The Scope of Non-destructive Testing

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The common techniques of non-destructive testing are discussed briefly to provide a background for more detailed comments on their scope and limitations. Such testing involves an extra cost in production, so that such testing methods should be applied intelligently in relation to those defects that are important. In recent years the scope of such testing has been, and is being, increased by the introduction of new methods based (as for the currently accepted methods) on the fundamental properties of materials. Currently there is insufficient information on the importance of such defects in service. The extent of non-destructive testing in Great Britain is indicated, and information is given on training facilities available.

INTRODUCTION

The term "non-destructive testing", as a generic title for any method of testing which does not harm the product under test, is relatively new It was unknown in this context prior to 1940 and seems to have arisen to bring together testing methods which came to fruition mainly during, and subsequent to, the Second World War.

In fact, however, many of the methods which today are covered by this title were well-known and in use long before the war[2], e.g. radiography, for which the non-destructive nature of the test was usually emphasized[1], and magnetic tests[2]. The subject does not, therefore, deal with a new science but with developments of some well-established techniques, coupled with methods which have been introduced in the past twenty years or so.

The present paper endeavours to put these various methods into perspective in relation to their scope and present stage of development in Great Britain. As the increasing acceptance of such testing has called for agreed standards in terminology and techniques, these will be indicated as appropriate.

It will become evident that the most outstanding problem lies not in the use or scope of those methods discussed, but in deciding, first, on the choice of method, and second, on the importance of their findings in relation to service behaviour. It must be admitted, however, that recent inspection standards have shown a greater tolerance towards the presence of defects.

DEFINITION OF NON-DESTRUCTIVE TESTING

The term "non-destructive test" is, as it implies, any test which can be applied as a check on the quality of a product without rendering a sound product unfit for service; alternatively, it may be described as the use of some physical method for evaluating the soundness of a material, or product, which does not impair its ultimate usefulness. The most obvious, and yet frequently overlooked method, is, of course, visual examination, possibly with a magnifier or even a binocular microscope. There is, it seems, a tendency to push aside such simple tests in favour of some more impressive and elaborate method which appears to be more scientific, but which may not necessarily have more scope, and may even be less suitable for the job in hand.

It will be clear that such a definition is also applicable to many long-established methods of test, e.g. proof testing, pressure testing, and leak testing. It might even be applied to a test such as a diamond hardness test, in which the minor damage has no adverse effect on quality provided, of course, that this damage is not in an obvious place. In fact, the term "non-destructive testing" could be applied to many long-established tests, which have never been considered as being non-destructive, e.g. measurements on dimensions and electrical resistance.

By common usage, however, the term is generally restricted to certain well-established techniques such as radiography, ultrasonics, including resonance methods, magnetic crack testing, penetrant methods of crack detection and eddy-current testing, and to other methods of relatively recent origin, e.g. leak testing and thermal tests which automatically fall within the scope of the definition. As a general rule, it will be found that any particular technique may be especially good for detecting specific types of defects under specific conditions; this aspect will be discussed later. For this reason it is generally safe to say that any one method does not provide a universal test for *all* defects, and also that the methods are both complementary and supplementary. In some instances more than one non-destructive test may be essential to detect the various types of defect. It is important to realize that in many types of non-destructive testing the evidence for a defect is *indirect,* for example, the distribution of a magnetic powder on a magnetized specimen is not uniform, and, therefore, the presence of a crack is inferred. For this reason great care is necessary in interpretation as the effect observed may be due to some feature which may be of no importance in the service of the product inspected. For example, tool lines on the forming tool may give rise to misleading images in the magnetic field. Again, the radiographic image of undercut in a weld may sometimes simulate that of a linear inclusion *within* the body of the weld.

During the past few years there has been a growing opinion that many more tests, in addition to those so well-established, could be developed for specific problems by utilizing basic and well-known phenomena. To help to this end, there is an increasing interest in those properties of materials which might affect the quality of the made-up product. Accordingly the unsolved inspection problems which exist in all types of industry are being collected and collated by a working party sponsored by the British National Committee for Non-Destructive Testing[5]. One interesting aspect of this work is that, in some instances, it has been found that problems arising in one industry have already been solved in some other industry.

This trend to new methods is excellently illustrated by

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the development of thermal phenomena for inspection procedures, based on heat transfer. A homely example of this kind is seen every winter when the frost layer on the front of a timber door reveals the position of the cross-bracing members on the other face. A few years ago, Powell[34], who is responsible for some of these new methods, very effectively reviewed the possibilities of thermal methods for inspection.

The application of such tests can be well illustrated by considering the problem of inspecting the stressed laminar sheet structures, as used in aircraft, which consist of a sheet of thin metal bonded (usually by brazing) on each side of a honeycomb structure. The strength of such a structure is dependent on the efficiency of brazing. In the search for a successful method, radiography[3, 44], fluoroscopy[3, 44], and ultrasonics[3, 4], have been investigated as well as a variety of thermal methods.

In the thermal method one face is heated uniformly and the inspection procedure is applied to the other side to detect the uniformity of heat transfer by one of the following methods:

a) a heat-sensitive paint[3];
b) fluid repulsion (as with water on a hot plate)[3];
c) photographing each surface of the plate area by infra-red[3];
d) a phosphor coating which is excited by ultra-violet, the fluorescence varying with the temperature[35].

Summing up, it can be said that the present trend is to seek new methods of non-destructive testing by applying basic principles to known problems. Progress is, however, likely to remain slow unless more co-operative efforts arise from industry, and the necessary funds are made available for the basic research. An outstanding demonstration of the success which can be achieved under such circumstances was the development of the ultrasonic test. In 1939 the need to detect hair-line cracks was urgent and the Hair-Line Crack Committee of the British Iron and Steel Institute saw to it that the necessary research was done[6]. Another example, but with a less lasting result, was the development, under contract, of a transportable linear accelerator for the inspection of the thick ferrous sections in nuclear power plants. For the present, it seems that, unless additional funds are made available, the less urgent developments will have to wait until organizations can be found to undertake the basic investigatory work that is necessary.

The research associations offer some scope here, but generally the competition of other work for their funds is likely to be so great as to leave little money to spare for work on new non-destructive tests. This is most unfortunate, as the effective use of non-destructive testing with efficient feed-back of resulting information to the production line may well lead to advantages, in the end, in the form of improved products at the same cost, or even in a reduction in overall production cost.

It is of interest to note that Lewis[7], primarily writing on the need for developing new methods of non-destructive tests for non-metallic substances, such as concrete, has summarized the position as follows:

1) if in any field there exists a standard for controlling either homogeneity or material property (even if this is a destructive test on a sample basis) then a new non-destructive test is unlikely to be worth development unless it can be expected to achieve equal control at a much lower cost;
2) assuming that in any field there is a need for one test of each kind, i.e. one for homogeneity and one for property, then, if there is a standard test of one kind, only the other kind is probably the most fertile ground for developing a new non-destructive test or adapting one already developed in another field;
3) when there is clearly a need for a new test, a study of the way in which its development is going to be financed before it can become a viable standard test is highly desirable;
4) in cases where a new test would seem worth while when developed, but trade practice or the way in which commercial arrangements have evolved provide no financial drive, the necessary work might be submitted as a reasonable subject for direct or indirect financial assistance by the Government.

THE METHODS AVAILABLE

The techniques discussed briefly here are those which are normally grouped as non-destructive inspection techniques.

These notes are intentionally brief, because text books and other literature are readily available[8-13, 43]. The present notes therefore merely provide a reminder of the principles involved and of the scope of each method.

Radiography

The basic elements of this technique are comparatively well known because of its similarity to medical X-ray examinations. Essentially the radiation passes through the object, and variations in its thickness and/or density are revealed by localized differences in the blackness of the film image. The nature of the test involves access to *both* sides of the object, in order to direct the radiation towards the region concerned and to place the film in position; the latter does not involve quite so much free access space as the former. Such a simple description, of course, hides many complexities which call not only for a wide knowledge of the technique, but also much experience in order to ensure that the maximum advantages are achieved. Reference to any knowledgeable treatise on radiography will readily convince the reader that it is never sufficient to specify simply "subject to X-ray test"; yet how often is this found in specifications? It is even worse if the specification says something like "subject to radiographic approval", because this allows the use of either X-rays or gamma rays, even though the latter may in some instances prove less critical than X-rays in revealing defects.

Radiography both by X-rays and gamma rays has expanded greatly during the past twenty-five years. Just prior to the war, there were said to be between six and twelve industrial radiographic laboratories in the country. In the author's opinion it was probably fewer than six. Now it is reckoned that there are several hundred. This figure is supported to some extent by information recently collected in a survey made for the office of the Minister for Science[14]. According to this, the number of firms and organizations in Great Britain using gamma-radiography totals 470. It is reasonable to suppose that around one third to one half of these will also use X-rays, and that in addition there will be, say, 300 using X-rays alone for purposes for which gamma rays are unsuitable. This gives a total of 770 radiographic departments in the country. This expansion has arisen partly because of the proved value of radiography and partly because the cost of the basic equipment for gamma-radiography has fallen appreciably with the increasing availability of gamma ray sources. This may be readily deduced from the Government Survey mentioned.

Radiography has been written into the inspection codes of various organizations, such as Lloyd's Register of Shipping, the Admiralty, I.C.I. Ltd., as a mandatory test for fusion welds in Class I chemical and pressure vessels. In addition, various British Standards indicate radiography as a reliable means of inspection, for both light and heavy metals.

It is also used as a convenient means of checking the quality of welds, e.g. in ships' structures and pipelines, by examining welds chosen at random when it is sometimes decribed as "spot radiography". Recommended techniques for the radiography of welds have been provided in British Standards[17, 18].

Radiography is also demanded for the inspection of important aircraft castings and is now being used in the routine inspection of aircraft at their periodical overhauls. Guidance is available on the interpretation of radiographs of welds[38] and castings[39], and several text books[9-13] have been published detailing the technique of the method. Such literature is mainly concerned with what radiography can detect and its limitations may be overlooked. However good the technique, it will not (in general) reveal changes in metallographic structure, e.g. arising from cold-working or annealing. It will usually not reveal the presence of laminations which lie in a plane at right angles to the beam direction. A planar defect, such as a crack and lack of fusion, may be missed if its plane does not lie roughly in line with the radiation beam direction. Fortunately the plane of most cracks lies normal to the metal surface and the chance of detecting them is fairly good[15]. It will not detect very fine defects below the limit of sensitivity of the method. In fact, the defect must cause a differential absorption at least equal to ½ to 2 per cent of the metal thickness before it can be revealed. The actual figure depends on many aspects, but mainly on the technique used.

There seems to be no reason why radiography should not remain a reliable and accepted method of inspection, provided that its inherent limitations are borne in mind. It is significant that, despite these limitations and the availability of other methods, the use of radiography is expanding rather than diminishing. Recently industrial radiographs in colour have been reported[16]. This technique uses standard photographic colour films and offers advantages where the specimen has a complex structure leading to a wide range of thicknesses, e.g. as in a radio valve. This technique also has advantages in minimizing radiation fog when radiographing specimens which are radio-active, e.g. fuel elements. These excursions into colour radiography are however, unlikely to fore-shadow the need to use colour films for established inspection work; rather are they likely to extend the scope of radiography.

Ultrasonics

This technique involves the transmission of pulses of high frequency radiation within the specimen, in a suitable direction, and determining the time taken for the echo, or reflection signal, to return, or to reach a probe at another point on the same surface of the specimen. In a defect-free plate, the signal sent at an angle from the surface of the plate will be reflected from the opposite face, and can be detected on the same surface of the plate, at a point some distance away from where the signal entered the plate, by means of a probe connected to a cathode ray tube. If a defect exists in its path, the beam will be deflected or reflected at this point and a change in the cathode ray tube display will indicate the presence of the defect. Its position can be deduced from the relative positions of the signals from the input, the defect and the normal reflection. It may also give a clue to the nature of the defect, provided that the operator has the necessary training *and* experience. Several variants of this technique are used; most use the reflected signal but use of the transmitted signal is feasible. The techniques to be used have been defined in British Standards[40, 41].

For the present discussion it is sufficient to note that the echo signal may be detected by a second probe, as already indicated; or, alternatively, a single probe may act as both the transmitter and receiver. Generally in most ultrasonic work the operator moves the probe, or probes, over the specimen surface and watches the cathode ray tube display, but automation with chart recording has been used successfully for certain types of work[41].

The method is particularly valuable for detecting laminations in plate, and defects in welds. It is also capable of giving indications through extremely thick sections and, therefore, has considerable merit for the inspection of castings and forgings. In fact, it is possible to detect a flaw to an accuracy in position of about 0·10 inch up to a distance of two feet, and is capable of detecting defects up to 25 feet or more from the probe.

The usefulness is however limited to some extent by the following factors:

a) unfavourable size or shape of object; a complicated casting, for instance, may give rise to misleading signals;
b) the surface condition of the object; the smoother the surface the more critical the inspection;
c) how the defects are orientated and positioned relative to the beam;
d) misleading signals which may arise from very small or very large grain size;
e) unless special techniques are used, it is impossible to detect defects *immediately* below the test surface.

In recent years, an immersion method has greatly extended the scope of this method of testing, particularly for large and complicated shapes. Both the specimen and the probe are immersed in a tank of water, so that the distance between the probe and the nearest face of the specimen is known. This technique offers an important advantage in that the probe can be mounted on an overhead rail system which allows movement in two-directions at right angles. By use of the appropriate movements the probe can scan the whole of the specimen systematically and the position of a defective region can be defined with ease by reference to the rail positions.

As it can be used to assess metal thickness by measurement from *one* face only, the ultrasonic method offers obvious advantages where wall thickness may have been reduced due to corrosion on the opposite face, which it may be impossible to inspect otherwise. This is particularly valuable for pipelines.

There are, of course, other acoustic tests which are equally non-destructive, e.g. the familiar wheel-tapping and the resonance test. The latter has received more attention during the past few years[27, 28] and it appears that, with suitable equipment, it offers an important and useful technique in appropriate instances.

In the twenty odd years in which this technique has been established, the sphere of application of ultrasonics has steadily increased and equipment will be found in most large works making welds, castings and forgings. Its extension has been hampered by two factors. First, the method requires an experienced and conscientious operator of high integrity who really knows his job; training schemes started during the past few years are helping to reduce the problem. Second, the lack (in most circumstances) of any permanent record (as distinct from notes made by the operator); this resulted in a rather tardy acceptance of the method by surveying and insurance bodies, but this attitude has been changing over the past few years. Now, many surveying bodies accept ultrasonic inspection for both castings and welds in prescribed conditions. There is no doubt that such moves will give fresh impetus to the application of the techniques to welds, castings and forgings. Its use in the inspection of concrete structures, e.g. roads, is noteworthy because this is probably the only non-destructive method available for such work. Detailed information on the use of ultrasonics for non-destructive testing can be found in the literature[8, 9].

Magnetic Crack-Detection[19]

In this method, which is usually applied only for the detection of defects open to the surface in magnetic materials, the specimen is magnetized, and then treated with a suspension of fine magnetic particles in oil. These particles form in lines along the side of those cracks, or any other fissures, which lie across the lines of magnetization. The important features here are, firstly, that in general only cracks or fissures open to the surface are revealed; secondly, that the magnetization should be repeated in a direction at right angles to the first, to ensure that cracks in every direction may be detected; thirdly, that the magnetic field is adequate. By suitable techniques, defects below the surface may also be revealed. These criteria illustrate how meaningless it is to write in the specification, "subject to approval by magnetic testing", without a more detailed specification of the technique to be used, particularly in magnetizing the specimen. This technique is now well established and is in wide use for ferrous materials. A British Standard[20] specifies the properties of the magnetic "ink" which is used for finished machined aircraft parts.

Other magnetic tests of a different type can be used for determining the thickness of non-magnetic coatings on ferrous material.

Penetrant Method

This is a modern technique based on the well-established oil and whitewash method of detecting cracks open to the surface. In one variation, the specimen is soaked in a special oil of a type which glows when excited by ultra-violet light. Excess oil is cleaned off the surface, and residual oil trapped in cracks is sought by examining the specimen in the dark, under ultra-violet light. Any fissures are immediately evident because of the fluorescence of the residual oil. It is perhaps symbolic of the scientific mysticism which creeps into such techniques that the ultra-violet radiation used is sometimes called "black light". In another variation of this technique, a dye in a solvent is used, instead of the oil mentioned above; after removing excess fluid on the surface, the specimen is dusted over with a detecting powder, which changes colour where the dye in its solvent is leaking from surface cavitation. Examination may be by the unaided eye, by simple magnifying lens, or by a binocular microscope.

This method of detecting apertures, e.g. cracks, open to the surface has received marked impetus during the past decade, due to the attempts of the various manufacturers of the dye and fluorescent penetrants to improve them. This has promoted researches into the phenomena involved in entrapping the test chemicals in cracks and other fissures open to the surface[21].

Eddy-current Testing

This technique involves the electromagnetic induction of currents in the specimen; the flow of such currents is affected by the presence of defects in the specimen, and this change of flow can be used to reveal the presence of defects. The conditions of testing are very dependent on the nature of the specimen, and on the type and position of defect being sought. Although the method has been used mostly for non-ferrous materials, it may be applied also to ferrous materials.

Having in mind that many non-destructive testing methods are based on earlier discoveries, it is of interest to note that this method was worked out in detail as long ago as 1879 by D. R. Hughes[25]. Lacking an electronic oscillator, Hughes used the ticks of a clock falling on a microphone to produce the exciting signal. The resulting electrical impulses passed through a pair of identical coils and induced eddy currents in objects placed within the coils. Listening to the ticks with a telephone receiver, Hughes adjusted a system of balancing coils until the sounds disappeared and noted the different adjustments needed for objects of different sizes, shapes and materials.

In his paper, which was given before the Physical Society (London), Hughes commented as follows about the sensitivity of this equipment, to which he referred as an "induction balance":

> "A milligramme of copper or a fine iron wire, finer than the human hair, can be loudly heard and . . . its exact value ascertained . . . I have thus been able to appreciate the difference caused (in a shilling) by simply rubbing the shilling between the fingers, or the difference of temperature by simply breathing near the coils . . . If I place two gold sovereigns of equal weights and value, one in each coil, there is complete silence, indicating identity or equality between them; but if one of them is a false sovereign, or even gold of a different alloy, the fact is instantly detected by the electrical balance being disturbed. The instrument thus becomes a rapid and perfect coin detector, and can test any alloy, giving instantly its electrical value . . . We find that the induction balance is exceedingly sensitive to all molecular changes which take place in all metals subject to any of the imponderable forces. Thus we have already by its aid studied the effects on metals of heat, magnetism, electricity, etc., and of mechanical changes such as strain, torsion, and pressure, and propose in some future paper to describe the remarkable results already obtained".

Despite this early work, it was not until just over twenty years ago that successful efforts were made, by Vigness, Dinger and Gunn[26] to utilize the technique in routine equipment. In their eddy-current flaw detector, the eddy currents are induced by an exciter coil, and the induced currents are detected by a pick-up coil and suitably amplified. The intervening years have produced important developments, due largely to Förster's work[45]. Commercial equipment is now available for:

1) determining the presence of defects;
2) checking the thicknesses of coatings, e.g. of paint on metal;
3) checking thicknesses of metals;
4) sorting alloys and metals;
5) detecting differences, e.g. heat treatment, between batches of the same metal.

As all these factors can influence the signal it is essential to know that all the other factors are constant when making a check. Because of the many different conditions which affect the magnetic properties, and because the magnetic properties are more effective in determining the inductance rather than the conductivity, eddy-current methods are of very restricted value in the inspection of magnetic materials. The higher the applied frequency, the more effectively eddy currents may be confined to a very thin surface skin, thus rendering it easier to detect cracks open to the surface. The method may also be applied to ferrous materials, provided that suitable saturation techniques are used. So far as defects are concerned, eddy-current response is a function of the area of the discontinuity projected on a plane which is perpendicular to the eddy-current paths.

This technique has limited application, but, where it is appropriate, it has proved far more successful than the other techniques, as for instance in the inspection of metal tubes, for all types of imperfections which may have an effect in service. The method is relatively inexpensive and can be operated on a production scale by unskilled personnel who watch for reject signals shown on a meter or by flashing lamps. An important feature of the technique is its ready application to automation in certain conditions.

General Comments on the Foregoing Methods

The methods all leave the specimen in as sound (or as unsound) a condition as it was at the outset. They offer, therefore, an outstanding advantage over sectioning, which indicates only the quality of the particular casting or weld sectioned. Although sectioning may prove that the specimen examined was sound, it leaves nothing more than a lot of useless pieces, and the realization that a sectioned sound casting is no longer acceptable for service; moreover, some doubt must always remain regarding the quality of those components which were not sectioned.

It is even possible for sectioning to give misleading information. For instance, a casting may contain defects (which could be shown radiographically), but these may be missed because the cuts do not pass through them. Accordingly, on the evidence provided by sectioning alone, it may be assumed that the metal is free from defects; and as a consequence, castings from the same batch may be accepted as sound on the evidence provided by cutting *one* up.

This point was brought home very forcibly following the radiographic inspection of six cast crankshafts, two of which were rejected, as a result of the test, because of extensive sponginess in the counterweight. The two condemned castings were then sectioned by the foundry without reference to the detailed radiographic findings. In accordance with their usual practice the sectioning was along a plane of symmetry; it so happened that none of the defects passed through this plane; and the resulting sections suggested that the castings were sound. It was only when sections were cut along directions indicated by the radiographs that extensive cavities were revealed, and the radiographic findings were confirmed. At the best, therefore, sectioning (without the guidance provided by some non-destructive test), is a hit and miss process of questionable value. Even when radiographic evidence is available it is necessary, if a section through the defect is required, to take great care to section in the correct position, as much depends on a consideration of the geometry of the radiographic technique used.

CHOOSING THE TEST TO BE USED

Before deciding to use *any* non-destructive test it is essential to define what "defects" it is expected to reveal. The word "defects" has been written in this way intentionally because, in fact, it is deviations from normal which are to be revealed. For this reason there is a tendency to use the word "imperfection" instead of "defect" by some people. How far these will rank as unacceptable defects insofar as they render the product unsuitable for use will depend on the service conditions. For example, fine gas porosity in a weld in a ship's hull is unlikely to be of much importance in service but may be very important, based on strength considerations, in a fusion-welded joint in a pressure vessel. Its importance might be even greater if it happens to be adjacent to a surface subject to corrosion in service. In fact, modern practice in relation to ferrous welds in Class I pressure vessels[36] recommends the rejection of a total area of porosity (in the radiographic image), projected radially through the weld, exceeding 0·01 inch per inch of wall thickness in any square inch of projected weld area. This total area corresponds to three gas pores $\frac{1}{16}$ inch in diameter. Again, a considerably greater amount of porosity is permissible in fusion butt welds in vertical mild steel storage tanks for petroleum[33], and, under certain conditions, incomplete penetration up to one-third of the thickness of the thinner plate is also accepted, subject to the customer's approval. British Standard 1500, Part 3[37], also allows defined amounts of porosity, oxide inclusions and tungsten inclusions in aluminium fusion-welded pressure vessels for the chemical, petroleum and allied industries. A descriptive classification for porosity has been devised in relation to both light alloy[37, 38, 42] and ferrous[38] welds.

A further reason for deciding on what "defects" are to be sought is to ensure that the correct method of test is used. For instance, if laminations in steel plate are to be detected then ultrasonics must be specified, as radiography is quite unreliable for detecting such defects. If surface fissures, e.g. cracks, must be found then there is a choice between the magnetic particle test, and penetrant testing; but the former can, obviously, be used only if the material is magnetic.

Coupled with this, it will usually be necessary to specify details of the technique to be used. As mentioned earlier, it is not sufficient to say "subject to radiographic test", because this would leave it open for the radiography to be done by X-rays or gamma rays and these may not give the same degree of fault sensitivity.

A further factor of importance is the cost of the inspection procedure relative to the basic cost of the production and its final value. This is a difficult aspect because very little reliable information on costs of such tests is available. More will be said on this in the next section.

Cost Factors and Economics of Non-destructive Testing

The promise of improved reliability arising from non-destructive testing is likely to encourage its specification and application until the costs are considered alongside the advantages. It is unfortunate that the economics of such testing have only rarely been effectively reviewed in the literature, and it is therefore impossible to give any well-substantiated facts on this aspect. It is perhaps because for this reason that the Society for Nondestructive Testing in America has coined the phrase "Nondestructive Testing does not cost, it pays". In some instances, the merits of using any sort of inspection which ensures reliability are obvious, e.g. in inspecting welds in submarines, or for detecting incipient cracks in aircraft.

The uncertainty regarding cost goes as far back as the equipment needed, its housing and the type of labour used. It may at first seem easy to state the cost of equipment, but this is not so. It all depends on what method of inspection is to be used and on the nature and quantity of the items to be inspected. Of the various methods, the use of dye penetrants involves least capital expenditure, unless a binocular microscope must be used. In fact it has been said that this involves the purchase of no more than an aerosol container of the testing fluid. Magnetic methods are more costly as they involve the purchase of suitable magnetizing equipment. Ultrasonic equipment can be purchased from around £500 to £600, but here again the choice of the equipment must be related to the type of work.

For radiography, gamma-ray sources and suitable containers generally involve less capital expenditure than X-ray equipment. Whereas the thickness ranges covered by gamma-ray sources are fairly wide, there is no doubt that for steel thicknesses below about two inches, and for any thickness of light alloy, X-rays give more detail in the radiograph.

Having these comments in mind it is best to consult some independent authority who can advise on the best methods for the work to be done, and who will also be able to give some idea of the likely capital expenditure.

The sparsity of cost information has recently been commented upon by Campkin[22], who has made a praiseworthy attempt to provide such information for a non-destructive testing service in power-generating plant. In this he has calculated the cost of shut-downs arising from faults in the system, relative to the cost of non-destructive testing facilities and planned shut-downs. With these figures he has shown that an expenditure of £40 250 for providing non-destructive testing facilities and tests for a year led to a saving of £55 000 *after* paying the bill for the non-destructive testing equipment and services.

Many others have written in more general terms of the advantages of non-destructive testing and there are even more who have spoken in public (but not written) to the same effect. To those familiar with non-destructive testing two important points are obvious, namely:

i) the extent of such testing in all types of industry surely indicates that it is considered worth while;
ii) the cost must inevitably be passed on to the final customer.

Perhaps the latter factor partially explains the absence of reliable data on the actual cost of such testing.

On the other hand, it is undeniable that where non-destructive inspection is used in the course of production, the cost is not simply a function of the capital cost of the equipment, its depreciation, the cost of running the inspection department (including staffing and overheads), and the time and material involved in the inspection. It must also be related to the costs involved in replacing faulty work, and in the cost of re-organizing work schedules to accommodate the extra work arising. On the other hand, the *results* of introducing non-destructive testing may lead to savings which must be set against the cost. For example, there will be savings because there will be no lost time on machining castings which prove to be faulty in the course of machining; work schedules at this stage will be more reliable; and there may be a bonus of improved techniques giving the high reliability involved[32].

The radiographic inspection of a Class I pressure vessel illustrates this clearly. It has been estimated that the average cost of radiography in the boiler shop per foot run of weld varies between 12s. 6d. and 25s., but this bears no relation to the costs involved when a defective section is found. This must first be cut out, to remove the defect, and ideally (particularly when a crack is being cut out) it is desirable to radiograph the gouged-out section to confirm complete removal of the defect. The weld has then to be re-welded, with possible need of preheating, chipped, ground and re-radiographed. Such repair work not only interferes with normal programming of work, but may also hold up further work until the vessel has been removed from the inspection bay. The costs of such deviations from the work programme can, perhaps, be assessed, but they are unknown for each vessel until its completion; all that can be done is to allow a contingency factor for such interference with routine.

The cost of ultimate repairs, necessitated by defects in the welding explains why radiography is used to check the quality of butt welds in steel pipelines for oil or gas. In neither case do the service conditions approach those in Class I pressure vessels and high-pressure steam lines. Nevertheless radiographic inspection is generally routine. It has been said that a failure in a welded pipeline may cost as much as £300-£500 to repair, having in mind the tracing of the failure, transport of men and equipment to site, digging out, sealing off for repair, cutting out the faulty weld, repairing it and making good on site. This figure does not, of course, include the loss of fuel or gas which occurs, nor does it take into account any consequent liability arising from damage due to the leakage.

This unknown cost factor can be equally important in the production of castings to a defined quality standard. Suppose that twenty "perfect" castings are required. Is it sufficient to make only twenty, or should (say) twenty-five be made? Either can lead to wastage of effort, unless only twenty are made and all are acceptable, but if only seventeen are acceptable then moulding, metal melting and casting will have to be set up for the remaining three, and here again all may not be acceptable. On the other hand, if twenty-five are made initially, short production runs will be necessary if twenty good ones are not found. If more than twenty good ones are found, then there is wastage due to excess production.

In these examples of the pipeline and the castings it is seen that non-destructive testing may increase the total cost of the job, but in both instances, it is really greater reliability which is being paid for. Such costs would not of course be necessary if the quality was right in the first place. This theme of getting the product *right first time* is one which has been taken up very forcefully recently by the quality and reliability engineers, both nationally and internationally. How often is it that inspection is made all the more necessary by scamped or rushed work in the early stages of production?

A further factor which contributes to the variability and uncertainty of such few figures as are available is that of the method of charging overheads on the inspection department. In some works, the inspection department appears to be a part of the management function and may, or may not, carry appropriate overheads; in other instances, it is a part of the production line and is then likely to carry different overheads. Whatever method is used, the cost must nevertheless be paid.

From what has been said above, it will be clear that the charges for non-destructive testing made by contracting inspection firms do not give the whole picture. Some of the firms offering a service in industrial radiography have two scales of charges, one for merely providing the radiographs and the other for providing an interpretation of the radiographs in addition, but this may not always include a judgement on the acceptance or rejection. Other firms offer a more extended service, for example, in the installation of pipelines. Here the service provides ordinary routine inspection of the welding techniques, the carrying-out of physical tests as required by the production contract, non-destructive inspection, and consequent acceptance or rejection in accordance with the terms required by the contract. Generally such overall control applies to large contracts, e.g. cross-country pipelines, and it is highly competitive.

It is perhaps as well to make clear that interpretation means solely the identification of the nature of the defects revealed, and is itself not concerned with the final decision whether to reject or accept. This decision should rightly be the function of the stress engineer; unfortunately it is often left to the radiographer or radiologist, who may not necessarily be at all familiar with the stress factors involved.

Costs of Examining Castings

The cost of radiographing castings can vary appreciably according to the type of material, the thickness and the number of exposures required. A large casting, e.g. a car crankshaft, could involve up to nineteen radiographs, if X-rays are used, but this number could probably be halved by using gamma-rays. However, the latter may give poorer sensitivity of fault detection, though it may be adequate depending on the nature of the defects being sought. Each radiograph involves the cost of a piece of film slightly larger than the area of metal under examination, separate setting up for each exposure, the processing of the films, depreciation on the X-ray or gamma-ray equipment, and the reading of the films. The total cost might, for the crankshaft, be in the region of £5 with gamma-rays and perhaps 50 per cent more with X-rays. This may be considered a high sum relative to the cost of the casting, but if it is to be fitted to a prototype engine then the cost may be well justified.

On the other hand small castings like jet-engine rotor blades may be radiographed up to 20 or 30 at a time on one piece of film, with one setting up. The *total* cost per casting may then be but a shilling or two, and this cost is very small relative to the cost which may arise from failure in service.

It has been shown on various occasions that the use of radiography in the early production stages of a new casting can often lead to foundry techniques which give fewer faulty castings in the production run[32]. An example has been quoted[23] where the initial runs of a gear-blank casting produced 14 per cent faulty castings in the first batch of 50 000 blanks. With a revised foundry technique, guided by radiography, the failures fell to 1·2 per cent in the next production run of 75 000. In such work radiography replaces the sectioning which was once commonplace.

In discussing the inspection of crankshafts earlier, it was assumed that only one crankshaft could be examined by gamma-rays at a time. Frequently it is possible to arrange a ring of such castings around the source, so that all are radiographed simultaneously, with some reduction in inspection cost mainly in relation to setting up. The cost of the films and their processing will remain constant, but there will be savings on the use of the X-ray and gamma-ray equipment, and it should be possible to increase the rate of inspection; at the same time the inspection capacity will be increased. Such economies will best be achieved when a trained radiographer is employed.

In some instances ultrasonic inspection can usefully replace radiography. This is often true for ferrous sections over about two inches thick when the high-energy X-ray units or gamma-ray sources required are not available. As mentioned earlier, surveying authorities will accept ultrasonic inspection of steel welds in certain circumstances. In some instances, e.g. where very fine cracks are suspected, ultrasonic testing may be more reliable than radiography. In fact, the detection of cracks by radiography depends very much on the coincidence of the beam direction with the plane of the crack. Where these differ by more than a few degrees, cracks may not be revealed. A typical example is the fine dendritic crack which sometimes occurs near the fusion face in a weld; its plane is usually at an angle to the beam direction and consequently for this reason, and also because of its small dimensions, it may not show in the radiograph. On the other hand, careful ultrasonic testing will often reveal such a crack. Fortunately for radiography, cracks usually occur with their planes reasonably well oriented for detection. However, it is fair to say that a radiograph can confirm that a crack is present, but cannot prove its absence. Consequently the ultrasonic inspection may be essential for certain jobs and the relative cost, which is often less than for radiography, may be an important feature. The cost of such ultrasonic inspection is primarily related to the operator's time, plus allowances for overheads and depreciation of equipment.

With such costs in mind, whatever method is chosen, the question must arise why the products are being examined. Is it necessary to determine the presence of all defects or is freedom from surface fissures all that is necessary in service? In the latter event, the cost of inspection can generally be materially reduced by the use of magnetic or dye penetrant methods. Where, however, very severe standards are set and examination by binocular microscope is necessary, the cost of this less exotic method may still be high.

Cost of Inspecting Welds

It has already been indicated that the cost per foot run of radiographic inspection varies from about 12s. 6d. to 25s. This figure relates to continuous inspection, e.g. of pressure vessels, say up to two inches thick, in the works, where there is no extensive loss in operator time. In such works, two operators may achieve a rate of up to 12-15 films an hour, but of course this will depend on the ease of access to the vessel.

On the other hand, in shipyard work the rate may decrease to as few as 12 radiographs a day, because the equipment must be moved to several parts of the ship, or even to another berth, and staging may have to be erected. The work may also have to be done when workmen are not around (e.g. lunch-time, evenings) owing to the radiation hazards. Similar consideration may apply to work on site. The cost per foot of weld examined is therefore appreciably higher than for pressure vessel work.

In most instances, ultrasonic inspection would generally be much cheaper. However, there is normally no permanent record, apart from the operator's notes, and it may, in some conditions, be necessary to supplement the technique by radiography where defects are detected by ultrasonics, in order to assess the extent and nature of the defects found.

For some types of work, ultrasonics may be preferred because they may reveal more information than radiography. This applies particularly to the detection of lack of fusion in flash butt welds, lap welds and fillet welds for which radiography offers little scope.

THE EXTENT OF NON-DESTRUCTIVE TESTING IN GREAT BRITAIN

It is impossible to make a reliable estimate of the amount of non-destructive testing being undertaken in Great Britain, even if the tests are restricted to those more commonly accepted. No reliable figures are available and only guesses can be made. Some indication of the present extent of its use can be obtained by noting that the total membership of the three British technical organizations concerned with non-destructive testing amounts to 1170. As many are members of more than one society, it is reasonable to reduce this total to one of say 600 people *actively* concerned with the application of non-destructive testing techniques. Each may well be responsible for say from four to ten operators who will not be members of any of these technical bodies. With this as a basis it seems reasonable to argue that some 3000 to 4000 people are occupied in non-destructive testing in Great Britain.

A cross-check on this can be made by noting that 229 delegates to the Fourth International Conference on Non-Destructive Testing held in London in September 1963 were from Britain. Having in mind the relatively exclusive membership of this Conference imposed by the registration fee of £15, it seems reasonable to assume that say ten to twenty times this number are working on non-destructive testing, giving a grand total of 2290 to 4580.

There is yet another way of getting *some idea* of the numbers involved. There are probably around 500, or more, firms using radiography. The number employed will vary but, using an *average* figure of five people per department (which seems reasonable), this gives a figure of around 2500 persons engaged on *radiography*. Some of these will also use some of the other methods. In addition there are laboratories using methods other than radiography. The number of these is not known, but it seems reasonable to assume that they will be about as many as are engaged basically on radiography. This gives a grand total of around 5000.

In deriving these figures, the author realizes that they must be influenced by his own judgement, but it can be said that these figures do not seem to be unreasonable to others familiar with the extent of non-destructive testing.

British Technical Societies for Those Interested in Non-Destructive Testing

Three Technical Societies or groups have been established in Great Britain to meet the needs of those concerned with non-destructive testing. They are:

The Materials and Testing Group of the Institute of Physics and Physical Society— As its name implies, this group is mostly concerned with the basic properties of materials which affect their properties in service.

The Society of Non-Destructive Examination—Membership is mainly restricted to those concerned with the management of groups utilizing non-destructive testing methods.

The Non-Destructive Testing Society of Great Britain—This society is open to all working on non-destructive testing.

In addition, the Institution of Engineering Inspection is also taking a keen interest in non-destructive testing.

These organizations work closely with one another, and together with some nineteen others (which have rather less interest in this specialized field) have formed the National Committee for Non-Destructive Testing, which acts as the national co-ordinating body. This Committee sponsored the Fourth International Conference on Non-Destructive Testing in London mentioned earlier, which attracted about 500 delegates from all over the world.

Training Facilities

With the growth of the various techniques available, the need for training has become increasingly evident and many attempts have been made to provide suitable facilities. Probably the greatest activity has been shown by the many technical colleges which have organized short courses on either:

a) the various methods of non-destructive testing; or
b) one particular technique.

These have been organized either as short courses of say 10 to 20 lectures in a short (e.g. one week) residential course; or as a similar number of evening lectures, so that the course extends over three or four months. Generally these courses do not provide practical training, so that the training is mainly theoretical. The quality of these courses varies appreciably and, probably, the best have been those in which various aspects are discussed by specialists in their appropriate subject. Unfortunately such courses tend to show a wide variation in the standard aimed at. In some instances attempts have been made to develop a unified course, but the remuneration offered for the lectures has not always justified the calling of a preliminary meeting to agree on unification of standard and scope. Despite such criticisms, these courses have provided much-needed facilities and have introduced large numbers of inspectors and technicians to the important subtleties of the various methods.

A few technical colleges have provided training to the syllabus on industrial radiography devised by the London City and Guilds Institute, which grants certificates to those passing the examination. The syllabus is very extensive and anyone attaining the certificate can be considered well-trained particularly as the course demands a good knowledge of associated sciences. The course occupies a total of 340 teaching hours and extends over two years. Unfortunately this course has not attracted many candidates. Various reasons have been put forward, the most usual being that the training includes theoretical aspects of physics, mathematics and chemistry which are not essential to the *practice* of industrial radiography: this ignores the fact that such supplementary knowledge can lead to a more intelligent approach to the subject. In an effort to meet this criticism the syllabus is being revised. Another equally cogent reason is that so few technical colleges have seen fit to provide the necessary equipment for the practical training. This is associated with another aspect which has contributed to the relative failure of the course, namely that there are rarely enough candidates in any one area to justify setting up the necessary facilities for the course. It is questionable whether, over the whole country, there would be more than eighty candidates a year. As these live at widely scattered points, it can readily be seen that it is likely to be difficult for many colleges to attract sufficient students to justify training courses being set up.

Probably the most successful scheme for training radiographers is one set up by a commercial organization which has been providing such training since the war years[24]. Four-week and two-week intensive courses are provided for radiographers and inspectors respectively. Almost all the students are sent by firms and inspecting organizations, but a few attend on a private basis to enable them to apply for work in radiography. Whilst most come from Great Britain the school has attracted a fair sprinkling of students from many countries overseas.

In both courses the students attend lectures and undertake practical exercises which illustrate fundamental aspects of the work and, at the same time, provide training in the interpretation of the radiographic images. The four-week course is accepted by Lloyd's Register of Shipping as the essential basic training for radiographers seeking its approval. It also provides the basic knowledge for those seeking approval by the Aeronautical Inspection Directorate of the Ministry of Aviation. More will be said on the subject of approved radiographers later. It is perhaps worth while examining the reasons for the continued success of these facilities in view of the relative failure of the City and Guilds course to become established.

Probably the most important reasons are that the training is intensive, that, because of the limited time, it is restricted to what is essential for the practising radiographer and inspector, and that the Classes are all restricted to twelve students. A further very important reason is that a high standard of teaching is offered by enthusiastic experienced radiographers who know what is wanted in practice. As these courses cost firms far more than it would to send their employees to local technical colleges with their subsidized fees, it is clear that the cost is not an important factor. A measure of the success of these training facilities is that there is always a long waiting list, and it is rarely possible to get a place earlier than eight to twelve months from the date of booking. This course created great interest amongst the American delegates to the Fourth International Conference on Non-Destructive Testing.

Within the last year the Institute of Welding, in collaboration with the Non-Destructive Society of Great Britain, has established a School of Applied Non-Destructive Testing at the Institute's headquarters. The courses organized appear to be logical developments of the Institute's courses on the non-destructive testing of welds. One course, lasting nine days, consists of lectures by specialists in the various techniques, who also give demonstrations on ultrasonic testing and provide exercises in the interpretation of radiographs. As the school has only just started, it is too early to judge the success of the scheme.

Qualifications in Non-Destructive Testing

The City and Guilds Institute certificate in industrial radiography mentioned earlier is the only academic qualification currently available in Great Britain in any aspect of non-destructive testing.

The Society of Non-Destructive Testing in Great Britain offers its Associateship to those accepted by its Council as having the necessary experience and ability. So far, this qualification has been granted by the Society's Council on the basis of evidence submitted by the candidate and his referees in relation to education, experience, ability and responsibility. For some time the Society has been trying to establish a qualifying examination, but this has met with many difficulties.

Lacking any other accepted qualification, two inspection authorities, namely the Aeronautical Inspection Directorate of the Ministry of Aviation, and Lloyd's Register of Shipping have, for many years, had a system of approving inspectors, for specific types of work coming under their survey. Although the principles of the two systems are very similar, minor differences of detail exist. Lloyd's Register of Shipping, for instance, expects firms applying for approval of their radiographers, to send them to the four-week course mentioned earlier and to ensure that they take the examination at the end. The Register then takes into account the examination result, the practical ability and experience of the candidate, and the conditions under which he will be working, which must also be approved. In many instances, the company and its operator receive only provisional approval at first. This allows the Register to review the ability shown by the firm and its personnel on its first Class I contract. Subject to the satisfaction of the Register, the radiographer becomes known as an "approved radiographer". This qualification is held by the radiographer only for so long as he remains with the firm for which he is approved and for so long as his work continues to satisfy the Register.

The A.I.D. system differs mainly in that the candidates need not take a prescribed course of training, and the theoretical and practical examination is organized by the A.I.D. on its own premises. Both organizations approve the operator for specified work only, e.g. pressure vessels in ferrous materials, or welds in ships' structure, or light alloy castings. Recently a somewhat similar system for approving radiographers has been established in Canada[29], but this provides for two standards of operators. Details have also been published of a proposed American system for approving and classifying personnel engaged on non-destructive testing work[30, 31].

CONCLUSION

The intelligent use of all methods of non-destructive testing can make considerable contribution to the quality and reliability of a product. There is still scope for a much wider understanding not only of the scope of such methods, but also of their limitations and cost, so that those specifying such inspection methods as a requirement understand how far such methods may be used to check on the quality standards required. Vagueness in such inspection specifications may well lead to a false sense of security. Above all there is a need for a much greater knowledge of the influence of so-called defects on service reliability, so that the information yielded by the inspection method can be of greatest value.

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Discussion

Mr. E. G. Hutchings, B.Sc. (Member) said that first of all he wished to thank Dr. Mullins for a very interesting paper. When he had read the introduction, he had thought it very interesting but not really for him, as he was no specialist in the subject. However, as he had continued to read the paper through he had found that there was something far more interesting than the technique of non-destructive testing. The paper brought to his notice the value and limitations of non-destructive testing. It also brought to his notice the fact that Dr. Mullins, despite his undoubtedly great knowledge of techniques of non-destructive testing, seemed to have some popular misconceptions which had often given rise to a considerable amount of trouble.

Mr. Hutchings indicated that some of his remarks would be apropos Dr. Mullins' verbal presentation, rather than the printed text.

Mr. Hutchings continued that he felt a little personal pique at the remarks made about designers, because he had been a designer himself for some time. Having got over that personal pique, he wondered whether perhaps Dr. Mullins had his terminology wrong. Dr. Mullins seemed to be suggesting that designers should decide when non-destructive tests should be applied, specify accurately what that test was and design their part accordingly. This was all very fine, and the majority of designers would love to do this, but they were not permitted to do so. The real people to whom Dr. Mullins should address his remarks were the survey authorities, since the tests for practically every item designed for the type of equipment with which he was involved—boilers—were dictated by the rules of the surveying authorities.

Lest he be misunderstood he wished to say that he was quite in agreement with the laws and rules of most of the survey authorities, but all these rules included a factor of safety which was based on a certain amount of defect, ignorance and prudence. The designer might say that by the use of modern ultrasonic testing devices, or other non-destructive tests, he could ensure that this piece of material was one hundred per cent homogeneous and therefore that no factor of safety was needed. However could any survey authority ever be persuaded to accept that argument? If he were a surveyor he certainly would not accept it. If it were true, as Dr. Mullins suggested, that the use of non-destructive testing could enable a designer to reduce thicknesses and costs, and improve the product, then the real place to aim these remarks was the survey and insurance authorities.

In his paper Dr. Mullins had said that there seemed to be a tendency to push aside such simple tests as the ordinary human eye in favour of more scientific methods. Mr. Hutchings said he would go further than that in that there was sometimes a tendency to ignore the human eye completely. One could take the example of a piece of equipment which had passed all the specified tests, but where one only had to look at it to see that it was quite useless for the job for which it was intended, particularly if it had been badly painted or severely corroded which might not necessarily show up on the tests prescribed.

On the question of money for these tests, generally speaking he would say—although this was rather a broad simplification—that there were only two incentives for finding better testing methods. One of these was the interest of public safety, the other was when a piece of equipment was shown to fail frequently, or even relatively frequently. With danger to life and limb, then obviously that piece of equipment had either to be banned completely or, alternatively, some satisfactory method of non-destructive testing had to be found. If the incentive to use that piece of equipment was big enough, then he was sure the money would be found for the testing method.

On the question of customer satisfaction, until one's competitor started using this particular system of testing, one would rarely go to the extra expense oneself. This was perhaps unfortunate and not very high-minded, but it was one of the facts of life.

Later on in the paper Dr. Mullins had referred to the radiographic inspection of Class I pressure vessels and had made the point that there were a lot of side effects of costs which must be taken into account if non-destructive testing were to be used. The point Dr. Mullins was making was correct, but in Mr. Hutchings' opinion it was a bad example, because, with a Class I pressure vessel, the tests and any consequent repairs were essential if a serious risk to life and limb were to be avoided. Could Dr. Mullins say whether there was any possibility, in the foreseeable future, of developing a really first-class method of testing a weld on a thick pressure vessel so that the cut-outs could be made without removing the pressure vessel from the shop. This could be done with small thicknesses at present, but even so this was sometimes done after the weld was executed and had therefore been moved off the machine or alternatively the machine had been lying idle while the test was carried out. This might be a possible source of investigation of new methods, if there was a chance, because this would save the very large expenses referred to in Dr. Mullins' paragraph on Class I pressure vessels.

On page 431 of the paper, in the penultimate paragraph of the left hand column, Dr. Mullins referred to the identification of the nature of the defects revealed, and said that the decision as to whether the defect was acceptable or not should rightly be the function of the stress engineer, but unfortunately, it was often left to the radiographer or radiologist. Was this really so? Was it the function of the stress engineer? Could the stress engineer really assess what the increase in stress was going to be from any non-destructive test? Surely this was part of the factor of safety. Also, it was not usually the radiographer or the radiologist who made the final decision, but the surveyor or welding supervisor. These people had their own ideas on what was acceptable and what was not.

Mr. Hutchings continued that he was always a little worried about non-destructive testing, and whilst he would always agree to err on the side of safety, a tour of inspection of British shipyards making boilers would reveal that the costs involved in boiler making between one shipyard and another could vary by a considerable amount due entirely to the popularity of non-destructive testing with some surveyors. It would be found that a certain type of weld was accepted according to the rules and regulations of the safety authorities without any non-destructive tests. The surveyor in one shipyard would keep an eye on the welders, and providing he was satisfied that the welders were good, conscientious and doing their job he would then accept these welds. In another shipyard, exactly the same weld would be inspected by a surveyor from the same society and he would insist on one hundred per cent X-ray, and would sometimes try to insist on one hundred per cent perfection in those X-rays. In fact, this was not practical because it was almost impossible to achieve one hundred per cent perfection on all such welds.

It was one of the problems that, as more sophisticated testing methods became available, there was a tendency for people to think that just because these methods were available they should be used. In some cases there was a very good case for them, and in others not so much. A typical example of this was that one form of non-destructive testing was a simple pressure test with a measurement afterwards for any permanent deformation which took place. A particular item—of which there were many thousands in service at sea—had been tested many years ago by hydraulic test to find if there was any initial deformation. There had been none, and so it had been considered acceptable. The item in question had been used for twenty-five years or more and then there had been the advent of the more sophisticated method of measuring deformation making it possible now to measure a much smaller deformation, and so for a while the item referred to had no longer been acceptable. Fortunately, the members of the survey authorities were reasonable, intelligent engineers, and that situation no longer applied. Although an initial deformation could now be found on this item, it was still acceptable.

In concluding his remarks, Mr. Hutchings said he wished to apologize if, in attempting to be brief, he had sounded a little caustic about non-destructive testing. He had not intended it that way at all. He was very interested to hear of these developments, and the more everyone knew about them, the more intelligently they would be used. He was really making a plea that the choice of testing methods and the interpretation of the results should be entrusted solely to people who fully understood them.

Mr. J. McNaught (Member) said that the paper gave a very good survey of the methods available for non-destructive testing, and would be of considerable assistance to superintendents. The methods with which he had been mostly associated had been the magnetic and some experimenting with the ultrasonic and the dye penetrant, but his favourite had become the magnetic, particularly with the double-acting Diesel machinery. Parts of that engine were subject to periodic fractures and cracks, particularly on the piston rods. When magnetic crack-detecting was started about ten years ago it almost replaced the older method of testing by visual inspection. This had been useful, but it had not always found the ends of cracks, so that sometimes parts would be repaired by welding and put back with some cracks still there.

Reverting to the question of piston rods, there were two likely defects: one was the fracture of threads; the other was the fracture of rods in various places. Since the advent of magnetic crack-detecting, the incidence of fractures had been reduced. He would tempt fate by saying that they had practically stopped since there had not been one for some seven years.

Probably the most interesting, but most difficult, aspect from the crack detector point of view was checking for cracks inside piston rods. The piston rod had a double thread and nuts for connexion to the crosshead, and the total length between the bottom of the rod and the top thread was about 2ft. 6in., or just over. In order to stiffen the section of the piston rod at the crosshead, the bore had been reduced, but the manufacturers at that time had been unable to bore the complete rod with the smaller hole, and therefore there had been a change of section about three feet from the bottom of the rod. The last rod which had fractured had been from this change of section, and the fracture had progressed, from the inside, radially outwards. From then until the design was altered these rods had been crack-detected and inspected about three feet inside. When the crack-detecting showed up surface defects, these were polished out, and as he had stated earlier they had had no further fractures.

Many of the other parts in the double-acting engine were also subject to various failures. Another unusual one was the fracture of the bottom half of the bottom-end bearings from the inside of the dovetail outwards. It had therefore become the practice that when a bottom end was being remetalled, the dovetail was crack-detected. It was quite surprising how many small cracks were found which were cut out and welded.

Another use to which magnetic crack-detection had been applied was on certain generator crankshafts where cracks developed. His company had had an old type of engine—now out of service—which developed torsional cracks due to running close to a critical. It had become the practice to examine these first of all at survey, with crack-testing. He could remember two cases where the fracture was found the day after arrival, which had allowed plenty of time to get the spare shaft fitted, instead of finding the defect a week later.

Most of these examinations had been done by one of the contractor's people, and this man had become very skilled in the use of equipment and in finding cracks. This underlined what Dr. Mullins had said about the need for a skilled experienced operator. This man had been able to see cracks which no one else could see at first, and he had usually been proved right.

Mr. McNaught continued that he thought that crack-detecting should be looked on as one of the tools of operation. If it were considered part of the normal overhaul procedure, and was done at the right time, whilst it might present the superintendent with some very difficult decisions, on the whole it would provide information which would make ships more reliable—which was what they were all seeking.

Ultrasonics had been tried on the crack-detecting of piston rods in order to find out whether cracks could be detected in place. This had happened many years ago now, but because of the false shadows, to which Dr. Mullins had referred, this method had been abandoned. His company had also tried ultrasonics on other parts, and at the time had had enough defective material—and he meant defective and not imperfect—to experiment with ultrasonics, then cut it apart and see how correct the operator was in his diagram. With castings, unfortunately, the operator had usually been wrong, but it had given them some good experience. Most of the troubles were due to defects, and as a matter of interest they had tried many new parts with crack-detecting methods to find out if initial defects were present, and in every case there had been no initial defect.

Dr. Mullins had made the point about designers keeping non-destructive testing in mind when designing, but he would go further and say that most of the magnetic crack-detecting tests for parts in service had to be done because of poor design. This was not confined to engines which were thirty years old, but those which could be seen any day in almost any engine works. In spite of experiences with fracture, these bad designs were still being used and would produce the type of crack about which he was talking, perhaps not in such numbers because of the large number of single-acting engines, but in due course trouble would ensue. He referred particularly to the position of the upper palm of the connecting rod where the designer initially had provided an excellent radius and then cuttered into it to provide a landing for the bolt head. In a double-acting engine cracks were usually found there, and no doubt this would also be the case in other engines as time went on.

In conclusion he wished to say that much crack-detecting could be avoided if designers would look at the simple things at the initial stages.

Mr. W. McClimont, B.Sc. (Member) said that Dr. Mullins had given a paper which would be a very valuable addition to the Transactions, and for this he was to be thanked.

The use of any particular material in a product was usually dependent on its possessing certain characteristic properties which various destructive tests on similar parts or on specimens had shown the material normally to possess. However, this was no assurance that the particular part would have the desired properties and was fit for the designed duty, and if the risk of failure were significant and the consequences of the failure serious, then quality checks were imperative.

The philosophy of non-destructive testing was that, if each part could be examined using some method by means of which its properties would be ascertained within reasonable limits, with the reasonable assurance that any defects of consequence would be detected, it was a much better procedure than examining a few only of a group, even by a test which was so searching that it would be destructive of the part. The word "reasonable" could not be over-emphasized in the foregoing, and much careful thought had to be given to the suitability and adequacy of non-destructive testing for any particular application. If one could not determine properties with sufficient accuracy, or observe defects with sufficient certainty, one could be in a fool's paradise.

Dr. Mullins had referred to the question of who should make the decision or the interpretation. He had said that this decision should rightly be the function of the stress engineer. Mr. McClimont said that one point which always intrigued him was how many people, classed as stress engineers, were really able to assess adequately what the affect of a defect was. It was surprising how many of them had been trained in the classical disciplines of perfect materials, and appeared to be very poorly capable indeed of doing an analysis which included defects in the material.

Non-destructive tests could be divided into two general classes: those used to determine physical or mechanical characteristics, and those used to locate defects. Dr. Mullins had concentrated mostly on the latter.

Before leaving Dr. Mullins' catalogue of tests, one might comment on the absence of moisture content determination. The sonic method of determining modulus could also warrant some comment. They had had an interesting paper*, in November 1965, from Mr. Morrison, which had covered the application of sonic modulus testing to shafting and one could visualize other conditions, where the modulus might change, where sonic testing would be of great value.

Before leaving the section on the trend to seek new methods of non-destructive testing, one might regret that Dr. Mullins appeared to have laid all the emphasis on testing during production, and had not paid attention to the need for non-destructive methods for use in periodic surveys during service.

Turning then to the section on the methods available, Mr. McClimont continued that Dr. Mullins had made his first remark on the prevalence of inadequate specifications. As a consultant, Mr. McClimont said he was inevitably involved in writing specifications and he very much appreciated Dr. Mullins' concern. However, recommended practices had been slow to become available and the codification of inspection procedures was the best antidote to the ills to which Dr. Mullins had drawn attention.

In general, it would appear that X-rays were better than gamma rays for sections up to about two inches thick, and it was normally the more rapid method. Above four inches in thickness, and for parts of varying thickness, gamma rays became the more satisfactory. For annular parts where the source could be placed at the centre, the use of gamma rays was attractive.

Dr. Mullins had suggested that in deciding between the use of gamma-ray sources and X-ray equipment one should consult some independent authority who could advise on the best methods for the work to be done, and who would also be able to give some idea of the likely capital expenditure. Was it really so easy to find an authority who was independent? The use of cobalt 60 appeared to have made gamma rays economically attractive, but it would be useful to have Dr. Mullins' comments on whether this was really so. Much was usually said in such economic comparisons about the potential obsolescence of the X-ray unit, ten years being quoted, and again Dr. Mullins' views would be welcome.

Mr. McClimont said that, in the discussion on the sensitivity of detection by radiography, he felt that Dr. Mullins had been somewhat optimistic. He would suggest it was exceedingly difficult to be sure of detecting defects which caused a differential absorption of less than one per cent, even with care and a reasonably large defective area. Of course, two per cent could be reasonably attained. These figures were for X-rays, and could not be anticipated with gamma rays where care was required to get 1½ per cent under favourable conditions.

Perhaps it was naughty to ask, but it would be interesting to have Dr. Mullins' views on Xero-radiography.

On ultrasonics, three observations came to mind. The beam from the probe was very narrow, and it was necessary that every bit of the surface was covered by a progressive movement of the probe so that automation of the probe movement had more virtue than just the reduction of operator fatigue. To cover the risk of unfavourable defect orientation, two passes at right-angles were essential. To keep an adequate check on the performance of ultrasonic testing equipment, the regular use of standard reference blocks was also essential.

Dr. Mullins had spoken of the obvious advantages of ultrasonic measurement in assessing metal thicknesses, where wall thicknesses might have been reduced due to corrosion of the opposite face. Mr. McClimont said that he was suspicious of this technique, as he felt the accuracy was very low when there had been severe corrosion on the reflecting surface.

The remarks that ultrasonic testing required an experienced and conscientious operator of high integrity who really knew his job were very important, but they should be repeated in the next paragraph concerning magnetic crack-detection. The risk here was not only missing significant defects, but also costly rejections if the various false indications were not understood. Although magnetic testing was in wide use for ferrous materials, it should be realized that satisfactory results could not be obtained with alloys which were only very faintly magnetic, and the method was not applicable to austenitic steels, such as 18/8. In those cases, cracks might be located by penetrant tests.

Eddy-current tests were comparative tests most suitably applied to mass production processes. To the marine engineer they were likely to have more interest than value.

On the economics of non-destructive testing, one factor which might have been given more attention was how much improvement in reliability did the various techniques give. Small defects might be as serious as gross ones in producing an unacceptable failure rate. For example, if the failure rate was ten per cent, and an inspection technique would only ensure that the twenty per cent most gross defects were detected, the resultant drop in failure rate to eight per cent was hardly likely to be economically viable.

This led one to re-read two most important sentences of the paper which should have been printed in bold type—"Above all there is a need for a much greater knowledge of the influence of so-called defects on service reliability, so that the information yielded by the inspection method can be of greatest value" and "It is perhaps as well to make clear that interpretation means solely the identification of the nature of the defects revealed, and is itself not concerned with the final decision whether to reject or accept".

In conclusion, Mr. McClimont said that he wished to emphasize that one should realize that non-destructive testing should be a tool and not an alibi.

Mr. H. Capper said that, as Dr. Mullins had started his paper with some historical background, his own experiences might be of interest to the meeting, and might also be a little amusing.

He had started with radiography in about 1933, and his company had had a 250kV X-ray set for examining lead-bronze bearings. In those days, which was before Dr. Mullins had joined his firm, Dutch film was used, which was considered better than the British types. In about 1939, when he was

* Morrison, J. 1966. "Recent Developments in the Measurement of Propeller Shaft Torque and Thrust". *Trans.I.Mar.E.*, Vol. 78, p. 193.

attached to H.M. Dockyards, the company had portable magnetic crack-detection equipment which they had made themselves, and which had been very useful indeed. All the ships were d.c. in those days, so that there was no difficulty with the current supply. There was also a most fantastic X-ray set with a mechanical half-wave rectifier, which could not be considered portable except inasmuch as it was on wheels. It weighed about two tons, and to see the thing in action was quite an experience. It had a corona like the Aurora Borealis. Nevertheless, a certain amount of work had been done with it. There was also a 250 milligram source of radium. As there were no isotopes available at that time, the actual radium salt was used, which was a very small source, of only 250 millicuries intensity, by to-day's standards. It had been about that time that Dr. Mullins was contacted, when he had just started at the firm where he was still; he had been one of the very few people in the country who had any knowledge on this subject at all. It was probably correct to say that in those days the Armament Research Establishment at Woolwich and Dr. Mullins were two of the very few establishments who were operating in this field.

One of the attributes of the radium source was its portability, although transporting it had its difficulties. In times of crowded rail travel during the war, it was one way of getting a first class compartment to oneself to say that there was a radium bomb on the rack.

Subsequently, much higher intensities had been used, and one now spoke in terms of five curies and larger. It thus became much more difficult to transport such items, because of the weight of the container necessary for shielding.

Turning then to the paper itself, Mr. Capper said that he was very surprised that Dr. Mullins had not mentioned etching. He had always considered this as a non-destructive test, even on a finished part. It was quite possible, and extremely beneficial, to etch lightly, and many defects could be shown up in that way. There was also the use of the eye to which Dr. Mullins had referred, and the benefit of low-power microscopy in conjunction with etching.

He was rather surprised to find Dr. Mullins mentioning wheel-tapping. He had always understood from one or two of his railway friends that this never had been of value for detecting cracks. The only benefit at all from it was that the man who ran along with the hammer looked for hot axle boxes, but nothing had ever been found in the way of cracks by tapping the wheels. He understood the practice had now been discontinued.

There was perhaps one point on costs which had not been high-lighted, and this applied particularly to welding. When the first few defects of, say, a Grade A weld on a pressure vessel, were found, although it might involve costly cutting out and re-welding, this stimulated the operator to greater care; as his defects were found so did he get better at his work, which aspect should certainly be set off against the cost of inspection. Flaw-detection really increased the quality of subsequent work.

He wished to make one point with regard to training and research. It seemed to him that training and research could well be incorporated in one establishment. He would suggest that this would be an ideal subject for one of the new technological universities to adopt. The theoretical aspects involved many of the physical properties of materials, and the practical aspects required a knowledge of metallurgy if a metal were being examined and a keen sense of observation. It seemed to him to be largely a metallurgical subject and in all its aspects could be considered suitable to form part of the curriculum for material science.

MR. J. CALDERWOOD, M.Sc. (Honorary Vice-President) said that he would like to disagree first of all with one of the remarks of the previous speaker who had said that wheel tapping had never found a defect. He had been in a train going to Glasgow late one night when the wheel tapper had found a defect. They had all been turned out of the train which had been delayed for over half an hour while the carriages had been changed round. He had learned from railway people that such things did happen occasionally and that wheel tapping could show up defects. This really had nothing to do with the paper, except that it confirmed that wheel tapping was a non-destructive method of testing.

The first point he had intended to raise had already been mentioned, namely the importance of the last few words of the paper. He would not re-quote them as they had already been quoted, but there was no doubt that one of the greatest difficulties of non-destructive testing was not the technique but the technique of knowing what was meant when the results were obtained. Tied with that was the previous sentence about the specification having to be right and to say what was wanted. There was one inspection body overseas which was just now beginning to insist on ultrasonic testing of crankshafts. Some years ago his firm had thought that this would be a grand idea, and they had asked their suppliers for ultrasonic tests. Crankshafts were a horrible shape, and all he could say about the results obtained was that odd reflections from various places on the odd shape of the crankshaft would have scrapped every crankshaft on ultrasonic test.

That led him to another point on which he supported Dr. Mullins, and that was that one had to be very careful in choosing the non-destructive method to suit what one wished to find, and also to be sure that the part, to which one was applying it, was suitable for this method, whatever it might be. One or two omissions had already been mentioned, but there were other methods which were not listed in the paper. Dr. Mullins had included the best known, but had he come across the resistance method of detection of various faults? The inspector at the works of Mr. Calderwood's company had come across this being used somewhere in America for metal thickness, and he had thought that it would be a fine idea for adhesion of metal in bearings. His company had a particular bearing, at the time, on which there had been a whole spate of failures in service due to bad adhesion. The old penny tapping method was tried, which certainly reduced the number of defects in service due to the fact that more bearings were rejected. Then a resistance test was rigged up and had now been in regular use for all the company's bearings for some twelve or thirteen years and which showed up almost every adhesion fault. The company had not been interested in manufacturing the equipment except for its own use and it was taken up by a firm with which it was friendly and which was now selling it and using it for a variety of purposes.

On page 427 of the paper, Dr. Mullins referred to the honeycomb structure adhesion problems. Fairly recently Mr. Calderwood had heard of a number of troubles arising through lack of proper adhesion and had thought that the time resistance method could be used for examination. He suggested it to the people who sold the equipment. Unfortunately, contrary to Dr. Mullins' statement, these items were no longer tied together with brazing, in which case this would have been quite effective, but with plastics, for which the resistance technique was of no value at all.

Mr. McNaught had referred to the use of magnetic testing. In the cases he had cited it would appear that the crack was round the rod to be tested, but Mr. Calderwood was able to quote a very well known continental firm, which he visited some years ago and which had dropped magnetic testing on connecting rods, because the cracks were usually along the rod and not around them, and magnetic testing did not show them up. This firm had gone back to the old-fashioned paraffin and whitewash technique, and was finding defects which magnetic testing never showed up. They simply used a hot paraffin bath to soak the part, and then sprayed the whitewash on, instead of painting it on.

There was one other very important non-destructive test which Mr. Calderwood's firm used quite a lot, and that was the metallurgical examination of the structures of the material to make sure that it had been heat-treated or heat-treated properly. This had started some years ago when the company had had more than one connecting-rod failure due to decarburization of the surface, giving practically no fatigue life on the surface. Such defects did not cause early failure. In one case it had taken twelve years, and in two or three other cases eight years before the failure had actually occurred. However, micro-inspection had been started when there was the slightest suspicion of any surface fault. In one case, something like thirty per cent of a large batch of connecting-rods had been scrapped, and without doubt every one of those would have failed in service, perhaps after three years or perhaps after ten years, but they had all been defective.

There were many other things where the company had used the micro-structure examination of the surface, and he looked on it as one of the most valuable items in non-destructive testing.

Mr. D. H. Butler said that he had been most interested in the paper as a survey of present methods of non-destructive testing. Particularly he valued the extensive list of references at the end of the paper.

It might be of interest to the meeting if he spoke for a short time about his own experiences with eddy-current testing of copper alloy tubes. About seven years ago, when his company had first begun looking at eddy-current testing of tubes, the only test—apart from visual examination—which they had was pressure testing. A comparison had been made between eddy-current testing and pressure testing. Two experiments had been carried out, one in which about 100 000 tubes of normal production had been pressure tested and then subsequently eddy-current tested. On this occasion the eddy-current test found defects in about $\frac{3}{4}$ of one per cent of the tubes which had passed the pressure test. On the other hand, a further batch of 100 000 tubes were eddy-current tested first and then pressure tested, and only two tubes were found to leak which had passed the eddy-current test.

Mr. Butler said that he felt, from these experiments and from more recent experience, that eddy-current testing was an extremely sensitive method of inspecting thin copper-alloy tubes, and it could certainly be considered as a test which could be relied upon. This was perhaps just as well these days when, for some purposes, tubes up to sixty or seventy feet long were required. These very long tubes were pressure tested, but visual examination of the bores was almost impossible and in this application eddy-current testing with its ability to find minor defects was invaluable.

The recent developments in eddy-current testing were to be welcomed, particularly regarding its application to stainless steel tubes, made possible by the advent of magnetic saturation. A further very useful development was the ability to phase out the kind of defect which one did not wish to see. That might sound a peculiar thing to want, but in fact every type of defect appeared in a certain phase and it was possible to ignore such a thing as mild plug chatter which would normally mask ordinary defects completely.

This type of testing was also being applied to aluminium tubes, six thousandths thick, which were used in the aircraft industry to separate the fuel from the lubricating oil, and here one simply had to rely on this method for the reliability of the tubes.

Finally, he wished to mention the use of eddy-current testing, with an internal probe, for examining condensers and heat exchangers on site when these had become corroded in service. It was an extremely good method for the examination of individual tubes, without removing them from the ship and without removing them from the condenser, and it did enable an engineer on the job to decide which tubes needed to be replaced and which did not. It could give a very accurate idea of where the corrosion had occurred in a tube stack.

In conclusion, he wished to add a word of caution. He agreed that the last paragraph of Dr. Mullins' paper was extremely important, and that non-destructive testing had to be used intelligently. Dr. Mullins had written that the sensitivity of ultrasonic testing depended on the surface finish of the tube itself. Was this because it was becoming so sensitive that the defects found were similar in size to slight etching on the surface of the tubes?

With the advent of extremely sensitive equipment, some customers were, in fact, demanding ever more exacting standards. There was a tendency to think that because an echo could be seen on ultrasonic testing, or perhaps because a ripple could be seen by eddy-current testing, that the defect must necessarily demand the rejection of the tube. He felt that setting intelligent levels of rejection was a most important factor.

Mr. I. Redmayne asked to borrow a little of the audience's time as he came from the other side of the fence, where people were trying to find problems on which to use all their non-destructive testing techniques. Many different techniques were available, most of which were known to some people, but he doubted whether all of them were known to everybody. A real problem in communications existed between the people who had the know-how—although maybe individually they did not have all the know-how—and the people were in a position to put to good use the techniques of non-destructive testing. He did not know quite what the solution to this was, but at least if the problem were recognized they were half-way towards solving it.

Of late, a much greater interest had been taken in the application of these techniques to what was called, in the oil industry or in the power generation industry, "on-stream inspection". This was not only non-destructive, but could be carried out while the plant was in use. It could be summed up as the art of seeing whether there was still any life left in the old dog.

It was possible to measure wall thicknesses, to detect not only the extent of corrosion, but to show the type of corrosion which was taking place and, if this were carried out at known intervals, to predict corrosion rates and to deduce the conditions which varied with these corrosion rates. The build-up of sludge could also be detected. If a component such as a valve was known to have failed, it could be seen how it had failed. Mr. Redmayne said that he felt that there was a great potential use in non-destructive testing techniques on the maintenance side of the business. Of course, one was very interested in this because a thing could only be made once, but if it were going to be in use for several years there was a lot of good money to be made and a lot of headaches saved, by giving the operator a picture of how the component was reacting to its service conditions.

The main advantage of these techniques, as Dr. Mullins had pointed out was that it was possible to plan ahead for shut-downs. It would be possible to have available all the special bends and all the new components to replace those, the life of which could be predicted to be nearly at an end. In this field, almost all other industries could learn from the aircraft industry. The aircraft industry itself had to be very quick to learn, because the consequences of failure were usually pretty rapid and dramatic. Therefore, used intelligently, non-destructive testing could give a better understanding of the exact nature of the component when it went into service, how it was behaving itself in service and, since one was not going to get it right every time, some indication of the condition of the component just before it failed. This knowledge was most vital in the search for reliability.

The first speaker to the discussion had made a plea for the results of non-destructive testing to become available in a shorter time. People had probably heard that there was going to be a pipeline to bring the gas from the well-head in the North Sea to the shore, and every single weld on this pipeline had to be radiographed. The time that the welder pulled the electrode off the bottom of the weld to the time that the results would be available was less than five minutes, and that sort of speed was far greater than was needed in the shop to prevent delays.

His company had recently been told of a case of magnetic testing of connecting-rods where the method of inspection had failed to reveal the longitudinal cracks, and this was typical of many of the examples of the misuse of non-destructive testing. It was essential to select a method which would reveal the conditions affecting the fitness of the component for its intended purpose. The method for the job must be picked.

Similarly, it was not feasible to rely on the non-destructive testing technique as a "go, no-go" gauge. It was not right to look at a radiograph and, seeing no defects, to consider that the component was good. Similarly, it was not possible to look at a radiograph and, seeing a black image, to justify rejection.

It was not a question of adjusting the sensitivity of the non-destructive method, it was not even a question of picking the right non-destructive testing method, it was a question of knowing what to do with the information once it had been obtained. As far as saying exactly what was there, in so far as his own side of the business was concerned, Mr. Redmayne said that he was prepared to accept responsibility for interpretation, but since one could never know the service conditions or the design parameters of the components one could never stick one's neck out far enough to say that a certain component would fail or that it was good enough. One had to have some indication from the stress engineer, the designers, the classification society, the Air Registration Board, or whoever was responsible.

Perhaps one or two comments on points made by previous speakers might be useful. On the question of strength of sources, iridium sources with a strength of well over five curies were now being used. In fact, the tendency was to throw them away when they dropped to about this value. This was in order to keep the rate of output of the inspection unit sufficiently high to keep costs down.

The question of whether to use X-rays or gamma-rays in any given instance was best left to non-destructive testing engineers, and anybody who had any doubt on a question of this type had only to ask one of the many firms in this country who offered all the different methods. It was unwise to choose one which only had X-ray equipment or one which did not have X-ray equipment. By following this method, it was possible to get the right answer.

The life of an X-ray set existed from the time it was bought until the time it was dropped. That was about the nearest guide he could give. It was rather like the old man in Shaw's book—Life was a question of when the Accident happened.

Referring to the comment about the manual against automatic ultrasonic techniques, he said that by automating a technique one had to know far more about the acceptance and rejection levels before one started. It was, perhaps, good to be subject to this type of discipline. On the other hand, one did throw away perhaps the most useful aspect of ultrasonic examination, which was that one could "play it by ear". A skilled operator would get an indication, and just as when one was interpreting a radiograph one had to explain what caused this indication, so in ultrasonics an explanation must be found for each indication. One certainly tried moving the probe and then working out what gave this indication. If it were something within the material which caused a defect, or which could be classed as a defect, then notice had to be taken of it. If it were one of those spurious echoes from the webs or journals of the crankshaft, then it should be noticed or the operator should not be entrusted with ultrasonic inspection.

Another point about ultrasonics was that when they were used for wall thickness measurement they offered a reliable method, again within limits, and where it was not possible to use a resonance technique, accurate results could be obtained by using the pulse-echo technique. This was far less liable to misrepresentation because of the corroded state of the component's surface. After all, the assumption that there was the likelihood of some corrosion there initiated the wall thickness investigation.

Where ultrasonics could not be used, it was very often possible to go back, Dr. Mullins would be pleased to hear, to radiography. These techniques were now being refined and used in many refineries and other installations.

Just as when the X-ray sets had begun to get too heavy, if designed to get through bigger sections of material, industry had accepted gladly radio-active isotopes which were better on the thicker parts, so now could be found, in eddy-currents, the solution to many of the testing problems where magnetic particle methods could not be used.

Mr. B. R. Byrne said that reference had been made to inspection services of the kind which offered engineering and metallurgical facilities, non-destructive testing and everything else. In these lay the possibility of combining the expertise of all the people who were necessary to carry through an inspection project as it should be, i.e. right from the earliest stages, including the design stage. There was a need of more services of this kind.

Designers could help a great deal by making non-destructive inspection possible, especially in service. There were many types of mechanisms which could not be proven in the design and exploratory stages by "running them into the ground", as was done for instance with some types of aircraft engine. Designers could be very useful here in producing designs that allowed for adequate inspection in service.

At least one speaker had referred to job training. Mr. Byrne pointed out that it was important to ensure that operators would work under enlightened supervision and that appreciation courses should therefore be provided for supervisory staff.

It had been suggested that training might be centralized in one teaching institution. There were arguments in favour of this, but when one went to industry for capital, or for encouragement, or for money to pay the right kind of man and to look after him, it was found that so many of the people, to whom one was talking, just did not want to know.

Some of the points raised concerning the cost of non-destructive testing, or the failure to detect defects that should have been found, seemed to stem from failure to appreciate and apply the methods properly. Too many engineers displayed a lack of awareness in this connexion which, if applied to their products or processes, would quickly put them out of business.

Correspondence

Mr. D. Birchon (Member) observed, in a written contribution, that the paper gave a most excellent summary review of the technical and economic viability of non-destructive testing techniques in this country at the present time.

There was, however, a very important development in the application of non-destructive testing techniques to which attention must also be directed, since it represented one of the most useful advances made in modern technology. This was the use of non-destructive techniques to monitor changes in the performance of critical areas in a structure during the normal operation of the equipment, e.g., to detect crack development or rate of crack growth.

This was being done at present by a variety of methods. Since it was necessary for the sensors to be inexpensive, stable in performance over long periods of time, and rugged, current techniques included the use of strain gauges, various kinds of linear displacement transducers and eddy-current devices. These sensors were attached to critical areas, i.e., either where a crack might be expected to develop, or where the extension of an existing defect would be embarrassing, and provided remote read-out facilities at a central monitoring position.

Another very valuable advance was that of "fatigue gauges". These were really electric-resistance strain gauges, made of a material similar to that of the structure upon which they were to be used. They were attached to the structure in appropriate locations and left in place, rather like a postage stamp, without any leads or instrumentation attached to them. From time to time the electrical resistance was determined by conventional methods, and from changes in the resistance it was possible to determine the rate of accumulation of fatigue damage in the structure beneath the gauge, so that one could actually anticipate the imminent development of a fatigue crack. This was a spectacular advance, and one which took non-destructive examination techniques out of the field of routine inspection and turned them into tools for engineers to use during the operation of equipment.

Perhaps the greatest compliment which one could pay to the value of non-destructive testing techniques in general, was that they had conclusively proved that most engineering structures lived through their useful lives despite the presence of defects (both those from original manufacture and resulting from service operation). One could, therefore, only endorse Dr. Mullins' plea for more knowledge of the influence of defects on service reliability, so that one might be sure that only that which really required rejection was rejected, yet be sure that one had not accepted, or continued to operate, anything which went beyond the bounds of a reasonable risk.

Mr. A. Gibbs wrote that Dr. Mullins' paper raised a number of long-standing questions regarding the true relationship of non-destructive testing to industrial production and technological progress. Perhaps it was more correct to consider non-destructive testing as an important link between destructive evaluation in the laboratory and subsequent production. The apparently aimless applications, to which Dr. Mullins referred, too frequently stemmed from complete absence of any background evaluation of a product prior to production.

The vexed question of additional cost was open to considerable discussion. Personally, he did not believe that non-destructive testing could be assessed in isolation from the many other factors which, together, contributed to quality control. Any contribution which reduced the factor of ignorance (politely referred to as factor of safety) would eventually lead to technological advance and reduced production costs by making fuller use of potential material properties.

Considerable emphasis was placed on the use of non-destructive testing in initial production. Modern trends in integral plant installations had opened up a widespread field of applications aimed at reducing maintenance costs and plant "lay off" periods, by using non-destructive testing techniques to measure deterioration in components and systems. Full advantage of such applications would not be achieved until component designs incorporated strategically-placed inspection points for the introduction of the appropriate non-destructive testing tools.

Dr. Mullins had already emphasized the gaps in our knowledge concerning the effects of flaws in service. Where large-scale production was involved, specific acceptance standards were feasible, based on full-scale destructive tests; in this context the marine engineer was singularly unfortunate. However, trends were now being established, as a result of world wide research, which at least gave guidance regarding the significance of different types of flaw which, in turn, enabled one to use more appropriate inspection methods and make better use of the evidence thus obtained.

Mr. S. H. Frederick wrote that, in the conclusions to the paper, the author referred to the need for a greater knowledge of the influence of so-called defects on service reliability. Mr. Frederick endorsed this statement and drew attention to the attitude of many designers who adopted a "play-safe" attitude and insisted on rejection for unimportant defects.

In view of the introduction of new methods of non-destructive testing coupled with increasing sensitivity of established methods, the interpretation of the results obtained was becoming of ever greater importance.

No man-made component was perfect and it was all too easy to reject a forging or casting on account of the presence of defects which in the past would have gone undetected. To take a specific example there must be many turbine rotor forgings which had been in service for the last 15 to 20 years, containing internal defects in the form of segregation which, if subjected to modern methods of ultrasonic inspection, would be rejected out of hand.

There was no doubt that the high standards of non-destructive testing available today allowed the designer to have more confidence in the components he used and permitted him to design to higher stresses with reduced safety factors. If testing procedures were not intelligently applied however, much unnecessary expense could be incurred in rejection for defects which would have no adverse effect on service reliability.

It was becoming more important to place greater emphasis, in the training of inspectors, on the selection of the most appropriate method of non-destructive testing for a given component, and the correct interpretation of the results obtained. Too good could be just as expensive as too bad.

Mr. H. W. Taylor wrote that he thought that the paper gave a very balanced appraisal of the value of the various techniques of non-destructive testing. He would like to stress, however, that it was wrong to imagine or assume that the various techniques were competitive. This was not correct. They were complementary, and where the product could be tested by two methods, then the only reliable touchstone was that of the cost of inspection per item.

He thought that it was true to say that in the period covered by the last war and the succeeding ten years, non-destructive testing was something of an art, but that in recent years considerable steps forward had been made in establishing it as a reliable production tool. His own company had been particularly active in the development of fully-automatic methods for the ultrasonic inspection of a wide range of materials and components, i.e. welding, castings, forgings, rough sheet products, extrusions, etc.

There were indications that industry was now ready to apply automatic methods of inspection and this should prove to be an expanding application, involving many acute problems in mechanical handling of the inspection probes, or the material to be tested.

In the application of automatic methods of inspection, one must always appreciate that the machine was attempting to replace a human operator, who had been defined as the best portable computer in the whole world. As a result, the electronic circuits required in automatic installations were more complicated and costly than in a manually-operated unit. However, correctly-designed systems could achieve a very high and consistent standard of inspection.

Finally, he would like to make a general comment on the number of test specifications that were being issued for various non-destructive test methods at the present day. He thought that Dr. Mullins would agree if he said that the primary function of these specifications was to establish reliable and consistent standards of inspection in different works and countries throughout the world.

In some of these specifications the indications obtained by ultrasonic inspection were compared with indications from flat-bottomed, drilled holes which served as artificial targets. This method was not a reliable means of establishing the size of a defect in material, as experience had shown that defects producing the same amplitude of indication on the screen could have considerably different physical dimensions, the amplitude of indication on the screen being influenced by other configurations and orientations relative to the inspection probes. However, it was possible to select the size of a standard-drilled, flat-bottomed hole which would ensure, to a very high standard, that a material would not contain defects greater than a certain size.

He was very strongly in favour of the establishment of reliable inspection specifications, but pleaded that each should be followed by an explanatory note, outlining the limitations and problems in applying these specifications.

Author's Reply

Dr. Mullins said, in reply, that he was very grateful to all those who had come to the meeting to hear his verbal presentation of the paper, and he was gratified that it had promoted such a long discussion. No author expected everyone to agree with him on all points, and the measure of support he had been given on some aspects more than compensated for any disparity of opinion which had arisen.

With reference to Mr. Hutchings' comments, the author said that he had used the word "designers" in a general way. It appeared that in Mr. Hutchings' particular type of work, the responsibility for design was a joint one between the designer and the surveying authorities. The author's remarks would still apply here, namely that in designing a vessel (irrespective of whose responsibility it was) attention should be paid to facilitating the non-destructive tests which were specified. In his comments relating to this aspect, Mr. Hutchings had suggested that a designer might expect non-destructive examination to ensure one hundred per cent homogeneity. The author considered that designers were far too intelligent to make such an assumption. In fact the comment suggested that Mr. Hutchings had not read the paper in sufficient detail, as it was made abundantly clear that certain defects might be missed; and the author had again emphasized this point in his verbal presentation.

Despite Mr. Hutchings' doubt on the point, he was sure that non-destructive examination could enable the designer to reduce thicknesses and costs, and improve products. He commented that, in this context, B.S.1500 and B.S.1515 both permitted the use of higher joint factors for welds proved acceptable by radiography. In addition, he said, there were plenty of examples in aircraft structures to show that the "safety factor" could be reduced when the materials came under non-destructive testing control.

The author said that he did not understand why Mr. Hutchings should think that the example of Class I pressure vessels was a bad example to illustrate the extra costs which might arise if non-destructive testing was applied. The author thought it a good one. In any case, whatever the example, the fact remained that the cost of non-destructive examination was not restricted to that of the test. The author regretted that he could not see any immediate possibility of a test of the type described for thick welds. Having in mind, however, that a method had been devised for getting a visual image of defects in hot blooms by means of an X-ray image intensifier*, such a test might be feasible. On the whole, however, in its present form, it was questionable whether the sensitivity in the detection of fine flaws would be adequate.

With reference to Mr. Hutchings' comments on the responsibility and scope of the stress engineer, the author said that he would discuss this more fully in his reply to Mr. McClimont. He agreed that, in practice, it was usually the function of the surveyor or of the welding engineer to decide on the acceptability, or otherwise, of the defects found, and not that of the approved radiographer or radiologist. Nevertheless, he said, there were many instances where the approved radiographer or radiologist went beyond his prime duty of identifying the defect; in some instances this was expected of him.

The author said that he was not prepared to comment on the remarks about the varying standards set by surveyors, except to suggest that this surely was a matter which Mr. Hutchings should bring to the notice of the surveying authority concerned.

The examples quoted by Mr. McNaught were most interesting and provided valuable supplementary support to the paper.

It was of interest to note that both Mr. Hutchings and Mr. McClimont had commented on the author's remarks about the responsibility and scope of the stress engineer. There was no doubt that it was sometimes true that the stress engineer could comment only on perfect material. In some fields, e.g. in aircraft castings, his guidance was particularly valuable because it could indicate what regions were critical. However, it was not entirely the stress engineer's or the designer's fault that he could not say much about the importance of a defect in service. At present there was far too little information available about the effects of internal defects in service and, as a consequence, it was likely that rejection arose for a defect which might be unharmful in service; but who would take the risk of accepting it?

The author was pleased to note that Mr. McClimont had commented on the value of non-destructive testing in service. This had been found particularly valuable in the inspection of aircraft at the periodic service overhauls. In this context Mr. Birchon's written contribution was particularly apt.

Mr. McClimont's summing up of the relative merits of X-rays and gamma rays was as near as one could get to the truth in so few words, and in relation to the equipment generally available, and was in keeping with what had been said in the paper. If, however, megavoltage equipment was available, then this could offer advantages over gamma rays for steel sections over two inches and for parts which had wide ranges of thickness. With such specimens, lower kilovoltage X-rays could frequently provide more information than gamma rays if two films of different speed were exposed simultaneously in the same cassette. The slower film could provide excellent detail in the thin sections, and the thicker sections were registered on the faster film.

It was certainly true that, owing to their generally smaller bulk, gamma ray sources were superior to X-rays for annular welds as the source could be placed at the centre of curvature. By this means it was possible to radiograph the whole length of the weld at one exposure. This could, of course, also be achieved (and much quicker) by means of a rod-anode X-ray tube.

The author agreed that cobalt-60 sources had greatly extended the scope of radiography but he appealed for the gamma ray source to be matched, so far as possible, to the thicknesses to be examined. Only by this means was it possible to get maximum benefit from gamma rays.

* Lueckerath, W., Fink, K., and Flossman, R. 1960. "A Non-destructive Method to Detect Pipes and Cavities in Hot Steel Blooms During the Rolling-Process by Means of Betatron, X-ray-Image-Intensifier and Television Set-up." *Non-destructive Testing*, Vol. **XVIII, No. 1, p. 27.**

Author's Reply

Mr. McClimont's query regarding the obsolescence of an X-ray unit had been answered partly by Mr. Redmayne. The author had known X-ray units in use for well in excess of ten years and had known others (particularly on site work) where the normal hazards reduced the life to less than one year. Of course, they could be repaired, but X-ray tube inserts were costly items. It was probably best to think of a "write-off" period of five years, where the tube received extensive use under hazardous conditions.

The author said that he was glad that the question of the sensitivity of radiography had been brought up, as this was an aspect of radiography which had probably caused more misunderstanding than any other. In practice the penetrameter sensitivity figure was a measure of the quality of the radiographic technique used and should not be taken as a guide to the size of the defects which might be detected. In fact this was the prime reason why the penetrameter was increasingly being called an image quality indicator (I.Q.I.). This was why he had used the phrase "differential absorption", and he was pleased to see that Mr. McClimont had used the same term. Taken in this context the figures quoted in the paper were not optimistic as would be shown later. The author said that he would have liked to have had more information from Mr. McClimont regarding the type of penetrameter he had in mind, and how the value of sensitivity had been assessed. He raised these points because such sensitivity figures had restricted value without reference to the way they had been obtained. There were at least five types of penetrameter (I.Q.I.) in general use, namely:

a) A.S.M.E. single thickness;
b) A.S.M.E. step;
c) B.W.R.A. step;
d) D.I.N. graded wires;
e) A.F.N.O.R. step;

and if used on the same weld under the same conditions they were likely to give different values of penetrameter sensitivity (not flaw sensitivity) because of their inherent characteristics. For example Halmshaw* had quoted penetrameter sensitivity values for $\frac{3}{4}$-inch steel, using fine-grain film and 300 kV X-rays for the following penetrameters as:

B.W.R.A.	1·0 per cent;
plain step	0·4 per cent;
A.F.N.O.R.	2·0 per cent;
wire type (D.I.N.)	0·7 per cent.

Such differences arose because the penetrameter design showed up the ability of the radiographic method to reveal both contrast (thickness changes) and definition (detail rendering). The density change dD in the radiograph, due to a thickness change dT in a thickness T, could be shown† to be given by

$$dD = 0{\cdot}434\gamma\ \mu dT$$

where μ = the linear absorption coefficient of the incident radiation
and γ = the slope of the "straight" line portion of the characteristic curve of the film. (In practice γ increases with density of the radiograph).

This equation demonstrates the need to have μ and γ as large as possible; hence the use of low kilovoltages to give high values of μ and high-contrast films exposed to high densities which in turn give high contrast (γ). This equation relates however, only to the detection of thickness differences in a penetrameter and not to image definition which could not be put in the form of an equation. The best penetrameters had features (e.g. very fine holes) which must be revealed in addition to thickness variations, and the system must then be capable of revealing both definition and contrast. Usually, where definition rather than thickness change must be revealed the penetrameter sensitivity figure was higher, indicating a poorer penetrameter sensitivity figure. It was mainly because of these different features of the penetrameters that differing penetrameter sensitivity figures were obtained under the same radiographic conditions on the same specimen. Apart from this the method of reading might influence the results; for example, must all the dots show in a step in the B.W.R.A. penetrameter to justify its acceptance, or was it sufficient just to see the step? The latter would give an apparently better sensitivity figure. With the D.I.N. penetrameter was it necessary to see the whole length of a wire before it was counted?

A further factor, which might influence the penetrameter sensitivity value, was that the observer knew what to look for when he was reading the penetrameter image, and imagination might therefore encourage him to assume that a step or wire was visible when it was barely visible.

The penetrameter reading was a measure of a metal thickness difference, where the penetrameter was placed on the face of the specimen facing the radiation. Under these conditions the value obtained was the worst value of sensitivity which would be obtained. A gas cavity, i.e. absence of metal, would be the nearest approach of a defect to the artificial "defect" provided by the penetrameter. If the defect was an inclusion, then it would be less readily revealed than a gas defect, because the defect itself absorbed radiation and hence the differential absorption of radiation was reduced. In addition, the nearer the defect to the film the more likely was it to be detected.

With all these facts in mind it would be clear that the value obtained should not be taken as a measure of the size of defects which could be detected.

With reference to Xero-radiography, the author said that this was tried out industrially some years ago, but had made no headway. So far as steel was concerned, there seemed an upper thickness limit of about $\frac{3}{4}$ inch for reasonable results. The image was not permanent—an important feature in some types of work—but it could be photographed, if required, to give a permanent record. A detailed report on this technique was given by Burns, Durant and Pollitt* and the author thought it would be better for Mr. McClimont to judge the results obtainable from this paper.

Mr. McClimont's query regarding improvement in reliability as a consequence of non-destructive testing, was one to which no one could give an answer except in specific cases. This was largely because defects in castings or welds were usually not identical and in the same place. Consequently, it was rarely possible to check on the service life of a "defective" product, and on the same product when this defect had been removed and a repair made. The comparison should be made with the latter rather than with a perfect specimen, because the repair itself might introduce defects, such as locked-up stresses, unless adequate thermal treatment was given. In order to get an answer to Mr. McClimont's question, it would be necessary for someone to summon up enough courage (and to obtain enough money) to make such tests under working conditions.

In reply to Mr. Capper, the author said that he had not mentioned etching, because it was not one of the methods normally classified as non-destructive. He had no doubt that, in suitable cases, this method was likely to be very valuable. Whether or not it could be applied would depend on the circumstancs; in service, the possibility of adverse effects of residual etchant and its by-products must be carefully considered. The author agreed that, in some instances, the introduction of non-destructive testing might lead to better workmanship; this was an added benefit.

Passing on to Mr. Calderwood's contribution, the author said that he was aware of the resistance method of testing, which he had described in a Croxson Memorial Lecture (reference (2) of the paper). He had omitted it on this occasion because of its limited application. Mr. Calderwood's reference

* Halmshaw, R. 1963. "Image-Quality Indicators for Weld Radiography." *Welding and Metal Fabrication*, Vol. 31, No. 3, p. 107.
† Tasker, H. S. 1949. *Handbook of Industrial Radiology*. Edited by J. A. Crowther. Arnold, London. P. 73.

* Burns, Durant and Pollitt. 1961. *Progress in Non-Destructive Testing*, Vol. 3.

to the failure of the magnetic method of testing suggested that the magnetic field was not in the right direction for detecting the defects described. The use of metallurgical procedures for checking, for example, the heat-treatment was a useful addition to the list of methods available for non-destructive testing.

Mr. Butler's report on the relative merits of pressure testing and eddy-current testing for tubes was noteworthy. Such experiments, the author said, were all too rare. Mr. Butler's query, the author said, regarding ultrasonic testing and surface finish of the tube had prompted the author to refer back to his paper. Under item (b) on page 428 it might have been better for him to have written that "the rougher the surface the less critical is the inspection". He had not intended to imply that fine surface marks would be more easily detected when the surface was smooth. In fact (see item (d) on page 427) fine defects in or near the surface were not likely to be revealed by ultrasonics. Part of his intention in mentioning item (b) on page 428 had been to emphasize that care must be taken in comparing the results obtained by ultrasonic testing two objects, similar in design, but differing in surface finish.

The author said that the interesting contributions by Messrs. Capper, Redmayne, Byrne, Frederick, Taylor, Gibbs and Birchon all served to demonstrate, in one way or another, the value of non-destructive testing; in the main they supported the author's comments, which was always a pleasant experience.

INSTITUTE ACTIVITIES

The Parsons Memorial Lecture

Minutes of Proceedings of the Ordinary Meeting Held at The Memorial Building, on Tuesday, 19th April 1966

An Ordinary Meeting was held by the Institute, following the Annual General Meeting, on Tuesday, 19th April 1966, at 6.30 p.m., for the presentation by Captain N. J. H. D'Arcy, R.N., C.Eng., M.I.Mech.E.(Member of Council), of the 1966 Parsons Memorial Lecture.

Mr. H. N. Pemberton (Chairman of Council) was in the Chair, and the meeting was attended by Lord Fleck, K.B.E., F.R.S., D.Sc., Treasurer and Vice-President of the Royal Society, and one hundred and nineteen members and guests.

A vote of thanks to Captain D'Arcy for his lecture was accorded by acclamation, after which the Chairman presented him with the Charles Algernon Parsons Medal, accompanied by a cheque.

The meeting closed at 7.45 p.m.

Minutes of Proceedings of the Ordinary Meeting Held at The Memorial Building, on Tuesday, 26th April 1966

An Ordinary Meeting was held by the Institute on Tuesday, 26th April 1966, at 5.30 p.m., when a paper entitled "The Scope of Non-destructive Testing" by L. Mullins, M.Sc., Ph.D., F.Inst.P., A.I.M., F.R.P.S., was presented by the author and discussed.

Dr. S. Archer (Member of Council) was in the Chair and fifty-three members and guests were present.

Eight speakers took part in the discussion which followed.

The Chairman proposed a vote of thanks to the author which received warm acclaim.

The meeting ended at 7.40 p.m.

The Autumn Golf Meeting

The Autumn Golf Meeting of the Institute was held at Grim's Dyke Golf Club, Hatch End, Middlesex, on Thursday, 29th September, 1966. The weather was fine for the meeting and thirty-four members competed in a Stableford Competition in the morning and a Stableford Greensome Competition in the afternoon. The leading scores for both competitions were as follows:

Morning Competition

1st Prize	G. E. Dunk	(15)	34 points
Peter Brotherhood Trophy			
2nd Prize	A. D. Timpson	(20)	33 points
	J. White	(14)	31 points
	J. M. Mees	(20)	31 points
	C. J. Probett	(4)	30 points
	G. Bowmer	(24)	30 points
	F. C. Bown	(20)	30 points
	P. South	(18)	30 points
	A. B. Dickie	(9)	29 points
	J. F. Watson	(2)	28 points
	J. F. Howie	(20)	28 points
	L. M. C. Robinson	(22)	28 points
	J. Henderson	(16)	28 points
	C. A. Larking	(12)	28 points

Afternoon Competition

1st Prize	J. F. Watson	(2)	35 points
	P. South	(18)	
2nd Prize	C. J. Probett	(4)	34 points
	P. A. Sait	(18)	
	M. MacDermott	(22)	33 points
	T. Chapman	(18)	
	G. B. Halley	(17)	33 points
	G. E. Dunk	(15)	
	J. M. Mees	(20)	32 points
	L. E. Smith	(18)	
	C. A. Larking	(12)	31 points
	R. M. Hewlett	(20)	
	L. M. C. Robinson	(22)	31 points
	J. White	(14)	
	P. S. Wainwright	(18)	30 points
	A. A. Kelly	(24)	
	K. Grant	(14)	29 points
	H. P. Granlund	(18)	
	R. S. Skinner	(18)	29 points
	P. C. Smith	(14)	

Mr. Stewart Hogg, O.B.E., Honorary Vice-President and Chairman of the Social Events Committee presented the prizes which included a handsome rose bowl presented by the directors of Peter Brotherhood Ltd., to be competed for annually at the Autumn Meeting.

A vote of thanks to the committee and catering staff of the Grim's Dyke Golf Club for their assistance was passed by the members.

It was announced that the Summer Meeting next year will be held at Burhill Golf Club on the 8th June, 1967, and the Autumn Meeting at the Addington Golf Club on the 5th October, 1967.

Branch Meetings

Auckland

Annual Dinner Dance

The Annual Dinner Dance of the Branch was held on Saturday, 24th September 1966, in the Berkeley Lounge, Mission Bay, Auckland.

One hundred and five members, their ladies and guests attended the function and were welcomed by the Chairman of the Branch, Mr. H. Whittaker (Local Vice-President).

The guest of honour on this occasion was Commander G. Mitchell, R.N., representing Commodore L. G. Carr, D.S.C., R.N.Z.N., Commodore, Auckland.

At the conclusion of the Dinner guests were entertained with a group of songs by Ann Stott, a well known Auckland artiste.

Following the recital dancing was enjoyed until midnight.

Hong Kong

Annual Report

The inaugural meeting of the Hong Kong Branch took place on Tuesday 12th April 1966, in the Shell Building, Queen's Road, Hong Kong.

Membership of the Branch which includes 100 corporate members, now stands at 133.

Upon the inauguration of the Branch the Committee formally notified the Engineering Society of Hong Kong—which has a membership of about 560—of the existence of the Branch and received a very cordial acknowledgement in reply. The Government was also notified.

As a result of the formation of the Council of Engineering Institutions in 1965, the Joint Group in Hong Kong—originally consisting only of members of the Institutions of Civil, Mechanical and Electrical Engineers—opened its membership to all institutions who were constituent members of C.E.I. These are fourteen United Kingdom institutions—not all represented in Hong Kong—who are eligible to participate in Joint Group activities. The Group has a membership in Hong Kong of approximately 786 persons.

Members will be interested to learn that following the inauguration of the Branch, the Council signified their intention to re-institute an office of Local Vice-President for Hong Kong.*

Future activities of the Branch include a joint meeting with the Engineering Society of Hong Kong on 14th December, 1966 at the Mandarin Hotel, Hong Kong, and a meeting designed to be of particular interest to younger members and students, to be held at the Hong Kong Technical College, Kowloon, in March 1967.

W. Grieve (*Chairman*)

*At the Council Meeting held in London on 19th September, 1966, the Council approved the appointment of Mr. W. Grieve as Local Vice-President, Hong Kong.

Annual General Meeting

The First Annual General Meeting of the Branch was held on Tuesday, 16th August 1966, in the Shell Building, Queen's Road, Hong Kong, 7.30 p.m.

The Chairman of the Branch, Mr. W. Grieve presided at the meeting which was well attended, some forty members being present.

In his report the Chairman discussed the activities of the Branch, details of membership and the arrangements for the presentation of papers.

It was agreed in view of the short time the Committee had been in existence that they should continue in office until next year.

He expressed his appreciation to the Hong Kong Shell Company for the use of their theatre for Branch meetings, and also thanked the members of Committee for their services during the past months.

The adoption of the Honorary Treasurer's report was proposed by Mr. Grieve, seconded by Mr. J. Manson and unanimously adopted.

At the conclusion of all business a film show, shown by courtesy of the Shell Company, was introduced by Mr. P. J. Davy in the absence of Mr. T. R. MacLean.

Vice-Chairman of the Branch, Mr. E. L. Green, concluded the meeting which appeared to be well enjoyed by the members present.

Northern Ireland Panel

The second annual golf outing and competition took place on Monday, 12th September at Clandeboye Golf Course, Co. Down.

The winner of the trophy was Mr. W. P. Hewitt, B.Sc. (Member), with Mr. R. Harrison (Member) as runner-up.

The visitor's prize was won by Mr. J. Fullerton, the runner-up being Mr. H. McLune.

The Chairman of the Panel, Mr. D. H. Alexander, O.B.E., F.C.G.I., M.Sc., Wh.Sc. (Local Vice-President) presented the prizes.

South Wales

A general meeting of the Branch was held on Monday, 3rd October 1966, at the South Wales Institute of Engineers, Park Place, Cardiff, at 6.00 p.m.

The Chairman of the Branch, Mr. T. W. Major, presided at the meeting and welcomed the seventy-four members and guests present to the first lecture of the session. He went on to outline the radical changes being introduced by various shipping companies to improve their operational efficiency, then called upon Mr. N. V. McAslan to present his lecture.

Mr. McAslan, a member of the Operational Research Department of J. and J. Denholm Limited, explained how method study and critical path analysis had revealed costly flaws in the operation of a fleet.

The speaker told of the difficulties encountered in removing suspicion of these methods when used to improve fleet operation. He concluded by enlarging upon the research still required to be carried out and suggested that some of this work, particularly that of engine breakdowns and machinery wear, also overhaul experience could be carried out in conjunction with other shipping companies.

A keen discussion and argument followed which was reluctantly terminated by the Chairman.

In proposing a vote of thanks to the speaker, Mr. G. S. Taylor (Member of Committee) thought that Mr. McAslan would appreciate the interest his lecture had aroused by the number present of members of the Superintendent's Union. The vote of thanks was supported by warm acclaim.

The meeting closed at 8.15 p.m.

Western Australia

A lunchtime meeting of the Western Australian Branch was held on Wednesday, 21st September 1966, at the new Flying Angel Club, Fremantle. Mr. E. E. Freeth, B.Eng. (Chairman of the Branch), was in the Chair and led a lively discussion on "Automation".

The meeting which was attended by nineteen members and visitors was the first lunchtime function to be held this year, owing to the difficulty in finding a suitable venue. It was hoped to arrange two meetings each year in future as they were well supported and the new venue should always be available to the Branch.

Election of Members

Elected on 19th September 1966

MEMBERS

Yecheskel Arkin
Harold Thomas Blake, B.Eng.
Thomas Joseph Campbell, Eng.Lt.Cdr., R.N.
Bruce Thomas Carr
Eric Dumbreck Cook
Victor John Way Crompton, Eng.Lt.Cdr., M.V.O., R.N.
Alan Cumyn
Maurice Elliott
Kenneth Henry Hobbs
George Keith Inglis, Cdr., C.D., R.C.N.
Philip Reginald Mellor, Eng.Lt.Cdr., R.N.
Thomas Douglas Potts
Clement Stephenson
Robert Stinchcombe
William Tipler, M.A.
Douglas Clare Waring, Cdr., C.D., R.C.N.
Alan Wignall

ASSOCIATE MEMBERS

Ian Anderson Allan
Jack Bowen Crawford
Stephen D'Souza
Lionel Caine Ellison
Maurice William Farr, Eng.Lieut., R.N.
Douglas Fulthorpe, B.Sc.
Charles T. Gunning, Lt.Cdr., R.C.N.

Robert McKenzie Haddow
Peter Ian Hedley
Gordon Edmond Wilfred Hickey
David Holmes
Antonius Jacobus M. Lauwers
Hamish Strachan MacLeod
Maurice Miles
Raymond Murphy
Spyridon Papadopoulos, Eng.Lt.Cdr., R.H.N.
Terence Adrian Rogers
Stephen Suttie
Gerald Walter Waters

ASSOCIATES

George Edward Blakey
David James Durell
Madjead Entezari, Lieut., Imp.I.N.
Noel Gilbert
Timothy Hall
David Patrick Harris, Eng.Sub.Lieut., R.N.
Aziz Khan
David Henry McGowan
James May
Percy Richard Micklewright
Laurence Adrian Stinchcombe
Robert Tait
Frank Owen Tapson, Eng.Lieut., R.N.

GRADUATES

James Francis Corrigan
Peter John Furbank
Kenneth Arthur Livingston
Avinash Kumar Puri
George Albert Vieira-Ribeiro
Michael Whelan

STUDENTS

Syed Iqbal Ahmed
Timothy Ramsay Chaplin
Harjit Singh Chopra
Nigel Cowcill
Mir Tehseen Ali Khan
Michael Robert Miles
Vinay Kumar Sood
Mohammed Saeed Suleman
Jehangir Sultan

PROBATIONER STUDENT

Michael Jennings

TRANSFERRED FROM ASSOCIATE MEMBER TO MEMBER

Stephen Crosby
Roy Lloyd Hughes
Harry Leah
Kenneth Alfred Smith

TRANSFERRED FROM ASSOCIATE TO MEMBER

John Comston Edwards
Sinclair Dinnen
Richard James Norman Kerr
Vilips Liepins
Arthur Ross
James White

TRANSFERRED FROM ASSOCIATE TO ASSOCIATE MEMBER

Bruce Auld
Ernest Brady

TRANSFERRED FROM GRADUATE TO ASSOCIATE MEMBER

Brian Crolley
Antony John Edwards
Satya Prosad Ghosh, B.Sc.
Derek George Goddard
Thomas Arthur Hind
Harry Matthias
George O'Brien
Ian Alexander Smart

TRANSFERRED FROM STUDENT TO ASSOCIATE MEMBER

David George Hosgood

TRANSFERRED FROM PROBATIONER STUDENT TO ASSOCIATE MEMBER

David Arthur Eastham

TRANSFERRED FROM GRADUATE TO ASSOCIATE

John Colin Branton

TRANSFERRED FROM STUDENT TO GRADUATE

Emmanuel Aderemi Matan
Laurence Tebb

TRANSFERRED FROM PROBATIONER STUDENT TO STUDENT

John Stanley Dobson
Stuart George Walder

OBITUARY

George Cecil Arthur (Member 11167) was born on the 28th August 1904. He was apprenticed to Cuming Smith and Co., Ltd., of Perth, Western Australia, from 1921 to 1926. During the period between 1926 and 1938 he served at sea in steam and motor vessels, rising from fifth to third engineer and in 1939 served as second engineer in a motor vessel. In 1932 he obtained a First Class Steam Certificate and four years later a Motor Endorsement.

From 1941 to 1945 he was a prisoner of war in Germany. Following the War he served as engineer surveyor at the Cardiff branch of Municipal Mutual Insurance Ltd., until 1952, when he entered the Royal Fleet Auxiliary. He served with them until discharged through illness in 1960. After this he served with several concerns for short trips until taken seriously ill in September 1963, from which time he was a semi-invalid.

Mr. Arthur was elected a Member of the Institute in February 1947. He is survived by his wife.

Robert Cockburn (Member 20610) died on 20th December 1965. He was fifty-two years old.

He served his apprenticeship with Stevenson and McGuffie, and G. and J. Weir Ltd. and continued with the latter firm as a draughtsman until 1946. The following year he joined Cockburns Ltd., with whom he became superintendent engineer.

He was elected a Member of the Institute in November 1958 and was an Associate Member of the Institution of Mechanical Engineers.

Mr. Cockburn is survived by his wife.

Dennis Henry Corder Coward (Associate Member 17235) died on 16th February 1966, at the age of forty-two.

He served his apprenticeship with the Royal Mail Line, with whom he afterwards saw sea service from 1943 until 1955, serving in all ranks from senior sixth engineer to second engineer. In 1956 he gained his First Class Certificate. Until his death he was an engineer surveyor for Municipal Mutual Insurance Ltd.

Mr. Coward was elected an Associate Member of the Institute in February 1956.

Joseph Peter Daily (Associate Member 28641) was killed on 27th December, 1965 on the oil-rig *Sea Gem*.

His career at sea began in 1952 with Caltex, with whom he served for five years before coming ashore and obtaining his Second Class Ministry of Transport Certificate. After this he was with the Mobil Oil Co. until 1965, gaining his First Class Certificate during this period. On leaving Mobil he joined the *Sea Gem*.

Mr. Daily was elected an Associate Member of the Institute in December 1964. He is survived by his wife.

Russell John Hugh Duffay (Member 12078) died on 9th April, 1966, at the age of sixty-nine. Following his apprenticeship with R.N.M.T.E. from 1912 to 1916, he rose from engine room artificer to the rank of Lieutenant-Commander, in 1946; he was awarded the M.B.E. in 1938. Throughout his naval career he was closely concerned with air engineering training and on his retirement from the Royal Navy in 1948 he took up an appointment as a lecturer at the Salisbury and South Wilts College of Further Education. He took a very real interest in his students, helping many of them to settle into suitable careers. This interest was so appreciated that a memorial fund was opened at the college and an annual prize is to be awarded in his name.

Mr. Duffay was elected a Member of this Institute in October 1948.

Sidney Clarence Gardner (Associate 17559) started his business life with Wailes Dove Bitumastic of Newcastle upon Tyne in 1910. After the First World War he joined the company's London office, becoming a director in 1960.

He was elected an Associate of the Institute in May 1956 and was also an Associate of the Royal Institution of Naval Architects and a Freeman of the City of London.

He is survived by his wife and a daughter.

David Halkett (Member 12415) died on 7th August 1966. Born in Arbroath on 14th April 1906, he served his apprenticeship with William Beardmore and Sons Ltd., Dalmuir, and John Brown and Co., Ltd., Clydebank. From 1927 to 1930 he served as junior engineer with the Canadian Pacific Steamship Co. Ltd. From 1931 to 1939 he served as second, and then chief, engineer in the Canadian Government icebreaker *Montcalm,* obtaining his First Class Steam Certificate (Canadian) in 1936.

From 1940 to 1941 he was superintendent in charge of plant for G. T. Davie and Sons Ltd., Lauzon, Quebec, before joining Lloyd's Register of Shipping with whom he served for the next twenty-five years as a senior ship and engineer surveyor.

He was elected a Member of the Institute in May 1949 and in 1962 was elected to the Committee of the St. Lawrence-Ottawa Section of the Canadian Division. He is survived by his wife.

Harry Joseph Hetherington (Member 6256) died on 11th April, 1966. He served his apprenticeship with the Union Castle Line and went to sea in 1921. The holder of a First Class Board of Trade Certificate, he served as seagoing chief engineer from 1929 to 1931. From 1932 to 1933 he served as junior third engineer on a motor vessel tanker, obtaining a First Class Motor Endorsement in 1934.

Mr. Hetherington was a Member of the Institute for nearly thirty-seven years, being elected in September 1929, and will be missed at the meetings in which he took such an active interest.

John Bibby Jones (Member 23024) died on 14th October 1965, aged sixty-one years. He was apprenticed to Cammell Laird and Co. Ltd. from 1919 to 1924, remaining with them until he commenced his sea career with the Ellerman Associated Lines. He obtained his First Class Steam Certificate in 1932.

At the time of his death he was serving in the t.s.s. *City of Pretoria*. He was elected a Member of the Institute in December 1960.

Mr. Jones is survived by his wife.