INSTITUTE OF MARINE ENGINEERS
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President: SIR ARCHIBALD DENNY, BART., LL.D.

The Thrust Shaft: Its relation to the Work and the Power Transmitted.

DESIGN OF AN IDEAL THRUST BLOCK, WITH DESCRIPTION OF DETAILS.

BY "HELIX" (MR. C. P. TANNER, Graduate).

IN propelling a ship through the water, the propeller exerts a certain thrust on the water astern of the ship, and of course, by Newton's Third Law, the water exerts an equal and opposite thrust on the propeller. This thrust is transmitted along the line of shafting to the engines. In an ordinary reciprocating engine, the thrust would have to be taken up by the crank webs bearing against the main bearings unless other means were taken to receive this. To effect this a thrust shaft and block is placed between the engines and the propeller. In smaller engines the thrust shaft is made integral with the crank shaft, but this is unsatisfactory, and now is very rarely carried out. The method that is almost universal now is to make a separate shaft for the thrust shaft, and place it just aft of the crank shaft.

The thrust shaft must of course be designed to take the necessary torque exerted by the propeller as well as to take up the thrust. The diameter of the shaft is found from Lloyd's or Bureau Veritas rules, and is usually the same size as, or a little smaller than the diameter of the crank shaft. It is also a little larger than those of the tunnel shafts, as if the thrust shaft breaks between any of its collars, it makes a repair somewhat difficult.

One of the first considerations is the number of collars to be employed to take up the thrust. Obviously, large collars will be less complicated, since there is a certain definite area to be used to take the thrust, and hence very few collars need be used if each is large. There are, however, several disadvantages to large collars. Forging is made difficult and also with a large diameter the inside of the shaft may contain flaws. Again, the peripheral speed of the collars is high, and this makes lubrication difficult, and increases the resistance due to friction.

The shaft is usually of mild steel, and should be carefully forged in one direction, and not half in one direction and half in the other, as this introduces a weakness in the shaft. In some cases 3 per cent. to 4 per cent. of nickel is added, and this gives a stronger shaft.

All the advantages lie with a shaft having a large number of small collars, except the fact that it is very complicated. In calculating the dimensions of the various parts of the shaft and the block, the formulæ used are largely empirical although theoretical formulæ can be used to a certain extent.

From elementary mechanics we have:—

$$\text{Work done} = \text{force} \times \text{distance}.$$

Thus we get

$$\text{Effective Horse-power} = \frac{\text{Thrust (in lbs.)} \times \text{Speed (feet/min.)}}{33{,}000.}$$

From this we have $\text{Thrust} = \dfrac{\text{E.H.P.}}{\text{Speed.}} \times 33{,}000.$

The effective H.P. bears some definite ratio to the I.H.P., depending on the mechanical efficiency of the engine and bearings.

The usual ratio may be taken as

$$\frac{\text{E.H.P.}}{\text{I.H.P.}} \doteq \cdot 77 \text{ for best High Speed Engines.}$$
$$\doteq \cdot 68 \text{ for Merchant Boats.}$$
$$\doteq \cdot 80 \text{ for Turbines.}$$

Thus we get $\text{Thrust} = \dfrac{\text{I.H.P.}}{\text{S.}} \times y \times 33{,}000.$

where y = mech. effy.

Hence we see that

$$\text{Thrust} \propto \frac{\text{I.H.P.}}{\text{S.}}$$

This thrust is usually called the mean normal thrust. It is clear that the thrust is excessive when the speed is slow, *i.e.*, when the ship is starting, or towing, or going against a strong head wind. Thus, although we have the mean normal thrust to base our calculations on, the shaft must be designed to take up the maximum stress, which occurs when starting or towing.

There are various formulæ available. One which gives the area directly, and with a fair degree of accuracy is

Bearing Surface of Collars in sq. ins. = ·6 × I.H.P.

i.e. 0·6□″ for each I.H.P. developed.

A better way is to take a certain allowable pressure on the working bearings.

Good values for these pressures are

50 to 80 lbs. per □″ for Mercantile Marine.

80 to 100 lbs. per □″ for Naval.

A rough rule for finding the number of collars to be used is given by

1 collar up to 5″ dia. of shaft
and an extra collar for every 1·8″ dia.

$$\text{or } N = 1 + \frac{d - 5}{1{\cdot}8} \text{ for Mercantile Marine}$$

$$\text{and } N = 1 + \frac{d - 5}{1{\cdot}25} \text{ for Naval and Express.}$$

The diameter of the shaft, as stated before is found from Lloyd's rules.

Hence we have to find the diameter of the collar

$$\text{Total bearing area } A = \frac{\pi}{4}(D^2 - d^2) \cdot N = \square''$$

where D = dia. of collar.
d = dia. of shaft.
N = No. of collars.

Total Thrust = total area × allowable pressure.

$$T = A \times P.$$

$$= P \times \frac{\pi}{4} \times N\,(D^2 - d^2)$$

From which D can be found.

In practice the rule for the thickness of the collars is given by

$$T = 0{\cdot}4\ (D-d).$$

The space between the collars is found by;

(i) with Rings of solid brass $T = 0{\cdot}4\ (D-d)$.

(ii) with Rings of cast iron lined with brass or white metal $\}$ $T = 0{\cdot}75\ (D-d)$.

(iii) with Rings of C.I., hollow to allow for water circulation $\}$ $T = (D-d)$.

Another rule for giving the pressure on a Thrust bearing is

$$\text{Pressure in lbs. } \square'' = \frac{800}{\sqrt{R\,d} + 100}$$

where R = revs. per min.
d = dia. of shaft in ft.

The thrust shaft and block are usually placed next to the crank shaft inside the engine room if possible, so as to permit inspection of the block by the engineer in charge. The shaft is supported at each end by a pillow block so as to prevent any vibration which would cause an inequality of pressure on the thrust bearings.

There are three types of thrust blocks in use. Type I. shown in the sketch attached consists of a cast iron base block and cover; the division being horizontal. Rectangular grooves are turned in these, in which brass thrust rings are fitted. The rings are scraped to make a good fit with the collars on the shaft, and small radial oil grooves are cut in the former. Since, if this block were to heat, it would necessitate the stopping of the engine and the removal of the thrust shaft or the block, in the event of a serious heating and damage to one or more of the collars. The block is not generally constructed to admit of slipping it out by dropping sufficiently to clear the shaft, so that the disconnecting of the shaft is necessary as a rule before the block can be got out.

Both the cover and base of the block are water cooled, but even with this the block is unsatisfactory, and is rarely used now.

For large engines Type II., the horse-shoe type, is universal. This is also shown in the sketch, and the list appended needs little enlargement to get a clear idea of the details.

It consists of a cast iron bed, cast so as to provide a bath for lubricant, in which the shaft runs partially immersed. Cast iron shoes, hollow to permit of water circulation, and lined on each face with white metal, rest in position between the collars as shown. A fine threaded screw goes on each side of the shaft down the whole length of the block, and gunmetal nuts on these hold the shoes in position.

The water service, not shown in the sketch, is arranged so that each shoe has a separately controlled supply of water. Hence the temperature of the whole block can be equalised, and this is conducive to smooth running. The bearings at each end have stuffing boxes, so that the oil can rise above the bottom of the shaft, and usually immerses half the shaft.

This oil, in many cases, is cooled by small water tubes passing starboard to port, through the oil bath. The cooling surface need not be large if the shoes are water cooled, as most of the heat generated by the friction is carried away by the water service through the shoes.

Since the shoes are of the horse-shoe type, the centre of pressure of the bearing area is above the centre of the shaft. The thrust screws are, however, arranged so that they are on the same level as the centre of pressure, and thus the shoes bear evenly against the collar.

The chief advantage of this type is the fact that each shoe can be adjusted independently of the rest. Also if one shoe "fires up," it can be removed and replaced without stopping the engine. It also entails less spare gear.

Lubrication is greatly assisted by the oil bath, and the oil grooves are cut in a special manner as shown. The chief difficulty in lubrication is due to the fact that the centrifugal action of the collars tends to throw the oil out immediately. Also there is no real point of "no pressure" at which to introduce the lubricant as in an ordinary journal bearing.

A third type, not shown in the sketch, is due to Mr. Seaton. This is similar in general construction to Type I., but the division of the two halves is vertical and not horizontal. This enables the block to be examined without removal of the shaft, as the two halves are made so as to slide out horizontally. Another improvement in the construction enables the whole of the bearing surfaces to run in a bath of lubricant. This type, however, is only used for small engines. In every type there is a small clearance between the shaft and the inside of the shoe or brass ring, since the block is designed solely to take the thrust of the propeller, and not the weight of the shaft.

The block is bolted to the frames of the ship by means of a seating plate on which it rests. This plate is secured by tie beams and girders longitudinally to several frames, so that no excessive strain is exerted on any part of the ship.

With modern thrust blocks the loss due to friction is now comparatively small, although authorities differ on this subject. Good values for the loss expressed as a percentage of the total power are as follows:—

Mercantile Marine	0·4 %
Express Steamers and Large Naval Boats	0·5 %
High Revolution and Small Naval Boats	0·65 %
High Revolution Turbines	1·0 to 1·3 %

A general rule for all is

$$\text{Loss } \% = 0{\cdot}5\sqrt{\text{R.P.M.}}$$

When Parson's turbine's first came into prominence, the thrust block was not so important, as the steam pressure was arranged to balance the thrust, but now that helical gearing has been introduced the thrust must be taken up as before. Experiments have been carried out with roller and ball bearings, but these have had, so far, little success. Perhaps now that greater accuracy in making the balls has been obtained, this may be more successful.

"Helix."

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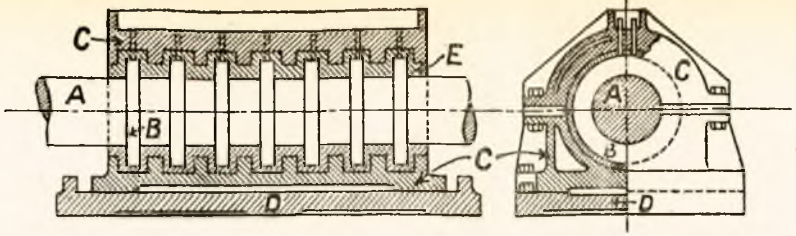
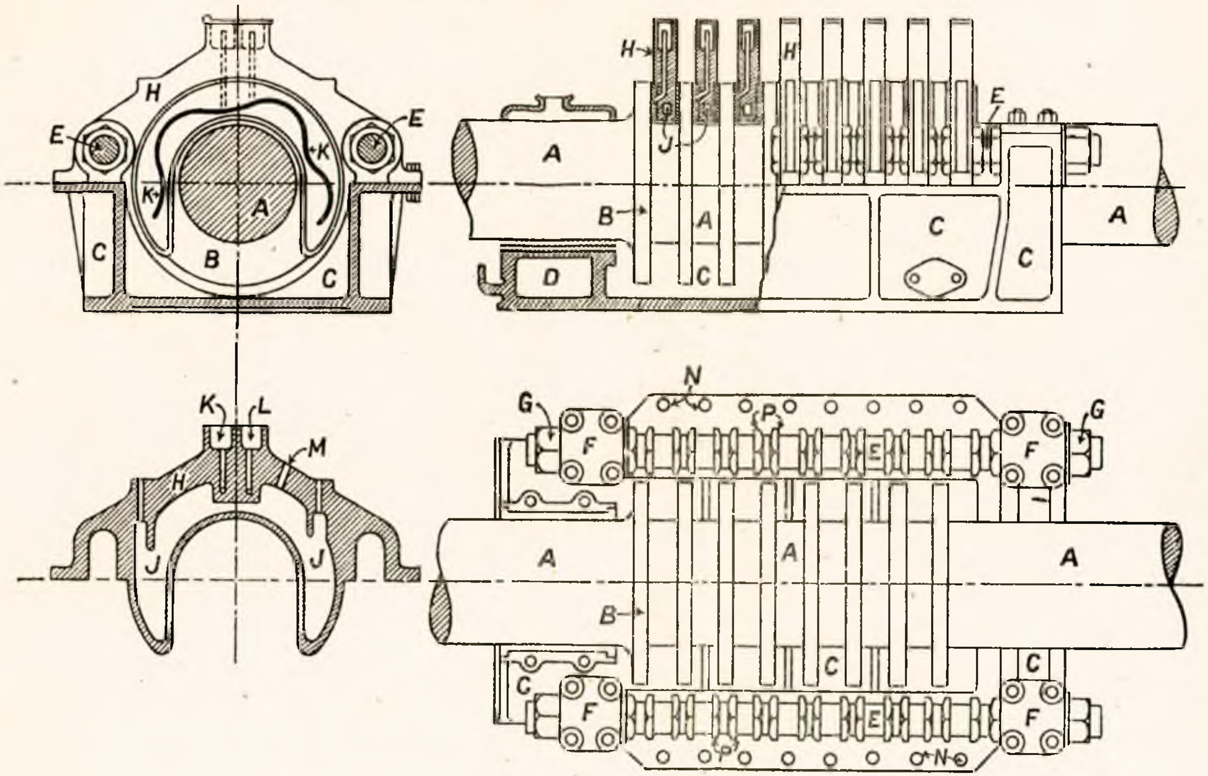
The illustrations shown of Types I. and II. are reproduced from the drawing submitted with the essay. Type No. 3 is added with the permission of Mr. A. E. Seaton (see Pocket Book of Marine Engineering Rules and Tables) by the courtesy of the Publishers, Messrs. Chas. Griffin & Co., Strand, W.C.

J.A.



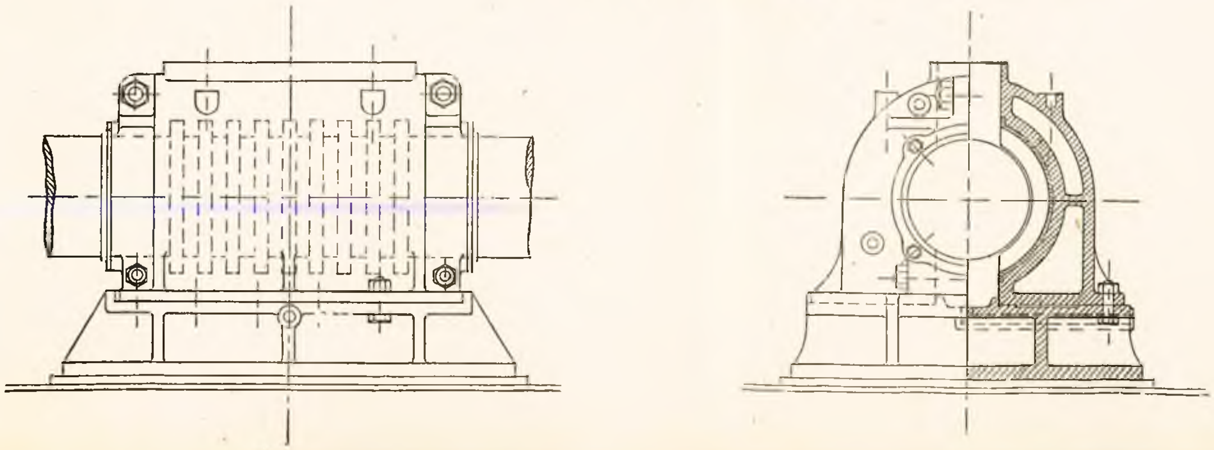
TYPE No. 1.
SOLID THRUST BLOCK.

A. Steel Thrust Shaft.
B. Collars on Shaft.
C. Cast Iron Base Block and Cover, bolted to seating D.
D. Cast Iron Seating bolted to ship's framing.
E. White Metal Lining, cast in base Block and Cover.



TYPE No. 2.
HORSESHOE THRUST BLOCK WITH INTERNAL WATER SERVICE.

A. Steel Thrust Shaft.
B. Collars on Shaft.
C. Cast Iron Frame, securely bolted to ship's framing, which takes thrust.
D. Part of C, which takes the plummer block at after end of Thrust Shaft.
E. Steel Screwed Thrust Bars, secured to framing C.
G. Thick Phosphor Bronze Nuts to take up thrust. Often wrought iron.
H. Horse-shoe Thrust Rings, lined with white metal on both sides next collars on Shaft.
J. Hollow space for water circulation.
K. Oil Ways and Groove for ahead thrust in white metal.
L. Oil Way for astern thrust.
M. Air Outlet, fitted with a cock, from water service.
N. Bolt Holes for holding down each shoe to frame.
P. Phosphor Bronze Nuts for adjustment of thrust shoes independently.



TYPE No. 3.
THRUST BLOCK.

Tunnel Bearings and Thrust Blocks.

(Issue of January, 1910).

"Another interesting point in this connection* is the design of thrust shafts. The opinion may be expressed that, generally speaking, these are not designed with a sufficient margin of strength; it would be imagined that most engineers would know sufficiently about the requirements as regards strength and lubrication, and that the designers would be called upon to see that these conditions were adequately fulfilled, but in a very large proportion of steamers afloat at the present time it will be found that there is a continuous flow of sea water through the thrust blocks in order to keep them cool. The effect of this water on the shaft itself in corrosion is obvious, and this process must be continuous, as in most instances the water cannot with any degree of safety be shut off while the shaft is running. This is aggravated by the fact that owing to neglect of details in design, sharp corners are left at the junction of the thrust collars with the main body of the shaft, and at this weakest part, mechanically speaking, the effect of corrosion will be felt the soonest. The thrust shaft is generally of the same diameter as the tail end and the crank shafts, but the tail end shaft is protected from corrosion by one or more brass liners, excepting at the part that stands out into the water near the tapering. This unprotected part of the tail end shaft in itself gives an indication of the damage which is simultaneously proceeding on the thrust which is flooded with sea water. The grooving that proceeds on the tail end shaft near the propeller is too well known to require much emphasis in view of the large number of propellers which are lost every year due to such grooving, and the same effect of sea water must be proceeding in a less degree in the thrust block. When one also considers the fact that there must be galvanic action constantly proceeding in the thrust owing to the mild steel collars being in intimate contact with their white metal bearings in the presence of sea water, it is apparent that the weakening takes place in the worst part possible, viz., the outside fibres of the shaft, and such shafts are by no means strong enough to withstand continuous sea-going wear and tear, even if, according to the theory of design, they meet all conditions when they pass out from the shops.

A certain proportion of the failures of thrust shafts may be traced to the way in which the work involved in the design is

* The reference is to the desirability of arranging to keep the cooling water outlet away from vital parts likely to suffer damage.—J.A.

carried out in the shops. In one instance where such a shaft broke under heavy stress, the fracture showed, somewhat indistinctly, but nevertheless sufficiently well, that the forging was a bad one, inasmuch as the outline of scrap could be seen in the centre of the fracture. This indicated that either the shaft had been forged under a light quick steam hammer, or else that the metal had been too cold, and it is worth remembering that such shafts should be forged under a heavy hammer which gives ponderous blows which can be felt throughout the entire mass of the material. Moreover, these blows should not be delivered too quickly, as when the metal is in a ductile state, it should be given an opportunity to flow or set itself at the centre before it has been too much distorted by constant blows on the outside. Moreover, the material should be heated to very nearly its plastic heat before being worked, and the correct forging heat is indicated to the men who understand their work by the material giving out a shower of white hot sparks when it is drawn out of the furnace; these are entirely different from the appearance of the sparks when the material is being burnt.

Yet another detail which would materially assist the life of thrust shafts and bearings, would be greater attention to the following point which, although it is only apparently a small detail, nevertheless causes a considerable amount of trouble if not attended to. The design of many of the thrust shafts in some boats is bad, inasmuch as the bottom of the collars on the shaft are finished to form a right angle, and it is evident that this sharp angle is sufficient to form the beginning of a line of cleavage between the collar and the shaft, which must under exceptional conditions, such as the racing of a propeller, cause a very considerable amount of trouble. Care should always be taken to place fillets, however small, at this angular junction as these would add wonderfully to the strength of the shaft. The thrust block should also have a radius to suit the fillets on the collar, and this radius would therefore be considerably larger than those usually given.

In order to show how these considerations actually affect the working of the thrust blocks it may be interesting to relate two actual experiences which occurred in sea-going practice. The first trouble was due to the fact that sea water was continually standing upon the plate A in Fig. 2 about the thrust block and this corroded the plate. The thrust itself was noticed to be working loose when the engines were racing, and it therefore became necessary to stop the engines and to put a compensating plate underneath the corroded one in order to strengthen it as shown in the sketch. This plate was fortunately on board among the cargo, but the fixing of this one inch thick steel plate into position in a rolling sea, and with the limited means available on board ship was a very long and heavy business which took two days to accomplish. Had the working of the thrust not been noticed and corrected, however, it might have been entirely uprooted, and a complete breakdown to the engines would thereby have been caused. In order to protect such plates from corrosion they require constant chipping and painting, and a very good plan in order to prevent the effects of the continuous splashing about of the cooling sea water through the thrust block is to place a layer of cement upon the floor all round the thrust block. The important bearing of this accident upon the question of ample design of thrust blocks is, however, obvious.

Another accident might have been much more serious, if by good fortune the engineer had not been standing near the throttle valve when it occurred. This was the fracture of a 10 inch diameter thrust shaft during very heavy weather, at the section of the shaft where one of the collars was joined to the shaft proper as shown in Fig. 3. As soon as it occurred the engineer stopped the engines, and the repair indicated in the sketch took two days and nights to finish. The first thing done was to lift the keeps on the tunnel bearings, and to put pieces of plate with coarse emery cloth wrapt round them under the caps. These were then tightened down, and this device kept the shaft from turning while the engineers were busy. The next step was to uncouple the thrust shaft and lift it, and then the thrust block was moved aft one space between the collars on the shaft, so that the forward collar where the fracture occurred was left projecting out of the thrust block. It was fortunate that in making this replacement, it was found that the only thing which had to be done with reference to the thrust block holding down bolts was to cut two extra holes in the seating aft of the others, all the other holes working in. The thrust shaft was then put in place again, and repaired as shown in the sketch. Bridge pieces were made of strips of mild-steel, and bolted to the top of the collar and on to the shaft. In addition a piece of angle iron was bent round and fastened by means of tap bolts, both to the shaft and the forward face of the first collar. Another piece of angle iron was then bent round the shaft, and secured by tap bolts in order to form a sort of auxiliary collar to help the parts where they were fastened together, and to keep the crank shafting from working either forward or aft. The necessary bearing for this collar was secured by bolting two stout hatches together, and shoreing them together in every conceivable manner from the roof of the thrust block recess and also from the floor. The auxiliary collar, therefore, ran up against the wood, as shown in the sketch, and this wood also acted as a means of steadying the shaft. The bridge pieces were half-inch thick, and the angle iron was half-inch thick in the flange, while the bolts used were seven-eighths of an inch. This repair was sufficiently satisfactory to enable the boat to proceed with the engines running slow after the packing had been removed from under the tunnel bearing keeps, for about 150 miles until a port of repair could be reached. All this trouble might possibly have been avoided however, if the shaft had been thicker in diameter and again if the junction between the collar and the thrust shaft had been rounded instead of left a sharp corner."

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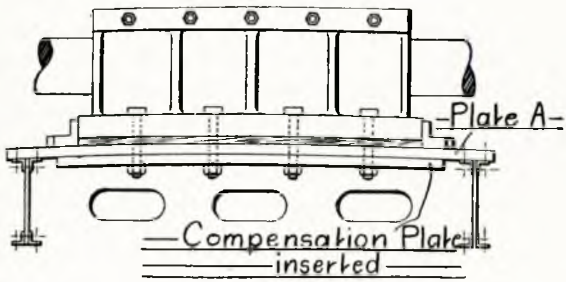

FIG. 2.

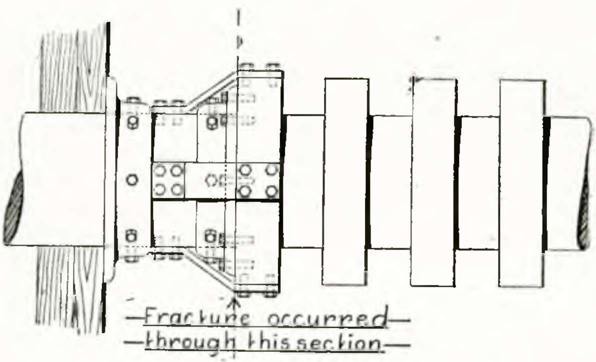

FIG. 3.

LLOYD'S REGISTER SCHOLARSHIP.

The Awards Committee had the pleasure of reporting as follows to the Council, and to the Secretary of Lloyd's Register of Shipping:—

It is interesting to note that Mr. C. P. Tanner, who has just closed the second year of holding Lloyd's Register Scholarship, has gained the B.Sc. degree at Glasgow University, and has further obtained a Commission in the Royal Navy as Engineer-Lieutenant.—J.A.

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TITANIC ENGINEERING STAFF MEMORIAL (BENEVOLENT) FUND.

The Committee had under consideration an application from the Superintendent Engineer of the Atlantic Transport Line on behalf of a child of one of the greasers, R. McFarlane, who was lost when the *Minneapolis* was sunk. The circumstances placed before the Committee were such that the case was recommended to the Council for nomination to the Merchant Seamen's Orphanage. This having been approved, the necessary steps were taken to carry the recommendation into effect. There are five children, and the candidate is a boy, 9 years of age.

Wanstead Infant Orphanage.—One of our members was interested in a candidate for this Orphanage, and on application received the support of the Committee.—J.A.

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ELECTION OF MEMBERS.

The following were elected at a meeting of Council of the Institute held on Tuesday, March 14th, 1916:—

As Members.

Arthur George Burdick, 53, Belgrave Road, Ilford, E.

James Hall Duncanson, *c/o* Irrawaddy Flotilla Co., Ltd., Box 129, Rangoon.

James Sinclair, *c/o* Messrs. Butterfield & Swire, Hong Kong.

Chas. P. Tanner, Engineer Sub.-Lieut., R.N.

AMONG those reported killed on H.M.S. *Indefatigable* in the naval battle which took place on May 31st off Jutland, it is with great regret we note the name of Chas. P. Tanner, Engineer Sub-Lieutenant, R.N., whom we noted in a recent issue as having completed his University course at Glasgow, with the aid of the Lloyd's Register scholarship under the auspices of the Institute of Marine Engineers, and obtained the B.Sc. degree. He then received a commission in the Royal Navy as engineer sub-lieutenant and after a short time at the naval training college, he joined the *Indefatigable*, on May 8th. His engineering training as an apprentice was gained in the works of Messrs. David Rowan & Co., Glasgow, and during his apprenticeship he was elected a graduate of the Institute of Marine Engineers. His name has been in successive years on the list of those receiving awards for essays, contributed by competitors on subjects set by the committee. Shortly after war broke out, Chas. P. Tanner and his brother offered themselves for the army and enlisted. During their period of training their father, a clergyman in Rutlandshire, died, and under the circumstances Charles was granted freedom from military duties to return home. Although he had laid aside, when enlisting, the desire to take up the University course in Glasgow, he now made application and was granted permission by the senate with the concurrence of the scholarship authorities to enter the course some weeks late, but such was his industry and perseverance that he took excellent positions in several of the subjects and passed in all. Continuing with Messrs. Rowan, he resumed the University course in the 1915-16 session with the result already referred to. He was a young engineer of great promise and it was anticipated that he would give every satisfaction to all those interested in his future career. Very deep sympathy is felt with his mother in the loss of her son, who laid down his life for his country. His only brother is still serving with the army. He was dangerously wounded last September, and has just had the distinction of the Military Cross conferred upon him.