Fluoroscopic Image Brightening by Electronic Means

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MORE THAN SIX years have passed since Dr. W. Edward Chamberlain delivered the annual Carman Lecture before the Radiological Society of North America. In this lecture (1), he described in great detail the limitations of present-day fluoroscopy, and held out hope that these severe restrictions might soon be removed, or greatly alleviated, by the application of modern electronic technics to the amplification, or brightening, of fluoroscopic images. Such amplification has recently been accomplished in the Research Laboratories of the Westinghouse Electric Corporation, and it is hoped that before long practical realization of the method for use in clinical fluoroscopy will become available to the radiologist.

There are two reasons why image amplification, or brightening, is necessary if large increases of brightness are to be obtained. First, x-ray intensities are already at the patient's tolerance level and may not be further increased without danger of injury. Second, there is not sufficient energy in the emerging x-rays to form an adequately bright picture even if all the energy were converted into light.

Image amplification has been achieved by converting the x-ray pattern into an electron stream, and accelerating these electrons to high velocities. In this way, energy from an external source is introduced into the system and, when the electrons impinge on a phosphor layer, a brighter image results. This paper deals with the technical aspects of fluoroscopic image amplification, and describes in some detail the mechanism just outlined.

Were it not for the dimness of the image, fluoroscopy would replace to a large extent the taking of roentgenograms. A single fluoroscopic examination would be equivalent to hundreds of films taken in cinematographic sequence and revealing the subject in all phases of movement and from many angles of projection. Unfortunately, however, the fluoroscopic image is excessively dim, and at existing brightness levels the human eye is capable of perceiving only a fraction of the detail which is actually on the screen. Dr. Chamberlain covered this aspect of the problem very thoroughly, and it will suffice to present here only a few aspects of retinal physiology which will serve to illustrate the tremendous ranges of brightness over which the eye is adaptable, and the great loss of definition which is incurred at low levels.

The brightness level at which roentgenograms are ordinarily viewed is roughly 30 millilamberts. At this level, the eye is capable of recognizing as discrete two contours which are separated by as little as one one-thousandth of an inch. As the brightness of the object is decreased, the visual acuity of the eye deteriorates. At about one thousandth of this intensity we have reached the point where cone vision is no longer effective, the color sense is gone, and the fovea centralis is no longer the most sensitive part of the retina. Only rod vision is now present, and visual acuity is such that two contours must be separated by about 1/64 inch to be distinguishable. But we are still a long way from fluoroscopic levels. At a brightness of 0.001 millilamberts (1/30,000 of the brightness of the film mentioned above!) we are in the middle of the fluoroscopic range, and we find the contour separation required is about 1/32 inch.

For the worst cases, *i.e.*, extreme abdominal thicknesses, the brightness may approach 0.00005 millilamberts, and the necessary contour separation 1/4 inch. Even this poor result does not describe the full extent of our difficulty, since it refers to an idealized situation not realized in fluoroscopy. Discrimination between neighboring areas axis of the tube. These helices, though of varying diameter, will intersect this line at the starting point and again at some other point down the line. By adjusting the relative strengths of electric and magnetic fields, this second intersection may be made to take place at the plane of the phosphor. Thus the paths of all electrons leaving a point on the photosurface converge to a point on the phosphor layer, and a sharp image is produced.

In such a system it is important that the light produced by the output phosphor be prevented from traveling back to the photosurface. If this were not done, an unstable situation might develop, whereby light from the output phosphor would return to produce electrons from the photosurface, these electrons would produce still more light, and eventually the whole system would "run away." This "feedback" can be effectually prevented by backing the output phosphor with an extremely thin membrane of aluminum. The aluminum is made thin enough to permit electrons to penetrate it with little loss of energy, and still be opaque to light. At the same time the aluminum performs two other functions: it brightens the image by returning to the observer light which would normally be lost from the back of the layer, and it maintains the phosphor layer at the desired electrical potential.

The fluorescent screen selected for use in the pilot model is prepared from a zinc sulfide phosphor similar to the type used in screens for miniature radiography. This screen has a very high intrinsic efficiency, and fluoresces in the deep blue and near ultraviolet where the cesium antimony photosurface is most sensitive. The output phosphor is a zinc cadmium sulfide phosphor similar to the usual fluoroscopic screen material, but it has a much finer crystal size. The fluorescent color of this layer is very nearly that for which the eye has maximum sensitivity.

A very great technical difficulty had to be met because of the chemical nature of the materials used in the tube. The zinc sulfide phosphors are very susceptible to impurities, and the cesium vapor used in making the photosurface, being highly active, would attack the zinc sulfide readily. In order to alleviate this problem somewhat, the fluorescent screen in the pilot model was placed outside the tube. The relatively thick glass window separating the screen and the photosurface lowered the resolving power so that the tube was of no practical value, but this did not interfere with measurements of the brightness gain.

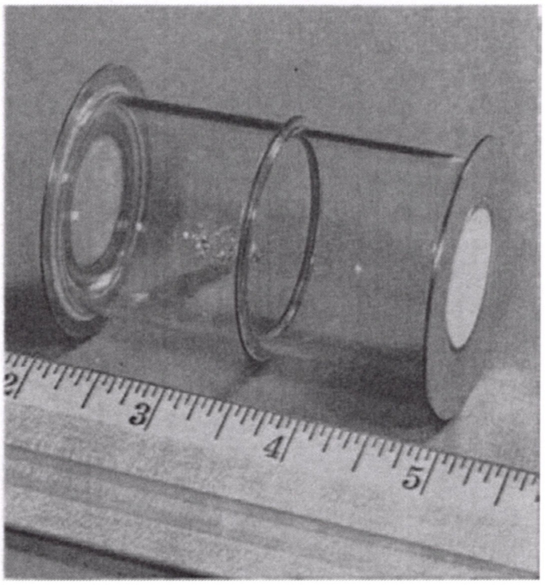

Fig. 2. Photograph of the pilot model first produced.

Because the color of the first fluorescent screen is not the same as that of the output phosphor, it is of doubtful meaning to quote brightness gains in the tube itself. A more significant procedure is to compare the brightness of the final image on the tube to that of a Patterson "B" fluoroscope screen under the same x-ray conditions. Though this does not measure a unique property of the image tube, it is a direct measure of the practical results obtained. On this basis the pilot model shown in Figure 2 had a measured brightness gain of five times when operated at 13 kv. accelerating potential. The photosurface in this particular tube did not have the high sensitivity which had been attained in some previous experiments.

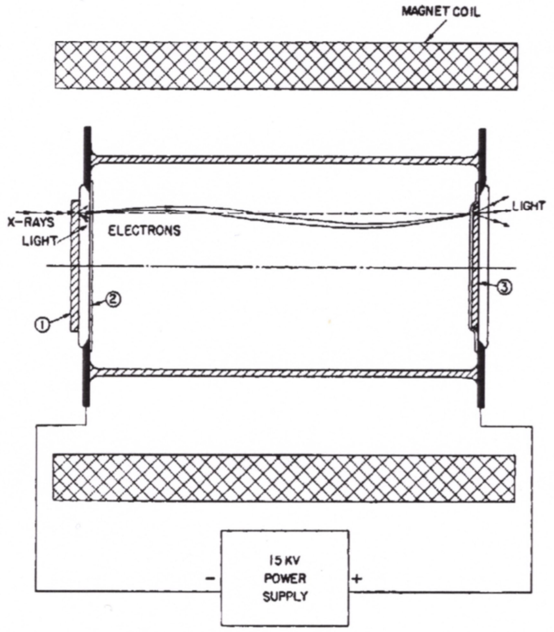

Fig. 1. Diagram of the pilot model operation. X-rays striking the fluorescent screen (1) produce light photons which eject electrons from the photoelectric surface (2). These are accelerated by the electric field from the 15-kv. power supply and focused by the magnetic field of the coil so as to form an image on the output phosphor (3). This image may be twenty times as bright as that from the conventional fluoroscopic screen.

plied axially. The electrons impinge on a phosphor layer (*3*) on the opposite end, where they form an image identical to the original pattern. If the efficiencies of the fluorescent screen, the photoelectric surface, and the phosphor are high enough, and sufficient accelerating energy is supplied, a gain in brightness will result.

Though this process is simple in principle, its success depends very much on the properties of the materials used. First we must make sure that we utilize as many as possible of the available x-ray quanta, for failure to do so will result in the loss of detail which cannot be restored by any subsequent amplification. Thus we require that the absorption of a single x-ray quantum in the screen ultimately results in the ejection of many electrons from the photoelectric surface. Thirty per cent of the energy of an x-ray quantum may be transformed into light by the fluorescent material. Now this light is also composed of quanta, or photons as they are often called, similar to the x-ray quanta except that they contain a very much smaller amount of energy per quantum. Specifically, the energy in any quantum is inversely proportional to the wave length of the radiation which it represents. Since the wave length of x-rays in the fluoroscopic range is about 0.2 Angstrom units, and the wave length of the light from the screen is about 5,000 Angstrom units, each x-ray quantum contains 25,000 times as much energy as each light quantum or photon. If the efficiency of the fluorescent process is 30 per cent, about 7,500 light quanta will be generated by a single x-ray quantum. Not all of these light quanta can be utilized, for many of them are lost before they emerge from the surface of the screen. Furthermore, only a fraction of these photons will eject electrons from the photoelectric surface. The most efficient photosurface known, and the one employed in this tube, is a compound of cesium and antimony. This surface, if properly prepared, may have a quantum efficiency of about 1/10, that is, on the average one electron is ejected for every ten incident photons. Taking this loss into account, we end up with an average of about 450 electrons for each initial x-ray quantum absorbed. From a statistical standpoint this is quite satisfactory, for even though the number of electrons ejected will fluctuate somewhat from one x-ray quantum to the next, this fluctuation will not be very large, and we shall be almost certain to utilize effectively each x-ray quantum absorbed.

The electrons thus ejected from the photosurface must be focused to give a sharp image when they impinge on the phosphor at the viewing end of the tube. In the pilot model this was accomplished by the uniform magnetic field from a coil surrounding the tube. Under the influence of the uniform electric accelerating field (supplied by the potential difference between the ends of the tube) and the uniform magnetic field, electrons leaving a point on the photosurface will describe helical paths about a line parallel to the inders shown forms with its neighbor an electrostatic lens. The electric fields between these cylinders act on the electrons in a manner similar to the action of glass lenses on light. Essentially the system consists of one main lens of considerable strength and a series of weak correcting lenses. The fluorescent screen and photosurface are coated on the inside of the curved dish which is five inches in diameter. The electron lens system forms an image on the output phosphor layer which is inverted and reduced to one inch in diameter. This is viewed through the optical magnifier, which re-inverts the image and restores it to its original size. The various lens cylinders in the tube are supplied with suitable voltages from a power supply which delivers about 20 kv. at a negligible current. One of the lens voltages is adjustable to permit focusing.

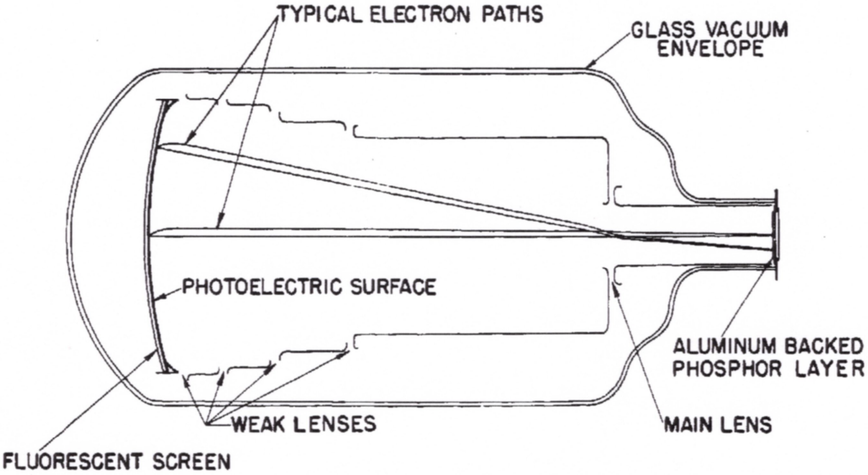

Fig. 4. Diagram of the large image tube. The mechanism of this tube is similar to that of the pilot model (Fig. 1) except that an inverted, reduced image is formed by a series of electrostatic cylinder lenses. The reduction in size produces another factor of 25 in brightness gain, bringing the total gain to 500. An optical magnifier (not shown) restores the size of the image to its original five-inch diameter with no loss of brightness.

A diameter of five inches was chosen for the field of view as a compromise among many factors. A larger diameter screen would have meant a proportional increase in the length of the tube, and would have added considerably to its bulkiness. Furthermore, it is increasingly difficult to maintain the resolving power of the electron optical system, and the requisite light-gathering power of the erecting ocular. Actually, the 12 × 16 screens now employed in fluoroscopy are seldom fully utilized over their entire area. For critical work the x-ray beam is invariably stopped down to include only the object of interest, as this improves the contrast by cutting down the scattered radiation. Moreover, the eye can examine critically only a rather small field of view at one time. For these reasons it was thought best to choose a screen large enough to cover a reasonable area but small enough to make the whole tube light and flexible, so that it might readily be moved over the region of interest. The electrostatic focusing system makes light weight construction relatively easy. The entire tube together with its housing, optical system, and protective lead shields, will be light enough to mount in place of the present fluoroscopic screen assembly on existing equipment. The power supply is relatively simple, for the current drain of the tube is only a fraction of a microampere, and a small power supply such as is used in some television receivers will suffice. Only two controls, for optical and electron focusing, are provided, and these will require only occasional readjustments.