EXPERIMENTAL SET UP FOR SPECTROSCOPIC MEASUREMENTS OF PLASMA ARCS IN FUSES

P. Bezborodko, J. Fauconneau, R. Pellet
Laboratory Arc Electrique et Plasmas Thermiques
U.R.A. 828 C.N.R.S.,Université Blaise Pascal
Clermont-Ferrand, France

Abstract

The aim of this paper is to present our latest experimental set up for spectroscopic measurements. Two different experimental sets have been used. The first one includes a 500 mm focal spectrograph and light is collected via an optic fiber placed in sand near the fuse element. This set up enables us to obtain large band spectra without modifying the physical phenomena. The second one includes a bigger spectrograph (f = 1500 mm) where spectral lines are focused on an O.M.A. (Optical Multichannel Analyser) array. The array is used in a streak camera mode for data acquisition. Light is optically collected by means of lenses and diaphragms. In this case the fuse is a half-fuse whose partition is a glass wall. This set enables us to obtain a succession of time resolved spectra (down to 100 µs) during the fuse arc phenomena.

Introduction

Our investigations are devoted to the comprehension of physical phenomena occurring during the breaking period of a high breaking capacity (H.B.C) fuse.

The range of our experiments is the following: electrical field E is about 30 V/mm, instantaneous breaking current I_{max} is about a few 10^3 A and we try to obtain current density j of about 10^9 A/m^2. We have chosen fuse elements with constrictions with a view to obtaining a burn-back process which occurs in typical modern H.B.C. fuses.

Our questions are about energy or matter transport which permit to dissipate the electrical energy of the circuit. We also asked ourselves what are the relative contributions to energy losses in the following phenomena: gas and vapor evacuation through sand, increase in sand enthalpy by temperature increase (heat content) or fusion (latent heat), optical radiations, pressure transfer (gas evacuation, sand packing). Another problem is to understand physical mechanisms which induce the burn-back of the fuse element.

Our approch is mainly an experimental one. We try to carry out different kinds of experiments, the spectroscopic ones can give valuable qualitative information. However physical parameters such as electronic density, temperature, instantaneous pressure will require special attention on account of unfavourable conditions (optically thick plasma, radiations of neighbouring black body).

1 Experimental set up

1.1 Test fuses

Fuse elements have an effective length of 36 mm, are 0.105 mm thick, 99.99 % pure silver strip. As one of our interests is the burn-back phenomenon, we have chosen fuse elements with a single row of notches punched at their centres. Depending on the number of notches (1, 2, or 3, 0.5 mm large each), we dispose of three strip widths: 2.5, 5, 7.5 mm. The fuses are filled with approximately 99 % pure silica grains with a mean diameter of 400 µm. To test these fuses, we have a capacitor bank which can release an energy of 2100 Joules (U_{charge} = 540V, I_{max} = 4000 A).

Therefore, we have made two sorts of test fuses (Fig. 1):
- The first (Fig. 1-a) is a standard reproduction of a normal fuse with a 2 mm hole perpendicular to the plane of the fuse element. This hole is located just opposite the notch. A ceramic tube is inserted to within 3 mm of the element and glued into place. A 1 mm optical fiber is introduced so as to be 2 mm recessed of the tube end. Like this, an alteration of the fiber end is avoided. To insure that the pressure is identical to the real case, we have conformed to the volume of sand required.
- The second (Fig. 1-b) is like a half-fuse with a glass wall. On the one side, a 4 mm wide glass wall is put on the fuse element. On the other side, the fuse is filled with silica grains.

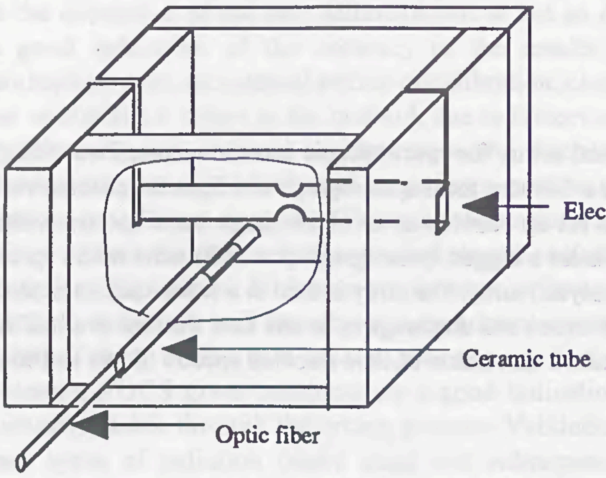

Fig. 1-a : Fuse1

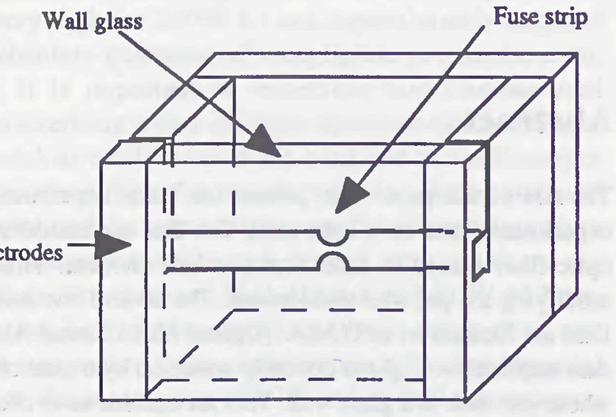

Fig. 1-b : Fuse2

1.2 Large band spectra : set up 1

Fuse 1 is associated with a 0.5 meter focal length spectrograph which has three gratings (150, 600, 2400 grooves/mm).The detector is a linear diode array which gives an image coupled with fiber optic bundles. This set up enables us to obtain large band spectra without modifying physical phenomena. The minimal exposure time is 30 ms. The mechanical shutter has an opening time of about 6 ms, which explains why it is impossible to synchronize precisely data acquisitions with the phenomenon.

1.3 Time resolved spectra : set up 2

Fuse 2 is associated with a 1.5 meter focal length spectrograph with two gratings (600, 2400 grooves/mm). The detector is a Charge Coupled Device array (512 x 512 pixels). The CCD detector is used in streak mode operation. This mode permits to record the behaviour of the phenomenon as a function of time with an exposition time as short as 100 μs. In fact, the light is just focused on one track of the array (10 or 15 rows). Successive spectra are acquired and then shifted down to the rest of the array providing a storage area for data. This set up makes it possible to synchronize precisely data acquisitions with fuse arc. The oscilloscope recording enables us to visualise the exact timing of spectra acquisitions associated with the current behaviour.
This test configuration is shown in Fig.2.

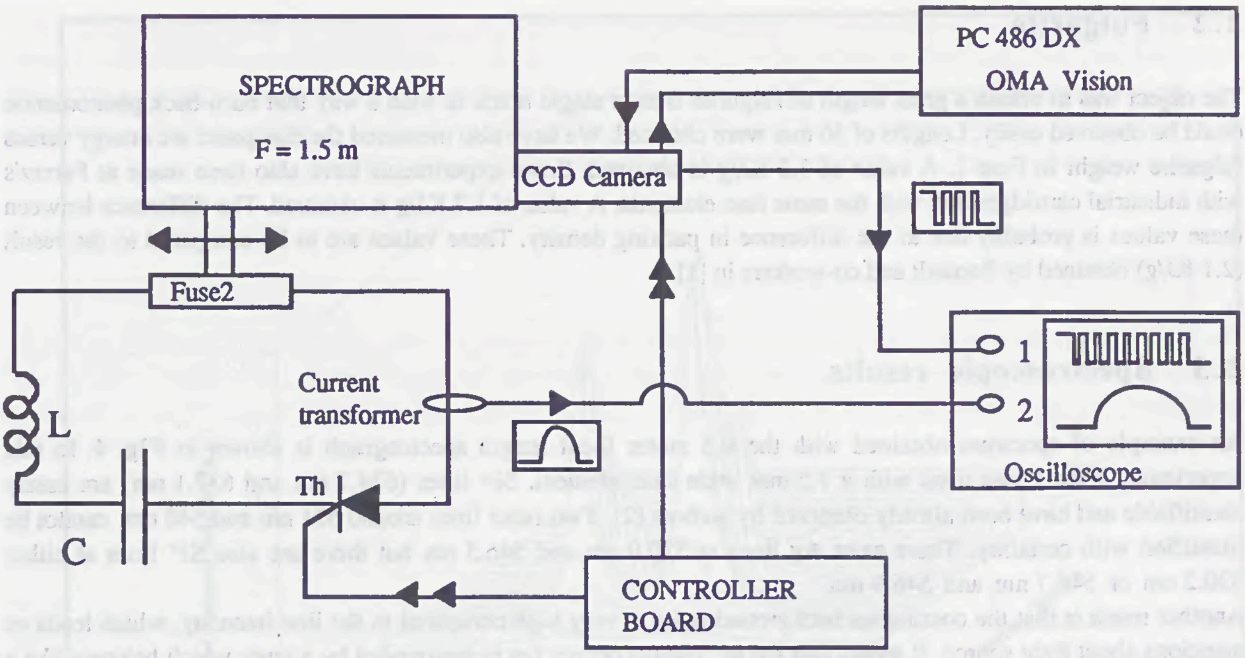

Fig. 2 : Set up 2

2 Experimental results

2.1 Discharges characteristics

A certain number of electrical measurements have been done with the aim of verifying that our fuse presents suitable electrical characteritics. One example of electrical characteristics is shown in **Fig.3** where the fuse element is 7.5 mm wide. The voltage across the capacitor bank for this experiment was 540 V.

The electrical field values have been estimated taking into account the maximum voltage across the fuse and the final length of fulgurite. The values obtained vary from 20 V/mm to 30 V/mm. These characteristics are of the same order as those obtained in industrial fuses.

Whatever voltages are applied on fuse, arcs begin at constant current values (2.5 mm width : 1200 A, 5 mm : 1800 A, 7.5 mm : 2400 A). These characteristics are important for Set up 2 to identify the start of arc from current curves.

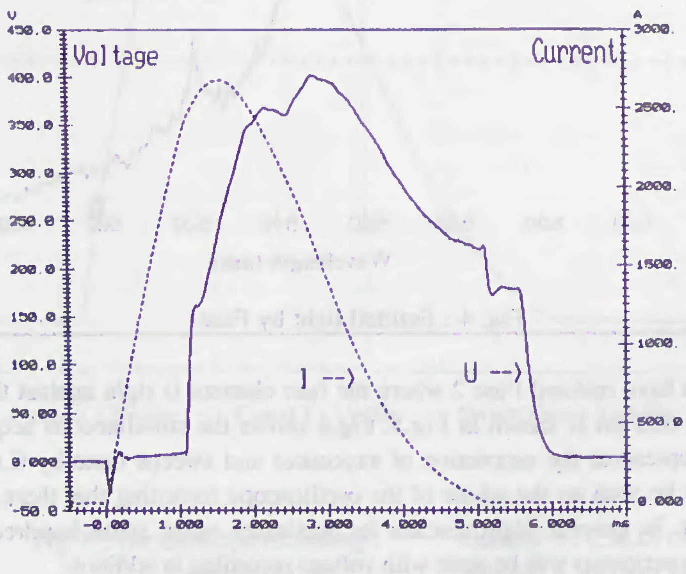

Fig. 3 : Voltage and current characteristics of Fuse1.

2.2 Fulgurite

The object was to obtain a great length of fulgurite from a single notch in such a way that burn-back phenomenon could be observed easily. Lengths of 36 mm were obtained. We have also measured the dissipated arc energy versus fulgurite weight in Fuse 1. A value of 1.3 KJ/g is obtained. Some experiments have also been made at Ferraz's with industrial cartridges and with the same fuse elements. A value of 1.7 KJ/g is obtained. The difference between these values is probably due to the difference in packing density. These values are to be compared to the result (2.1 KJ/g) obtained by Barrault and co-workers in [1].

2.3 Spectroscopic results

An example of spectrum obtained with the 0.5 meter focal length spectrograph is shown in **Fig. 4**. In this experiment, Fuse 1 was used with a 7.5 mm wide fuse element. Si^+ lines (634.7 nm and 637.1 nm) are easily identifiable and have been already observed by authors [2]. Two other lines around 521 nm and 546 nm cannot be identified with certainty. There exist Ag lines at 520.9 nm and 546.5 nm but there are also Si^+ lines at either 520.2 nm or 546.7 nm and 546.9 nm.

Another result is that the continuous background noise is very high compared to the line intensity, which leads us questions about light source. It seems that the arc plasma occurs but is surrounded by a layer which behaves like a blackbody.

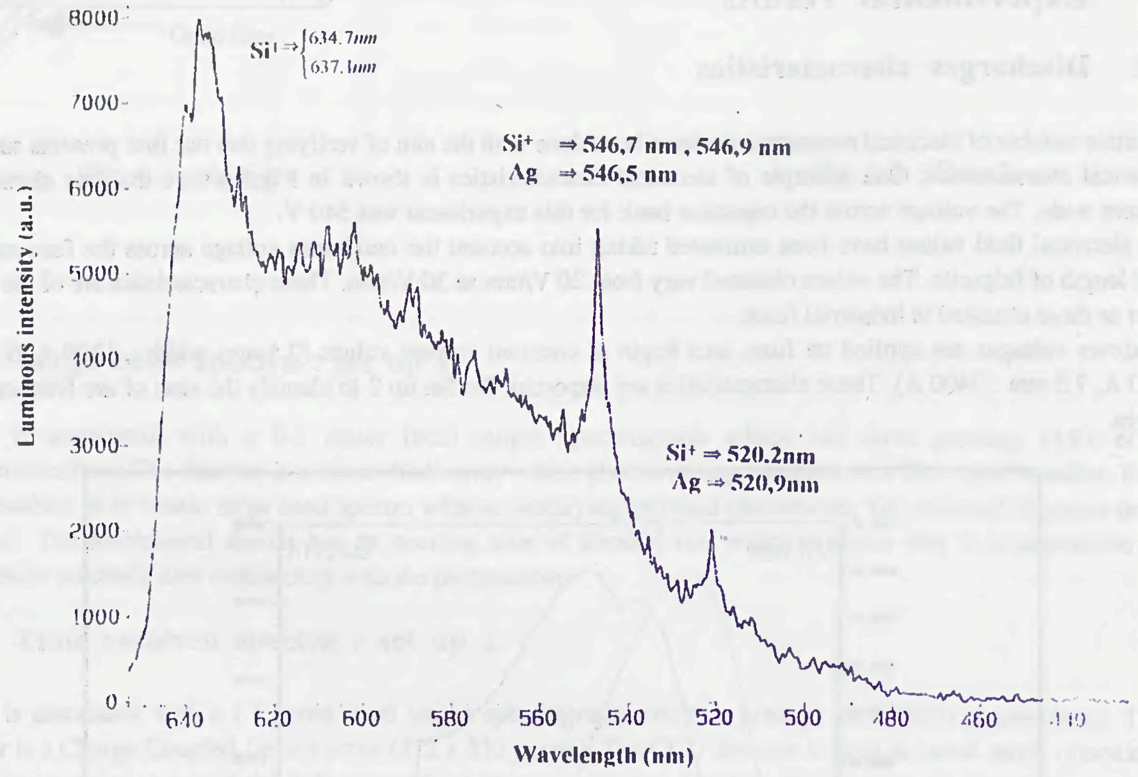

Fig. 4 : Emitted light by Fusel

To avoid this problem, we have realised Fuse 2 where the fuse element is right against the glass wall. A band of 10 nm wavelength around 636 nm is shown in **Fig.5**. **Fig.6** shows the simultaneous acquisition obtained on the oscilloscope. Channel 1 represents the succession of exposures and sweeps done by C.C.D. camera. Channel 2 represents current I. It can be seen on the whole of the oscilloscope recording that there is no exact simultaneity between light and current. In general, light reaches its maximum value some hundred µs after the supposed beginning of arc. Further experiments will be done with voltage recording in addition.

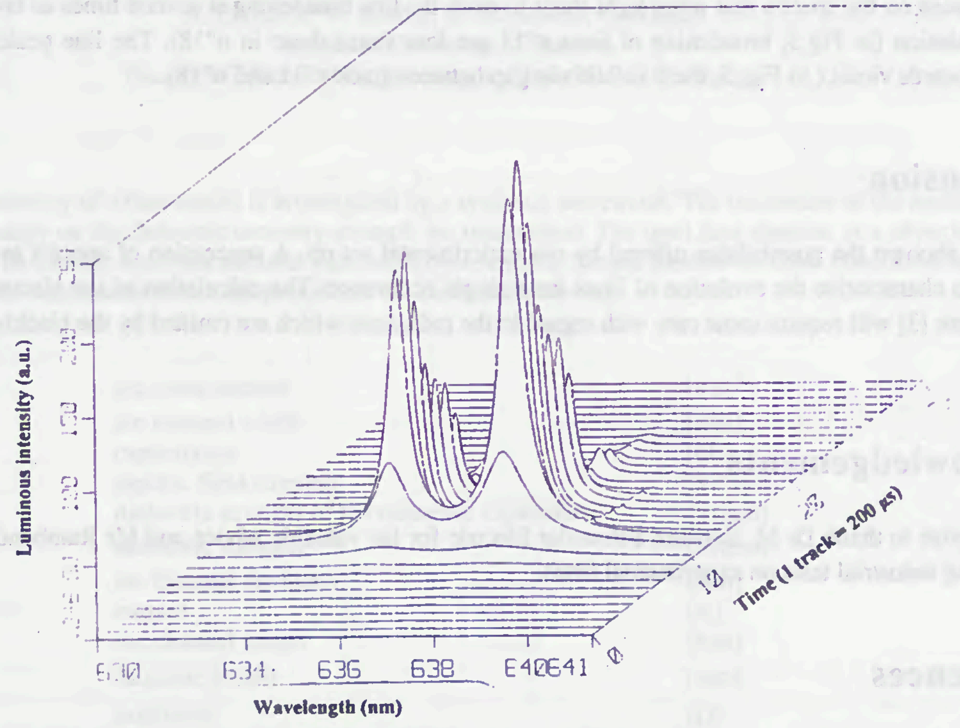

Fig. 5 : Spectra evolution of a single fuse arc (test n°22 : Fuse2)

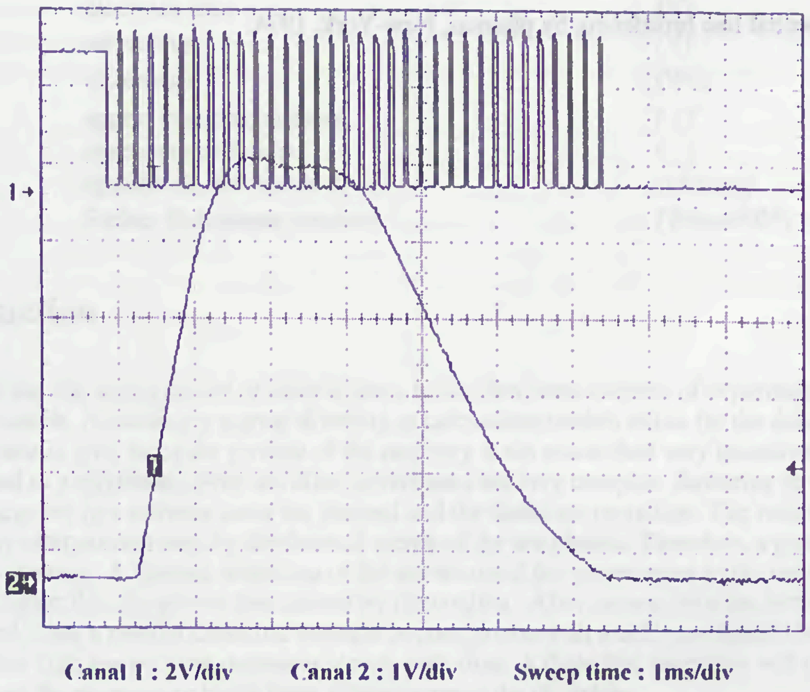

Fig. 6 : Oscilloscope recording : (test n°22) channel 1 : C.C.D. camera channel 2 : current fuse

The spectra show that Fuse 2 continuous background noise is much less than with Fuse 1 (the intensity of O.246 before and after the experiment is an electronic offset). However, current and fulgurite sizes are comparable. Morever, it can be seen on the spectra that when light starts to emit, the line broadening is several times as broad as at the end of the emission (in Fig.5, broadening of lines n°11 are four times those in n°18). The line peaks are sometimes shifted towards violet (in Fig. 5, there is 0.06 nm gap between track n°11 and n°18).

Conclusion

We have shoown the possibilities offered by our experimental set up. A succession of spectra as short as 100 µs permits to characterize the evolution of lines for a single occurence. The calculation of the electronic density and temperature [3] will require some care with regard to the radiations which are emitted by the blackbody surrounding plasma.

Acknowledgements

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