DEALING WITH TECHNICAL PROBLEMS
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THE APPLICATION OF THE X-RAY IMAGE INTENSIFIER

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For many years electronics has been engaged in the problems of amplifying very weak currents and voltages. In recent years, partly owing to the stimulus of television, a new branch of electronics, that is, the intensification of light, has emerged. The original object of this development was the conversion of long-wave into short-wave light ("wavelength-transformation") which was investigated in the Philips laboratories at Eindhoven as long ago as 1934. Now, however, the emphasis is on luminance intensification with special reference to the intensification of weak fluorescent images.

The first article on the X-ray image intensifier to appear in this Review was published in 1952; since then, laboratory experiments and practical tests have produced much new and interesting information concerning this intensifier, and it is now considered worth while to publish one or two articles describing these developments. The main points considered here are: the minimum size of detail perceptible with the image intensifier; the optical problems involved; photography and cinematography with the image intensifier.

The present articles refer mainly to the existing type of image intensifier. Little is said as to the probable future trend of development in image intensification; this does not imply, however, that the present results are considered the last word in this field. On the contrary, we should emphasise that the subject is still developing and we hope to report further progress in due course.

I. GENERAL SURVEY

by M. C. TEVES.

By way of introduction, the purpose, principle and design of the X-ray image intensifier at present in regular production 1) will be briefly re-stated.

The purpose of the image intensifier is to enable as much information as possible to be extracted from the fluorescent image of the particular object, for a given X-ray dose. The theoretical and practical factors governing the amount of information obtainable from the image are discussed fully in the second article of this series. It can be shown from these considerations that with ordinary fluoroscopy, the information in the screen depends on the X-radiation absorbed by the screen. The amount of radiation absorbed is closely related to the dose to which the patient is exposed. However, the observer cannot extract all this information, owing to the weakness of the optical link between the fluorescent screen and the human detecting organ (that is, the retina of the observer's eye). The same applies to fluorography (miniature radiography), which likewise involves

an appreciable loss of light in an optical link, viz. that between the fluorescent screen and the film; the loss is so great, that only about 1% of the information latent in the screen is transmitted to the film.

Full-size radiography is very much better in this respect. The direct optical contact between fluorescent screen and film here prevents any loss of light. With regard to the first two methods referred to, an image intensifier tube considerably increases the amount of information obtainable with a given dose. Compared with full-size radiography, however, it offers only secondary advantages, namely that it enables the dose to be reduced. It has the further advantage that it enables cinematography to be employed.

Hence the main purpose of the image intensifier is to make good the light loss in the optical link between the fluorescent screen and the light detector (retina of the eye, photographic film or plate, or, possibly, the photo-cathode of a television camera tube).

Description of the image intensifier

The image intensifier is an evacuated glass tube containing a fluorescent screen on a thin aluminium base (fig. 1); in contact with the screen is a photo-cathode. X-radiation striking the screen makes it fluoresce and the light then releases electrons from the photo-cathode. The "electron image" is reproduced, reduced in size, between 10 and 15 times $\times$ magnification, so that the image is seen in its original size, that is, roughly 13 cm in diameter, and upright, but about 1000 times brighter than before.

The luminance intensification arises from two factors (which, however, are not independent of each other). Firstly, an increase in the overall luminous flux (or "lumen intensification") due to the fact that the electrons from the photo-cathode are accelerated by the electric field: there is an accelerating voltage of roughly 25 kilovolts between the photo-cathode and the viewing screen.

The higher the energies of the electrons striking the viewing screen, the more intense the fluorescence produced. Although only about 1 in every 10 light quanta falling on the first fluorescent screen releases an electron, and only about one tenth of the electron energy is converted into light on the first fluorescent screen, the energy imparted to the electrons nevertheless results in the latter screen producing between 10 and 15 times as much luminous flux as an ordinary fluorescent screen viewing the same subject.

The second factor is the electron-optical reduction of the image size; it enables all the photo-electrons to contribute to the formation of the image, so that the amount of light generated does not depend upon the area over which these electrons are distributed. By employing a reduction of 9 times, we reduce the area within which the electron energy is concentrated by a factor of $9^2$; hence the total luminous flux is emitted from an area about 80 times smaller than it would be with reproduction on a scale of 1 : 1. This, by definition, means an increase in luminance by a factor of 80. The total luminance intensification is the product of the lumen intensification and the gain from the reduction of the image size; with the tube under consideration, it is between 10 and 15 times $9^2$, or from 800 to 1200. Thus the luminance is so increased as to make good all the light loss involved in the forming of the image.

In the conversion of a low-luminance image into a high-luminance one, special precautions are necessary to avoid loss of contrast or definition in the image owing to imperfections in the apparatus.

With the present image intensifier, sharpness is limited mainly by the thickness of the first fluorescent screen. However, it is also affected to some extent by the viewing screen. Blurring in the electron-
optical image forming system is almost negligible. In principle, subtle contrasts in the low-luminance initial fluorescent image are not affected by the light-transformation (the $\gamma$ of the image intensifier is unity). In practice, however, there is a slight, but unavoidable loss of contrast owing to “fogging”, that is, a luminance contribution distributed more or less uniformly over the whole image. On the other hand, the increase in contrast sensitivity of the eye with increasing luminance far outweighs this slight loss. In photography, it can be made good by employing a film with a higher $\gamma$.

Although it is essential that the properties and possibilities of the image intensifier be fully investigated in the laboratory by means of “phantom tests” (see article II), its merits from the medical point of view can be determined only in actual medical practice. Such practical tests are being carried out in a number of places, e.g. in the Philips Health Centre at Eindhoven under Professor Burger and Dr. Feddema, and in Maastricht by Dr. van der Plaats.

Without particularizing unduly, we may quote the following examples of the usefulness of the image intensifier from these investigations (see article V).

In chest fluoroscopy, the intensifier gives good results with only one tenth of the normal X-ray dose. Apart from the fact that the resolution is at least as good under these conditions as in the direct image, the image intensifier enables the subject to be examined in a moderately lit room and without any preliminary adaptation of the eyes.

The intensifier is eminently suited for locating foreign bodies (e.g. metal particles), and for the routine examination of the setting of bone fractures.

For the examination of an oesophagus, stomach or colon into which contrast medium has been introduced, the investigation is considerably facilitated by the image intensifier.

An important use of the image intensifier is as an aid to visual positioning before the taking of an ordinary, full-size radiograph (spot film technique).

Medical experience has shown that in fluoroscopy, better results are obtained with, than without the image intensifier, especially in circumstances where the relatively small size of the field, i.e. 13 cm in diameter, is not a handicap.

As applied to fluorography, that is, photography of the viewing screen of the intensifier on film with a camera, the medical uses of the intensifier may be divided into two categories:

1) The taking of still photographs, singly or in series.

2) X-ray cinematography.

A great deal of information concerning both these uses has already been collected. It is found that the quality of a photograph taken with the image intensifier on fine-grain 35 mm film is very much the same as that of an ordinary full-size radiograph, although, with a suitable optical system, the X-ray dose required per photograph is a factor of 2-3 smaller than in full-size radiography. With regard to X-ray cinematography, it is enough to say that even with quite a long film, the X-ray dose is not heavy enough to endanger the patient; hence photographic X-ray examination can now be employed in physiological, as well as anatomical studies.

Briefly, then, we may safely say that the present image intensifier has demonstrated its value in many medical applications. However, it is still far from perfect. One of the practical improvements still required from the medical point of view is a larger image field. Moreover, the methods of presenting the image to the observer also require attention; this is important not only in fluoroscopy, but also from the point of view of cinematography. Another problem is how best to convey all the information in the film strip to the observer.

Finally, it should be pointed out that the image intensifier is also useful in industrial radiography. The relatively brighter image produced permits the visual examination of much thicker objects than has been possible hitherto. One or two examples are given in article VI.