PRESSURE INSIDE THE ARC CHANNEL OF A HIGH-VOLTAGE FUSE

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I. INTRODUCTION

Pressure is one of the key arcing parameters of high-voltage, high breaking capacity fuse. An accurate mathematical model will require exact estimates of pressure values inside the arc. Most of the models assume constant pressure that is not realistic in the fuse arc. Therefore, these models fall short in predicting the exact behaviour of these arcs.

The phenomena of generation and propagation of pressure when a fuse wire is exploded in air have been studied for a long time [1]. It is generally accepted that when a wire is exploded the instantaneous release of energy causes a cylindrical shock wave [2-4]. The generation of pressure associated with the HBC fuses was first addressed in the 1970's [5]. There have been several reports of pressure estimates inside the fuse arcs [6-8]. However, all these studies are restricted to the determination of the pressure values at the cartridge wall of the fuse. Empirical relations correlate these pressure values to the pressure inside the channel.

Our studies are related to the experimental determination of the pressure evolution inside the arc channel of a sand-filled high-voltage fuse. We have successfully measured the pressure inside the arc channel with the help of a piezoelectric pressure transducer that has a frequency response of 100 kHz.

III. EXPERIMENTAL SETUP

We have constructed an experimental model of a high-voltage, high breaking capacity fuse. It consists of a cylindrical ceramic fuse holder with length of 240 mm and diameter of 43.70 mm. Both ends of the fuse holder are fitted with metal end-caps and a uniform silver wire of 0.55 mm diameter is used as the fuse element. Pressure near the fuse element, after it had exploded, was transmitted to a transducer located outside the cartridge.

The fuse is energised using the synthetic test circuit as shown in Figure 1. A short-circuit prospective current was varied from 1 kA to 4 kA, in steps of 1 kA, by using different combinations of parallel inductors and capacitors. The capacitors were charged at 6 kV and the frequency of the waveforms of current through and voltage across the fuse was 50 Hz.

III. EXPERIMENTAL RESULTS

The voltage across the fuse was measured as a function of time by a resistive voltage divider: a Tektronix P6015, 1000:1, 20 kV, 100 MΩ voltage probe (rise time of 5 ns). Current was measured using a 190.8 A/V coaxial current shunt (rise time approximately 60 ns). The pressure developed inside the arc was measured using a piezoelectric pressure transducer. The pressure wave generates an electrical pulse in the transducer which, is calibrated in terms of pressure. The pressure signal in Figures 2-5 before the start of the arcing actually represents atmospheric pressure. Thus a correction was applied to values for pressure after the arcing. The pressure transducer was linked to the arc space through a high-temperature ceramic tube that was filled with glycerine. The function of glycerine is two-fold; first to transmit the pressure generated and second to protect the transducer from the high-temperature arc. When the arc burns in the fuse, the generated gas exerts pressure on one end of the tube that is transmitted through the filled glycerine to the transducer.

Voltage, current and pressure signals associated with the test fuse are recorded using a Nicolet Pro 42C digital oscilloscope. The measured pressures are from the radial forces. From the curves of the voltage across and current through the fuse, the energy and instantaneous power in the arc was calculated. These curves are shown in Figures 2-5.

VI. DISCUSSION

Disintegration of fuse element is associated with sudden release of energy that causes an arc to be generated. As a result, arc behaviour is determined by the development of pressure inside the HBC fuse. Lipski [7, 9, and 10] found out that there are two components to the pressure wave when the fuse interrupts a heavy current. One component is fast rising and due to the initial explosion. The other is slow rising and due to burn-back. The second component is more important when the fuse element contains constrictions. The wire melts first at the constrictions and then burns back. When the fuse wire is uniform, as in the present case, the second component is insignificant. The whole length of the fuse wire is subjected to erode simultaneously in this case and the pressure wave is dominated by the first component. Table 1 shows the results of our study. The peak pressure in column 2 corresponds to an explosion of the fuse element whereas pressure afterwards decreases very sharply and stays almost constant towards the arc extinction. This corresponds to the second component of pressure as discussed by Lipski. It is the pressure shown in column 8. It is evident that both values of pressures are proportional to the arc's prospective current and energy. Peak values of pressure are proportional to maximum values of instantaneous arc power. Maximum values of pressure lags almost between 0.2 ms to 0.3 ms behind the peak instantaneous power. This delay underlines the importance of thermal storage in the molten phase [6].

Table 1: Summary of results for pressures, arc energy and speed of pressure shock waves at different prospective currents.

Prosp. Current (kA) (1)	Peak pressure (bar) (2)	Time between arcing and press. signal (ms) (3)	Max. inst. power (MW) (4)	Time lag between (2) - (4) in ms (5)	Arc energy (kJ) (6)	Initial slope of (6) (kJ/ms) (7)	Press. at current zero (bar) (8)	Speed of the press. wave (m/s) (9)
1	16.54	0.200	4.10	0.240	2.123	3.395	1.32	425
2	25.58	0.120	7.35	0.222	6.690	5.242	1.48	708
3	45.63	0.110	10.90	0.275	13.080	8.850	1.72	773
4	55.64	0.108	12.46	0.199	17.870	9.235	2.35	787

Column 3 of Table 1 shows the time between the arc initiation and the rising of the pressure wave. In each of the tests, the length of the ceramic tube used was 85 mm. Thus we can calculate the speed of the pressure shock wave detected by the pressure transducer. These values shown in column 9 of Table 1 are dependent upon the arc energy (and prospective current); the higher the arc energy the larger the speed of the spherical shock wave generated. These values are to be compared with 700 m/s, a value calculated by Yukimura et al [11]. These authors used a copper wire exploded in air with a test energy that was very low as compared to that used in our study. According to Barbu [12], the pressure is less dependent on the electric arc energy than on the shape and dimension of the interruption arc itself. Our study reveals that the pressure is strongly dependent upon arc energy when physical parameters of the fuse i.e., size and shape of the wire, fuse cartridge and filler are not changed.

Our measurements show that the peak of the pressure wave follows almost immediately the arc initiation and the magnitude of the peak depends upon the energy to be dissipated in the arc. We have recorded the pressure peak above 50 bars when the fuse was energised at 6 kV, 50 Hz, for 4 kA prospective current.

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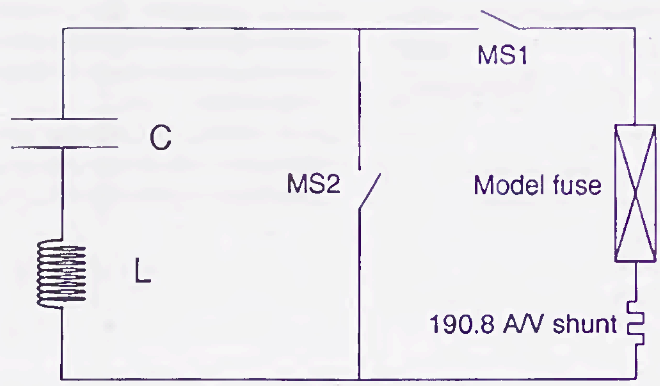

Figure 1: Electrical circuit to energise the test fuse.

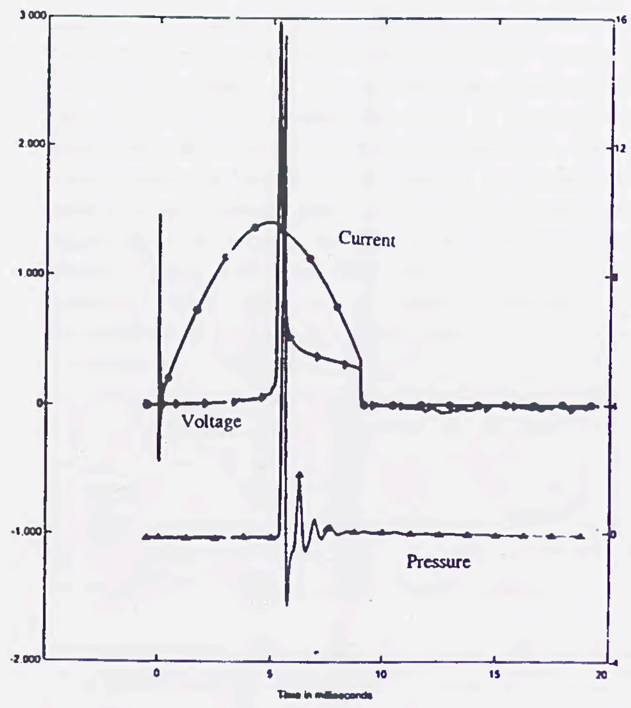

Figure 2A: Plots for current and voltage (on left side) and pressure (on right side) for 1kA prospective current.

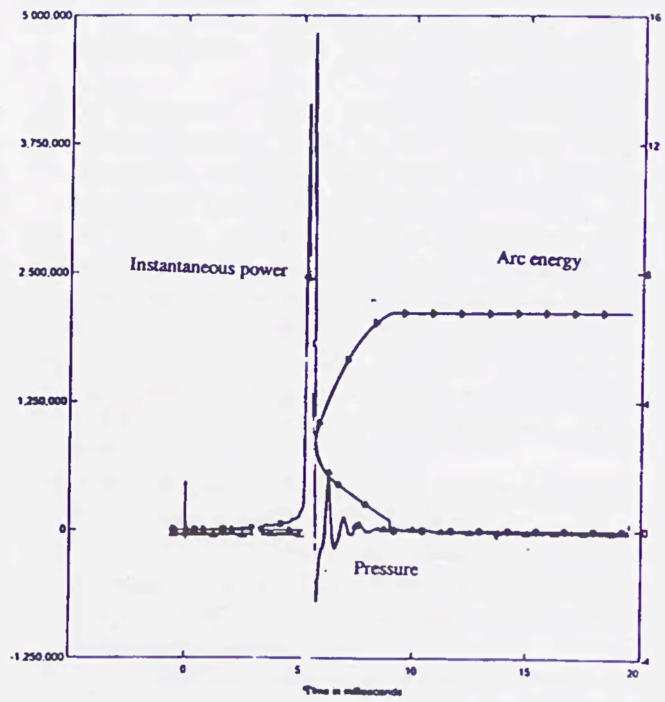

Figure 2B: Variation of pressure (right side) with instantaneous arc power and arc energy for 1 kA prospective current.

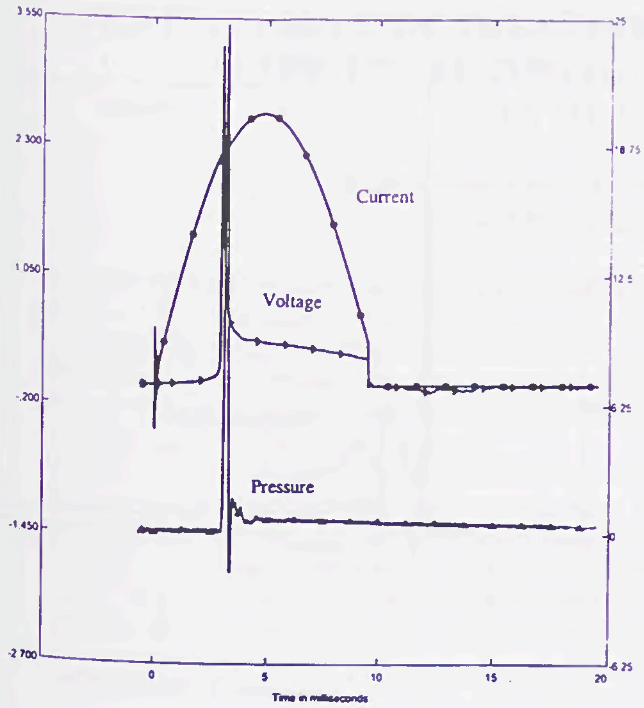

Figure 3A: Plots for current and voltage (on left side) and pressure (on right side) for 2kA prospective current.

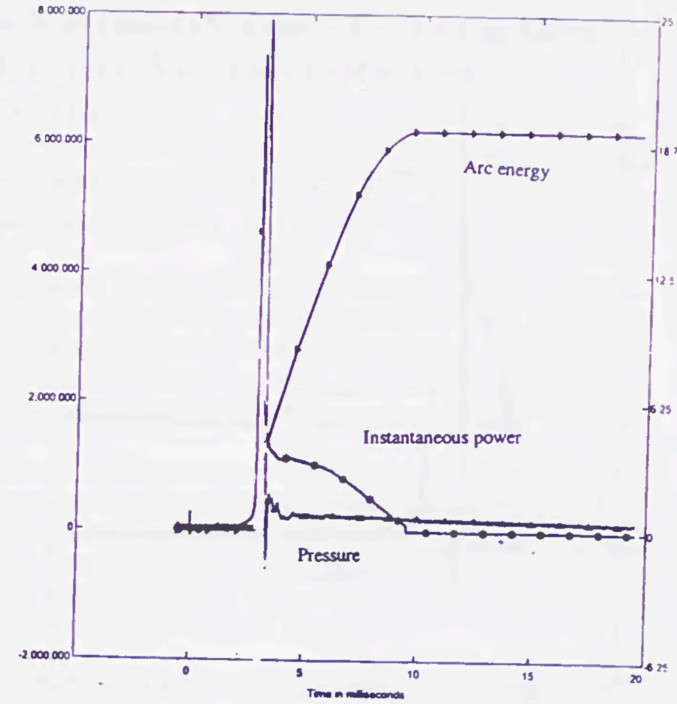

Figure 3B: Variation of pressure (right side) with instantaneous arc power and arc energy for 2 kA prospective current.

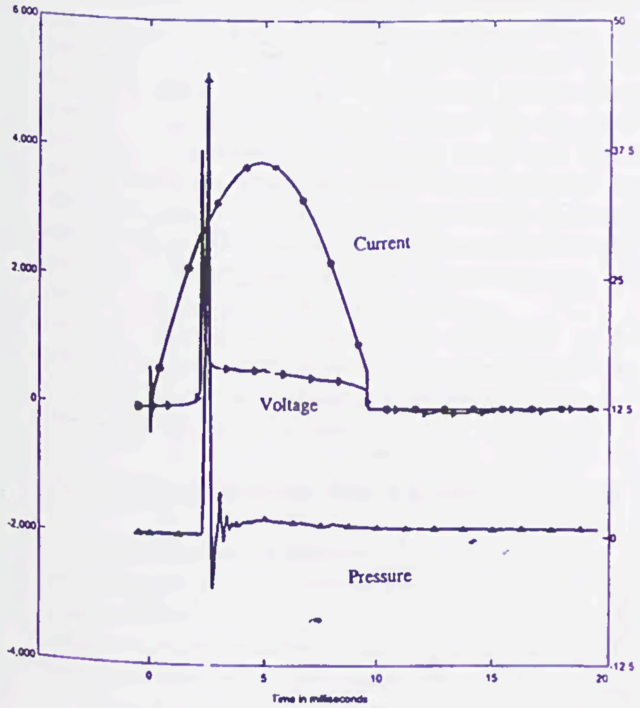

Figure 4A: Plots for current and voltage (on left side) and pressure (on right side) for 3 kA prospective current.

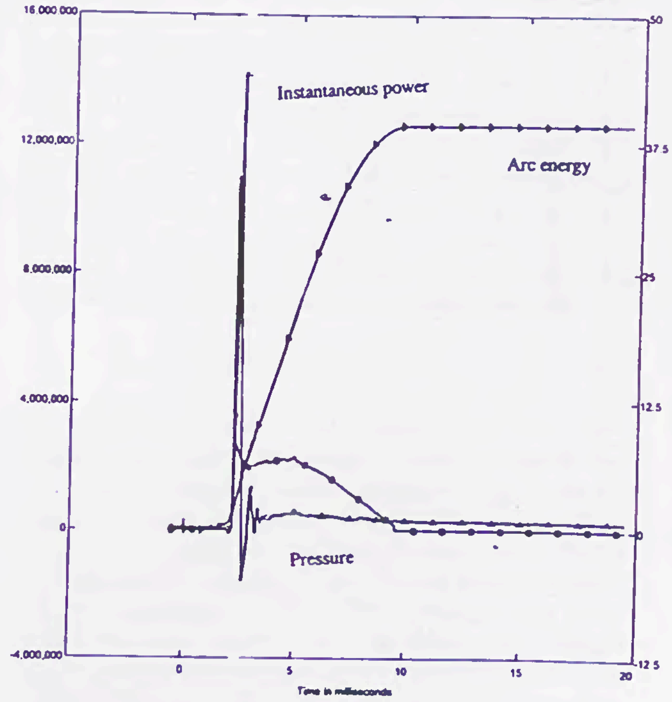

Figure 4B: Variation of pressure (right side) with instantaneous arc power and arc energy for 3 kA prospective current.

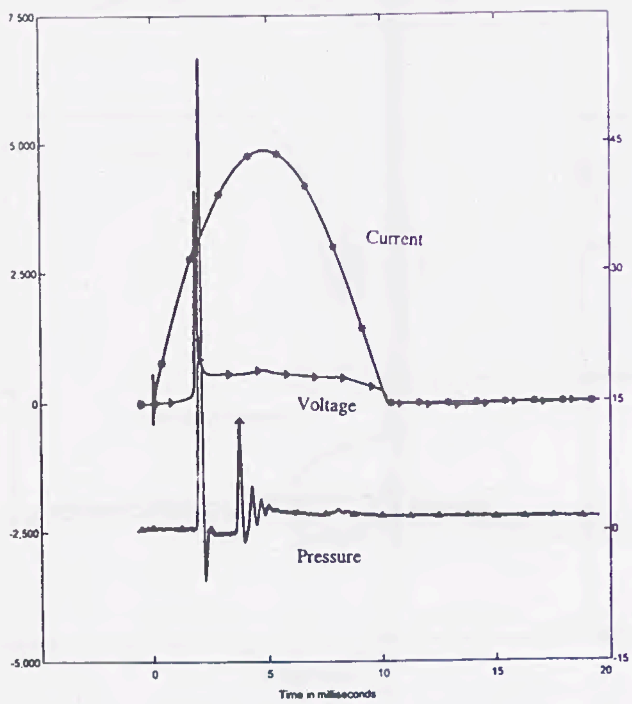

Figure 5A: Plots for current and voltage (on left side) and pressure (on right side) for 4 kA prospective current.

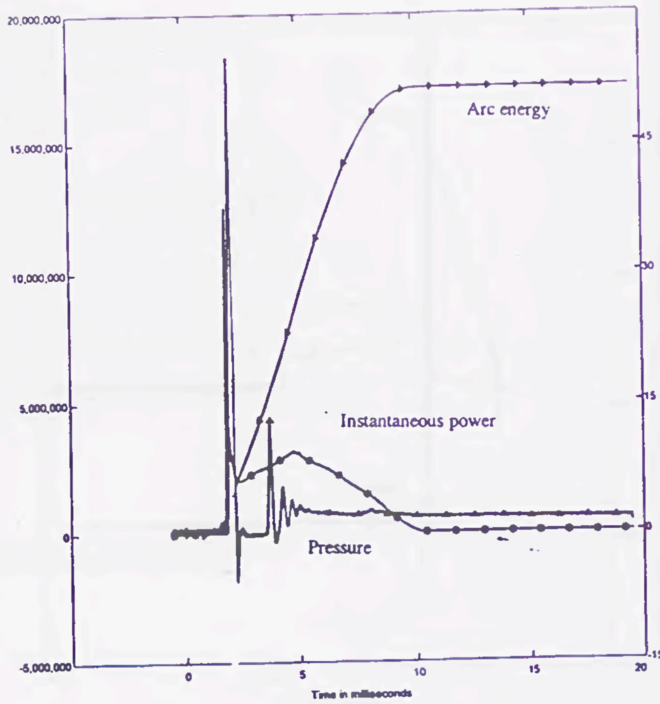

Figure 5B: Variation of pressure (right side) with instantaneous arc power and arc energy for 4 kA prospective current.