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High Creep Strength Austenitic Gas Turbine Forgings.

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Synopsis.

The paper describes recent rotor forgings for land and marine gas turbines, and discusses this new field of work in high strength austenitic steels. A full discussion is given of the properties and characteristics of a specific high strength austenitic steel (G. 18B), and the considerations which govern the choice of gas turbine rotor and blade materials for long term service. Certain aspects of creep testing receive detailed attention and the paper concludes with a brief summary of the present state of gas-turbine development from the metallurgical point of view.

INTRODUCTION.

Gas turbines with high power ratings for use in land installations have been under active development for a number of years, and are particularly associated with Brown, Boveri & Co. in Switzerland. These turbines, operating mainly on the open-cycle principle, have been designed to run at maximum blade temperatures of the order of 500/550° C. and to have reliable working lives of many years. They necessarily do not have high overall thermal efficiencies and typical installations range between 18 per cent. and 22 per cent., but with special heat exchangers this figure can be raised to about 27 per cent. The materials used in these installations were either well-known low-alloy constructional ferritic steels or the better varieties of ferritic and austenitic stainless steels generally available prior to 1938.

Subsequent to 1938, British engineering efforts in this field were almost entirely devoted to the development of the gas turbine for aircraft applications. It would probably be true to say that American workers noted Swiss developments with active interest and followed quickly the British lead in jet engines for aircraft. In Great Britain and since the war, great interest has been taken in the gas turbine for land and marine applications, and this has been paralleled particularly in Switzerland and the United States. At the present time, it is probably true to say so far as marine installations are concerned, practical experience of their performance has been obtained only in America, but that other projects in different parts of the world are already well advanced.

At this point it is important to emphasize that the land or marine gas turbine installation is far from being a single unit power pack as in aircraft applications, and the designer, freed from stringent limitations on permissible weight and available space, is free to lay out a composite arrangement of a series of turbines and compressors which gives him the best compromise for the purpose in view. For instance, a gas turbine installation required to generate electricity at an oil field may be required with emphasis on low initial capital cost rather than on high efficiency implying fuel economy. Alternatively in a marine installation there may be less insistence on initial capital cost but efficiency and reliability are vitally necessary to secure overall economical service.

AVAILABILITY OF SPECIAL MATERIALS FOR GAS TURBINES.

As already pointed out, the materials formerly used in gas turbines for land use were not, from the metallurgical point of view, outstandingly novel or particularly remarkable for their creep and fatigue properties at elevated temperatures. In fact it must be admitted that because of the limited and localized pre-war interest in gas turbines, very few organizations deemed it necessary to conduct extensive investigations at high temperatures outside of the then current requirements of steels for steam turbine installations. Furthermore, there is still a dearth of certain information on steels even for steam applications, and thus it is not surprising that the weaknesses of materials available before the war were not fully exposed. Such studies would have given a real stimulus to greater pioneer research. However, so far as Great Britain was concerned, this stimulus did arise when the aircraft jet engine pioneered by Air Commodore Frank Whittle,(1, 2) was officially admitted as being the probable power unit for fighter aircraft of the future, and applicable for immediate operational use. We can therefore trace the situation arising whereby the research metallurgist was asked to supply materials having high strength properties at temperatures well beyond the range then under active examination. Naturally enough, the early attempts to meet the need were on a small scale and somewhat faltering. However, it is interesting now to trace in Great Britain how an initial foothold was secured by studying the precipitation-hardening, titanium-bearing

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18/8 type stainless steels, followed by the late Dr. W. H. Hatfield's Rex78,(3) which played an important rôle in early developments. This was superseded later for blades by the Nimonic 80/20 nickel-chromium alloys.

Towards the end of 1943, the place of the simpler austenitic stainless steels was taken by the more complex niobium-bearing stainless steel "G. 18B", with the development of which the present authors were particularly concerned. There were, of course, many applications of existing stainless and other alloys made to components operating under less onerous conditions of stress and temperature than those to which discs and blades were subject. Regarding those materials having the highest performance, it would appear that Great Britain secured a pre-eminent position in jet engine development with about only five or six special steels or alloys. This is superficially deceptive as many thousands of separate experiments were conducted to winnow the wheat from the chaff. It was important also to concentrate on a minimum number of good materials so that the available high temperature testing facilities could secure the maximum amount of test data. Even to-day there are many gaps in our knowledge and metallurgists and engineers necessarily have to advance with great circumspection.

THE CHOICE OF STEELS FOR GAS TURBINES.

In assessing a steel for high temperature use, especially in land or marine gas turbines, the following characteristics are desirable.

(*a*) A maximum stress at room temperature of not less than 30 tons per square inch and a 0·1 per cent. proof stress of not less than 10 tons per sq. in., associated with a percentage elongation (on $L=4\sqrt{A}$) of not less than 10 per cent. and an Izod impact value of not less than 10 ft.-lb.

(*b*) Sufficiently high creep strength characteristics and general consistency in creep behaviour when working stresses have been chosen sufficiently low not to cause the component to fail prematurely.

(*c*) Sufficiently high fatigue strength characteristics at elevated temperatures to cope with the range of fluctuating stress likely to be experienced during the full working life.

(*d*) Freedom from embrittlement and major secular metallurgical changes at the maximum working temperature (either with or without a superimposed stress), and the maintenance of minimum mechanical properties over extended periods of working.

(*e*) Freedom from serious sulphur compound attack by the combustion gas.

Naturally in dealing with such complex phenomena it is not possible to specify all the necessary requirements precisely, but the above considerations are certainly among the more important.

It is useful to distinguish between highly-alloyed complex steels, which can be successfully produced for components of limited size like individual blades, and those having attractive properties which are capable of being cast into large ingots and forged into components of appreciable size. It is therefore convenient to divide the subject broadly into rotor steels and blade steels, because what may be feasible for blades does not necessarily hold true for large rotor forgings.

Rotor Steels.

Up to about 1938 gas-turbine rotors working at maximum blade root temperatures of the order of 500° C. were usually forged from low-alloy constructional steels or 18/8 stainless, stabilised with additions of titanium. Since 1945 two new niobium-bearing steels have been adopted quite extensively, namely R. 20 and G. 18B, which have made history by being first in the field to satisfy the new operating requirements involving blade root temperatures of up to 700° C., particularly when using G. 18B. The chemical compositions of these steels are given in Table 1.

TABLE 1.

Chemical Compositions of Heat Resisting Steels: Weight Per Cent.

	Rex. 78	Nimonic 80 (U.S. Source)	R.22	R.20	G.18B
Carbon	0·07	0·04	0·3	0·14	0·4
Manganese ...	0·80	0·56	0·9	0·8	0·8
Silicon	0·70	0·47	1·3	0·3	1·0
Nickel	18·0	74·23	14·5	14·0	13·0
Chromium ...	14·0	21·18	25·0	19·0	13·0
Cobalt	nil	nil	nil	nil	10·0
Tungsten ...	nil	nil	3·2	nil	2·5
Molybdenum ...	3·75	nil	nil	nil	2·0
Niobium ...	nil	nil	nil	1·7	3·0
Titanium ...	0·65	2·44	nil	nil	nil
Copper	3·6	nil	nil	nil	nil
Aluminium ...	nil	0·63	nil	nil	nil

The principal object of this paper is to describe some examples of the applications of these steels to gas turbines, and to present data of their high-temperature characteristics which will facilitate design and give an established basis for confidence in their use.

Blade Steels.

For inlet nozzle blades there is a choice of the 25/15/3 (Cr, Ni, W) stainless steel type (R.22) which is more scale-resisting and less strong at temperature than G. 18B, which has been adopted with success for operating temperatures not exceeding 900° C. For the highest and intermediate temperature stages of the rotor blades two varieties of G. 18B are available, namely "warmworked" and "solution treated".(4) For the lower temperature stages R. 20 has proved on occasion to be a very suitable alternative.

New materials are just becoming available for still higher blade operating temperatures including "G. 32". Table 2 gives the stress for rupture in 100 hours at 816° C. on a comparative basis.

TABLE 2.

Rupture Strength at 816° C. of Heat Resisting Alloys.

Date first available	Material	Origin	Stress to rupture 100 hrs. at 816°C. tons/sq.in.
1936	Rex. 78(3)	Firth Vickers	5·5
—	Nimonic 80 (U.S. Origin)	International Nickel Co.	7·7*
1943	G.18B	Wm. Jessop	6·5
1947	G.32	Wm. Jessop	12 approx.

* Symposium on Materials for Gas Turbines p. 19, 1946, A.S.T.M.

GENERAL CONSIDERATIONS.

During the war rapid development of high creep strength austenitic materials took place because the total working life of gas turbines for aircraft was considered satisfactory if the turbine gave trouble-free performance for 50 hours running at full load. In other cases this time was extended to 100 hours total running time, and tests on materials extending to a minimum of 300 hours and in some cases up to 1,000 hours were considered more than adequate.

In the marine propulsion field, current demands appear to range for between 2,000 hours and 10,000 hours satisfactory performance at full rating, although the general position is at present vague on account of the diversity of projects under consideration. Gas turbines in land installations are normally expected to give reliable service for periods ranging between 10,000 and 100,000 hours, with complete overhauls at regular intervals and with replacement of certain parts after stated expected individual lives.

Some of the steels developed for use in aircraft turbines have proved when operated at lower stress values to be quite suitable for long-term applications. However, it is not necessarily true that a material satisfying short-term tests will be satisfactory for land and marine use. In Fig. 1 are shown typical curves for actual materials on a basis of stress-to-rupture, and whereas 18/8 low carbon stainless steel⁽⁵⁾ behaves normally, a similar steel with niobium additions⁽⁶⁾ which had been cold-worked shows a drastic change of slope after 200 hours. It is clear that extrapolating from short-term data in this instance would lead to erroneous predictions of reliability if linearity had been assumed. In the same figure, curves for G.18B and R.20 are also given with the experimental points which summarize the available information. So far as the investigations have proceeded, there is no suggestion of lack of linearity in these cases. In other cases, the sudden change of slope probably occurs on account of major metallurgical changes in the steel which may also be expected to give rise to alterations in other properties such as percentage elongation, percentage reduction in area, and impact strength. In austenitic steels operating at temperatures of 700° C. and over, certain metallurgical changes inevitably occur, especially as these steels in most instances are purposely enriched with complex carbides in solid solution to confer high creep strength properties. A summary of new experimental work dealing particularly with the effects on the ordinary mechanical properties of holding G.18B and R.20 steels at elevated temperatures for periods up to 4,000 hours is given later. Again so far as the evidence goes, the conclusions can be drawn that no serious embrittlement occurs, although certain properties change with time to a significant extent.

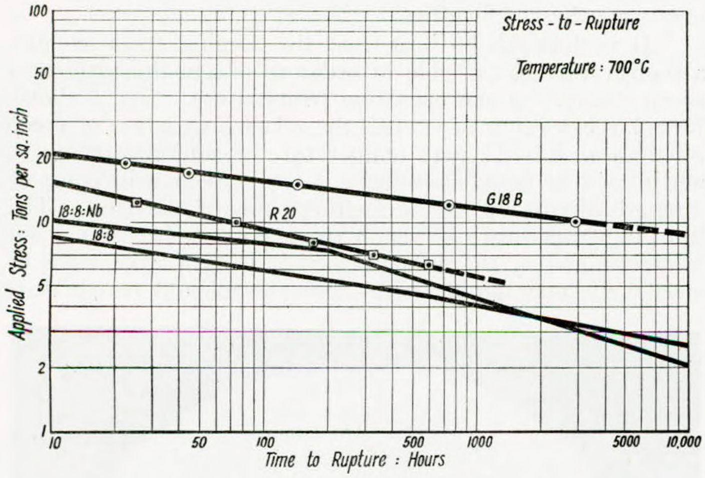

FIG. 1.—*Stress to rupture curves at 700° C. for various steels.*

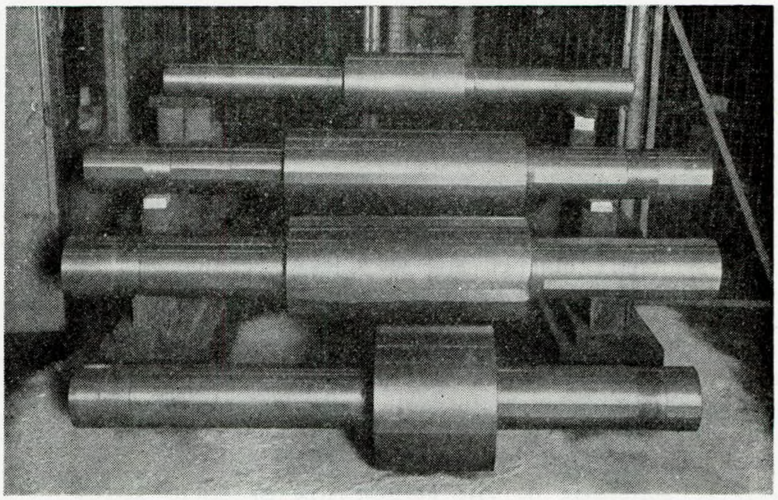

FIG. 2.—*G.18B and R.20 solid gas-turbine rotor forgings for Sulzer Bros., Switzerland. (Three upper forgings G.18B). (Note machined flats for supersonic examination).*

Types of Rotors for Gas Turbines.

Broadly speaking, gas-turbine rotors can be divided into two general types :—

(1) Solid rotors machined from integral forgings made from ingots of adequate size.

(2) Composite welded rotors built up from individual forgings.

Examples of solid rotors for Sulzer Bros., Switzerland, are given in Fig. 2, in which the top three rotor forgings are made from G. 18B steel and the bottom rotor forging from R. 20 steel.

Due to the fact that, so far, designers of gas turbines have not called for forgings of excessive size, it has been possible to produce successfully most of the rotor designs proposed. At present rotor drum maximum diameters tend to lie in the range 25 to 30in., but in some cases do not exceed 20in.

An example of the second type of rotor, showing the

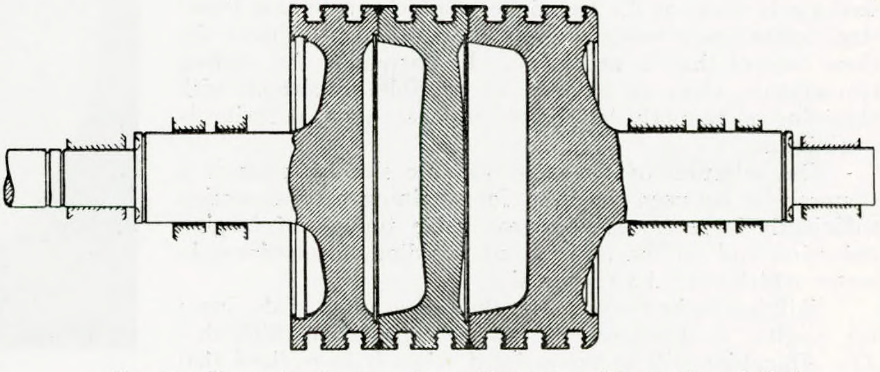

FIG. 3.—*Example of composite welded rotor (Brown-Boveri Co.).*

built-up welded construction pioneered by the Brown-Boveri Co.[7] is shown in Fig. 3. It is not proposed to discuss this type in detail, but it is important to realize that such constructions open the way to the building of large diameter rotors from high-quality unit forgings, and designs of this type may well become more common in the future. In general, the welded junction is not highly stressed, having mainly to deal with the stresses induced by the bending of the rotor under its own weight, it being clear that due to axial symmetry imposed stresses due to rotation will be small, provided the portions welded together have similar elastic and expansion characteristics. Composite rotors of this general type are at present receiving detailed consideration, but it is believed that very few are actually in service and operating at temperatures in the range 650/750° C.

An outline of some of the problems involved in the production of solid rotor forgings will now be given.

SPECIAL PROBLEMS IN THE PRODUCTION OF SOLID ROTOR FORGINGS.

Consideration of the processes involved in the production of such rotors in special steels shows that unusual problems are met with at all the stages of manufacture. The simplified production procedure involves in sequence :—

(*a*) Melting.
(*b*) Casting.
(*c*) Forging.
(*d*) Heat treatment.
(*e*) Machining.
(*f*) Examination.
(*g*) Testing.

Many of the most attractive alloys developed for use in aircraft gas turbines can only be made in high-frequency melting furnaces and are limited to comparatively small forgings. Therefore, for the production of large rotors it is necessary to select a steel or alloy which can be melted in the large melting units usually found in a steel works. The two steels under consideration, namely, G. 18B and R. 20, are both made in basic lined electric-arc furnaces of 12/15 tons capacity. This has necessitated the development of special melting techniques, because it is undesirable to employ any melting process which is oxidising. This implies that the melting procedure must in effect conform to the old crucible-steel melting practice but on a very much larger scale with rigorous precautions. Due to the large number of alloying elements the calculation of the charge itself is complex, and great care is necessary to maintain the final composition within the essential narrow limits of specified chemical composition. To avoid the danger of gas absorption, care also has to be exercised to maintain the temperature at a level which is not too high, and extensive use is made of the technique of quick-immersion liquid steel temperature measurement[8, 9] in order to achieve the close control that is necessary. In particular the casting temperature must be as low as possible consistent with obtaining a properly-fed ingot, so that axial porosity is a minimum.

The selection of the most suitable size of ingot is a compromise between the need for retaining a cross-section sufficiently large to secure a reasonable amount of forging reduction and on the other hand avoiding unsoundness in ingots which exceed a certain size.

Skill has to be exercised in the preparation of the ingot for forging, as this process is one of considerable difficulty. The difficulties will be appreciated when it is realized that these steels are designed to have unusually high strengths at high temperatures, so that the forging pressures are considerably greater than those normally employed on simpler steels. This involves close control of soaking times and forging temperatures, because the effect of excessive pressures at an unsuitable temperature invariably leads to central forging bursts. Particular care has to be exercised in the operation of setting-down the ends of forgings to make the shafts, and new methods have been developed to overcome these difficulties.

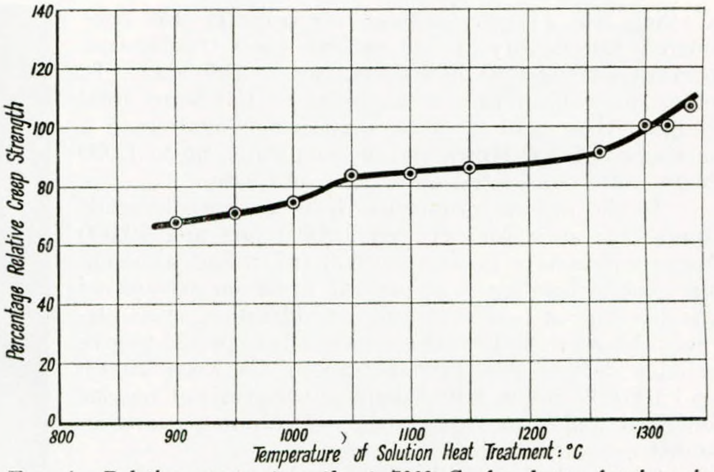

FIG. 4.—*Relative creep strength at 700° C. for large forgings in G.18B steel for different solution heat-treatment temperatures.*

It is desirable to heat-treat the forging from as high a temperature as possible in order to obtain the maximum creep strength at the operating temperature. Fig. 4 shows for a large forging of G. 18B the relative variation of creep strength at 700° C. with temperature of solution-treatment, and it will be noted that there is a progressive increase of strength almost up to the melting-point of the steel. The limit of temperature at which treatment can be carried out is determined by the difficulties of heating a large mass of steel while maintaining both close control and temperature

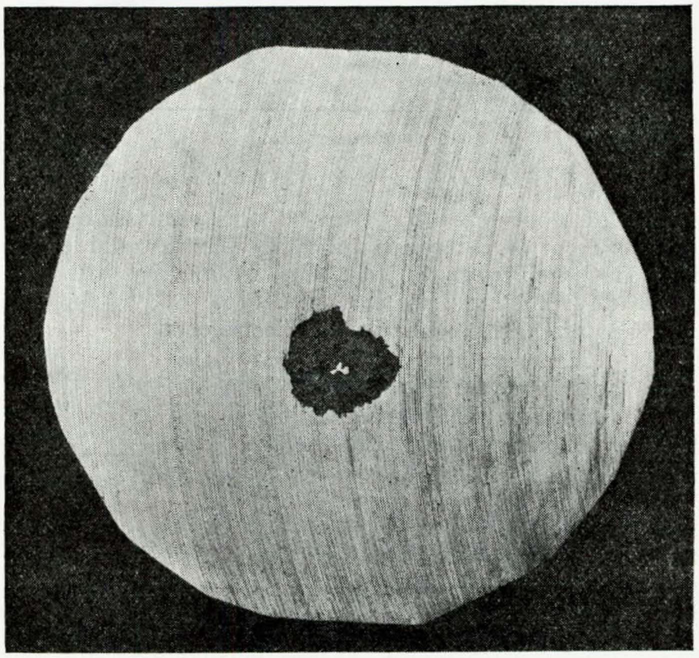

FIG. 5.—*Example of internal gas cavity located by supersonic testing.*

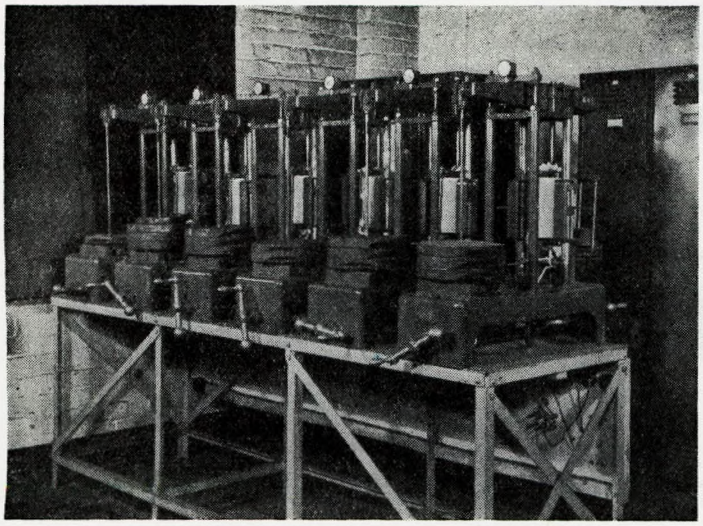

FIG. 6.—*View of small-scale creep testing units.*

uniformity, but it has been found possible to employ temperatures of the order of 1,200° C. in suitable furnaces.

The machining of austenitic steels has always been a matter of some difficulty due to the tendency to work-harden. The increased experience gained during the last few years on the machining of thousands of discs for aircraft gas turbines has shown that the problem is largely one of the selection of the most suitable tools and machining conditions, and former difficulties have been overcome.

The examination of these special rotors has raised new problems, as austenitic steel forgings tend to have a structure at their centre which is slightly "loose" compared with their ferritic steel counterparts. Such looseness, if not too severe, can be tolerated in austenitic steels, as they are largely insensitive to notches and to the propagation of cracks. It is necessary, however, to check that any porosity that is present is not severe, and most valuable non-destructive tests have been made using the Hughes Supersonic Flaw Detector.(10) A transverse section of a G. 18B rotor forging which was found by supersonic examination to contain two large but localized defective areas is shown in Fig. 5. The cavity detected supersonically but revealed by sectioning was traced to an unusually low casting temperature which facilitated the trapping of two pockets of gas evolved during solidification. This forging was the first really large rotor made in G. 18B steel, and the experience gained was valuable in developing a successful technique for subsequent rotors.

The ordinary mechanical tests at room temperature do not indicate whether the steel has the desired strength at elevated temperatures. Special tests are therefore applied to test-pieces cut from rings trepanned from the surface of the forging. These tests mainly comprise short-time creep-tests for durations of the order of 100 to 300 hours, and are sufficient to check that the material conforms to the anticipated standards. These standards are set up after the full properties of the steel have been determined by long term tests. The check tests are usually carried out in small creep testing units(11) which are shown in Fig. 6. The full determination of the high-temperature properties involves other precision equipment and methods which are discussed later.

PROPERTIES OF G.18B AND R.20 STEELS.

The history of the development of new austenitic steels leading up to the evolution of G. 18B has recently been described by the authors.(4) This development was largely bound up with the precise measurement of the creep strength and fatigue strength of steels at high temperatures. The phenomenon of creep is well-known and many papers have described the measurement of the creep characteristics of a material. The equipment used in the authors' laboratories for the determination of creep strengths largely follows the practice and pioneer work of the Engineering Division of the National Physical Laboratory. A photograph of some of the creep units is shown in Fig. 7, from which it will be apparent that they are of the double-lever jockey-weight Denison type of machine in which a steady load is applied to the test-specimen maintained at a fixed temperature. The test-piece is heated by an electric furnace some 18in. in length, wound with three separate windings so that the temperature distribution can be closely adjusted. The temperature of the specimen is measured at three points by means of platinum/platinum-rhodium thermocouples and a precision potentiometer. The temperature of the specimen is maintained constant by a thermostat of an electronic type(12) operated by changes in a platinum resistance thermometer immersed in the furnace. These thermostats control the temperatures of the specimens to within about $\pm\frac{1}{4}$° C. which, until quite recently, is considerably better than the

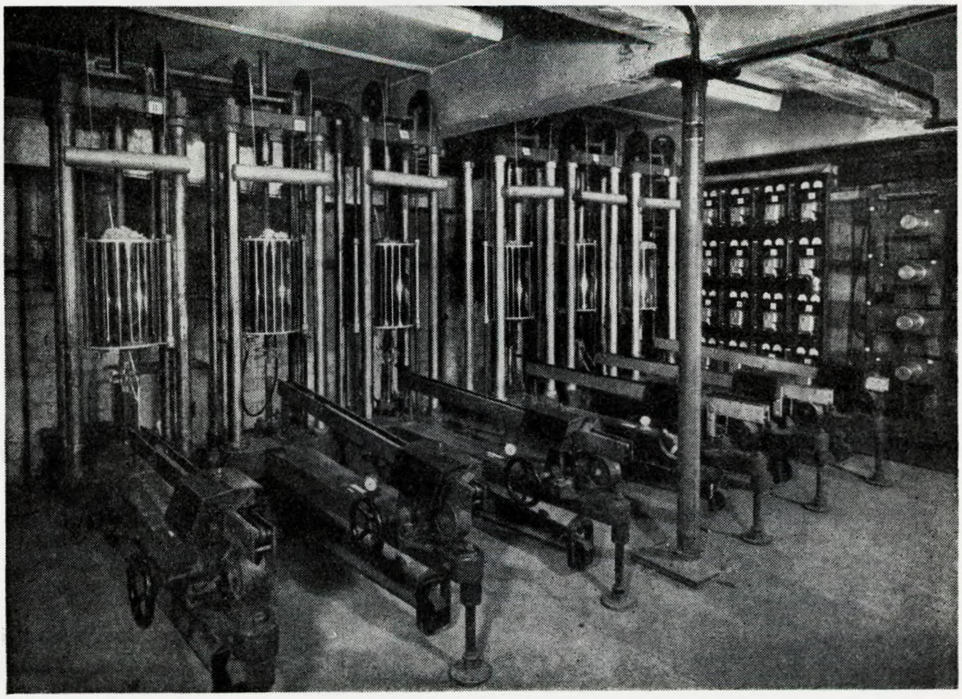

FIG. 7.—*Precision creep units for long-term testing.*

precision obtainable with any commercially available controller. Measurement of the strain in the test-piece is carried out by a double-mirror extensometer attached to opposite sides of the test-piece in order to compensate for any irregularity in extension. For most purposes the sensitivity is of the order of 5×10^{-6} strain, which is sufficient for the determination of creep rates down to 10^{-7} per hour or somewhat below. Tests on these machines have been carried out successfully up to 5,000 hours or for about six months duration.

The determination of the fatigue strength at high temperatures is an even newer activity than that of creep testing. Hot fatigue tests can be carried out either on a machine of the Haigh push-pull or of the Wöhler rotating beam type. A photograph of a Haigh machine in use at elevated temperatures is shown in Fig. 8. This machine operates at a frequency of about 2,000 per minute and enables determinations of the fatigue strength to be carried out with both reversed stresses and with zero mean stress and with fluctuating stresses superimposed upon steady predetermined tensile stresses. A turbine rotor blade is actually subjected to a complex state of stress consisting of a centrifugal tensile loading with a steady gas bending loading and a further superimposed fatigue bending loading due to vibration of the blade. The Haigh machine(13) partly simulates these conditions, but machines for applying the complete stress system more exactly are under development.

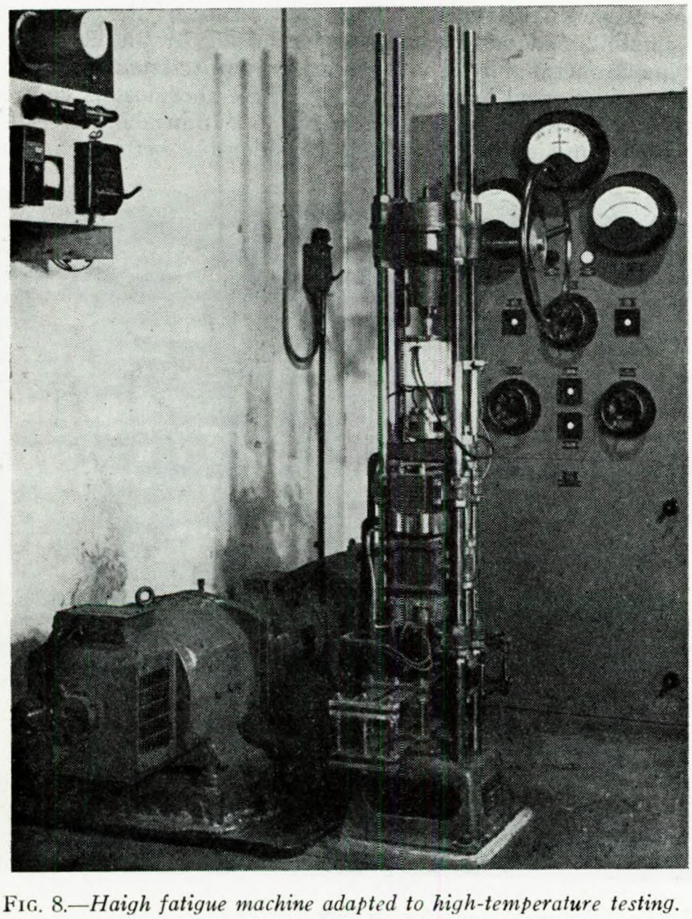

FIG. 8.—*Haigh fatigue machine adapted to high-temperature testing.*

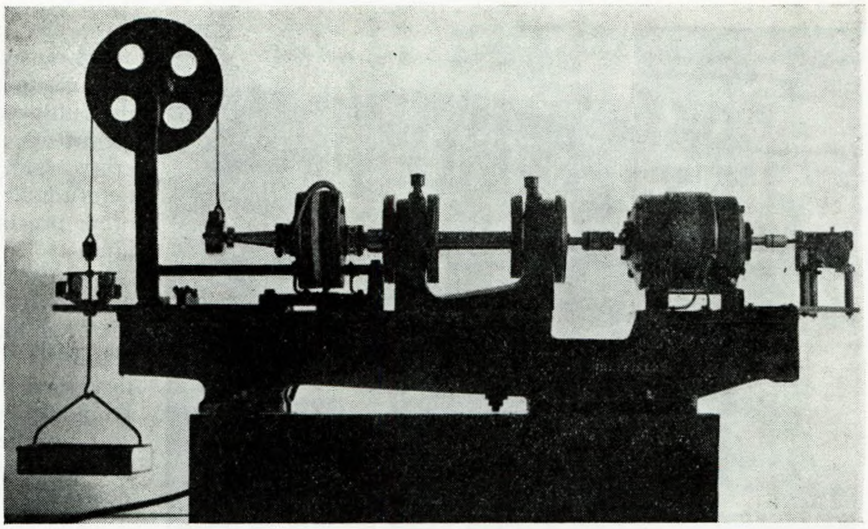

FIG. 9.—*Jessop Wöhler type hot-fatigue machine.*

A simpler machine for sorting tests on heat-resisting alloys is shown in Fig. 9. This is a Jessop single-point loading rotating-beam machine of the Wöhler type, modified to run at high temperatures up to 900° C.

The fatigue strength obtained at high temperatures depends upon the number of test cycles and the time of test, and little information is yet available on the endurance limits after very large numbers of cycles (say, exceeding 100,000,000). Many hot-fatigue tests are now quoted on a basis of 40,000,000 reversals, but blade vibration usually occurs at such a high frequency that during the working life of a turbine, this figure must be exceeded probably by a factor of a hundredfold. Fatigue machines are now being developed which will operate at high frequencies, and in due course information will be available to indicate how the fatigue strength varies with extended life.

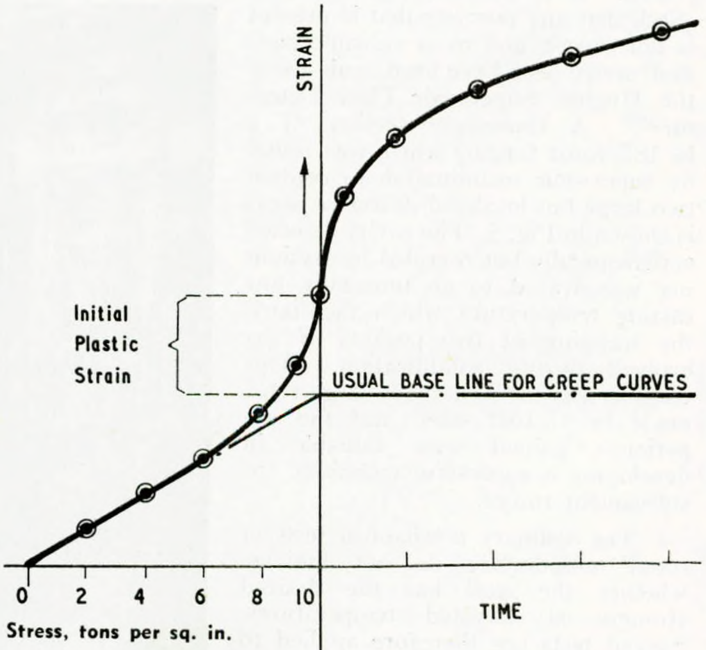

FIG. 10.—*Diagram showing initial stages of creep test.*

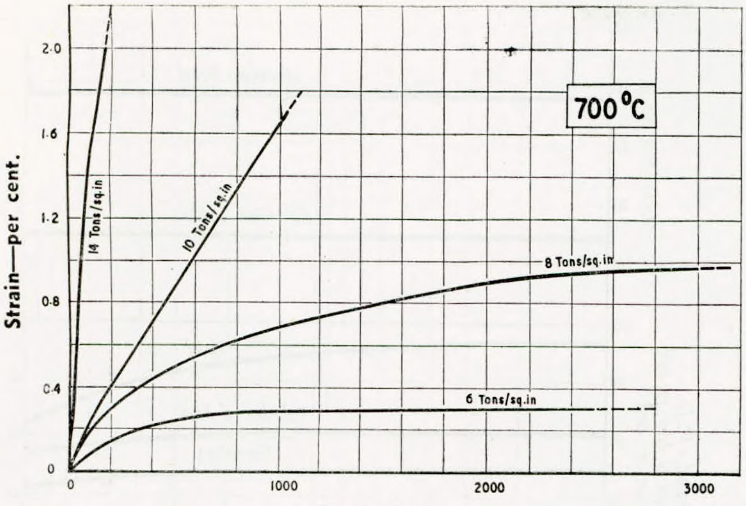

FIG. 11.—*Family of creep curves for G.18B steel (solution treated only) at 700° C.*

As an introduction to the strain-time creep curves, Fig. 10 shows the method of determining the base line from which the creep strain is measured. The portion to the left of the vertical axis shows the strain/stress curve obtained on applying the load at the test temperature in a typical test. The curve is linear up to 6 tons per sq. in., and plastic strain then occurs up to the final applied creep stress of 10 tons per sq. in. At this point the stress is maintained constant and the strain increases with time at constant stress as shown to the right of the vertical axis. The projection of the elastic portion of the loading curve to the strain axis gives the base line origin for plotting creep curves, which thus include the initial plastic strain as well as the subsequent creep strain.

A series of strain-time curves for G. 18B showing tests up to 3,000 hours duration are shown in Fig. 11. Physical and mechanical properties, including curves of stress against time to give definite amounts of creep strain between 0·2 per cent. up to 1 per cent. and fracture for G. 18B, have already been published.(4) Full information is set out in Table 3 for creep strains between 0·1 per cent. to 1 per cent. and for times up to 10,000 hours. Those figures which have been extrapolated or which are estimated from tests not yet complete are shown within brackets.

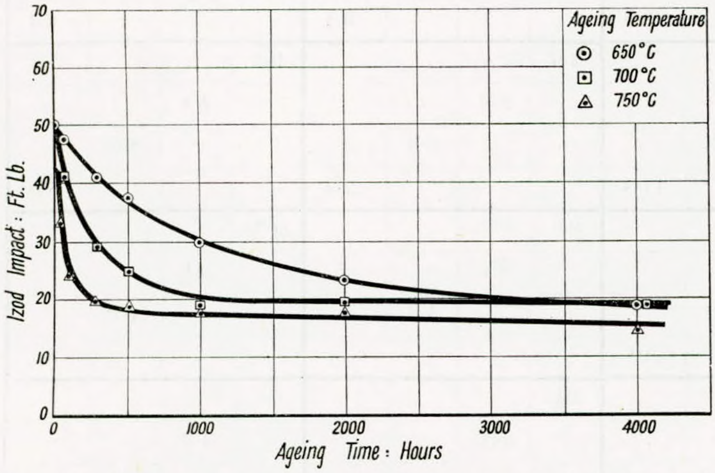

FIG. 12.—*Secular changes in cold impact strength of G.18B steel with ageing (linear time scale).*

Creep data on R.20 steel is still being accumulated and the test programme will occupy many more months, but sufficient information has already been secured to show that this material possesses interesting properties for blades and rotors which do not run at excessively high temperatures. A summary of the creep strength of R.20 steel is shown in Table 4.

Secular Changes in G.18B and R.20 Steels.

In connection with the use of turbines designed for long lives, it is important to know what changes in mechanical properties occur when the steels are held at temperature for extended periods. Tests have been carried out on the "ageing" of G. 18B for periods up to 4,000 hours and for R. 20 up to 1,000 hours. Fig. 12 shows the change of impact strength of G. 18B on soaking at temperatures between 650° and 750° C. for periods of up to 4,000 hours. It is clear that the impact values fall fairly rapidly and become asymptotic to a level of about 15ft.-lb. The same results plotted on a logarithmic time scale in Fig. 13 indicate that a minimum value of the impact is reached at about 2,000 hours

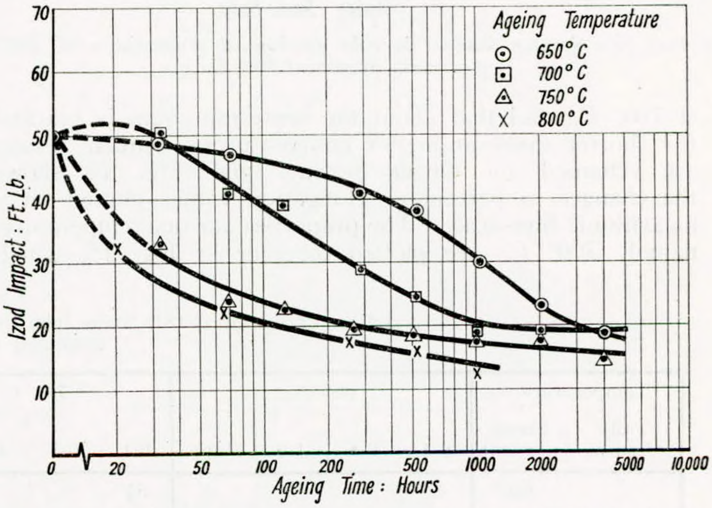

FIG. 13.—*Secular changes in cold impact strength of G.18B steel with ageing (logarithmic time scale).*

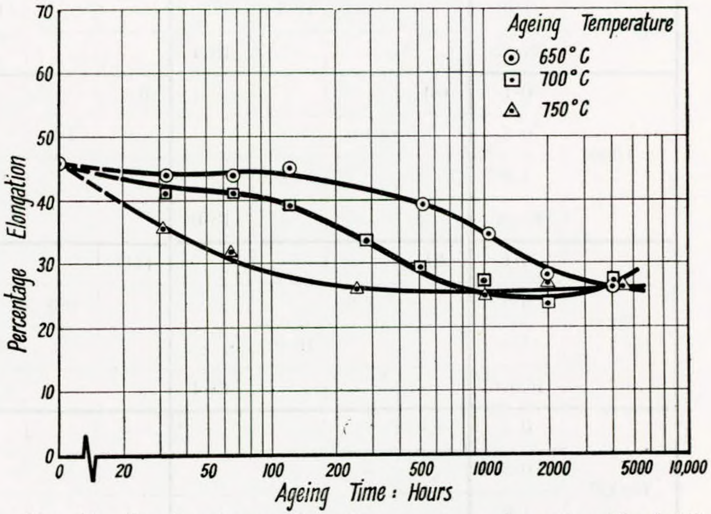

FIG. 14.—*Secular changes in cold percentage elongation ($L=4\sqrt{A}$) of G.18B steel with ageing.*

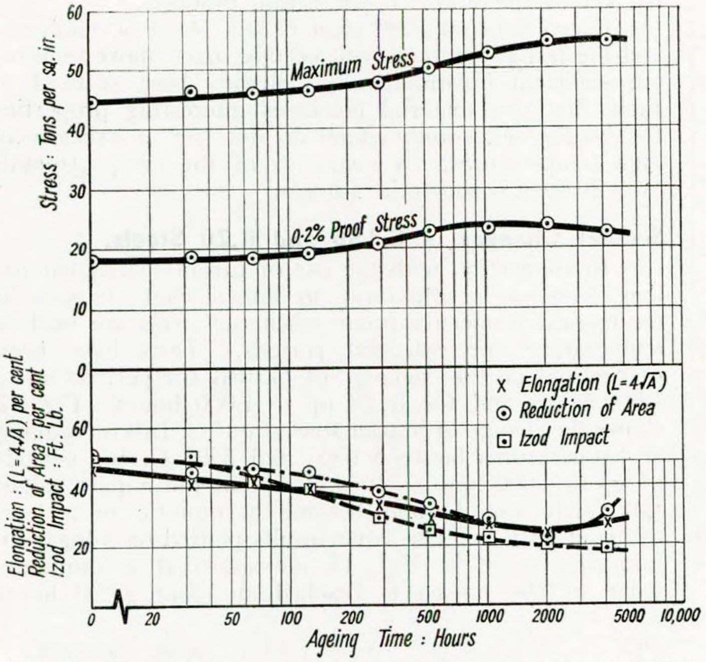

FIG. 15.—*Secular changes in cold mechanical properties of G.18B steel with ageing at 700° C.*

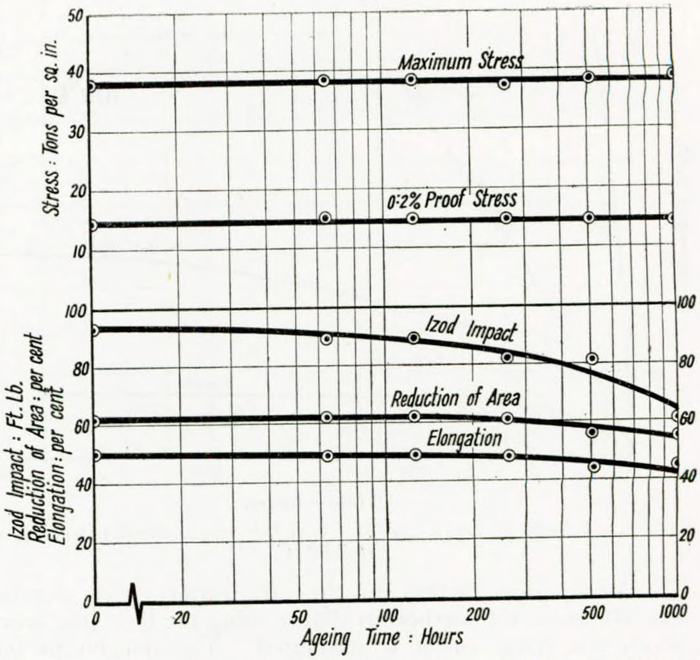

FIG. 16.—*Secular changes in cold mechanical properties of R.20 steel with ageing at 700° C.*

at 700° C., and that about the same minimum is reached for shorter times at higher temperatures. Similar results are obtained on tensile testing, and Fig. 14 shows the changes in percentage elongation values plotted on a logarithmic time scale. The properties for one temperature, namely 700° C., are plotted together in Fig. 15, which shows that as the ductility and impact values decrease, the proof stress and maximum stress of G. 18B tend to rise. Similar curves for R. 20 steel at 700° C. are shown in Fig. 16, from which it will be noticed that there are very small changes in properties up to 1,000 hours. Detailed further information on G. 18B cold tensile tests after ageing at

TABLE 3.

CREEP STRENGTH OF G.18B STEEL FOR SPECIFIED STRAINS, TIMES AND TEMPERATURES.
STRESSES IN TONS/SQ. IN.

Temperature		650° C.				700° C.				750° C.				800° C.			
Time hours	Strain per cent.	0·1	0·5	1·0	Rupt.	0·1	0·5	1·0	Rupt.	0·1	0·5	1·0	Rupt.	0·1	0·5	1·0	Rupt.
300	0·1	9½				5½				3·6				4·0			
	0·5		12·3				9·8				6·4				5·3		
	1·0			16·7				11·5				7·9				5·7	
	Rupt.				18·4				13·9				9·4				6·4
1000	0·1	(9)				5				3·3				3·9			
	0·5		10·0				7·2				5·9				4·8		
	1·0			14·0				9·3				6·6				5·0	
	Rupt.				16·0				11·3				7·4				5·6
3000	0·1	8½				(4½)				3·0				(3·7)			
	0·5		7·8				6·3				5·4				(4½)		
	1·0			10·6				8·0				5·6				(4·7)	
	Rupt.				13·4				9½				(6)				5
10,000	0·1	—				—				2½				—			
	0·5		—				—				(4½)				(4·2)		
	1·0			(8)				(7)				(5½)				4·4	
	Rupt.				(11)				(8)				—				(4½)

TABLE 4.
Creep Strength of R.20 Steel for Specified Strains, Times and Temperatures.
Stresses in tons/sq. in.

Temperature		550° C.				600° C.				650° C.				700° C.			
Time hours	Strain per cent.	0·1	0·5	1·0	Rupt.	0·1	0·5	1·0	Rupt.	0·1	0·5	1·0	Rupt.	0·1	0·5	1·0	Rupt.
300	0·1	7·5				7·3				5·5				(3)			
	0·5		9½				9				8				(4½)		
	1·0			11				10½				9				(5¼)	
	Rupt.				(26)				17				11½				7
1000	0·1	7·3				7·1				3				—			
	0·5		9				8½				6·4				(3½)		
	1·0			10½				10¼				7·6				(4½)	
	Rupt.				(20)				15				8½				5½
3000	0·1	7·1				7				—				—			
	0·5		8½				(8)				4				—		
	1·0			10·2				10				5½				—	
	Rupt.				(16)				(12)				(7)				(4)

other temperatures are given in Table 5.

As a further check on the effects of long-time ageing on the mechanical properties, tests have been carried out on the hot fatigue strength of G. 18B. The results of these tests are given in Table 6.

TABLE 5.
Long Time Ageing Experiments on G.18B.

Ageing		Cold Tensile Test					
Temperature ° C.	Time hrs.	0·1% P.S. tons/ sq. in.	0·2% P.S. tons/ sq. in.	M.S. tons/ sq. in.	Elongation per cent.	Reduction of Area per cent.	Cold Izod ft./ lb.
	0	16·2	18·0	44·8	46	51·0	50·0
650	32	16·3	18·3	46·3	43	50·0	49·1
	69	15·9	18·2	46·0	43	50·0	47·0
	125	15·5	17·6	45·0	45·5	51·0	(59·0)
	280	16·5	18·7	46·2	37	44·8	41·2
	512	17·0	19·5	47·0	39	43·0	38·0
	1016	18·3	20·5	48·0	34·5	36·0	30·0
	2004	22·5	25·0	52·6	28	31·0	23·0
	4096	21·1	24·5	55·2	26	27·5	18·8
700	32	16·6	18·7	46·2	41	44·8	50·6
	65	16·3	18·4	46·0	41	46·0	40·8
	128	16·6	19·1	46·4	39	44·8	38·8
	280	18·1	20·5	47·6	33·5	38·0	29·0
	511	20·0	22·7	50·0	29	33·6	24·5
	1024	19·7	22·9	52·6	27	28·5	18·4
	2082	21·1	23·8	54·6	23·5	22·5	18·6
	4096	19·7	22·5	54·4	27	31·0	18·8
750	32	16·4	18·8	46·2	35·5	40·6	33·0
	64	17·8	20·4	46·2	32	39·0	28·6
	128	18·1	21·0	49·4	24*	15·2*	22·5
	256	19·1	22·5	51·4	26·5	27·6	19·7
	512	18·5	21·4	51·0	15*	15·2*	18·5
	1024	17·8	20·8	52·0	24·5	22·0	17·2
	2060	19·3	21·7	51·8	27	29·0	17·8
	4200	18·2	20·9	50·8	26·6	27·2	14·5
800	32	18·9	21·3	46·8	35·5	37·0	29·5
	64	19·6	22·0	48·6	31·5	31·0	22·5
	128	19·9	22·7	49·5	22	16·5	14·8
	263	18·6	21·3	48·2	27*	22·5*	17·6
	508	20·3	22·9	50·0	19*	17·0*	16·2
	1048	17·9	20·4	48·8	22*	16·5*	12·5

* Broken outside gauge length.

TABLE 6.
Hot Fatigue Tests on G.18B Steel at 650° C.

Stress tons/ sq. in.	Solution Treated 1300° C.	Solution Treated 1300° C. +1000 hours 700°C.
	Reversals	Reversals
± 26	—	6,800 broken
± 24	—	40,000,000 unbroken
± 22	19,800,000 broken	40,000,000 unbroken
± 21	—	42,000,000 unbroken
± 20	42,500,000 unbroken	42,000,000 unbroken
± 19	—	40,000,000 unbroken
± 17	—	40,000,000 unbroken

These tests were carried out on the Wöhler type of fatigue machine (Fig. 9). The temperature of test of 650° C. may actually be in error by 10° C., but was definitely the same for both series of tests. The tests show that the hot fatigue strength has been, if anything, raised by the ageing treatment, and therefore follows fairly closely the effects on the proof and maximum stresses. Thus, there is definite evidence against lowering of ductility being accompanied by a decrease in hot fatigue strength.

The results of stress-to-rupture tests at high temperatures also indicate that even under the combined effect of stress and temperature the ductility does not decrease with time. For instance, the elongations at rupture of the

TABLE 7.
Percentage Elongation at Rupture of G.18B Steel.
Temperature of Tests: 700° C.

Stress tons/sq. in.	Time to rupture hours.	Elongation at rupture. Per cent.
19	22	7·4
17	44	6·2
15	145	10·2
12	740	12·0
10	3000	15·0

five points recorded in Fig. 1 for G. 18B are given in Table 7, and it will be seen that under creep conditions there is a definite tendency for the percentage elongation at rupture to increase as the rupture-time goes up from 22 to 3,000 hours.

The Use of Creep Data as applied to Solid Rotor Forgings.

It is not difficult to realize that very considerable time, effort and equipment are involved in mapping thoroughly the characteristics of a given material for use at high temperatures, and thus the number of alternative test conditions is severely limited. The tests on G. 18B recorded in this paper refer to steel of typical composition in bar form rolled from billet, which in turn was hammer-cogged from the ingot. Naturally, steel subjected to this degree of hot-working is likely to be of more uniform structure than that of a forging worked direct from the ingot with a cross-sectional reduction of area of the order of only 2½ to 1. This limited forging reduction has been imposed to limit ingot size, as it is more important to have a small sound ingot than a larger ingot with axial porosity. A further limitation arises on account of the ability or otherwise to heat-treat the complete forging at the highest desirable solution temperature. Reduction of properties due to this factor can be estimated from the curve given in Fig. 4. The result may well be that the creep strengths of the periphery of the drum of a rotor forging are lower by between 10 per cent. and 30 per cent. of the properties given in the tables and curves.

In estimating the working stress to be imposed on the rotor drum at the blade roots, it is common practice to estimate the stress-to-rupture at 10,000 hours, 50,000 hours or 100,000 hours as the case may be, and then to fix a working stress ranging between 0·6 and 0·9 of this value according to the factor of safety desired or the margin which the adoption of the material permits from an engineering point of view. However, these matters are still in a rapid state of development, and it is not proposed to attempt to lay down dogmatically any design rules, as the judgment of the designer is paramount in this connection.

GENERAL OBSERVATIONS ON THE LONG-TIME TESTING OF MATERIALS AT ELEVATED TEMPERATURES.

It would have been gratifying to the authors to have been in a position to include comprehensive data on actual gas-turbine components. However, the ordinary room-temperature mechanical properties obtained from four large rotor forgings in different steels are given in Table 8. Tests taken tangentially and radially from rings trepanned adjacent to the rim are recorded, and show the variations likely to be encountered due to variations in the degree of forging. However, it must be freely stated that it will be several years before complete creep information is likely to be available, and only then if much discipline and foresight are exercised in planning experiments and recording actual plant performance.

Laboratory creep tests on standard steels should be conducted for at least two years to prove that present extrapolated stress values are truly valid. Moreover, the observations should be repeated in part on actual rotor material to secure a precise basis for future designs and any service comparisons. Long-time hot-fatigue tests are also desirable with and without special atmospheres surrounding the specimens. Information of this type is at present almost entirely lacking. Studies on secular changes and their effects on different characteristics need to be continued and extended.

TABLE 8.

MECHANICAL PROPRETIES OF G.18B AND R.20 ROTORS.

Rotor	Steel	Direction of Test	0·1% Proof stress, tons/sq.in.	Max. stress, tons/ sq.in.	Elonga-tion, per cent.	Reduc-tion of area, per cent.
1	G.18B	Longitudinal Tangential Radial	18·2 16·8 —	42·4 40·0 42·8	45 33 31	50 31 31
2	G.18B	Longitudinal Tangential Radial	18·8 17·3 —	44·0 36·8 39·4	41 19 17	47 18 —
3	G.18B	Tangential Radial	17·0 —	37·2 39·7	16 20	15 18
4	R.20	Longitudinal Tangential Radial	13·3 12·7 —	35·2 34·0 36·1	54 41 43	60 39 35

It is inevitable in the present state of knowledge of gas-turbine materials that, for some time to come, designers will have to work on limited data and to consult their metallurgical advisers for estimates of "risk". The present trend is for a relatively few special steels and alloys to be employed by a large number of gas-turbine manufacturers. This has the advantage of narrowing the field of enquiry and enabling fuller data to be secured quickly, but conversely it implies that any unsuspected deleterious characteristics are liable to affect a large number of users. The utmost encouragement should be given to the provision of more high-quality creep and fatigue testing laboratories as the tasks lying ahead appear immense. It is easy to occupy a complete laboratory for years with one material in one initial state of heat treatment. The national facilities at present are probably too meagre to cope with the necessary investigations which should be carried out, and failure to expand now may result later in expensive service breakdowns.

THE PRESENT STATE OF GAS-TURBINE DEVELOPMENT FROM THE METALLURGICAL POINT OF VIEW.

Unlike aircraft jet engines where the rotor blades operate at 30°-50° C. above the blade root disc rim temperatures, the axial-flow land and marine gas turbines operate with blades and rotor drums at very nearly the same temperature. Thus the advent of a newer rotor blade material while very significant in the first case is less so in the second.

Assuming therefore that there is no appreciable temperature difference, it would appear that the present maximum temperature of operation would lie in the 700°-750° C. range so far as solid-forged rotors and their blades are concerned. An operating temperature of this order does enable overall thermal efficiencies of over 34 per cent. to be achieved, and thus makes the gas turbine competitive with its steam counterpart.

Development of new alloys along orthodox lines will probably enable these operating temperatures to be raised eventually to about 850° C. This development will probably take about another five years. For temperatures higher than 850° C., it is probable that built-up constructions will be resorted to because of the extreme difficulties in manufacture of large rotors in these creep-resisting materials, and because it is obviously uneconomic to provide a large mass of steel, of which, say, only one-tenth need resist the highest combinations of stress and temperature. With intensive research and development, such built-up rotors should be available within the next 10 to 15 years, with drums that can run at temperatures of the order of 950° C. Presumably this will involve the extreme application of welding methods, including most likely the use of "solid-phase" or "pressure" welding. After 15 years, it is possible that the emphasis on the operating temperature requirements will change, but if efficiencies then demand still higher working temperatures, these efficiencies are likely to be achieved by the use of hollow components internally cooled.

The newer problems of utilizing the vast heat energy generated in atomic energy "piles" may be solved eventually by leading heated gases under control to gas turbines of suitable type. The gas turbine may then be the principal prime-mover on land, sea and in the air.

Acknowledgments.

The authors wish to express their thanks and indebtedness to the Ministry of Supply, the Admiralty, the National Physical Laboratory and many industrial organizations, including Sulzer Brothers and Brown, Boveri & Co., Switzerland, for helpful discussions on many aspects of steels for gas turbines. Thanks are also due to Mr. L. Chapman, managing director, William Jessop & Sons, Ltd., for unfailing support in carrying through a long and costly programme of research and experimental development, to Mr. D. W. Hammond, B.Sc., F.R.I.C., works manager, William Jessop & Sons, Ltd. and his skilled production staff for overcoming many difficulties, and to Mr. W. H. Bailey, Assoc. Met., Mr. H. C. Child, B.Sc., and the high-temperature laboratory staff for unremitting efforts in the common cause.

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Discussion.

Mr. W. J. Ferguson (Member), opening the discussion, said that Dr. Dorey would sincerely regret that he was unable to open the discussion on this paper. He was not yet back in this country from his visit to the United States and therefore his absence was unavoidable.

The subject was of vital interest to marine engineers, and the admirable presentation of the information in the paper enabled one to appreciate the immense amount of work that had been done, and to make some estimate of what remained to be accomplished before the application of the gas turbine to marine propulsion became a commercial proposition. In the latter respect the paper was particularly helpful because the authors had so frankly discussed manufacturing difficulties and the limitations of the information at present available, and in this regard had earned the warm appreciation of all engineers interested in the subject.

During a visit to Switzerland he had been impressed by the vast amount of research undertaken during the war period by the three leading firms interested in gas turbines for land and marine use, and by the fact that their research had been independent and that three distinctively different lines of development had been adopted. The problems were numerous, but the most vital was that of suitable materials. It was therefore very encouraging and a matter of considerable pride to note that at the conclusion of the war their Swiss friends came to this country and were surprised and delighted to learn of the progress made during the war, particularly by the authors' firm.

Knowing something of the design, construction and testing now under way at home, and of the co-operation between firms, one was confident that this country would not lag behind in the use of the gas turbine for marine propulsion.

In detailing five desirable characteristics of steels for use in the construction of gas turbines, the authors would be well aware that the list was not exhaustive. When assessing the relative merits of two steels, it was a good thing to have all the factors in sight, and it was therefore suggested that the following items might be added to the list:—

(f) Good welding properties.
(g) At working temperatures the damping properties should be high and notch sensitivity low.
(h) The coefficients of expansion and thermal conductivity should be low and high respectively. Unfortunately the special steels tended to be in the reverse order.
(i) Ease of machining.

It would be ungenerous to add low cost to the already formidable list, but perhaps the authors would state how G.32 compared in other respects.

On page 81 the authors stated that satisfactory performances at full rating for a total of 2,000 to 10,000 running hours would satisfy *current* demands for marine propulsion, but it was suggested that before the marine gas turbine was accepted as a commercial proposition, a reliability at least as great as that demanded for land use would be required. Further, it would appear that the efficiencies of other competitive types of prime movers would require an operating temperature of about 700° C.

When dealing with the use of creep data as applied to solid rotor forgings, the authors very rightly stressed the fact that the test results referred to steel in the bar form and that corresponding creep strengths on the periphery of the drum might be 10 to 30 per cent. lower than the figures given in the tables. The creep strength at the core would be appreciably lower than at the periphery and one felt somewhat nervous of the "looseness" at the core referred to by the authors. On the other hand, to bore the rotor involved a large increase in stress.

Having in mind the special problems in the production of solid rotor forgings stated in the paper, it would appear that the future lay with the rotor of the built-up welded construction for all but the smallest sizes. In any case, it appeared certain that future requirements would include turbine rotors having a diameter in excess of 30in. Further, in addition to the advantages mentioned in the paper, fabricated rotors could be designed to offer an improved heat flow.

Would the authors state the welding properties of G.18B and indicate the technique required.

With regard to the tests at room temperature after ageing, had any creep tests been undertaken after ageing at a higher temperature?

As regards the hot fatigue tests, was there any indication that, for a given temperature, the results would lie on a curve similar to the Wöhler curve for tests at room temperature?

Finally, referring to the results of the creep tests in Table 3, it was noted that one test had a duration of 10,000 hours. The authors clearly indicated the desirability of long-time creep and hot-fatigue tests and the difficulties in way of their accomplishment. It was to be hoped that these long-time tests could be carried through.

Mr. J. H. Darley (Engineer-in-Chief's Department, Admiralty) asked if the authors could give some information, where they stated that the R.22 material was more scale-resisting than G.18B, as to the method by which scaling tests were carried out.

With regard to welded rotors, could the authors indicate more clearly what mechanical properties could be expected across the weld, also what they would consider to be a suitable stress-relieving heat treatment to apply to welded rotors with G.18B material?

The authors had carried out some ageing tests on G.18B material at temperatures up to 800° C., and it would be useful to hear if they had obtained any Izod impact values on this material after ageing and stressing at similar temperatures.

From Fig. 2 it would appear that longitudinal flats had been machined on the surface of the rotors which, it was assumed, were for the purpose of supersonic testing. If that were the case, why had the authors not used curved probes so that a search could be made over the whole surface of the rotors? Also, it would be interesting to know whether the authors had carried out any supersonic testing longitudinally along the rotor by testing from an end face, and, if so, whether this direction of testing had discovered any defects not disclosed by testing in a transverse direction from the prepared flats.

Mr. H. L. Chamberlain (Development Officer, Tube Investments, Ltd.) said he had listened with great interest to the paper which described a very creditable piece of work in the development of high-temperature materials. The availability of these alloys might help engineering progress over the next few years.

The authors had given a great deal of information about one of the alloys developed in the later war years, an alloy which contained a considerable percentage of the relatively expensive element cobalt, and the still more expensive and almost rare element niobium. Did the authors feel that the results they had obtained were fully in line with the heavy expenditure entailed with expensive alloys?

One of his reasons for asking that question was that in some work which had been reported abroad, he had seen figures, particularly stress-rupture figures, which were very similar to the stress-rupture figures given for G.18B, but in the alloy concerned the two expensive elements to which he had referred were absent. To all those who were interested in the future of these alloys, economics were a serious consideration when one came to the development of plant and equipment.

The authors had illustrated for comparison with G.18B a relatively limited number of the alternative alloys which were available in different parts of the world. Would it be correct to say that to use, for example, the late Dr. Hatfield's Rex 78 as a comparison was perhaps not a fair comparison of the materials of the present day? The authors' comments on that point would be welcomed.

Thirdly, were the creep curves and high-temperature data given the results of spot tests, and were the tests from casts on the low side of alloy content? Could any information be given as to the range of properties on different casts of material which had been commercially produced? It was quite important to know whether the figures quoted were mean figures or whether they were selected figures for the better casts of material.

Reverting to the work abroad, it was a fact that gas-turbine rotors had been manufactured on a considerable tonnage basis, particularly in the United States, and especially for the smaller sizes of rotors. It would be of interest to know how the American material compared, in relation to its properties as determined by the normal tests applied in this country, with the G.18B material.

Mr. J. Calderwood, M.Sc. (Member of Council) referred to the notes towards the end of the paper where the authors mentioned 700-750° C. as being a safe operating range with materials now available and suggested that this would give a thermal efficiency of 34 per cent., which was equivalent to that of a steam turbine. In his opinion the authors were a little pessimistic in their figures as far as combustion turbines were concerned. Systems now being developed would give the efficiency they mentioned, i.e. 34 per cent. at a temperature of about 650° C. This would be much in advance of the steam turbine as no marine steam plant to-day could attain an overall efficiency much in excess of 25 per cent. On the other hand, the operating temperatures up to 750° which they mentioned seemed rather high in view of the very long life required from the forgings in marine service.

On page 88 the authors mentioned that tests were desirable with specimens in special atmospheres. Did the authors know of any such tests having been made and had they any indication, either by tests or otherwise, that certain atmospheres might have deleterious effects on the material? Also, in the authors' view, were the types of material discussed in the paper likely to suffer from any loss of strength due to working in combustion gases which would certainly contain sulphur dioxide, possibly sulphur trioxide and a variety of other compounds varying with the particular fuel being used?

Very little was said about the R.22 material mentioned in Table 1. Its composition was such that it would not seem to be suitable for forging. However, its other properties suggested that it might be a suitable material for the combustion chambers or any parts subject to high temperatures and moderate stresses.

On page 81 the authors stated that "In the marine propulsion field current demands appear to range from between 2,000 and 10,000 hours". Perhaps their intention was that this was the period of tests called for by the various engineers who were investigating a marine application of the combustion turbine. Certainly it could not be the intended service life, as for an installation for use in the Mercantile Marine it would be essential for the rotor in particular to work on a service life of at least 100,000 hours at or near full power.

With regard to Fig. 1, even the longest tests shown were of comparatively short duration in relation to the life required from the turbine. In the 18:8 niobium steel a break appeared in the curve at approximately 200 hours. All of the other curves remained uniform up to the maximum test period. Could the authors say that no similar break to that which occurred on the above-mentioned steel was likely to occur after a longer period than shown on the tests with any of the other grades of steel? Also, had any tests for long periods been made on test pieces taken off large forgings? The authors referred to short-time test pieces off large forgings and to the differences of properties of material of the large forging as compared to a small test piece, and it would, therefore, be of particular interest to see comparative long-time tests off large forgings.

In view of the great importance of the time element in the use of materials at high temperatures, would the authors recommend that when a forging was put into service, test pieces taken off it should be put under continuous test at the same time?; so that if after a long period of service the test pieces showed signs of failure, some warning could be given to the user of the forging.

The construction of the welded rotor shown on page 81 looked attractive, but one always felt a little scared of welding, even though in theory the welded joints were not subject to stress.

It would seem also that the forging problem was still difficult with the welded construction, due to the very large change of section from the disc to the shaft in the end pieces.

On page 82 the authors mentioned that many of the most attractive alloys developed could only be made in a high-frequency furnace and were, therefore, limited to comparatively small forgings. Was this a permanent limitation or was it due only to the fact that no sufficiently large high-frequency furnaces were in existence? If in the future sufficiently large high-frequency furnaces were developed, it would presumably be possible to use alloys for large forgings which at present could only be manufactured for smaller parts.

In the curves, Figs. 13, 14 and 15, there appeared to be some peculiarity. From these curves it would appear that after something in excess of 5,000 hours ageing time, the final condition of a steel aged at 650° would be worse than the final condition of a steel aged at either 700° or 750°, which did not on the face of it seem a reasonable result, although there might be some explanation. In the same connection, in Table 5 there would appear to be some error in the figures for elongation given in the last line of the section referring to 700° temperature. For all of the other temperatures there was comparatively small change in the elongation figure as between 2,000 and 4,000 hours ageing, whereas for the 700° temperature there was a very remarkable improvement suggesting that there might be some error in the above-mentioned figure in the paper.

On page 84, in referring to fatigue tests, the authors mentioned that the 40 million reversals that had been applied on test might be exceeded by a hundredfold in service. It seemed more likely that at the comparatively high frequencies of stress variation on turbine blades the number of reversals in service would be from ten to one hundred thousand times that of the number carried out in the above-mentioned test.

Finally, it must be said that the authors had presented a most valuable and interesting paper at the present time. The development of the combustion turbine had always been limited by the materials available, and this paper showed that they now had available steels which might reasonably be expected to stand up to the working life of a marine turbine at temperatures which offered an attractive turbine efficiency.

The **Chairman** said that engineers would expect to be able to rely on the 10,000 hours or 5,000 hours test curves not making a sudden change after that period. The authors spoke of 10,000 hours as being one year but, as a matter of fact, the average ship had 100,000 hours steaming at full power in an average life of 20 years. 10,000 hours therefore really represented a two-year period; hence the extrapolation the authors had to do in forecasting the performance was much reduced.

On the proposal of **Mr. J. Turnbull** (Member) a hearty vote of thanks was accorded to the authors with acclamation.

BY CORRESPONDENCE.

Mr. S. Archer (Member) wrote: The competitive position of the gas turbine was governed primarily by the maximum practicable gas temperature, and, thus, future progress would be regulated largely by the ability of the metallurgist to provide suitable materials capable of withstanding the increasingly high temperatures involved without undue limitations on operating stresses and thus on rotor diameters and blade heights.

With the development of materials such as R.20 and G.18B a considerable step forward had been made and, as the authors had indicated, further progress might shortly be expected.

One of the problems which would require solution concurrently with the question of improved materials, was undoubtedly that of the reduction gear. In steam-turbine Mercantile Marine practice, with rotor speeds of from 3,000 to 4,000 r.p.m., pitch line speeds seldom exceeded 10,000ft. per minute, whereas gas turbine rotor speeds at present ranged up to 10,000 r.p.m. Owing to the very considerable increases in tooth loading which were known to arise from gear-cutting inaccuracies, largely those derived from periodic errors in the gear hobbing machine, it would seem that further improvements in the accuracy of the latter would be called for, unless it was found possible to reduce rotor speeds by adopting larger diameters. The authors had indicated that at present a limit to rotor size was set by considerations of maintaining soundness in ingots of the special alloys required. It would thus appear that the composite rotor design described on page 81 offered the best possibilities, provided the problem of welding such heavily-alloyed materials could be satisfactorily solved. In this connection, would the authors indicate whether the materials R.20 and G.18B could be successfully welded by normal methods, also whether "solid phase" welding mentioned on page 89 could be applied to these alloys.

Both R.20 and G.18B included appreciable proportions of the element niobium. Could the authors state what particular properties this addition conferred on the alloys and its action on the microstructure? It would also be useful to know how it compared in cost with, say, molybdenum.

On page 80 the authors stated certain minimum requirements for gas-turbine steels which under (a) included a percentage elongation at room temperature of not less than 10 per cent. on $L=4\sqrt{A}$, also an Izod impact value of not less than 10ft.-lb. These values seemed somewhat low, particularly as they were likely to be appreciably reduced by secular changes with ageing time as indicated in Fig. 15.

On page 83 it was stated that austenitic steels were largely insensitive to notches. Had fatigue experiments involving notches been carried out on such alloys at high temperatures, also as affected by ageing? It would further be valuable if the effect of high temperature on the damping capacity, particularly of the blade materials, could be investigated.

It was assumed that both R.20 and G.18B fulfilled the requirements noted under (e) on page 80, namely, freedom from serious corrosive attack from the combustion gases.

In connection with Table 2 and Fig. 1, it would seem that provided adequate long-time data for a given material was available, covering the expected service life, it should be possible to lay down some such short-time schedule of acceptance tests as the following:—

(1) A minimum time to rupture of approximately 100 hours under a suitably chosen stress and at a temperature corresponding to the service maximum.

(2) Cold tensile tests giving 0·1 per cent. proof stress, maximum stress, percentage elongation and reduction of area on, say, three specimens tested after ageing for 24, 48 and 100 hours, respectively, at the service maximum temperature.

(3) Cold impact tests on three specimens similarly aged.

(4) Hot Wöhler or Haigh fatigue tests on, say, three specimens to give a minimum average endurance corresponding to a total testing time of, say, 100 hours at a suitably chosen stress, and at the service maximum temperature.

The fatigue tests would be particularly desirable for the blade materials.

The authors' comments on these proposals would be appreciated and, in particular, it would be interesting to know whether they considered cold tests after ageing as in (2) and (3) were necessarily indicative of the structural stability of the material in its hot state after ageing.

On the question of permissible working stress in relation to service life, it was stated on page 81 that in the marine field current demands ranged between 2,000 hours and 10,000 hours at full rating. From the classification point of view it was probably desirable that the minimum period should correspond at least to the four-yearly interval between special surveys. On the basis of, say, 240 days per annum at full rating, this was equivalent to a life of 23,000 hours or, say, 25,000 in round figures. On this basis and assuming a factor of safety of, say, 1·5, then it would appear from the graphs in Fig. 1 that working stresses of about 5 tons per sq. in. and 1·8 tons per sq. in. could be allowed for G.18B and R. 20 respectively, at a service temperature of 700° C. The superiority of G.18B was thus very marked.

It would be of interest to the layman if the authors could enlarge on the meaning of the term solution heat treatment used throughout the paper and in particular in connection with Fig. 4.

The results of room temperature mechanical tests taken from four large rotor forgings and given in Table 8 were informative inasmuch as for G.18B the effect of different forging ratios had relatively small influence on the proof or maximum stresses but, as evidenced by a comparison of rotors 1 and 3, greatly affected the ductility. Presumably the steels were all similarly heat-treated.

Dr. W. Siegfried (Research Metallurgist, Sulzer Bros. Ltd.) wrote: The fact that the behaviour of steels when red hot was quite different from that at room temperature meant that careful study and thorough testing work was required in order to attain in the gas turbine, with its high working temperatures, a reliability in service similar to that expected from steam turbines.

Up to the present, a relatively short life was often accepted for the gas turbine and frequent overhauls were regarded as being necessary to enable certain parts of the plant to be replaced at short intervals.

In the writer's opinion, however, this situation was only temporary. Through intensive study of materials and through the collaboration of steel works with steel users, as practised in the example cited in this paper, the writer felt sure that the point would be reached at which similar requirements could be fulfilled for the gas turbine as for the present-day steam turbine.

With this aim in view, research work in the domain of heat-resisting steels had been intensively prosecuted at Sulzer Brothers, the phenomena which were of importance for design in particular being accurately investigated. Their viewpoint on the assessment of heat-resisting steels would be put forward in a detailed paper on the occasion of the Summer Meeting of the Iron and Steel Institute in Zurich. Only a few of the main points needed to be referred to here.

Tests were carried out to determine the influence of three-

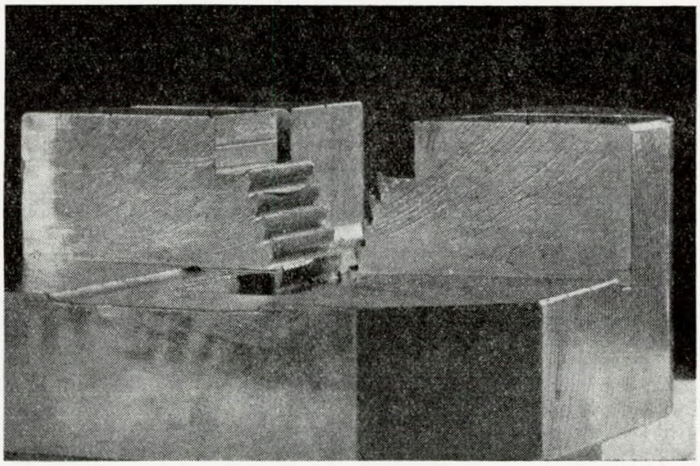

FIG. 17.

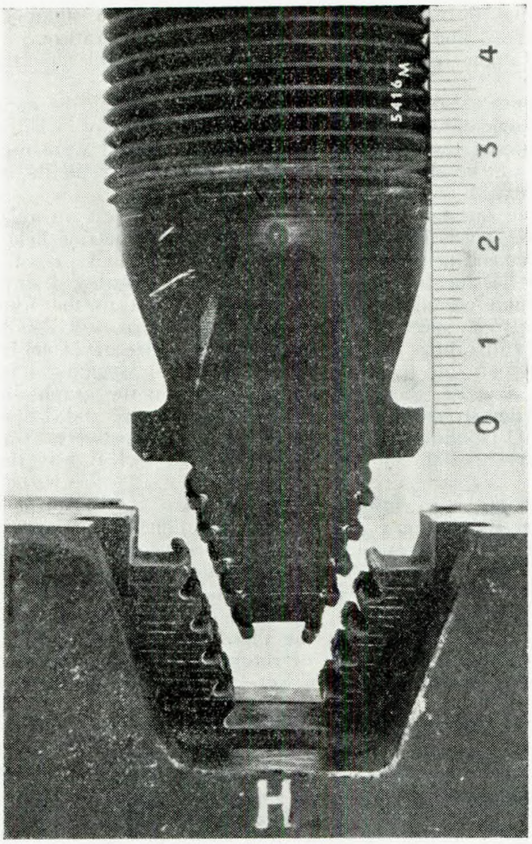

FIG. 18.

dimensional stressing and of notches during protracted loading at high temperatures, not only on test bars but also on actual engine parts.

The importance of such tests could be seen from Figs. 17 and 18. Fig. 17 showed a blade root connection which was tested at room temperature on the tensile testing machine, while Fig. 18 was a photograph of the same connection with the same steel, this time tested at high temperature for a duration of several hundred hours. The fundamental difference in the nature of the fracture was at once apparent. At room temperature the steel in question had so great a capacity for deformation that the teeth deformed until the blade piece could slip out of the opposite part. At high temperatures, however, the material was much more brittle and the joint gave way because the teeth broke off along cracks beginning at the point of stress concentration.

In the writer's opinion, rotors of built-up welded design might offer certain advantages, particularly for large size units, and besides the forged rotors this type of construction had also for a long time been the object of special studies at his Company's Works.

Mr. N. McLeod (Lloyd's Register of Shipping) wrote: The combination of stress-rupture and creep-test data as detailed in this paper for the R.20 and G.18B steels provided the engineer with the four factors, viz. stress, temperature, allowable deformation and expected service life necessary for the design of a gas turbine. In the application of the gas turbine to marine propulsion, it was generally accepted that the service life of the turbine should be 100,000 hours continuous running at the service rating with a maximum creep elongation of 0·1 per cent.

Regarding the presence of niobium in the R.20 and G.18B steel as compared with titanium in Rex 78 and Nimonic 80, it was concluded that the former element was added because there was less tendency to embrittlement resulting from precipitation than with titanium.

Referring to the stress-to-rupture curve for 18:8:Nb steel in Fig. 1, if that part of the graph to the right of the point of change of slope be produced in the direction of decreasing time, then the upper line would indicate intercrystalline failure, whilst the lower would indicate transcrystalline failure. Since both processes presumably continued simultaneously, their respective rates being functions of time and temperature, and it was known that certain methods were available for determining indirectly the change in structure, e.g. the relation between magnetic permeability and change in structure due to temperature; also, the intensity of electronic emission was a function of the temperature range, it would be of interest to know of the possibility of some such method being used to determine the slopes of these lines, from short-time tests, and hence predict their point of intersection, or the transition point for the particular steel.

What was the influence of cold deformation of the material on the creep strength of R.20 and G.18B?

Since the co-efficient of expansion of austenitic steels was some 50 per cent. greater than that of the more commonly-used steels and the thermal conductivity somewhat lower, would the authors give these values over the working range of temperatures for the steels under consideration. The authors' views on the relative merits of fully-built diaphragm-type rotors, solid-forged, and composite-forged rotors would be appreciated, having regard to thermal stress concentration, and the time taken to reach equilibrium temperature when starting up the plant; also the possibility of using "heat dams" in the rotor forging to turn to advantage the low thermal conductivity inherent in these steels by providing a reheating effect in the low-pressure stages of the turbine by using the heat flow from the high-pressure stages, at the same time preventing heat flow along the rotor shaft to the bearing.

Referring to Figs. 10 and 11, the comparatively high initial plastic strain and creep rate during the initial period of the test would appear to be undesirable from the point of view of blade attachment, especially with "fir-tree" fixings, because of the large number of slip surfaces. For other fixings, e.g. bolts, etc., this plastic strain might be an advantage in that it effected a more uniform distribution of the load in the stressed parts.

It was a fortunate coincidence that the same metallurgical measures which improved the "hot strength" of a material generally brought about improved corrosion resistance. It would be interesting to know if a very high polish of the blade surfaces had any detrimental effect on the surface structure of the material from the point of view of creep resistance.

It was apparent from the paper that the production of such materials as those dealt with involved the highest degree of manufacturing uniformity. The authors were to be congratulated on presenting this valuable information in so concise a manner, since the subject covered so wide a field.

Mr. H. J. J. Redwood (Member) wrote: The authors' remarks concerning the properties of materials relative to the degree of hot working and heat treatment indicated the necessity for close collaboration between the metallurgist and the designer at the drawing board stage of any new design. It was apparent that the size of each forging might be of paramount importance in obtaining the best material. The authors suggested that for operating temperatures higher than 850 deg. C. built-up construction might have to be resorted to, but it would appear that this method of construction would pay at much lower temperatures than this.

The statement that the creep properties at the rim of a rotor might be up to 30 per cent. lower than those of bar material was somewhat alarming. Although very desirable, to carry out creep tests on specimens cut from the rim of an actual rotor might be a very expensive process if special rotors had to be produced for the purpose. This might well be necessary if a large number of specimens were required to obtain full creep characteristics of the material. Some quicker and cheaper method of producing specimens having similar characteristics to the material at the rim of any size of rotor appeared to be indicated.

The writer had yet to discover where it was common practice to design rotor drums for gas turbines on the basis of stress to rupture and for the factors of safety quoted by the authors. The permissible stresses were a subject of great controversy between designers, and arguments which could be deduced for one application might be fallacious for another. This was more particularly the case when considering discs, cooled and uncooled. In large drums, or discs, where no cooling was employed, it would appear that creep rate would play an important part in the design, and stress to rupture might be of secondary importance. Further, some designers preferred to select the stresses from a safe part of the creep-to-rupture curve and due to the varying characteristics of materials, the factor of safety in relation to the stress to rupture might vary substantially from the figures quoted.

Although the authors were confident that new alloys would be produced to enable operating temperatures of 850 deg. C. to be used, one wondered whether this was the correct approach. No doubt, better materials would be evolved, but they would be more expensive and from the economic aspect it would be preferable so to design the gas turbine that higher temperatures could be used with cheaper materials (particularly in large power plants).

Whereas the early development of the gas turbine was dependent upon the metallurgist, the position might now change and it would be up to the designer to evolve means of using higher temperatures with existing materials by cooling.

The Authors' Reply to the Discussion.

The authors, in reply, expressed their thanks to all those who had contributed to the discussion, either at the meeting or later by correspondence.

Mr. Ferguson's additions to the list of desirable characteristics were accepted. In reference 4 a longer list had been given, but had been cut down in the present paper. Item (f) was satisfied by G.18B and R.20, of which the welding properties were remarkably good. This was partly due to the relatively high niobium content which facilitated the welding of high-alloy high-carbon bearing steels. The fact that the first application carried out by the authors' firm had been a flash butt-welded rotor disc and shaft which had met aero requirements, was worthy of note. Subsequent experience in the Welland turbine jet engines fitted to Meteor aircraft, which first flew operationally against the flying-bomb, had provided practical proof of the high-class weldability of those steels.

Regarding technique, three methods of welding had so far been used, namely, electric flash butt-welding, arc welding and solid-phase pressure welding. The flash butt-welding was limited to about twenty square inches in cross-section; arc welding was highly successful using covered wire of the standard composition, and creep strength properties in the weld could be obtained broadly equal to that of the parent metal. Solid-phase pressure welding was in its infancy, but was showing great promise for joining together large finish-machined component parts. The mechanical properties in the weld were found to be comparable with those given by flash butt-welding.

Item (g) called for high damping properties at working temperatures. These were likely to be present at elevated temperatures, and of the same order as those of most austenitic stainless steels. The damping properties had not yet been actually measured. Notch sensitivities were certainly low, as might have been anticipated. The effect of notches on creep performance was believed to be under examination by Dr. Siegfried, and his forthcoming paper was anticipated with much interest.

The thermal conductivity was low when it should be high, and the thermal expansion high when it should be low. This was opposite to the desired requirements in item (h), but little could be done about it. At operating temperatures, *circa* 650 deg. C., most steels had thermal conductivities of about the same order. Item (i), calling for ease in machining, was open to flexibility in interpretation. Turning operations with hard-metal carbide-tipped tools were quite straightforward for the steels described, and all machining had so far been overcome by a suitable choice of tool angles and tip material. Drilling and boring were both regularly practised.

Regarding Mr. Ferguson's interest in the comparative behaviour of G.32 as compared with G.18B, it could be stated that the former was more difficult to machine at room temperature and more difficult to manipulate at high temperatures. The creep resistance of G.32 was, of course, much higher, and its high-temperature fatigue properties were under investigation. It was primarily of interest as a blade steel.

Several contributors had referred to the expected life of a marine gas turbine installation and the authors' ideas had been refined thereby. It was a difficult requirement to equal the reliability of a good steam-turbine installation, but further research would doubtless indicate the way to achieve such a performance.

Experience so far had indicated that slight "looseness" in the axial regions of rotors did not affect their creep resistance to any appreciable extent—in fact to a degree less than that of the normal mechanical properties at room temperatures. Rotor core temperatures could be expected to be 50/100 deg. C. lower than working blade root temperatures, which notably affected the creep stress corresponding to a given strain.

With regard to the assessment of "looseness", the authors were using the supersonic method, which was most sensitive compared with ordinary methods of inspection. It was not always desirable to bore rotors to be quite certain of soundness and, even if a small risk was taken, the austenitic steels in question were not inherently notch-sensitive and small areas of porosity were not likely to give rise to plastic flow and cracking failure. Plastic flow in the vicinity of a small hole or non-metallic inclusion did, however, take place to a considerable extent in an experimental over-stressed turbine disc, which was reassuring. Cracking was absent and the regions referred to were substantially at room temperature.

In reply to Mr. Ferguson's enquiry regarding the effect on creep strength of ageing at still higher temperatures, it was a fact that such ageing did lower creep strength owing to too rapid precipitation of the carbides and phases held in solid solution. In service at lower temperatures, the combined effects of stress and temperature were normally experienced together, in which circumstances there was no decrease in creep strength.

In hot fatigue tests carried out so far, the evidence indicated that the form of the usual Wöhler curve for tests at room temperature was not reproduced. It therefore appeared necessary to state testing-time, temperature, and stress range and to correlate results with creep characteristics.

In reply to Mr. Darley concerning the method by which scaling tests were conducted, comparative oxidation tests were carried out in a current of air at different elevated temperatures, scaling being assessed by loss in weight determinations. It was projected that work be carried out in other atmospheres in due course, notably those containing sulphur dioxide and water vapour.

With reference to the mechanical properties across welds in composite rotors, the tensile properties obtained in experimental welds were practically the same as those from the parent metal. For instance with G.18B, maximum stresses of just over 40 tons per sq. in. were obtained associated with elongations of about 30 per cent or higher: $(L=4\sqrt{A})$. Cold fatigue strengths had so far only been ascertained on flash butt-welds, and in that case the fatigue strength was about the same as that of the parent metal, and in the case where the two steels were different, about the same as the steel having the lower properties. A suitable stress-relieving heat treatment to apply to welded rotors with G.18B steel was normally 10 to 20 hours at 550 deg. C., which proved sufficiently high to relieve internal stresses yet not high enough to permit appreciable phase precipitation to occur. Impact values on G.18B steel after simultaneous ageing and stressing had not been extensively observed because unfortunately the creep test specimens were stricted limited in size.

In connection with Mr. Darley's point on supersonic testing, curved probes had not been used because when longitudinal flats had been machined on the surface of rotors it was feasible to explore a large proportion of the total volume either by diametral transmission or by longitudinal transmission between the end faces of the rotor drum.

Replying to Mr. Chamberlain's interesting question on the effectiveness of expensive alloying additions, the authors submitted that they did not consider G.18B to be very highly alloyed in that sense. It would have been possible to have added 20 per cent. cobalt, whereas G.18B contained 10 per cent. Alternatively 4 per cent. of molybdenum might have been employed whereas 2 per cent. had been adjudged the optimum economic addition. To have removed cobalt from the steel would have been less damaging than to have eliminated niobium, which would have had catastrophic results on properties. In reference 4 the authors had given the history of the early development regarding the ascertainment of composition, and while it was agreed that it was possible to obtain a large range of steels with good stress-rupture properties, the inherent ductility had left much to be desired. The target had been to achieve high creep strength with the property of pulling-out on over-stress like warm toffee. It was securing that last characteristic which had proved so difficult.

The comparison of G.18B with Rex. 78 and the United States version of Nimonic 80 was conditioned by the fact that it was legitimate to refer only to available published information.

Mr. Chamberlain's enquiry as to the limitations to be placed on the data was valuable. The principal data were actually average results on typical compositions. It had been found in well-forged bars and discs of G.18B, that on statistical analysis 95 per cent. of the product fell within limits of ±8 per cent. Occasional results showing abnormality were in all instances discovered by short-time quality control. Under normal conditions, therefore, the creep properties could be expected to be reproducible within ±10 per cent., which appeared to be satisfactory.

A comparison between British and United States practice in rotor-disc production was difficult because, while it was known that a large number of small disc forgings had been produced and put into service, notably in superchargers for the Flying Fortress, it had emerged that British compositions and practice had apparently secured greater success in large gas-turbine disc production and on large rotor forgings which were the subject of the paper.

In reply to Mr. Calderwood, the authors were grateful for his remarks regarding working temperatures for a stated thermal efficiency. It was true that an operating temperature of 750 deg. C. was probably too high for long service-life conditions in marine service, but it emerged that a lower temperature was consistent with high working efficiency and thus the further development of marine gas turbines could be viewed with confidence.

Little information was available on the effect of special atmospheres as affecting high temperature properties, but atmospheres of sulphur dioxide and water vapour could be expected to be deleterious to the very high nickel-containing alloys. The steels described in the paper were not likely to prove very susceptible to "sulphur attack".

The R.22 steel was not a new one and it had been available for some years. Its strength properties were not very attractive but its scale-resisting properties were very good. R.22 steel was not expected to scale heavily under 1,100 deg. C., whereas G.18B on a comparable basis might do so under the 1,000 deg. C. level. R.22 steel could be forged and rolled and might be well worthy of consideration for combustion chamber construction in the larger marine gas turbines.

The question of whether a non-linearity would occur in the stress-rupture characteristic of G.18B over a long period of time, was one of the matters kept in view in undertaking the work which had now been described. The conclusion which had been already arrived at was that G.18B and R.20 were not likely to exhibit that distressing characteristic, but tests were being continued for the longest periods which were possible. There was no ***primâ facie*** evidence for expecting anomalous behaviour, as linearity had been maintained for periods of up to half a year. The authors agreed that it would be of particular interest to have comparative long-time tests from specimens removed from large forgings. They also attached much importance to the continuance of the work on normal forged bars which already had been commenced. Further accumulation of data of all kinds was of paramount importance. Mr. Calderwood's recommendation that when a forging was put into service test-pieces taken from it should be put under continuous test at the same time was an excellent one and should be followed whenever possible.

Large-scale investigations on welded composite rotors had commenced, and important developments could be anticipated along that line. It was also true that a large number of independent investigations would have to be conducted as ancillary researches.

There appeared to have arisen a misunderstanding regarding the use of high-frequency furnaces. Some materials demanded the use of such furnaces but the point the authors were endeavouring to emphasize was that the steels described in the paper were not limited in that way and had been made in standard 15-ton capacity electric-arc furnaces and could be made in still larger ones. The main difficulty which would arise when casting large ingots to forge large masses would probably prove to be one of degasification during solidification. The specially highly-alloyed materials which needed extra precautions were fortunately those mainly required for blades and thus small-scale production was no serious handicap.

Mr. Calderwood's point concerning the final condition of the steel after ageing at 650 deg. C. being worse than after ageing at either 700 or 750 deg. C., should be viewed as a problem in rate of precipitation and precipitate coalescence. The properties genuinely varied in a curious way dependent upon the approach to the final state of precipitation or aggregation of the precipitated phase. At 650 deg. C., aggregation was so slow that embrittlement proceeded farther before the minimum was reached.

The authors were grateful to the Chairman for pointing out so clearly how to correlate test-period with service-life.

Mr. Archer had pointed out an important point in connection with new demands on the performance of reduction gears which in the future would have to operate under more onerous conditions. It was interesting that Mr. Archer supported the composite rotor construction, and his questions in that connection had already been dealt with in the reply to Mr. Ferguson's contribution.

The function of the strong carbide-forming element niobium consisted in conferring strength without concomitant brittleness under conditions of stress and temperature over extended periods of time. Further details concerning its rôle in the steel had already been published (reference 4). The cost of niobium was very approximately three times that of molybdenum.

Mr. Archer commented that the authors' minimum values of 10 per cent. elongation and 10ft.-lb. Izod impact seemed low. It was, however, intended that these values should refer to the rotor at any time during its history, and not prior to the secular changes introduced by ageing at temperature or resulting from thermal cycles in service operations. As far as the authors were aware, very little work had been undertaken on notched hot-fatigue test-piece performance. Regarding the damping capacity of blade materials at elevated temperatures the important contribution of the blade-root-fixing to the overall mechanical damping should not be overlooked, because this contribution might well have exceeded the inherent damping of the material under working conditions.

Mr. Archer's acceptance test proposals were interesting, but would probably have to be curtailed in practice in view of the time and expense which would be involved, as well as the necessary laboratory facilities. The authors' experience had indicated that, providing mechanical properties at room temperature were normal, one or two true creep or stress-rupture tests of a few hundred hours' duration were effective for quality control. Other properties then fell into line provided the chemical composition fell within predetermined limits and manufacturing practice and heat treatment had been under full control. The term "solution heat-treatment" implied heating the steel to a high temperature and holding it at that temperature for a period sufficiently long to take into solid solution those carbides and phases some of which would later be precipitated slowly, thereby conferring high-temperature strength. Further details had been given in reference 4.

The G.18B rotors referred to in Table 8 were all similarly heat treated.

Dr. Siegfried's contribution was much appreciated and his careful researches about to be published would be anticipated with deep interest. The effect of temperature on type of deformation illustrated by the photographs was of particular interest. Finally, Dr. Siegfried's endorsement of the opinion expressed in the paper of the possibilities of welded composite rotors was gratifying.

Mr. McLeod had referred to a maximum creep elongation of 0·1 per cent. for a service life of 100,000 hours' continuous running. It appeared that this strain of 0·1 per cent. was laid down originally for ferritic steels, and the authors submitted that for gas turbines it might well be revised to 0·5 per cent. or even 1·0 per cent. Mr. McLeod's interpretation of Fig. 1 was stimulating, and his suggestions would be given further consideration. His conclusions, however, had gone farther than the authors could confirm or refute. The influence of cold deformation on the creep strength of steels of the R.20 and G.18B type was to increase the maximum stress and proof stresses of each steel, but with a tendency to lower the creep strength dependent upon the amount of cold work imposed. The technique of the warm-working (outlined in reference 4) was to achieve the first desirable state of affairs without the handicap of the second. The coefficients of expansion and thermal conductivity values had already been made available (reference 4).

Mr. McLeod's invitation to comment on composite rotor design was appreciated. The questions raised were most interesting but hardly within the authors' province as metallurgists and outside the authors' prior experience. It would appear that the engineer should outline the kind of design he would like to develop, at which stage the steel-maker should be consulted, when he should be in a position to comment helpfully.

Regarding high initial plastic strain and creep rate, some designers had exploited this to equalise stresses and to ensure uniform load distribution.

A very high polish on blade surfaces, far from being detrimental from the point of view of creep resistance, might actually be advantageous as inhibiting scaling or corrosion attack at intercrystalline boundaries. It should be pointed out, however, that elements which improved scale resistance did not always increase the hot strength or creep resistance of a steel or alloy and examples of unexpected tendencies could be quoted.

Mr. Redwood's observations had been most interesting as the expression of the view of the designer in this new and difficult field of engineering. His point that built-up constructions might be adopted for operating temperatures less than 850 deg. C. was agreed and the possible economic advantage of so doing was noted.

The warning by the authors that the creep properties at the periphery of a rotor might be up to 30 per cent. lower than those of bar material was closely linked with the implications of Fig. 4 and the feasibility of solution-treatment at the highest desirable temperatures. With increasing experience the authors anticipated that the full range of this reduction might not have to be conceded. Creep data was being collected on steel specimens machined from typical rotors in order to obtain full information and to ascertain the influence of a particular forging procedure. Mr. Redwood's comments relating to the use of stress-to-rupture data were of great interest and the statement which was made in the paper might well prove to represent the views of only a few individual designers. Mr. Redwood had usefully stressed the controversial nature of design criteria.

Operating temperatures of 850 deg. C. might prove to be beyond the economic temperature, but the authors were of the opinion that the metallurgist must advance on the steel side while the engineer advanced on the engineering design side, so that a greater range of workable alternatives would be open for adoption. Possibly Mr. Redwood had water- or air-cooling in mind, in which case it was evident that less highly-alloyed steels could be adopted for higher-temperature operation.

Finally the authors wished to thank again very cordially all contributors who had expressed appreciation of the paper.

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*Cleaning External Boiler Heating Surfaces

Water Washing Method Used on Oil-Fired Marine Water-tube Boilers

By F. W. Wright, Jr.

Profitable operation of all classes of merchant vessels requires that they be kept in the continuous service for which they were designed and that their operating costs be reduced to a minimum, consistent with safe and efficient operation. Many vessels to-day operate from one year's annual inspection to the next with comparatively little available outage time. On some vessels, such as tankers, the loading and discharging times are so brief as to afford little opportunity for shutting down the boiler plant for even a perfunctory periodic check-up. In addition, the port pumping and heating load on these vessels is very heavy; thus often imposing an additional restriction on the availability of the boiler plant for inspection and cleaning.

Under normal operating conditions, the soot-blowing equipment installed is designed to keep the boiler reasonably free of soot deposits, provided this equipment is kept in good mechanical condition, and provided it is used periodically in accordance with recommended instructions. This mechanical soot-blowing should, of course, be supplemented by air or steam-lancing when necessary, as indicated by periodic visual inspections of the heating surfaces. It is particularly important to check economizers and air heaters for soot collections, and to keep these surfaces free from such accumulations.

In certain operations, the use of fuel oils having a high ash content cannot be avoided. It is obvious that the use of this high ash content oil over any extended time interval will result in more severe cleaning problems than would normally be the case. In addition, the chemical and physical characteristics of the ash in the bunker oils in general use vary over wide ranges. This is particularly true with regard to the softening or melting point of the ash and the slag. With low ash-fusion temperatures, the ash deposit tends to become very "tacky" and adheres easily to the metal heat-transfer surfaces. This is particularly true of any interdeck superheater.

In consequence, then, the superheater surface is the section which generally requires the most attention from the standpoint of both the accumulation of slag and the difficulty of removing it once it has taken hold.

Slagged up or plugged superheater lanes have a number of definitely deleterious effects on boiler performance and life, which may be summarized as follows:

1. A marked increase in the air pressure required at the double front.
2. The boilers cannot be operated at high rates unless sufficient excess fan pressure is available to take care of the increased resistance to gas flow through a plugged or partially plugged superheater.
3. "Laning" effects will result. This causes high gas velocities in the open gas lanes and may mean overheating of the tubes.
4. Inefficient operation of the entire plant results both from improper temperature distribution and poor combustion efficiency in the boiler itself, as well as from materially lowered steam temperature to the main engine from the superheater outlet.
5. Gases must by-pass around, under or over the superheater and can easily burn out header protection plates, drum protection plates, support plates, and soot-blower bearings and elements as a result of a so-called "torching" or high-velocity action.

In practice it has been found that if boiler heating surfaces are thoroughly cleaned down to fireside bare metal once or twice a year, routine soot-blowing and hand-lancing will keep the surfaces in a generally satisfactory condition. It is with the procedure for this thorough annual or semi-annual cleaning that this article is concerned.

Water washing is a cleaning process developed of a necessity during the last war. Due to the shortage of bottoms, as well as to the necessity for sustained full power operation, some means had to be developed to keep every available ship in the best and most efficient condition possible for the longest period of time and with the shortest outage periods. Water washing solved this cleaning problem, although the effect of water on brickwork and insulation was not too well known at that time.

During the last six years, experience in hundreds of water washings has definitely established that if certain basic precautions are observed, the damage to brickwork, insulation and other fireside boiler parts is so negligible as to make water washing, with its resultant cleaned heating surfaces and highly efficient operation a "must" for those units where uninterrupted service is desired.

Since nearly all of the slag formed in a boiler tube bank consists essentially of a non-soluble base bonded by a relatively water-soluble binder, the use of water under pressure accomplishes the dual purpose of (a) loosening the binder, and (b) flushing away the loosened insoluble residue. Essentially then, water washing consists of the following steps:

1. Supplying fresh water at a temperature of approximately 150 degrees F.
2. Delivering the hot water to a lance at pressures between 200 and 250 psi.
3. Directing the lance into the slagged section so as most expeditiously to remove the accumulations.
4. Drying up the unit.

The following is pertinent to these four steps:

Temperature of water. It has been found that the hotter the water, the faster and better the desired results can be obtained. However, water above 150-160 degrees F. is generally too hot to handle in the manner required; while water at about 130 degrees F. prolongs the work and does not result in as satisfactory a cleaning job. The direct-contact or deaerating-type heater may often be used to advantage as a source for the hot water supply.

Operating pressures and lance details. Various available pumps can be used for supplying the pressure required. A relatively high pressure, 200-250lb. per sq. in., must be maintained. In order to obtain the desired effect, the jets must penetrate into the banks and impinge with force on the slag accumulations. The auxiliary feed pump can often be used advantageously for this purpose if the main feed pump is in service supplying the boilers with feed water.

A 1-in. to 2-in. diameter steam hose, preferably wirebound, is ideal for carrying the water from the pump to the nozzle.

The lance or nozzle itself is usually made up from odd lengths of $\frac{1}{4}$-in. pipe. From one to five $\frac{3}{16}$-in. or $\frac{1}{4}$-in. holes should be drilled along the pipe near the terminal or capped end. At times it may be more convenient in reaching certain areas to drill only the end pipe cap at the desired angle so that the spray is directed out the end of the pipe to reach those points. The type of nozzle and the number of holes together with their angles are largely determined by a study of each individual case. In addition several types of nozzles may be required for any one boiler. However, since the only equipment needed is sections of $\frac{1}{4}$-in. pipe, caps, and a $\frac{3}{16}$-in. or $\frac{1}{4}$-in. drill, each operator may best determine for himself the set-up that is most suited to his needs.

Lancing sequence. Water washing should start at the top of any boiler unit and systematically work down to the furnace rows. Water dripping down from an air heater or economizer through the tube banks tends to soften the slag accumulations in the areas below those being washed, thus making the cleaning job faster and easier when those lower areas are reached. Regardless of where washing is started, everything below that section must be thoroughly washed in order to prevent the possibility of external corrosion.

Drying. The unit must be dried out upon completion of the washing procedure. *No water-washing procedure should ever be started unless or until it is possible to dry out the unit immediately following completion of the washing procedure.*

A question and answer summary is given as follows:

Q.—Will water washing damage the furnace brickwork or insulation?

A.—No—*provided* routine precautions are observed and provided the unit is thoroughly and slowly dried out immediately after washing.

Q.—How long does it take to water wash a boiler unit?

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*Reprinted from "Marine Engineering and Shipping Review", March, 1947, pp. 97-98.

A.—From 4-10 hours depending upon the extent of slag accumulations (for average conditions, 6-8 hours).

Q.—How long does it take to dry out a unit after water washing?

A.—Usually from 8-12 hours when using a very light fire such as that obtained from one burner operated intermittently with a lighting-off size sprayer plate.

Q.—What precautions should be taken to minimize brickwork damage other than the drying out procedure?

A.—On header-type boiler units, cover the top front and rear wall seals with a temporary waterproofing coat of any available material. This will prevent the water from dripping down behind the bricks. While this precaution is desirable, and will reduce the drying out time, it is not absolutely necessary.

Q.—How is the water that drips into the furnace removed?

A.—One of the easiest ways is to run a 1-in. or 2-in. rubber hose to the suction of the bilge pump. The open suction of the hose in the furnace should be covered with a wire screen. The speed of the bilge pump may be varied to keep a minimum amount of water in the furnace.

Q.—Should a canvas or other protective covering be used on the furnace refractories?

A.—This is not generally practical or desirable, although in certain cases a canvas may be used to advantage. For instance, when washing an economizer, a canvas laid over the outer or top row of boiler tubes will keep the water and debris out of the boiler tube bank and furnace. Canvas used for such purposes usually rots quickly and therefore must be washed thoroughly (preferably with a mild soda solution) before being dried and stowed away.

Q.—Is a hole in the brickpan to provide for the removal of the water necessary or desirable?

A.—No.

Q.—In water washing does the operator usually work from above the surface to be cleaned?

A.—Generally this is the case. However, in some cases, it may be necessary to clean the furnace face of the superheater from the furnace. This is necessary when support plates or other structural obstacles prevent other access to the surfaces to be cleaned, or when the tubes are so badly slagged that forceful direct contact of the water spray is necessary at a close range.

Q.—Is water washing a shipyard job?

A.—While water washing is often done in the shipyard, it can easily be done by the vessel's crew, and at sea, if necessary or desirable.

Q.—How soon after securing a boiler can the water washing procedure be started?

A.—Generally, as soon as the unit is cool enough for a man to enter and remain in the furnace.

Q.—How does water washing compare with other methods of cleaning?

A.—Economically, it is cheaper and faster. Physically, it is more thorough. A good water-washing job will leave all tubes "factory" clean the full depth of the tube bank. Further, because of the comparatively clean surfaces resulting from the water washing, the unit remains cleaner for a longer operating period due to the fact that there are fewer rough areas to which new slag can adhere.

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"The Design and Production of Pressure Gauges".

With reference to the above paper which was published in the May, 1945 issue of the TRANSACTIONS, Vol. LVII, Part 4, we have been asked to state that it would be incorrect to assume from the author's acknowledgments that either Mr. C. R. A. Grant or his Company, Barnet Instruments, Ltd., are in agreement with the statements or conclusions put forward in the paper.

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Corrigendum.

In Mr. Wm. Alexander's contribution to the discussion on the paper "Dryness of Steam and Priming in Marine Boilers", which appeared in the May, 1947 issue of the TRANSACTIONS, Vol. LIX, No. 4, the word "intermediate" in line 15 from top, left-hand column, page 75, should read "indeterminate".

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JUNIOR SECTION.

Joint Junior Branch I.N.A. and I.Mar.E., Southern Area

A meeting of the recently-formed Southern Area Joint Junior Branch of the Institution of Naval Architects and the Institute of Marine Engineers took place at Portsmouth Municipal College on Thursday, 17th April, 1947 at 7.30 p.m., when Mr. W. N. Kemp delivered a lecture on "Underwater Electric Arc Welding" to an audience of 50 members. Mr. R. W. L. Gawn, R.C.N.C. (Vice-President of the Branch) occupied the Chair.

The display of a large number of slides and pieces of equipment added greatly to the interest of Mr. Kemp's lecture, which reviewed the progress made in the underwater use of electric arc welding from 1917 until the recent world conflict, during which many H.M. ships were repaired by this method.

The lecturer explained that any D.C. generator with 50-70 volts and 20-400 amps output, of quick recovery type, is used. Tests with A.C. supply have been made but more elaborate safety precautions are required. The electrode holder should be completely insulated with no exposed parts in contact with the water, and if part of the job is above water and the metallic continuity known to be good, it is desirable to connect the earth above water. A standard diving suit is satisfactory and a hinged screen of "C" grade glass is clamped over the front face glass of the helmet. Special electrodes are not necessary, but they should be coated with some impervious composition such as paraffin wax a few hours before use.

The principal difference between air and underwater arc welding is in the handling of the electrode holder and the fact that vision is restricted. The diver must position himself so that the gas bubbles set free by the arc do not strike his face glass.

The normal and smaller electrodes of 12, 10 and 8 gauge give the best results. Large welds should be built up by multi-pass runs. Lap joints are most suitable, and joggled patches cut out much overhead welding and are normally used for repair work.

The lecturer added that in repair and salvage work the salvage vessel must be moored so that it does not move while the diver is submerged, and adequate staging must be built around the job. All ragged ends must be cut back to leave a fair working surface and templates taken to facilitate the manufacture of the patches, stiffeners or structure required. On completion of the work the vent holes are plugged or welded to enable the compartment to be pumped out. If the compartment is then accessible, second inside fillets should be made by the normal air welding. Such a repair can be relied on for an almost indefinite period of normal service.

An excellent discussion followed the lecture, and the proceedings terminated with the passing of a hearty vote of thanks to Mr. Kemp, proposed by the Chairman.

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ADDITIONS TO THE LIBRARY.

Presented by the Publishers.

The following publications of the British Standards Institution:—

B.S. 325: 1947—Black Cup and Countersunk Bolts, Nuts and Washers, 15pp., 13 illus., 2s. net, post free.

B.S. 1368: 1947—Dimensions of Ignition and Lighting Units for Motor Cycles, 21pp., 12 illus., 9 tables, 3s. 6d. net, post free.

B.S. 5027: 1947—Dimensions of Unscreened Magnetos, 26pp., 14 illus, 10 tables, 3s. 6d. net, post free.

B.S. 3024: 1947—Ships' Side Scuttles, 23pp., 5 illus., 3s. 6d. net, post free.

P.D. 607. Amendment No. 2: April, 1947 to B.S. 876: 1939—Hand Hammers.

Presented by Captain (E) A. W. Richardson, R.N.(ret.), O.B.E., M.I.Mar.E.

Finding and Stopping Waste in Modern Boiler Rooms.

Third Edition. Cochrane Corporation, Philadelphia, Pennsylvania. 1928.

B.R. 16. Engineering Manual for his Majesty's Fleet, containing Regulations and Instructions Relating to the Machinery and Engineering Personnel of His Majesty's Ships.

Admiralty. 1939.

Presented by the Publishers.

The Institution of Naval Architects.

Transactions of the Institution of Naval Architects, bound volume 88, 1946.

The Shipbuilder and Marine Engine-builder.

Bound volume 53, 1946.

Time and Thermodynamics.

By A. R. Ubbelohde. Oxford University Press (Geoffrey Cumberlege). London. 1947. 110pp. 6s. net.

In the study of change in physical things it is clearly desirable at the outset to understand the meaning of time in order that a direction may be attached to the passage of time. A serious student of the subject will, sooner or later, discover that the second law of thermodynamics—the law that entropy never decreases—provides a unique method for measuring change by statistical means. The method is of fundamental importance in the study of natural phenomena, since nothing in the statistics of an assemblage, such as, for example, the constituent molecules of a given volume of gas, can distinguish a direction of time when entropy fails to distinguish one.

The origin of the theory lies within the province of science, but the ramifications of the subject are numerous and varied, as Mr. Ubbelohde shows in his instructive essay bearing the above title. Starting with the contributions of thermodynamics to scientific humanism, he draws the reader's attention to the development of the principles of thermodynamics during the age of power, from the era of the simple heat engine to that of large-scale tests with atomic energy. In this field improvements in the quantitative measurement of temperature and heat have been followed by the formulation of thermodynamics, and in this chemists and others have been notable contributions to our knowledge of statistical equilibrium, as is to be inferred from Chapter V. This applies also to the subject-matter of the next chapter, namely, radiation equilibrium, which merits special attention on the part of a reader approaching the problem for the first time, since it is essential at this stage to understand why there can be no statistical criterion for a direction of time when there is thermodynamical equilibrium.

In Chapter VII the author discusses the primacy of vision, and so approaches the boundary between inanimate things alone. This calls to mind a problem of great interest to philosophers throughout the ages, which is, man's place in Nature, and, in turn, gives point to several questions that arise in the later chapters of the book, especially those on "Thermodynamics and Life" and "Mensuration and Emergence".

The essay as a whole forms an excellent introduction to a field of inquiry in which the aim is to bring mankind into the closest possible relationship with the external world, and it deserves wide circulation among those who are in any way concerned with present trends in civilisation.

Ships.

By J. S. Redshaw. Vickers Armstrongs, Ltd., Barrow-in-Furness. 1947. 80pp., profusely illus., 10s. 6d. net.

There are many books about ships, very few on the art of shipbuilding other than highly technical publications. In this book *Mr. J. S. Redshaw, who is himself chief naval architect to a Company which has built some of the finest examples of British shipbuilding, makes clear to seamen and landsmen alike the mysteries of his craft.

Combined with the simple and forceful style of the author is a collection of pictures, many unique in the literature of the sea. A series of 12 direct colour photographs by Mr. P. G. Hennell is particularly noteworthy, and combined with 61 pictures in monochrome, all taken from within the great Vickers-Armstrongs organisation, present a fascinating study of one of Britain's oldest and most vital industries.

Ships of the Royal Navy—1947.

By Francis E. McMurtrie. A.I.N.A. Editor of "Jane's Fighting Ships". Sampson Low, Marston & Co., Ltd. London, 1947. 288pp. with over one hundred illus., 10s. 6d. net.

The last edition of this book appeared early in 1945. Since that date a large amount of fresh material, much of it relating to new construction, has become available, involving extensive revision. This has also been necessitated by the fact that a great many old and worn-out ships have been scrapped or sold, a process which will continue to operate for some time to come.

Full particulars of our newest and most powerful battleships, H.M.S. *Vanguard,* are given on pages 7 to 9.

In aircraft carriers of various types additions have been numerous, though several which had been ordered late in the war have been cancelled.

Particulars of new cruisers, destroyers, sloops, frigates, fleet minesweepers, submarines, and smaller craft have also been added. These would have been even more plentiful but for the return to the U.S. Navy of ships of various categories under the terms of the Lend-Lease Agreement.

A certain amount of information concerning the war service of the more important ships has been incorporated in the present edition.

It will be of interest to readers of *Ships of the Royal Navy* to know that this title was originally selected for the book by the late Fred T. Jane (the founder of *Fighting Ships*) when it was planned by him thirty years ago. Owing to his sudden death, first publication was deferred until after the Great War had ended. He chose the title in remembrance of an earlier book of the same name, the work of Dr. Francis Elgar, who enjoyed the collaboration of the leading naval artist of the 'seventies and 'eighties, W. F. Mitchell. The first edition was published in 1873, and the last appeared in 1885. It has long been out of print, and copies are scarce.

The Welding Engineer's Pocket Book.

(Seventh edition). Edited by E. Molloy. Newnes & Pearson. London, 1947. 304pp., profusely illus., 6s. net.

This publication covers a large field, dealing with most welding processes in a clear and easily understood manner which makes it a most useful reference book for the reader in his own class of welding and offering a very fair idea of all the other phases of the welding industry.

It should prove helpful to anyone contemplating the introduction of a welding process into his organisation, assisting him to make a choice of the most suitable for his needs.

The publishers have obviously made an effort to keep this pocket book up-to-date, the present edition including as it does some of the most recent developments.

Some sections, while containing information both sound and useful, seem to be rather brief, while others contain far more than might be expected in a book of this size, which can probably be attributed to the usual difficulty of catering for individual readers.

Quin's Metal Handbook and Statistics—1946.

Compiled by F. B. Rice-Oxley, M.A. Metal Information Bureau Ltd. London, 1947. 424pp., 12s. 6d. net, post free.

Whilst the stringent paper supply position in this country has prevented the inclusion of many new features, the thirty-third edition of this international annual reference book on metals incorporates much statistical information for the war years and post-war years, which owing to security bans, has not hitherto been available.

Details of United Kingdom imports and exports for the years 1940-44 are given, together with fuller statistics on British iron and steel and ferro-alloy production during World War II. War-time consumption of light metals, stocks and consumption figures of the leading base metals and details of monthly output of iron and steel in a number of countries is also embodied in this edition. The memoranda on aluminium, copper, magnesium, minor metals and non-ferrous ores have been revised and brought up-to-date A popular pre-war feature, the list of brands of base metals, hard spelter and Swedish iron and steel (which has been excluded since 1942) has also been brought up-to-date and re-included, whilst a new feature is a summary of the White Paper on the British Iron and Steel Federation's Report on plans for the modernisation of the British iron and steel industry.

Electric Motors and Generators.

By F. Harrabin and others. Odhams Press Ltd. London, 1947. 384pp., over 400 specially drawn illus., 9s. 6d.

This book seems to cover in a very concise form all types of A.C. and D.C. generators and motors with associated control equipment and is the result of a combined effort of a number of competent authorities. The publishers explain that the authors have avoided the use of advanced mathematics, which does not detract from the value of this work.

It is clearly a book which would be of great use to both operating and maintenance engineers, and although electrical equipment for ships is not dealt with specifically, every sea-going engineer and those associated with marine electrical apparatus ashore, will find value in this book.

The work is profusely illustrated with over 400 specially drawn pictures and the authors are to be complimented on the excellent detail disclosed in these illustrations.

The simplicity of treatment and layout will to a large extent overcome the difficulty experienced in this type of text book when the various types of equipment dealt with tend to age or become obsolete due to the passage of years.

For the amount of information contained in this book and the quality of the technical presentation, the price would appear to be very reasonable.

Handbook of Structural Design in the Aluminium Alloys.

By J. E. Temple, Whit.Sch., D.I.C., Consulting Engineer. James Booth & Co., Ltd. Birmingham, 1947. 147pp., 26 figs., 21s. net.

This book covers the most advanced study that has yet been made of the use of aluminimum alloys in constructional work, and the author has been fortunate in having the guidance of eminent authorities in the course of his research work.

Many engineers consider the present time to be appropriate to attempt a re-survey or re-valuation of the structural and mechanical designs in which they are interested, not only because of the incidental

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*Author of the paper "Fundamentals of Ship Stability", Trans.I.Mar.E., Vol. LIX, No. 3, April, 1947.

advantages which would be derived from construction in a light weight metal material, but particularly because of the changing economies of design and construction brought about by alterations in the relative price levels of the alternative materials.

An attempt has been made by the author to summarize such information as is required by the engineer in such evaluation or redesign. The book is intended primarily for those interested mainly in framed structures and the use therein of the alloys in the form of rolled plate and sheet, and of extruded sections. It is hoped, however, that the information presented will be of equal interest to those concerned with transport and marine applications and in the design of ordinary plant and machines generally.

The handbook is divided into two parts. In Part I the most suitable alloys are described both as regards their general properties, characteristics of strength and general working.

Part II covers the more technical aspects of the subject. It is written for engineers already experienced in the design of steel structures. In order to keep the length within reasonable bounds, stress is laid chiefly on those questions in which, because of divergence of properties, practice might be expected to differ as between the use of the alloys and steel.

Sir Joseph Whitworth—a Pioneer of Mechanical Engineering.

By F. C. Lee. O.B.E., D.Sc., M.I.Mech.E.. M.Inst.C.E., Wh.Sc., Hon. Fellow Imperial College, Emeritus Professor. Published for The British Council by Longmans, Green & Co., Ltd. London, 1946. 31pp., illus., 1s. 6d. net.

This brochure gives a brief account of some of the work of a mechanical engineer who took a greater part than any other man in the remarkable development of machine tools during the nineteenth century. Precise measurement, true surfaces, standardisation and workmanship of the very highest quality, accompanied by elegance of design and the use of the best materials available, were the essentials of his great success as a pioneer and successful manufacturer of many types of machines. He made important contributions to the design of guns and rifles, and he was a great educationalist.

Osborne Reynolds and His Work in Hydraulics and Hydrodynamics.

By A. H. Gibson, D.Sc., LL.D., M.Inst.C.E., M.I.Mech.E., Beyer Professor of Engineering in the University of Manchester. Published for The British Council by Longmans, Green & Co. Ltd. London. 1946. 33pp., illus., 1s. 6d. net.

Osborne Reynolds was one of the outstanding engineer-physicists of the latter half of the nineteenth century. Though his work is famous in the field of Hydraulics and Hydrodynamics, the extent of his interests and of his contributions to other branches of physics and of engineering science are probably not so widely known. In this memoir an attempt has been made to indicate the wide scope of his activities. Professor Gibson was in turn one of his students and, during the last year of his active life, a member of the staff of his department in the University of Manchester.

Electrical Fire Alarm Systems.

By G. W. Underdown, Member of the Institution of Fire Engineers. Lomax, Erskine & Co., Ltd. London. 1946. 86pp., profusely illus., 10s. 6d. net.

This book contains complete descriptions and illustrations of the more common electric fire alarm systems as used by the public fire services. It should be clearly understood that it does not include more than a brief chapter on private or automatic fire alarm systems, and has no reference to fire alarms or detectors on ships.

The author acknowledges the aid of the manufacturers and he has collected in useful form much of their descriptive data with the addition of simple technical information so that "the good workman understands the tools he uses, and it is to assist the fireman to understand his electrical fire alarm that this book has been written".

Whether these forms of alarm will continue to be used in view of the unfortunate increase in false alarms remains to be seen, but meantime the book will be useful to professional firemen and to those interested in something a little outside their normal sphere of operations.

Marine Steam Engineering.

Steam Engines, Book 1, Lessons 1 to 8; Marine Auxiliary Machinery, Book 2, Lessons 1 to 4; Reciprocating Engines, Book 3, Lessons 1 to 4. By R. C. Dwyer, Chief Engineer, California Maritime Academy, operating Training Ship "California State". Prepared for the Division of Training, United States Maritime Commission. D. Van Nostrand Co., Inc., New York. 1941. British Agents: Macmillan & Co. Ltd. London. 828pp., 372 illus. Set of 16 booklets, 66s. net.

The purpose of preparing this text in Marine Steam Engineering in lesson form for cadets under the regulations of the U.S. Maritime Commission has been to arrange the study of the principles of construction, operation and care of marine boilers, engines and their appurtenances into separately contained units, thus avoiding, as much as possible, the overlapping or duplication of other engineering subjects.

In instruction of those beginning the study of steam engineering, the author has found that better progress can be made by approaching from the practical rather than the technical side of the subject, particularly with cadets who have had the necessary grounding in physics and chemistry, leaving those engineering problems which confuse the beginner until later, when he will better understand their application.

With this view in mind these lessons have been prepared to present the subject in a simple explanatory manner, and to arouse sufficient interest on the part of the cadet, that he will continue the study of technical engineering detail after they are completed.

The many improvements in principles of construction and changes in engineering practices which have occurred in recent years make it advisable to confine these lessons to the steam plant, rather than to attempt to cover the entire marine engineering field in one textbook. It is believed that, in this manner, greater emphasis can be placed on the more modern equipment and later practices and at the same time reduce the study time on the types of apparatus which are rapidly approaching obsolescence.

Stability and Trim for the Ship's Officer.

By John La Dage, Lieutenant, U.S. Maritime Service, and Lee Van Gemert, Lieutenant, U.S. Maritime Service. Instructors in Ship Construction, United States Merchant Marine Academy, Kings Point, N.Y. D. Van Nostrand Company, Inc., N.Y. 1946. British Agents: Macmillan & Co. Ltd., London. 180 pp., profusely illus. with figs. and charts. 16s. 6d. net.

In their foreword to this book the authors, who are Instructors at the United States Merchant Marine Academy, Kings Point, convey that their purpose has been to present the subject wholly from the Merchant Officer's point of view without leading the reader through a morass of unnecessary technical terms.

While they do not claim to have made the study of stability easy, they have certainly succeeded in the ten chapters of this handy little book in making a very lucid and easily flowing exposition of the general elements of stability problems from the practical operator's standpoint. That is not by any means to say that its value is confined solely to ships' officers for in spite of the absence of the advanced theories and technicalities, the book covers a wide field and is well worth reading by any student inasmuch as it provides a valuable complement to ordinary text book studies in its emphasis on the practical aspects of ship loading, maintenance of trim and metacentric height on service, etc.

In addition to consideration of initial stability and stability at large angles of heel, sections are devoted to the ever important influences of free surfaces in tanks, and loss of reserve buoyancy and stability in damaged conditions.

An interesting chapter gives descriptions and instructions for using various types of mechanical stability and trim computors. Of these the "Ralston Indicator" will be already familiar to many, but the equally ingenious "Stabilogauge" which is presumably its American counterpart will be new to most readers on this side of the Atlantic.

In dealing with stability at large angles of heel, examples are shown of both statical stability curves and cross curves, and here, as a minor criticism, the authors might with advantage have included a brief account of the drawing office or integrator process of calculating the inclined values of GZ to avoid any impression that the rather crude artifice of balancing cardboard sections is the common or only practice.

The book is clearly printed and the text plentifully interspersed with diagrams, features which commonly characterise American technical publications.

Introductory Quantum Mechanics.

By Vladimir Rojansky. Prentice-Hall, Inc., New York. 1946. British Distributors: H. K. Lewis & Co., Ltd., 136, Gower Street, London, W.C.1. 544 pp., 110 figs., 40s. net.

The contents of this book are aptly indicated by its title. It is a survey of the modern branch of applied mathamatics which has developed in fifty years out of Planck's theory of the spectrum of thermal radiation, in which he introduced the quantum constant now universally called *h*.

As quantum mechanics replaces Newton's mechanics and Maxwell's electrodynamics only for atomic entities, and in general becomes asymptotically identical with classical mechanics and physics for macroscopic systems, it follows that knowledge of it is not essential for the whole of ordinary mechanical engineering and for most of electrical engineering.

It is nevertheless not without interest, since it is by application of quantal rules that N. F. Mott and others have made a beginning on the fundamental atomic theory of such practical subjects as the failure of solids under mechanical stress, and the dependence of the properties of alloys on their atomic constitution.

The algebra of Rojansky's book appears formal and prohibitive at first sight. Actually, although beyond the range of most university engineering degree courses, it is not unduly difficult once the underlying ideas and notation have been grasped, and any engineer familiar with that great classical account of mechanical vibrations—Lord Rayleigh's "Theory of Sound"—will find much in common between its mathematics and the mathematics of quantum mechanics.

Diesel Maintenance.

(Second Edition). By T. H. Parkinson, M.I.A.E., Motor Vehicle Rolling Stock Engineer, Leeds City Transport. Edited by D. H. Smith, M.I.A.E., Assoc.Inst.T. of "Motor Transport" and "Bus and Coach". Iliffe & Sons, Ltd. London, 1946. 197 pp., 130 illus. 6s. net.

All those who are interested in Diesel engines will find in this book an efficient guide to the avoidance of troubles with this type of engine. The author obviously knows his subject, being a practical man in charge of the Leeds City Transport, and the book is also well edited. The author has gained expert experience through his breakdown experience; he employs common sense and useful reasoning capacities in all cases, and shows in this book how to apply them to all problems. The book contains useful and easily understood illustrations, which show cause, effect and remedy. Mr. Parkinson has technical knowledge, but he is also a practical teacher and avoids the mass of technical jargon which often confuses the seeker of knowledge in books. He does not lead his reader into a maze of difficulties, but guides him out of whatever difficulty that may confront him on the job in hand.

The reading of this book will be a joy to any sea-going engineer, who often has to depend on books in time of trouble. Many technical books are not practical, being full of extracts from catalogues and useless photographs. "Diesel Maintenance" is definitely not of that category.

The reviewer has nothing but praise for this book, and recommends its acquisition by all Diesel engineers and apprentices.

Modern Production Control.

By A. W. Willsmore, A.M.I.I.A., F.R.Econ.S. Sir Isaac Pitman & Sons, Ltd. London. 1946. 165 pp., 50 figs., 12s. 6d. net.

The author of this book has had, in the course of his career, direct contact with the three fundamental types of manufacturing enterprise—jobbing shop production, batch production, and flow production—and he writes from first-hand experience of the different demands they impose. He ably discusses and defines the principles of modern production planning and control in engineering works and illustrates their practical application to typical engineering problems of production.

Some sections of the book seem unnecessarily "wordy", whilst a few others, e.g., that on "Time and Motion Study", are dismissed briefly, with little information.

This work should be highly valuable to executives, works managers, foremen, department heads, inspectors, and members of Joint Production Committees.

Purchased.

Reports on German Industry.

Copies of the report of Intelligence Objectives Sub-Committee on German Industry listed below can be obtained from H.M. Stationery Office at the price stated.

No. of report. B.I.O.S.	Title.	Price, net
605	Some Marine Applications of Light Alloys in Germany	1s.

Commemoration Ceremony in Glasgow Cathedral.

To commemorate the many activities carried on during the years of the war on the River Clyde by the Royal Navy and the Merchant Navy, a White Ensign and a Red Ensign were presented to Glasgow Cathedral by the Lords of the Admiralty and the Honourable Company of Master Mariners respectively, at a special service in the Cathedral on Friday, 6th June, 1947 at 4 o'clock.

The Cathedral was closely filled for this very impressive ceremony, in which deputations of deck and engineer officers of almost every ship in the Clyde, of both Royal and Merchant Navies, took part. Representatives from various sections of the Armed Forces, including the Highland Regiments, the R.A.F., the R.N.V.R., Sea Cadets, and W.R.N.S., as well as those of numerous public bodies, were also present.

The service commenced promptly at six bells with the singing of Psalm 93, followed by prayers offered by the Rev. Denis Daly, B.A., Chaplain of the Mission to Seamen. While the congregation were singing a hymn, the White and Red Ensigns, accompanied by the respective escorts, were carried up the centre aisle to the chancel steps. After the trumpets had sounded a fanfare the White Ensign was handed to Vice-Admiral Sir Frederick Dalrymple-Hamilton, K.C.B., who presented it to the Minister of Glasgow. The Red Ensign was then handed to Air Chief Marshal Sir Frederick Bowhill, G.B.E., K.C.B., C.M.G., D.S.O., the Master of the Honourable Company of Master Mariners, who in turn presented it to the Minister.

An address by the Rev. Nevile Davidson, D.D., Chaplain to the King in Scotland and Minister of Glasgow, followed, and passages from the Old and New Testaments were read by Vice-Admiral Sir Frederick Dalrymple-Hamilton and Commodore Sir David Bone, C.B.E. respectively.

During the singing of the next hymn the clergy, followed by the officers carrying the Flags, Vice-Admiral Sir Frederick Dalyrymple-Hamilton and his staff officers and Air Chief Marshal Sir Frederick Bowhill and his officers, proceeded to the west door of the Cathedral where the Flags were handed to the Minister who placed them in position at each side of the door.

The trumpets sounded the Last Post and the Reveille, and after prayers had been said by the Rev. Alexander Campsie, M.C., R.N., Senior Chaplain (Church of Scotland), Admiralty, the service concluded with the National Anthem. .

The members of the Institute present at the ceremony included Sir Stephen Pigott, D.Sc. (Past-President), Messrs. L. C. Davis (Vice-President, Glasgow), Murdoch McAffer (Vice-President, Greenock), A. R. Riddell, T. D. Shilston, N. Kissel, T. Spence, D. Blair, W. G. Baird, James Boyles, David Bruce, A. R. Graham, A. M. McAlister, H. Hillier, O.B.E., D. H. M. Bee, J. S. Thompson, R. Thomson, H. A. Varian, J. Sim, B.Sc. and W. T. Tucker.

Annual Golf Competition

The Institute's annual golf meeting was held at the Royal Blackheath Golf Club on Tuesday, 10th June. The members taking part numbered 22, and they were favoured with perfect weather throughout the day.

In the morning stroke competition, the Institute Cup, presented in 1931 by Mr. John Weir, was won by Lieut.(E) R. G. Boddie, R.N., with a net score of 70; Mr. R. B. Gray gained second place with 71, and Mr. H. M. Gorringe third with 73.

A bogey greensome was played in the afternoon in which Messrs. J. S. C. Marshall and W. D. Heck, Jun'r. came first with a score of 2 up; Messrs. R. K. Craig and R. Wallace finished all square, gaining second place, while Messrs. R. B. Grey and F. Sands came third with 2 down.

As Mr. Grey had won prizes in both morning and afternoon competitions, and as no competitor is allowed to take two prizes on one day, he chose to forego the second prize in the morning, and to take the third in the afternoon with his partner. The second prize in the morning therefore went to Mr. H. M. Gorringe, and as Messrs. R. K. Craig (4th), J. S. C. Marshall and R. Wallace (tied 5th), who secured the next places in the stroke competition, also won prizes in the afternoon, the third prize in the morning went to Mr. J. A. Goddard who was sixth with a net score of 80.

The prizes were distributed by Mr. A. Robertson, the Convener of Social Events, during tea. On his proposal a hearty vote of thanks was accorded to the Royal Blackheath Golf Club Committee and to the Secretary, Mr. F. Barker, for the excellence of the arrangements which had been made for their comfort and entertainment. A vote of thanks was also passed to those who had so kindly provided prizes or contributed to the prize fund, namely the Hon. Kenneth Weir, B.A., C.B.E., Messrs. W. Sampson, W. Lynn Nelson, O.B.E., J. A. Rhynas, A. F. C. Timpson, M.B.E., R. B. Grey, F. Sands, W. Smith and W. Tennant.

It was agreed by all who participated in this meeting that it had been thoroughly enjoyable and in every way up to the high standard of the preceding similar events.

MEMBERSHIP ELECTIONS.

Date of Election, 9th June, 1947.

Members.

Guy Dixon.
Walter Edwin Downs.
Lewis John Ferguson.
Leslie Stuart Gratwick.
Bruce Bousfield Greaves.
Charles Green.
Sydney Alick Harrison-Smith, Com'r(E), R.N.
Robert Holmes.
John Douglas Gordon Kinvig.
Lalit Mohan Kundu.
Robert John Kerrich Ling.
Harry Lundgren.
Norman McLeod, M.Sc.
Hector McNeill, B.Sc.
John Alexander Nicol.
John Munn, M.B.E.
Robert Scott Briercliffe Parker.
Peter Sampson.
Claude Woodthorpe Shepherd.
Fred Cox Smith.
George Siddle Storey.
Hugh Gaskell Patrick Taylor, Com'r(E), R.I.N.
Paul Wilkinson.
James Wilson.
Leander George Zoukis.
George Macdonald Dunbar.
Frederick David Minors Gamble.
Thomas Gibbons.
Arthur Douglas Gillam.
William Edward Harris, D.S.C., Lieut.(E), R.N.
Robert Harrison.
David Jackson.
Arthur Caeser Jones.
Neville George Line.
George Geoffrey Lord, B.A.
Hugh Matthews.
John Lloyd Morris.
John Alan Morton, B.Sc.
Peter Reginald Prior.
Poduri Lakshmikant Rao.
Andrew Burt Robb.
John Simpson.
Jack Stewart Sinclair.
Roland Victor Smith.
John Craik Stenwick.
Francis Ralph Tarry.
Roy Wakeham.
David Houston Walker.
Joseph Howard Wilson.
Richard Woof.

Associate Members.

John Caldwell Shire, Lieut.(E), R.I.N.
Keith Ivan Short, Lieut.(E), R.N.

Associates.

John Richmond Gale Braddyll, B.Sc.

Graduates.

Marcus Holmes Rainsford Brockman.
Arthur George Debbage.

Transfer from Associate Member to Member.

John Kerr.
Harold James Tabb, R.C.N.C.

Transfer from Associate to Member.

John Redmond Buckley.
Claude Henry Verity.

Transfer from Associate to Associate Member.

Omer Tarik Aygen, B.Eng.

PERSONAL.

(When notifying changes of employment, members are requested to state whether they are agreeable to the information being published in this column).

The Birthday Honours List published on 12th June includes the names of the following:—

C.B.E.—Capt. W. H. Coombs (Companion) and G. F. Silley (Member); O.B.E.—W. F. Brown, Wh.Ex. (Member), A. Caldwell (Member) and John Lamb (Member).

John Buckley (Associate) has been appointed marine engineer superintendent to the Kuwait Oil Co., Kuwait, Persian Gulf.

A. L. Covell (Associate) has been appointed an assistant engineer at the London Branch of The Anglo-Swedish Electric Welding Co., Ltd.

M. J. T. Henderson (Member) has been elected an Associate Member of the Institute of Fuel.

R. R. Holtum (Member) has been appointed an engineer surveyor to Lloyd's Register of Shipping and is at present stationed in London.

John Houston (Member and late Vice-President, Leith), who recently retired from the service of Lloyd's Register of Shipping on reaching the age limit, has been the recipient of a pleasing tribute in the form of a presentation, in which Mrs. Houston shared, by the engineers and shipbuilders in the Leith area, in appreciation of the efficient manner in which he has carried out his duties as the Society's local representative. Despite a limited maximum being placed on individual subscriptions, a substantial sum was contributed, and at a gathering of representative engineers and shipbuilders at the North British Station Hotel, Edinburgh, on May 22nd, Mr. Houston was presented with a wallet and cheque while Mrs. Houston received an easy chair of her own choice. Mr. W. Wallace, C.B.E., Mr. Houston's successor as Vice-President for the Leith area, made the presentation.

W. L. McKaine (Member) has been appointed engineer to the Castle Brewery, Cape Town.

P. Watkinson (Member) has been appointed mechanical superintendent of the N. V. Mijnmaatchappij of New Port, Curacao, N.W.I.