The
INSTITUTE of MARINE ENGINEERS
Founded 1889. Incorporated by Royal Charter, 1933.

Patron: HIS MAJESTY THE KING.

SESSION 1935.

Vol. XLVII. Part 10.

President: MAURICE E. DENNY, ESQ., C.B.E., S.B.

The Testing of Engineering Materials.

READ

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On Tuesday, October 8th, 1935, at 6 p.m.

CHAIRMAN: Mr. T. R. THOMAS, B.Sc. (Chairman of Council).

Synopsis.

THE paper discusses certain aspects of the testing of engineering materials, many of which have especial interest in connection with marine engineering. Some mention is made of the method of test employed, but attention is primarily given to current or recently-completed researches carried out at the National Physical Laboratory. In each aspect covered, reference is made to some practical problems which appear to require future research; it is expected that the experiences and views of members on this aspect alone should lead to a valuable discussion. The subjects dealt with are: High Tensile Structural Steels, Welded Joints, Lubricants and Bearing Metals, Failure of Metals under Complex Stress Distributions, Fatigue and Corrosion-Fatigue of Metals, Cracking of Boiler Plates, Materials for High Temperature Service, Contact-Corrosion under Stress, Lifting Gear Components and Failures in Service.

Introduction.

In preparing a paper for reading and discussion before this Institute, the authors have been aware of the very wide range of activities and interests dealt with by the marine engineer. The course might have been adopted of selecting and discussing in very great detail one special aspect of the testing of engineering materials, but a paper on such lines would necessarily have been of restricted interest only. The present scope and method of treatment was therefore decided upon, by which reference is made to a number of widely different aspects of testing, each of which, however, represents some problem or group of problems of practical interest, directly or indirectly concerned with marine engineering. It is hoped that considerable discussion will thereby be evoked, eliciting experiences and views which, while being of great general interest, will also be extremely valuable to those engaged at the National Physical Laboratory on the various current researches to which frequent reference is made in the following pages.

I. The Testing of Materials at High Temperature.

Modern developments in power plant and chemical plant have created an urgent demand for materials capable of withstanding extremely severe conditions of high temperature and stress. The essential problem arises, of course, from the property of metals to behave at elevated temperatures in a quasi-viscous manner and deform continuously for extremely lengthy periods under stresses far inferior to that producing fracture, or even measurable extension, at atmospheric temperature; this property is commonly termed "creep". The present day problem is not so much to guard against actual fracture, or, on the other hand, to ensure entire freedom from distortion, but rather to be able to design so that the total deformation occurring within the required service life of the component shall not exceed permissible limits. For example, in turbine blading, a limiting maximum extension, rather than a total absence of permanent deformation, is the practical requirement, for the latter may be impossible of attainment under service conditions; it has yet to be established that metals, under operating conditions, deform for a certain period only after which no further distortion takes place. After considerable investigation in many laboratories, major reliance is now placed on the results of simple tensile tests, and one of the chief problems is the devisement of testing appliances of sufficiently great sensitivity. To realise this need, let us consider a practical requirement of certain high pressure vessels in the chemical industry, where a deformation of 1 per cent. per year only can be allowed; this is *not* a severe condition. But even this value is equivalent to 1·14 millionths of an inch per inch per hour; this rate is too small to be perceived over a short time except by the aid of sensitive measuring instruments, yet it produces quite large total deformation after a long period. Now, modern power plant requirements impose much greater restrictions on the permissive deformations, hence the most reliable testing method reduces to observations of the total creep and rate of creep extending over very lengthy periods. Such a method is very irksome and expensive, and naturally much effort has been devoted to the problem of discovering a reliable "short-time" test; methods have been suggested by Hatfield,* Pomp and Enders,† Bailey and Roberts‡ and others. Such methods appear to possess distinct value, especially for specification and comparative purposes, but further research must be made before it can be accepted that reliable indications of the creep resistance at working stresses are given by such accelerated methods of test. It must also be pointed out that certain steels and alloys exhibit a very dangerous type of failure by intercrystalline cracking, which is only revealed after prolonged stressing at the test temperature; a short-time test might give a false sense of security in such cases. A typical example is a nickel-chromium alloy tested at the N.P.L. at 800° C. at a stress of 1·8 tons/inch^2; less than 0·0001 strain was observed during 34 days testing but complete failure by cracking took place after 54½ days.

*Jour. Iron & Steel Institute, 1930, Vol. 2, p. 215.
†Mitt. a. d. Inst. f. Eisenforschung, Vol. XII, July, 1930.
‡Proc. Inst. Mech. Engrs., Vol. 122, p. 209, 1932.

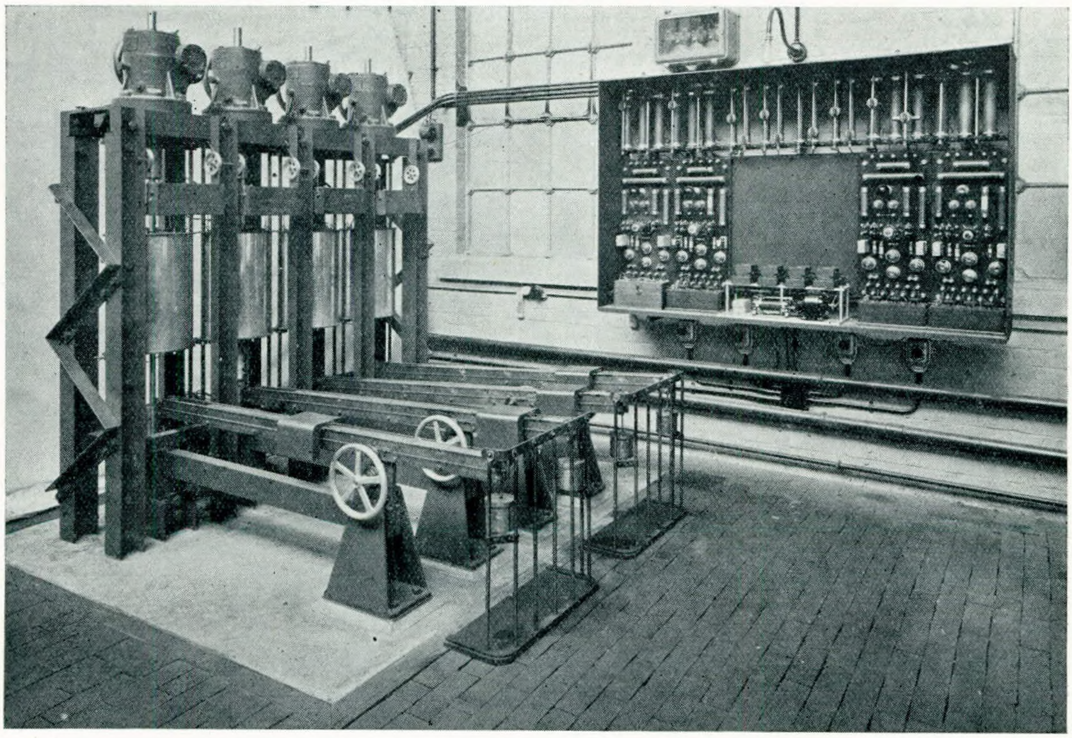


FIG. 1.—"Creep" units of high precision.

As a result of extensive experience of testing at high temperatures, the usual scheme of tests practised at the N.P.L. is as follows :—(*a*) to determine the short-time tensile properties, including limit of proportionality, proof stresses, etc., (*b*) to examine the time to fail and the nature of failure under prolonged stresses, (*c*) to determine the stress corresponding to a creep rate of strain of 10^{-5} per day after 40 days. This group of tests furnishes useful data for comparative and general purposes. In addition, it is becoming increasingly common practice to measure the amount of total deformation and the creep rate at stresses in the neighbourhood of *actual working stresses.* This requires the use of special apparatus of exceptionally great sensitivity which may be briefly described.

Fig. 1 shows a battery of these especially sensitive testing machines together with the electrical controls for maintaining very accurately the required test temperature; four units of this apparatus were installed in 1932, and an additional two units are under construction at the present time. The loading is applied by a compound lever and the electric furnaces are designed for a maximum temperature of 800° C. Temperature control is obtained by means of a platinum resistance surrounding the specimen; this forms one arm of a Wheatstone-bridge network which controls the current supplied to the furnace through a system of four relays. A test lasting for 2,500 hours showed that the *maximum* variation of temperature in the specimen did not exceed $\pm\frac{1}{2}$° C. The third essential component of the apparatus consists of the specially designed extensometer shown in Fig. 2; rough measurements are made with the micrometer, while the accurate readings at very slow rates of creep are recorded by means of rhombs, to which mirrors are attached, and illuminated scales and telescopes (not shown in Fig. 1). A scale reading of 0·1m/m. corresponds to a strain of the specimen of 8×10^{-7} for the normal 5″ test piece.

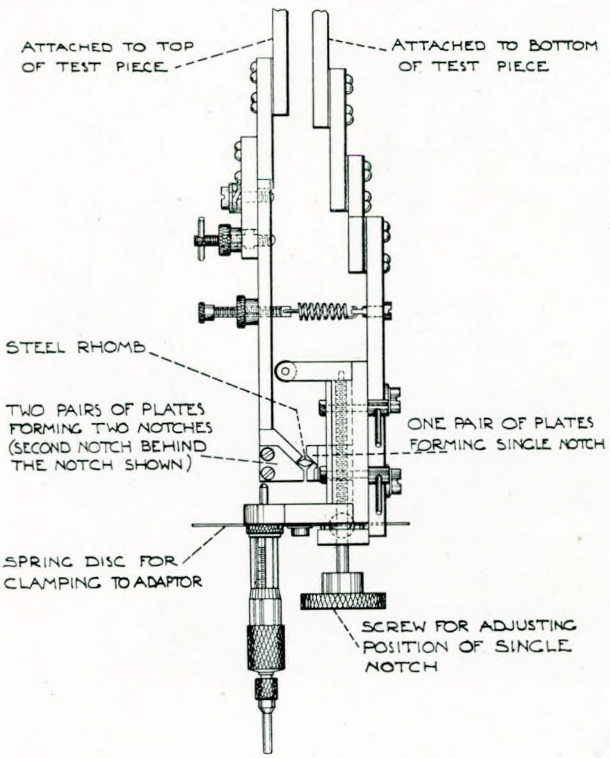


FIG. 2.—Sensitive extensometer for high temperature testing.

Space does not permit the presentation of the very comprehensive test data that has resulted from the N.P.L. investigations; these are available in various publications* by Tapsell, Clenshaw, Bradley, Johnson, Prosser and Remfry.

In a preliminary attack on the more fundamental aspects of creep phenomena, other investigations are in progress at the N.P.L., one of which relates to a study of creep characteristics under combined tensile and torsional stresses. Information of this general type will be especially valuable for design purposes as, almost universally, simple tensile stressing only is receiving attention. Then a study of the stresses and strains arising when a material is subjected to bending moments under conditions which produce creep offered promise. Use was made of the fact that metal possessing a relatively low melting point behaves at air temperature in a manner equivalent to that of steel at elevated temperatures; a beam of *lead,* subjected to pure bending couples, was therefore employed. It was found that plane sections remained plane, also that the behaviour of the complete beam could be computed with fair accuracy solely from the stress strain relations, deduced by simple tensile tests on samples cut from the beam. A detailed report of this interesting experiment has just been issued.† A study has recently been completed of the effects of deformation at high temperatures of several varieties of iron and mild steel; microscopical examination was made of material subjected to creep and short-time tensile tests, the specimens being kept free from attack by air by stressing in vacuo in special testing units. The work has shown that slip, grain-boundary movement and recrystallisation are prominent features in the mode of deformation; spheroidisation is also of importance in mild steel below the critical range. A report‡ on this work has now been issued.

Reviewing broadly the present state of knowledge of the subject, it is clear that, primarily due to the pressing demands made by industry for information concerning the properties of suitable materials for design purposes, major attention has hitherto been paid in research laboratories to the

*D.S.I.R. Special Engineering Reports No. 1, 2 (1927), 6 (1928), 15 (1929), 18 (1930); "Engineering", Vol. 120, p. 614, 1925, Vol. 137, p. 212, 1934; Proc. Soc. Chem. Ind., 10th Feb., 1933; Jour. Inst. Metals, Vol. 35, p. 75, 1926; Jour. I. & S. Inst., Vol. 117, p. 275, 1928.

†Tapsell & Johnson: Jour. Inst. Metals, 1935, Vol. 57, p. 712. (Advance copy).

‡Jenkins and Mellor: Jour. Iron & Steel Inst., Sept., 1935. (Advance copy).

accumulation of what can only be regarded as test data, valuable though these are; a wide and attractive field remains to be explored in the study of the more fundamental characteristics of the deformation of metals by "creep".

II. High Tensile Structural Steels.

As the result of extensive experience of service behaviour, engineers have acquired a great faith in the use of a sound mild steel for structural work of all kinds, and until comparatively recently the employment of a high tensile steel for this purpose has been regarded with the gravest suspicion in this country. But the need for greater economy in the design of large structures has acted as a special incentive to manufacturers to produce other materials. Some of these new materials have, in the last two years, been entrusted to the N.P.L. for thorough investigation of their mechanical properties. On considering the programme of tests to be adopted, it was concluded that the usual tests—as usually laid down in specifications—were not adequate to reveal data concerning some aspects of the general problem on which engineers would require assurance; accordingly, a related series of special tests was devised and it is now our practice to apply these to this class of material. A description of these tests, together with the reasons for their adoption, should be of general interest; in addition, the authors are permitted, through the courtesy of the firm for whom the tests were made, to illustrate the article by the inclusion of a complete set of recent test data.

For structural purposes, the static tensile properties are, of course, of primary importance. Since the failure of struts, in practice, is determined by the yield point, a high value of the yield stress is essential. But the form of the stress-strain curve immediately after the first yield has occurred is at least of equal importance, for engineering structures and machines impose *strains* rather than *stresses* on their components. Assume a strain—probably local in extent—has been imposed and yielding occurs; if a further permanent strain is applied, the resulting *stress* induced in the material depends entirely on the form of the stress-strain relation. It is this fact that makes the drop of stress at yield and marked extension at the lower yield point such a valuable property of mild steel. For this reason, in addition to the usual form of complete tensile test, autographic diagrams to fracture are also taken, using a Dalby recorder. Also, other tensile specimens are subjected to a few successive strains exceeding the initial yield strain, and autographic records are taken of these load-strain relations at the lower yield point. Then, as structural shapes are intentionally and accidentally deformed, cold bend tests of the usual form are included in the testing programme. In a riveted structure increased economy will result if, in conjunction with high tensile plate, rivets of the same material are also employed; the usual forms of cold bending and hot flattening tests are carried out on sample rivets and, in addition, tensile tests are made on specimens machined from formed (but not driven) rivets. To determine the resistance of the material to sudden shock applied in the neighbourhood of a discontinuity of section, notched bar impact tests are made, using the B.S. three notch cantilever type of test piece (10mm.×10mm.).

The above tests provide comprehensive data concerning the static tensile properties, ductility under bending, resistance to shock and suitability for riveting purposes.

The remaining tests were specially designed to afford information which, while not provided by the tests in common use, is of considerable value in meeting special cases of stressing which might arise in service.

In the first place, the extent to which the intrinsic properties of the material may be modified by the condition of the surface as it emerges from the rolling mill is of obvious importance; this effect

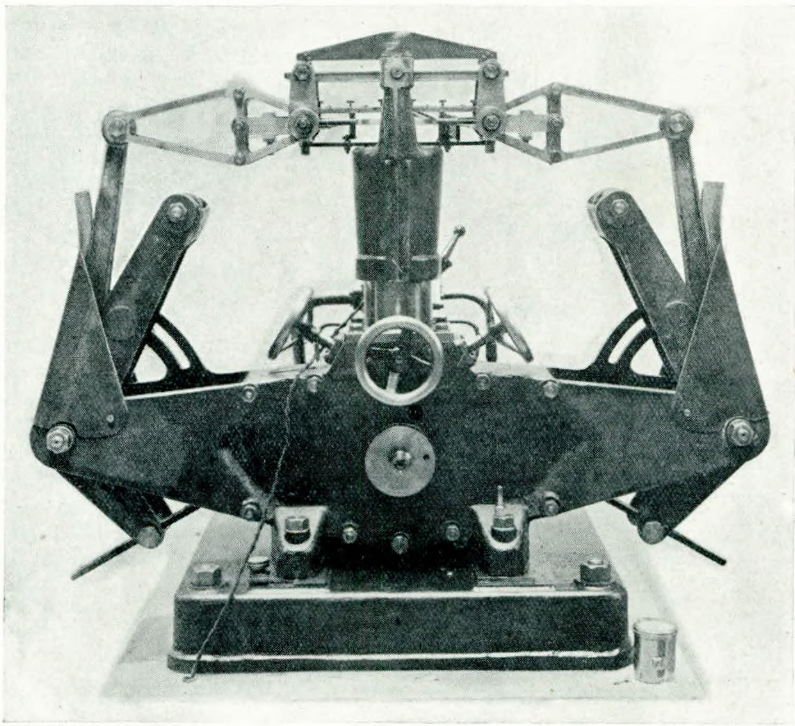


FIG. 3.—Plane bending fatigue machine for testing plates.

is known not to be marked in structural mild steel, but may be more important in steels of other composition. Information is also required concerning the effect of stress concentrations due to rivet holes, changes of section, etc.; statements have often appeared in technical literature that low alloy steels, even those possessing considerable ductility, are particularly sensitive to such stress concentrations. Static tensile or bending tests to destruction are quite useless in showing up the deterioration due to surface effects or stress concentrations, and fatigue stresses only can be relied on in this direction. It may be true that the failure of large structural members by fatigue is a comparatively rare event, but abnormal local vibrations are commonly imposed in practice and no material possessing extremely poor fatigue resisting properties could safely be considered for structural design.

Three series of fatigue tests are, therefore, carried out. In each series the fatigue limit under repeated bending stresses (0 to a maximum) is determined; the specimens are machined in the form of rectangular plates and tested in the plate bending machine illustrated in Fig. 3. One series is made on plates in the condition as rolled, a second on plates from which the rolling surface is removed by machining and polishing, a third on plates in the condition as rolled but containing five drilled holes of $\frac{5}{8}$in. diameter and $1\frac{1}{8}$in. pitch; these tests reveal the deterioration due to the rolled surface, also to the rolled surface plus rivet holes, as compared with the intrinsic fatigue properties. For purposes of general information and comparison with other materials, the Wöhler fatigue limit under reversed bending stresses is also determined (*a*) on polished specimens (0·275in. diam.) and (*b*) on polished specimens containing two circumferential notches, 1/9mm. deep and 1/9mm. root radius; these tests are made in a special two-point loading fatigue machine designed by one of the present writers (H. J. G.) and illustrated elsewhere.*

The complete scheme of tests can thus be summarised as follows:—

(1) Tensile Tests in accordance with B.S.S. No. 15-1930.
(2) Determination of Tensile Limit of Proportionality and Yield Point.
(3) Bend Tests in accordance with B.S.S. No. 15-1930.
(4) Rivet Tests in accordance with B.S.S. No. 15-1930; also Tensile Tests on specimens machined from the rivets.
(5) Notched-bar Impact (Izod) Tests.
(6) Determination of complete tensile load-elongation curve using a Dalby Autographic Recorder.
(7) Examination of the effect of repeated tensile over-straining using a Dalby Recorder.
(8) Determination of limiting range of repeated plane bending stresses using:—
    (*a*) rectangular plates with original rolled surface;
    (*b*) rectangular plates with machined and polished surface;

*Gough: "Fatigue of Metals" (book). E. Benn, Fig. 15, p. 28.

TABLE I.

MECHANICAL TEST DATA RELATING TO A HIGH TENSILE STEEL AND A MILD STEEL.
(All stresses expressed in tons/inch²).

	Material. Chromador steel. (Column A).		Mild steel to B.S.S. No. 15, 1930. (Column B).		Ratio. Column A. / Column B.
Ultimate tensile stress ...	37·5		28·5		1·32
Elongation on 8in. per cent. ...	23		27		0·85
Reduction of area, per cent. ...	53		46		1·15
Tensile limit of proportionality ...	10		6·5		1·54
0·005 per cent. proof stress ...	23		12		1·92
Upper yield stress ...	26		18		1·45
Lower yield stress ...	24		17		1·41
Extension at yield, per cent. ...	1·4		1·8		0·78
Young's modulus (E) ...	13,300		12,800		1·04
Tensile overstraining experiments ...	very satisfactory		very satisfactory		
Yield stress of rivet material ...	19·5		16·4		1·19
Ultimate tensile stress of rivet material ...	32·3		27·2		1·19
Cold bend test on plate to B.S.S. No. 15, 1930 ...	complied		complied		
Manufactured rivet tests to B.S.S. No. 15, 1930 (cold bend and rivet head flattening tests) ...	complied		complied		
Notched bar impact value: ft./lb. ...	55		51		1·08
Plane bending fatigue limits:—		Ratio		Ratio	
(*a*) on polished specimens ...	0 to 30	1·00	0 to 28	1·00	1·07
(*b*) on specimens as rolled ...	0 to 20·5	0·68	0 to 19·5	0·70	1·05
(*c*) on specimens as rolled and containing circular holes ...	0 to 17	0·57	0 to 15	0·54	1·13
Rotating bar fatigue limits:—		Ratio		Ratio	
(*a*) normal specimens ...	±18·5	1·00	±14	1·00	1·32
(*b*) grooved specimens ...	±11·7	0·63	±8	0·57	1·46

(*c*) rectangular plates with original rolled surface and containing drilled holes.

(9) Determination of limiting range of reversed bending stresses (rotating bar machine) using:—

(*a*) polished specimens;

(*b*) polished specimens containing small semi-circular grooves.

It is our practice to make these tests on the high tensile steel under investigation, also an exactly similar set on a standard mild steel, for purposes of comparison.* An investigation of this type has been made on "Chromador" steel, on behalf of Messrs. Dorman, Long & Co., Ltd., who have kindly given the authors permission to include the results of the tests in the present paper. A summary of these average results is given in Table 1.

Fig. 4 shows the typical autographic records of the tensile nominal stress-strain relations of the two materials, and the records of the tensile overstraining experiments. All the static tests reveal the excellent ductility of the Chromador steel, while the results of the impact tests exhibit good shock resisting properties. Especially interesting and important features of the fatigue results lie in the disclosure that fatigue resistance of the high tensile steel is not affected either by the condition of the rolled surface or by stress concentrations, or by a combination of these two, to a greater degree than the mild steel.

For earlier reference to this interesting subject, attention may be drawn to valuable papers† by Roberts and Haigh.

Diagrams Showing Complete Tensile Curves and Results of Overstrain Tests.

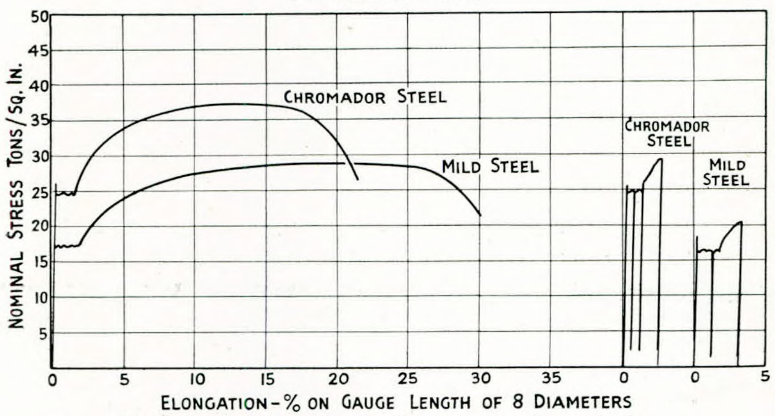


Fig. 4.—Autographic tensile stress-strain records.

III. Lubrication.

Although lubrication is a subject of great interest to the marine engineer, reference in the present paper to the testing of lubricants would hardly be justified were it not that the inadequacy of existing theory to meet modern practical requirements renders necessary much further experimental investigation, employing somewhat complicated testing methods. To the engineers' question "What is oiliness?" no real answer can yet be given, for the classical theory of Osborne Reynolds, based on hydrodynamical laws, does not enable the engineer to choose from a series of oils of known physical properties the most suitable for his particular use in service. For example, given the dimensions, speed of revolution, relative attitude of a journal and its bearing, also the viscosity of the lubricant, both the frictional resistance and the pressure distribution over the bearing should be directly calculable; while the latter result is, in fact, closely obtained,* the former is not. This partial failure is due to the fact that whereas, in the theory of a completely flooded bearing, the viscosity of the oil is the factor of primary importance, while the materials of which the journal and bearing are composed do not enter into the problem, experience has shown that "oiliness" cannot be defined in terms of viscosity alone, while the choice of the combination of oil and material is of the greatest importance. Hardy has shown that when the film is very thin and the pressure very great—conditions often encountered in engineering practice—a state called "boundary lubrication" is achieved, when the friction coefficient is much greater in amount and obeys entirely different laws from those predicted by hydrodynamical theory. The molecules of the lubricant appear to form a "physico-chemical" union with the metallic surface, producing a friction surface which may be regarded as a combination of the lubricant and metal. For such reasons, considerable attention has been and is being devoted to the experimental study of lubrication, which not only possesses great scientific interest but can afford reliable data relating to service problems.

Fig. 5 shows the Daimler-Lanchester worm-gear testing machine installed at the Laboratory, which has a capacity of 150 h.p. at 1,750 r.p.m.; in this machine the efficiency of worm gearing can be determined to an accuracy of ±1/5 of 1 per cent. Experiments made in this machine, also related experiments, have established clearly that under these conditions of high pressure no relation exists between the viscosity of an oil and its lubricating properties. The valuable fact was established that with the standard worm-gear fitted to this machine a constant efficiency value is obtained for any given set of conditions of oil, temperature, load and speed.

*For *specification* as against *comparative* purposes, the results on a high tensile steel are examined with respect to the recently issued B.S. Specification No. 548-1934 (High Tensile Structural Steel for Bridges, etc., and General Building Construction).

†Roberts, G.: "The Structural Engineer", Vol. 12, July, 1934. Haigh, B. P.: "Engineering", Vol. 138, 28th Dec., 1934.

*See "Friction", Stanton: Longmans, Green & Co., 1923.

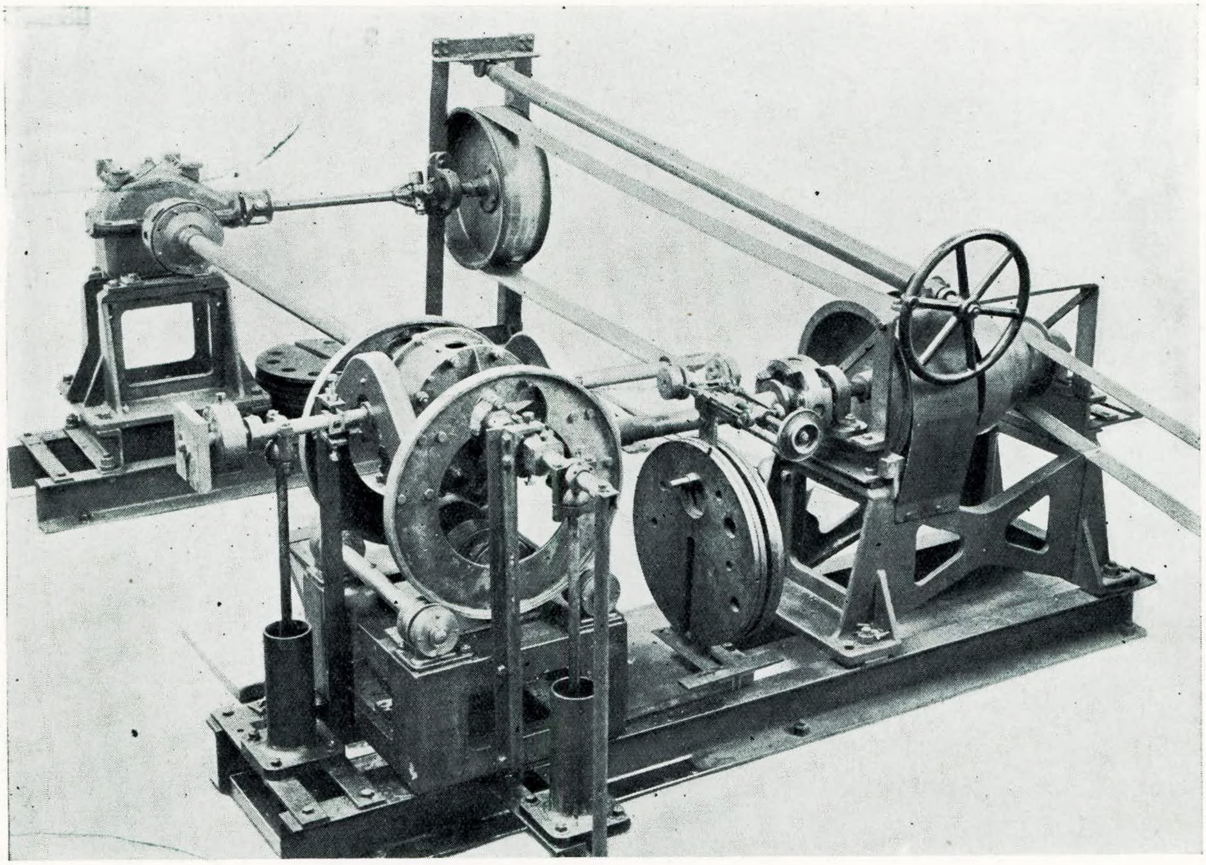


FIG. 5.—Daimler-Lanchester worm gear testing machine.

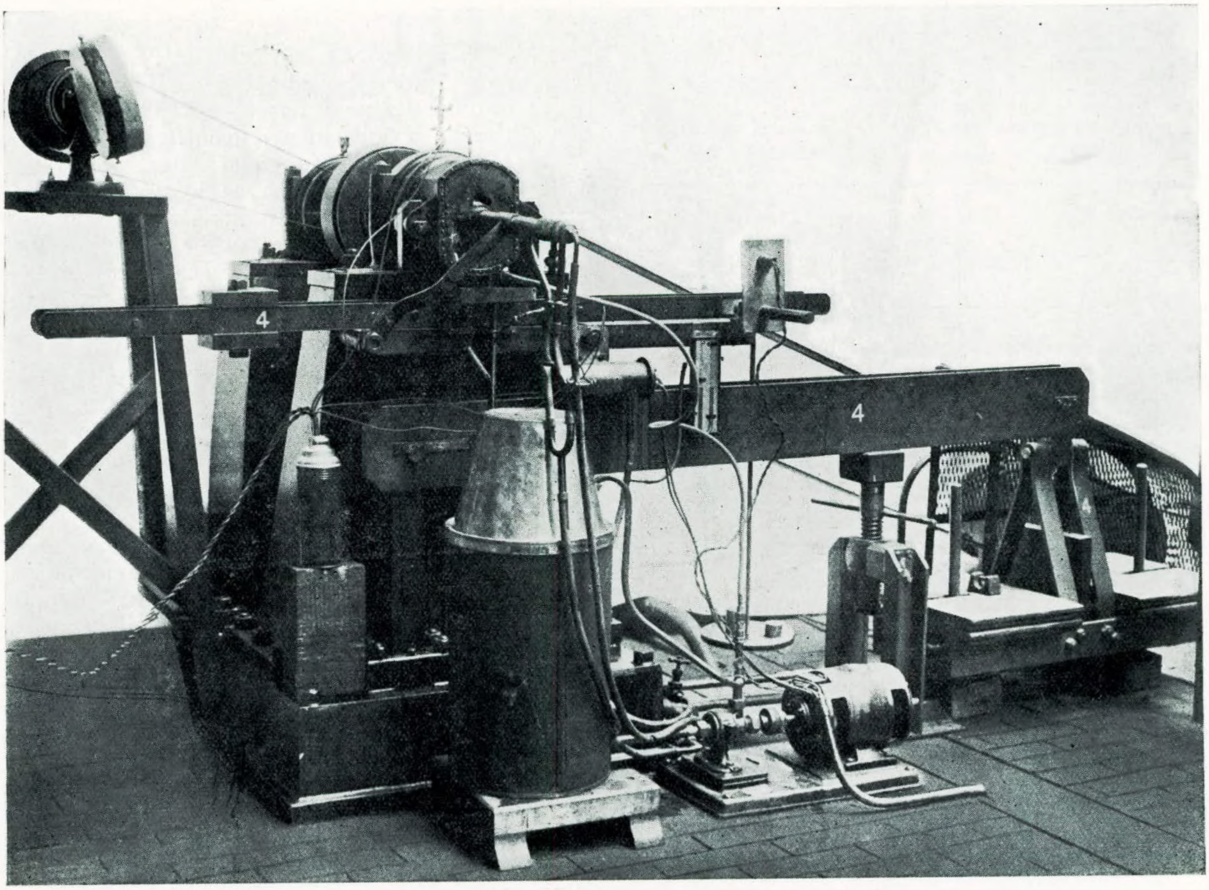


FIG. 6.—Journal friction testing machine.

Hence the machine can be used either to determine the relative efficiencies of various gears using known oils, or the lubricating properties of various oils can be compared using one gear equipment. This machine thus forms a valuable testing equipment available for industry, for whom much work has been undertaken.

Fig. 6 shows the journal friction testing machine developed at the N.P.L., usually employed to test complete bushes 2in. in diameter and 2¼in. long on a steel journal. The operating speed is variable up to 2,000 r.p.m. and the maximum working load is 13,500lb., equivalent to a pressure of 3,000lb. per sq. in. on the projected area. Oil is fed to the underside of the bush by a pump; the oil can be oxidised by blowing with hot air if required. The bearing can be tested at the temperature which it normally assumes under running conditions, or can be heated by means of a special gas burner applied to the inside of the hollow journal. The friction of the bearing is measured with very great accuracy; the running temperature of the oil film is estimated by means of a thermo-junction placed in a hole drilled partly through the wall of the bush. Apart from various investigations of purely scientific interest, the battery of these machines is employed for two main types of test:—(1) using one or several oils of known lubricating properties in a standard journal and bush, comparative tests are made on various bearing metals; this method is extremely useful in picking out the most promising of a series of new compositions, for example, or comparing any new metal

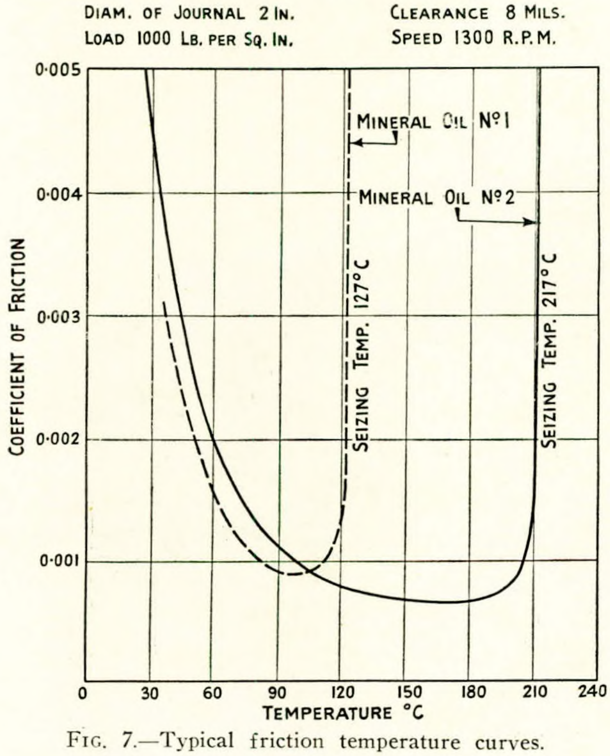


FIG. 7.—Typical friction temperature curves.

or form of bearing with existing practice; (2) using the standard bush and journal, to investigate the lubricating properties of a particular oil or oils. In general, friction-temperature and/or friction-pressure curves are determined. Fig. 7 shows typical friction-temperature curves, which show clearly the essential characteristics of journal friction. The friction at first falls as the temperature rises due to the reduction in viscosity of the oil. A minimum friction is then reached and further increase in temperature causes an increase in the friction. The explanation of this rise in friction has not yet been discovered; it may be that the true fluid friction has been replaced in part by some other form of friction but the condition is stable, as a reduction in temperature produces a reversion to the earlier conditions; finally "seizing" occurs. The last portion probably indicates an approach to boundary friction, but the thickness of the oil film is many times greater than that required for true boundary conditions.

In general, it may be said that an oil suitable for any particular purpose should, as far as possible, fulfil the following conditions:—(1) the seizing temperature should be well above the working temperature, (2) the friction at the working temperature should be low, (3) the friction at air temperature should be low to ensure ease of starting from cold, and (4) the minimum friction should be maintained over a large temperature range to ensure safety if accidental rise of temperature takes place; the significance of these aspects is exhibited in Fig. 7.

The difficulty now arises—how can the results of tests made on oils in a journal testing machine, or any other apparatus for that matter, be correlated with their actual performance in an engine, for example, where other conditions also enter into the problem? This very important aspect has resulted in the development at the N.P.L., during the last three years, of an interesting combined method of test, in which friction tests, also engine tests under service conditions, are made on the same oils and the results compared. The precise details of the tests are designed, of course, to suit the special requirements of the client for whom the investigation is undertaken; a general description of a typical series of experiments will reveal the essential principles adopted.

Information was required of the relative merits under strictly controlled and known conditions of a series of lubricating oils for use in automobile engines. In the tests made on each oil, using the journal friction machine, the bush and journal were first accurately measured. Starting from cold, observations were made of the friction torque and temperature as the bearing warmed up. Artificial heating was then applied to produce a steady rate of rise of temperature, which was increased until minimum friction was recorded, which temperature was then maintained constant for several hours; later, the temperature was again increased until the seizing temperature was attained. Similar runs were made until a total of 50 hours' running had been completed on each oil; the test was then discontinued and measurements made to determine the wear of the journal and bush. The viscosity of the oil was determined before and after the test.

The engine bench tests were made using two 10 h.p., 4 cylinder engines, also, a 16 h.p., 6 cylinder engine; Fig. 8 shows the testing lay-out. The engines were first dismantled and accurate measurements made, also photographs taken, of the important parts liable to wear. The two smaller engines were each run continuously for 100 hours while developing 10 b.h.p. at 2,640 r.p.m. corresponding to a road performance of 4,000 miles at 40 m.p.h. After test, the engines were dismantled and selected parts measured and photographed, and the weights of carbon and other deposit on valves and pistons were obtained. Generally similar tests were made on the large engine, which was submitted to a 300 hour test, developing 26 b.h.p. at 3,000 r.p.m., equivalent to a road performance of 15,000 miles at 50 m.p.h. Cold starting tests were also made on the oils, using the large engine which was enclosed in a refrigerating box at a temperature of 0° C.; the starting torque and running torques at various speeds were determined by motoring the engine.

The above general method of test, which gives new data* not otherwise available, has been described in some detail because it provides a most valuable link between laboratory and service performance of lubricants. Also, the friction coefficient is not the only criterion by which the suitability of a lubricant can be decided; carbon deposit on pistons, rings and valves, tendency to "gum", "sludging", and general deterioration in the engine are all aspects of great importance. The described test method is proving very useful by giving valuable information on all these aspects.

IV. Lifting Gear Components.

What may be generally classed as "lifting operations"—the loading and unloading of ships and craft, and of material in building and constructional work, haulage in mines and quarries, movement of machinery and prime movers in workshops, for assembly, inspection or repair purposes, etc.—are liable to involve considerable risk of injury to the personnel engaged and the valuable products concerned. Many interesting problems arise in connection with the lifting ropes, chains and their terminal fittings; the N.P.L. has been and is still engaged in investigations relating to these. Some of these problems are of especial interest in connection with the testing aspect—the subject of the present paper—and merit brief mention herein.

One of the earlier researches was concerned with the causes of the brittle failure in service of wrought iron chains and cables which had, hitherto, presented a baffling problem. It was clearly shown* that failure was due to a "skin" effect, caused by

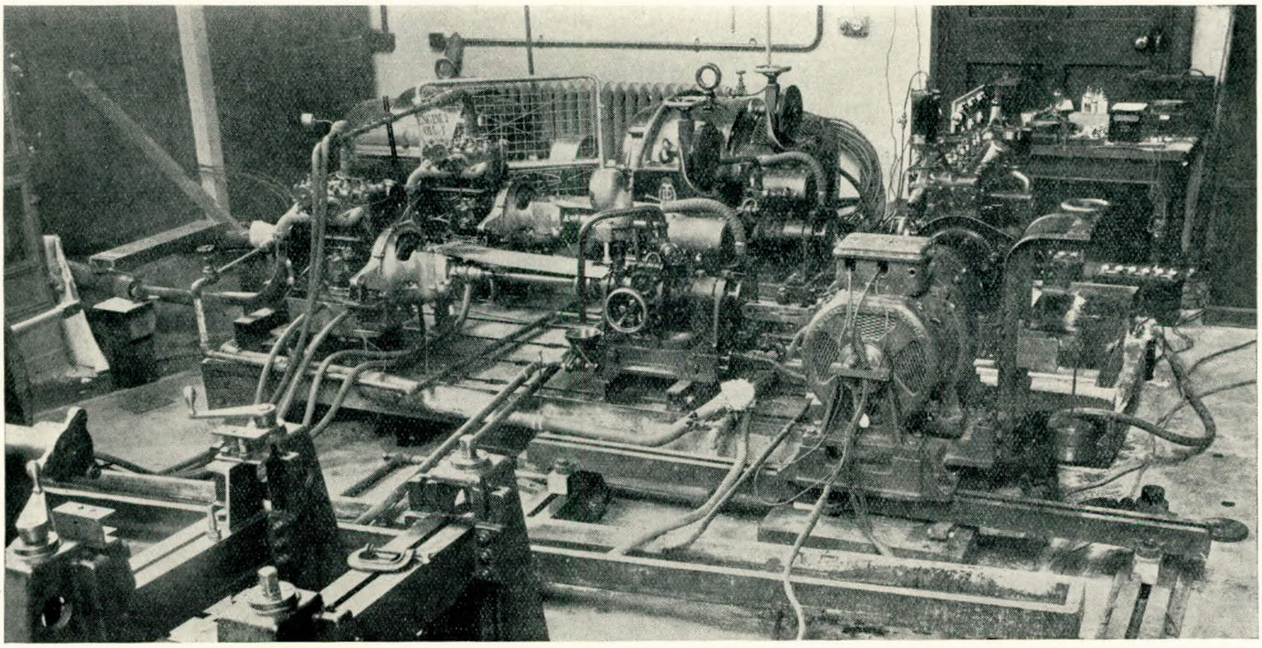


Fig. 8.—Engine bench tests on lubricants.

*Note.—Original N.P.L. reports are, of course, confidential, but the firms for whom such tests have been made have, in several cases, prepared pamphlets on the investigations: any readers especially interested in the subject can be put into touch with these firms.

*Gough and Murphy: Proc. Inst. Mech. Engrs., 1928, p. 293.

surface hardening resulting from impacts endured in inter-link action, hammering on ground, rattling through hawse-pipes, battering on chain wheels, cleaning in rumbling machines, etc.; it was astonishing to find that the responsible surface layer was extremely thin, thicknesses of a few thousandths of an inch only in many cases. The value of a shock test—tensile impact being especially suitable—in the testing of suspected cable, emerged clearly; this form of test had not hitherto been employed either in service or the laboratory. The same method was found to possess great value in an investigation† which was made to assess the liability of chain and cable to behave in a brittle manner at moderately low temperatures. It was established that carefully prepared specimens of wrought iron do *not* develop temperature brittleness even at −78° C. On the other hand, both new and worn chains may behave in an extremely brittle manner even at ordinary frost temperatures as encountered in this country; failure occurs at irregularities of section or where surface damage has occurred owing to misuse in service, the responsible influence being "temperature notched brittleness" to which wrought iron is susceptible. Again, brittle failures in service of wrought iron components often reveal a curious laminated appearance, the fracture consisting of alternate layers of ductile and brittle material. It was established* that the cause of the defective layers—whose brittleness is due to a high phosphorus and silicon content—can be traced back to defective puddling; subsequent heat-treatment cannot remedy the defect. This problem was solved when it was possible to make tensile and impact tests on small specimens cut from defective layers.

An extraordinarily interesting aspect of testing in relation to design will now be referred to. The manufacture of chains and terminal fittings for lifting gear is of great antiquity and a very wide diversity of types and designs are in current use. The forms and dimensions of these components in relation to the loads they are required to bear have been decided largely from accumulated experience acquired before scientific methods had been, or indeed could be, attempted; although the majority of such components in use by responsible firms may be regarded as representing *safe* practice, many are far from being economical, while some existing components are definitely unsafe. A B.S.I. technical committee, ME/12, in 1929, entered on the difficult and extensive task of standardizing the more important lifting components, and there are now available specifications for Crane Chain (B.S.S. No. 394), Pitched Chain (B.S.S. No. 465), Electrically-welded Steel Chain (B.S.S. No. 590), Hooks for General Engineering Purposes (B.S.S. No 482), Hooks of the "C" Type (B.S.S. No. 591), Steel Eye-Bolts with Collars (B.S.S. No. 529), while a Specification dealing with Rings, Alternative Flat Links, Egg Links, Intermediate Links and Chain Slings has been prepared and will shortly be issued. In these specifications, the form and dimensions of each type of component are specified in addition to the usual requirements for material, heat-treatment, testing, etc. The strength and design aspects of this work were undertaken at the N.P.L., and a comprehensive account, in which special attention is devoted to the mathematical methods employed, has recently been published.*

Now, the majority of lifting gear components consist essentially of curved beams and the radii of curvature of portions of many of these are relatively small, also the shape or design of many are such that the induced forces and bending moments cannot be derived directly from a statement of the applied loading, and design from first principles—as actually practised—involves the use of mathematical methods of some complexity. These necessarily imply design on the basic assumption that *elastic* conditions obtain throughout. Assurance is needed on two main points:—(1) Is the calculated stress distribution realised and (2) What is the factor of safety on the working stress adopted? Experimental demonstration is obviously the only reliable method to be adopted, but one soon finds that the usual methods of test are useless and may be actually misleading. For example, consider a wrought iron hook, of the "C" or Liverpool type shown in Fig. 9. The basis of design is a maximum induced stress of 9 tons/inch^2 at the working load; the tensile strength of the material of which the hook is composed is about 24 tons/inch^2. Static tensile tests to destruction on sample hooks showed that these failed at loads between $7\frac{1}{2}$ and 8 times the rated working load at the hook. A hasty consideration of these results might lead to the conclusion (*a*) that the mathematical basis of design is incorrect as a material of 24 tons/inch^2 ultimate stress cannot withstand an estimated stress of $8 \times 9 = 72$ tons/inch^2 and (*b*) that the real factor of safety is between 7 and 8; these conclusions are neither correct nor applicable to practice. For, under service conditions, we require the hook to retain its original shape and are concerned only with the strength of the hook in that shape. Hence the tensile test method is not relevant. Now, the only test to destruction in which the shape of the test component remains practically unaltered is a fatigue test, and such tests† were made as affording the most reliable information‡ regarding the basic principles of the

†Gough and Murphy: Proc. Inst. Mech. Engrs., 1930, p. 1159.

*Gough and Murphy: Jour. Iron & Steel Inst., 1931, Vol. 123, p. 285.

*Gough, Cox and Sopwith: Proc. Inst. Mech. Engrs., Vol. 128, Dec., 1934, pp. 253/360.

†Note.—Static tensile and impact tests were also made on complete components, however, to afford other and valuable information.

‡For a very recent application *see* "Fatigue Tests on a 'Safety' Type Hook", Gough and Sopwith, Engineering, 26th July, 1935.

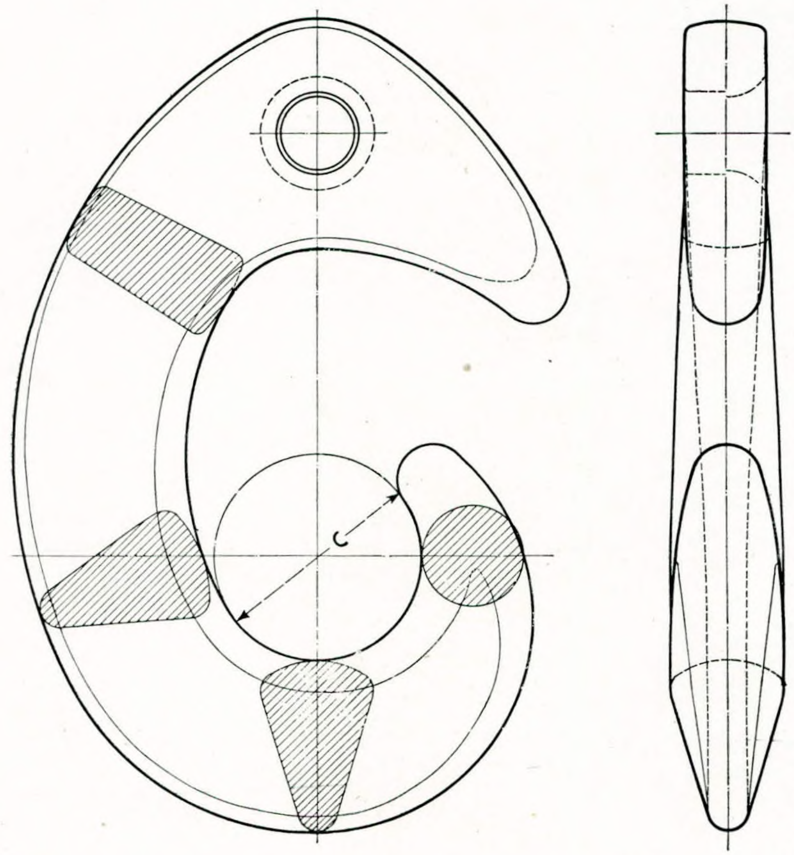


FIG. 9.—B.S.I. Standard "C" Hook.

design. Under repeated tensile loading, the limiting safe load of the complete hooks referred to emerged at a value equal to twice the rated safe working load; the fractures occurred at the calculated position of the maximum induced stress, while the actual value of the stress (18·4 tons/inch^2) at the fatigue limit was in extremely good agreement with the known properties of wrought iron, thus affording strong evidence that the calculated stress distribution, both in nature and amount, could be relied on with confidence. *In short, the fatigue test has assumed a new and important rôle as affording a valuable confirmation of the correctness of a calculated complex stress distribution for which any other mechanical test would have been quite useless and, in fact, misleading.*

The method has been applied, not only to hooks, but to chain links, eyebolts, etc. The most remarkable case occurred in the case of the ring of the eyebolt. The stress-distribution in the latter is very complex; theory showed that, under vertical loading, the maximum stresses—very nearly equal in amount, occur at the extrados under the load, also at the intrados at radial positions inclined at 110° and 250° to the line of loading. Fig. 10 shows a sketch of such an eyebolt; under fatigue stressing, cracks appeared, simultaneously, exactly at the predicted positions; this agreement with theory is very striking.

The above aspect of testing has been discussed in some detail as it clears up several misapprehensions regarding the real strength of lifting gear components; also, the method will, no doubt, have many valuable applications in other engineering problems.

Lastly, a word concerning the future of lifting chain. There is no doubt whatever that chain will continue to be extensively used for lifting and other purposes; for many purposes its chief rival—wire rope—possesses grave disadvantages. Up to the present, chain has mainly been made of wrought iron prepared by a hand-forging process. Future developments, however, appear to lie in other directions. With regard to large studded cables for anchors, moorings and similar purposes excellent results are now being obtained by the electrically-heated pressure welded process developed in this country by Messrs. Samuel Taylor & Sons, Ltd., Brierley Hill, Staffs. An equally attractive future field of development appears to lie in the electrically-welded short link steel chain. At present, this industry has been

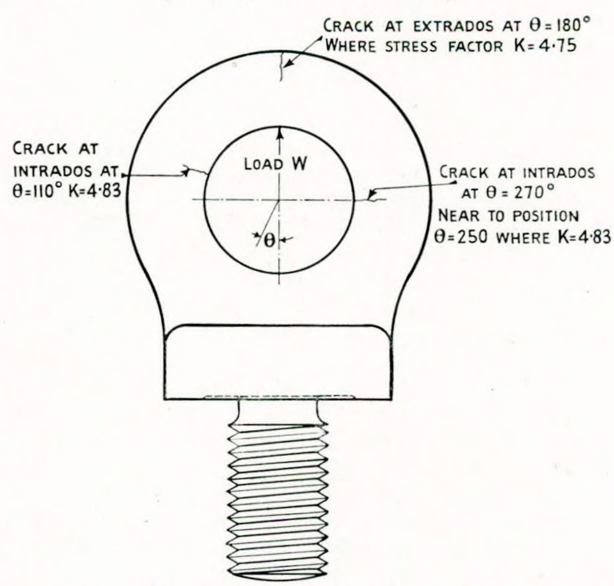


FIG. 10.—Sketch showing positions of cracks in ⅞in. eyebolt after fatigue test.

neglected in this country, although considerable success is being obtained in America and certain Continental countries. An extensive series of tests is in progress at the N.P.L. on representative samples of electrically welded chains obtained from abroad, from some of which excellent results are being obtained; others are decidedly unsatisfactory. The experiences of others on this development would be very welcome.

V. Contact Corrosion

When two metal surfaces are in contact and subjected to vibration, an accelerated form of corrosion is liable to occur. This is a practical problem, examples of which are encountered in practically every branch of engineering, yet, curiously, it has hitherto received little special study. Components of machines that are firmly assembled, apparently beyond the possibility of any relative movement and therefore of ordinary wear, are commonly found to have their mating surfaces corroded. In the case of steel, the surfaces are found to have become cemented together by relatively large quantities of oxide, are often badly pitted, and often damaged to such an extent that reassembly is impossible and replacement becomes essential. Serious trouble due to this cause has been brought to the attention of the N.P.L. in such cases as seatings of shafts on which couplings or gear pinions have been pressed, in the bosses of airscrews, etc. The "seizing" of nuts, the pitting of ball and roller bearings, and the "staining" of micrometer anvils are everyday examples familiar to all. It is a peculiar feature of the phenomenon that the most highly finished surfaces and the best types of fit appear to be most susceptible to this trouble; it is not corrosion of the usual type, as the oxide—or "cocoa" as it is often termed—is produced copiously on surfaces which are totally immersed in oil. Very little literature exists on the subject. An N.P.L. experimental investigation by Tomlinson,* using spherical and plane surfaces in contact, was made in 1927, while more recent work, by Stott and Shotter,† on the wear of pivots and jewels has an indirect bearing on the subject. Tomlinson established clearly that "cocoa" was produced by relative motion—rotating or sliding—between loaded steel surfaces and, also, even between glass spheres and steel surfaces. Relative motion is an essential condition, for a steel ball bearing merely placed on hard steel plate, loaded normally to produce a contact pressure of about 160 tons per sq. inch for 40 hours, produced no visible effect, whereas a small relative movement repeated 100 times, but using a contact pressure of less than 2 tons per sq. inch, produced a considerable amount of brown debris. Pure rolling conditions do not usually produce this form of "rusting"; sliding or relative tangential motion is the ideal condition.

It was decided recently to resume the study of contact-corrosion under conditions more resembling those occurring in engineering practice, and research on these lines is now in progress at the N.P.L.; some results have already been obtained* which possess considerable interest.

The optimum condition for contact corrosion is when two surfaces are pressed together under a steady normal pressure and then subjected to repeated relative tangential stresses (or strains); it was decided to commence by a study of various steel surfaces under these conditions, and a special apparatus was designed and constructed. This apparatus consists essentially of three cylindrical rings arranged side by side on a central shaft, the rings being pressed together axially by means of a spring. The two outer rings are held rigidly, whilst the centre one is subjected to an alternating torque which has the effect of causing relative elastic strains or relative actual cyclic movements (slip) between the annular surfaces of the rings which are in contact. The apparatus is contained in a metal box attached to an electro-magnetic alternating stress machine, from which the alternating torque is obtained; the speed of operation is about 2,000 cycles per minute. The object of the box is to enable later experiments to be made under ambient conditions other than atmospheric.

Experiments have been made with three types of steel, viz., hardened and tempered tool steel, "stainless" steel and mild steel and with combinations of these materials. Tests have also been made with a soft metal in contact with the hardened steel. In all cases, the surfaces were used in both the clean and oiled conditions. The pressure between the contact surfaces was 6,000 and 4,000lb. per sq. in. for the dry and oiled surfaces respectively. A measuring device of very great accuracy was employed to record the relative motion occurring between the contacting surfaces.

The most important result so far obtained is the definite establishment of the fact that there is a marked difference in the rate of corrosion according to whether the surfaces are subjected to slight positive relative motion or not. Whenever a minute amount of slip is permitted, even if it is only a few millionths of an inch, rapid corrosion of the surfaces with the formation of oxide debris always results, whether they are clean or oiled. Soft brass is found to cause pitting and oxidation of a hardened steel surface; stainless steel also shows a strong tendency to seize and, in some cases, marked oxide debris has been observed between two specimens of this material. When the applied tangential force is below the value necessary to cause definite slip no perceptible corrosion takes place. The presence or absence of slip appears to be a definite criterion as to whether contact-

*Proc. Roy. Soc. A., Vol. 115, 1927.

†Journal Inst. Elec. Engrs. (*a*) Vol. 69, 1931, (*b*) Vol. 75, 1934.

*N.P.L. Report for 1934.

corrosion will occur. Further experiments are in hand using another type of apparatus in which the relative movements of the contacting surfaces can be more closely controlled and measured. Corrosion has been found to take place with very slight relative movements of the order of 10^{-7}in. Movements of this amount can hardly be called slip; they are of the order of "elastic" strains, and cyclic movements of this order might conceivably take place in actual practice between surfaces which are apparently rigidly connected, as in the examples quoted above. This work, which is of great interest, is being pursued; it is throwing light on a very puzzling and important practical problem.

VI. Welded Joints.

The extent to which welding construction is employed by nearly every branch of industry throughout the world and the great part it is destined to play in the future are made abundantly clear by a study of the 150 valuable papers contributed to the Symposium* on the Welding of Iron and Steel held in London during May of the present year. The importance of the testing of welded joints was such that one group (Group 4) of papers dealt principally with this aspect, while many other papers contained many references to the same problem. For the devisement of suitable tests on welded joints, the manner of carrying out these tests and a correct interpretation of the results together with a critical assessment of the dependence to be placed on the test results all continue to receive careful attention and thought. A brief reference may here be made to the present position of three general aspects of testing of welded joints as gathered from a study of the papers submitted to the Symposium.

It is general practice to carry out mechanical tests to determine whether the electrode or filler rod is suitable for its purpose. These tests include all-weld-metal tensile and bend tests, ductility, tensile and bend tests on simple welded joints, fillet shear test, cruciform test, Charpy, Izod or tensile impact tests, also, in some cases, fatigue tests on all-metal specimens and on simple welded joints. Some doubts are expressed regarding the value of tests on all-deposited metal, also, on the fillet shear, cruciform and impact tests as such. It is clear that no uniformity at present obtains either in the test schemes adopted or in the forms of specimens used; useful work remains to be done in obtaining an agreed simple scheme of acceptance tests for electrodes or filler rods.

The quality of the rod being established, current practice then requires tests on the joint as used in service; by the majority of users these tests are made to investigate the correctness of the welding procedure, in relation to the weld metal, in producing a sound joint, rather than as a check on the operator. It is general practice to employ bend tests of various types, also tensile tests on butt welds and shear and tensile tests on fillet welds. Given approved electrodes, procedure and welding plant, efficient inspection at all stages of the work, together with occasional mechanical tests on sample joints, further static mechanical tests are then rendered unnecessary.

Abundant evidence was advanced of the attention that is being given to the fatigue aspect of welded joints; this is, of course, due to the powerful influence on the resistance to cyclic stresses caused by local stress concentrations produced by sudden changes of section, cavities and internal flaws, to which welded joints are inherently susceptible. The experimental values of the effective resistance of welded joints to repeated tensile stresses* recorded by various investigators is summarised in Table 2.

*Organised with the joint co-operation of 15 British technical societies which included the Institute of Marine Engineers; the proceedings of the Symposium will be published before the end of the present year.

*Probably the most important case of cyclic stresses in welded components for structures, pressure vessels, pressure pipe lines, etc.

TABLE 2.
RESULTS OF FATIGUE TESTS ON WELDED JOINTS.

Investigator.	Type of Joint.	Safe range under repeated tensile stresses. tons/in.²	Number of cycles on which fatigue strength was determined. millions.
Graf	V butt welds (good)	15	2
"	V butt welds (bad)	7¼	2
"	Side fillet welds (good)	7½ to 9	2
Haigh	V butt welds (bad)	9½	10 (about)
Hankins	X butt welds, covered electrode, machined ...	13½	20
"	X butt welds, covered electrode, not machined ...	8	20
"	X butt welds, bare electrode, machined	4½	20
"	X butt welds, bare electrode, not machined ...	6 (greater than)	20
"	V butt welds, bare electrode, machined	4	20
"	V butt welds, bare electrode, not machined ...	5 (about)	20
"	Transverse fillet welds, covered electrode ...	7	20
"	Transverse fillet welds, bare electrode	4	20
"	Longitudinal fillet welds, covered electrode ...	6	20
Rôs and Eichinger	V and X butt welds, electric and oxy-acetylene ...	7½ to 9	1
" " "	Longitudinal fillet welds, electric	3¾ to 4½	1
" " "	Transverse fillet welds, electric	4½ to 5	1

The seriousness of the problem will be realised in regarding the values given in the table in the light of a statement, made by a contributor to the Symposium, that alternating stresses of 7 tons/in.^{2} are quite common in ships' structures. It is necessary to record that this country is at a disadvantage, with respect to the Continent, in its ability to explore the fatigue weakness of existing full-sized welded joints and thus to devise new forms of joint, owing to lack of equipment of sufficient capacity. Several Continental laboratories possess fatigue machines of nearly 200 tons capacity, while those of about 50 tons capacity are quite common; the largest known type of machine in use in this country has a capacity of 7 tons only! This is a disadvantage which should be repaired without delay.

There exists a great need for a reliable non-destructive method of testing a welded joint. Many forms have been tried, involving X-rays, magnetic, electrical and acoustical methods. That the X-ray method is undoubtedly the best represents an agreed opinion, and it is clear that this method is being adopted in service to an increasing extent. Regarding the reliability of the X-ray method of testing, many are enthusiastic but others are more cautious. If defects in a weld are so minute that they cannot be detected by X-rays, they certainly cannot be detected by any other method; this is a fair summary of the present position. But great difficulties arise when complicated shapes are involved, also, in large structures or fabrications, the cost of X-ray examination brings in an economic aspect of the greatest importance.

When repairs to existing engineering works are effected by welding, the thermal stresses induced may be very serious. Valuable mechanical tests are reported on the amount of these stresses and their influence on the strength of repaired structures. In general, tensile stresses are called into play; the effect of repairing, by welding, a member in a state of compression may thus throw that member entirely out of active commission, imposing additional stresses on its neighbours. Considerable experimental evidence is advanced showing that, in the case of tension members, girders, repaired and strengthened by welding, little influence is exerted, in general, on the *stress* induced at failure, while the total *resistances* of the constructions had been considerably increased; it may not, however, follow that the fatigue resistance of these repaired structures is also unaffected by the presence of severe thermal stresses, and some experiments to investigate this aspect would be very valuable.

The above remarks may serve to draw attention to some of the interesting aspects discussed in the papers submitted to the Symposium; those interested are referred to the original papers and to the detailed reporters' summaries which cover each of the respective groups. At the N.P.L. an interesting investigation into the strength of welded joints, with non-destructive and mechanical methods of testing, primarily in connection with structures, is in progress; accounts of these will be found in two papers* submitted to the Symposium.

VII. Cracking of Boiler Plates.

Some discussion of the problem of the cracking of boiler plates is entirely revelant in a paper dealing with the testing of materials in view of the present very unsatisfactory state of knowledge regarding this important practical type of failure. For it is a sound attitude to adopt in investigating the cause of any type of service failure, to remain unsatisfied that the true cause has been definitely established until similar failures can be produced at will under accurately controlled laboratory conditions. One type of boiler failure commonly called "Caustic embrittlement" is definitely associated with intercrystalline cracking, i.e. the cracks in their general path follow the grain boundaries and do not run through the crystals—which is the usual course of fracture in ductile metals. That many failures of boilers in service occur by intercrystalline cracking there is no doubt; many examples have been sent to the N.P.L. for investigation and report. In spite of many attempts that have been made, it is extremely doubtful whether laboratory conditions have reproduced exactly the characteristics of these failures. Hence the present unsatisfactory position and the experimental attention that is being given to the problem in several laboratories, including the N.P.L.

In general, it may be said that failures of this type occur in boilers at positions where regions of localised stress exist, as in the riveted seam, usually under the rivet heads, or through the rivets at the junction of the plates, or in the plates between the rivets; they have been observed in plate material of excellent quality as well as in material of inferior grade. In such enclosed regions, the proportion of caustic present may, owing to evaporation, considerably exceed the average concentration of the feed water supply. It is now commonly agreed that this type of failure is a combined effect of high local stress and chemical attack; also, it is extremely likely that the required conditions are critically balanced. The literature of the subject is very voluminous and space forbids even a summary of the various investigations which have been made; brief reference will merely be made to some of the lines of atack now being pursued at the N.P.L.

A boiler shell may, in the first place, be regarded as a component subjected primarily to a steady static stress under conditions of high temperature and pressure in the presence of a corrosive agent. This aspect of the problem has received some experimental attention. In order to assess the effect

*(*a*) Gough: "The Welding Research Programme of the Steel Structures Research Committee of the Department of Scientific and Industrial Research".
(*b*) Hankins: "Fatigue Tests and Non-Destructive Tests on Welds".

of stress and temperature only, some specimens containing local stresses, concentrated at drilled holes and machined notches, were subjected to static tensile stresses, at a temperature of 300° C. for periods up to 5 years in duration. It was found* that although considerable local deformation occurred at the regions of stress concentration, no cracking took place, indicating that such localised stress, in the absence of a chemical accelerating agent, is insufficient to cause cracking of the intercrystalline type. Further prolonged static tests† have therefore been made inside a pressure vessel on specimens immersed in a strong solution of caustic soda held at a temperature sufficient to maintain a steam pressure of 300lb./in.^{2} When the applied stress was less than the ordinary yield point of the material, the specimens survived lengthy exposures (65 days) without failure. With a stress exceeding the yield point, fracture took place fairly quickly, but in no case was observed the intercrystalline type of cracking associated with caustic embrittlement; generally similar results were also obtained with notched specimens.

A second way of attacking the problem is to regard a boiler shell as a component subjected to fatigue stressing, consisting either of a combination of steady stress and small superimposed variations due to fluctuations in boiler pressure, or to larger and less frequent cycles of stress induced when the boiler is "let down". That boiler cracking is thus due to a "corrosion-fatigue" effect of this type was first suggested by McAdam;* the experiments he made were on small specimens only and were carried out at room temperature and cannot, therefore, be regarded as affording real evidence, although his suggestion was a most valuable one. This suggestion is now being explored at the N.P.L. under conditions approximating more closely to those of an actual boiler. A special testing machine, shown in Figs. 11 and 12, has been designed and constructed to apply repeated bending strains to specimens of boiler plate, or to complete riveted or welded joints, arrangement being made for the specimen to be tested either in air, or when immersed in boiling water or in boiling solutions of suitable salts, such as sodium hydroxide, etc. The machine applies a maximum cyclic load of 10 tons and operates at 35 cycles per minute; the specimens which are now undergoing test consist of samples of ¾in. boiler plate, 27in. long and up to 9in. in width, and double riveted butt-joints, with double cover straps, of ¾in. plate and up to 12in.

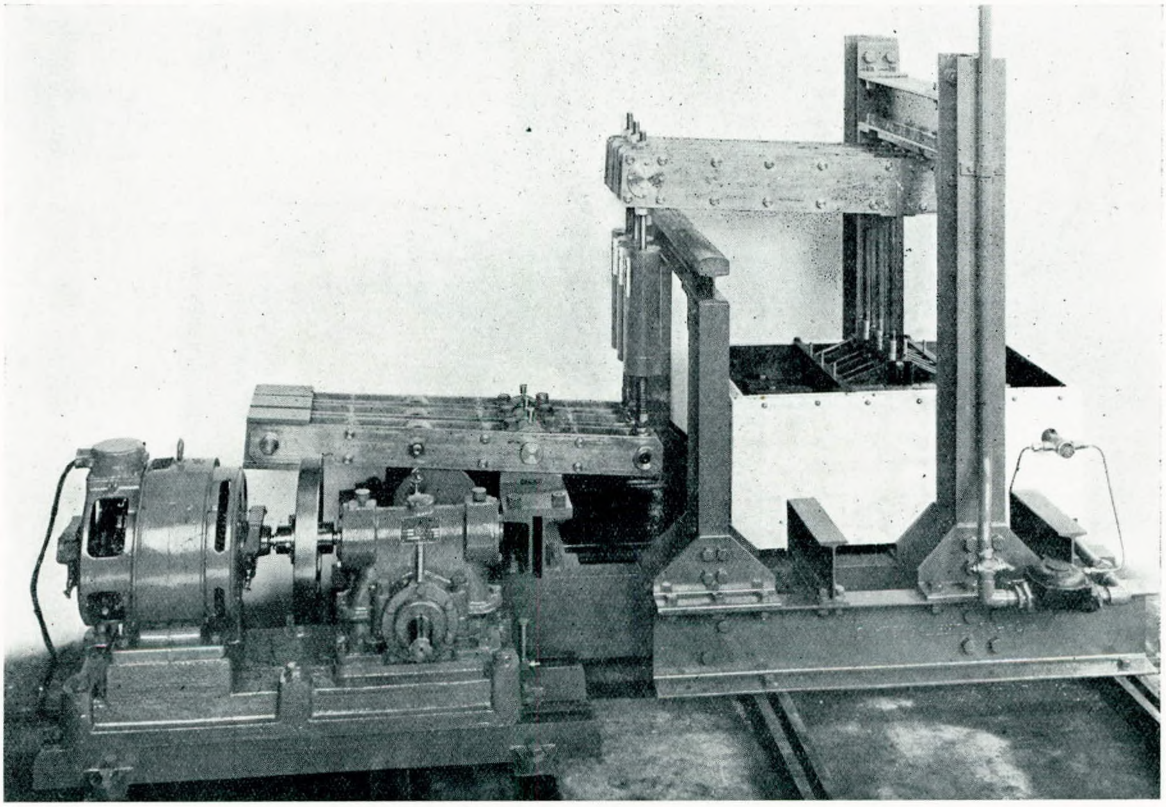


FIG. 11.—Machine for testing boiler plates and joints: general view.

*C. H. M. Jenkins: Jour. Iron & Steel Inst., Sept., 1935. (Advance copy).

†*See* 1934 N.P.L. Report, p. 178, for progress report.

*Proc. 3rd Inter. Cong. App. Mechanics, 1930.

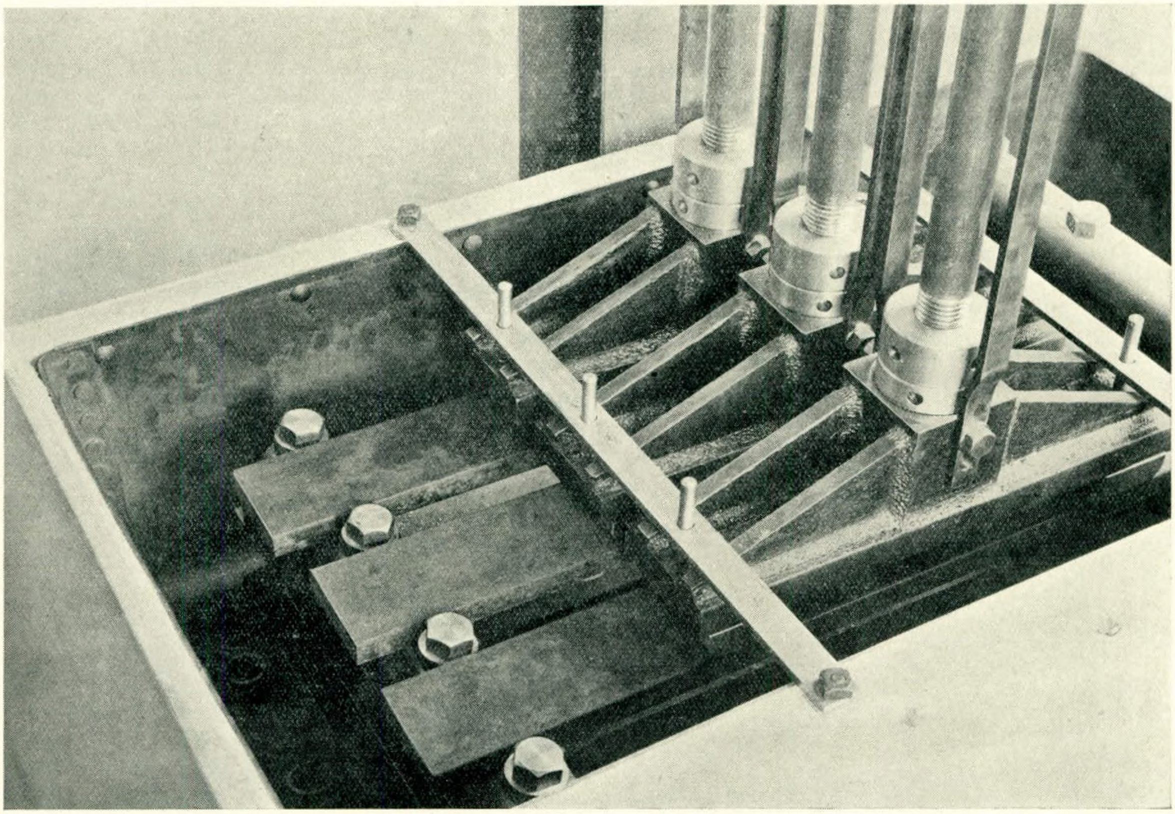


FIG. 12.—Machine for testing boiler plates and joints: loading arrangement.

in width. The boiling solution consists of 6,000 grains of NaOH per gallon of distilled water. The plate samples tested have fractured* by cracking and exhibit the irregular jagged visual appearance typical of failure by corrosion fatigue. Microscopical examination showed that, although in some places, the cracks followed grain boundaries, yet the general path was definitely transcrystalline; some preferential attack was observed in the vicinity of non-metallic inclusions. Four riveted joints only have yet been tested; a typical example is shown in Fig. 13. In each case, cracking occurred in the main plate, at a position close to the edge of the butt-strap. The general paths of these cracks were very similar, in general, to those causing the failure of the specimens of boiler plate. The tests are proceeding and as longer endurances to fracture occur, it may be that a nearer approach to the special service type of failure may be obtained.

At the present time, therefore, the experiments described above have failed to reproduce typical caustic embrittlement. The experiences of readers on this interesting boiler problem will be very helpful to, and greatly welcomed by, those engaged on this investigation. It may be pointed out, of course, that all boiler failures encountered in service are not of the "intercrystalline" type and the results described above have practical value, although the special objects of the experiments have not yet been realised.

*See 1934 N.P.L. Annual Report for progress report.

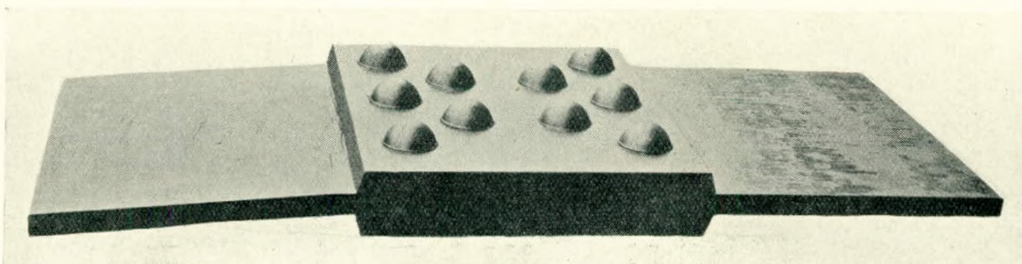


FIG. 13.—Riveted joint after test.

VIII. Fatigue of Metals.

In practically every branch of engineering, design against failure under service conditions is, or should be, much more related to the resistance of materials to fatigue stresses than to mere static or dynamic stresses. The truth of this statement is evinced sufficiently both by the estimate that 90 per cent. of service failures have been ascribed to fatigue and by the vast amount of experimental attention that has been devoted to the study of fatigue phenomena; to this study, the N.P.L. can claim to have contributed many valuable researches. In the brief space here available, a discussion of the whole problem obviously cannot be attempted; reference will merely be made to what appear to be three* aspects of major importance to engineers at the present time. To begin with, we require to know the fundamental aspects of fatigue failure; the acquisition of this knowledge necessarily implies the employment of methods of investigation which are scientific rather than technical, but, as past experience has shown, undreamed-of fields of technical and industrial development usually result from the firm establishment of basic scientific principles. The remaining two aspects of importance are purely technical, representing phases of the same problem. Many data exist regarding the fatigue limits of metals; the data are, however, usually acquired from tests made on small specimens of carefully prepared form and surface finish. But the finished practical component often does not correspond to the condition and shape of these test pieces. In the first place, owing to the method of manufacture, e.g. in casting, forging, or heat-treatment, the surface often differs considerably from the interior material, it must be remembered that, in general, the most severe service stresses are set up at a free surface. Then again, for technical reasons, the *form* of the component suffers sudden changes in shape, due to transition fillets, imperfect machining, oil holes, screw threads, etc., and the presence of these causes local concentrations of stress which may seriously and adversely affect the fatigue strength. Thus two fatigue aspects of current major importance may be described as "surface effects" and "stress concentration effects".

An extremely valuable discussion of the present state of knowledge of stress concentration effects, principally in relation to marine engine design, has quite recently been published in a paper† in which the importance of the problem is so clearly brought out that little more remains to be said until further experimental evidence and data become available; research in this field is urgently required.

To illustrate the serious deterioration that may be caused by "surface effects", brief reference may be made to an extensive research which has been in progress at the N.P.L. for some years. The major section of this work relates to heat-treated plate springs as used in cars, lorries, railway vehicles, etc., but the general lessons derived are of wider application. Such springs as received from the manufacturer after forging, rolling and heat-treatment develop an abnormally low resistance to fatigue stresses, equal to from 20 per cent. to 50 per cent. only of the intrinsic resistance of the materials. Fatigue tests on full sized springs and spring plates showed that the full strength could be restored if a surface layer of about $\frac{1}{16}$in. thick was removed. Examination showed that possible causes for this marked surface effect might include some or all of the following:—(*a*) Surface cracks formed during heat-treatment, (*b*) the presence of a decarburised surface layer possessing greatly reduced fatigue resistance, (*c*) surface irregularities of form, presence of small pits, scale, non-metallic inclusions, etc., produced during manufacture, (*d*) internal stresses at or near the surface. It has now been finally established that the factors of primary importance are surface decarburization and surface irregularities; the former defect arises both in the manufacture of the steel and in the heat-treatment of the finished spring, while the presence of the latter arises almost entirely in the manufacture of the plate and is not affected by subsequent heat-treatment. The relative influence of the two factors was investigated by fatigue tests, typical results on two steels being as stated in the following table:—

TABLE 3.

THE EFFECT OF DECARBURIZATION AND SURFACE NOTCHES ON THE FATIGUE RESISTANCE OF SPRING STEELS.

Description.	Endurance limit (rotating bending) tons per sq. in. Chrome vanadium steel.	Silico-manganese steel.
Surfaces completely machined and polished after hardening and tempering	±42	±46
Material machined and polished, then subjected to normal hardening and tempering treatment	±31	±24
Surfaces completely machined and polished, and specimens notched after hardening and tempering	±20	±21
Surfaces machined and polished, then decarburized, then hardened and tempered ...	±20	±21
Surfaces machined, then decarburized, notched, and finally hardened and tempered ...	±15	±11

In these tests, small semi-circular grooves 1/9mm. deep were used to represent surface irregularities. It is seen that the decarburized layer and the irregularities produced equally adverse effects on the fatigue resistance, with a further reduction in strength when *both* were present simultaneously. Accounts of some of this work have been pub-

* The interesting case of corrosion-fatigue will be briefly discussed in a separate section.

† "The Relation of Fatigue to Modern Engine Design", MacGregor, Burn and Bacon, Trans. N.E. Coast Institution of Engrs. and Shipbdrs., Vol. 6, January, 1935.

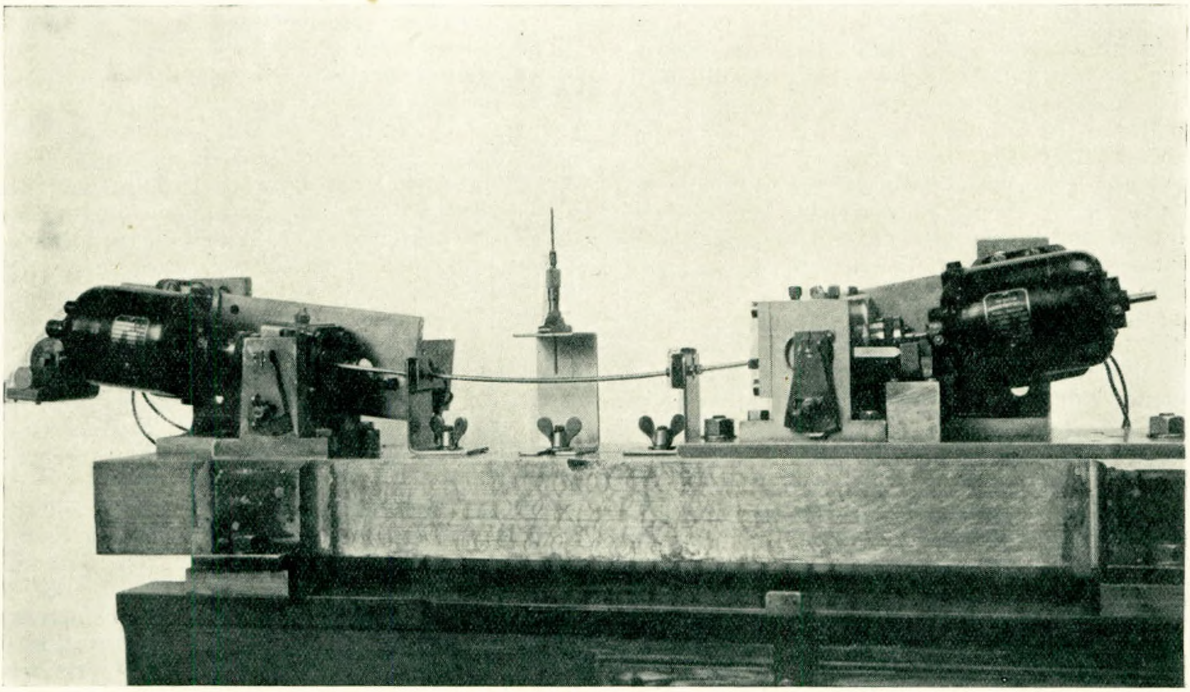


FIG. 14.—Fatigue machine for testing wires.

lished,* while further reports are in course of preparation. Fig. 3 shows the special fatigue machine designed for testing steel plates, while Fig. 14 shows a new fatigue testing machine to investigate the properties of wires for coil springs.

Some experience of service failures of high tensile steel forgings by fatigue led to an investigation which also possesses considerable technical importance; a comparison was made of the fatigue resistance of unmachined heat-treated steel forgings with that of the same forgings when machined and polished. The principal results† are summarised in the following table :—

*Hankins and Becker: Jour. I. & S. Inst., No. 11, 1931.
Hankins and Mills: Jour. I. & S. Inst., May, 1935.
N.P.L. Annual Reports for 1932, 1933 and 1934.
†Hankins and Becker: Jour. I. & S. Inst., No. 2, 1932.

Other tests made on ordinary rolled mild-steel bar showed that the effect of the forged surface was small (11 per cent. deterioration only). Recently, similar tests have been made on two high class alloy steel forgings of about 130 tons/sq. in. tensile strength; the fatigue limit in the machined and polished condition was about ±60 tons/sq. in. but, in the unmachined forged and heat-treated condition was ±9 tons/sq. in. only, a really remarkable result. From these results, it is evident that in order to use quenched and tempered forgings to the best advantage, it is very necessary for these to be machined and polished; the economic aspect of these findings deserves the attention of designers.

The elucidation of the fundamental aspects of fatigue failure presents an elusive and fascinating problem which has received intensive study at the

TABLE 4.
SUMMARY OF RESULTS OF FATIGUE TESTS ON FORGINGS.

Description.	Sample.	Average Brinell number.	Average tensile strength tons/sq. in. (estimated from Col. 1).	Endurance fatigue limit. As forged specimens.	Endurance fatigue limit. Machined and polished specimens.	Ratio. Col. 3./Col. 4.	Ratio Col. 3./Col. 2.	Ratio. Col. 4./Col. 2.
		1	2	3	4	5	6	7
0·20 per cent. carbon steel ...	A	135	30	±12·1	±14·2	0·85	0·40	0·47
	B	149	33	±11·7	±14·7	0·80	0·35	0·45
0·40 per cent. carbon steel ...	A	205	45	±16·5	±21·0	0·78	0·37	0·47
	B	185	41	±12·7	±21·6	0·59	0·31	0·53
3 per cent. nickel steel ...	A	274	59	±15·0	±32·5	0·46	0·25	0·55
	B	240	52	±15·8	±27·9	0·57	0·31	0·54
Nickel-chromium steel ...	A	308	66	±18·0	±31·5	0·57	0·27	0·48
	B	278	60	±14·4	±31·0	0·46	0·24	0·52

N.P.L. for the past 12 years and is still being vigorously pursued. The ultimate solution of this problem must involve an understanding of the atomic structure and cohesive forces* of matter and these still remain involved in mystery, in spite of the powerful weapons at the command of the physicist. In the N.P.L. fatigue research, the high powered metallurgical microscope and X-ray methods are employed and, although the ultimate goal is not yet in sight, a deep insight into fatigue phenomena has already been obtained and even more fruitful results are anticipated in the near future.

It will be realised that the results of mechanical tests, although affording useful data to the designer, cannot throw any light on the fundamental problem; we must look deeper. Now metals, as we use them, consist of an aggregate of crystals, about 100,000,000 to the cubic inch. Polished specimens were therefore subjected to various types of fatigue stressing and careful study was made of the changes occurring on the surface, as seen through a high powered microscope. Markings, called slip bands, appear on the surface of the metal and an extensive research† established that fatigue cracks were always, and only, initiated in regions of heavy slip. The next obvious step was to investigate these bands and endeavour to ascertain what position they occupied with respect to the atoms themselves and any law relating to fatigue cracking and the applied stress system. For this purpose, it was necessary to employ specimens consisting of *one* single crystal throughout. Such a crystal consists of a space-lattice of atoms forming a regular three-dimensional pattern repeated throughout the crystal. To ascertain the "orientation" of this pattern with regard to the axis of the fatigue specimen, it was necessary to invoke the aid of X-rays and the research necessitated the use of mechanical, microscopical and X-ray methods. The fatigue properties of single crystals of aluminium, iron, zinc, antimony, bismuth and silver were exhaustively studied.‡ It was established that the fatigue failure of ductile metals was caused by crack formation on the site of slip bands, which always occurred on certain crystallographic planes and along certain lines of atoms and was controlled by a relatively simple stress criterion, known as the resolved shear stress law. Fig. 15 shows a typical field of slip in a single crystal with fatigue cracks. Much has thus been achieved; certain knowledge§ has been gained of the geometry and stress laws of the deformation in relation to the atomic structure. The slip band was established as the *seat* of the initial fatigue crack; the remaining, very difficult problem was to ascertain the limiting conditions under which a crack formed and why it formed. X-ray studies then revealed that during slipping the planes of slip became distorted, indicating that the structure became broken up into small portions inclined to each other at measurable angles. Now it appears reasonable to surmise that severe internal stresses must be set up in the regions between these small portions and that, if the applied range of stress or strain is inferior to a certain

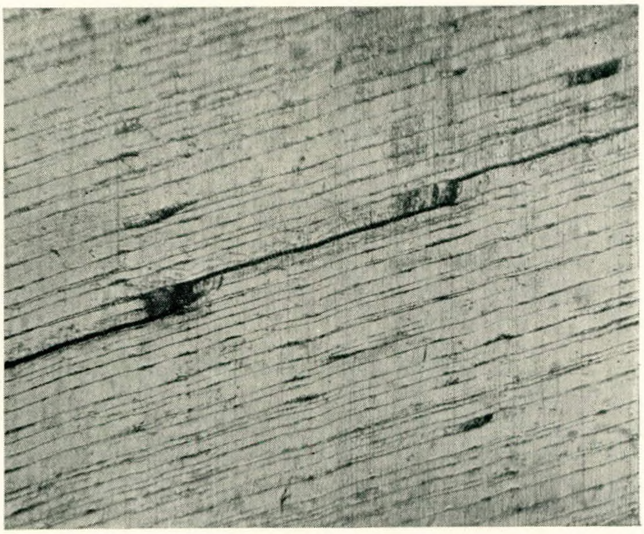


FIG. 15.—Slip bands and fatigue cracks in a single crystal of aluminium.

limiting value, a stable state will obtain, but if this range is exceeded, atomic bonds will be progressively broken. A spreading crack will commence and lead to complete fatigue fracture. A qualitative theory of fatigue elaborated on these general lines is as far as we can go at the present time; it is very helpful in suggesting lines of further attack. The next problem is to confirm that the structure is broken up, to ascertain the size of the fragments and the cause of the initial weakness at the boundaries of these fragments. Research on these lines is in progress at the present time and evidence on the first two problems appears to be emerging. It will be realised that the fundamental problem, although attacked at the N.P.L. from the aspect of fatigue, really embraces the whole field of the failure of materials by *any* type of stressing. In passing, it may be remarked that the evidence in favour of a sub-structure of metals, by which their mechanical properties are largely controlled, appears to be steadily increasing.

IX. Corrosion-fatigue.

Failure by corrosion-fatigue, i.e. under conditions where materials are subjected to cyclic stresses

*We cannot reasonably expect to understand, in a quantitative manner, the forces and nature of the actions which cause metals to break while we are yet unaware of the forces which originally bound together the fractured parts.

†Gough and Hanson: Proc. Roy. Soc. A., Vol. 104, 1923.

‡*See* Gough, 8th Edgar Marburg Lecture, Proc. A.S.T.M., Vol. 33, Part 2, 1933, for review of this extensive research.

§*See* also (*a*) Gough, Cox and Sopwith: Jour. Inst. Metals, Vol. LIV, No. 1, 1934; (*b*) Cox and Clenshaw, Proc. Roy Soc. A., Vol. 149, 1935.

while exposed to a corrosive environment, although merely an aspect of fatigue in general, deserves a brief separate treatment because failure may be so enormously accelerated when corrosive conditions are present. Failure by corrosion-fatigue is a serious engineering problem; in a comprehensive critical review,* in 1932, of the state of knowledge of this subject, examples of service failures which had been definitely and reliably traced to corrosion-fatigue were quoted including: marine propeller shafts; ship's rudder main piece; turbine rotors, discs and blading; water-cooled piston rods of Diesel engines; boiler and superheater tubes; tramway and locomotive springs; flying wires of aeroplanes; piping conveying corrosive liquors; pump shafts, pump rods and pump bodies exposed to water; steel railway sleepers, etc. Now although the problem is serious, it can often be overcome if the cause of the failure is recognised and if the essential principles of corrosion-fatigue are understood. The failure of the water-cooled piston rod† is a good example; when these first occurred, some endeavoured to find a cure by using steels of higher tensile strength and found that the failures continued to occur. When the principle of the cause of failure was better understood, the employment of corrosion-resisting steels, of separate sleeves not subjected to severe stress, or the substitution of oil for water as the cooling medium, gave excellent remedial results.

Corrosion-fatigue has received detailed study at the N.P.L. for several years past; several interesting technical points which have been cleared up may be briefly mentioned here.

In the first place, much of the work of the earlier investigators appeared to indicate that a definite limiting range of stress was developed under corrosion-fatigue conditions; the term "corrosion-fatigue limit" began to be widely employed; the validity of this assumption demanded careful investigation. Then again, in the past attention had been paid chiefly to corrosion-fatigue under reversed flexural stresses; it was important to check whether similar characteristics were exhibited under other types of stressing actions. An extensive investigation was therefore made at the N.P.L. of the comparative influences of great numbers of cycles of reversed direct and reversed flexural stresses while the specimens were sub-

*Gough: 11th Autumn Lecture, Jour. Inst. Met., Vol. 49, No. 2, 1932.

†For accounts of European and Japanese experience respectively, *see* (*a*) Dorey, Trans. Inst. Naval Archit., April, 1933, and (*b*) Motor Ship, Vol. XIV, No. 164, Oct., 1933.

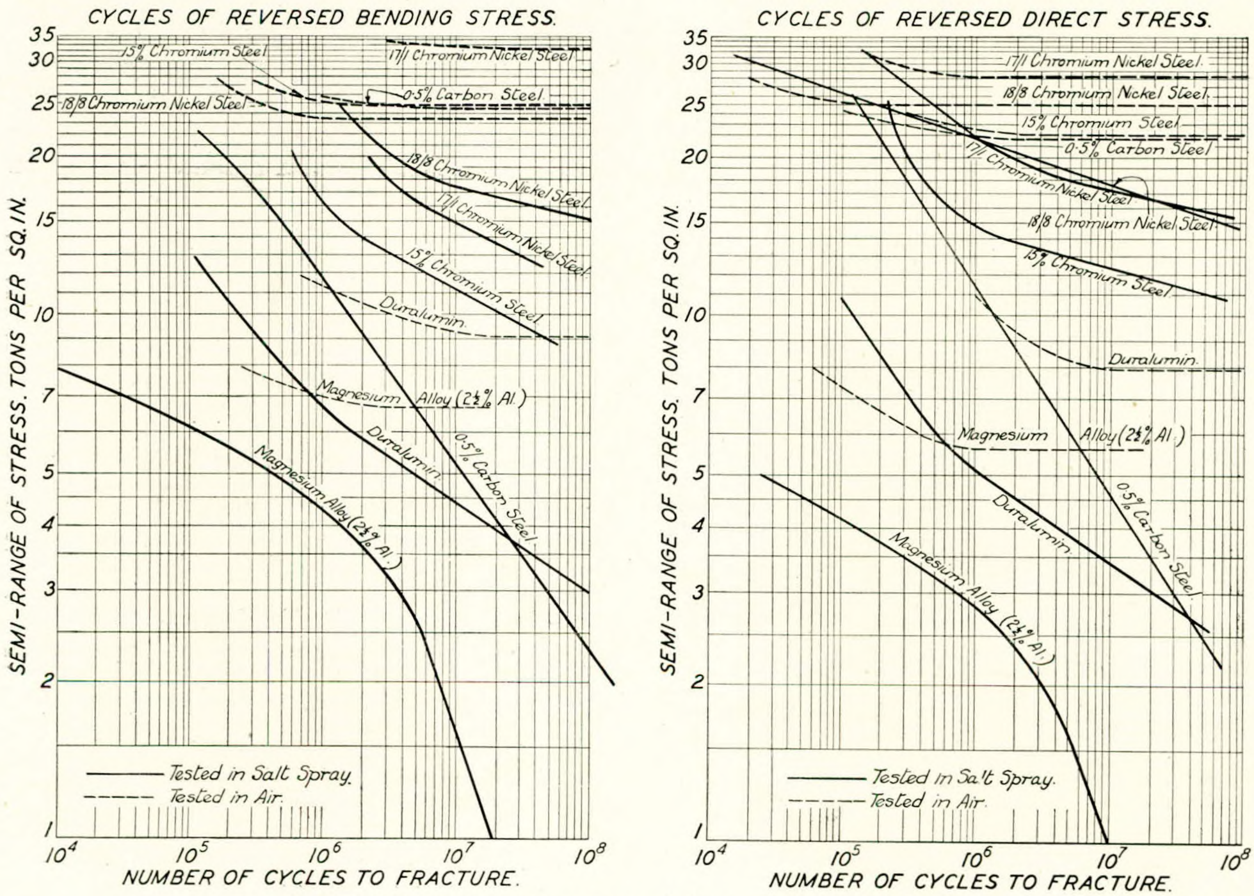


FIG. 16.—Stress-endurance curves: fatigue and corrosion fatigue.

jected simultaneously to an air-borne salt spray. The apparatus is described fully elsewhere*; these test conditions are admittedly severe, but extreme "marine" conditions were required. Fig. 16 summarizes concisely the results obtained on a range of materials. These show that the stress-endurance curves obtained with the two types of stressing are generally similar. It is, however, of the utmost significance to note that in every case the S/N curve is falling steeply at the greatest endurances investigated; this shows definitely that the idea of a "corrosion-fatigue limit" must be abandoned. Engineering structures are not designed to last for ever and the figure brings out clearly the relative superiority, under these test conditions, of the corrosion-resistant steels to the other materials. At the present time similar tests are being made on a series of bronzes; these alloys are developing extremely good resistance, at least equal to the corrosion-resistant steels.

Other investigations recently completed or in current progress relate to the effect of deposited metallic protective coatings, the study of atmospheric corrosion,† studies‡ of the more fundamental characteristics of corrosion-fatigue using single crystals and the effect of the mean stress of the cycle on the corrosion-fatigue resistance.

Reverting to the practical problem of design against this form of failure, future developments will probably proceed along the lines of the greater employment of materials possessing high intrinsic corrosion-resistance, of deposited metallic protective coatings and, possibly, by the addition of inhibitors to the corroding medium; more test data on each of these aspects would be valuable.

X. Failure of Metals under Complex Stress Distribution.

Very few important engineering components are subject in service to simple stressing actions and knowledge of the criteria of failure of metals under complex stress distributions constitutes a matter of great importance to designers. Two aspects are of primary importance to engineers:—(1) the stress conditions which cause yielding to occur, the material being either in a virgin or in a strain-hardened condition, and (2) the stress conditions which produce complete fracture. With regard to the first case, although the literature records many experimental studies of this aspect, the majority of these have been carried out under conditions insufficiently critical to afford reliable information and only in very recent years has it been possible to subject various theories to strict examination in the light of accurate experimental data. The second case embraces two types of failure, caused, respectively, by the application of static and cyclic stresses, of which the latter only is of principal engineering importance, especially where engines and machinery are concerned; reference will be made to a research into combined fatigue stresses now in progress at the National Physical Laboratory, which represents the first really comprehensive attack on this aspect of the general problem. The following discussion will be confined to ductile metals only as representing the major engineering interest.

*Gough and Sopwith: Jour. Iron & Steel Inst., No. 1, 1933.

†Gough and Sopwith: (*a*) Jour. Inst. Metals, Vol. XLIX, No. 2, 1932, (*b*) Jour. Inst. Metals, Vol. LVI, 1935.

‡Gough and Sopwith: (*a*) Proc. Roy. Soc. A., Vol. 135, 1932, (*b*) Jour. Inst. Metals, Vol. LII, No. 2, 1933.

Any state of combined stress, however complex, is completely specified by a statement of the three mutually-perpendicular principal stresses p_1, p_2 and p_3; the principal stress differences (p_1-p_2), (p_2-p_3) and (p_3-p_1) representing the maximum shearing stresses, S_1, S_2 and S_3, respectively, which occur on three planes that are severally perpendicular to one of the planes of principal stress and equally inclined to the other two principal planes.

(1) *Stress conditions producing plastic deformation or yielding.*

It is now established that yielding of ductile metals is not produced by hydraulic compression. Therefore, as the changing of a stress system, denoted by p_1, p_2, p_3 to (p_1+x), (p_2+x), (p_3+x) produces no effect, it follows that certain criteria of yielding which have been suggested can be excluded from consideration; such criteria include the theories of Maximum Stress, Maximum Strain and Constant Total Energy of Deformation. Hence the true criterion of yielding must involve principal stress differences, and suitable existing theories are reduced to three in number, namely, (*a*) *Maximum Shear Stress Theory,** which states that the criterion of failure is determined by the greatest principal-stress difference; (*b*) *Mohr's Theory,* by which the criterion of failure is determined by the maximum value of the shearing stress which is itself dependent on the normal stress acting across the plane of shearing stress and, also, dependent on the properties of the material; i.e. if $p_1>p_2>p_3$, failure occurs at a value of $\frac{1}{2}(p_1-p_3)$ which must be a function of (p_1+p_3) whose form depends on the material in question; (*c*) *Misés-Hencky Theory,* according to which failure occurs at a constant value of the potential energy stored in the material due to purely elastic strains *excluding* uniform tension or compression, expressed by the relation

$$(p_1-p_2)^2+(p_2-p_3)^2+(p_3-p_1)^2=\text{constant}.$$

It will be apparent that the essential difference between the theories of Maximum Shear Stress, Mohr and Misés-Hencky is that in the latter, the value of the intermediate principal stress, p_2, is a factor which does not enter into the two former theories. Accordingly, the more recent and authoritative experiments have been designed to study the influence of the intermediate principal stress.

*Usually termed "Guest's Law" in this country.

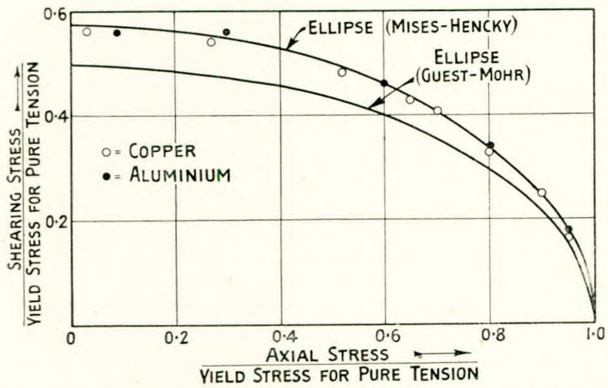


FIG. 17.—Combined static tension-torsion results (Taylor and Quinney).

Lodé's* experiments were made on thin walled tubes of iron, copper and nickel, the applied straining actions being direct tension, internal pressure and combinations of these two. The results clearly established the influence of the intermediate principal stress and agreed extremely closely (within 3 per cent.) with those predicted by the Misés-Hencky relation. Then came the extensive researches of Taylor and Quinney† on thin walled tubes subjected to direct and torsional stresses; the conditions employed covered all ratios of the principal shear stresses. As shown by Fig. 17, the results obtained for copper and aluminium conformed extremely closely to the Misés-Hencky relation; other results also decided mainly in favour of this hypothesis for iron, cadmium and lead, the slight differences encountered in the latter group being attributed merely to lack of isotropy in these materials. Further tests were made by Nadai and Lodé*, on thin walled steel tubes subjected to tension and torsion; the results conformed exactly to the Misés-Hencky relation. The foregoing experiments all relate to thin walled specimens in which the stresses and strains were closely uniform throughout; under these conditions it may safely be concluded that the Misés-Hencky relation affords the most satisfactory criterion for the condition of yielding of ductile metals under combined stresses. Cook† has investigated the stress criteria which govern the failure of elasticity of thick-walled steel tubes, and the plastic distortion of thick cylinders of mild steel. In the first case, results were obtained which, although conforming exactly neither to the Misés-Hencky relation nor to a constant value of Maximum Shear Stress, were interpreted as being in much closer agreement with the latter criterion; in the second case, the forces producing distortion were in close agreement with those calculated on the assumption of constant shear stress.

(2) *Failure under Combined Cyclic Stresses.*

As an unexplored field in the study of the properties of materials, the experimental examination of the criteria of failure of metals under com-

*Zeit Physik, Vol. 36, p. 913, 1926

†Phil. Trans. Roy. Soc. A., Vol. 230, Nov., 1931.

*Trans. Amer. Soc. Mech. Engrs., Applied Mechanics Division, Vol. 1, No. 3, 1933.

†(*a*) Proc. Roy. Soc. A., Vol. 137, 1932, p. 559; (*b*) Proc. Inst. Mech. Engrs., Vol. 126, 1934, p. 407.

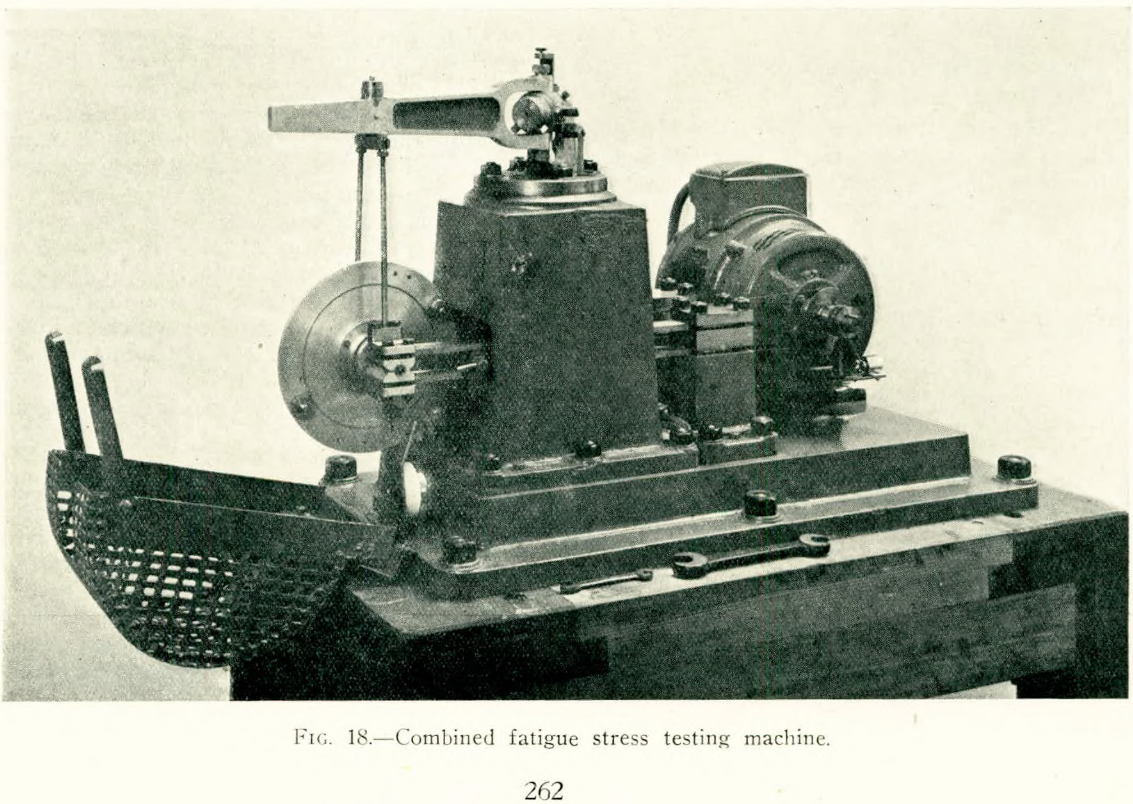


FIG. 18.—Combined fatigue stress testing machine.

bined fatigue stresses is probably unique. As a commencement of the general attack on this important practical problem, the National Physical Laboratory is carrying out an extensive investigation into the case of combined reversed bending and reversed torsional stresses with both these straining actions in phase. The results obtained will be of direct application to the design of crankshafts and similar engineering components.

The high-speed testing machine specially designed for the research possesses features of interest; the machine is illustrated in Fig. 18. It is of the inertia type*, the force which applies the desired load being due to the centrifugal action of unbalanced weights fixed to a rotating flywheel. This force is transmitted through a lever arm which is attached to the specimen in such a manner that the angle between the axis of the arm and the specimen can be adjusted to any value between 0° and 90°; at these angles are imposed, respectively, cycles of bending and torsional stresses, while intermediate angles give any desired combinations of these stresses; in this manner, the fatigue limits of all possible combinations can be determined. A brief discussion of the general problem† of the failure of ductile metals under these conditions of stress will disclose a feature of considerable interest to designers. In the foregoing discussion on plastic deformation under static stressing we have seen that two theories receive considerable support. But when fatigue failure is concerned, neither of these criteria—or any other—can be strictly applied, for a *range* of stress is the factor controlling failure. For purposes of comparison, however, this difficulty can be overcome if we substitute the value of the fatigue *range* in place of the equivalent static *stress* in the various equations representing the theories. Following this plan, it can be shown that the following expressions can be deduced :—

$$\frac{1}{f_1^2}\,(f^2+aq^2)=1 \qquad (1)$$

where $2f_1$ = fatigue range under bending only
$2f$ = safe range of direct stress due to bending
$2q$ = safe range of shear stress due to torsion
} at the fatigue limit of the combination.

while the constant a has the values of 1 and 0·75, respectively, according to the Maximum Shear Stress Theory and the Misés-Hencky Theory. Now equation (1) means that the ratio of the fatigue limit under simple reversed torsional stresses to the fatigue limit under simple reversed bending stresses must be constant for all materials, having the values of 1 and 1·155, respectively, for the two theories mentioned. Experiment has shown that this constancy of ratio is *not* fulfilled and, hence, neither theory is generally applicable. But it will be seen that equation (1) represents the equation to an ellipse, the length ratio of whose axes is determind by the value of the square root of the constant a. We can make provision for a variable ratio of fatigue limits under simple bending and simple torsional stresses merely by rewriting the equation in the form :—

$$\frac{f^2}{f_1^2}+\frac{q^2}{q_1^2}=1 \qquad (2)$$

where $2q_1$ = safe range of shear stress under simple torsion only. The ductile steels so far investigated conform very closely indeed to this criterion which should be of great value for design purposes, as it is only necessary to determine experimentally the value of f_1 and q_1 for any given material; the safe values of combined stress can then be calculated directly from equation (2).

XI. Failures in Service.

The investigation of service failures offers a fascinating and instructive field of enquiry often demanding the widest knowledge of the properties of materials and a balanced appreciation of the possibilities and limitations of testing methods coupled with keen observation and attention to detail. A great variety of failures drawn from all branches of engineering are received at the N.P.L. for investigation; on some future occasion it may be possible to present a comprehensive account of these and the useful lessons derived; the present note will indicate the general methods adopted, illustrated by a few examples.

The method of experimental enquiry adopted

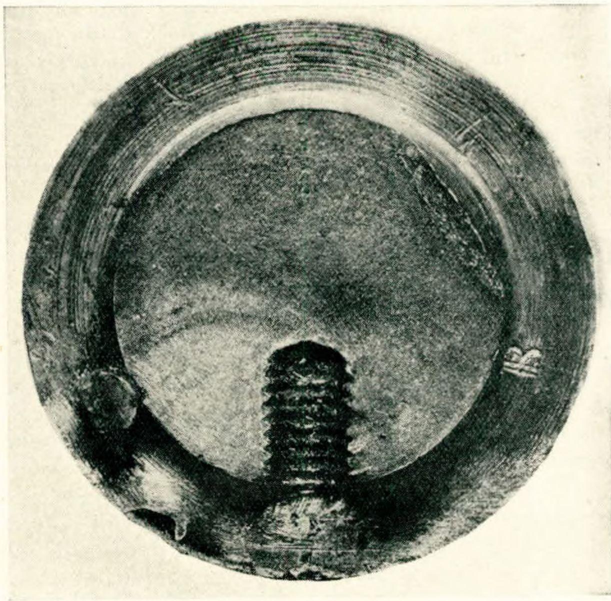


FIG. 19.—Fractured big-end bolt.

*A detailed description of the machine will be found in the Annual Report of the N.P.L. for 1934.

†For a full account of the detailed results of this research see: "Strength of Metals under Combined Alternating Stresses". Gough & Pollard: a paper to be read and discussed before the Inst. Mech. Engrs. on 1st Nov., 1935.

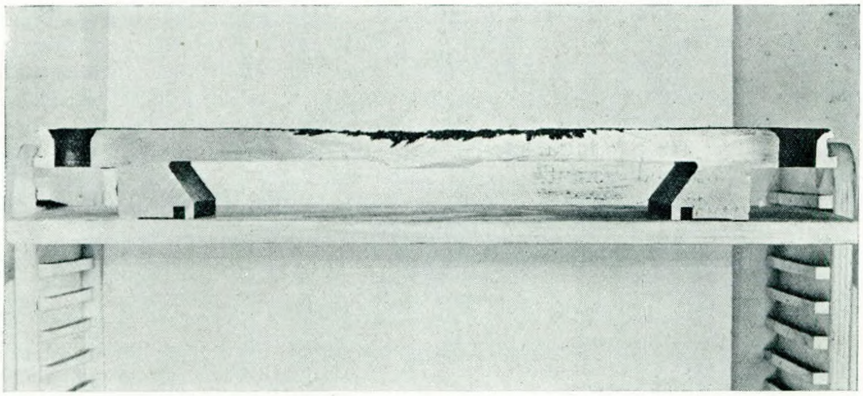


FIG. 20.—Corroded steel diaphragm: cross section.

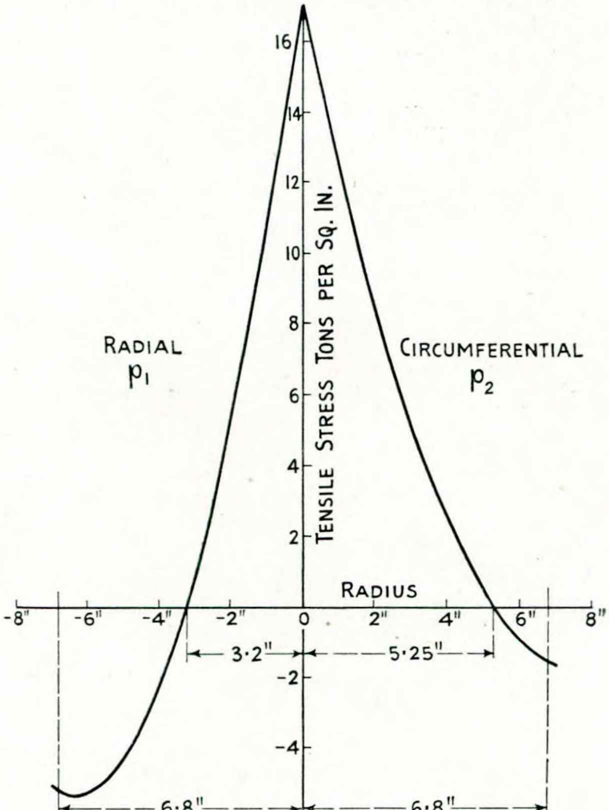
in the head of the bolt. At this position, also, a sudden change in diameter occurred at the junction of the bolt head and shank while deep machining marks were present on the transition fillet which was itself of small radius. The material proved to be a steel of poor quality containing high proportions of segregated sulphur and phosphorus and large non-metallic inclusions. This is an example of execrable design and manufacture, illustrating a combination of many faults each of which might be sufficient to lead to premature failure.

at the N.P.L. in dealing with problems of service failure usually embraces two principal and related series of tests—mechanical tests and stress analysis to assess the suitability of the mechanical properties of the material for the particular service in which it is used, and metallurgical investigation to disclose the condition of the internal structure and heat-treatment of the material. The results of these tests, coupled with observations of the type and position of the fracture and a careful consideration of the circumstances in which failure occurred, are often sufficient to disclose the cause of failure and suggest suitable actions to prevent recurrence. The actual tests employed are, of course, selected to meet the particular case. In general, however, the mechanical tests which yield sufficient guidance are the static tensile, notched and un-notched bar impact and hardness tests, to which fatigue tests of various types are sometimes added. The metallurgical investigation consists essentially of chemical analysis and microscopic examination; macroscopic examination, sulphur printing, determination of internal stress and crack detection by magnetic methods are often valuable. Certain types of problem are especially suitable for the employment of X-rays, while the use of the most refined metrological methods sometimes affords valuable clues where distortion effects are observed or suspected.

The most common cause of service failure in our experience is that of fatigue; many failures are due to stress concentration effects such as sudden changes of section, deep machining marks, transition fillets of insufficient radius, the placing of oil holes, or location holes, at high stressed regions, etc. Unfortunately it is clear that the marked effect of stress concentrations on fatigue resistance is not yet sufficiently realised either in the drawing office or the workshop.

One example of ordinary fatigue failure must suffice. Fig. 19 shows a fractured big-end bolt on the scavenging pump connecting rod of a Diesel engine. The fracture has commenced in a region situated between the tapped hole and a locating pin hole (visible to the left of the larger hole) drilled

When corrosive influences are allied to cyclic stresses, greatly accelerated damage results. An unusual example of exceptional interest was the failure, by corrosion-fatigue, of a steel diaphragm which formed the base of an electro-mechanical hammer fitted to a ship's bottom. Fig. 20 shows a cross-section through the diaphragm. It will be noted that the deeply corroded region is confined definitely to the central portion. Making certain reasonable assumptions, the stress distribution in



CIRCUMFERENTIAL AND RADIAL STRESS DISTRIBUTION

FIG. 21.—Calculated stress distribution in diaphragm.

the disc at the impact of the hammer was worked out; the results are shown in Fig. 21. The area within which the cyclic stresses are entirely tensile is seen to correspond with the region of failure; further, an approximate estimation of the total number of blows endured in service and the intensity of the applied stress cycle agreed extremely well with our experience of the endurance of laboratory specimens under corrosion-fatigue conditions.

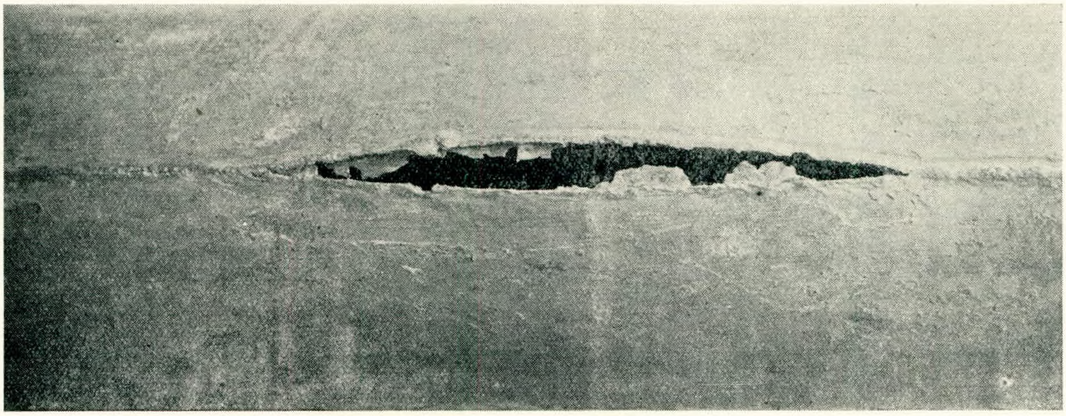


FIG. 22.—Fractured ammonia container.

Fig. 22 shows a service fracture of a welded gas cylinder used as a container for anhydrous ammonia. The steel itself was found to possess good mechanical, chemical and metallurgical properties. The failure has obviously occurred at the weld but it was necessary to find out if this weld had originally been up to a satisfactory standard. X-ray photographs showed clearly that this was not the case. Referring to the radiographs reproduced in Fig. 23, all the prints disclose marked variations in thickness of the weld and that, in places, complete junction of the fused metal had not been effected; Fig. 23(D) shows that part of the circumferential weld near the valve end of the cylinder was in an especially unsatisfactory condition.

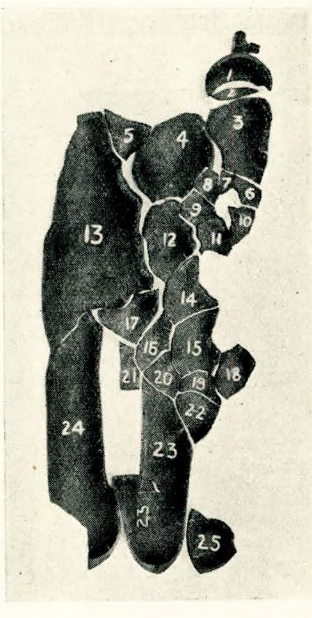


FIG. 24.—Fragmented oxygen cylinder.

Fig. 24 shows a gas cylinder which "fragmented" when the explosion occurred. The material was of very poor quality, possessing very low ductility and inferior shock resistance. Owing to faulty manufacture, the inside surface of the cylinder contained serious folds and creases which provided sharp notches. This was a clear case of failure caused by a shock or series of shocks imposed on a material of low ductility possessing a surface containing very sharp re-entrant angles.

Fig. 25 shows a failed bronze condenser tube. After the final drawing operation in manufacture, these tubes had not been annealed; further serious work hardening occurred during the expanding of the belled-ends of the tubes. Microscopical examination showed that the cracks were intercrystalline, typical of the failure of brass by "season-cracking", a combined result of internal stress and corrosive action; enquiry elicited that traces of ammonia were always present in the cooling water. At the Laboratory the presence of serious internal stresses in the belled ends was clearly revealed by X-ray methods and by chemical reagents.

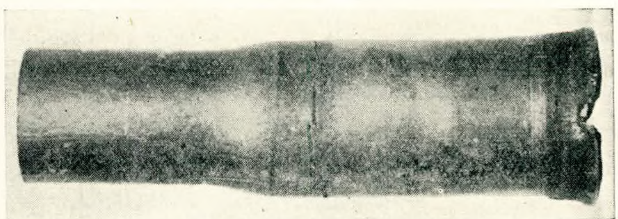


FIG. 25.—Failure of bronze condenser tube.

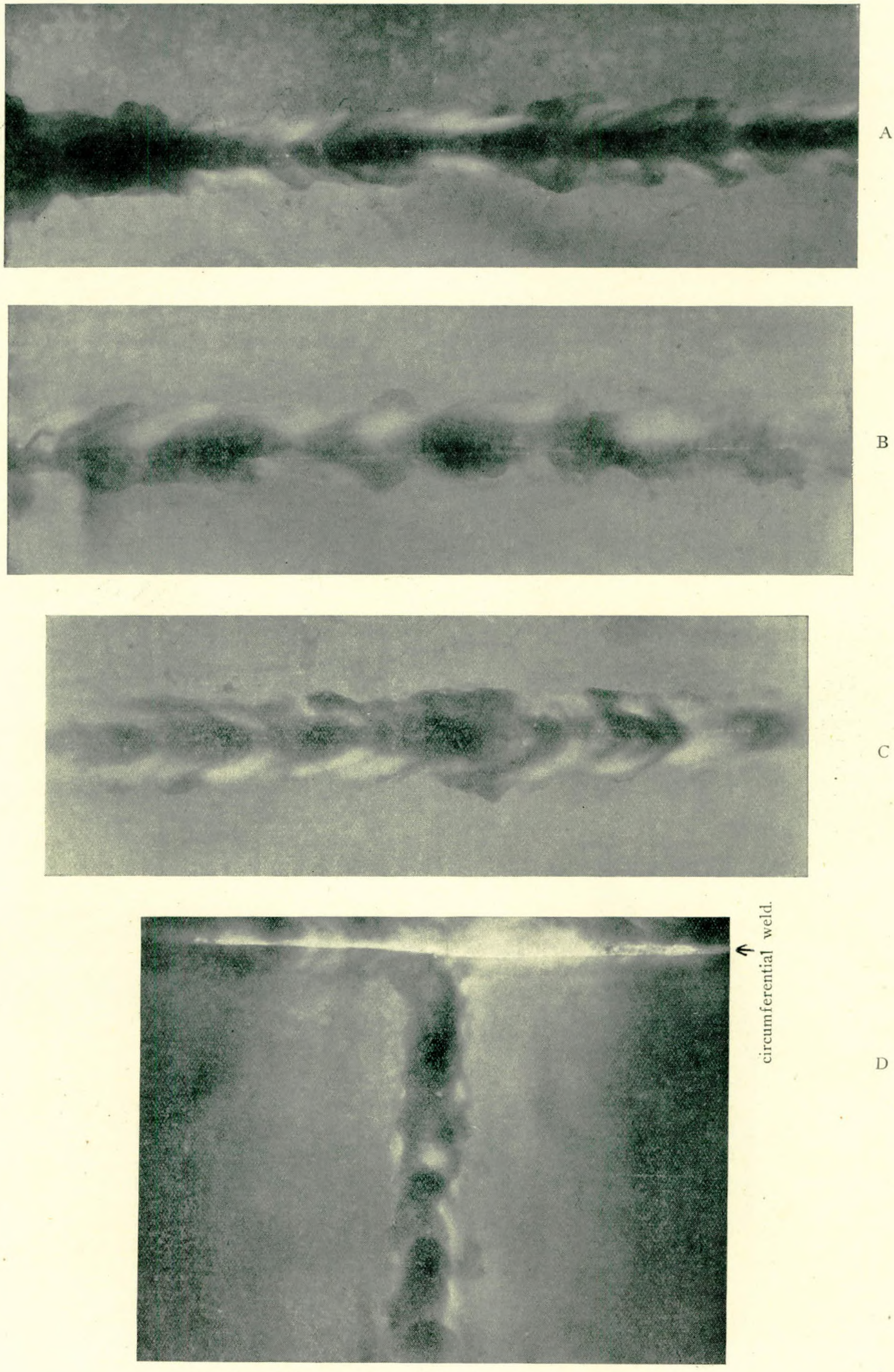


FIG. 23.—Radiographs of welded joints of an ammonia container.

Fig. 26 shows the interesting case of a boiler drum which was shown by a hydraulic test to be in a cracked condition *before* putting into service. Complete mechanical and metallurgical tests revealed that the material of the drum was perfectly satisfactory in composition and structure. A very careful microscopical examination of the crack itself afforded the solution to this unusual type of failure, for it was found that the material at the bottom (1in. deep) of the fine crack was in a decarburised and oxidised condition and, hence, must have had its origin in the earliest stages of manufacture of the steel. It was finally established that the original ingot had been heated at too great a rate; cracking occurred at that stage and probably extended during the subsequent forging operations.

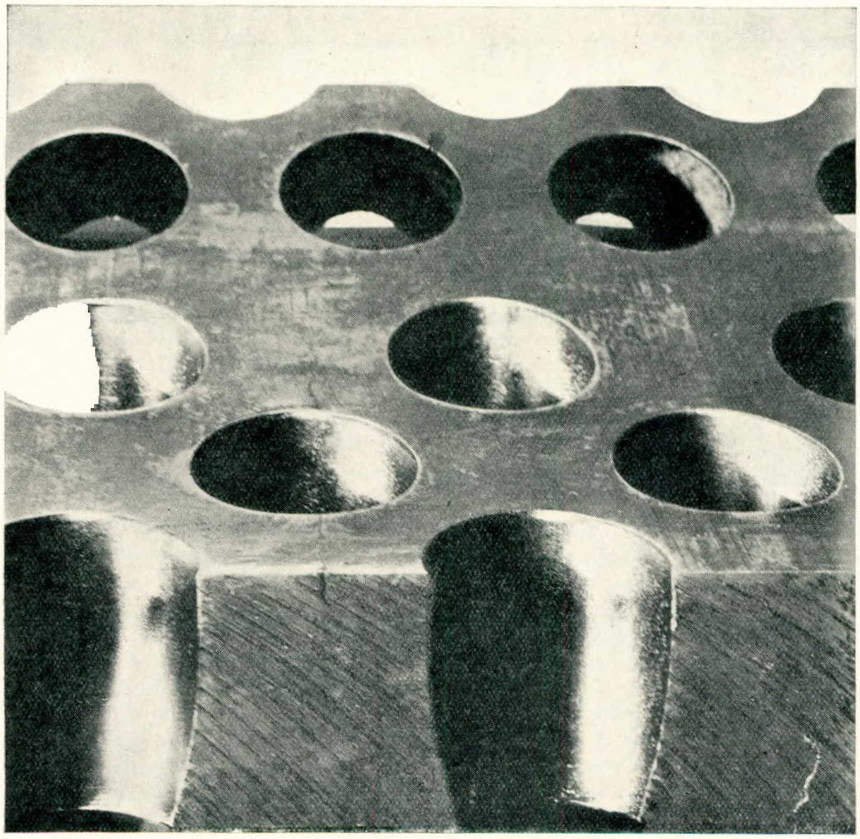


Fig. 26.—Cracked boiler drum.

Description of further interesting service failures might be continued at great length, but space limitations forbid.

The National Physical Laboratory consists of eight great technical departments:—Aerodynamics, Engineering, Electricity, Metallurgy, Metrology, Physics, Radio, and Tank. Each can justifiably claim to possess expert scientific and technical knowledge of the subjects falling within its various specialised fields of research, but the closest co-operation exists between these departments and their individual and collective experience and resources are at the service of industry. A general example of the effective co-operation of at least four of these departments in the solution of engineering problems has been given above in the few quoted cases of the investigation of service failures; many of the researches referred to in other sections also represent investigations carried out jointly by two or more departments. The present paper may, therefore, appropriately be brought to a conclusion by a reference to the research facilities and experiences available to British industry at its own National Physical Laboratory.

Discussion.

Dr. S. F. Dorey (Vice-President), opening the discussion, warmly congratulated the Authors on their efforts. They all appreciated the good work being done by the National Physical Laboratory and were glad of every opportunity of learning what the research workers of that establishment had achieved. Quite frequently they thought of scientists as people who were out of reach of ordinary people, but in Dr. Gough they had the type of man who could descend from those higher regions and explain in simple language the problems which had been investigated.

The marine engineer nowadays, in the interests of efficiency, had to consider the developments in all classes of materials, and it was essential that information of the kind given in the paper should be available. Turning to the question of high temperature research, he thought that one of the features being specially considered at the present time was that of measuring creep at working stress. For some time engineers had been supplied with information which dealt with the creep limit of materials at high temperatures, but in which it had not been possible, owing to limits of accuracy of the apparatus, to measure very small elongations in a reasonable time. Consequently, higher stresses were applied, yielding a standard rate of creep after a given time. The stresses so obtained were used in conjunction with a factor of safety to give suitable working stresses, but the creep rate at the working stress so obtained was unknown. Now the engineering side of the National Physical Laboratory had been able to carry out investigations affording reasonable information on creep in the neighbourhood of actual working stresses. The only point that concerned Dr. Dorey was what were the actual working stresses? Information was available about certain stresses, but the marine engineer often wanted to know the actual stresses in the article in service. It was quite simple to calculate what might be termed nominal stresses, but what were the stress concentrations, particularly in high temperature work where failure would be more rapid than it might be when subjected to the nominal stress? The special need seemed to be some method of getting a reliable short time test. He appreciated the difficulties, because a satisfactory basis could only be obtained after tests had been carried out for long periods, in order to be assured that the short time test was sufficiently representative of the creep properties of the material tested. In a short time test it must also be remembered that all the information desired could not be obtained, because the duration of the test might not permit of such things as embrittlement taking place.

At the top of page 243 the Authors referred to the number of tests carried out, and Dr. Dorey concluded that in addition to these embrittlement tests and microscopical examination of test pieces after the creep experiment were also made. Could the Authors give some information on what these were? It was interesting to note that a study of the stresses and strains arising when a material was subjected to bending moments had also been made. In this connection, would the Authors state whether from this work information had been gained which would be useful to apply to heat transmission stresses in tubes where temperatures were in the creep region?

In connection with Table I, he would like to raise a point on the question of the value of a high tensile steel compared with a medium carbon steel. If for a high tensile steel the yield stress was higher than the fatigue limit for a particular range, then a lower fatigue resistance would be anticipated because fatigue would occur at a stress concentration before yielding. On the other hand, if the yield stress was lower than the fatigue limit for a particular range, then the yield might relieve a stress concentration before fatigue asserted itself. The fatigue results (*a*) and (*b*) for both plane bending and rotating fatigue limits indicated that that might be the case. The testing procedure for these steels including as it did fatigue testing and determination of stress-strain curve immediately after the first yield appeared to be the only safe manner of dealing with high tensile steels.

The information on lifting gear given in the paper was very useful. It brought out the point regarding impact which took place in chains and hooks under ordinary service conditions, which the majority of people did not realise. With repeated impact and sudden loading the surface material at points of contact was hardened and embrittled, and as a result broke down due to fatigue. It would appear that moderate low temperatures had considerable effect on embrittlement caused by the inter-lock action.

He was glad the subject of contact-corrosion had been mentioned in the paper. Marine engineers had occasionally noticed this in practice, and it had been usually attributed to a little moisture being present causing an oxide film, but the Authors had shown by experiment that if two materials moved slightly in intimate contact corrosion could occur. His attention had recently been drawn to a particular case of this nature in a Doxford engine where the pins in the rocking levers, which had only a very small motion, frequently were found rusted, "cocoa" having been deposited for some unknown reason; probably contact-corrosion was the answer. Did the Authors consider the pitting found in turbine gear might be due to this effect? Sometimes there was evidence of sulphur in the oil, but at high speeds there would be intimate contact continually repeated with a small sliding movement. It appeared to him that although there was a lubricant there, contact was so close that the oil film might be continually broken down, causing pitting.

Naturally this paper dealt almost entirely with fatigue, and the Authors had mentioned the subject of fatigue testing machines. They had no machines in this country comparable with those used in Germany. Two or three years ago in Germany he had seen tests carried out on a really large test specimen. These were specimens which would give definite information. In this country fatigue testing machines generally were only capable of dealing with specimens of somewhere about ¼in. to ⅜in. diameter, and it had already been established that the fatigue limits decreased with increased size of specimen. They knew that with specimens of 1in. diameter the drop in fatigue limit might be up to 15 per cent. compared with that obtained with a ⅜in. specimen. In the case of a 3in. diameter specimen, he thought a drop of 40 per cent. might be obtained. If engineers were going to base their calculations on the fatigue limits of material obtained by investigators on small specimens, it was necessary to consider size effect, otherwise failure would occur earlier than expected. It was evident that some united effort should be made in this country to get larger testing machines. There was no doubt that the best results were obtained where the best facilities were available for research.

He gathered from the Author's remarks on the cracking of boiler plates that they had not been able quite to align experimental work with what had happened in actual service. Nevertheless, they would notice that it was stated on page 256 that "although in some places the cracks followed grain boundaries, yet the general path was definitely transcrystalline". Dr. Dorey would call attention to the expression "in some places", and he thought the Authors were to be congratulated on being able to produce some sort of evidence in this way. The Authors had asked for the experience of readers of the paper, but from the point of view of the marine engineer this was not a matter which gave much concern. Cases had occurred, but not very frequently, in cylindrical boilers where cracking had been found through rivet holes in the longitudinal shell seams. They were all familiar with the cracking which took place at the root of a flange, but he gathered that the question which the Authors were trying to solve was cracking between the rivet holes, which had frequently been observed in land boilers. Dr. Dorey wondered whether caustic embrittlement was the right term to apply. He thought this embrittlement was not necessarily caustic, and in carrying out laboratory experiments it was essential that the actual working condition should be reproduced. Take the case of boiler plates of different quality. Some firms did not normalise plates up to ⅞in. thickness after rolling, but only the thicker plates. Other firms did not normalise at all. Then there was work hardening around the rivet hole, little rough sharp edges round the rivet holes due to fast drilling, excessive pressure applied during riveting, surface and heat treatment effect. All these things happened in practice, and it was essential that items like these should be taken into account as far as possible in experimental work.

The cracking which was shown in Fig. 13 might possibly be largely due to the caulking. There was a notch effect at this point due to caulking with which those who had had experience of naval water-tube boilers would be familiar.

He agreed with the Authors that there was no corrosion fatigue limit. Undoubtedly if cyclic stresses occurred for a sufficient length of time in a steel specimen subjected to a corrosive environment there would be ultimate breakdown. A simple calculation, for instance, of the screw shaft of an engine working at 100 r.p.m. for 250 days per year showed that in three years the shaft had completed one hundred million revolutions. It was therefore essential that tests should be carried out for a sufficiently large number of cycles to show how the material behaved under conditions similar to those in service.

Dr. Dorey desired to call attention to the use of iron from the point of view of corrosion-fatigue. Many instances had been brought to his notice where iron under the conditions of corrosion-fatigue was superior to steel. Once a notch had been formed due to the combined action of cyclic stress and corrosion, failure was very much more rapid with a mild steel or any steel that was homogeneous in structure than in the case of wrought iron where, owing as it were to the method of manufacture, the material prevented propagation of the cracking. As marine engineers familiar with cylindrical boilers, they would appreciate that iron screwed stays gave better service than steel screwed stays; the steel would corrode at the threads and then snap completely across. Another case was the pintles used in the paddle floats of tugs running on the Thames. Steel pins were tried and found unsatisfactory on account of corrosion, but iron pins had given complete satisfaction.

He congratulated the Authors on their experiments in connection with complex stresses. The machine designed at the National Physical Laboratory had given most useful information of a fundamental character. There were, however, very few cases where combined alternating bending and alternating torsion were encountered. In very few cases was torsion reversed, excluding of course engines going astern, although in the case of a six-cylinder 4 S.C.S.A. oil engine the fluctuation of torsional stress was almost alternating.

Mention had been made on page 264 regarding the determination of internal stress and crack detection by magnetic method, and it would be of interest to know how this was done.

Regarding the illustration showing cracks found in a forged boiler drum, in these days when there appeared to be more probability of welded drums being used in service, it should be remembered that the average forged drum was not necessarily 100 per cent. perfect. It had to be very carefully worked at the right temperature and heat treated. In the case of a welded drum the plate could be uniformly worked and heat treated and the quality of the welded joint was the criterion of safety. Provided the welding was satisfactory and the drum truly cylindrical, a welded drum would give as good service as a forged drum.

Mr. E. F. Spanner, R.C.N.C., ret. (Member) said that Dr. Gough had mentioned during the lecture that in one of the papers read at the recent Symposium on Welding a naval architect had stated that ships were exposed to a stress of ±7 tons per square inch. He could confirm that. A point that should be made clear, however, was that in the structure for which the naval architect was responsible, the rate of reversal of these stresses was not 200 per minute, but perhaps 2 to 10 per minute. He desired to ask the National Physical Laboratory to carry out experiments at much slower rates of reversal than they investigated at present, or to do other experimental work of equivalent value.

Mr. Spanner had an idea that there was a time lag between the application of stress and the development of strain even within the elastic limit. In his opinion, when stress was applied to a piece of material it took time to alter its shape and develop what was called strain.

Imagine a steel rod 1in. square and 1,000ft. long. Suppose that a load of 5 tons per square inch was applied to this rod along its length. The end of the rod should move nearly 5in. to develop

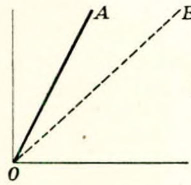


FIG. 27.

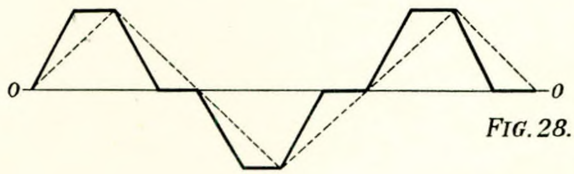


FIG. 28.

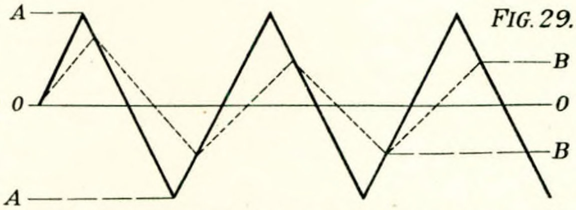


FIG. 29.

the strain proper to this stress. It was not credible, in his opinion, that such a movement could take place *instantaneously*. It would be necessary, among other things, that the mass of the rod should move 2½in. *instantaneously*, i.e., at an infinite velocity, requiring an infinite force and creating an infinite momentum, suggestions which were quite unacceptable for purely mechanical reasons.

While, when stated so simply, it appeared obvious that there *must* be a time lag between stress and strain, the fact remained that specialists in fatigue research seemed most reluctant to accept the idea that this time lag existed at all. All their ideas and fatigue testing machines were based on the theory that no time lag existed between stress and strain within the elastic limit. However, let it be assumed that such a time lag as this did exist and consider how the existence of this time lag would affect fatigue experiments.

Consider a specimen loaded in accordance with the time load curve OA—a straight line—in Fig. 27, and suppose that the strain developed in this specimen, plotted on the same time basis, followed some such line as OB, i.e., a curve indicating that there was a definite time lag between the application of stress and the development of strain. Assuming that in a fatigue test on such a material, strain was regularly given opportunity to catch up to stress, the sequence of conditions might be represented by Fig. 29.

If the stress reversals were not delayed, Fig. 29 would represent the sequence of events, and, no account being taken of time lag, the material would be credited with having sustained fatigue limits AA, instead of which it would actually have failed between limits BB. The more rapid the tests, clearly the greater the discrepancy between AA and BB, i.e. the *higher* the ***apparent*** fatigue limits in relation to the *actual* fatigue limits. In other words, a machine having loading characteristics similar to Fig. 28 might be expected to give more truthful results than one having loading characteristics similar to Fig. 29.

This next illustration (Fig. 30), taken from *page 10* of Dr. Gough's book "The Fatigue of Metals",* showed that such variations in loading characteristics were not unusual in fatigue testing machines, while Table XIV from page 98 of Dr. Gough's book drew attention to certain striking differences in fatigue results obtained with two different types of machine.

TABLE XIV.

Comparison of results obtained on the Farmer and Upton-Lewis machines (Moore and Kommers).

Material.	Ultimate tensile strength tons/in.²	Limiting range of stress, tons/in.² Rotating beam.	plane bending.
0·02% C. Steel ...	18·9	±11·6	±10·3
0·37% „ ...	32·1	±14·7	±13·4
0·49% „ ...	42·8	±21·4	±17·4
0·52% „ (a) ...	43·8	±18·8	±14·3
„ „ (b) ...	49·8	±24·6	±19·7
0·93% „ (a) ...	37·6	±13·6	±12·7
„ „ (b) ...	51·4	±25·0	±19·7
1·20% „ ...	52·1	±22·3	±20·1
Nickel chrome steel ...	61·9	±30·4	±23·2

Moore and Kommers regarded these discrepancies as due to differences in the loading characteristics of the machines, a suggestion which supported the view that time-lag investigations were

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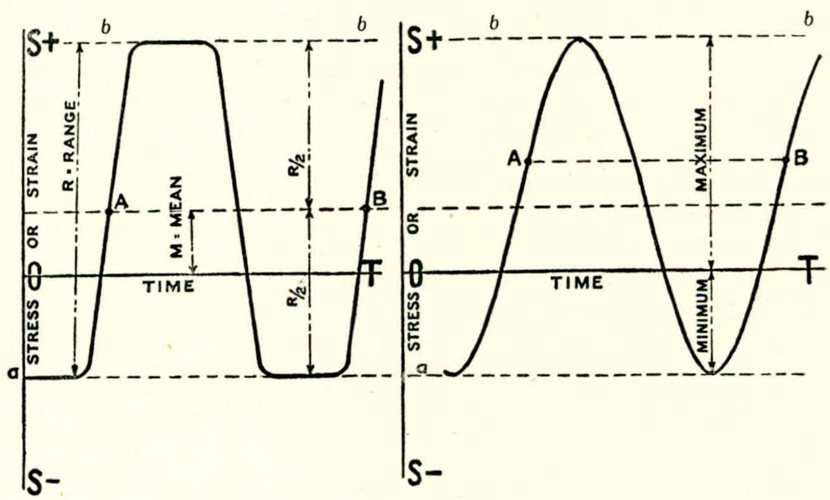


FIG. 30.

worthy of detailed research, since they might seriously affect apparent fatigue limits.

It had already been shown that logical development of the time-lag ideas put forward indicated that the "apparent" fatigue limit would rise with increase in speed of reversals. At one time the opposite idea was held (*see* Table XVII, taken from page 105 of Dr. Gough's book), and much work had to be done to prove that Reynolds and Smith were wrong (*see* also Table XVIII taken from page 106 of Dr. Gough's book).

TABLE XVII.
Reynolds and Smith's Results.

Material.	Speed (r.p.m.).	Fatigue range under reversed direct stresses (tons/in.^{2}).
Annealed mild steel ...	1,337	20·9
	1,428	20·1
	1,516	19·2
	1,656	18·1
	1,744	15·2
	1,917	12·4
Cast steel	1,320	20·1
	1,660	18·3
	1,820	16·8
	1,990	13·1

TABLE XVIII.
Summary of experiments on speed effect.

Experimenter.	Type of machine.	Material.	Speeds investigated.	Conclusion.
Eden, Rose and Cunningham	Rotary bending	Mild steel	600, 1,300;	No speed effect
		Vanadium steel	600, 1,300;	"
		Wrought iron	250, 620, 1,300	"
Haigh	Direct stress	70/30 brass	2,000, 3,600 5,760	"
Hankins	Rotary bending	Nickel	400, 2,000	"
Kommers	Plane bending	Mild steel	150, 750	"
Roos	Rotary bending	0·65% C. steel	1,200, 2,400	"
Stanton and Pannell	Rotary bending	Swedish iron, Axle steel, Spindle steel	200, 2,200	"
Moore and Jasper	Rotary bending	Armco iron, 3 Carbon steels, 5 Nickel steels, Chrome-nickel steels	200, 1,500 - 5,000	"

In Mr. Spanner's opinion Table XVIII was purely negative in its message, and could not be accepted as *proving* the *non-existence* of speed effect. Those engaged in disputing the results of Reynolds and Smith did not go sufficiently far, he considered, to discover that the earlier experimenters were not only wrong in their results, but actually were headed in the wrong direction.

Two tables taken from the ultra high-speed researches of Professor Jenkins unquestionably appeared to show a definite rise in the apparent fatigue limit with rise in speed of reversal, and added another link to the chain of circumstantial evidence put forward in support of the contention that time lag between stress and strain was a matter deserving very close study and investigation.

Tables from Professor Jenkins' Researches.

	R.p.m.	Fatigue limit.
Mild steel	3,000	16·3
	30,000	16·85
	60,000	17·35
A. carbon steel ...	3,000	22·7
	66,000	23·19
	330,000	24·18
	600,000	25·00
	900,000	26·95

Naval architects concerned with ships' hulls and marine engineers concerned with such items as boilers, rudders, propeller shafts and shaft brackets, were not so much interested in high speed reversals as in slow speed reversals, say, down to from 2 to 10 reversals per minute—a region which had been almost entirely neglected by fatigue specialists.

So far as could be discovered only two men had carried out experiments at these slow speeds—Bairstow and Mason. Bairstow's results were, in part, inconsistent with other data and had already been subjected to serious criticism. As for Mason's, it was significant that Mason found, in torsion tests, that the strain became greater when the speed of applying the cycles was reduced from 200 to 2 per minute, and became smaller again when the speed was increased, the stress remaining the same throughout. It was important to note, of course, that Mason stated that "this effect was absent when the strains were purely elastic". But it was equally important to note that highly accurate investigation of the time relation between stress and strain over ranges of stress from zero up to the fatigue limit, might prove that such results applied also to "elastic" strains.

Incidentally, stress-strain hysteresis phenomena also tended to suggest the possibility that time-lag might be a very important factor in fatigue experiments?

To sum up, Mr. Spanner was strongly of the opinion that systematic research at slow speeds of reversal—say, down to from 2 to 10 per minute—would prove that there were possibilities, hitherto unsuspected, of failure at comparatively low stress amplitudes at low speeds of reversal. The point was one of very great importance to ship designers, especially in view of the increasing use of welding in ship hull construction. Naval architects knew that lag of strain behind stress had been detected when ships were launched. Further, they had occasionally to face failures of parts of ship structures in circumstances in which it was difficult to reconcile failure with existing data on fatigue values. Recently a welded vessel had been lost. The cause of her loss was problematical, but the possibility existed that her longitudinal welded joints might have failed under slow speed reversals. Specialists in fatigue research could not yet point to any experiments which proved conclusively that slow speed reversal was not more serious in its effects than high speed reversal. It was possible, on the other hand, to make a strong case, based partly on logical development of elementary physical ideas and partly on circumstantial evidence, to prove that fatigue limits were likely to be lower at slow speeds of reversal than at high speeds of reversal.

Mr. Spanner asked the Authors to consider these comments very seriously. He hoped that Dr. Gough would decide to initiate a series of highly accurate stress-strain tests aiming at determination of the time-lag between stress and strain. Data on this point might avoid spending a long time waiting for slow speed tests, and at the same time provide a key to the solution of many problems which were baffling at the moment. Meantime, Mr. Spanner was very dubious indeed of the value to naval architects of fatigue tests carried out on modern machines at high speeds of stress reversal.

Eng. Lt.-Com'r. V. Lockney, S.R., R.N. (Member) said that Dr. Gough and his colleague had presented a very interesting paper on a subject of vital importance to-day, particularly in view of the fact that engineering developments were demanding better quality materials. This led to the use of newer and more complex materials, and as a result of the activity of the metallurgists, materials having new characteristics were being constantly presented.

The days when the bulk of material testing was confined to 28-32 tons steel and 26-30 tons steel were fast disappearing, and this had necessitated the development of new and more involved technique of the testing of materials.

The Authors made some remarks on the question of testing materials at high temperature. So much investigation had already been done in this field that there was now a very voluminous literature on the subject. The speaker would have liked the title of this section of the paper to have read "The Testing of Materials for High Temperature Service", because the title as given in the paper was only a part of the wider subject which was covered in the title he had suggested, some tests of materials for high temperature service being carried out at room temperature.

In discussing tests of material for high temperature service, there were, he thought, two distinct and separate motives to be taken into account:—

(1) Tests on a new material to see if its properties were such that it was likely to give good service under working conditions;

(2) Routine or acceptance tests on material made to a specification which had given satisfactory results in the preliminary tests.

Experience with very high temperature work was still rather limited, and it followed that they had not reached the stage where high temperature materials were so well established as, say, 28-32 tons steel. Therefore, as new materials came forward, it was necessary to subject them to a schedule of tests which would indicate, with reasonable assurance, that the material would be suitable for its purpose. He had hoped that the Authors would indicate what they considered a suitable schedule of such preliminary tests, but as they had not done so he would suggest such a series and looked forward to a thorough criticism of it by them. He suggested that when a new steel was put forward for high temperature service, the following preliminary tests should be carried out:—

(1) The N.P.L. creep limit, i.e. the stress which gave a rate of elongation of 10^{-5}in. per inch per day after 40 days, should be determined for at least three temperatures, namely, working temperature, 50° C. above working temperature and 50° C. below working temperature.

(2) Embrittlement tests. After taking the impact value on normalised material at room temperature, the impact value should be taken on specimens of standard section which had been subjected to working stress at three temperatures as in (1) for long periods, say 20 or 40 days.

(3) Impact tests should be carried out on unstressed specimens at working temperature.

(4) Ultimate tensile strength and elongation at room temperature at standard rate of loading.

(5) Ultimate tensile strength and elongation at working temperature at standard rate of loading.

(6) Gaseous corrosion tests for parts to be exposed to furnace and flue conditions.

(7) Micro examination of specimens which had been subjected to working stress at various temperatures for long periods, in order to see to what extent spheroidisation had occurred, as it was understood that the resistance to creep was reduced where spheroidisation had occurred.

He suggested that such tests should be carried out on two sets of specimens within the range of chemical composition which was likely to be met with when producing material in large quantities. The results of such tests on a new material could be laid down as standard for that particular material, its identity being determined by chemical composition. Routine tests on such material should take the form of comparing results with the standard laid down as described above.

In routine tests time was generally an important factor, and here a difficulty arose because, whilst it was very desirable to verify the creep properties of the material which was presented, he personally was not at all sure that it was possible to compare any short time creep test results with long time results. In one case he had examined he found that the short time creep limit of a given material was lower at low temperatures and higher at high temperatures than the N.P.L. creep limit.

The requirements, then, of routine testing should be :—

(1) To verify the creep properties, but frankly he was doubtful about the value of any known short time creep test. Perhaps, however, Dr. Gough could give some guidance here. In this connection he would like to ask whether, in the Authors' opinion, similarity of tensile properties at high temperature would ensure similarity of creep properties and, if so, whether short time creep tests could be dispensed with.

(2) The ultimate tensile strength at working temperature should be taken and compared with the standard.

(3) The ultimate tensile strength at room temperature should be taken and compared with the standard.

(4) The impact value at room temperature should be taken and compared with the standard.

(5) An embrittlement test such as described for the preliminary tests, but in order to shorten time it should be carried out on specimens which had been subjected to higher stress at working temperature for a shorter period. He thought that experiment could determine a suitable relationship of stress and period for this purpose.

(6) Micro examination of the specimen in (5).

He would be interested to have the Authors' remarks on these proposed schedules.

On page 243 of the paper the Authors mentioned a schedule which included the determination of limit of proportionality and proof stress at high temperatures. So far as the speaker had been able to discover from stress-strain curves at high temperature which he had examined, there was no clearly defined limit of proportionality such as they knew in tests carried out at atmospheric temperature; the use of the term was therefore misleading and was, he thought, liable to give a false confidence in the material. Similarly, he failed to see that any useful information was derived from the proof stress, i.e. the stress which gave a particular permanent set at a standard rate of loading.

Before leaving the subject of high temperature tests, he would mention that there were so many different definitions of limiting creep stress, no two of which meant quite the same thing, that it was a matter of real difficulty to assess and calculate a factor of safety where the working stresses were known, and a real service would be rendered to engineers when people of the calibre of the Authors threw some of these overboard and standardized a creep definition—or possible two, a long time one and a short time one.

One final word on creep. He observed the Authors' comments on the increasingly common practice of carrying out creep tests at the actual working stress, and he specially noted that the words "actual working stress" were in italics as they should be. These tests might, he thought, give useful additional information after the N.P.L. creep limit had been taken, but alone would be of next to no value.

The whole object of this type of testing was to try and produce in the specimen, in a short time, the type of deterioration which would occur in service, and the only test at working stresses and temperature which would be of any value would be one carried out for a length of time equal to the anticipated life of the boiler or superheater as the case might be.

There was another phase of this subject of the testing of materials which had not been dealt with in the paper, but which was rather interesting. The Authors would no doubt be aware of the suggestion coming from certain eminent authorities, that tensile tests should be carried out with a view to determining the lower yield point of a material rather than its ultimate tensile strength and elongation. This suggestion was forcibly put at last year's meeting of the British Association, and it would be interesting to know the views of the Authors on this point. The speaker remembered also that at this meeting another startling claim was made, namely, that by suitably "nursing" a testing machine when carrying out a limit of proportionality test, a limit of proportionality could be obtained which was higher than the true limit of proportionality and might even be higher than the ultimate tensile strength. This sounded rather fantastic, but it was seriously maintained by the authority in question, and some comment by the Authors would be enlightening.

Mr. H. J. Vose (Vice-President) said that if high tensile steel for structural purposes was "regarded with the gravest suspicion in this country", it occurred to him that the Authors might get one of the midship shear strakes of the "Mauretania" and subject it to tests. A lot of useful information would be obtained, as these plates were made of special high tensile steel and had been subjected to various stresses for twenty-five years. It would be interesting to get their present condition and structure.

In Table I the special steel had an elongation figure of 23 as against 27 for the mild steel. This seemed a low elongation for a special steel, and it would be a definite factor in the results obtained in the tests.

With regard to creep specimens, Mr. Vose would like to know whether the fractures of these specimens were transcrystalline or intercrystalline. Were they one or the other, or both?

The theory of caustic embrittlement came from America, and like some other things from that country required full investigation. Mr. Vose did not favour it as a general theory. Many years ago, when in the service of a boiler insurance company in the northern districts, he went to the works of a number of firms who did a great deal of commercial caustic work. Some of the keirs had been working for forty years and the insides were coated with caustic soda—yet they showed no signs whatever of failure or fracture. The pressures and temperatures certainly were not of a high order. He had come into contact with many failures of boiler plates, and in one case the theory of caustic embrittlement had been put forward. The seam which failed was in the steam space; other seams in the water space were found on test and examination to be perfectly good and normal. It was a pure fatigue fracture. He did not think it was fully investigated as far as intercrystalline fracture was concerned, but he thought it would be intercrystalline and not transcrystalline. He thought that in a good many other cases which had been put down to that cause, further investigation would have shown that the fractures were due to something else, such as some of the causes which had been mentioned that evening—for example, surfaces coming together and corroding due to the formation of oxide. In a boiler shell the material was rolled into a ring, imposing stress upon the structure beyond the elastic limit, and at the joints this was intensified by the riveting machine. He wondered whether the orientation of the crystals had been adversely affected by this (as suggested by the Authors and shown on one of the slides), resulting in an initial fracture in the plate, or perhaps by some of the other causes mentioned in the paper, and not by caustic embrittlement. It would appear that some plates were more susceptible to damage than others, though the reason for this had not yet been accurately determined.

On the proposal of **Eng. Rear-Admiral W. M. Whayman, C.B., C.B.E.,** a very cordial vote of thanks was accorded to the Authors.

The Authors' Reply to the Discussion.

The Authors, in reply, stated that they would first record their great appreciation of the cordial reception given to the paper, of the extremely interesting discussion which followed and of the very kind references which have been made by the various speakers.

Dr. Dorey drew attention to the discrepancy that might exist in some cases in service, between "nominal" and "actual" values of working stress in the neighbourhood of stress concentrations in parts subjected to high temperature service. Very little, if any, systematic work had been done on this aspect, but it was almost certain that the effect of such concentrations would be less than in equivalent static or fatigue conditions at atmospheric temperatures. For, at such high temperatures, the metal was in a condition approaching the plastic state and the "creep" set up initially due to the stress concentration, would itself result in a local change of shape of the discontinuity producing the concentration and thus lessen its effect.

The Authors agreed with Dr. Dorey—and other speakers—that the establishment of a "short-time" test of proven reliability would be invaluable, but no such test had yet been made available. In answer to the question relating to embrittlement tests after creep, these were usually made in two ways: (*a*) by notched bar impact tests on specimens, and (*b*) by a careful microscopical examination to determine the type of fracture and the course of the cracks. With regard to the study of stresses and strains arising from plastic bending, it could not be said that the results were directly applicable to the problem of heat transmission stresses in tubes, although the general lessons gained would, no doubt, be found useful in this connection. The Authors agreed entirely with Dr. Dorey's remarks on the possible effect of the yield stress on the fatigue limit of specimens with and without stress concentrations and were glad to note that the scheme of tests adopted met with his approval.

Contact-corrosion was undoubtedly a subject of considerable engineering importance and the example which Dr. Dorey had quoted was very interesting and typical of this phenomenon. It did indeed appear probable that pitting in turbine gears might be partly set up in this way; as Dr. Dorey remarked, intensely high local pressures might be induced which caused a local breakdown of the oil film. "Size effect" was undoubtedly a matter of great importance in fatigue testing. As Dr. Dorey pointed out, some German experiments had indicated that this effect was encountered even when smooth specimens of uniform section were employed; on the other hand, certain American experiments did not support this conclusion; thus more research was urgently required to settle this important point. When specimens containing discontinuities of section were concerned, there was practically no doubt whatever that a serious "size effect" obtained. Dr. Dorey's experiences on the cracking of boiler plates were very valuable and of extreme interest. Apparently, caustic embrittlement was not a serious problem to the marine engineer. It was agreed that the other factors mentioned—lack of heat treatment, work hardening during manufacture, etc.—might lead to serious trouble.

Dr. Dorey's experience of cases where wrought iron had given better performance than steel under corrosion-fatigue conditions, agreed with the experiences of others; it was possible that the slag streaks present in iron tended to retard or prevent the progress of spreading cracks. With regard to the investigation involving complex-stress distributions, the Authors were in complete agreement with Dr. Dorey's view that cases other than reversed cycles of stress were of great engineering importance; it was hoped to attack the general problem of complex fatigue stresses at the N.P.L. in the very near future. A full description of the methods adopted at the Laboratory in the determination of internal stress, also crack determination by magnetic methods, would make unjustifiable demands on the present space, but, during one of Dr. Dorey's very welcome visits to Teddington, these methods would be exhibited to him.

Mr. Spanner drew attention to the fact that in some cases of engineering practice where cyclic stresses were involved, the frequency of the cycle might have much lower values than those usually employed in laboratory fatigue tests; he suggested that the results of the latter were not, therefore, directly applicable to design and urged that much slower cyclic speeds should be investigated. The Authors agreed that no strictly comparable test data had yet been obtained, but ventured to point out the enormous time that would be required for the determination of the fatigue limits of, say, half-a-dozen materials at a speed of less than 10 cycles per minute. His suggestion of a systematic research at such low cyclic frequencies, must, they feared, be regarded as impracticable, certainly as far as the N.P.L. was concerned. Unless certain fundamental principles were to be abandoned—and Mr. Spanner had advanced no evidence to warrant such action—the Authors regretted that they were unable to accept some of Mr. Spanner's contentions.

Surely, no one had ever suggested that the effect of a load suddenly applied at the end of a steel rod of 1,000ft. in length would be *instantaneously* felt throughout that length! It should be unnecessary to remind Mr. Spanner that, assuming elastic conditions prevailed, the stress waves set up and their velocity were directly calculable. Similarly, with regard to his previous point, it was difficult to imagine how there could be any lag, at a specified point in the material, of the stress and strain *at that point* if elastic conditions obtained; were not stress and strain interdependent? Neither could they agree that the above arguments were at all relevant to "speed effect" in fatigue testing. But assuming *plastic* conditions were involved, they agreed that errors in calculated values of nominal stress might cause pitfalls to the feet of the unwary. For example, consider a small test specimen undergoing cyclic strains at high frequency. If the observed strain was multiplied by Young's modulus (or its equivalent) the deduced stress value might be in excess of the real value due to hysteresis effect, but this was merely an error of calculation.

Again, the difference in values between the last two columns of the Table (XIV) quoted by Mr. Spanner might have no bearing whatever on "time-lag"; in the first place machines of different types were employed, also the stress distributions in the two types of specimen—rotating bar and plane bending—were quite different. The Authors were conscious and regretted that the above remarks were unlikely to satisfy Mr. Spanner with regard to the points he raised, but such differences appeared to exist on certain fundamental premises that a more prolonged discussion would probably not be helpful.

The range of discussion covered by Eng.-Com'r. Lockney was so wide and important that it should receive a much more extensive reply than the present space would permit; they must content themselves with an endeavour to answer the main points raised in this valuable contribution. The Authors agreed entirely with the suggested general scheme that, in the case of a new material for high temperature service, two main series of tests should be made, i.e. a general preliminary investigation, followed (in the case of a suitable material) by a series of acceptance tests. They also agreed entirely with the schedule of tests proposed for the preliminary investigation, and would comment on test (7) that not only should "spheroidisation" be studied, but also any tendency of the material to fail by intercrystalline cracking which was an insidious and dangerous form of embrittlement. They must point out, however, that subsequent batches, identically similar in chemical composition, *might* not give identical creep properties; existing N.P.L. test data showed that differences in manufacture might modify seriously the creep characteristics developed. The difficulty to which Com'r. Lockney referred in connection with routine tests—that, as yet, it was impossible to rely on short time tests as an index to long time creep behaviour—was a real one; much research attention was being given to the attempt to reconcile this discrepancy. Thus, with regard to the first routine test that was suggested, it was doubtful whether a creep test of medium length could yet be dispensed with. Agreement was expressed with routine tests Nos. 2, 3 and 4. With regard to the embrittlement test, listed as routine test No. 7, it was very doubtful whether the "time" factor could be reduced by an "equivalent" higher value of "stress"; they agreed with the speaker that much further experiment was required before a definite conclusion could safely be reached. They were in entire agreement with Com'r. Lockney in his scepticism of the real validity of "limit of proportionality" and "proof stress" in short time tests. At the N.P.L. the values obtained were regarded as of use only for purposes of general information and could be applied to design only with the very greatest reserve and after the most careful consideration. There was no doubt that the use of the term "limiting creep stress" had caused much confusion. Some had assumed that the term indicated a stress at which creep *ceased* after the period stated; such an interpretation was entirely false and unjustified and the time had probably arrived when inexact terms of this sort should be abandoned entirely. With regard to the "lower yield stress value" of a material, there was no doubt that a knowledge of this was very useful in design. Assuming that plastic deformation had occurred but that the total yielding deformation had not been reached, then a valuable indication was given of the probable stress remaining in the material at that amount of set provided the external straining action was still applied. Fig. 4 of the paper made this point clear. But as Com'r. Lockney reminded them, the form of the stress-strain curve, when plastic conditions prevailed, was dependent on the rate of straining, i.e. due to "viscosity" effects and "strain-hardening" the "time" factor was involved; in this field also, much further work was required before they could visualize clearly the process in operation.

In reply to the valuable contribution by Mr. H. J. Vose, a possible misapprehension might first be cleared up. The remark in the paper with regard to the suitability of high tensile steel for structural purposes was not meant, necessarily, to represent the views of the Authors of the paper; it referred to a prejudice in the minds of engineers in general against the substitution of such steels for mild steel until the merits of the newer materials had been amply demonstrated. However, in view of the responsibility involved, such a conservative attitude appeared quite justifiable. It would indeed be interesting to examine the structure and properties of material taken from the midship shear strakes of the "Mauretania" to which Mr. Vose referred; the Authors would welcome an opportunity to make such an examination. With regard to the type of fracture of steels tested at high temperatures, no general statement could be made. In general, at *very* high temperatures, the fracture tended to change over to the "intercrystalline" type from the "transcrystalline", the latter being the more normal type for engineering materials of construction at working temperatures and stresses. It was probably safe to say that, under working stresses, an "intercrystalline" type of fracture would be regarded as undesirable and one to be avoided. In *any* fracture, the line of separation might appear to follow the crystal boundaries for *some* part of its length. The experiences of Mr. Vose with regard to caustic soda were extremely interesting and fitted in exactly with similar experiences of others; the present state of knowledge certainly indicated that a definite value of concentration marked a danger zone, while lesser or greater concentrations might be relatively harmless. The view of Mr. Vose that fatigue, as such, was often responsible for failure received considerable support, e.g. from McAdam's experiences of boiler failures in the U.S. Navy. In general Mr. Vose did not agree with the oft-expressed view that "caustic embrittlement" was the most common cause of boiler failure in this country; Mr. Vose's opinion would receive general support.

In conclusion, the Authors would repeat their appreciation of the very kind reception afforded to the paper, which amply repaid the efforts devoted to its preparation. It was apparent that many of the current N.P.L. researches to which reference had been made were of direct interest to marine engineers in their professional work and, perhaps, the paper might have performed a useful object in drawing attention to the research and test facilities which were available at the National Physical Laboratory for the elucidation of problems which might be encountered by designing and operating engineers.

INSTITUTE NOTES.

ELECTION OF MEMBERS.

List of those elected at Council Meeting held on Monday, November 4th, 1935.

Members.

Leland Stanford Andrews, 13, Hillcrest Place, Hudson Heights, New Jersey, U.S.A.

Frederick Austin Bell, 58, Norfolk Road, Byker, Newcastle-on-Tyne.

George Brabender, The Harbour Engineer's Dept., Colombo, Ceylon.

Cecil Ernest Cloudsdale, 74, Hurstwood Road, Sunderland.

Edmund Clough, 10, Halton Bank, Pendleton, Salford, 6, Lancs.

David Frank Cormack, 111, Croydon Road, Beddington Estate, Surrey.

Frank Willian Cuer, 16, Fairfield Avenue, Peverell, Plymouth.

Gordon James Donovan, 22, Rankine Road, Torrensville, South Australia.

Bernard Stanley Everett, Bungalow 142, c/o The Burmah Oil Co., Chauk, Upper Burma.

Vincent Leonard Harlow, 85, Exeter Road, Southgate, N.14.

Peter Millar, 140, New Street, Musselburgh.

Robert Neesham, 18, Park Grove, West Ham, E.15.

John Stobbs, 9A, Dorbett Drive, Great Crosby, Liverpool.

Frederick William John Webb, 6, Whorlton Road, Peckham, S.E.15.

William Thomas Williams, Engineer Surveyor-in-Chief, Board of Trade, Great George Street, S.W.1.

Associate Members.

George Whyte Cowie, 11, Wellington Street, Montrose.

William Alexander Hutcheon, Dockyard Superintendent, Irrawaddy Flotilla Co., Ltd., Moulmein, Burma.

George James Nicholson, 77, Cedar Grove, Yeovil, Somerset.

Charles Stewart Parnell, 1, Mansted Gardens, Chadwell Heath, Essex.

Associates.

Edward Alexander Chard Daniell, Ellerslea, Hursley Hill, Whitchurch, Bristol.

Harry Frederick Keen, 14, Burton Road, Kingston-on-Thames, Surrey.

Students.

Leonard F. Butler, 111, Alpha Road, Millwall, Poplar, E.14.

Frank George Moore, 162, Elmbridge Avenue, Berrylands, Surrey.

Braham Swarup Sood, 15, Tankerville Terrace, Newcastle-on-Tyne, 2.

George William Turner, 140, Ashgrove Avenue, Cleadon Park, South Shields.

Transfer from Associate Member to Member.

Thomas Telfer, 176, Gateside, Greenock.

Transfer from Associate to Associate Member.

Frank Alfred James Larter, 11, Ravenscourt Square, Hammersmith, W.6.

Transfer from Student to Associate Member.

George Alexander Gray, Invercloy, Mill Road, Yoker, Glasgow.

Edwin Charles Plastow, 89, Convamore Road, Grimsby, Lincs.

Ivor James Evans, 17, Stephenson Street, Riverside, Cardiff.

ADDITIONS TO THE LIBRARY.

Purchased.

Air Raid Precautions Handbook No. 7: Anti-Gas Precautions for Merchant Shipping. H.M. Stationery Office, 3d. net.

Report of the Court into the circumstances attending the loss of the s.s. "Millpool". H.M. Stationery Office, 10d. net.

King's Regulations and Admiralty Instructions—Amendments 4/35 and 5/35. H.M. Stationery Office, 3d. and 4d. net respectively.

Review of Oxidation and Scaling of Heated Solid Metals (Department of Scientific and Industrial Research). H.M. Stationery Office, 2s. 6d. net.

Presented by Mr. John McLaren (Vice-President).

"Dredging of Harbours and Rivers". A work of descriptive and technical reference combining hydrography, dredging, hydraulics and seamanship, by E. C. Shankland, F.R.S.E. Brown, Son & Ferguson, Ltd., Glasgow.

Presented by the Publishers.

Board of Trade Notice No. M.146. Prevention of Fire in Cargo Ships using Oil Fuel.

Munro's Engineer's Annual, 1936. James Munro & Co., Ltd., 191pp., illus., 2s. 6d. net.

Ohio State University Bulletin No. 89 on "The Flow of Water through Orifices".

"Science in Parliament—Questions in the House of Commons".

The British Electrical and Allied Industries Research Association: Sub-Committee J/E: Joint Committee: Steels for High Temperatures: Particulars of Manufacture of Carbon Steels (Tested in normalised conditions); Bibliography of literature on the behaviour of steels at high temperatures, furnished by "The Engineering Index Service".

Nickel Bulletins on "Recommended Materials for Electrical Appliances" and "Heat-treatment of Nickel-Aluminium Alloys".

New Zealand Government (Marine Department)—Safe-Working Loads (Departmental Tables governing the Safe-working Loads for Chains and Ropes).

Report of the Operations of Lloyd's Register of Shipping for the year 1934-1935.

Institute of Metals: Metallurgical Abstracts, Series II, Vol. I, 1934.

The Journal of the Institute of Metals, No. 1, 1935, Vol. LVI, containing the following papers:—

- "Corrosion-Fatigue Properties of Duralumin with and without Protective Coatings", by Gerard and Sutton.
- "Some Further Experiments on Atmospheric Action in Fatigue", by Gough and Sopwith.
- "The Effect of Five Years' Atmospheric Exposure on the Breaking Load and the Electrical Resistance of Non-Ferrous Wires", by Hudson.
- "Unsoundness in Aluminium Sand-Castings. Part III. —Solidification in Sand Moulds under Pressure", by Hanson and Slater.
- "The Reduction by Hydrogen of Stannic Oxide Contained in H.-C. Copper", by Alkins and Hallowes.
- "Alloys of Magnesium. Part II.—The Mechanical Properties of Some Wrought Magnesium Alloys", by Prytherch.
- "The ϵ, γ, and β Phases of the System Cadmium-Silver", by Durrant.
- "The Constitution and Properties of Cadmium-Tin Alloys", by Hanson and Pell-Walpole.
- "Some Properties of Tin Containing Small Amounts of Aluminium, Maganese, or Bismuth", by Hanson and Sandford.
- "Type Metal Alloys", by Weaver.
- "The Penetration of Steel by Soft Solder and other Molten Metals at Temperatures up to 400° C.", by van Ewijk.
- "The Spectrographic Analysis of Aluminium", by Smith.
- "Atomic Arrangement in Metals and Alloys", by Bragg.

The Institution of Civil Engineers: Selected Engineering Papers as follows:—

- "The Construction of the New Sea-Locks of the Crinan Canal", by Weston.
- "Depreciation of Plant and Machinery", by Ingham and George.
- "Photo-Elastic Investigations of Sheer-Tests of Timber", by Coker and Coleman.
- "Manœuvring of Single-Screw Ships: The Effect of Rudder Proportions on Manœuvring and Propulsive Efficiency", by Bottomley.
- "The Bridges of the Egyptian State Railways", by Hopkins.
- "The Survey and Reconstruction of the Lyme Regis Sea Defences", by Clark.
- "The Theory and Design of Propeller-type Fans", by Poole.
- "Catenarian Functions", by Watson.
- "Caisson-Sinking at Plantation Quay, Glasgow", by Mallagh.

"Canals and Canalized Rivers", by Saner.
"Military Bridging", by Sayer.
"The Construction of Two New Canals for Inland Navigation in the Netherlands", by Wentholt.
"Hydro-Electric Power Development on the Rhine", by Gruner.
"Modern Methods and Plant for Excavations", by Japp.

"Electrical Measurements in Principle and Practice", by H. Cobden Turner and E. H. W. Banner, M.Sc. Chapman & Hall, Ltd., 354pp., 219 illus., 15s. net.

This book has been written primarily for those engineers and others who are concerned with the application of electrical measuring devices to specific purposes, but who do not require a textbook involving such mathematical theories of operation as are essential to the student and research worker. The reviewer considers that the authors have succeeded admirably in their aim. The subject matter is particularly detailed and eminently practical in outlook. The range of the work may perhaps be judged from the fact that the table of contents occupies more than four pages in small type and the index occupies a similar number of pages. The book is divided into five parts as follows:—

(*a*) Units and standards.
(*b*) Measuring instruments, testing sets, frequency and power factor indicators, Wattmeters, oscillographs, potentiometers, etc.
(*c*) Measurement of current, voltage, power, energy and quantity.
(*d*) Measurement of resistance, impedance, inductance, capacitance and magnetic quantities.
(*e*) Indirect electrical measurements, pyrometers, light speed, boiler house tests, fault testing, etc.

The above brief summary only gives a vague idea of the scope of the book. It can be cordially recommended to the notice of all electrical engineers and students, and to all types of engineers whose duties involve the use of electrical instruments either directly or indirectly.

"Inventing the Ship" and "The Sociology of Invention", both by S. C. Gilfillan, Ph.D., of Columbia, America, sometime Instructor of Social Sciences in the Colleges of Grinell and Sewanee, and Curator of Ships and of Social Science and Industry, Chicago. Follett Publishing Co., 1257 S. Wabash Avenue, Chicago, illus., $2.50 and $2 (postpaid) respectively.

These are curious books, the first a treatise on the evolution of the merchant ship, tracing this from "her very origin in the floating log . . . down the main lines of her genealogy . . . . to to-day's rotorship"; the second, an ambitious attempt to establish certain "principles" in respect to "invention" for which the author claims a respectful hearing.

With the first book those who are intensely interested in marine affairs can spend a very entertaining hour or so, although there are quite a number of statements throughout the volume which tend to deprive it of authority, lack of detailed study of the practical achievements of shipbuilding firms and a too ready acceptance of mere hearsay (or its equivalent, specialist publications) having led the author to attach undue importance to particular developments of less value than the Author would evidently have his readers believe.

Perhaps the best example of this tendency in the book is Mr. Gilfillan's extraordinary belief in the rotorship. It will be remembered that Flettner published a book "The Story of the Rotor". This has evidently been studied very closely by the Author, who appears to regard Flettner's work as of outstanding importance in relation to ship design, a curious opinion in view of the present attitude of practical shipbuilders and shipowners towards this particular invention.

Provided that one takes care to preserve a balanced judgment when considering Mr. Gilfillan's statements, and is prepared to investigate independently the evidence he quotes in a very voluminous bibliography—and a great many other books which have not been mentioned by the Author—there is much in this book to afford interest. Most emphatically, however, it is not a book for young students of shipbuilding or marine engineering.

The second volume, "The Sociology of Invention", is an extremely puzzling book. It appears to have been written after the Author had completed the compilation of all the data from which he had prepared "Inventing the Ship", and consists of an attempt to establish what the Author terms the "38 Social Principles of Invention", mainly by statistical investigation of the mass of Patent material collected for the other treatise.

It is a most difficult book to understand, normal grammatical construction having been departed from in so many instances that it is quite a problem to determine precisely what the Author is intending to say. As with "Inventing the Ship", however, there is much to interest a mature reader, even if Mr. Gilfillan's message is occasionally obscure.

Both books are published by the Follett Publishing Company, Chicago. The first-named book costs $2½, the second $2. The first book is by far the better value.

"Seaplane Float and Hull Design", by Marcus Langley. Sir Isaac Pitman & Sons, Ltd., demy 8vo, cloth, 128pp., illus., 7s. 6d. net.

The Author, in stating that this work is intended primarily for the use of students, complains that there are "advanced books and technical papers which assume too much initial knowledge, or which rush over it too quickly". But this complaint can be applied to the Author's own work. The basic principles of displacement, moments, centres of gravity and buoyancy, transverse and longitudinal stability and metacentres are condensed into 13 pages (only half-a-dozen lines are given to the exposition of the transverse stability of a twin float system) whilst the initial formula in the book contains the symbols of the calculus.

In any sphere of learning a complete knowledge of the fundamental laws is essential, and no student would derive much benefit from Mr. Langley's book unless he first thoroughly acquainted himself with the elementary principles of hydrostatics and hydromechanics. But having so equipped himself, the student will find this textbook of considerable assistance in his further studies.

The chapter on tank testing contains carefully arranged information which should prove of interest to a wide class of readers, including those who are engaged in the design of high speed launches and motor boats. In this chapter, however, the Author does not discuss the phenomena of porpoising, the effect upon stability following alterations in the longitudinal step angle, or the effect of change in the pitching moment of inertia upon disturbed motion and such similar considerations which vitally concern the experimentalist, and upon which knowledge is eagerly sought.

The latter portion of the book dealing with the more practical aspects of float and flying boat hull design is informative and concisely written, and will no doubt prove very useful to those aeronautical draughtsmen who desire to gain a working knowledge of some of the problems involved. In addition, much care has been taken by the Author in collating and generalizing information relating to structural and equipment weights, to loading ratios and coefficients and to performance data; as a source of reference, this section of the book will be of value to chief draughtsmen and members of designing staffs in the preparation of their preliminary lay-outs and estimates.

The book suffers from over-compression, and the Author's neglect to treat many of the important considerations and problems attaching to hull and float design, detracts somewhat from his otherwise commendable effort to fill a long-standing gap in the literature of æronautics.

"Modern Heavy Oil Engines Simply Explained", by R. Bernard Way. Percival Marshall & Co., Ltd. 267pp., illus., 5s. net.

The Author states in his preface that the object of this book is to describe the working principles of the oil engine with a minimum of technical terminology. He also expresses the hope that the book will be of interest to the technical man. The first of these objects has undoubtedly been obtained, and the Author can be congratulated on producing a book which should prove of great value to the non-technical man, while it will also give many students and qualified men much information which, if not entirely new, is served up in a very readable style.

The book is divided into sections covering stationary engines, marine, road, and rail transport. With the limited space at his disposal the descriptions of the engines are necessarily short and concise, but are well illustrated with numerous drawings and sketches.

In the chapter dealing with the history of the oil engine the Author stresses the work of Akroyd Stuart, who was undoubtedly the pioneer of the heavy-oil compression-ignition engine—particularly the airless-injection type. It must, however, be borne in mind that the tremendous advances which have been made are largely due to the experience gained with air-injection engines which one associates with the work of Dr. Rudolph Diesel, and also that of Emil Capitaine.

Since the Author says that he is trying to give special prominence to British engines, it is a pity that the Doxford engine is not mentioned; also it should be remembered that while many of the well known Continental engines are foreign in origin, yet many improvements have been due to the work of British engineers building these engines in the British Isles, and vice versa.

To many the chief interest in the book will be found in the excellent presentation of most types of small modern high-speed engines. There is a tendency for the mind to keep in ruts and, in consequence, to miss the sweep and perspective of the wide spaces of progress. To many this book will prove a revelation as showing how wide has become the application of the heavy-oil engine to all classes of service, and how variable is its design in the smaller type of engine—particularly in combustion chamber design.

While not perhaps to be classed as a textbook, it can be cordially recommended as a good introduction to those who are taking up the subject, while its pages will be of interest to those with more detailed technical knowledge.

"Lloyd's Calendar, 1936". Lloyd's, London, E.C.3, 828pp., 3s. 6d. net, postage extra.

As usual "Lloyd's Calender" for 1936 contains a mass of standard information of everyday importance and utility to Masters, and those directly concerned with shipping.

This year special attention has been given to the Atlantic traffic, interesting inclusions being details of the "Blue Riband", articles on the "Mauretania", and an account of the tracks taken by North Atlantic passenger vessels at various seasons of the year.

Another section of particular interest brings together information with regard to docks, arbitration cases of salvage and collisions, and notes on salvage vessels and appliances available at many of the principal ports of the world.

If anything the indexing of this volume, which runs to some 828 pages, has been improved, so that ready access can be obtained to the wide variety of data which it contains.

"Fuels—Solid Liquid and Gaseous", by J. S. S. Brame, C.B.E., and J. G. King. Fourth edition. Edward Arnold & Co., 422pp., illus., 25s. net.

First published in 1914, the third edition of this book was issued in 1924. During the last decade, however, development in combustion technique has been so great as to call for complete revision and extension to bring it up-to-date. Hence this fourth edition.

The use of coal for steam raising purposes has been strongly challenged by oil; in the marine field in particular, coal has steadily declined for many years. Latterly, however, great efforts have been made by the protagonists of coal to meet the challenge.

One of the principal attributes of liquid fuel lies in its mobility and ease of being mechanically fired, characteristics to which oil owes its superiority over coal for many services. Efforts to overcome this deficiency of coal have resulted in the development of such processes as pulverising, coal-oil suspensions and to the production of fuel oils by the treatment of coal by the hydrogenation process.

Turning to fuels for internal combustion engines, no section of fuel technology has been the subject of more research than this, particularly since the introduction of the high-speed engine. The "anti-knock" properties of petrols and the expression of this characteristic in the form of "octane numbers"—the ignition temperature and delay period of heavy fuels for Diesel engines—are subjects among many others of primary importance to engineers at the present time.

The work under review, therefore, will not only appeal to engineers concerned with the latest developments of fuel technology, but is to be thoroughly recommended as a work of outstanding merit to engineers generally. It is divided into four parts. The first, dealing with solid fuels, contains an introductory chapter followed by one chapter on wood peat and minor solid fuels. Coal is covered in four chapters under the headings "Coal and its Constituents", "Coal—Composition and Classification", "Commercial Varieties of Coal", and "Treatment and Storage of Coal; Briquettes and Powdered Coal". The section on solid fuels is completed by a chapter on cokes.

The second part deals with liquid fuels and opens with a chapter entitled "Composition and Characters of Fuel Oils", followed by "Systems of Burning Oil Fuel". The lighter fuels, petrol, gasoline, benzole, alcohols and fuel mixtures are covered in two chapters, and the section concludes with a treatise on heavy fuels for internal combustion engines.

The third part, gaseous fuels, treats of coal gas and coke oven gas, gaseous fuels of low calorific value, water gas and total gasification, and producer and blast furnace gas, while the fourth part comprises three chapters entitled "Fuel Analysis", "Determination of Calorific Value", and "Purchase of Fuel and Control of Combustion".

An appendix contains several useful tables. The book is well illustrated and contains numerous references to research.

"Strength of Materials", by F. V. Warnock, Ph.D., B.Sc. Sir Isaac Pitman & Sons, Ltd., 373pp., illus., 10s. 6d. net.

The scope of this volume is well summarised by the sub-title "Engineering Degree Series". It is another of those invaluable books, helpful mainly to the engineering student studying for the B.Sc., A.M.I.C.E., A.M.I.Mech.E. and A.M.I.Mar.E. examinations, and convenient to teachers for reference purposes.

There is little in the book to distinguish it from other well-known orthodox works on this subject, although it is highly mathematical in character. More correlation between the academic and practical treatment of some of the work would greatly enhance its value, but it is evident that it is intended for advanced engineering students studying for examinations.

The arrangement of the chapters is conventional and a sound knowledge of the calculus is assumed. There exists, however, a certain incompleteness in some of the mathematical deductions as is evident on page 241 where the solution to a differential equation is given with no reference as to its method of computation.

There is no need to enumerate the contents of various chapters, since the book well covers the syllabuses of the examinations mentioned above. The concluding chapter is confined to testing and testing machines and is very general and rather concise, the diagrams of the machines with attachments being well produced. The mathematical solution of the extension recorded by the optical extensometer on page 349 is very clearly explained. Very little reference is made in this chapter to the work done by the British Standards Institution, which would have given the book a more modern aspect. There is a liberal supply of examples with answers to each chapter together with a few typical worked examples. At the conclusion of the book a rather brief summary of formulæ which appears to be superfluous is added. The print is clear and the work well set out, with adequate diagrams, and should appeal to the students for whom it is written.

"Engineering Shop Practice" (Vol. II) by Orlan William Boston, B.M.E., M.S.E., M.E. New York: John Wiley & Sons; London: Chapman & Hall, Ltd., 485pp., illus., 25s. net.

This fine work, which is complementary to Vol. 1, deals with the various machine tools and machining processes which were outside the scope of the first volume. The illustrations are excellent and the layout of the text, which is in accordance with the usual practice of the House of Wiley, is such that the book will be a valuable addition to the technical library of the student, or the practical man whose business is concerned with machine tool work. The Author is to be congratulated on the completion of these two volumes which give an up-to-date review of the latest types of machine tools and machining processes.

Each of the eleven chapters opens with a definition of one particular class of machine and then goes on to deal with the various types of machine in that class, a description of tools and work holding devices, tables of cutting speeds and feeds. A useful bibliography of the subject matter of each chapter is included.

The subjects dealt with comprise turning machines, broaching and finishing machines, presses, punching, die-casting and measuring instruments, and as each of the chapters reaches such a uniformly high standard it is difficult to particularize. Some, however, call for a brief comment.

The first two chapters deal with hand-operated and automatic turret lathes and screwing machines, and the outstanding features of these chapters are the interesting drawings and descriptions of various types of chucks and tool holders. The practical man will doubtless find these chapters of great interest for they contain much valuable information.

Chapter IV, which extends to 60 pages, is entitled "Gears and their Manufacture" and deals concisely with the various phases of gear production from a definition of standard tooth forms to a description of the instruments used in the measuring and inspection of gears. This chapter will give the student a clear conception of the design and production of gears.

Chapters V and VII are of special interest. The former deals with various types of finishing machines including grinding, buffing and honing and a comprehensive list of the various types of abrasives used for different classes of work. In Chapter VII the Author describes the tools used for the production of parts in non-metallic substances such as bakelite which is now widely used for small electrical fittings, etc.

The book is confidently recommended to all those interested in modern machine shop practice and particularly machine shop superintendents, production engineers and to students, who will all appreciate the comprehensive manner in which the author has presented his subject.

"The Tanker in Practice", by L. R. Anderson and L. H. Morrison. "The Journal of Commerce and Shipping Telegraph", 245pp., illus., 10s. 6d. net.

The subject matter of this book is essentially practical. There are chapters on the general arrangement and fittings of oil tankers, the pumping connections, the routine adopted in loading, discharging, ballasting, cleaning, and gas-freeing the cargo oil tanks, and the precautions necessary to prevent fire and explosion.

The treatment of the pumping arrangements is particularly clear, both as regards sketches and text. A slip, however, appears to have been made in Example 26 in the omission to open the master valve L on the deck crossover line. The chapter on stability is not so clear as regards the ready application by busy deck officers of the approximate methods proposed by the Authors, and it is to be hoped that a stability indicator will become the normal fitment of a modern tanker.

The Authors state in the preface that the volume is intended to instruct the young officer and seaman of the tanker service regarding the loading, discharging and ballasting of his ship. This statement is perhaps incomplete, since the book should be in the hands of all who are interested in tankers, engineer officers as well as deck officers, and all ship draughtsmen who are engaged in the design of this class of vessel.

JUNIOR SECTION.

Recent Developments in Ship Forms, including Rudders

A paper was read before the Junior Section on November 18th by the Chairman of Council, Mr. T. R. Thomas, entitled "Recent Developments in Ship Forms, including Rudders".

The author gave a general description of the Isherwood arc form, the Maierform and the Yourkevitch form, and explained the characteristics of each and showed how the designers of these forms had achieved improvements in economy of propulsion and seaworthiness.

Films of the arc form ships were shown and of experiments on Maierform models in the Hamburg Experimental Tank. Slides showing conversions of existing ships to the Maierform were also shown, and the Yourkevitch form was illustrated by views of the hull of the "Normandie".

Various types of rudder design were illustrated and described, including the balanced reaction rudder, and various forms of streamline rudders. The influence of these on performance and steering was also briefly discussed.

The author's interesting and effective presentation of his subject evoked a hearty vote of thanks, which was accorded on the proposal of Mr. T. A. Bennett (Member of Council) at the close of the proceedings.

ABSTRACTS.

The Council are indebted to the respective Journals for permission to reprint the following abstracts and for the loan of the various blocks.

The British Association at Norwich.

"The Engineer", 11th October, 1935.

On Monday, 9th September, Section G (Engineering)—in addition to a meeting in its own room when three papers on electrical subjects were presented—took part in a joint discussion with Section A (Mathematical and Physical Sciences) on Lubrication. The chair was taken by Dr. F. W. Aston, F.R.S. (President, Section A).

Lubrication.

The discussion was open by Mr. J. Hamilton Gibson, M.I.Mar.E., who suggested that at long last engineers could claim that bearing troubles had been finally overcome. Journals and thrusts of all sizes, loads, and speeds need no longer cause concern to operating staffs, afloat or ashore; wear had been eliminated, and metallic friction abolished. What friction remained was not attrition, but merely the inevitable viscous resistance of the lubricant between the moving surfaces. This was exactly calculable, thanks to the early research work of Tower and Reynolds, and later to that of Goodman, Michell, Boswell, and others. The whole secret of this satisfactory state of affairs depended not on the materials used, but on the means whereby pure oil was coaxed in and out of a finely tapered wedged-shaped space between the relatively moving surfaces.

When a journal bearing was assembled with the appropriate radial clearance, it was obvious that, if the shaft rested upon its bottom "brass", there must be a very thin tapered space or wedge at each side of the line of contact. It remained only to maintain a continuous supply of oil to feed the wedge, and that was provided automatically in a properly designed bearing. The question arose, "But what about the sides and top of the bearing? Were they of no value?" The answer was, "None whatever", except that they helped to retain the oil and locate the shaft, but in doing so a viscous drag was created which retarded motion and reduced the mechanical efficiency. It was interesting to note that an ordinary journal bearing possessed the inherent advantage of being able to produce within itself, however fortuitously, the necessary tapered pressure oil film at the one place where it was most needed, i.e., where the load was greatest.

Thrust bearings presented a very different proposition.

After briefly describing the principles of the Michell thrust bearing, Mr. Hamilton Gibson said that in 1917 he experimented with journal bearings designed and constructed to embody the same principle. A 12in. bearing with tilting pads in place of fixed "brasses" was tested with remarkable results. The conditions were very severe, the load being applied both top and bottom by means of a "nut-cracker" rig. Pipet holes were drilled in the pads and hydraulic Bourdon gauges fitted, when pressures up to and exceeding 5,000lb. per sq. in. were registered at 1,400 r.p.m. Circulated oil was used and the bearing ran quite cool for several days and nights continuously, with no sign of wear or distress. Incidentally, the bearing was only about 2in. long. One fact that emerged was the importance of preventing any tendency of the pads to "cross-wind", i.e. they had to be guided by side flanges to maintain their short circumferential surfaces coincident with the journal.

British Admiralty engineer officers witnessed these journal bearing tests, and were impressed with the possibilities of reduced weight and space allied with greater reliability. The turbine bearings of a 40,000 s.h.p. leader then building were altered to accommodate tilting pads, and the vessel, after 16 years, was still in active service. There had been no wear, and therefore no renewal of working parts during that long period. Equally good results had attended the adoption of these journal bearings in later vessels at home and abroad. For single and double-reduction gears, such bearings were admirably suited, as the original centres between wheels and pinions were maintained unaltered and the bearing length need not exceed half the shaft diameter. For safe maximum loading, Michell journal bearings were usually designed for 350lb. to 500lb. per sq. in., and, as regards speed, an upper limit had not yet been reached. Going to the other extreme, an interesting case was that of a large slow-running bearing in a 250-ton oil cake crushing mill installed some 12 years ago. Its diameter was 29¾in., the speed 3 r.p.m., and the load 1,080lb. per sq. in.

The working temperature of oil-lubricated bearings was a matter that had received some attention in recent years. Normally, a "hot" bearing was so designated if it was hot to the touch, although it might not be more than 100° F. Nowadays, a comfortable running temperature was 140° F., and if a good quality of pure mineral oil was used, its viscosity became about 0·2 C.G.S., corresponding to 92·5 Redwood seconds. The cooler the oil the greater the drag resistance, therefore a big saving in power was effected by deliberately running bearings at a higher temperature. Mr. H. L. Guy worked this out for a 32,000-kW. power station, and found that by raising the bearing temperature from 120° to 140° F., a saving of £296 per annum was possible. A higher running temperature would, of course, give a still greater saving. Apparently, there was no reason why bearings should not run up to 200° F., but the oil manufacturers might have something to say about this. High-pressure turbine bearings ran quite happily at 180° F.

Finally, Mr. Hamilton Gibson remarked that oil was not the only lubricant, and that in very special circumstances pure water or even air was preferable. "Electro-mersible" pumps were sometimes fitted at the tail end of a pipe in a deep artesian well, and their bearings were lubricated with the drinking water to obviate contamination with oil. The bearing surface was, of course, increased to give a small unit load suitable for the reduced viscosity of the lubricant. As proving that air was a perfect lubricant if the bearing surfaces were capable of adjusting themselves to form tapered air films, a model thrust bearing was exhibited, and it was added that air-lubricated bearings were an essential part of certain very high-speed, lightly loaded, scientific apparatus.

Streamlined Tankers of New Design.

Novel Features in Two 14,500-ton Swedish-built Norwegian Vessels witn Maierform. Extensive Employment of Electric Welding.

"The Motor Ship", August, 1935.

It may be thought that on a tanker with a trial trip loaded speed of only 13 knots, and a probable average service speed of 12 knots, the air resistance would not be important in the matter of speed and fuel consumption. But it appears from experience and experiment that there is an advantage in avoiding air resistance, so far as possible, and that the flat bridge front causes a larger resistance than is generally thought to be the case, even at low speed, or perhaps especially at low speed. The general impression that the beneficial effect on power requirements by the adoption of streamlining does not come into question, except at high speed, appears to be unfounded.

Experiments were made by A. B. Götaverken on the different types of deckhouses, at the Tekniska Högskolans Laboratory at Stockholm, and it was ascertained that with a midship deck erection, as shown on the plans of the new tankers, published on the opposite page, as much as 40 per cent. reduction in air resistance can be obtained compared with the old type. This represents a saving of one ton of oil per day when the head wind is 15 metres per second, whilst the deckhouses, as shown, are also lighter in weight and cost less to build.

The economy thus gained therefore appears to be sufficient to warrant the adoption of the streamlined design, even allowing for the fact that conditions of wind and sea do not always allow of full advantage being attained.

The two ships are similar, and the leading details are given below:—

Length b.p.	490ft.
Breadth moulded	62ft. 9in.
Depth moulded to upper deck	36ft. 7in.
Draught on summer loadline	28ft. 3in.
Corresponding deadweight capacity about ...	14,500 tons
Capacity of cargo tanks	712,500 cu. ft.
Speed loaded on trials	13 knots
Engine power	4,500 b.h.p.
Engine speed	108 r.p.m.

Seven-cylinder Double-acting Machinery.

The engine is a Kockums-M.A.N. double-acting two-stroke seven-cylinder type, with cylinders 600mm. in diameter; the piston stroke is 1,100mm. It has a piston-type scavenging pump and is of the airless-injection design. The output, as stated above, is 4,500 b.h.p. at a speed of 108 r.p.m., and the power is sufficient to give the vessels a full speed of 13 knots on trial, so that they will probably maintain a service speed when fully laden of well over 12 knots. The exhaust gases are discharged through a silencer in the low funnel, which is also streamlined.

The general layout of the accommodation is somewhat different from the old style, as the saloon is arranged on the captain's deck, adjoining the captain's dayroom, and this is considered to be an advantage over the normal arrangement with the saloon below on the bridge deck. The deckhouse aft is also streamlined, and the accommodation is arranged so that the messrooms for petty officers and crew are on the poop deck, with an entrance from the galley to a pantry.

In these vessels, as in most of the recent Norwegian tankers, there is a common messroom for the motormen and sailors, and, so far as is known, there has never been any complaint about this, and obviously it represents a simplification so far as the serving of food is concerned.

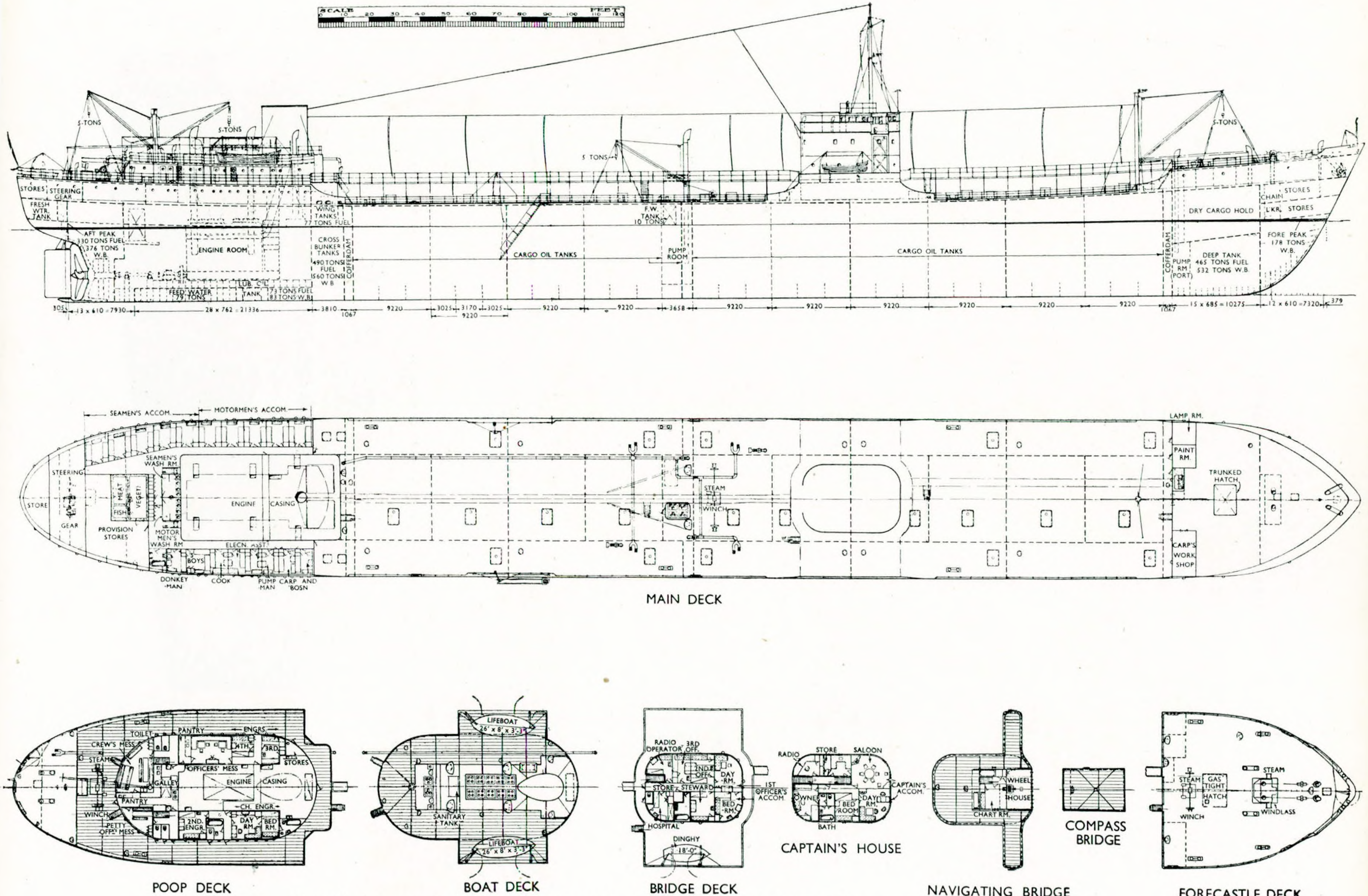
The normal two large steel masts have been eliminated, and light hollow wood masts are placed on the top of the steering house to carry the antenna and the signal yard. A short derrick post for the dry hold hatch carries the foremost signal light. Electric welding is being carried out on a larger scale in these ships than in any other vessels of corresponding size, and they will, therefore, be of special interest from this standpoint. A certain saving in weight has been effected by the employment of welding.

The details of the tank capacity are given in the table below:—

Capacity of Tanks.

Tank.	Cub. feet.	W.B. (35 cf/t)	F.O. (40 cf/t)	F.W. (36 cf/t)	Lubr. Oil (38 cf/t)
Fore Peak Tank ...	6,250	178	—	—	—
Deep Tanks	18,600	532	465	—	—
Cross Bunker Tanks	19,600	560	490	—	—
Wing Tanks	3,080	88	77	—	—
Double Bottom, Fuel Oil Tank	2,920	83	73	—	—
Double Bottom, Lubr. Oil Tank	950	—	—	—	25
Double Bottom, Feed Water Tank ...	2,850	—	—	79	—
After Peak Tank ...	13,200	376	330	—	—
Fresh Water Tanks Aft.	2,050	—	—	57	—
Fresh Water Tank in Pump-room... ...	360	—	—	10	—

The deep tank is arranged under the dry cargo hold forward and immediately aft of the fore peak tank. Aft of the deep tank is a pump-room on the port side, and amidships between the cargo oil



General arrangement plans of 14,500-ton tankers with streamlined deck erections, now being built in Sweden. *(For description see previous page).*

tanks is another pump-room. Aft of the cargo oil tank is a cofferdam and cross bunker tanks. The total amount of fuel oil that can be carried is 1,435 tons. The daily fuel consumption for all purposes at the normal speed will probably be in the neighbourhood of 17 tons, and the ship will have a range of between 20,000 and 25,000 sea miles without rebunkering, making the usual reserve allowance.

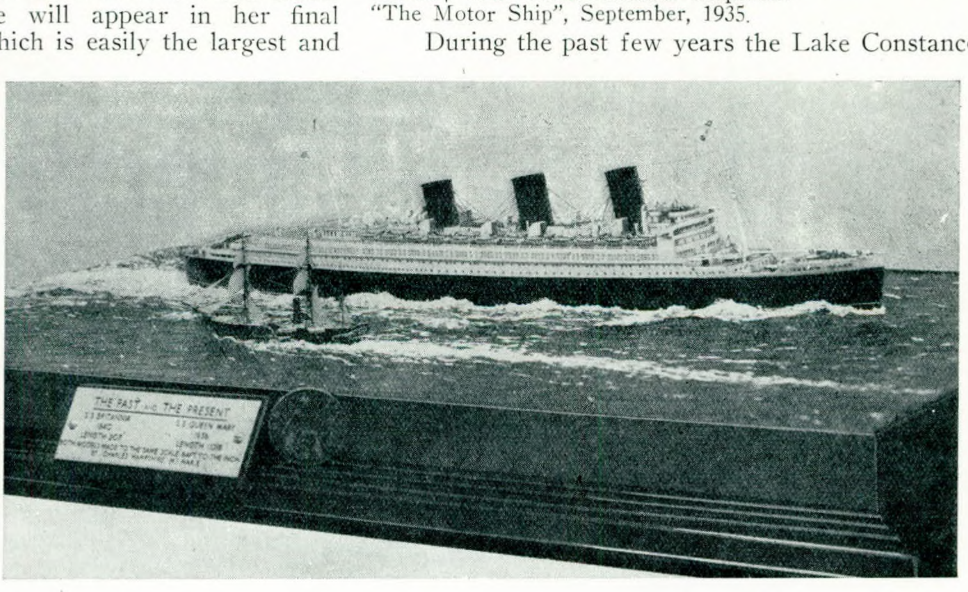
In a recent issue of "The Motor Ship" we criticized the existing classification rules relating to net tonnage, showing that the engine-room of a motor ship could be made substantially smaller, with a saving all round, were it not for certain regulations. In the vessels described the engine-room is three frame spaces longer than is essential, with the result that the cargo tanks are placed unnecessarily far forward, thus giving the ship a tendency to trim by the nose when fully loaded with oil. There does not seem to be any doubt that the existing regulations should be provisionally modified as soon as possible.

Sooner or later such changes will have to be made, and it is desirable they should be effected at an early date, so that full advantage may be taken at once of the latest developments in naval architecture.

The "Queen Mary" in Miniature.

"The Marine Engineer", October, 1935.

On previous occasions we have published illustrations and brief descriptive notes on the striking very small-scale models which Mr. Charles J. Hampshire, M.I.Mar.E., makes in his spare time. Several months ago Mr. Hampshire, with commendable enterprise and skill, completed a most creditable model of the "Queen Mary", based on the meagre amount of information then available to him. More recently, however, with the collaboration of the Cunard White Star Line, he has constructed a very fine and much more detailed model of the vessel as she will appear in her final form. This model, which is easily the largest and most ambitious of the many Mr. Hampshire has made, has occupied two years of his spare time. It was completed just before the opening of the Shipping, Engineering, and Machinery Exhibition and, along with other of Mr. Hampshire's models, was on view on the stand of our contemporary, "Engineering".



The model is associated with that of the early Cunard paddler "Britannia", which was built in 1840. This vessel, which was 207ft. long, is shown in the same glass case passing the "Queen Mary", both vessels having the appropriate (and accurately made and painted) signals flying. The sea on which the two models are shown is one of the best which Mr. Hampshire has made and, as our illustration shows, is particularly realistic. The models are made to a scale of 64ft. to the inch and illustrate in a most striking manner the great strides which have been made in passenger-ship construction in 95 years.

The special feature of these models is the use of human hair, of which the whole of the riggings of the "Britannic" is composed. The sails of this vessel are made of special tissue paper treated in a certain way by the constructor; all hand railings and wireless aerials are made of very fine radio-condenser copper wire, this being the finest copper wire ever made.

On the "Queen Mary" model there are over 1,000 portholes, ingeniously made by winding very fine silver wire spiral form around a needle $^1/_{64}$in. in diameter. The wire is then cut with a sharp knife between each turn, thus making a perfect circle the correct diameter. The 48 Welin-MacLachlan davits were made by winding the desired thickness of wire round a steel mandrel shaped to the inside dimensions of the davits, thus getting all davits exactly the same size.

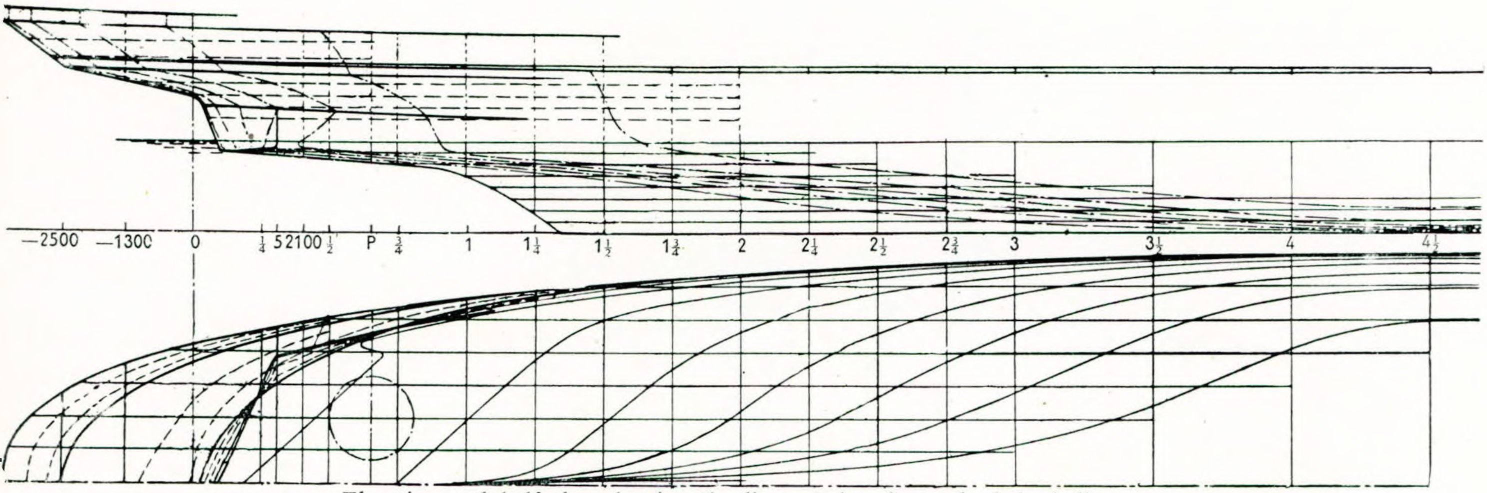
Mr. Hampshire has always tried to make his models as life-like as possible, and the illustration on this page certainly shows that he has succeeded in this instance. The flags and ensigns for instance, are so shaped as to make them appear fluttering in the wind, while all ropes and halliards are bending to the direction of the wind, also the seas and bow waves are correctly shaped.

Elimination of Noise and Vibration.

Novel System in a 600-b.h.p. Twin-screw 350-ton Passenger Ship with Voith-Schneider Propellers.

"The Motor Ship", September, 1935.

During the past few years the Lake Constance

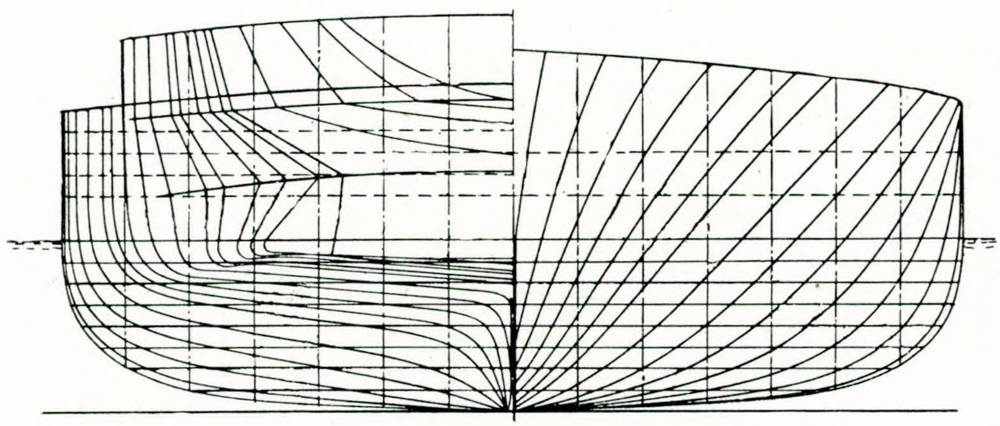


Elevation and half-plan showing the lines at the after-end of the hull.

service of the German Railways (Reichsbahn) has been noted for the additions to its fleet, which embodies a number of vessels having novel features in their general arrangement and as regards the machinery installed.

The latest vessel is named "Deutschland", and the general arrangement plans are published on the next page. She has been in commission a few months, and is an unusually interesting example of a modern vessel for inland navigation. Of particular importance are the means employed in order to avoid noise and vibration; these points will receive reference later. In the meantime, it may be recorded that the "Deutschland" is a passenger vessel intended particularly for summer tourist traffic. She is designed to carry 270 first-class passengers and 570 in the second-class accommodation. The leading details are given in the table below:—

Length, overall	184ft.
Breadth, moulded	39ft.
Draught, fully loaded	5ft. 8in.
Corresponding displacement ...	350 tons
Maximum speed	14·5 knots
Service speed	12 knots
Machinery	600 b.h.p.
Normal revolutions	500 per minute.



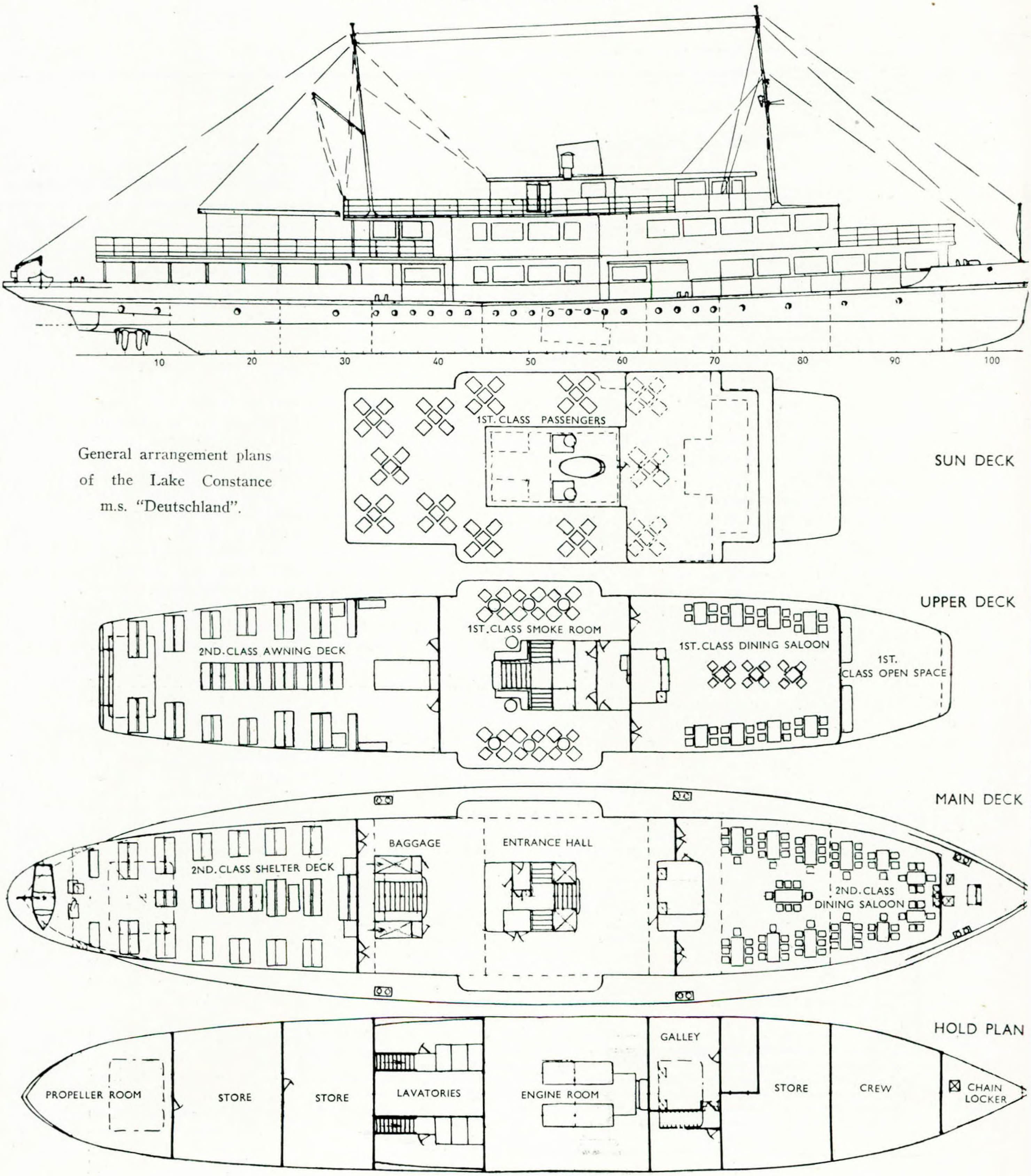
Cross sections, showing the lines.

The vessel was designed and built at the Deggendorf Shipyard, which is located on the Danube, and the twin-screw machinery is of the M.A.N. airless-injection four-stroke single-acting type. The engines have an overload capacity of 375 b.h.p. each at 600 r.p.m., but the service rating is given in the table. Each engine is coupled to the propeller shaft through an electric synchronizing device.

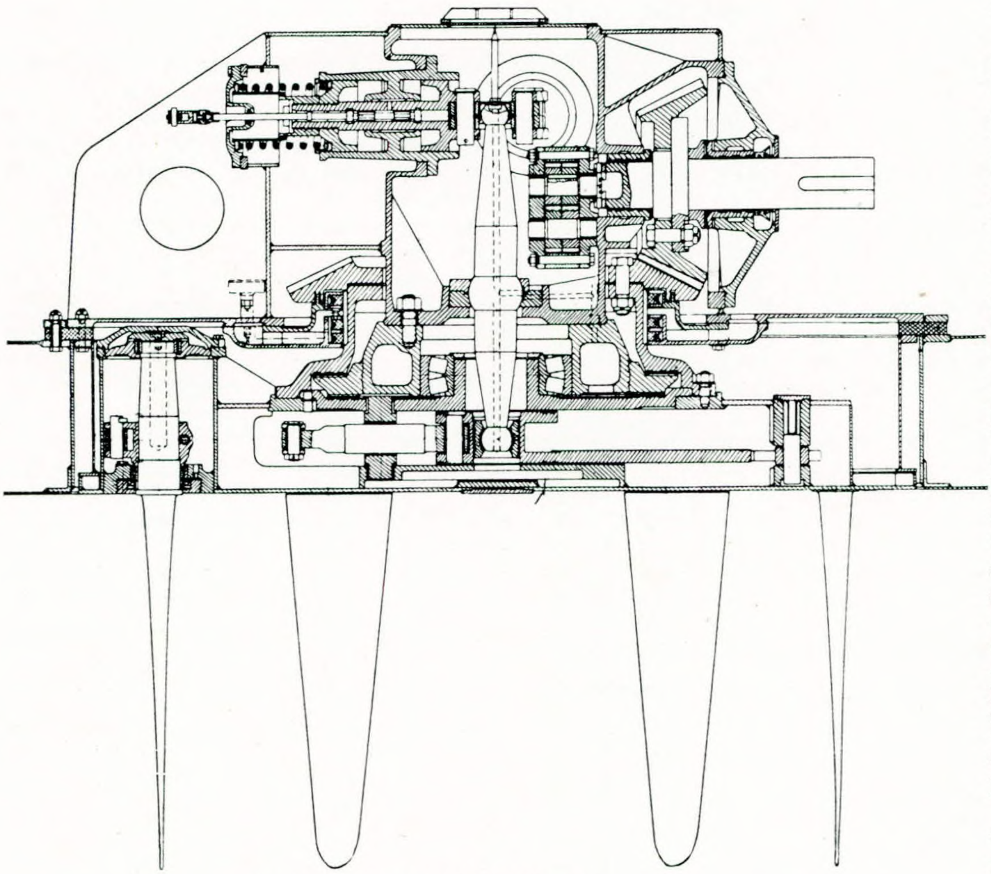
The propellers are of the Voith-Schneider type, and the peculiarities of their design will be noted from one of the accompanying illustrations. They have six blades, the diameter being 5ft. 3in. and the length of the blades 2ft. 11in. All the Lake Constance vessels owned by the German Railways and constructed since 1931 have been fitted with Voith-Schneider propulsion. Compared with former types of propellers of the same design, various improvements have been made to those fitted to the "Deutschland". The new propellers are lower than those hitherto employed, while the pinion shaft is low enough to avoid the spur-wheel drive which was necessary in the earlier Lake Constance ships.

The propeller housing is not fastened directly to the propeller well, a thick rubber ring being interposed between the foundation and the housing. The complete motion is under the control of oil-pressure servo motors, which are mechanically connected to the bridge by means of a system of rods.

The ship is built with a main deck and an upper deck extending the full length of the hull, whilst a sun deck is comprised in the central superstructure. The engine-room is arranged amidships; forward



General arrangement plans of the Lake Constance m.s. "Deutschland".



Sectional view of Voith-Schneider propeller.

of it are a galley and a storeroom, accommodation for the crew, a general store and a chain locker. Aft of the machinery space are two further storerooms and the propeller gear space.

Forward of the main deck are the second-class dining saloon, the entrance hall and a covered space for passengers. On the same deck are the purser's office, the battery-room and a baggage-room. An open space for first-class passengers is arranged on the upper deck; on the same deck are the first-class dining saloon, a lounge and a covered deck space.

Forward on the sun deck, separated from the passenger space by windows, are the bridge and a roomy wheelhouse. The sun deck is reserved for first-class passengers, the covered front part having windows forward and at the sides.

In the construction of the hull electric welding has been largely employed; there are eight watertight bulkheads, and a double bottom is arranged forward and aft of the engine. The Lake Constance vessels built before "Deutschland" have square sterns in conjunction with the Voith-Schneider drive, whereas with the new vessel there is a more pleasing effect obtained by the combination of a square stern and an overhanging stern above the waterline.

Auxiliary Machinery.

Starting air for the engines is supplied by a pair of two-stage compressors, one driven by a 25 b.h.p. Diesel engine, running at 800 r.p.m. and coupled to a 10-kW. 110-volt dynamo, while the second compressor is driven by a belt from one of the main shafts. Belt drives are also employed for the cooling-water pumps, one for each engine, and each has a sufficient capacity to supply all the cooling water required. The electrically driven machinery comprises a deck-washing pump, a fire pump, a sanitary pump, a stand-by bilge pump, and fuel and lubricating oil pumps.

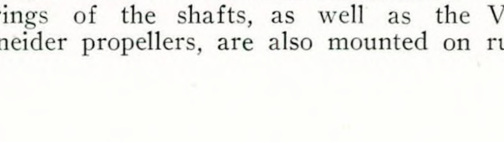
The arrangements which have been made for the elimination of noise and vibration may be divided into the undermentioned groups:—

(*a*) Rubber seatings for the engines and propeller mechanism.

(*b*) Electric synchronizing of the engine and propeller blades.

(*c*) Keeping the firing order, the crank positions and the relative positions of the blades of both units in symmetry.

The main engines and the synchronizing sets are mounted on a stiff, welded frame connected to the foundation by a rubber layer of about 2in. thickness. Steel rails are vulcanized to the rubber on both sides, so as to receive the bolts connecting either the frame or the foundation; the frames supporting the engines, therefore, float on the foundation.



Vibrographs showing synchronized and unsynchronized operation.

All the pipe connections between the engines and the hull are elastic and afford isolation. As the bearings of the shafts, as well as the Voith-Schneider propellers, are also mounted on rubber in a similar way, there exists, virtually, no metallic connection between the engine installation and the hull. It has, of course, been necessary to determine the thickness of the rubber so that the frequency of the parts set upon it is well below or above the frequency caused by the engines, as otherwise self-induced vibrations of considerable intensity might be set up.

Each engine is connected to a three-phase synchronous Siemens Schuckert alternator, both being electrically connected. Moreover, it has been indicated that the crankshafts have symmetrically arranged cranks with the same firing order, so that the corresponding cylinders on both sides always fire simultaneously, and both engines operate, therefore, as a twin unit.

The propellers can also be brought to a position where the blades on both sides are symmetrical with reference to the ship's axis and can be kept so during operation. It is evident that with such synchronized and symmetrical operation all forces in the horizontal plane of both units must balance each other, and that the primary causes of vibration in the whole plant are obviated.

One of the illustrations shows two vibrographs taken with synchronized and unsynchronized operation in the engine-room, and demonstrates conclusively the effect of the arrangements described. Before deciding to adopt the system on the "Deutschland" these arrangements were tested on the m.s. "Augsburg". With the synchronizing sets in operation it was not possible to record, by an ordinary vibrograph, any vibrations on the decks or in the passenger accommodation. The relative horizontal motions between the frame and engine were found to amount to 0·1mm. in the athwartships direction and 0·25mm. fore-and-aft. The vertical motion of the frame was 0·88mm.

It should be added that this electric synchronizing arrangement is not a necessity with vessels having the Voith-Schneider propeller drive. The system has, first and foremost, been installed because it permits the synchronization of the crankshaft necessary when mounting the engines on rubber, or on a "floating" frame. The possibility to obtain, at the same time, synchronous operation of the propellers is a further feature which would be equally valuable in the case of an ordinary screw drive.

BOARD OF TRADE EXAMINATIONS.

List of Candidates who are reported as having passed examinations for certificates of competency as Sea-Going Engineers under the provisions of the Merchant Shipping Acts.

Name.	Grade.	Port of Examination.
For week ended 3rd October, 1935:—		
Carnegie, John G. ...	1.C.M.E.	London
Hall, Kenneth A.	1.C.M.E.	,,
Stephen, James M. ...	1.C.M.E.	,,
Fawkes, Harold G.	1.C.	Newcastle
Hopper, William	1.C.	,,
Kelleher, Edward H. ...	1.C.	,,
Sanders, Ronald R.... ...	1.C.	,,
Renton, John E. M. ...	1.C.M.	,,
Wilson, James B. ...	1.C.M.	,,
Weedon, Richard W. ...	1.C.M.	,,
Butterworth, Arthur ...	1.C.M.E.	,,
Hunter, George	1.C.M.E.	,,
Lorimer, Ian M.	1.C.M.E.	,,
Megginson, James	1.C.M.E.	,,
Turner, Gerard V. ...	1.C.M.E.	,,
Grainger, Thomas W. ...	1.C.	Dublin
Matthews, Michael C. ...	1.C.	,,
Downing, Albert	1.C.	London
Davies, Nathaniel T. ...	1.C.	Liverpool
Ghandy, Kaikobad	1.C.	,,
Lockley, Arthur S. DeV. ...	1.C.	,,
Lawrie, Charles	1.C.M.	,,
Lynch, James	1.C.	Glasgow
MacPhail, Malcolm J. ...	1.C.	,,
Dalton, James G.	1.C.M.	,,
Duncan, George L. ...	1.C.M.	,,
Gray, George T.	1.C.M.	Glasgow
Niven, William B.	1.C.M.	,,
Buchanan, George W. ...	1.C.M.E.	Liverpool
McClurg, William A. ...	1.C.M.E.	,,
Rawcliffe, James	1.C.M.E.	,,
Howard, Claude	1.C.M.E.	,,
Selby, Ernest W.	1.C.M.E.	London
For week ended 17th October, 1935:—		
Burkes, Frank	2.C.	Liverpool
Fellows, Geoffrey W. H. ...	2.C.	,,
Moss, Herbert G.	2.C.	,,
Smith, Alexander	2.C.	,,
Snowdon, James L.	2.C.	,,
Beer, Clifford N.	2.C.M.	,,
Evans, Ivor J.	2.C.	Cardiff
Miles, Edwin	2.C.M.	,,
Cowie, George W.	2.C.	Glasgow
Swanson, James	2.C.	,,
Cay, Godfrey	2.C.M.	,,
Gray, George A.	2.C.M.	,,
Plenderleith, Alexander P.	2.C.M.	,,
Blyth, David W.	2.C.	London
Kirby, Stanley	2.C.	,,
Parnell, Charles S.	2.C.	,,
Larter, Frank A. J. ...	2.C.M.	,,
Doel, Harold J.	2.C.	Newcastle
Lilley, Roland	2.C.	,,
Taylor, Stanley	2.C.	,,
Bourner, George W. ...	2.C.M.	,,
Owen, William H. ...	2.C.M.	,,
Tye, Charles	2.C.M.	,,
Witty, Richard E.	2.C.M.	,,