HIGH SPEED PULSE TECHNOLOGY

FRANK B. A. FRÜNGEL

Volume IV

Sparks and Laser Pulses

VOLUME IV

SPARKS AND LASER PULSES

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High Speed Pulse Technology

VOLUME IV

SPARKS AND LASER PULSES

High Speed Pulse Technology

I CAPACITOR DISCHARGES, MAGNETOHYDRODYNAMICS, X-RAYS, ULTRASONICS

II OPTICAL PULSES, LASERS, MEASURING TECHNIQUES

III CAPACITOR DISCHARGE ENGINEERING

IV SPARKS AND LASER PULSES

Preface

The lightning flash is nature's most spectacular light pulse. Generally speaking, all optical radiation which is not continuous has more or less the characteristics of pulsed light. Even the shutter of an ordinary camera permits the passage of only a limited fraction of light—in a sense, a light pulse. The photographic applications of light pulses have been dominant for more than a century.

Pulses of light are like bullets of radiation energy. They generate high peak power when they meet an absorber, but they consume comparatively little energy relative to the repetition rate. Because of their high peak power, sparks are much hotter and emit shorter wavelengths than do continuous light sources of the same average power. The radiation power emitted by high intensity xenon short arc lamps may reach the kilowatt range, spark light pulses in the visible or ultraviolet range produce megawatts, and the peak power of big laser systems with multistage amplifiers seems to be unlimited. The basic technologies of strobe lights, flash lamps, and the first lasers have been described in Volume II of this monograph.

During the past 18 years a new type of light pulse for which there is no example in nature has been discovered, namely the laser pulse and its sophisticated Q-switch techniques, which open up a whole new world in optical radiation. This volume concludes with the most recent work on laser fusion experiments.

The aim of this volume is to give a comprehensive account of light pulse research and technology for the period from 1964 (when Volume II of High Speed Pulse Technology was published) to mid-1978.

Another important application of light pulses is optical signal transmission, for example, the measurement of cloud heights and atmospheric visibility (Volume II, Chapter L). However, the field of lidars, atmospheric measurements, transmission of pulses, and optical signal degradation has diversified so much that I intend to deal with it in a special volume of High Speed Pulse Technology.

Naturally, the research and development work that we at Impulsphysik GmbH and Impulsphysics USA have performed over the past 14 years is described in more detail, while in excerpting the large number of papers by other scientists I have tried not to "mutilate" them but to summarize the essentials of each publication, so that the interested reader can refer to the complete text of any article that is of particular importance to him.

In this sense one may say that the register and the references quoted will certainly be the most valuable parts of this book, more valuable than the table of contents, because many problems will touch various techniques so that relevant information may be found under several terms.

I wish to thank Mr. Horst Patzke and my daughter Uta for their valuable assistance in compiling and writing this book and my wife Ursula for her help and patience.

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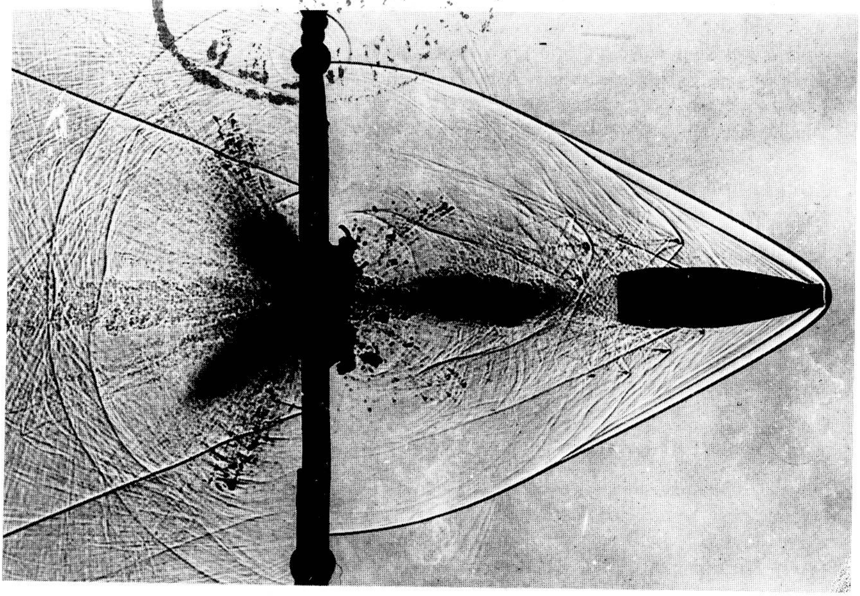
VOLUME III

A. The capacitor, its characteristics and its applications in discharge circuits

B. Switching means

C. Line conductors

D. Conversion of capacitor energy into current impulses



Shadowgraph of a bullet passing through a paper board. Taken at the Military Academy of Belgium by a 14 nsec Fischer Nanolite spark in air.

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6. Visualization of flows, cracks, and particles

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1. Motion analysis of rapid events by white light pulses

1a. Classification of Photographic Methods of High-Speed Analysis

Two large organizations have been influential in the development of instruments and principles: the Society of Motion Picture and Television Engineers (SMPTE, formerly SMPE) and the Society of Photo-Optical Instrumentation Engineers (SPIE). John H. Waddell, a senior scientist specializing in high-speed photography, gave [1365] an introduction to this particular field in which he stated:

When one has spent the greater part of a lifetime in engineering and scientific photography and then is asked to define "High Speed Photography," the approach can be made two ways—either the prosaic approach or the personal definitions based on experiences covering forty years.

A bullet in flight is too fast for the eye to see. If a motion picture were made at a conventional speed of 16 or 24 pictures/sec, the bullet would not be recorded by the camera but, if the camera speed were increased manyfold, discrete sequentially exposed pictures would result. These pictures could be analyzed one by one or, as was probably done with early pictures, specially printed so as to be projected as a motion picture.

Two definitions can be derived from the above observations. High-speed photography is a photochemical process with which a permanent record can be obtained of a phenomenon occurring too rapidly to be observed visually or to be recorded by conventional photographic techniques. A high-speed photograph is a discrete pictorial record of a phenomenon which has an exposure time of 1.0×10^{-4} sec or less.

The high-speed photographic committee of SMPTE defined various types of high-speed photography in 1948. Improvements in equipment and performance, primarily in mechanical shutters and in the maximum picture-taking rate of intermittent cameras, have necessitated the upgrading of some of the limits. Table 1a-1 reflects these changes for discrete photographs, sequential pictures, motion pictures, and streak photographs.

The minimum number of exposures is two. Rates are expressed in pictures per second. If only two pictures are made with a microsecond interval, the sequential rate is 10^6 pictures/sec. The Russians have built a camera capable of taking 3.3 ×

TABLE 1a-1

TIME INTERVALS AND MAXIMUM PICTURE-TAKING RATES [1365]

Speed	Photograph (sec)	Sequential (sec^{-1})	Motion picture (sec^{-1})	Streak
High	1×10^{-4}–1×10^{-5} or $<1 \times 10^{-4}$	>500 exposures	>500	$<7.5 \times 10^{4}$ mm/sec (250 ft/sec)
Very high	1×10^{-5}–1×10^{-6}	2×10^{4}–5×10^{5}	4×10^{-4}–5×10^{5}	7.6×10^{4}–5×10^{5} mm/sec
Ultrahigh	$<1 \times 10^{-6}$–10^{-12}	$>5 \times 10^{5}$–10^{9}	$<5 \times 10^{5}$	$>5 \times 10^{5}$ mm/sec

10^7 pictures/sec. If 1 sec worth of 16-mm film were used, the footage would be 825,000 ft. In practice, for such cameras, the sequence is limited to about 20 pictures.

At times there will be overlaps in terminology. For example, time-lapse pictures may be made of the opening of a flower. If an electronic flash is used as an illuminant to prevent wilting of the flower due to heat, these are considered high-speed photographic studies.

a. *High-Speed Photographic Instrumentation and Systems*

Those who plan to use high-speed photography must remember that this is a systems concept. The photographic system is composed of a number of subsystems:

(1) The camera subsystem
- (a) Still camera (single exposure)
- (b) Multiple-chambered still camera
- (c) Sequential camera
  - (1) Fixed film with a rotating mirror
  - (2) Rotating drum with a fixed mirror
  - (3) Pulse-operated camera
  - (4) Image dissection camera
  - (5) Image converter camera
- (d) Motion picture camera
  - (1) Synchronized electronic flash continuous camera
  - (2) Rotating-mirror continuous camera
  - (3) Rotating-lens continuous camera
  - (4) Rotating-prism camera
  - (5) Intermittent camera provided with a synchronizer for a light source and/or a high-speed shutter