ELECTRONIC FLASH PHOTOGRAPHY

A SURVEY OF PRINCIPLES AND PRACTICAL TECHNIQUES IN INDUSTRY, RESEARCH AND RADIOGRAPHY

by

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PREFACE

THE importance of the flash discharge tube as a light source for the photographic study of transient events and for application to night aerial photography was appreciated during the war. As a result of experience gained during this period and subsequent developments the modern flash tube is now employed in almost every branch of physics and engineering, serving as an indispensable research tool in government establishments and industrial organizations the world over.

Deceptively simple in appearance, the electronic flash tube is the most complex artificial light source known. It is also the most flexible. Given suitable tubes and circuitry one may illuminate several square miles of territory with a single flash, or, on the other hand, capture a sequence of incidents taking place in the lifetime of an event which may last for only a few millionths of a second. Recording the 'unseen' in this way provides technical information which cannot be secured by any other means, opening up a new and fascinating field with endless possibilities for original work. Although the apparatus necessary for many investigations is much too elaborate and costly to be borne by the individual, certain technical problems do come within the scope of the private experimenter. Their solution demands ingenuity together with a knowledge of fundamental processes rather than elaborate equipment.

This book introduces the many techniques now in use or being developed in flash photographic and radiographic practice, giving a condensed survey of the present state of the art, with selected references for the assistance of those technicians or engineers who require information on the subject but who specialize in other directions.

Theoretical outlines of principles involved have been given briefly in various sections in the hope that this will, together with the examples of practical work, present a picture of the technique as a whole which will be found of value to every reader who wishes to get the most out of existing equipment or extend the scope of his work.

A book of this nature necessarily records the investigations of many, and grateful thanks are due from the author to his colleagues at the Royal Aircraft Establishment, to Dr Harold E. Edgerton of the Massachusetts Institute of Technology, U.S.A., the Westinghouse Company, U.S.A., Recherches Mécaniques et Physiques, Paris, Dr J. N. Aldington of Siemens Ltd.,

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Also, the author's thanks are due to his wife who, in the early days during the war, assisted in taking some of the pictures reproduced herein.

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CHAPTER ONE

THE DEVELOPMENT AND PURPOSE OF ELECTRONIC FLASH PHOTOGRAPHY

REFERENCES to the electric spark are to be found in the records of Hawksbee's experiments on low-pressure phenomena, written in the early part of the eighteenth century, and from that time until the present day the study of the electric discharge through gases has continued; a research extending over two hundred years but accelerated from time to time as new and important scientific discoveries have been made. These milestones of progress are not without interest.

The transient nature of the spark in air was recognized in the very early days. Fox Talbot patented its application to instantaneous photography in 1851[1]; the principle was used for taking pictures of bullets in flight by Professor E. Mack at the University of Prague in 1881; and by Sir Charles Vernon Boys[2] in this country in 1893. Over a hundred years ago Fox Talbot employed the high-voltage discharge as a light-source to photograph a few square inches of rapidly-rotating newsprint—the first recorded demonstration of high-speed photography.

Fundamentally the technique has not changed; the light required for these early experiments was obtained by discharging a Leyden jar—an early form of high-voltage capacitor. When electric energy stored in this way is released suddenly across an air gap, the result is a noisy blue-white spark, rich in actinic radiation: a very short-duration light pulse which has, and will continue to have, important applications in specialized branches of scientific photography. The amount of light provided by the spark in air is inadequate for the illumination of extended objects, but if the open gap is replaced by a glass or quartz tube containing a suitable gas at the correct pressure, the capacitor discharge may be made to generate a brief flash of light of very great intensity.

Experiments with discharge tubes were being conducted at the Royal Institution in 1821, and the idea of discharging a capacitor through a tube under reduced pressure is as old as photography. The high-speed flash tube in a primitive form is therefore a very old device but the production of the modern tube was delayed for a long period until many problems associated with the development of gas-filled lamps for general lighting purposes had been overcome.

It is probable that much of the enthusiasm of the early workers in this field was due to the beauty of the phenomena which may be produced so readily by passing a high-voltage discharge through a partial vacuum.

Geissler made the complex and attractive tubes which bear his name for Plücker, who was engaged in investigating the phenomena in 1838. A typical example, which was photographed in operation, is shown in Fig. 1. Geissler tubes, often of the most intricate design, at first contained merely air under reduced pressure. Subsequently various gases and vapours were used to provide a range of colours which it would be difficult to surpass today.

Such tubes, operating from a small spark coil, were for many years of scientific interest only, and long development was necessary before Moore, towards the end of the last century, succeeded in employing carbon dioxide and nitrogen for commercial lighting purposes in America. Carbon dioxide gives a soft white light approximating to daylight; nitrogen a golden yellow. The large-diameter tubes used were often several hundred feet in length, the sections actually being joined up by glass blowers on the site where the lamp was erected. Afterwards the tube was pumped and filled with gas to the required pressure.

The practical success of the Moore light was due to a very ingenious valve which automatically admitted fresh gas into the tube to maintain the pressure at its normal value. All the common gases—and no others were available at this period—are chemically active and if any combination with tube or electrode materials is possible the gas pressure may decrease until the resistance is so high that the tube fails to function.

Moore's system of replenishing the lost gas was one solution to the problem. The next step forward followed the investigations on the constituents of air by Raleigh, Ramsay and Travers, and resulted in the discovery and isolation of the five noble gases—helium, neon, argon, krypton, and xenon. These gases are all inert and will not combine chemically with any other element; also, they are readily ionized and better conductors in a discharge tube. The importance of gases with such desirable qualities was quickly realized and experiments with them marked the beginning of a new development in discharge-tube techniques.

By 1910, neon-filled tubes were in general use. The employment of neon, also helium and argon, in lamps, advertising signs, and electronic valves of various kinds, is now familiar to everyone. Argon is often employed as the filling in high-speed flash tubes, the other important gases being krypton and xenon. These gases, which give a purple or blue light under low currents are of little use for lighting purposes but under the high current densities present in a flash discharge they become very efficient. The radiation characteristics are changed completely, the pulse of light being white and of great intensity. Krypton and xenon are the rarest of the gases, being present in air in very small quantities indeed (krypton 0·000015 per cent. and xenon 0·000003 per cent.).

With increasing knowledge of fundamental discharge-tube processes, modern high-vacuum techniques, new hard glasses, new glass and quartz to metal seals, and the growing need in scientific research for new methods of high-speed photography, the rebirth of the flash tube was inevitable. The work of Professor Edgerton in the pre-war years[3–5] led to the development in America of the first commercial tubes, and 1939 saw the publication of a magnificent series of high-speed flash pictures[6] illustrating the possibilities of the new light-source in both single flash and stroboscopic applications.

A tube is said to be 'strobed' when it is flashed repetitively at short intervals, the pulsing light being used either for visual observation of

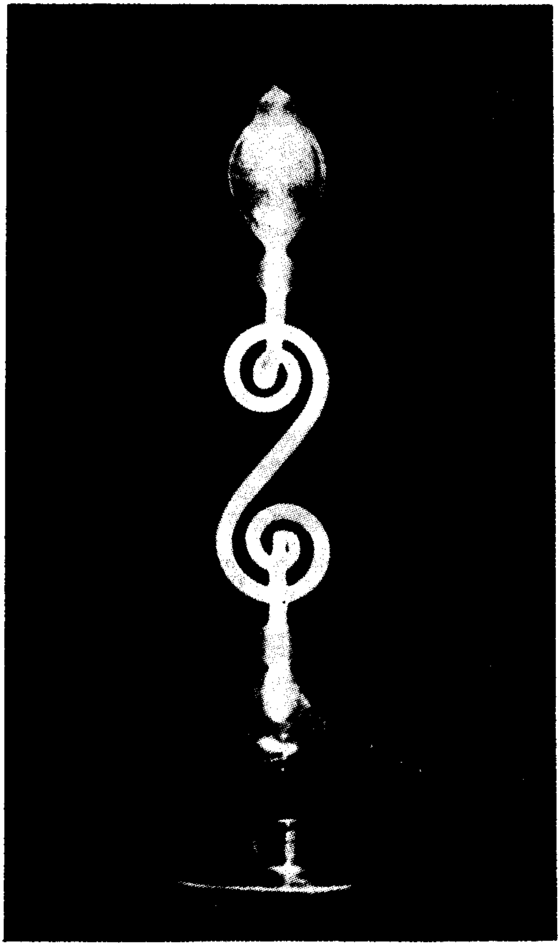

Fig. 1. A typical Geissler tube in operation.

mechanisms or to record photographically a sequence of pictures. With few exceptions the tube is triggered by a high-voltage pulse initiated either by contacts in the camera which synchronize the flash to the shutter open position, or by external circuitry which will synchronize the light-pulse to any given phase of an event.

The stored energy in a capacitor available for discharge through a flash tube is proportional to the capacitance and the square of the terminal voltage, and is given by the equation

$$E = CV^2/2 \qquad (1.1)$$

where E = the energy in joules (J) (= watt-seconds (W-sec)),
C = the capacitance in farads (F),
V = the voltage on the capacitor.

Flash tubes are rated in joules for single discharges at intervals long enough to prevent overheating. For strobing they are rated in watts mean dissipation (the product of capacitor energy and flashing frequency) or

$$W = En \qquad (1.2)$$

where W = power in watts (W),
E = the capacitor energy in joules (J),
n = the flashing frequency in cycles/second (c/sec).

Neglecting circuit losses the capacitor energy is discharged through the tube to appear in the form of heat and light. Thermal losses are high. The radiation component, which is useful, depends upon the gas content and other factors. Spectral quality may closely resemble daylight, being ideal for colour photography. On the other hand, the light may be rich in blue: photographically very efficient but unsuitable for colour. Again, the light quality depends upon the time taken to dissipate the stored energy. A hundred watt-seconds (an average capacitor storage for a portable flash unit) discharging at the rate of a hundred watts for one second would be quite useless as a light-source. The flash tube, however, has a very low impedance and 100 J of energy may readily be dissipated in one five-thousandth of a second. For this short period the power level is 100/0·0002 or 500,000 W. Both peak current and light intensity during a flash discharge are therefore extremely high.

Krypton was largely used as a filling in the early days because xenon, which has a higher luminous efficiency, was difficult to procure. An increased supply of this gas was made available during the war, however, and in this period British lamp manufacturers and government establishments developed a great variety of specialized tubes for research purposes. One of the most important of these was the 'Arditron', an argon-filled ultra-high-speed tube capable of producing flashes with an effective duration of one or two millionths of a second. This, the first of the microsecond region tubes, was developed at the Armament Research Establishment for ballistic photography. An early model is seen at (6) in Fig. 10 (page 24).

While experiments in this direction were taking place the United States Air Force demanded an extremely high-power flash tube for night aerial photographic reconnaissance, providing an amount of light sufficient to take pictures from an altitude of at least 5,000 ft. At this period it was not known whether the requirement could be met. Such a tube was produced, however, together with the associated electrical gear, by Dr Edgerton and his associates at the Massachusetts Institute of Technology, in the United States of America.

In the United Kingdom an equally powerful tube was developed for the same purpose by Dr J. N. Aldington at the Siemens Lamp Research Laboratory, to be followed by many special forms to meet specific technical requirements[7–9]. As a matter of interest, the first Siemens high-power quartz tube produced is illustrated at (1) in Fig. 10. The development of powerful aircraft installations presented many problems,[10] a very considerable amount of research and extended night-flying tests being necessary before the technique could be applied to operational use, but before the end of hostilities electronic flash had been used successfully on nearly all fronts.

The largest airborne unit produced, the American D.5, is shown in Fig. 2. The total weight is 3,700 lb. Two flash tubes are employed in this installation, each mounted in a large reflector assembly shown at (4). The tubes consist of 30 in. of $\frac{1}{2}$ in. diameter quartz tubing coiled into a helix and filled with xenon at a pressure of one-sixth of an atmosphere. The 6,000 microfarad (μF) capacitor bank (3) operates at 4,000 V, storing 48,000 J, and weighs one and a half tons. This is charged by the inverters and rectifier unit shown at (1) and (2) and flashes may be repeated at intervals of 15 sec. The tubes are fired by synchronizing contacts in the aerial camera (5), the whole installation being operated from the remote control box (6).

Under favourable atmospheric conditions this big unit has taken excellent pictures from altitudes in excess of 10,000 ft, using a lens aperture of $f/2{\cdot}5$. A typical night air photograph is reproduced on page 7.

Such powerful equipment is not required in photographic aircraft operating at lower altitudes and high speeds. These conditions require a shorter flash and a smaller capacitor. A considerable amount of operational work on anti-submarine missions was undertaken at a height of a few hundred feet with single-lamp units very much smaller than the D.5.

The high-energy flash tube has numerous applications in the scientific and commercial field. Powerful installations have been used in public buildings for the recording, especially in colour, of important events. Smaller units are manufactured to give a wide range of light energies and