Radiography at High Speed

LOUIS F. EHRKE
ASSOCIATE AIEE

CHARLES M. SLACK
NONMEMBER AIEE

Development of a cold-cathode X-ray tube makes it possible to make records on film of distortion inside objects opaque to visible light, thus supplementing high-speed photography

THE interesting results attained by ultrahigh speed or flash photography are well known to newspaper and magazine readers everywhere. Distortion due to momentary strain can be shown in many familiar objects, such as golf balls and rapidly vibrating open relays. A new technique using X radiation instead of visible light makes it possible to record distortion or change in the interior of opaque objects as well as that visible on the outside.

To make such radiographs at speeds of about one microsecond, enormous currents must be passed through the X-ray tube for that very short time interval. In the conventional hot-cathode X-ray tube, the available electron current is definitely limited by safe cathode temperature and space-charge effects. These limitations are avoided by the use of a cold-cathode X-ray tube recently developed in the Westinghouse lamp research laboratories at Bloomfield, N. J.

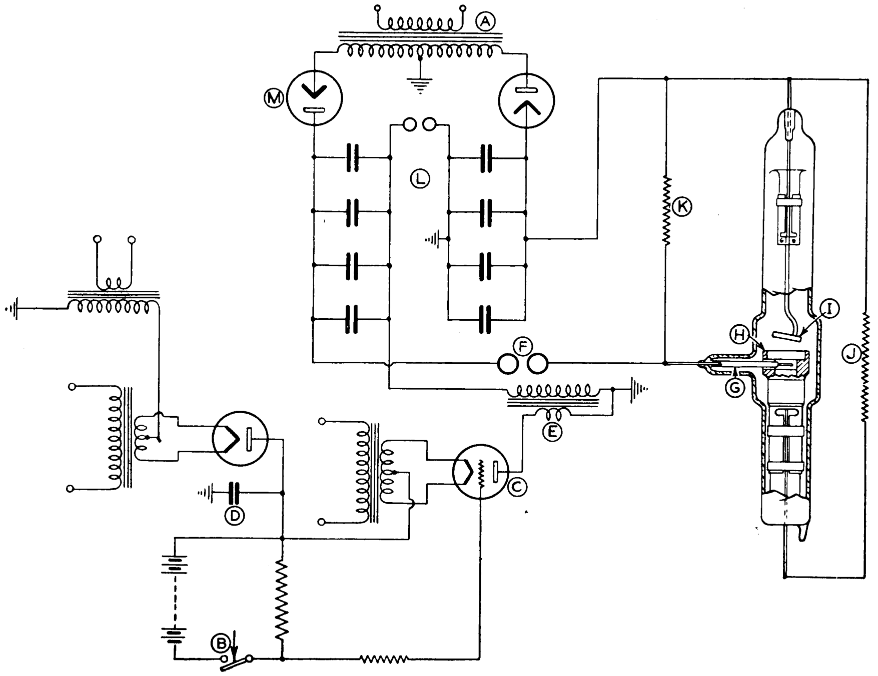
In place of the conventional filamentary cathode, this tube employs a pair of cold electrodes *G* and *H* (figure 1). *G* is the true cathode and is so shaped and located with respect to its auxiliary electrode *H* that enormous potential gradients are built up when voltage is applied between these electrodes. Under the influence of these high gradients, a copious supply of electrons is obtained by cold emission from electrode *G*. Currents of from 1,000 to 2,000 amperes pass through the tube for periods of about one microsecond. The X-ray energy produced under these conditions is sufficient to produce radiographs of many objects in this short time interval, and consequently rapidly moving objects may be radiographed without blur caused by motion.

LOUIS F. EHRKE and CHARLES M. SLACK are research engineers with the Westinghouse Lamp Division, Bloomfield, N. J.

Figure 1. Circuit diagram of the new ultrahigh-speed X-ray tube and auxiliary equipment

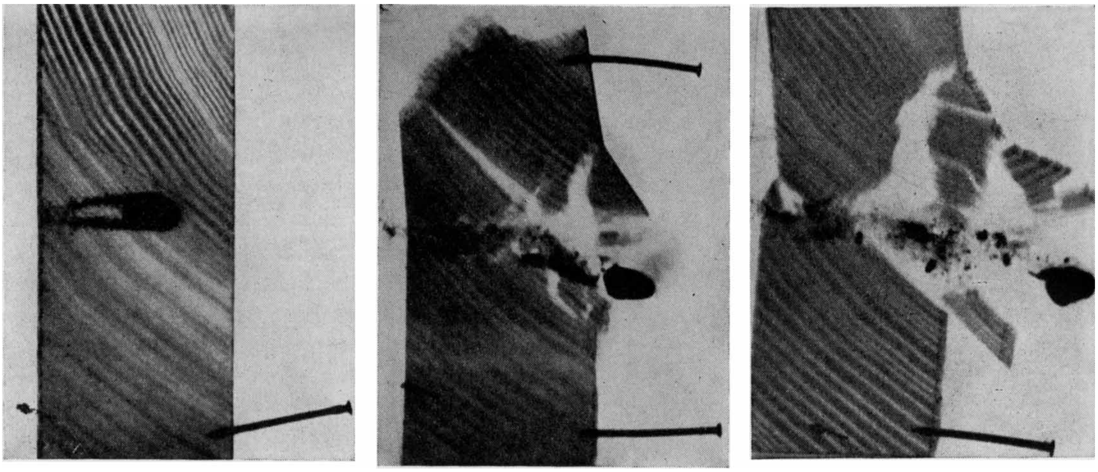
Operation

A—High-voltage transformer for charging capacitors *L* through rectifiers *M*. When timing circuit is broken at *B*, a negative charge on the grid of thyratron *C* is dissipated, allowing capacitor *D* to discharge through the primary induction coil *E*. This voltage is carried through main capacitors, causing spark gap *F* to break down, activating the X-ray tube. This places the total voltage between the negative or cathode electrodes *G* and *H*. Cold or field emission working across this narrow space causes electrons to be pulled from the cold metal of *G* to *H*. As soon as this current starts to flow, the voltage between *G* and *H* diminishes, and the electron stream from the cathode "hot spot" on *G* is diverted to the anode *I*, directed or focused by *H*. X rays are generated at *I* by the impact of this electron stream. The diminution of voltage is caused by blocking action of high resistance *J*. Resistance *K* is placed directly across the capacitors and gap to insure that the breakdown at gap *F* will be consistent with its spacing



Constants

A	125 peak kv, 5 milliamperes, center grounded
Valves	125 peak kv inverse—10 milliamperes
Capacitors (*L*)	60 kv direct current 0.04 microfarad (two only needed for most applications)
D	4 microfarads, 1,000 volts,
E	Equivalent of an automobile coil giving a negative high-voltage impulse approximately 20 kv
K and *J*	Approximately 100,000 ohms



a) Bullet entering block

(*b*) Bullet has entered block; note rapid closing of hole by wood fibers

(*c*) Bullet emerging from block

(*d*) Bullet has left block. Note lead particles broken from bullet in its passage

Figure 2. Radiographs showing penetration of a projectile into a wooden block

A basic circuit is shown in figure 1. The high-voltage transformer *A* feeds capacitors *L* through rectifiers *M*. Capacitors are charged to a potential slightly less than that required to break down the gap *F*. When it is desired to fire the tube by passing the capacitive charge through it, the firing circuit is opened at *B*. This permits the negative charge on the grid of the thyratron *C* to leak off and the charge on capacitor *D* then passes through the thyratron and through the primary of induction coil *E* to ground.

This sudden passage of current produces a high voltage in the secondary of *E*, which raises the potential of capacitor bank *L* so that the total voltage across the capacitor is now great enough to break down gap *F*. When this occurs, a discharge starts between *G* and *H*, the discharge immediately transfers to anode *I* which is of conventional design, and X rays are produced.

Current measurements, made by noting the voltage drop across a straight resistance wire in series with the anode of the tube, indicate that peak currents of from 1,000 to 2,000 amperes are common. Several wires of different lengths and diameters but of the same resistance are used to avoid errors caused by the self-inductance of the wire. Time of discharge and capacitance are also a measure of the current.

The time during which this large current passes and during which X rays are produced is of course extremely short—about one microsecond. The method used to measure this time interval is as follows:

A 0.220 Swift bullet was radiographed in free flight. The velocity of this projectile is about 4,100 feet per

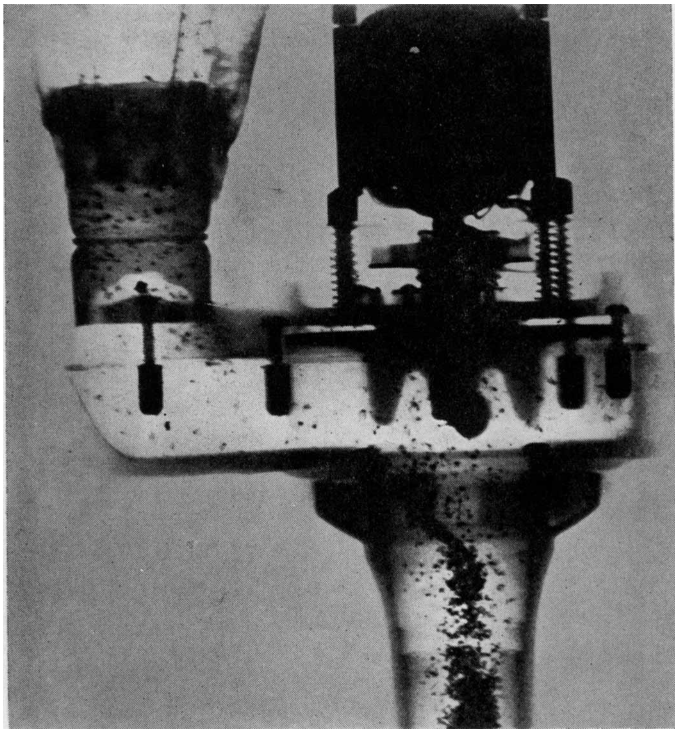
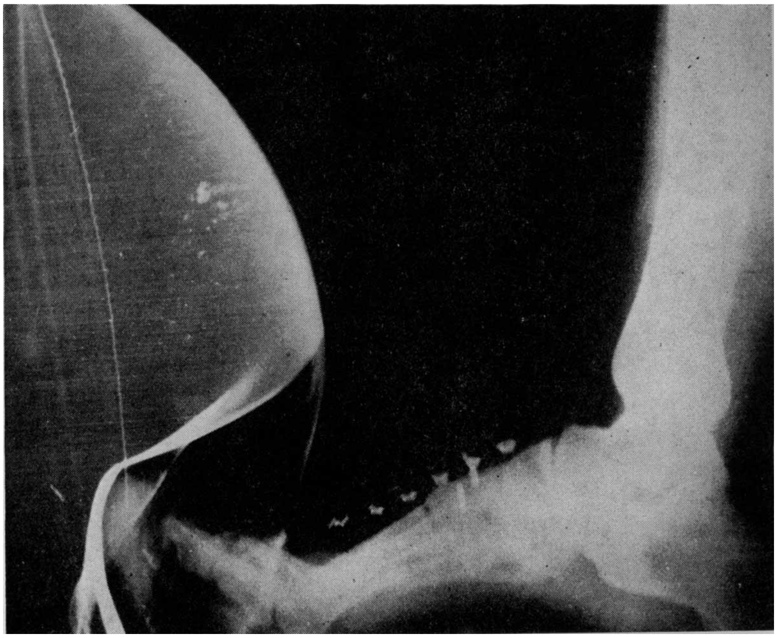
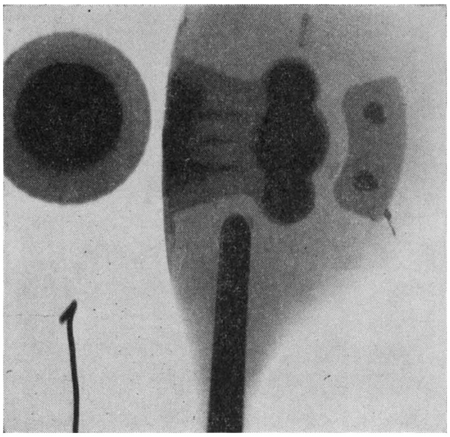


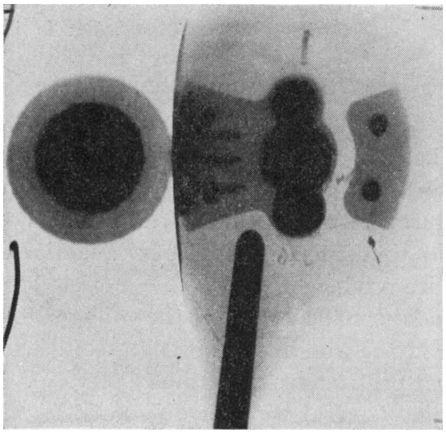
Figure 3. Here the high-speed X-ray tube has radiographed the interior of a vacuum cleaner in a millionth of a second. Flow and relative air velocity can be judged by the distribution of the particles

Figure 4. A radiograph showing a foot striking a football

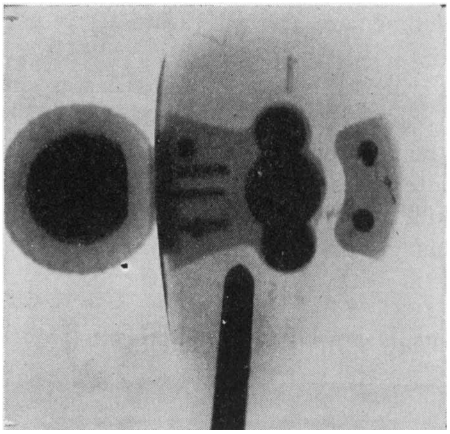




(a)



(b)



(c)

Figure 5. Radiographs showing club striking golf ball

(a) Club head approaching ball

(b) Club head makes contact with ball

(c) Core of ball partly compressed

(d) Maximum compression of core

(e) Core starts to re-expand

(f) Ball leaving club

second. Therefore, the projectile moves 1.25 millimeters in one microsecond. The amount of blurring in the radiograph of the bullet is measured and indicates the duration of the X-ray exposure. Blurring of about one millimeter with this type of projectile is common and the exposures are, therefore, about one microsecond. Calculations from the charge on the capacitor system and peak current also indicate exposure times of this order.

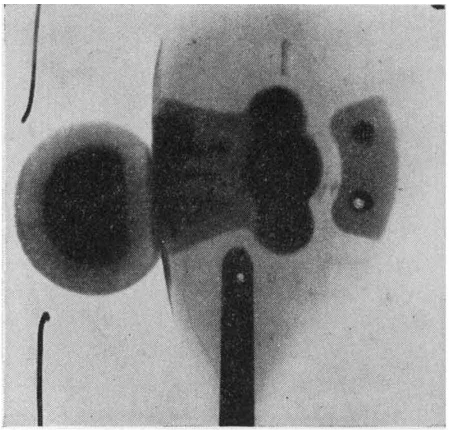
The field for ultrahigh-speed radiography of this type as yet has not been widely explored. The ability to record the interior change in shape of rapidly moving enclosed parts under stress, or a momentary condition in a short-time phenomena such as the striking of a golf ball or the penetration of a projectile into a wooden block, would seem to place a new tool at the service of those investigating such phenomena.

The usual method of firing the tube is to bridge switch *B* with a fine wire which is broken by the projectile, in the case of the bullet pictures. Variations of this method include a double swinging contact device of high sensitivity which was used for the golf pictures. The time interval which elapses between breaking this contact and the firing of the X-ray tube may be controlled by suitable choice of the grid-leak resistor in the thyratron circuit. The desired phase of the action also may be selected by the location of the wire with respect to the object to be radiographed. These methods are adaptable to a wide variety of conditions, and are cited merely to show the general principles involved.

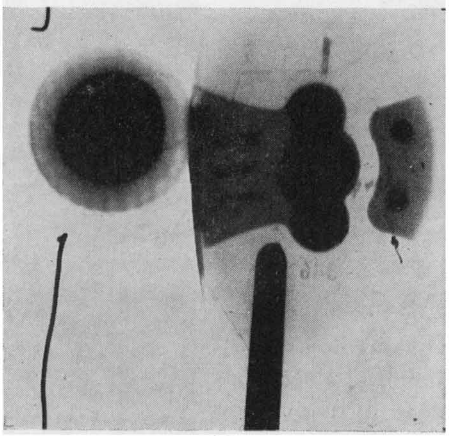
Series sets of various phases in the golf ball cycle and the bullet going through wood are made up of separate X-ray shots of separate specimens, the exposures being so spaced through the cycle that a series of consecutive discrete phases is recorded. A similar series showing the passage of a charge of shot down the barrel of a shot gun has also been made.

The voltage used to produce the pictures shown here was in the region of about 120-kv peak. The wave length of the X radiation produced at this voltage is about 0.1–0.2 angstrom units, or about 10^{-9} centimeter, whereas visible light—for example, the yellow sodium line—has a wave length of about 5,800 angstrom units.

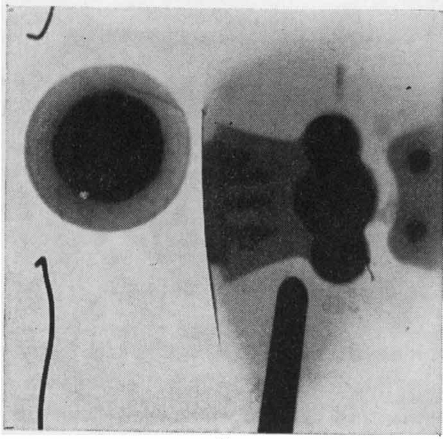
This short wave length of the X rays is responsible for their ability to penetrate objects opaque to visible light.



(d)



(e)



(f)

It also is responsible for the fact that one cannot refract or focus the X rays as one does visible light with a camera lens. For this reason, no lens is used, and the X-ray pictures are a type of shadowgraph made by placing the object between the X-ray tube and the film which is enclosed in a light-tight box known as a cassette. Under the influence of X rays, the object then casts a shadow of varying density on the film, and the picture is made.

The closer the object can be placed to the film, the better the definition obtained, other conditions remaining unchanged. For this reason, the bullet pictures made by firing close to the film show better definition than does such a picture as that of the football and foot, which were necessarily farther from the film. Efficiency of the photographic effect is increased, as in other radiographic practice, by the use of fluorescent intensifying screens, which are placed in contact with the film surface and enhance the direct effect of the X rays on the emulsion by fluorescent light.

Successful industrial applications of this system will depend largely on the thickness of the parts to be penetrated by the X rays, the degree of distortion or change to be detected, and the fineness of definition required in the picture. The exposure time of one microsecond appears to be short enough to freeze motion substantially in any application considered so far. The extent of the field to which this development will be applied will become clearer as experimental work proceeds.

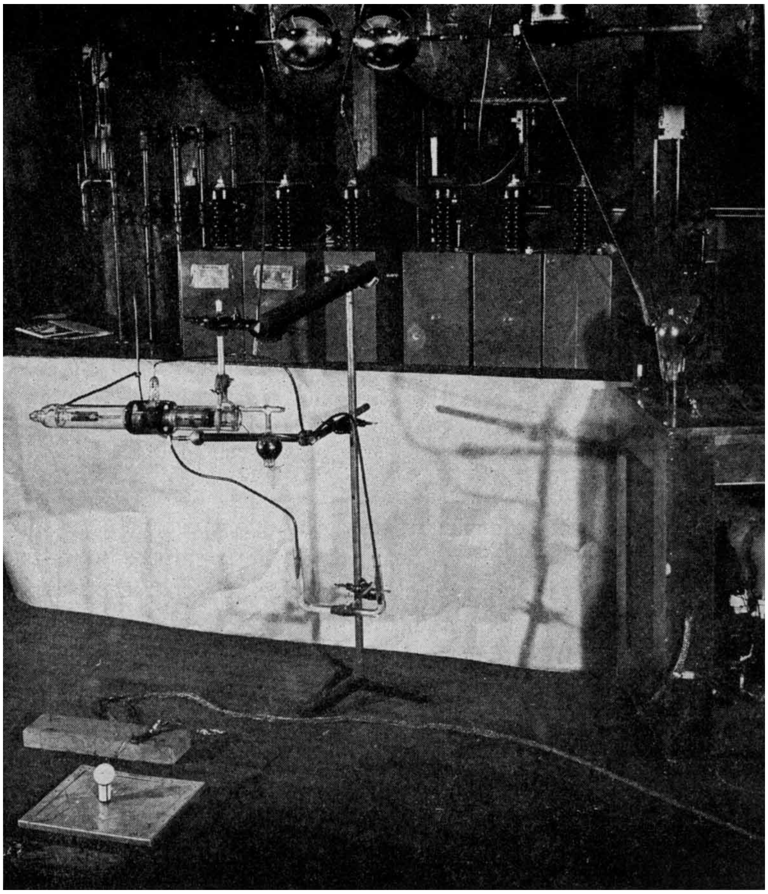


Figure 6. A typical setup as used for taking a golf picture

REFERENCES

Max Steenbeck, *Wissenschaftliche Veroffentlichungen aus den Siemens-Werken* (Julius Springer, Berlin, 1938), volume 17, chapter 4, pages 363–80.

K. H. Kingdon and **H. E. Tanis, Jr.,** *Physical Review*, volume 53, 1938, page 128.

W. J. Oosterkampf, *Philips Technical Review*, January 1940, page 22.

C. M. Slack and **L. F. Ehrke,** *Journal of Applied Physics*, volume 12, February 1941, page 165.

L. F. Ehrke and **C. M. Slack,** *Photo Technique*, January 1941, pages 52–5.

Effects of Corona and Spark-Over in Freon

FRANK T. DeWOLF

Gases are being used to an increasing extent as insulating media for high-voltage equipment; this article reports the results of tests of the chemical stability of Freon, which has been found most satisfactory in such applications.

PERHAPS the most effective means of increasing the compactness of high-voltage apparatus is the use of insulating media of higher dielectric strength. With the development of ultrahigh-voltage equipment[1,2] a number of gases have been examined as to their qualifications as dielectrics. Among these is Freon, CCl_2F_2, a gas having a dielectric strength about three times that of air at the same pressure[3,4,5] and a vapor pressure of 85 pounds per square inch absolute at 20 degrees centigrade. It is nonpoisonous, nonflammable, and noncorrosive under normal conditions.

However, the question of the chemical stability of Freon in the presence of corona and spark-over remained to be answered before its general use as a practical high-voltage insulating medium could be justified. When Freon was introduced into the field of refrigeration, tests showed that it breaks down chemically in the presence of a naked flame producing active decomposition products which are both corrosive and poisonous. Slight decomposition of the gas following corona and spark-over had been noted in early tests of its dielectric strength, but this phase had not been investigated thoroughly. This research was undertaken to see to what extent the disintegration of Freon by corona and spark-over limits its use as a dielectric. Further, it

---

FRANK T. DEWOLF was a graduate student in electrical engineering at Massachusetts Institute of Technology, Cambridge, during the course of the research reviewed in this article; he is now with the General Electric Company, Lynn, Mass.

The author wishes to express his sincere appreciation for the kind help that Doctor John G. Trump of the department of electrical engineering of Massachusetts Institute of Technology extended to him during the research on which this article is based.