THE TESTING OF ENGINEERING MATERIALS.

Modern advance and competition continue to exercise greater demands for economy, speed and high duty, together with the greatest lightness of construction, on all engineering productions, with the inevitable result that the possibility of " over design " creeping in is more likely.

The importance of a study of the methods employed in testing all materials which are used in constructive work cannot well be exaggerated, such study being of vital interest to all having to do with the design, manufacture or inspection of machinery.

The term " testing," of course, by itself means little or nothing and requires to be defined by the special quality or qualities which it is desirable to appreciate. Materials have many qualities, and tests may be applied to arrive at a measure of one or any quality. The term testing materials, however, has come into common use to express the testing of materials for the special quality of physical strength, or in a wider sense, their special quality of resisting external forces, and their behaviour when subjected to such forces.

In the practice of testing materials two general types of tests are recognised. In the one, an article comprising the material or sample of a material is submitted to a specified proof test, of which there are many kinds, and should its behaviour under the test meet specified requirements, the materials or sample are said to have passed the test. This is a simple and practical type of test which has much use commercially, and gives assurance that the material is suitable to perform the task for which it is intended, but stopping at the point where the particular standard has been attained, it does not indicate how much more resistant the material may be.

In another general type of test, an endeavour is made to measure the actual strength of a sample of the material under test, and its quality of resistance to various definite stresses is ascertained in detail. The first type of test has little scientific interest, but is eminently practical and of very much use in daily commercial practice. The second type of test is of considerable scientific interest and calls for the application of mathematical and mechanical principles, and provides a means of obtaining information of a nature which has been and is very essential to the engineer, designer, metallurgist, chemist, as well as to scientific investigators in many lines.

In addition to the mechanical tests, further assurance is sometimes desirable that the material comprising the finished article is at all points in agreement both in structure and homogeneity with the sample which has been subjected to the detailed physical tests. This particularly arises in articles which have during manufacture been subject to heavy and possibly irregular forging or in complicated castings or indeed in any article, possibly small, which is exposed to high duty and which by its failure may lead to grave consequential damage to the complete machine or structure of which it forms a part.

A particular example is a high-speed turbine wheel. Here the test pieces, if taken on completion of the forging operation, may not be representative of the wheel. The over-speed test will, however, indicate within limits the suitability of the wheel to resist forces somewhat beyond those expected to arise in normal running. But over and above this, in view of the serious consequences of failure of the wheel on service and the nature of the processes carried out during manufacture, possibly too on a high strength material with accompanying peculiar or lesser explored characteristics, the designer feels that he is entitled to a further demonstration of the soundness of the material before it is put on service.

Similar considerations apply with more or less the same force to many other parts : oil engine cylinder head castings, important bolts, ball bearings, may be mentioned and other examples will occur to the reader.

Mechanical testing as practised to-day, and from which a vast amount of useful, indeed essential, information has been and is daily being obtained, is, from a truly scientific point of view, at best a somewhat crude performance. But, fortunately, experience shews that only a very moderate degree of accuracy is necessary, and since mechanical testing is useful, primarily because it enables materials to be compared, it does not necessarily entail the employment of expensive and tedious appliances which are essential when a degree of accuracy which can be qualified as " high " is required:

That we can get along so satisfactorily in the engineering world on such a system of approximation as we do is perhaps rather surprising to realize, and the human element of personal judgment as to tolerance or degrees of accuracy which must be observed is a factor of no small importance.

Mechanical testing in its simplest aspect is the measurement of the changes of shape or condition which a piece under test suffers when acted on by known forces. The reasons why different materials act in different manners under similar conditions are largely unknown. Our knowledge of what has been described as the ultimate structure of material of any kind is very limited. Although much advance has lately been made in the search for a conception of the ultimate particle, very little so far has been discovered which explains why certain substances have certain characteristics. What, in fact, enables a material to exhibit such physical qualities as elasticity, hardness, strength, we do not know.

The commonest and possibly the most useful of all tests in the general run of testing is the tension test, in which the behaviour of a material is noted when it is subjected to a simple pull or, as it is called, is subjected to tensional stress.

Tensile testing machines, after long years of use, have been brought to a considerable degree of excellence, for although it would appear to be a simple mechanical feat to design and build a machine which will give a straight and variable pull, and at the same time indicate the amount of the pull with sufficient accuracy, a close examination of all the requirements necessary to be filled will make it clear that the problem is not easy. At the present day, however, there are many types of such machines on the market which are capable of giving results quite sufficiently accurate for engineering purposes.

The results of a tensile test, for example, on a specimen of steel intended for use in some mechanical structure are in the vast majority of cases reported in a way which must be somewhat confusing to an unexperienced observer who may be interested. An engineer, in designing some special machine wishes, of course, to know the strength of the steel which he intends to use. He therefore asks for the elastic limit, the ultimate strength, and the percentage of elongation and contraction of area of a specimen of that steel, as determined by an ordinary tensile test. The test is made but the results are not what they are reported to be; it is possible that there are many engineers who do not truly appreciate that the results of a tensile test are reported conventionally in a sort of technical jargon, of crude and inaccurate statements.

The terms elastic limit, proportional limit, and yield point, have entirely different meanings, and although it is true that in a material like steel these points may be very close together, it is unfortunate that there is so general a looseness in their use. The elastic limit and the proportional limit are extremely difficult to ascertain with more than a very moderate degree of accuracy, even with the best of instruments in the hands of careful scientific observers. In the case of the yield point, indeed, there has been much discussion as to what really constitutes the phenomenon.

The result which is reported to the designing engineer as "the elastic limit" or "yield point" should be recognised as a simple numerical approximation of a phenomenon exhibited by a material under stress when it is passing from the elastic to the plastic phase.

Again, it is not always appreciated that the reported ultimate or tensile strength, is only a conventional figure. This result is practically always reported in pounds per square inch of the original cross-section of the tested specimen, whereas the specimen has become reduced in cross-sectional area before the ultimate load is reached, and often does not break until this cross-sectional area is very much reduced.

It will be thus seen that the engineer obtains a series of approximations on which he bases his calculations, and after all has been done, a factor of safety is introduced, such factor being the reserve which, it is hoped, will cover the unknown or unexpected.

It is not to be inferred from the foregoing that the value of ordinary tensile testing is any the less, and that mechanical testing is simply a series of guesses. The explanation of this apparent carelessness lies, not in the failure to obtain test results which are of a very considerable degree of accuracy, but in the character of most of the materials which are available for structural purposes. Commercial material, which is homogenous, and consistently of similar nature throughout, does not exist.

Two test specimens of exactly similar dimensions, and made from material actually continuous in an original mass of steel, will not give exactly similar results when tested under the same conditions. The results may be very nearly alike, but they will not be the same. This is not surprising when the physical composition and structure of the steel is considered. Microscopic examination of steel shews it to consist of an agglomeration of crystals of different materials, of different sizes and differently orientated, and joined together by a matrix of non-crystalline material possibly different again in composition from the crystalline matter. The stresses to which the test piece is subjected are borne by these crystals and the amorphous matrix. What we therefore measure is the combined resistance of the crystals and the cementing matter which causes them to adhere together, and since the component particles differ, their individual resistances are different. The combined resistance of the particles in a unit cross-section area is very similar though not identical with the combined resistance of the particles in any other unit cross-section area of the same material.

It is also to be observed that it is impossible to make two heats of steel exactly alike in composition, a consideration which is very evident when a very cursory survey is made of the processes necessary in making steel, from the blast furnace to the steel conversion furnace, and if the changes which that steel may undergo in the various types of heat treatments adopted are also taken into account, it will be clear that two pieces of steel derived from different heats will be similar in general character rather than identical in every respect, however great care is taken to duplicate operations in every way possible.

Even wider variations may be noted in the case of non-ferrous materials as a result of small changes in the process of preparing the material. In the case of Admiralty gunmetal, for example, test samples from the same pot of metal can be cast with tensile strengths ranging from 8 to 14 tons per sq. inch, at the will of the melter, according to the temperature at which he chooses to pour.

For any particular brand of material when made in respect to composition and treatment with those precautions which are practically possible with commercial products, the test results may therefore vary somewhat widely. But if continuous tests are made of the productions from day to day, it is found that the majority of samples will give results falling within fairly narrow limits. The range in ultimate strength, for example, given in specifications, represents the limits within which productions made on a commercial scale might be expected to fall, and is the necessary concession to the variations which cannot be avoided in practical work, rather than to any desired variation from the user's point of view.

Apart from differences in composition and structure due to manufacturing conditions, a further factor to be kept in view is the human element in the testing operations as carried out in the shops. A so-called "expert" in testing can obtain fairly wide variations in the observed data by altering the speed at which the test bar is loaded.

The futility of super-refinements in recording the observations made in routine tensile tests is therefore evident, but it will be equally clear that it is unsafe to take the recorded results of a test on one sample of a steel as a measure of that steel. This point is demonstrated in the specifications for parcel tests, in so far as a further sample is permitted to be tested if the first fails. It is more satisfactory to form a judgment from the result of three or more samples, taking the average of three or more if the figures are near, but discarding any one which diverges greatly from the others.

These conditions, of course, apply in exactly the same way in other tests which are commonly made in routine laboratories, such as bending, torsion and shear tests, and it is recognised that the results reported from the laboratory are indications more of the order of magnitude of physical resistance of the tested material than absolute determinations of actual strength.

There are certain tests the results of which can only be used in a comparative sense, in that such tests only determine the differences of resistance to certain types of stresses between one material and others. This is well exemplified by the impact test and certain types of endurance of fatigue tests. Such tests are somewhat complicated by the introduction of factors which are up to the present largely unknown, and the reliability of such tests depend to a certain extent on the reasonable supposition that these unknown factors can be maintained as constants from test to test.

Much assistance has been given and much has been done to advance the usefulness of general testing, perhaps better expressed as the usefulness of laboratory test results, by the standardisation of tests and testing methods. It is evident that a satisfactory series of standards will clarify and simplify such data which emanate from various testing establishments. The difficulty, of course, lies in the selection of the proper standards to adopt, and there is also an added danger that a standard, once adopted to any great extent, may act as a brake on further progress.

As regards the various mechanical tests, it is only proposed to refer again, in any detail, to the questions of fatigue and hardness tests which have been, and in the latter case continued to be, the subject of much investigation and controversy.

Modern research has shown that the value of a material cannot be determined by the tensile test alone, and various other checks of the nature of impact or shock and fatigue tests have been devised. As already mentioned, such tests are comparative rather than absolute, and there has been much controversy, as might perhaps be expected, in regard to their value. For a great many purposes, therefore, the tensile test retains its place as the practical criterion.

There is, however, one property of structural materials which in most applications ought to receive consideration in assessing their suitability, and that is their power to sustain alternating stresses or fatigue. This has no doubt been realised for a considerable time, but it was formerly thought that the fatigue range was much the same as the "elastic range," and that provided the working stress was not allowed to pass beyond this limit, the material would be quite satisfactory. The difficulty of observing the stress at which the material passes beyond the elastic range has been mentioned, and in any case the point was susceptible of modification by prior treatment of the sample, so that this observation was a difficult one to obtain and possibly of uncertain value when attained. In lieu, there was substituted in some cases a proof load, that is, a stress was laid down at which the material should not show more than a certain very small permanent set. Research has, however, shown that the supposed connection between elastic limit and the fatigue limit cannot be sustained. Actually, of all the data obtainable from a tensile test, it would seem that the ultimate strength is the best guide to an estimate of the resistance to fatigue. The fatigue range, *i.e.*, the range of stress over which the material can endure an indefinite number of reversals without fracture, is found for most metals to lie in the neighbourhood of one half the ultimate strength. In isolated cases the value ranges from as low as 30 per cent. to as high as 58 per cent., but, even so, the relation between the fatigue range and the elastic limit is liable to vary to a much greater extent. Such metals as pure copper and Armco iron—a near approach to pure iron—show a fatigue range very considerably greater than their elastic limit.

Machines are now available, however, which permit of the rapid determination of the fatigue range by means of a test on a single test piece, no more difficult to carry out than a tensile test. There is, therefore, no occasion to rely on guess work, and while the tensile test will continue to yield the fundamental data, the additional information which the fatigue test affords can hardly fail to give added assurance of the suitability of the material to stand up to conditions which may arise on service.

A considerable amount of work has been carried out in recent years in the attempts to standardise and assess on a true comparative basis the quality known as the "hardness" of a material, without much success or even affording clues that would lead to a truly rational understanding of this elusive characteristic. Recent investigation has, however, thrown further light on some of the unsolved, fundamental problems connected with the hardness of metals.

The Brinell machine and the Scleroscope, which have been in general use for a number of years, have done very little towards a solution of the fundamental problem. There is, of course, a large amount of exact knowledge regarding such matters as the effect on the results of the manner of carrying out the tests by these instruments, such, for example, as the precise effect of varying the size of the ball and the magnitude of the load in the Brinell test, but this is only of use in obtaining comparable results in proceeding from one test to another.

So little, however, have the results obtained taught us, that it is still not possible to correlate, other than by empirical relations, the figure derived by one method with that obtained by the other.

An alternative means of testing hardness now available is afforded by what is known as the Herbert " pendulum " tester. It consists essentially of a loaded rocking device with a ball of ruby or steel on its underside making contact with the material to be tested, and a spirit level and scale on its upper side. Normally, the centre of gravity of the whole instrument is adjusted until it is very slightly below the centre of the ball. When testing, the device is set in oscillation through a very small angle, and the periodic time of oscillation is measured. This time is recorded as the "pendulum time hardness number." Alternatively the device may be tilted to any angle and then released. The angle reached at the end of the immediately ensuing half swing is measured and recorded as the "scale hardness number."

The instrument can be used, therefore, in two distinct ways, but seeing that the results obtained by these two methods on a series of materials do not in general show proportionate agreement, and indeed, in some cases, run contrary to the ascending order of hardness by the ordinarily accepted standards, it might be supposed that the instrument would prove even more arbitrary than the instruments hitherto employed. It is found, however, that the ratio between the " scale " and " time " test figures has every indication of itself being an important practical measure of hardness. The experimental figures strongly suggest that there are at least two factors influencing the figures obtained for the " time " test, and these have been called plastic and elastic indentation hardness. These terms cannot be regarded as final, as it seems possible that the question of elastic hysteresis may also enter, but they can perhaps be accepted for a consideration of the reasons for the discordance in the results being obtained in the case of the Brinell and Scleroscope methods. In the Brinell test it is evident that the indentation which is measured after the ball has been removed is not the total indentation made by the load, but only the permanent indentation—in other words, this test yields a measure of the plastic indentation hardness. The Scleroscope, on the other hand, would seem to give a measure of the elastic indentation hardness, since the rebound becomes less and less as the specimen under test becomes of a more plastic nature. There seems little doubt that in the Herbert pendulum " time " test the period of the swing is affected both by the permanent plastic deformation and the temporary elastic indentation caused by the loaded ball.

In the same manner it has been argued by the inventor of this instrument that the " scale " test figure is also influenced by two factors, viz., by the combined indentation hardness and by a property of the metal which he has called the " flow hardness," but which by analogy with liquids could be defined by the term " solid viscosity."

The case of manganese steel affords an example of the inadequacy of the existing methods to co-ordinate and standardise the property of hardness. Tested in the Brinell machine, and also for that matter by the pendulum " time " test, this material shows a hardness not very different from cast iron, notwithstanding the utterly different characteristics which these materials show in practical work; for instance, in resisting machining. When tested by the pendulum " scale " test, however, the manganese steel shows the exceptionally high " flow " hardness, conforming to its known properties.

It will be evident from these remarks and a consideration of the complicated mechanisms by which the readings in the pendulum machine may be influenced, that a great deal of work and investigation will have to be done before this machine can take its place in commercial work. But it seems likely that its coming into use would lead to a more rational assessing of this property of hardness than has hitherto been practised.

Turning now to the available known methods of ascertaining with any degree of assurance the entire suitability, in respect to soundness and homogeneity, of a completed item such as a forging or casting after it has passed the proof and material tests, it is to be first observed that such methods, or at any rate their extended commercial exploitation, are in their infancy. Methods are, however, available and can no doubt be developed to meet the requirements, but the greatest difficulty would appear to rest, not so much in the developing of the means, as in the interpreting of the results so obtained.

Examination by X-Rays.—In regard to the examination of hidden details of structure of completed articles or materials, the X-ray method would appear to offer great promise when the technique is sufficiently developed. Until recent years the development of radiographic technique was largely in the hands of the medical profession, but during the war attention was given to its possibilities as a means of testing materials. It has been used for locating structural defects in aeroplanes with considerable success, and to a limited extent for castings, welds and small metallic fittings, including the accuracy of assembly of small complicated fittings such as fuses, where it affords the only practicable means of checking this feature. Abroad, it has been employed to a somewhat limited extent, although in at least one case the results are applied directly to control foundry practice.

In applying it to metallic bodies, the scope of the application is limited by the penetration that can be attained by the existing appliances, and while there is no doubt that advances will be made in this respect, it may be noted that the difficulties in producing apparatus of increased power are by no means light.

The radiographic method is essentially a photographic process. The metal to be examined is disposed between the target of a Coolidge X-ray bulb and the photographic plate, which is mounted between two sheets of fluorescent material known as intensifying screens. These screens glow under the influence of X-rays, and the photographic action recorded is the sum of that due to the direct action of the X-rays on the photographic plate, plus that of the fluorescence of the screen.

With the appliances now developed but not yet available commercially, a thickness of 3 inches of steel can be penetrated to give a photograph for an exposure of 2 minutes, and material up to ½-inch in thickness will yield a visual field. By this process, any discontinuity of structure in a particular sample, such as a crack, fissure, or blow-hole is revealed as a lighter spot, due to the lesser resistance to penetration there, and in a composite structure the components of different metal are shown in a somewhat different shade, thereby allowing the assembly to be verified, if this be the particular object in view.

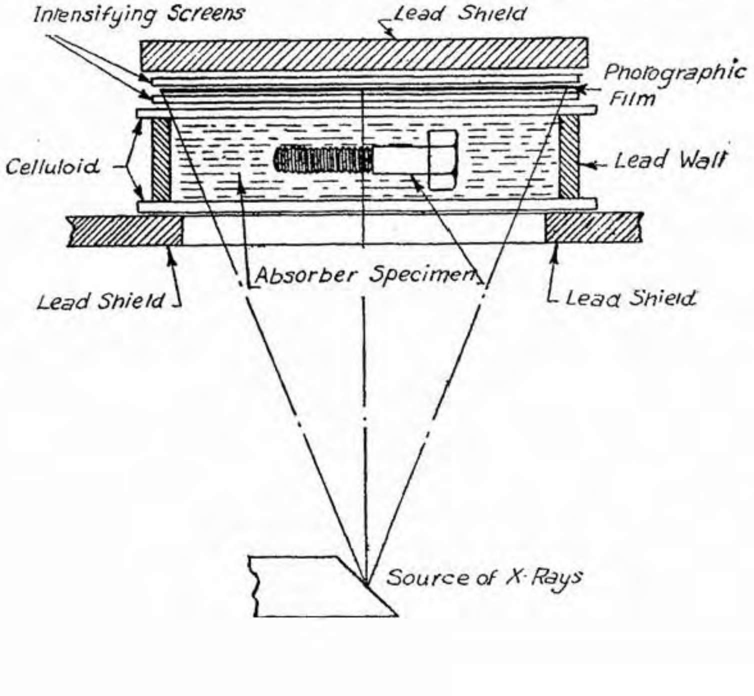
To enable a better appreciation to be formed of the possibilities of this method of detecting faults in such items as castings and forgings, it may be helpful to refer briefly to the significance of the image shown on the picture in relation to the cavity or other irregularity giving rise to it. It is to be noted that the X-rays proceed from a small area which approximates to a point and radiate from there in all directions. In passing through a spherical cavity, for instance, a conical pencil of rays would be intercepted by the cross section of the cavity, and the intersection of this cone with the photographic plate would define the image. So the area of the image will depend, not only on the size of the cavity itself, but also upon the respective distances of the cavity and photographic plate from the source of the rays.

If the cavity is not spherical and is inclined to the axis of the beam, then the image will be the projection of the sectional area of the fault subtended by the rays.

In general, it would not be known, of course, how any cavities lie with reference to the plate, so that it is not ordinarily possible to measure the sectional area of the fault, even when definite images are obtained. This information can, however, be obtained by a stereoscopic examination when the image is sufficiently defined. In cases where cavities are small, as compared with the area of the focal spot on the X-ray target and remote from the plate, it is found that the cavity acts like the aperture in a pinhole camera, and the image becomes a blurred image of the focal spot rather than an image of the flaw. The certain detection of very small cavities is therefore not possible. Experience shows also that where cavities of sensibly spherical shape occur in thick metal, the image appears dense in the centre and shades off at the edges, so that a definite outline cannot be obtained, even though the pinhole effect does not enter.

Sufficient has been said to indicate the difficulties in interpreting with any degree of precision the extent of such faults, but probably the type of subjects for which this method offers the greatest utility are those in which it is necessary to detect flaws of any description, irrespective of their size or precise axial location. In this connection, as representing what can be done in skilled and experienced hands, it has been reported by some investigators that where the linear dimensions of the flaw, that is the dimension parallel to the axis of the X-ray beam, is approximately equal to not less than 2 per cent. of the total thickness of metal in the region adjacent to the flaw, the image may be distinguished—that is to say, a cavity ·05 inches in depth could be detected in metal 2·5 inches thick.

Up to the present a difficulty has arisen in the application of the method to articles of irregular thickness, owing to the fact that the positions of the fluorescent screen or photographic plate corresponding to the thinnest part of the material are over-illuminated when the illumination for the thickest and least transparent parts is correct. Essential details are consequently obscured. A new method of mounting the specimens has now



been developed that makes possible the examination of such objects. In this method, the specimens are surrounded by a medium of slightly different transparency to X-rays in a container with opaque walls and the parallel transparency of the entire field is made of approximately the same order of magnitude. The arrangement is shown in the figure. Various substances have been used, but it appears that the best substance is a liquid, The choice of liquids is restricted to compounds of high density containing a constituent of high atomic weight so that the X-ray absorption may be high, in agreement with that of the metal that it may be desired to examine. Methylene iodide has proved satisfactory, and, mixed with benzine, suitable dilutions can be made to suit the various alloys generally met with in engineering practice.

It will be evident from these remarks that the process offers great possibilities for inspection work, and that it has indeed answered, so far as concerns the application to small and relatively thin fittings, where a certain assurance of their absolute soundness is of sufficient importance to warrant the examination by these means. For the thinner articles of uniform thickness indeed, the process may almost be said to have reached the workshop stage, in so far as a visual picture can be obtained with the Coolidge tubes, etc., that are already available. For their application on a workshop scale to the examination of thicker articles and of extensive surface, it appears necessary to await the development on a commercial scale of more powerful appliances.

Magnetic Analysis.—The possibility of utilizing magnetic tests on steel, for the estimation of its mechanical properties, is based upon the fact that the same factors which determine the mechanical properties also determines the magnetic properties. Any influence which operates to alter the mechanical properties produces a corresponding change in the magnetic properties. The change, however, is not directly proportional, and therein lies the difficulty in the way of the practical application of the method.

The degree of magnetization of steel is a complex function of the strength of the magnetizing force which has so far not been found susceptible of mathematical expression. As the magnetizing force is progressively increased, the magnetic induction increases, first slowly, then more rapidly, and afterwards at a slower rate. If at any point the magnetizing force is then decreased, the magnetization does not follow the same path by which it increased; when the magnetizing force is reduced to zero a certain amount of residual induction remains, to remove which then requires a certain amount of magnetizing force in the opposite sense, known as the coercive force.

It will be evident, therefore, that there are a number of combinations of data observed in the determination of magnetic properties which may conceivably be used in the estimation of the physical properties.

A considerable amount of work has already been done towards the accumulation of data necessary for determining the relationships that undoubtedly exist.

Perhaps the most direct application of this principle is in the detection of flaws in material. An early apparatus of this type consists of an electro-magnet between the poles of which the specimen under examination was magnetized. By means of floating test coils surrounding the specimen and a ballistic galvanometer, it was possible to explore the whole length of a bar, for example, and measure the leakage of lines of force at different positions over its whole length. A flaw in the material would cause an apparent change in the magnetic properties and consequently a disturbance of the normal distribution of flux, and this would be indicated by the variation in the galvanometer reading. This method has been applied for the examination of rifle barrels.

A subsequent development of this method consisted of magnetizing the specimen by means of a solenoid which surrounds it and moving this solenoid at a constant speed along the length of the specimen. Test coils mounted on the same carriage as the solenoid, and arranged within it, provided the means of measuring the variation in magnetic flux of the specimen under test. If the bar is magnetically uniform along its length its permeability is constant for a given magnetizing force, and the magnetic flux at each point as the solenoid is moving along is constant. In this case there will be no electro-motive force induced in the test coil as the solenoid travels along the length of the specimen. If, on the other hand, the permeability is not constant, the flux will vary and a corresponding electro-motive force will be induced in the test coil which, if the coils are moved at a constant speed along the specimen, is proportional to the change in flux. The use of two test coils connected in series opposition yields a result that is unaffected by any possible variation in the magnetizing current during a test.

The greatest difficulty in this line of investigation lies in the interpretation of the results. This is due to the fact that there are many causes which may produce magnetic inhomogeneity and it is difficult to differentiate between them.

Clearly, the method described is inapplicable to the examination of samples of other forms than bar or wire. Alternative forms are, however, available, and, in particular, apparatus has been devised for testing the homogeneity of turbine wheels. This method of examination is in regular use in one of the most important turbine manufactories of the U.S.A., and is said to have proved invaluable there. It is understood also that, in addition to structural inhomogeneity the apparatus also reveals the correctness or otherwise of the heat treatment of the material comprising the wheels.

Precise details of this method are not available. As described, however, the method consists in revolving the turbine wheel between two powerful solenoids. Any variation in the magnetic field, owing to differences in structure of the metal at the moment between the solenoids, show themselves on a sensitive galvanometer. A continuous photographic record of the galvanometer readings is obtained, the whole extent of the wheel being explored.

As in the other methods described, the real difficulty rests in the interpretation of the results. But there appears no doubt that, with the experience gained and data accumulated, this method leads to the certain diagnoses of those defects in structure to which the materials are particularly liable and thereby to an increased assurance as to the suitability of these important elements in high-duty turbines.

Whether the same certainty in ascertaining the correctness of the heat treatment can be obtained appears somewhat doubtful, but as in the case of defective structure, the interpretation depends upon the amount of data collected, and, as experience is gained, it should tend to become more definite.

A final example of the possibilities of magnetic analysis is afforded by investigations now being pursued in respect to cutting tools. Such tools are, of course, subjected to a heat treatment which includes both a quench and a draw. A physical test, such as a hardness measurement, may show that the desired standard in that respect has been attained, but it does not give certain assurance that the heat treatment has been correct. It is, however, a characteristic of magnetic data that intermediate processes in thermal treatment leave a definite stamp on the material; in other words, subsequent treatment does not entirely efface the effects of an earlier step. It is the heat treatment more than any other process in the manufacture of material for this purpose that settles whether or not the finished article will stand up satisfactorily to the conditions for which it is intended.

Briefly, the method followed is to arrange the sample to be tested within a solenoid which is energised by a source of variable electro-motive force through variable inductances and resistances. This test solenoid forms one arm of a bridge circuit, the other arms being resistances. Bridging these circuits is the moving coil of a galvanometer whose field coil winding is energised from the same source as the solenoid, through a variable inductance and variable resistance. In series with the galvanometer moving coil is a condenser, which may be cut out by a switch. By adjustment of the resistances and by running the circuit with the condenser and short-circuited respectively, two galvanometer readings are obtained which are indicative of different combinations of two different magnetic properties of the specimen under test. The condenser operates to cause a variation in phase relation between the current in the moving coil circuit and that in the galvanometer exciting field, and so allows the desired discrimination between two different magnetic properties.

This type of magnetic test is a commercially practicable one for small articles, and a comparison of these magnetic properties appears likely to afford an indication as to whether the individual steps comprising the heat treatment will lead to the desired results in the case of those features which cannot be tested otherwise than by a destructive test or by continued service.

Surface Methods.—A close surface examination of highly stressed turbine discs after finish machining is now becoming general practice. The whole surface is examined inch by inch by a trained man for slag inclusions and other irregularities. Any doubtful spots are polished, etched and examined microscopically. Small isolated slag inclusions are scraped out and surface defects are removed to form shallow depressions, thereby removing a possible source of initiation of a fatigue fracture. Sponginess, blown steel, dirty steel or extensive slag inclusions which are revealed by this examination, generally lead to rejection.

The surface of the bore of large high-duty shafts and turbo-generator rotors is similarly closely examined and doubtful parts polished and etched. Any cracks or surface defects are machined out by increasing the bore. Where the shaft or rotor can be bored by the trepanning process, the close examination of the core affords a good check as regards the homogeneity and continuity of the interior surface, and the quality of the material can be further ascertained by mechanical tests of the core material. Sulphur prints are also taken in the case of large generator rotors, which are to be slotted with a view to arranging if possible for the removal of the most marked segregation during the further machining operations; very large forgings are particularly liable to this feature.