Spark Light Source of Short Duration*

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A simple spark-gap light source together with an associated pulsing circuit has been utilized to produce light flashes of approximately 10^{-7}-sec. duration suitable for the study of shock waves produced by high speed bullets and for the photography of shock and turbulent disturbances in supersonic air streams.

THE detail revealed in schlieren and shadow photographs of rapidly moving objects depends upon the total time of illumination of the object. The shorter the light flash the better the detail, provided that light energy sufficient to activate the photographic emulsion is available. In the study of turbulence and phenomena in boundary layers very short exposure photographs are certainly of value, and motion pictures at a high repetition rate with very short exposure times are of particular interest. With these advantages in mind a source has been devised which produces light flashes of approximately 10^{-7}-sec. duration and has sufficient intensity for ordinary photographic purposes.

The source consists of a conventional spark gap operating in air at atmospheric pressure, which is energized by a pulsing circuit capable of supplying high current for a short time and then reducing the current to zero, or to a very small value.

It is well known[1] that in the ordinary type of spark discharge the spectral lines due to the gas (principally spark lines when air is used) appear first, followed by the spark and arc lines characteristic of the electrode material. The spectral lines of the gas are emitted with relatively high intensity during the high potential stage of the discharge before the low voltage arc is formed. That is, the first light emitted by the spark originates in the gas surrounding the electrodes. As the discharge progresses, vapor of the electrode material is formed on the electrodes and moves toward the center of the spark gap. This vapor gives rise to the spark and arc lines characteristic of the electrode material. At small gap spacings and minimum field strengths the transition from the high potential to the arc discharge takes probably from 1 to 5×10^{-8} sec. This time is not to be confused with the lag of the spark, but refers to the time taken by the discharge when once started to change from a high potential to a low potential arc type. This time can, of course, be made much longer by increasing the electrode separation, using extremely non-uniform fields, etc.,[2] but for two electrodes with a reasonably uniform field distribution and a gap spacing of one centimeter, it can be made less than 5×10^{-8} sec.

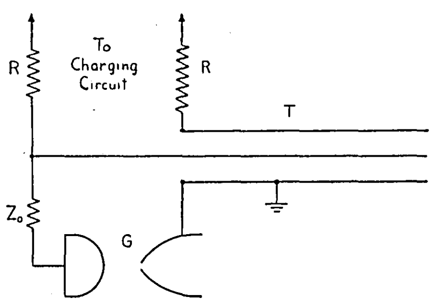

FIG. 1. Schematic diagram of spark-gap light source, G, and associated coaxial transmission line, T, for producing short current pulse. R—charging resistances. Z_0—resistance equal to surge impedance of line T.

In this work an attempt was made to reduce the current through the gap to zero or to a very small value as soon as the arc-type of discharge was formed and consequently limit the length of the current pulse to the high voltage transition period. After the removal of the external field there are, of course, various decay processes which prolong the light emission. However, these have not proved to be serious provided light flashes of 10^{-7}-sec. duration are considered satisfactory.

* This work was supported by the Bureau of Ordnance of the Navy under Contract NOrd-7873.

[1] J. W. Beams, Phys. Rev. 35, 24, (1930).

[2] L. B. Snoddy, J. R. Dietrick, and J. W. Beams, Phys. Rev. 52, 739 (1937).

The transition period probably could be decreased and the light emission increased by overvolting the gap. It is known[3] that the field strength in a gap in air at atmospheric pressure can be maintained at about 16 times the minimum value for periods up to 10^{-6} sec. without breakdown provided the gas surrounding the electrodes is free from dust nuclei, ions, etc. If during this period of high field the discharge is initiated by the liberation of an electron at the cathode surface, the light intensity should be greatly increased and the transition period decreased. While this gap would seem to have decided advantages, it was not necessary to use it in this preliminary work.

The circuit used is shown in Fig. 1. It consists of a transmission line, open ended at the output end, and shunted at the input end by a spark gap in series with a resistance equal to the surge impedance of the line. The line is charged initially from a conventional rectifier circuit with the charging current limited by high resistances to a few milliamperes. For random flashes, the line is charged slowly until the spark gap discharges. If it is necessary to have the gap discharge at approximately constant potential the gap electrodes should be made of photosensitive material and irradiated by ultraviolet light.

The operation of the circuit is simple in principle. When the spark gap breaks down a discharge wave travels from the input to the output end, is reflected at the output end, and returns to the input end reducing the potential of the line to zero. This of course implies that the spark-gap resistance has decreased to a value low compared to the characteristic impedance of the line by the time the reflected wave returns to the input end. If this is not the case, there will be reflection at the input end and the discharge will be prolonged. This means that the time length of the line should be at least as long as the transition period of the discharge. To increase the intensity of the light two or more transmission lines can be connected in parallel using one gap to discharge the combination. In this case, each line should be connected separately to the gap electrodes through a resistance equal to its characteristic impedance. It is ex-

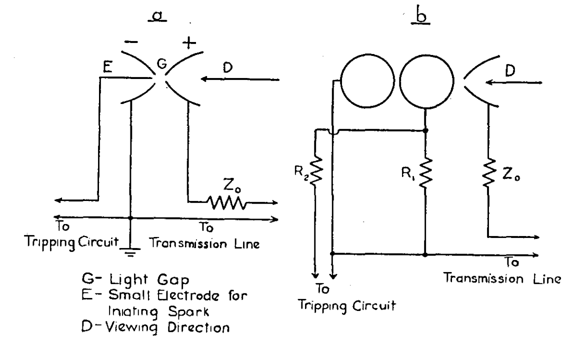

FIG. 2.

tremely important to keep the length of the connecting wires at an absolute minimum and to use non-inductive resistors in the discharging circuit. The gap used in this work was the conventional cone type with the discharge viewed in the axial direction through a small hole in one electrode.

If it is necessary to synchronize the light flash with other events, the gap can be tripped by any of the usual devices. Two possible arrangements are shown in Fig. 2. With either method the flash can be started within 10^{-6} to 10^{-7} sec. of any desired time. However, to produce accurate tripping the synchronizing potential pulse must have a steep front and an amplitude sufficient to raise the field strength in the gaps considerably above the minimum sparking value.

With a transmission line of about 10^{-7}-sec. electrical length (i.e., 10^{-7} sec. is the time required for the discharge wave to travel from input end to output end and back to input), the

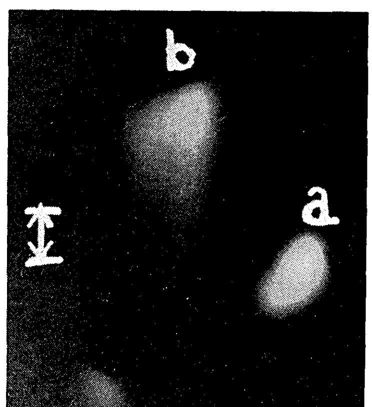

FIG. 3.

[3] J. C. Street and J. W. Beams, Phys. Rev. 38, 416, (1931).

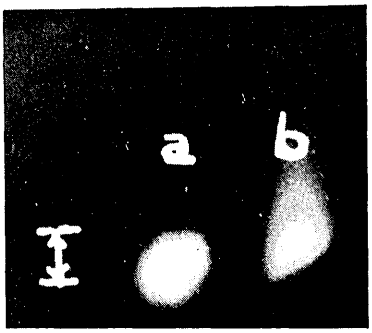

FIG. 4.

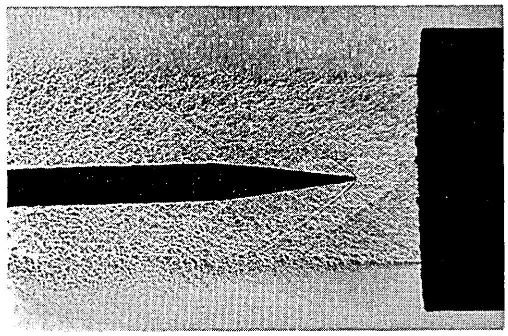

FIG. 5. Metal probe, diameter $\frac{3}{16}''$, in supersonic free jet. Mach number approximately 1.8.

duration of the flash was determined by the use of a high speed rotating mirror. The mirror was carried by an air turbine and rotated at 1500 r.p.s. The mirror-to-image distance was 9 feet.

The duration of the flash was determined by allowing the spark image to sweep across a photographic film. Since it is necessary to use a lens in this determination, there might be some question as to whether or not this corresponds to the actual experimental arrangement used in most shadow photography. In order to investigate this point, photographs were taken using quartz and glass lenses. Figure 3 was taken with a quartz-fluorite combination and Fig. 4 with a corrected glass lens. Two pictures are shown on each film, (*a*) with the mirror stationary and (*b*) with the mirror revolving at 1500 r.p.s. The distance marked by the arrow in each case represents 10^{-7} sec. In neither set of photographs does the light have any appreciable effect after 10^{-7} sec.

The electrical constants of the circuit are given below:

$$R = 2\times 10^6 \text{ ohms},$$
$$Z_0 = 52 \text{ ohms},$$
gap voltage = 20,000 volts,
diameter of hole in light gap = 0.020 in.

The transmission line T consisted of 9 feet of cable An no. RG8/U. Actually two lines were connected in parallel for most of these experiments.

This source has been used in our laboratory for the photography of various phenomena. The detail revealed by using a light source of short duration is well illustrated in Fig. 5 which is a typical photograph of the disturbances in a supersonic free jet. The nozzle used in this experiment was designed for a Mach number of 1.83.

It is clear that the above type of electrical circuit in various modifications can be applied to other than the simple spark-gap light source described above. Also that, if necessary, the length of the light flash produced can be made much longer by employing an artificial instead of a real transmission line.