size of about 63 μm it decreased to about 60 ms.
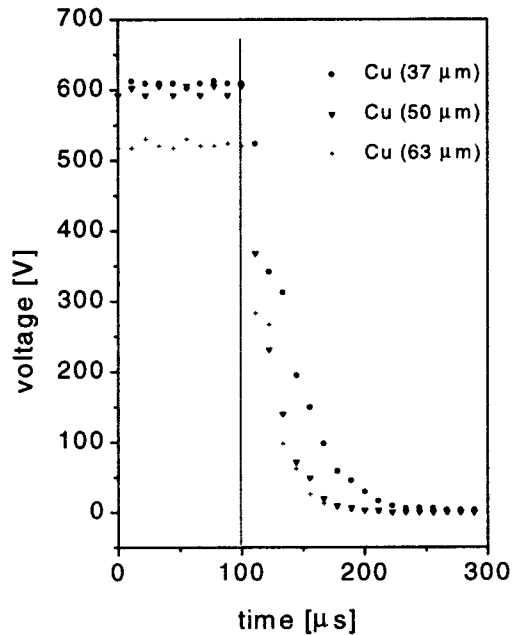

Fig. 9 Three voltage/time diagrams for copper powder of average diameter 37, 50 and 63 μm.

Discussion

The change of average diameter of Al powder, versus breakdown time is given in Fig. 10, where it is obvious that when the diameter of Al powder decreases the breakdown time increases having a hyperbolic character. The change of the breakdown voltage as a function of Al powder diameter gives a similarly shaped curve in Fig. 11. It is obvious that, this diagram could be used for sufficiently accurate determination of the particle size of Al powder, when the diameter is less than 40 μm. Here it should be mentioned that the actual powder size might be smaller than the values obtained this way because in the calculation it was supposed that each particle had a spherical shape and also that all particles were touching each other on a straight line, but that might not be true.
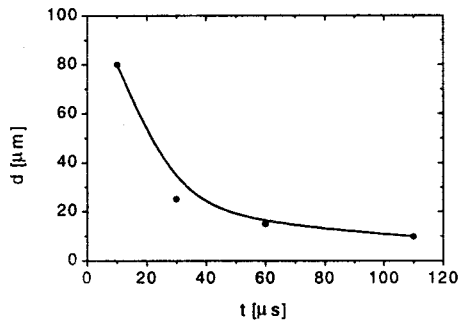

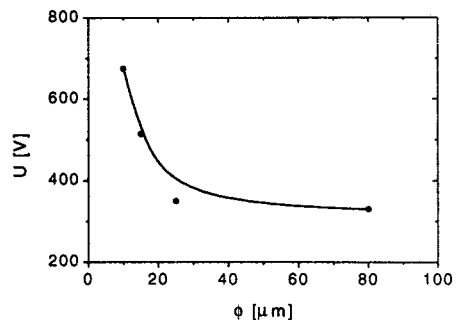**Fig. 10** Change of the average diameter of Al powder versus breakdown time.

Fig. 11 The breakdown voltage as a function of Al powder diameter.

Since the shape of the particles is not spherical, we intend to use fractal geometry to calculate the fractal dimensions of the particles. One also should take into the consideration that there is a range of sizes of particle diameters in each sample. Since the value for powder particle size determined by this method is always larger than the actual size, one should estimate the bias. Therefore, we measured the breakdown time and voltage for Al powder, which had the following declared distribution of powder size: +75 μm was maximum 1 %; -75 μm min 99 %, and -45 μm was 27 %. For a distance of 5 mm between the brass electrode the breakdown voltage was about 340 V and the calculated average particle size was about 56 μm. That is in reasonable agreement with the declaration.

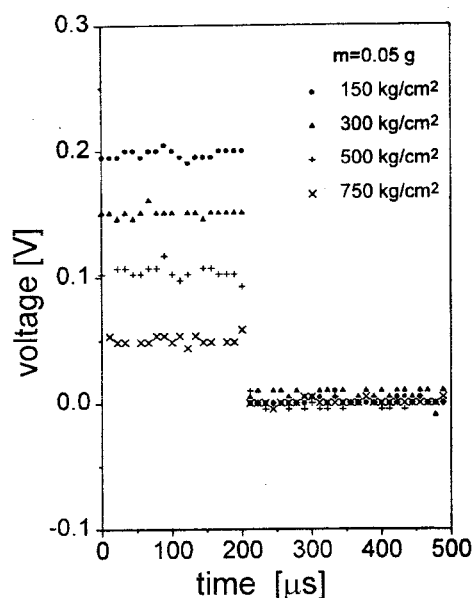Another example is given in Fig. 12, where the breakdown voltages for the same Al powder, from which pellets were made of mass 0.05 g using pressure from 150 to 2000 kg/cm^2, are shown. It is obvious that the breakdown time was very short, not much different from 10 μs, but the voltage decreased with increasing pressure.

In Fig. 13 the breakdown voltage is shown as a function of pressure, where one can see that the breakdown voltage decreases hyperbolically when the pressure is increased. This type of diagram may also be used to obtain some useful information.

Fig. 12 Breakdown voltage versus time for Al (with 99 % -75 μm) powder pellets made of mass 0.05 g using pressures of 150, 200, 300, 500 and 750 kg/cm^2.

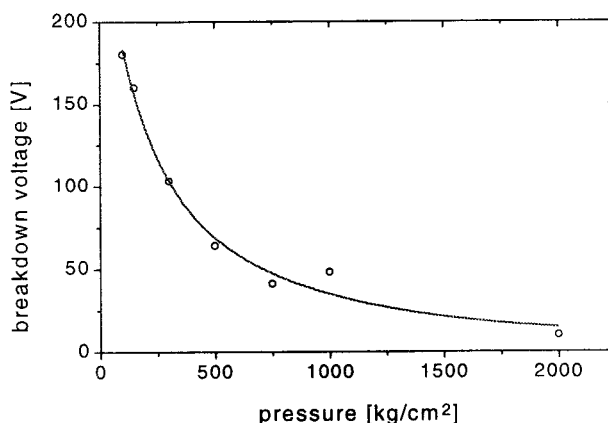**Fig. 13** The breakdown voltage as a function of pressure for Al pellets from Fig. 12.

Conclusion

The possibility of characterizing of Al powders using a calibrated horizontal coherer has been considered. The results obtained allow us to conclude that this simple and cheap method can be successfully used to obtain the average diameter of Al powders by measuring their breakdown voltage. A fractal geometry approach could increase the accuracy of this method. The activation time i.e. breakdown time for each sample was also measured and it could be concluded that for Al powders, of breakdown time less than 40 ms, it is possible to obtain, rather accurately the average particle size using the breakdown time measurements and a previously calibrated curve made for Al powders with known particle dimensions.

References

1. J. A. Fleming, The Principles of Electronic Wave Telegraphy and Telephony, 3rd Edit., London, 1916.
2. N. Tesla, Colorado Springs Notes 1899-1900, Nolit, Beograd, 1978.
3. Company "Yoshirio Hirakawa" (www.hirakawa.com), 2001.