THE POTENTIAL OF PROTON RADIOGRAPHY

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Abstract

The properties of two types of proton radiography, MARGINAL-RANGE and MULTIPLE SCATTERING are described briefly and examples of the radiographs shown. A practical application of one of the techniques, MARGINAL-RANGE, to an industrial problem is described. Certain outstanding features of MULTIPLE SCATTERING radiography which may lead to its use in the future are mentioned.

1. Introduction

Any penetrating radiation can be used for radiography. It so happens that one of the first such radiations to be discovered, X-radiation, is also for most practical purposes the best and most convenient to use by a very large margin. It has ensured the predominance of X-radiography over all comers for more than eighty years during which time a great many other penetrating radiations have been discovered and produced. The only serious contenders have been the radiations from radio-isotopes and more recently thermal neutrons. These have both merely been able to capture certain fringe areas from X-radiography. What I have to say about Proton Radiography should be viewed in this context.

I want to talk about two types of Proton Radiography, Marginal Range Proton Radiography first proposed by A M Koehler[1] in 1968 and Proton Scattering Radiography which we originated at Harwell in 1972[2]. We have tried to find areas of application for both these techniques and we were fortunate to have one such application come our way. We believe in fact it is the first practical industrial application of Marginal Range Proton Radiography.

2. Marginal Range Proton Radiography

Marginal range radiography requires the use of a mono-kinetic beam of protons and range considerations set the energy at above 100 MeV in order to penetrate a few centimetres of steel. We have used 160 MeV protons from the Harwell Synchrocyclotron which have a range of 33mm of steel. This type of radiography depends on the rapid change of the specific energy loss (MeV/ g /cm^2) near the end of the range of a charged particle. The Bragg curve, Figure 1, shows the variation of specific energy loss for 160 MeV protons in steel near the end of the range. If one adjusts the range of the protons, by supplementary absorber, so that the protons which emerge from the object sit at point A on the Bragg curve a high sensitivity to changes in the effective thickness of the object is obtained. Unfortunately multiple coulomb scattering blurs the image unless the detail examined is close to the film. However the contrast is so much higher than with X rays that the unsharpness does not rule out the technique.

Figure 2 shows the degree of contrast obtained in a test sample 6.4 mm thick containing areas of microporosity (pores in the size range 0.03 mm to 0.1 mm) as the supplementary absorber thickness is varied in the region of point A (Figure 1). It also

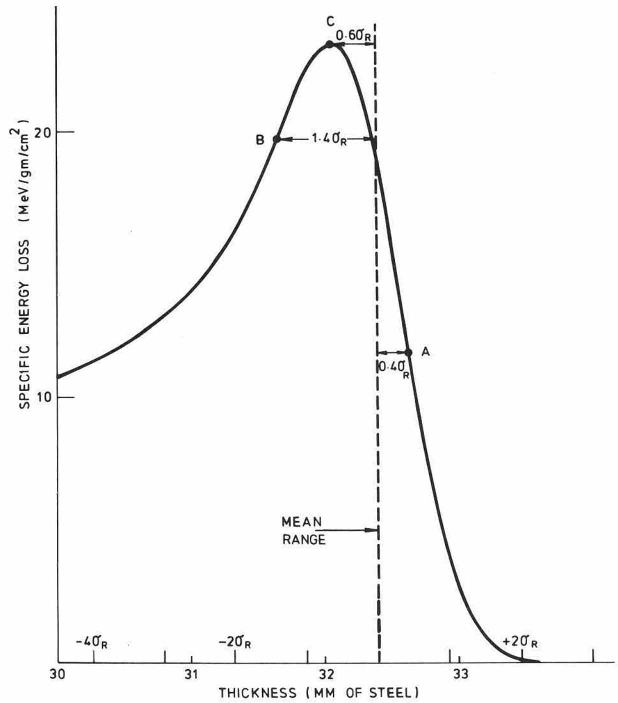

Figure 1. The end of the Bragg curve for 160 MeV protons in steel.

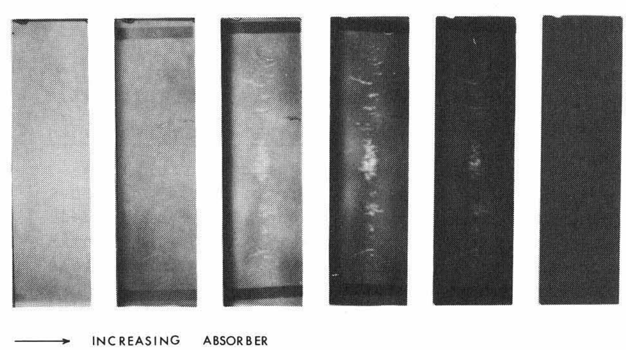

Figure 2. Marginal range proton radiographs of microporosity in a test slab as a function of absorber thickness, in steps of 1.6 mm (perspex), near the optimum thickness.

illustrates the point about the sharpness of the image. The test piece has surface protrusions on both surfaces. The one on the surface nearest to the film is sharply seen but that on the far surface is not. Figure 3 shows the situation with the opposite surfaces of the test piece in contact with the film in turn. The sharp mark becomes blurred and viceversa in the two views. The overall impression of the microporosity is not however influenced

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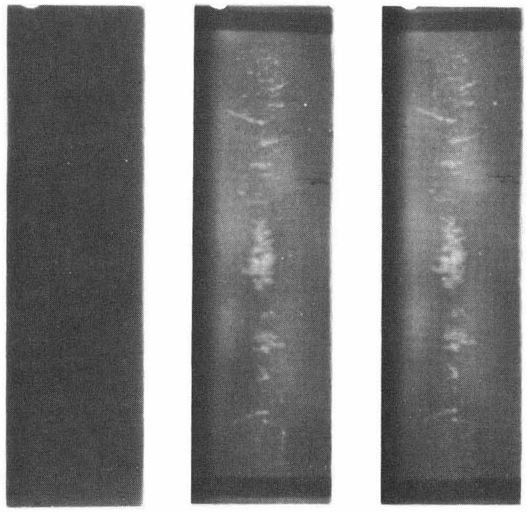

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Figure 3. Marginal range proton radiographs of microporosity in a test slab with surface protrusions (arrowed) on opposite faces taken from opposite sides (centre and right) and with X rays (left).

by this behaviour. A conventional X radiograph of the same test piece is also reproduced in Figure 3. It does not show up the microporosity with anything like the contrast of the proton radiograph. In fact sensitivity measurements we have made using artificial holes embedded in a layer of material showed for example that the marginal range technique was capable of detecting extensive voids of about 0.1% of the thickness of a copper layer 8 mm thick located at its centre. The corresponding figure for conventional X-radiography is just below 1%.

3. Application to Aero-Engine Turbine Blades

A practical application of this technique concerns the detection of microporosity in aero-engine turbine castings. Hitherto the only available technique was a destructive one, - sectioning and examining the polished sections. Conventional X-radiography did not show up the porosity as Bragg reflections from individual crystallites introduces a mottling effect which masks the porosity. The castings had an aerofoil section of varying profile and it was necessary to construct a supplementary absorber (anti-blade) to equalise the thickness in the direction of the proton beam. This is illustrated in Figure 4. Not shown in Figure 4 are the axial cooling holes in the casting. Figure 5 shows the microporosity detected in such a blade, with and without antiblade, with cooling holes plugged and with X rays. The microporosity was occuring in layers and it was this fact as much as anything which contributed to the successful use of proton radiography. The inevitable lack of sharpness of marginal range radiography which would have prevented seeing an individual micropore was in the event irrelevant. Over a thousand turbine blades have now been examined in a period of 1½ years and a

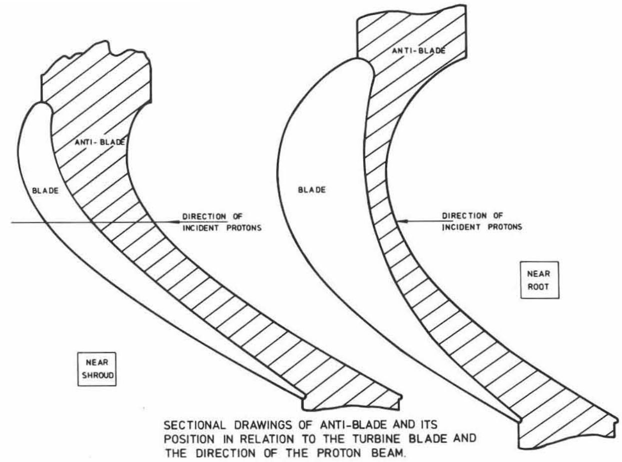

Figure 4. Section of aero engine turbine blade and anti-blade.

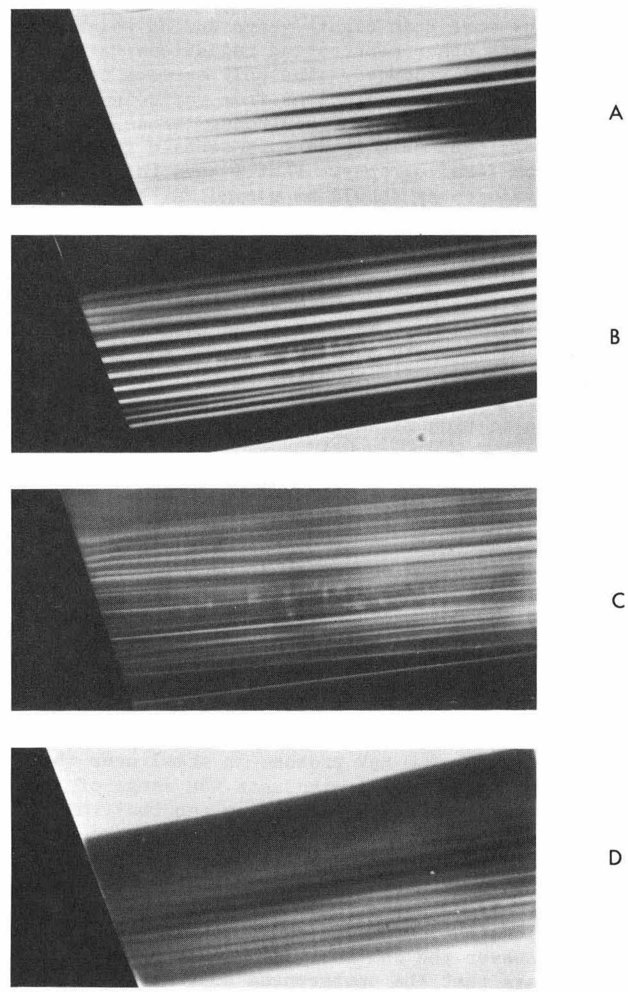

Figure 5. Microporosity detected in an aero engine turbine casting. With protons: A turbine blade alone, B blade and anti-blade, C blade and anti-blade with cooling holes plugged. With Xrays (140 kV): D blade and anti-blade.

combined technique of sectioning in places indicated in the proton radiograph has been evolved. The work is continuing in an attempt to reduce the incidence of the microporosity. An account of this work, done in collaboration with Rolls Royce Bristol, is to be published shortly [3] but a preprint is available [4].

4. Proton Scattering Radiography

Proton scattering radiography which I should like to mention in conclusion has not yet found any practical applications. The radiographs are sharp although they depend on multiple coulomb scattering but the contrast is not as high as with marginal range or other absorption type radiographs. The principle of the method is illustrated in Figure 6.

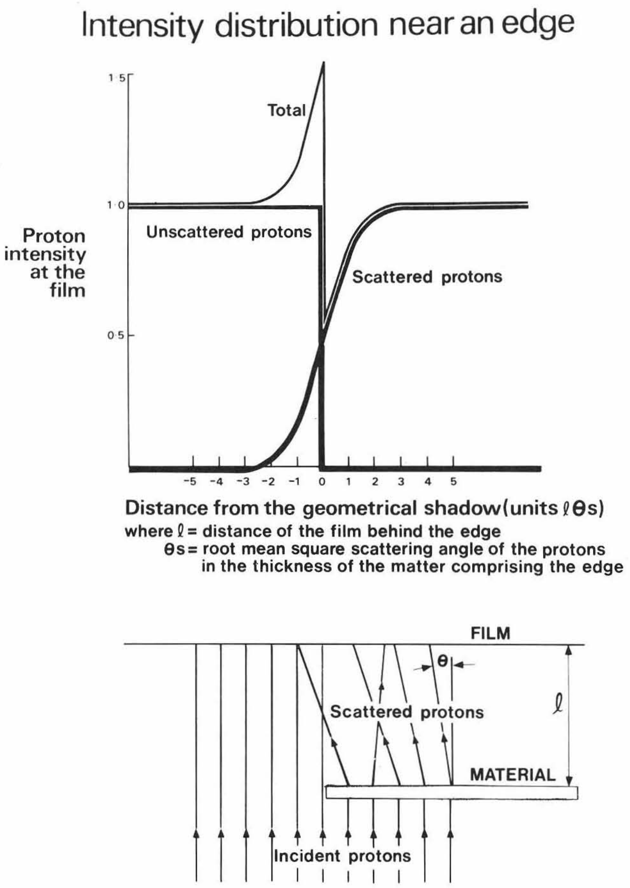

Figure 6. Principle of Proton Scattering Radiography

It has been described and illustrated in several recent publications by A C Sherwood and myself [5, 6]. The intensity distribution enhances edges and the radiographs resemble xero-radiographs taken with X rays. The special features of these radiographs are illustrated in Figures 7, 8 and 9. There is no tonal change away from edges which are sharply delineated. There is always difficulty in representing cylindrical or spherical edges with an absorption radiograph and this may represent one area of usefulness of the technique. A second point of advantage is the range of detail which can be seen on a single radiograph. Many objects, difficult to examine with X rays have been subjected to proton scattering radiography in the hope of

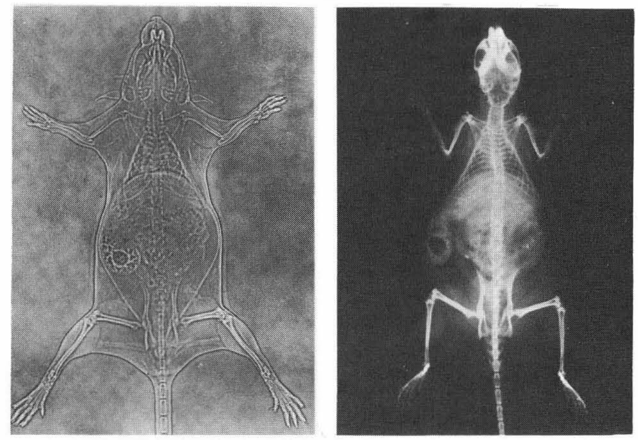

Figure 7. Proton (160 MeV) Scattering radiograph (left) and X radiograph (right) of a mouse.

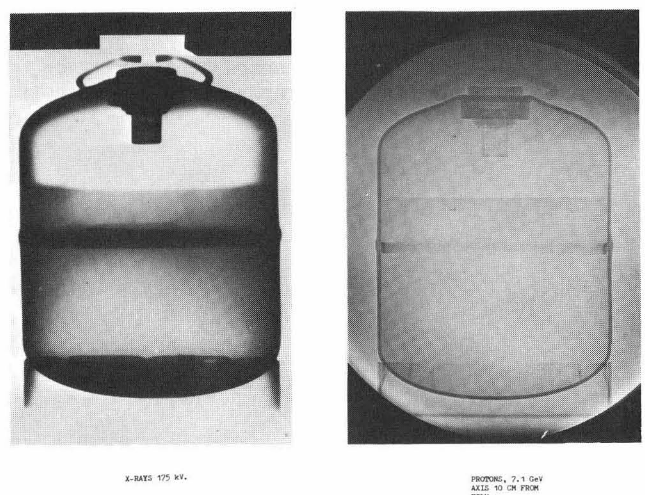

Figure 8. Camping gaz container, proton scattering and X-radiographs.

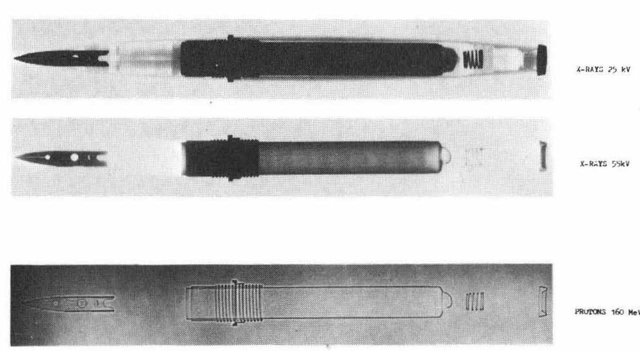

Figure 9. Fountain pen, proton scattering and X-radiographs.

finding an application for it. Among these objects are transistors, integrated circuits, carbon fibre composites, diamonds, Stirling Engines, heart pacemakers and their components, tooth fillings, an ancient Chinese bowl, an Egyptian ornamental cat, diseased mice, fast reactor fuel pins and reactor fuel pellets.

To summarise a commercial application has been found for marginal range proton radiography and it seems likely that other similar applications will exist. Proton scattering radiography also offers several points of difference from existing techniques which could justify its use in specialised applications.

5. References

(1) A M Koehler, Science, 160, 303, 1968.

(2) D West and A C Sherwood, Nature, 239, 157, 1972 and AERE R7190, July 1972.

(3) P Stafford, A C Sherwood and D West, Non-destructive Testing, in course of publication.

(4) P Stafford, A C Sherwood and D West, AERE R7995, May 1975.

(5) D West and A C Sherwood, Non-destructive Testing 6, 249, 1973 and AERE R7502, August 1973.

(6) D West, ATOM 222, 54, 1975 and AERE R7757, June 1974.

DISCUSSION

M.A. CHAUDHRI: Did you try to compare this proton radiography with thermal and/or fast neutron radiography?

D. WEST: The microporosity did not show up with thermal neutrons. Fast neutrons were not tried but neither technique has the enhanced sensitivity of marginal range proton radiography for small defects.

Y. JONGEN: Can you comment about the activation of the samples used in the first type of proton radiography?

D. WEST: It did not prevent direct handling within 15 seconds and was undetectable the following day. It is unimportant.