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President—Col. John M. Denny, M.P.

President Bristol Channel Centre—Sir John Gunn.

SOME REASONS FOR THE INCREASED NUMBER OF DEFECTIVE TAIL SHAFTS SINCE THE INTRODUCTION OF THE TRIPLE EXPANSION ENGINE.

By Mr. G. F. MASON (*Member*).

READ AT THE INSTITUTE ROOMS, 3 PARK PLACE, CARDIFF,

On WEDNESDAY, APRIL 4th, 1900.

Chairman:

Mr. T. W. WAILES (Vice-President B.C.C.).

Probably some of the members of this Institute will expect an apology or excuse from me, for being the means of again bringing forward the subject of propeller shafts, seeing that it has been so recently debated almost *ad nauseam*, but in my opinion the discussion has really only commenced. However, if any apology is needed, I consider the recent circular from Lloyd's Committee to their Surveyors sufficient justification, and so far as I know, no definite decision has been come to by the above-mentioned body as to what the sizes of the shafts are to be in the future; certainly no decision as to the cause of so many shafts giving out has been arrived at, and I hope this paper may throw some new light upon the latter subject, as I do not think it has been looked upon from the points of view I shall mention. In the few remarks I have the honour to put before the meeting, I should like the members to understand that my conclusions have been drawn from actual experience and experiment. I am sorry I cannot place them before you in a more complete form owing to the time which has elapsed since some of them were obtained.

One of the most essential duties of an engineer from the commencement of his apprenticeship is to keep a note book of his various experiences, but owing to the very nature of his employment, probably in every quarter of the globe, ashore and afloat, and the constant change of locality and circumstances, this is exceedingly difficult; mine having been unusually varied, I have not been able to keep the records I should have liked.

Before the triple-expansion engine became so generally adopted, I had a great many defective tail shafts under my notice, and my attention was drawn to the similarity of the fractures or flaws, so much so that I came to the conclusion they could nearly always be classified as longitudinal or grain fractures and circumferential.

To the best of my recollection I never came across a tail shaft up to ten years ago that showed any of the small star fractures or cracks now so common in the triple expansion tail shafts, of which I will speak further on. I was so much impressed with the family likeness of the defects that I determined when opportunity served to try and reproduce them on a small scale. When my chance came I procured some bars $2\frac{1}{2}$ in. and 3 in. diameter, and tried to get longitudinal and transverse fractures. I found the former could be pretty easily produced by applying an intermittent strain sufficiently powerful to overcome the initial rigidity of the bar; this treatment opened up the grain of the iron, but did not give me any circumferential fractures, so I tested some bars with a friction brake fixed as nearly as possible in the same condition as a tail shaft would work, viz., having the end overhung. On the overhung end I secured a forging with five arms, which geared into a weight so as to lift it up and allow it to fall on the arms in rotation as they came round. Two of my bars broke short off under this treatment, but in the others I found the fractures I was looking for, and all of them, tested under the hammer, afterwards broke short off at these marks.

My reasons for the foregoing experiments were as follows: I found from what information I could procure, that nearly all the tail shafts with longitudinal flaws had come out of vessels where the engines were pretty constantly run up to their maximum power, and it struck me that the shafts might be on the weak side. Most of the shafts showing the circumferential defects had been allowed to run with the lignum vitæ in the stern bush much worn.

You will, of course, gather from the above that I put the two principal causes for the breakages down to shafts out of line and weakness, but the foregoing only refers to the period preceding the general adoption of the three-crank triple-expansion engine, since which the mortality in tail shafts has risen enormously. In the days of the compound, so far as my experience goes, we had more trouble with the crank shafts, but the advent of the built shafts has changed all this. I say this advisedly, as I do not consider the multiplicity of cranks has anything to do with the lengthening of the life of the crank shafts; such I put down entirely to the more general use of white metal and built shafts.

I might mention in this connection that 60 per cent. of the fractures I have come across in solid crank shafts have been circumferential ones, or across the webs. But, to resume, I think I shall be able to prove to your satisfaction—at any rate I have to my own—that the advent of the three-crank triple engines of the present day—coupled with the unfortunate reduction of strength allowed in Lloyd's and Board of Trade rules for increased number of cranks in triple and quadruple engines—has been responsible for most of the tail shaft failures. To prove my assertion, I would like you to compare these two typical examples of compound and triple expansion engines. I can give you many such, but I think two will serve. The compound engines are

$$\frac{37'' \text{ and } 72''}{48''} \times 100 \text{ lbs. pressure.}$$

The triple engines are

$$\frac{28'' \text{ and } 45'' \text{ and } 74''}{48''} \times 160 \text{ lbs.}$$

Now, according to Lloyd's rules in force at the time they were built, their respective tail shafts should have been 13·9 and 13·5 diam. You will notice nearly $\frac{1}{2}''$ more in diam. for the compound than the triple, why, I am at a loss to say, unless the former is penalised by having only two cranks against the latter three. Now on the trial trip of the compound, the engines indicated 1,600 H.P. and 65 revolutions; but the triple indicated 2,350 H.P. and the same piston speed, 45 per cent. more power, and this is allowed to be taken out of a shaft less in area, diameter and strength. Of course it will be said, "Ah, but you forget you have three cranks in the one case instead of two, and therefore your shaft does not get so much punishment, the turning moment being so much more evenly divided"; exactly, and that is just where in my opinion the mischief comes in. You may, and of course I grant, you do put your power into your shafting with much less stress in the case of 3, 4 or 5 cranks, the more the better, against 2, but in each case the power is given out the same way with a propeller hammering away often in a heavy sea, very probably at the end of a shaft $\frac{1}{4}$ in. out of line and your engines racing in the most approved manner. Now, with a multi-crank job—by this of course I mean three cranks and over—directly the ship lifts her stern the engines gather way at a great rate, and although the propeller strikes the water a tremendous blow as she dips, it is not sufficient to bring the engines back to the normal speed at once, owing to the extra turning moments, and something of the following sort, I take it, happens—the heavy sudden shock and strain brings the propeller up, to a certain extent, quicker than the engine end of the shafting, causing the shafting to twist and this twist remains, so to speak, until the propeller end overtakes the crank shaft end, causing the grain of the shaft to open, giving the water in the stern tube a better chance of getting into the reeds of the metal, and this constant action keeps going on until the shaft is a mass of reeds—of course I am working on the hypothesis of the shaft being made to Lloyd's strength—or owing to the heavy hammering and a little slackness of stern bush, a circumferential flaw is developed or the shaft snaps off altogether.

In the case of the compound, however, the engines do not gather way nearly so rapidly, and after the shock of the propeller striking the water, quickly pull up; indeed, I have seen a compound pulled up to a dead stop, consequently the shafting does not get the punishment that it does in the former case.

Bearing out the above I find in two instances I tested—with loaded ship and weather practically the same in each case—that in a heavy head sea with throttle valve full open and engines allowed to run to give the same revolution in each case, that is to say, both would have run at 60 revolutions in smooth water, the compound's revolutions per minute were decreased slightly, but the triple's increased about 5 per cent. Again in each case the ordinary piston speed per second was 8 ft., in the compound it ran up to 13 ft. per second, but in the triple, went up slightly over 16 ft. per second—60 per cent. increase in the one case and 100 per cent. in the other.

This means again that with a shaft $\frac{1}{2}''$ less in diameter but indicating 45 per cent. more power, the propeller struck the water with 40 per cent. greater velocity. Can it be wondered at that under these circumstances propeller end shafts have been giving out in all directions? In the four-crank or quadruple engines, the mischief is of course accentuated. I do not think sufficient care is exercised in keeping the stern bush up in line. How many engineers would go to sea with their tunnel or crank shafts $\frac{1}{8}$ in. out of line, although quite possible for them to get at every bearing? And yet it is a common thing to see tail shafts running $\frac{3}{8}$ in. down. Imagine the strain on a shaft with a weight of seven or eight tons hanging on the end, with the nearest support 12 to 14 ft. away, for this is really what a shaft being down in the bush means. As regards the material of which the shafts are made, it is well known that the difficulty of getting good pure scrap iron has been very great and more often than not steel in greater or less quantities has crept into the forgings and I think the star fractures before mentioned may safely be put down to the non-homogeneous nature of the metal of which the shaft is made and this will have had its share in the failures.

I would here like to call your attention for a moment to the diagram. This is worked from a set of indicator cards of the two engines mentioned when running at their ordinary speed. The engines were designed to drive the respective vessels at $10\frac{1}{2}$ knots on the trial trip so as to secure a steady 10 knots at sea. They both steamed the speed on trial with engines running 65-66 revolutions and steam the 10 knots at sea running at 60 revolutions, at which speed the cards were taken. The indicated horse-powers are at 65 revolutions; triple engine 2,350; compound 1,600 at 60 revolutions, triple engine 1,772; compound 1,136. You will see at a glance the disadvantages under which the triple engine shafting is working, for, whereas the greatest strain in the case of the compound is 85·9 and lowest 44·8, the triple reaches 119·2 and comes down to 54·35 tons; the difference between the pressure being 41·1 and 64·85 respectively, and the difference in size of the shafting must not be overlooked. Now, if the vessel having the triple engines had been fitted with compound instead, the size of the shafting to take this strain of 119·2 tons, would have worked out to be 15½ in. diameter, 30 per cent. more than the rules consider sufficient in the case of the three-crank triple job.

I dare say you will notice I have said nothing about the much debated corrosion and galvanic action. I have omitted this part of the subject, as I do not see why it should be allowed to take place. I have never had a shaft condemned for either reason, or had anything of the sort to speak of; it is easily prevented.

Speaking with great diffidence, knowing how inadvisable it is to utter the semblance of a boast, especially as we as engineers never know what may happen, and, as a rule, are not much surprised at any sort of a breakdown, I have never had a shaft break at sea with one exception, about ten years since. This was a shaft about two years old, which I had never seen, and was a defective forging; a ¾ in. bolt 4½ in. long, which is still in my possession, being found lying intact in the heart of the shaft across the centre, in the direction of its diameter, and as I said before, I have never had to remove one on account of corrosion. I think if the following simple precautions were taken, propeller shafts would give very little trouble. See that your shaft is made strong enough, and, incidentally, corrosion and galvanic action will disappear. I have never fitted one less than 25 per cent. over Lloyd's rules for the power required, and if the engines are to be run constantly at full speed I should make it 30 per cent. over. Have your shafts made of perfectly homogeneous material, good scrap iron for choice, if not ingot steel. Manganese bronze is better still, but the cost is too high. If liners are fitted, see that the ends are well tapered out, the shaft either tinned or lapped with copper wire soldered where the ends of the liners finish. Never let your stern bush get slack, and have your shaft drawn and examined every eighteen months; use end wood in your bush. Run the shaft in oil or tallow, or see that the water in the tube is constantly changed. I have a simple way of doing the former. I fit an oil box holding about half a gallon of oil in the cowl of the tunnel ventilator carrying a pipe down the tube to the off peak bulkhead where it is attached to a cock, on the after side of this I run a pipe into the centre of the stern tube; the oil is allowed to syphon down with the ordinary worsted syphons in the usual way. I know many good engineers recommend fitting a continuous gunmetal liner in one piece the whole length of the stern tube, but I do not think this is an unmixed blessing ; I have seen many such shafts give way under the liners; I would sooner abolish them altogether. In conclusion, I am aware anyone reading a paper on such a controversial subject as this somewhat makes himself into a literary Aunt Sally for everyone to shy at, but I think I have approached the subject on new ground, and I hope it may be the means of raising a discussion that will throw even more light upon a very debatable and interesting topic. Of course, no one will deny for one moment that the tail shafts of the last few years have had to undergo very much more rough usage, owing to the vessels having been built much fuller and so frequently sent long voyages in light trim with insufficient ballast, but if my conclusions are correct, then my arguments apply with additional force to shafts working under these ballast conditions, as the evil is only intensified with light ships; and I, for one, look forward to some Act of Parliament being passed, or action taken by the underwriters, that will make a light load-line compulsory.

PREFACE.

PARK PLACE, CARDIFF.
May 21*st*, 1900.

A meeting of the Bristol Channel Centre of the Institute of Marine Engineers was held on Wednesday, April 4th, presided over by Mr. T. W. WAILES (Vice-President B.C.C.), when two papers on "Propeller Shafting," one by Mr. G. F. MASON (Member), the other by Mr. E. NICHOLL (Member), were read and in part discussed.

At a meeting held on Wednesday, April 25th, presided over by Mr. J. F. WALLIKER (Vice-President B.C.C.), the subject was further discussed, when also the paper read at Newcastle before the members of the North-East Coast Institution of Engineers and Shipbuilders, by Mr. MORRISON, on the position of the Engineers of the Navy, was referred to by the Chairman.

The discussion was continued at the meeting held on Wednesday, May 9th, and the reports of each evening's proceedings are as follows.

GEO. SLOGGETT,
Hon. Secretary B.C. Centre.

DISCUSSION.

3 PARK PLACE, CARDIFF.

WEDNESDAY, APRIL 4th, 1900.

CHAIRMAN:

MR. T. W. WAILES (VICE-PRESIDENT B.C.C.).

MR. J. F. WALLIKER, at the invitation of the Chairman, opened the discussion. Prefacing his observations by stating that he suffered from a cold and had not intended taking part in the discussion pending the printing of the papers, Mr. Walliker said he had for some time advocated that a linerless shaft was the best shaft, and next to that a shaft with a continuous liner. At the same time, his experience taught him that a shaft with a continuous liner had certain defects which could not be obviated unless the liner were made an integral part of the shaft—unless stepped down so that the propeller caught hold of it, the propeller and shaft being made practically one structure. He had seen liners fused up to 40 ft. in length, and they had been a perfect job. As to the material of which shafts were made, there had been great improvement in the past few years. Iron of very good quality was being used. It was carefully selected and supervised in all stages of its manufacture. Lloyd's Register took quite a fatherly interest in forgings. They not only look after the material and the machining, but they actually regulated the size of the hammer used for making the shaft. If they tried to make a big shaft with a small hammer they did not get a proper shaft; and they had had to suggest to their friends at the forges that the hammers they were using were fitted for shafts of a certain diameter only. The material was of an infinitely better quality than was the case a few years ago, the best iron being used in the shafts, and he believed much better results would be given than in the past. As to shafts being of larger size, in a paper read before the North-East Coast Engineers some time ago, Mr. Milton showed incontestably that the average life of shafts 40 per cent. over Lloyd's requirements was—if he remembered rightly—3·7 years, so that increased size did not prevent these shafts breaking. After all, the owners were the arbiters in all these matters. A ship of very full body was put upon the water, and was a commercial success, and what engineers had to do was to make a shaft that would be satisfactory for this structure. He agreed with the conclusion of the authors of the papers that what was wanted was a deeper ship. This was the crux of the whole question: Given a ship running with the propeller properly immersed and trouble with shafts would practically vanish. As to star cracks, he thought he was right in saying that they had practically disappeared. They were only found when shafts were made with a very large degree of scrap steel. As to nickel steel, he agreed that it was making great strides in public favour and it would prove of great value. The application of tallow to shafts was unsatisfactory unless the tallow was of very good quality, otherwise corrosion would be set up.

Mr. CHELLEW said he had a shaft that had been running for nine years, but the ship was of deep draught. He had a theory that weakness of the ship aft produced fractures of tail shafts.

On the proposition of Mr. W. SIMPSON, seconded by Mr. SCOTT, the discussion was adjourned.

A cordial vote of thanks was passed to the Chairman, at the suggestion of Mr. SHELTON, seconded by Mr. WALLIKER, and the proceedings closed.

DISCUSSION CONTINUED.

3 PARK PLACE, CARDIFF.

WEDNESDAY, APRIL 25th, 1900.

CHAIRMAN:

MR. J. F. WALLIKER (VICE-PRESIDENT B.C.C.).

PROPELLER SHAFT FAILURES.

CONTRIBUTORY CAUSES CONSIDERED.

MR. J. F. WALLIKER, a vice-president, presided over a meeting of the Bristol Channel Centre of the Institute of Marine Engineers, held on April 25th, at the rooms of the Centre, Park Place, Cardiff, when discussion was resumed on the papers of Mr. E. Nicholl, R.N.R., and Mr. G. F. Mason, treating of the subject of tail-end shaft failures.

The Chairman, before, however, consideration of the papers was entered upon, referred to the paper of Mr. O. D. Morrison, of Hartlepool, recently read at Newcastle, on the status of the naval engineer, and to the fact that the North-East Coast Institute, on the proposition of Sir Benjamin C. Browne, had decided to put itself into communication with kindred bodies with a view to their discussing what was really an important matter in the highest interests of the State, and to the incorporation of their deliberations in one volume, to form a part of the *Transactions* of each institute. It was at the same time resolved to form a committee to draw up a report for submission to the Government on the subject of the engineering *personnel* of H.M. Navy. He (the

Chairman) had no doubt but that the matter would be cordially taken up by the Bristol Channel Centre of the Institute of Marine Engineers.

Mr. W. SIMPSON, who opened the discussion, said the question was whether they had got to build the ship to suit the shaft or whether they could make a shaft to suit the ship. If the theory propounded in 1897 by Mr. Aisbitt that chemical action was the primary cause of shaft fractures, it did not matter how deep the propeller was in the water. But he disagreed with Mr. Aisbitt's theory. He was convinced that light draught ships were the great cause of these failures. He quite concurred with Mr. Nicholl, the author of one of the papers under consideration, in his suggestion that liners should be abolished and that as far as possible ships should be kept down in the water. As engineers it behoved them to set about devising a thoroughly reliable shaft which should suit the requirements of the modern cargo ship. If they were to have liners, he preferred a long one to take the strains right along. He considered ingot steel as good as iron for shafts, when it was got "clean," but the question of material was not the main point. As to crank shafts, he had already expressed the opinion that the built shaft had much to do in getting over the difficulty of their failure. In the case of the light ship there would be heavier "racing" with the triple than with the compound, and consequently there was a greater strain on the tail shaft.

Mr. T. D. WIDDAS recalled a shaft on a Cunarder, 22½ in. diameter, fitted with two liners, the joint being so good that the liners had to be scraped in order to see they were in two lengths. In the course of time the liners were taken off, when there was seen just the least evidence of water having come in contact with the shaft. Closer inspection, however, showed that the deterioration was more than superficial, and being broken at the point where the liners joined, the cut was seen to be from 3 in. to 3½ in.

And this was not an isolated instance in which liners were not joined together. As to the question of tensional strain on the shaft plus the bending stress due to partial immersion of the propeller, Mr. Nicholl had reduced the matter to figures, and told them that nine tons was the strain on the particular shaft he named, but Mr. Nicholl had omitted to say where the shaft failed. This information was necessary in order to see the connection between the 9-ton stress and the method of failure. With regard to the quality of material, Mr. Nicholl appeared to be inconsistent. In the first place he said that mild steel of low tensional strain had been discarded because it more readily crystallised than iron, and in the next place predicted that nickel steel of a very much higher tensional quality would come into use. He remembered the failure in about four years of mild steel shafts in a twin-screw steamer. Samples of the steel had been tested in his presence both for tension and bending, and the shafts were made under a forging press. Iron shafts were substituted, and these failed. He was inclined to think that chemical or galvanic action played a part in this. If chemical action could be set up through the water to iron in the vicinity, why not to a greater degree where the metal and the water were in contact with the shaft? If there were no chemical action, why was so much trouble taken to keep the water from getting to the shaft? Of course, there was something more and beyond chemical action. In one case which came under his notice, a shaft broken in the vicinity of the liner showed coarse crystals, but at a point away from this a very different texture was found. As to linerless shafts, he knew of a little vessel which never ran light, where there was no liner on the shaft, which had a white metal bush. That shaft was condemned because it had perished to such an extent that it began to grind away the bush. The shaft and stern bush were discarded, and a long liner adopted on the next shaft, the liner entering into the propeller. He might say that the condemned shaft had not been lubricated with oil.

Mr. M. W. AISBITT admitted that in a paper which he read before the Centre in 1897 he claimed that fractures of tail end shafts were primarily due to chemical action. On that occasion his dear friend and colleague, the late Mr. Nisbet, contended, on the other hand, that the cause was malformation of the shaft; and he was there to confess that his friend was right. The present-day tendency was to think too much of the chemical and to neglect the mechanical action. Mr. Nisbet's contention was that their shafts were ill-constructed mechanically. Forty years ago the Government thought lignum vitæ the best, but they never dreamt of the present broad-beamed, flat-bottomed ship going light so frequently. There was the ss. *Menapia*. Mr. Horn, of Liverpool, put the shaft in her; six months afterwards she went ashore, was got off and brought round to Newport, where the shaft was drawn in, and there was not the slighest mark. Nine months later she was dry-docked, the shaft drawn again, and was found not to have deteriorated 1-64th of an inch. Mr. Horn put in a common gland at the stern, over-lapping, and the gland kept the shaft from "slobbering"; and so long as the engineer could effect this, he need never be afraid of fractures. At one time the *Menapia* used to lose a shaft every twelve months. The man who made a parallel wrought iron shaft with cast iron or white metal bushes would succeed in preventing fractures so long as he kept the tube full of oil. Too much attention was paid nowadays to corrosion and too little to the causes of the original fracture. In his opinion, vibration caused fracture. Lloyd's dimensions of shafts were proper provided they were looked after. No amount of increased diameter would make up for the shaft not being properly looked after.

Mr. A. SCOTT YOUNGER, B.Sc. (Member): The members of the Institute of Marine Engineers are to be congratulated in having this subject brought so prominently before them just now, when the matter is attracting so much attention. This problem has been crying out for solution for many years, and the contributions from Mr. Nicholl and Mr. Mason form a welcome addition to the literature on the subject. The papers practically cover the same ground and so may be discussed together. I have read them both with great interest, and in the main agree with their conclusions, though I am unable to follow some of their reasoning. It certainly looks as if engineers were now making up their minds on this subject, and the causes which have contributed to produce so many failures of recent years are pretty generally recognised.

These are shortly: (1) The enormous increase in the size and fulness of the ship, without any corresponding increase in the power of the engines, resulting in

(*a*) A relatively smaller shaft.

(*b*) Much lighter draught in ballast. The effect of a ballast run is thus much more severe on the shaft in a modern steamer than was the case fifteen or twenty years ago. On investigation we find that in these cases a very severe bending moment is produced in the tail shaft, due to the propeller being only partially immersed. The effect of this is to bend the shaft backwards and forwards at each revolution, and, owing to the local strengthening afforded by the liners, the shaft ultimately fractures at the change of section.

In a paper I had the honour of reading at the recent meeting of Naval Architects these views were put forward, and it was shown that the stresses arising from this action reached a maximum at the ends of the liners where the corrosion is most severe, and where sometimes the shaft breaks short off.

Mr. Nicholl works out the bending moment on the shaft from the twisting moment at the engine, which seems to me to be wrong; in fact I am quite unable to see any direct connection between the two. I also do not see why he should take the centre of thrust at half the immersed depth of blade. Under ordinary statical conditions this point should coincide with the centre of water pressure, viz., about two-thirds the immersed depth.

I am sorry Mr. Mason has not tabulated the results of his experiments, and given sketches showing exactly how they were made. If he can add this as an appendix to his paper it would be very valuable. He is also alarmed at the idea of a tunnel shaft being $\frac{1}{8}$ in. out of line, though this is a comparatively small amount, and in a modern ship I would not be surprised to learn that this figure was largely exceeded, due to the working of the ship alone.

I agree with Mr. Nicholl in thinking that ingot steel would be the most suitable material for tail shafts, especially if liners are removed, as it is much more homogeneous and should be quite free from reeds. Recently I have heard of cases where iron shafts have been run on white metal without liners, and although fitted with a gland at the outer end and kept well supplied with oil they have not given satisfaction, as the water opened up the reeds in the material, thus producing a rough surface which wore away the bearing.

Mr. A. S. Jackson (Member): I have carefully perused Mr. Nicholl's paper on Propeller Shafts, which includes in the first place a letter from my friend Mr. Austin, of Lloyd's Register.

I quite agree with Mr. Austin, from my own experience, that no increase in size of propeller shafts is necessary for the horse-power of the engines, and also that the non-immersion of the propeller is one of the most serious causes in connection with these breakages in light ship runs.

Whether the vessel should be trimmed by means of deep ballast tanks or otherwise is in my opinion outside the question, but certainly the propeller, especially in trips across the Atlantic, should be as fully immersed as possible, and a B.T. minimum load line would be of great service.

I am also of opinion that one important reason why there are so many breakages of propeller shafts is on account of the absolute indifference of the majority of the makers as to the material employed, and I consider that if a standard brand of iron was employed, and tested during the making of same by the various Classification Societies' Surveyors, the majority of the breakages which occur would be avoided, and this whether the shaft is fitted with two liners or one liner or no liner whatever, or the shaft is run in oil or not, or run on white metal, cast iron, or lignum vitæ; but in any case good tested iron should be used and not steel, or any mixture of steel and iron.

Another cause of the frequent failure of propeller shafts is in consequence of the rapid machining from stocked forgings; the well advertised lathes used by various firms, which take a multiplicity of cuts at one time, not only take away the most useful and strongest portion of a shaft, whether well or indifferently forged—more especially when the latter is made, as is frequently the case, with mixed materials—and subject the shaft to a torsion strain which it was never intended to withstand in its normal state—i.e., when running at sea—and which severe and abnormal strain appears to be altogether overlooked by the Classification Surveyors.

Mr. WILLIAM EVANS said the fissure in the shaft occurred more frequently at the fore end of the after liner than at any other point. Some galvanic action affected the surface of the metal, and the extraordinary vibration on the modern light vessel aggravated it at the part where the shaft started. He had had great experience of linerless shafts in steamers in the Norwegian Register, and during the last nine years he had not been called upon to condemn one single shaft. The shafts mostly ran in oil. As to remedy for fractures, they must either have linerless shafts or shafts covered with long liners, the only fault of the latter being that a portion of the shaft could not be examined. Another plan was to have the after liner carried well forward, and every time the shaft was drawn in to take half an inch off the after end of the brass liner. This stopped the galvanic action which took place at the fore end of the after liner. They did not get the same class of material in the liners that they used to do, and superintendents, when a shaft was condemned, should cause analyses to be made and the results tabulated.

Mr. John Shearman agreed with the previous speaker, saying he had done repairs for Norwegian steamers for many years, and had never found defects in their linerless shafts where there were cast iron bearings and the shaft was properly lubricated. In his opinion the sleeves were the cause of the corrosion. Shafts should be made larger, and they should have white metal for a bearing. With propeller shafts made of the best scrap iron and without sleeves they would have little trouble.

Mr. Henderson cited the case of a new steamer which had to be towed home because of a tube failure. Here the shaft was parallel and the bush was of cast iron, and the lubricating tube was fitted and in good order, yet in the course of a few days the shaft wore down to the extent of about $1\frac{1}{8}$ in. The guarantee man was on board and gave it every attention.

Mr. Nicholson considered that the same action would take place even if the diameter was increased.

Mr. Haddon: Believing corrosion to be the cause of these failures I beg to submit the following as a remedy.

I propose to lap sheet lead closely around the shaft between the liners, solder it along the joint, thus making a leaden sleeve; this sleeve to be soldered to both liners, making a perfectly watertight casing.

Outside the ship, when other means are not adopted, I propose to apply the lead in a similar manner, except that the joint at the propeller should be made by means of a flange worked up on the lead, this to be secured to the propeller by a collar ring studded thereto.

It would then be impossible for any water to touch the shaft, either inside or outside the stern tube.

The reason I suggest lead is on account of its flexible qualities; not liable to decay quickly; may be easily removed for the inspection of the shaft, and afterwards the same material may be replaced; when once applied it would cost nothing to maintain; and, finally, the initial cost would not be great.

Mr. FRED JONES asked Mr. Mason how he regulated the oil in the stern tube when the ship was loaded and when it was light. He firmly believed if propeller shafts were made from good scrap iron, properly forged, accidents would be considerably reduced in number.

Mr. BOYD agreed with the authors of the papers that the diameter of tail shafts was too small compared with crank shafts, which were admittedly correct and gave no trouble. They were dealing with an over-hung bearing and with severe stress due to the over-hung weight; and if the crank shaft was right, they made the tail shaft the same as the crank *plus* a microscopic 20th. In his opinion, so long as they had ships running as they did, with the consequent severe vibration, the tail shaft ought to be 100 per cent. bigger than it is.

Mr. T. HARDY described a sleeve which he said stopped the nicking which was first caused by galvanic action. The stresses of the shaft opened out the nick and produced fracture.

Mr. JOHN FLEMING agreed with Mr. Nicholl that they should have the parallel shaft. Until they had this, and did away altogether with the brass liners, they would get no more satisfaction in the future than they had had in the past.

The CHAIRMAN challenged the statement of Mr. A. S. Jackson as to what took place at the forge. Lloyds were particularly careful in the inspection of these forgings in seeing that too much was not taken off the shaft, and it was not an unknown thing for forgings to be rejected for that very reason. In fact, a very good look-out was kept that the best part of the shaft was not spoiled before it got into the ship.

Mr. NICHOLL said of course Lloyd's forge inspectors did not live in the forge. How could they tell whether it was good scrap-iron or not, or whether there was steel in it, unless it was subjected in their presence to some test? With regard to the subject under discussion, he suggested that a vote of the members should be taken as to the best tail shaft and how to avoid fractures. This would lift the discussion from the mere academic to the practical stage, and might submit the result of their finding to the Board of Trade and Lloyd's.

Mr. MASON cordially concurred with Mr. Nicholl's suggestion.

The discussion was, therefore, further adjourned.

A hearty vote of thanks was extended to the Chairman on the proposition of Mr. AISBITT.

DISCUSSION.

3 PARK PLACE, CARDIFF.

WEDNESDAY, MAY 9th, 1900.

CHAIRMAN:

MR. M. W. AISBITT (VICE-PRESIDENT B.C.C.).

MR. W. SIMPSON said ten years ago he saw a parallel shaft in a small Swedish passenger boat that he was told had been running for thirty years in the same ship, although the shaft was supposed to be surveyed every year.

Mr. HORN described the shaft of the ss. *Menapia*, the character of whose trade necessitated her trailing through a sand bank off Wexford Harbour every week. Previously a new shaft was required every year, but a little over two years ago he drew the cage, replaced it with a cast iron liner running on wrought iron, fitted with oil by gravity, with a small gland on the outside, packed with three turns of cotton packing, to prevent the oil rushing out too fast as she raised her stern out of water. This arrangement had been a success. In introducing it his main object was to keep out sand. The shaft was of Lloyd's size, and had not fractured yet.

Mr. DAVID GIBSON said the Bristol Channel Centre had discussed this question on previous occasions, and they ought now to be able to lay down some definite rule for designing and fitting the troublesome propeller shaft. It was said that the shafts were not large enough, yet that shafts 30 and 40 per cent. larger than the requirements of Lloyd's rules had broken after a short time. He should be rather inclined to say, not that the shaft was not large enough, but that it was not strong enough. They knew the difficulty there was in getting suitable material for the forging, and the careless way in which scrap was gathered together. "Good scrap" was a misnomer. It was impossible nowadays to get suitable material out of scrap with which to make reliable propeller shafts. With regard to certain expressions in Mr. Mason's paper, he should like to point out an unintentional confounding of the words "fracture" and "flaw." Fracture, he took it, was the outcome of stress and fatigue, while a flaw was the result of a defect in the manufacture. The failures of propeller shafts were mostly due to fractures, not flaws. Failure would not be so frequently found at the end of the sleeve if it were due to a flaw. The example given by Mr. Mason of the triple and compound jobs was very interesting, and he agreed that Lloyd's had given too much for the turning moment of the three cranks, and not sufficient thought to the tail shaft, where the power was given out to the propeller. It was urged that the shaft was strong enough for the horse-power. This might be true, but it was not strong enough for the horse-power *plus* the various stresses that the modern steamer threw upon the shaft. The light draught steamer would continue to be built for many years, so that it became the duty of the engineer to deal with matters as he found them, and design a shaft to suit the modern type of ship, with a minimum risk of failure. As to the cause of failure, he considered it was primarily mechanical action, and they required to make the shaft inherently stronger. Another cause—as was pointed out by the late Mr. Nesbit—was malformation. When the continuity of a section was broken it was very injurious in its effects.

Mr. T. W. WAILES said they often found not only propeller shafts but intermediate shafts "piped." The other day he examined a shaft that had a hollow length of some three or four feet. If these shafts had been properly forged they would have been solid to the heart. The question was, were shafts all forged by hammers good enough—was a sufficient pressure put on? Were they not tampered with under the hammer for the purpose of getting a skin upon the shaft?

Mr. EVAN JONES apprehended that the principal object of the papers was to prove that Lloyd's rule as to the size of propeller shafts was not sufficient. Both authors seemed to aim at this, and both based their calculations upon I.H.P. But if the I.H.P. was to be taken as the basis of arriving at the size of the tail end shaft, he would like to know what were the factors the authors would introduce into the formula. For their fast boats they had to take speed into consideration, and if they ran the shaft fast enough they could get almost any I.H.P. out of it. Therefore he submitted that the I.H.P. was not a proper basis for arriving at the size of a tail end shaft. The only basis was that of Lloyd's—initial pressure on the piston and the length of the crank.

Mr. BOYD explained that when he spoke at the last meeting of 100 per cent. increase, he meant in strength, not in diameter.

Mr. T. D. WIDDAS referred to the zig-zag sleeve, and said chemical action was a considerable factor in the failure of propeller shafts.

Mr. CHICKEN (Newport) was also a believer in the chemical action of the sleeve.

Mr. W. EVANS said at Barry the other day a large ship belonging to Liverpool had a six months' old sleeveless shaft, white metal gland, and cast iron stern bush. The new stern bush having worn right through the white metal a new one was put in, and when she came back they had to put in the old shaft with brass sleeves. He did not attribute this to wrong design, but it must have been owing to negligence. As for chemical action, he did not think a sleeve had anything to do with it whatever. In the case of another vessel—a deep-keeled ship—sixteen years old, the shaft was taken out, because it was supposed to be bent, and put in the lathe. It was found to be quite true. The reason that it was supposed to be bent was that the gland was leaking so badly. The thought of a bilge pump had occurred to him. When they had a stop for the valve and it gave way, they put in a wrought iron one, because they had not another of the former with them. How long did it last? It was gone in about two months. The same principle applied to the cast iron stern bush acting on the tail shaft.

Mr. W. THOMAS asked if there were any reliable statistics showing the relative death rate among tail shafts in steel and iron ships. His theory was that the tunnel shafting resolved itself into an immense lever with aft bulkhead as fulcrum. Standing in a prominent position on board a modern type of steamship in a heavy sea-way, they would observe five or six different motions in the deck, and instead of the bottom being more rigid it would follow the deck line of motion right through. This would help the death rate of tail shafts.

Mr. J. HENDERSON handed in the following written remarks: The real trouble to my mind is in the ship where there is lack of ballast and non-rigid hulls. Modern hulls are light, and steel ships are more flexible than iron ships, great strains are thereby put on the shafting. In modern ships we have steel construction, meaning at least 10 per cent. saving in weight; the quick-running triples and high pressure are also 5 to 10 per cent. lighter than the old compound, and the saving in bunker coals is very great. In the construction we have flanging largely in vogue, also numerous patent sections of frames and beams, etc.; there are lapped butts, joggling of shells and frames, all tending to make light ships. The beam and coefficient of fineness has been enormously increased, which also tends to make the draft lighter. The outfit and accommodation is cut down. Masts are practically extinct; we have stumps for derricks stepped on the 'tween decks. Cementing is very meagre now, and in some cases barely covers the rivet heads. Wood sheathing and wood generally is done away with. The weight of engines and boilers does not increase in proportion to the dead weight, and, in fact, everything possible has been done to lighten hulls to gain dead weight. All this tends to make a light hull, consequently excessive light draft in ballast. While all this has been going on, the matter of ballast has in a sense been neglected and stationary. I mention these facts merely to show that ships are very light in comparison to what they were years ago, and the ordinary double bottom and peaks are not sufficient in themselves for proper submersion of hulls and seaworthiness in ballast. Here I maintain we have the key of the whole trouble, and I also maintain that were the modern tramp always loaded we would have very few fractured shafts, and instead of debating the failures of shafting I think the subject ought to be shifted on to ballasting. However careful we are with our shafting, whether we have liners or not on the shaft, whether we have them running in oil or water, whether we make them bigger or not, we will never do away with the racing, rolling, and pitching, and the propeller going around like an electric motor one second and brought violently up the next. It may interest you to know that the periphery speed of a 17-ft. propeller going 100 revolutions is over a mile a minute, and the weight, say, 7 to 8 tons overhung. The tail shaft and stern bearing, I maintain, is the most neglected part of the machinery. We make a tube and bearing and put a shaft in, and there it runs for months, sometimes for years; it is not examined and overhauled like the rest of the machinery, and it works under such adverse conditions which if they could be seen, would, I am sure, make one's hair stand on end. It is allowed to get out of line, corrode, and take its chance. Again, the after end of the ship ought to be much stiffer than at present, and some builders turn out very poorly constructed after ends indeed. However, we must take things as we find them, and coming back to the subject, I for one do not believe in linerless shafts. Theoretically they are the correct thing, and a parallel shaft, if running under perfect conditions, would be the ideal shaft, but our tail shafts run under extraordinary conditions, which, in my opinion, puts the linerless shaft out of the question. I admit linerless shafts are a success in some ships, but they are generally run on short trips, and the propeller well submerged, but for a tramp that offers to take or go for anything, anywhere, and in any weather, I for one would not have a linerless shaft, as I feel sure it is courting disaster, and the liability of cutting is very great.

The safest and best way of fitting a tube and tail shaft, in my opinion—and to a great extent I agree with Mr. Mason—is to have the tube as short as possible, and in an ordinary tramp steamer this could be got in about 6 ft. long. I would have the liner in one length, and this would be about equal to the combined length of the two ordinary liners, so this would be no worse than existing conditions. I should recess it well in the propeller, and carry it well inside the gland. I should have as long a lignum bearing as possible, with end wood, and run it in oil as described by Mr. Mason, or in water, which by this method could not get at the shaft and cause corrosion, and I would fit an efficient governor in the engine room. There is a good governor in the market, practically perfect and simple, that does automatically prevent heavy racing. I should also have the tail shaft larger than Lloyd's requirements, and made out of bar iron, sheared up and not of doubtful scrap, and, lastly, the most important is the keeping of the shaft in line. This matter is sadly neglected, and requires more attention.

It may interest you to know that I am aware of a gentleman who has two tramp steamers with parallel shafts running in oil, and having no confidence in them, has new tubes, shafting and propellers ready to fit when he gets an opportunity. In conclusion, until we get more ballast in our ships we are sure to have trouble with shafts, and if our ships had more ballast they would make better passages, have less wear and tear, and the increased cost of tanks would soon be written off.

Replying on the criticisms, Mr. E. NICHOLL said: I would say it has been proved that to ballast ships with water ballast, sufficient to keep the propeller immersed in ordinary Atlantic weather, would mean a very much increased first cost ; my contention therefore is that if this is not done we must have shafts of larger diameter, and shafts even 100 per cent. would only mean about 3 in. increase on a shaft about 12 to 13 in. I feel sure if something is not done, and that very soon, a compulsory light load line will be brought into force. I feel pleased at having been the first to publicly bring this question of increased size before this Institute, more especially when we consider the question of material of forgings, plenty of evidence having been given that it has not been all that we would desire. The question is such a serious and very large one that even Lloyd's fear to grapple with it, for if they admit now that the shafts are not large enough what excuse are they going to make for all the present ships' defects? One thing in their favour is, the rules were laid down years before the present leviathan tramp was considered, and undoutedly calculated on the basis of propellers constantly immersed, but they require to advance with the times. You are the best judges of the shafts of to-day in our 6,000 and 7,000 ton ships whether or not they are large enough *when in ballast trim.* Now, what Mr. Walliker says about the forge inspectors taking a "fatherly" interest in the manufacture of shafts is all very well, and quite true, but how can they or any man here tell what kind of scrap is worked into slabs? They are only present at most an hour or two a day, perhaps twice a week. And this question is far too serious a one to attempt to hide, or refrain from mentioning any matter likely to bring about a better state of things generally. I know full well every little piece cannot well be picked over. I know also that if they were, no amount of experience could tell rusty iron from rusty steel without fracturing them, but I think Mr. Walliker will vote that the large tramps of to-day, with propellers only partly immersed, when in ballast are not strong enough in the shaft for the ever varying strains they are subject to. Mr. W. Simpson in the main agreed with most of what I have written; in what he did not agree I have forgotten. Mr. A. Scott Younger, as far as he was reported, agrees with me in every particular. He states that he is unable to follow some of my deductions, but as he does not state particulars it is impossible to reply. I am informed that Mr. Younger has written a very clever paper which was read before the Naval Architects, but I am sorry to say I have not seen this paper, but taken generally he follows my lead entirely. Hearing he intended to read a paper made me anxious to read mine here before he read his. This I am pleased to say we managed. Mr. J. Chellew, if I remember rightly, said his experience had been that the ships were not built stiff enough, and the shafts generally were the necessary stiffening to an otherwise probable collapsible structure. "Of course he was joking," but if I understood him rightly, he intended to convey that the working of the ship as against the rigid shaft had much to do with the shafts breaking. There is undoubtedly very great reasoning in this, as I am unaware that the hull, whether iron or steel, is taken into consideration by Lloyd's when calculating for strength of shaft; and we all know that a steel ship works and vibrates very much more than an iron one.

Mr. Aisbitt withdrew all he had previously stated about chemical action being the only cause, and I think he has admitted now that he entirely agrees with my statement that the shafts breaking is caused at the liner ends entirely by, first, mechanical action which microscopically fractures the surface of the shaft, opening a way for chemical action, which undoubtedly with the aid of salt water then follows. Mr. Aisbitt said to a certain extent the shafts were large enough, because the *Menapia's* shaft was so clean and well preserved after two years in oil. I must say at once there is no comparison between the conditions under which the *Menapia* runs and our large tramp steamers in ballast across the Atlantic for 20 to 30 days continuously hammering and racing; the ship Mr. Aisbitt mentions always has more or less cargo on board and, for her size, a better ballasted ship altogether. Therefore to decide Lloyd's rules for shafting on the appearance of this ship's shaft, is hardly fair to the larger ones, labouring under very much more severe conditions. I am hoping therefore we shall have his opinion in favour of larger shafts. The better to illustrate the question and perhaps explain it more pointedly, especially as I have been asked by several who have read my paper, who evidently did not quite understand how an alternating load could be three times the fixed, we will consider the stress produced by a vibrating load. Such I will try to show by diagrams Nos. 1 and 2. I know this is a slight digression, but I want to emphasise my point. In the first place, suppose we have a weight of 1 lb. on a spring, and that 1 lb. stretches the spring 1 in.: now suppose we place a prop under the weight to lift it up 1 in., that is just to take the weight off the spring, and nothing more. Now sharply remove the prop and the weight will fall, but in falling through the first 1 in. the weight has acquired energy equal to 1 in. pound, whereas the spring has only resisted it to the extent of $\frac{1}{2}$ in. pound, since it started at no tension and ended with a tension of 1 lb., therefore the weight has left in it energy equal to $\frac{1}{2}$ in. pound. Again, in falling through the second inch the weight acquires another inch pound, which gives a total energy of $1\frac{1}{2}$ in. pounds, and the spring in being extended from 1 in. to 2 in. takes up $1\frac{1}{2}$ in. pounds, therefore the weight comes to rest when the spring registers 2 lb.

Hence we see that a load suddenly applied produces a stress equal to *double* what the weight would if applied gently. Again, suppose instead of allowing the weight to fall from zero, or no tension on the spring, we place a prop under the weight until the spring is compressed upwards 1 in., which would be equal to 1 lb.

Fig. 1.*

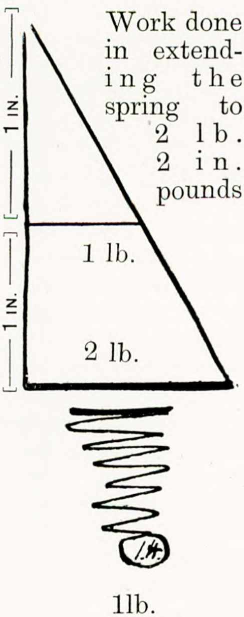
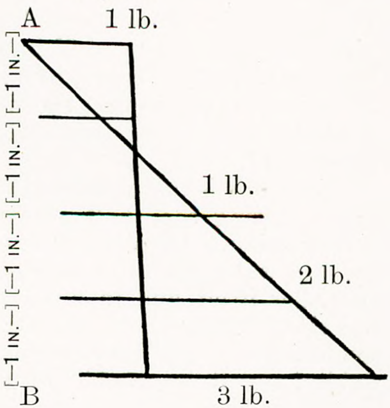


Fig. 2.*



The diagrams represent this work done by the weight falling from A to B and also by the spring. The weight in falling through the first inch from A acquires energy equal to 1 in. pound, and has also been assisted by the spring to the extent of $\frac{1}{2}$ in. pound, then at the end of the first inch the weight has a total energy of $1\frac{1}{2}$ in. pounds. In falling

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* See page 11, noted as Figs. 5 and 6.

through the second inch the weight acquires another inch pound, total $2\frac{1}{2}$ in. pounds, but is now resisted by the spring equal to $\frac{1}{2}$ in. pound. Therefore the energy remaining in the weight will be equal to 2 in. pounds. In falling through the third inch the weight gains another inch pound, which gives it a total of 3 in. pounds, but the work done in stretching the spring from 1 to 2 lb. has taken up $1\frac{1}{2}$ in. pounds, leaving work equal to $1\frac{1}{2}$ in. pounds in the weight at the end of the third inch. The weight again acquires 1 in. pound in falling through the fourth inch, which gives it a total energy of $2\frac{1}{2}$ in. pounds, but the spring in being stretched from 2 to 3 lb. takes up work equal to $2\frac{1}{2}$ in. pounds, so that the weight will come to rest when the spring registers 3 lb., which is three times the weight.

Now this is just what takes place with a vibrating load, putting the shaft alternately in tension and compression. In place of the weight we have the mass of water put in motion by the propeller and the propeller itself, and in place of the spring we have the elastic material in the shaft. Perhaps I should apologise for this very elementary treatment of the subject, as it is capable of a much more elegant demonstration, and many here could give it, but I feel sure there are many here, like myself, who have a strong aversion to anything going too deep into figures. I want to prove that to overcome these ever-varying strains, larger shafts even than 20 per cent. or 30 per cent. in excess of Lloyd's do not at times meet what the shafts have to contend with.

Mr. Widdas says in a case that came under his notice that the liners could not have been properly joined, and consequently the liner at the joint afforded no stiffening to the shaft at that point; this, I think, bears out my contention that the action is in the first place mechanical. Mr. Widdas also says I am inconsistent in the fact that I stated that mild steel crystallised more rapidly than iron, and then recommended nickel steel, but I simply stated a fact well known to most engineers, although the reason is not known. I favour nickel steel because of its high elastic limit.

Mr. Haddon believes in the chemical action, yet he actually recommends a lead liner, or sleeve. Well, I am afraid Mr. Haddon will be disappointed if he counts on any success from that idea. If he wants to know what the action of lead on iron is like, look at any railings where the iron is secured into the stone with lead, and he will find in a very short time the iron is very badly corroded. I would say more of this idea, but there is scarcely time.

Mr. Nicholson also thinks the same action will take place if we increase the diameter of the shaft, from the same reasoning, as far as I can judge, that if a man gets ill there is no use applying any remedy, he will be sure to die sooner or later.

Mr. Henderson speaks of a ship recently towed home from abroad with a linerless shaft, a failure. "How was it a failure?" is as easily answered as in the cases of many shafts running with liners. Something went wrong with the works, certainly, but I feel sure that if the shaft he mentions had been well lubricated and the gland had been in order, no bush would have worn down an inch or more, as he states this one did; and with that before us and one or two other isolated cases, we are not going to stop trying before we have tried everything and investigated the cause of failure, when failure occurs. If the Norwegians can run successfully with lubricated shafts, we certainly can, and the evidence from them alone is enough for me that it can be done. Some say don't have cast iron. Well, we have heard what Mr. Horn says, that after two years his cast iron bush was not down $\frac{1}{32}$ in.—I think he said $\frac{1}{64}$ in. Undoubtedly white metal has also failed to give always good results. Why? Because an iron shaft when exposed to the corrosive action of sea water becomes reedy, unlike a steel shaft, which pits; the consequence is, lubrication being temporarily stopped, the rough shaft in a short time tore lumps out of the soft white metal. I certainly foresee a little trouble in winter time, when the oil feels the effect of cold weather, but with care we can get over this. I should say the ideal bush would be a *Phosphor Bronze* bush and this I intend to try in a second ship now building, the first having white metal; and when a start is made, I am full of confidence that the old order of things, viz., two short or one long liner will not again be tried.

In conclusion I should like to say that it is my opinion that the members of this Institute, especially our local Vice-Presidents, have had as much experience with propeller shafts as any men in the land, and they are well able to judge. And when we consider that the Institute of Naval Architects is so often quoted as being an authority on all matters of naval construction, it is time we shouted louder to let those interested know that there is a kindred institute of equal importance, and one that took a ballot of its members' opinions, with the result that an improved and approved design was found necessary, and that it is our intention, in the interests of life and property, to lay the particulars before the proper authorities to bring this about. I certainly should like to hear opinions from Mr. Sibun, Mr. Rutherford, Mr. Wailes, Mr. Scott, Mr. John Scott and Mr. Jones. Captain Smith also could have given us some valuable information on the improved conditions and longer life of his ship's shafts, and I hoped to have seen him here, also Mr. T. A. Reed, and other members well able to express a candid opinion.

I thank you for your attention and the way you have received the paper, and I sincerely hope to see every member here in about two years' time to tell them my experience with a linerless shaft run in oil on white metal.

With further reference to the adjourned discussion, Mr. Gibson bears out pretty well all I have advocated. Mr. Wailes spoke of an exaggeration with reference to shaft turning. To avoid any misunderstanding, I think he refers to a remark in Mr.

Jackson's criticism, that the number of tools cutting in some lathes have much to do with the fractures found later. In reply to Mr. Jones, I am unaware of any reliable formula.

Continuing, Mr. Nicholl said, in reply to the question asked by Mr. Evan Jones, that he was unaware of any formula as to the increased size of shafts, but they knew that the crank and intermediate shafts had not to contend with the leverage of the propeller, which had great influence in bringing about the damage that occurred. He had only sought in his paper to show that propeller shafts were not strong enough. The matter of the formula was one to be gone into and by some more capable authority. His present formula for all the trouble mentioned would be, "*submerge the propeller*" and the best part of the difficulty would be overcome; failing that, he was too modest to suggest to the various "Corporations" any fixed diameter, as the conditions were so continually altering. But the first thing that should be strongly advocated to avoid much of the trouble would be more ballast and consequently less racing, otherwise the trouble would still go on. Even with a parallel shaft run in oil there would always be some trouble; therefore we can make no hard and fast line for a formula.

Mr. G. F. MASON also replied to the discussion as follows: I must confess to feeling rather at a loss in replying to the discussion on my paper, as I think, with one or two exceptions, all who have spoken have admitted that the fractures or defects found between the liners are primarily caused by mechanical action, so that the galvanic, chemical, or corrosive action, call it what you may, is not the great factor for mischief it was supposed to be. This being so, it follows that both Mr. Nicholl and myself are correct in pointing out the principal cause of so many shafts giving out to be weakness. Both Messrs. Aisbitt and Jackson, however, consider that Lloyd's rules have been sufficient. Lloyds themselves, though, have not thought so, having twice increased the size of shafting in the period referred to. I do not think either of these gentlemen have grasped my meaning in the examples I have quoted. What I particularly wanted to call attention to is the extraordinary fact that if you have a compound engine developing 1,600 horse-power, by adding another crank and engine to the existing shafting you could raise your horse-power to 2,400, 50 per cent. more at the same piston speed, or your shaft would still be considered up to Lloyd's rules and sufficiently strong. Now it stands to reason that either the shaft is too strong in the first case, or too weak in the latter. I say the latter view is correct and the shaft too weak, and I think Mr. Milton agrees with me when he corroborated my remark that "we did not use to have this trouble in the days of the compound," when he was criticising Mr. Younger's paper before the Naval Architects. I have two instances in my mind where the old boilers were taken out, new high-pressure cylinders and boilers fitted, another crank shaft being added at the fore end of the bed plate and the old shafting worked in. A very considerable increase of speed was got in both jobs, and over 40 per cent. more horse-power. Both tail shafts, however, gave out under eighteen months; they had never given trouble previously. I will not say anything about Mr. Jackson's assertion that shafts are reduced so much in the turning as to destroy their strength, or that makers care little what material is used, except that it is at variance with my experience. I am glad to see Mr. Aisbitt has dropped his chemical theory and become a convert to Mr. Walliker's or Mr. Nesbit's, viz.: that the flaws between the liners are caused through the shaft being weaker between the liners, owing to the extra strength they add to it where fitted. Like most converts Mr. Aisbitt becomes very enthusiastic and tells us how easily Mr. Nesbit converted him with his experiment of a sheet of tin, shaped like a liner-fitted shaft, and which when strained between the fingers showed the twist to commence and finish between the parts representing the liners—(a very elaborate series of experiments were made on bar-iron by Dr. Kirkaldy about forty years ago on a similar line)—and I think Mr. Nesbit's sheet of tin quite proves my assertion, and that I am right in saying the shafts are too weak, for it only shows the tin was not strong enough to pass the strain put on the ends through it without twisting. If Mr. Nesbit had had a sample of iron $\frac{3}{4}$ in. thick, I do not think Sandow himself would have been able to twist it. The experiment only shows *where* to expect the strain. It is needless for me to discuss Mr. Aisbitt's assertion that it is impossible to make the shafts strong enough to overcome the difficulty if they are fitted with liners, as Mr. Boyd (with whose remarks I entirely agree) has effectually disposed of it. However, to use his own proverb, "The proof of the pudding is in the eating," so, if Mr. Aisbitt wishes, I will show him shafts fitted with brass liners running in lignum vitæ, stern bush, and water, that have been in the ships over eight years and which do not show any signs of flaw of galvanic action between the liners. Moreover, I will undertake to fit a similar shaft into any ship Mr. Aisbitt chooses, to run the same time without showing any defects between the liners, provided the owner will agree to my recommendations as to size and inspection, etc. I am sorry Mr. Widdas did not finish his remarks, as I have seen similar instances of shafts being cut in fully one-third of the diameter like the one mentioned by him, where the liners were joined and with signs of water getting at the shaft.

Replying to Mr. Evans' remarks, I can remember three instances of linerless shafts giving way in the stern tube. Two were found in a state an exact copy of a defective shaft fitted with brass liners, and the third had broken in two halves, having a fracture all round the shaft decidedly watermarked. I do not agree with Mr. Scott Younger as to being able to run a shaft $\frac{1}{8}$ in. out of truth with comfort, and should prefer him to be looking after it instead of me. I am, however, trying to put my experiments in a tabular form as an addenda to the paper, though I am afraid I have not sufficient records to make them very valuable.

Mr. Horne has succeeded, as he tells us, in overcoming the difficulty of his stern bush wearing down and so destroying his shaft, by doing away with a stern bush open to the sand and water, and finds a linerless shaft to run well in a cast iron bush fitted with a gland at the outer end, and the shaft running in oil, but it does not follow that this arrangement would prevent the breakdown of tail shafts in the modern tramps, as his vessel has practically the propeller always immersed, and so running under most favourable conditions. Mr. Horne's trouble, as he informs us, was caused through the vessel having to plough through sand every voyage, and has little real connection with my subject.

Mr. Gibson in his remarks calls me to task for using the word "flaws," but he will understand that I used the word in a general sense, meaning by "flaws" and "fractures" defects that were caused through either over-stress or deleterious action on the shafts other than fair wear and tear. I quite agree with his description of the mechanical and corrosive action, and thank him for putting the matter more lucidly before you than I did. I would like to make one remark in connection with his criticism, and that is that I have pointed out in my paper one of the principal causes of shaft failures to be through the stern bush being worn and so putting the shaft out of line, and I think that must have been one of the reasons why Lloyd's reduced the time for drawing the shafts from four to two years. I make it a practice of doing this every eighteen months.

Mr. Evan Jones has fairly summed up my meaning in saying that Lloyd's rules are not strong enough; of course many of the failures were in shafts designed under Lloyd's old rules, and not under the present increased formula. Mr. Jones asks me what increase in strength I would suggest, and why I put it at 25 and 30 per cent. over Lloyd's, and points out that the indicated horse-power is no criterion. I agree with him to a certain extent in so far as the increased power is got by increased piston speed, but if the increased horse-power is got at by the same revolutions and stroke then you can use the indicated horse-power as a guide. However, I base my increase on the greatest turning moment on the shaft, which I find in ordinary triples amounts to from 30 per cent. to 40 per cent. over compounds in shafts of the same diameter and length of engine stroke, but I should not consider 30 per cent. sufficient but for the fact of my engines seldom being worked above three-fourths of their full power. In answer to Mr. Fred Jones, if he will think a moment he will see no adjustment of the oil in the tube is required, as it finds its own level, which is slightly above the water level outside the ship. I have only one remark to make in reply to Mr. Walliker, and that is that I do not agree with him in his estimate of the quality of the iron we get now. I certainly consider it is infinitely less pure than it used to be before the days of steel ships.

In conclusion I may say we have all been looking for some reason and cure for defective shafts for many years. I have tried and found one, viz., making my shafts strong enough for the work they have got to do; this has stood the test of over twelve years, and never given or led me to expect trouble. I thank you for the manner you have received and discussed my paper.

Continuing, Mr. Mason agreed that the wearing down of the stern bush was no doubt a frequent cause of shafts coming out. Shafts ought to be drawn every two years instead of every four. In answer to Mr. Fred Jones as to the oil in the tube, no adjustment was necessary, as the oil simply found its own level, being a little higher than the water level outside the ship. He could not agree with Mr. Walliker as to the quality of the iron they got nowadays. He submitted it was infinitely less pure than it used to be. As to Mr. Evan Jones and

I.H.P., in his (Mr. Mason's) diagram of the triple engine the initial pressure was 119 tons against 86 tons in the case of the compound, but Lloyd's rules made the shaft for the latter half an inch larger than for the triple. He had taken Lloyd's rule and had added 30 per cent. to the strength.

Mr. EVAN JONES asked what reason Mr. Mason had for adding 30 per cent. Mr. Nicholl had endeavoured to show by a diagram that an alternating stress should be taken at three times as much as a direct stress, and said this was taken into consideration with piston and connecting rods. He (the speaker) was not aware this was so, but that it was taken as doubled. Why should it be taken in this particular case at three times?

Mr. NICHOLL: Because of different treatment.

Mr. MASON: I am working on initial pressure.

Mr. EVAN JONES: Yours is an isolated case?

Mr. MASON: Yes. With regard to the question of Mr. Thomas, he thought the greater death rate of propeller shafts had arisen since the steelship came in with he triple engine. He could not say, however, how much the ship itself was responsible for it.

Replying to Mr. Evan Jones, Mr. MASON said in the last three boats with which he had to do the percentage above Lloyd's rules for shafts was 25.

Mr. EVAN JONES: And as Mr. Mason has never had a fracture that is evidently sufficiently high.

Mr. MASON: The point I want to raise is this. For trial speed, in one instance, where we had 2,350 horse-power, we did not indicate more than 1,800 horse-power, which adds a percentage on the shaft of over 30 per cent. besides the 20 per cent.

Mr. EVAN JONES: Then I take it that you advocate that shafts to run with very great safety should be 50 per cent. above Lloyd's Rules?

Mr. MASON: I would make it 50 per cent. if I had my way.

On the motion of the Chairman, seconded by Mr. T. W. WAILES, a hearty vote of thanks was extended to Messrs. Nicholl and Mason for their papers.

The meeting terminated with a vote of thanks to the Chairman, proposed by Mr. DAVID GIBSON, seconded by Mr. G. RUTHERFORD.