5.

EXAMINATION OF MATERIALS BY X-RAYS.

A brief description of the principles of examination of materials by X-rays was given on page 75 of No. 6 of this series of Papers, written in 1924. Appreciable progress has taken place in the intervening years and some interesting practical applications of this method of inspection have been made in important engineering work for the Service. It may therefore, be of interest to give a short account of the present position in regard to this process, together with a few notes on the difficulties which have to be overcome before such methods can become in any sense a general means of inspecting structural materials.

It may be well to recall that the process relies at source upon the fact that the penetration of X-rays through any body depends upon the nature of the material of which it is constructed, varying almost directly with the atomic weight of the substance. Thus lead is comparatively opaque, while air, steel and brass are less so, their order of penetrability being that in which they are here mentioned. When a steel object with an internal cavity is exposed to the action of X-rays more of these will penetrate in the region of the cavity than elsewhere. It is evident therefore, that if any means exists of indicating the quantity of X-rays that penetrate the specimen, then the location and shape of the fault may thereby be detected; even changes in the density of the material can be seen if these are of appreciable moment.

It was early discovered that certain materials had the property of fluorescence or glowing under the action of X-rays, the brightness of the illumination depending upon the intensity of the impinging ray. A screen made of such materials can evidently be used to indicate any differences in the opacity to X-rays of the various parts of a body placed between the screen and a source of such rays. Photographic plates are also affected by X-rays and are generally used for the foregoing purposes.

Depth of Penetration.

The thickness of material that can be penetrated by the ray depends upon the intensity of the latter and also upon the nature of the material itself. The intensity of the ray varies almost directly with the voltage applied to the X-ray tube, and thus it would appear that this factor is the main consideration in determining the scope of the method.

It is unfortunate that only a a very small part of the incident ray actually penetrates the material under examination, by far the greater proportion being " scattered " in all directions by the crystal facets of the material. Now this " scatter " not only passes out of the surface at which it entered, but also may travel from the sides of the specimen to the photographic plate, which may thereby be badly fogged. It has been shown for instance when radiographing a block of steel 3 in. thick, that only one part in 2,500 of the incident ray actually reaches the film direct, the remainder being scattered. It is now usual to cover the sides of the specimen and the back of the film with lead in order to curtail the effects of scatter, but even so about 1 per cent. of the scatter reaches the film. Evidently then this small fraction of general scattered radiation exceeds the direct image-forming radiation some twenty-five times, but fortunately even under such poor conditions there is sufficient photographic contrast to yield useful results.

It has been discovered that although the total scatter is so large, the actual quantity reaching the film from any one given direction is very small. This led to the use of lead grids or diaphragms of suitable depth being interposed between the specimen and the film, thus cutting off the scatter from all directions save that of the direct ray. It has been found that an enormous improvement in photographic contrast is obtained by the use of such diaphragms, which now constitute an essential part of the technique of radiographing thick materials. The sketch, Fig. 2, shows the type of grid used, which consists of lead strips closely and evenly spaced with gelatine or celluloid between the strips. Arrangements for moving the grid to and fro are necessary in order to avoid shadows of the bars appearing on the film or alternatively the grid may be rotated. It may be of interest to note that there is every reason to expect conditions to be better when it becomes possible to penetrate even greater thickness of metal than are at present dealt with.

The maximum thickness of steel that has been successfully penetrated is about 4¾ in., requiring a voltage of about 300,000 on the X-ray tube. Incidentally in 1917 the limit of penetration was only about 1 in. of steel. The extension of the present limit is mainly dependent upon the production of X-ray tubes capable of withstanding the enormously high voltages required, and there does not appear to be any immediate hope of an appreciable advance in this direction. It is, of course, evident that the problems involved in the safe use of apparatus working at pressures in the order of half a million or more volts are not easy of solution, and in practice the necessary safeguards add appreciably to the cumbersomeness of the plant and detract greatly from the speed of operation.

Location of Flaws.

The photographic process is capable of disclosing cracks of width equal to about 3 per cent. of the thickness of the material under examination, whatever that may be, up to the existing limit of about 4¾ in. A flaw smaller than (say), 1/100 in. wide, could not, therefore, be detected with certainty in 3 in. material, and this points to one of the limitations of the process, as such cracks might well be of considerable practical importance. Against this must be put the fact that very few discontinuities of any real significance would be less than 1/100 in. wide *in all directions*, and thus, although they might be invisible when photographed from one direction would in general be clearly distinguished under observation from another angle. It is thus essential to explore any suspected section from at least two different planes of " vision."

The visual examination of materials up to a limiting thickness of about ½ in. for fine cracks, etc., is possible and practicable, and there is some prospect that this limit may shortly reach the figure of 1 in. It is, of course, obvious that there must be a limit to the thickness through which such *visual* methods can be employed, for in order to use the fluorescent screen the action of the rays must be instantaneous ; with the photographic film a prolonged exposure can be given and the action then becomes cumulative.

It may be of interest to note that it has been found possible to desensitise the photographic films so that they are entirely unaffected by ordinary light, while retaining their sensitivity to X-rays. This means that the necessity for a photographic dark room can be avoided.

The interpretation of the " shadow " photographs obtained from the X-ray examination is a matter that requires some experience, which is, however, readily acquired—in particular, it is necessary to distinguish between markings due to photographic technique, *e.g.*, hair marks, faulty developing, etc., and those which indicate faults in the part. The unfamiliar types of picture obtained, coupled with the necessity for a certain amount of skill in order to understand them, is responsible for hesitation on the part of manufacturers to adopt the process—this prejudice and suspicion is rapidly dispelled when exploratory sectioning of a faulty part has been demonstrated conclusively to fulfil the indications afforded by the X-rays.

The exact size, shape and depth below the surface of deep seated blow holes may be located by stereoscopic X-ray photographs, a method which is frequently employed.

Exposure.

The length of exposure determines to some extent the rapidity of the whole process of examination, but, except in the case of very thick specimens, it is by no means the most important factor in this connection, as the setting up of the specimen, the arranging of lead screens to prevent sidescatter, etc. all require time. In the early days the time of exposure was extremely long, amounting often to an hour or more. Advantage is, however now taken of the fact that if a fluorescent screen is placed in close contact with the film, the time of exposure is reduced 30 or 40 times. With proper equipment 2 or 3 minutes is sufficient in the case of steel 2 in. thick and, although this figure is exceeded for very thick specimens, it may be taken that the normal exposure for practical work is anything up to 5 minutes and very rarely any more.

Applications.

It is fortunate that the existing limit of penetration is adeqate to cover the large majority of commercial needs, although the field of usefulness would be considerably extended if thicknesses of 8 in. to 10 in. could be dealt with. The research work which has been carried out at the Royal Arsenal Woolwich, during the past 10 years has, however, enabled the use of X-Rays for the examination of metallic structures to pass out of the laboratory stage into the dockyards and factories of the Services. A 200,000 volt set of a semi-portable and compact nature has been provided at Portsmouth Yard, principally with the object of testing welds: this set is entirely self-protecting, that is the safety of the worker is assured. It may be used for direct visual examination for thickness up to ½ in., above which photographic means are employed. The dimensions of this set are shown in the accompanying sketch, while its weight is about 1¾ tons. An apparatus of this nature is admirably adapted for the examination of castings in particular cases, but the speed of the process is not yet sufficiently great to warrant its use as a matter of routine, desirable as this undoubtedly is.

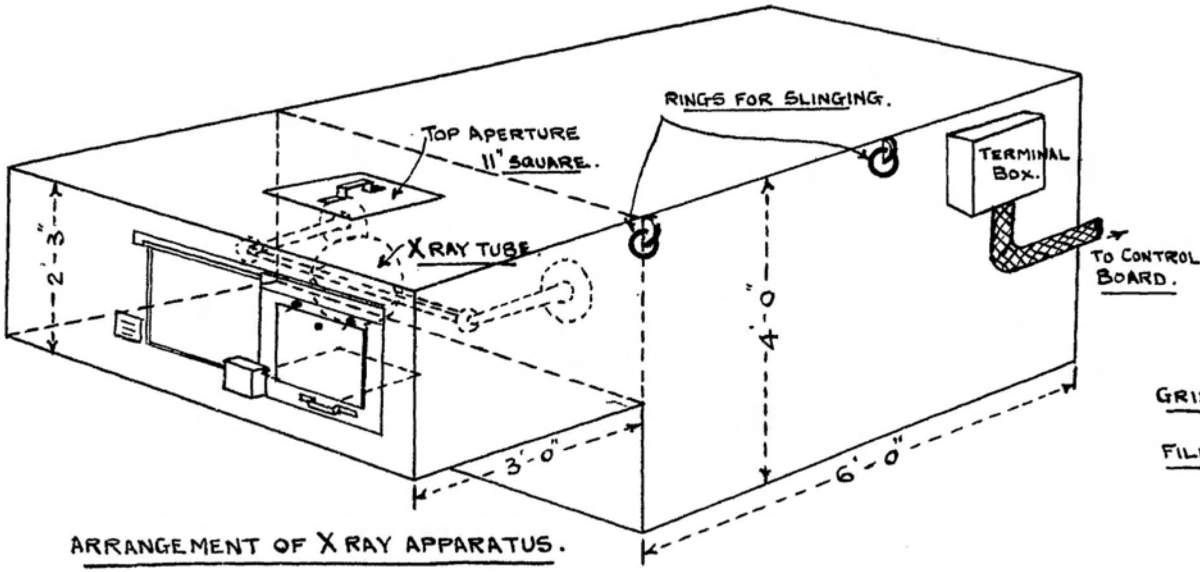
The principal difficulty in the production of sound castings, especially of steel, lies in ensuring that the proper technique is employed in each individual case. Whether this is in fact achieved in practice can only be ascertained if the internal condition of the casting is definitely known, a question which cannot be answered with certainty on the result of external examination or by the testing of test pieces provided on the casting. It appears possible that X-Ray examination of trial casts of important castings will enable the best method of producing sound articles of any particular shape to be determined—once the proper teehnique has been evolved in a given case it should be merely a question of application to ensure that repeat castings are of the desired quality.

This is the most probable immediate application of X-Rays to engineering work, but the number of instances where the cost and time of inspection by these means are justified by the importance of the particular part will no doubt multiply with some rapidity when the possibilities of the method are more generally understood.

The present trend of research is in the direction of improving both the rapidity of the process and the mobility of the apparatus, while it is of course desirable that the cost (even now by no means excessive) should be cut down as far as possible. It is upon the degree of success attending these investigations that the future employment of welding in important engineering structures may very largely depend.

The use of welding for machinery purposes offers considerable attractions in the direction of reducing weight and cost, with attendant simplification of design. It is, however, unsafe to depend upon the strength of a weld, and, although much time and thought has been expended both in this country and elsewhere in the attempt to ensure the soundness of such a method of connection, it is only

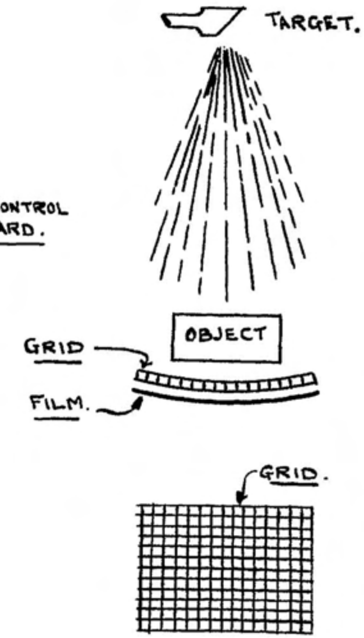
P.3926, 21199C 8635, 1000, 1/31.



ARRANGEMENT OF X RAY APPARATUS.

MAIN PORTION (6FT x 4FT) CONTAINS ALL THE ELECTRICAL EQUIPMENT (TRANSFORMERS &c). SMALLER PORTION IS LEAD LINED TO PROTECT THE OPERATOR, AND CONTAINS THE X RAY TUBE AS INDICATED. THERE ARE 3 APERTURES 11" SQUARE (AT TOP, BOTTOM & FRONT) AND EITHER CAN BE USED FOR MAKING AN EXPOSURE. THE DOOR IN FRONT IS FOR ACCESS TO THE TUBE AND HAS A SPECIAL CONTACT BOX ON IT WHICH ENSURES THAT THE X RAY TUBE CANNOT BE WORKED UNLESS THE DOOR IS CLOSED. THE FRONT APERTURE IS CONTAINED IN THE DOOR. IT WILL BE SEEN THAT SPECIMENS CAN BE PLACED UNDERNEATH, ABOVE OR IN FRONT. ALL THE APERTURES HAVE LEAD COVERS.

FIGURE. 1.



GRID.

FIGURE 2.

...ay & Sons, Photo-Lith

by the development of some means of " seeing " the internal structure of the joint that the essential degree of certainty can be obtained. X-Rays are even now capable of performing this service, but it will be evident from what has been said already, that the existing apparatus is not adequate to render rapid examination of welds a routine process.

Other uses of X-Rays.

A very modern application of X-Rays is that termed " crystal analysis," which bids fair to yield much information regarding the arrangement of the crystals in a material, thus enabling the state of strain to be ascertained, and also providing fundamental data for many types of investigation. This process is based upon a similar principle to that embodied in the spectroscope. Just as a prism is capable of splitting up a ray of light into its component wavelengths, so also a fine crystalline structure causes dispersion of a beam of X-Rays. The configuration of the image formed on a fluorescent screen by the dispersed beam has been found to vary with the arrangement of the crystal units in the material, so that the crystal structure may now be recognised from the " pictures " taken in this way.

Now it has long been suspected, and the suspicion has in recent years been confirmed, that the crystalline structure of any material is appreciably affected by strain. Experimental work now in progress aims at interpreting a change of crystal arrangement (in known materials) in terms of the accompanying strain—this in turn may conceivably be translated into stress. If such proposals as these fructify and pass from the laboratory to the workshop, it may be possible to actually measure the stresses in machinery parts or in structures, thus checking design calculations. An equally important application would be to see whether castings and the like were properly annealed or whether undesirably heavy internal stresses exist in any part.

The effects of a given heat treatment can also be studied by means of crystal-analysis, and the completeness to which such a process has been carried out should thus be determinable: an important point in some cases.

Another use for X-Rays lies in the inspection of complicated mechanical devices after assembly—this particularly applies to small articles such as fuzes and the method has been of great service in this special field.

In the case of forged air bottles and similar products it is frequently impossible to ascertain the thickness of certain parts of the finished article, *e.g.*, in the fillet joining the body of the bottle and the end. This type of inspectional work is ideal for X-Rays and there can be little doubt that further uses for the process will suggest themselves to an ever-widening degree as engineers become gradually familiar with its possibilities.