SOME NOTES ON THE DISTRIBUTION OF POWER IN A DOUBLE-ENDED SCREW STEAMER.

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In the course of his professional work, the writer has had occasion to feel the lack of data with regard to the performances of double-ended screw ferry boats, such as are much used in Sydney Harbour.

The necessity of more detailed knowledge of how the power is absorbed in such vessels, is found when it is required to rationally design propellors for particular cases. The information available is meagre and unsatisfactory, giving as it does, the power absorbed by the vessel as a whole, and not analysed in such a way as to show what proportion of the power is taken by each screw, and used efficiently for propulsion.

With the idea of trying to throw some light on this question of the division of power, it was set as a thesis subject for fourth year students in Engineering at the University of Sydney.

Messrs. Flashman and Clayton took up the subject in 1906, and devised an electrical apparatus for measuring the twist in the propeller-shafts of the ferry boat "Kurraba."

Although the results obtained were interesting, as showing that the torsional vibrations were more severe than usually thought probable, they were useless for determining the main question.*

Mr. Flashman then initiated the design of a mechanical torsion-meter of the Föttinger type, which design was simplified and carried to completion by Mr. H. G. Carter in 1907.

With this instrument (of which a description is given hereafter) the power absorbed by each screw was measured directly, and it is the analysis of the results obtained, that is attempted by the writer in this paper.

DESCRIPTION OF THE TORSION-METER.

A sketch of the apparatus is shown in Figure A.

Discs A and C are fixed rigidly to the shaft by means of set screws. Disc B is rigidly connected to disc A by means

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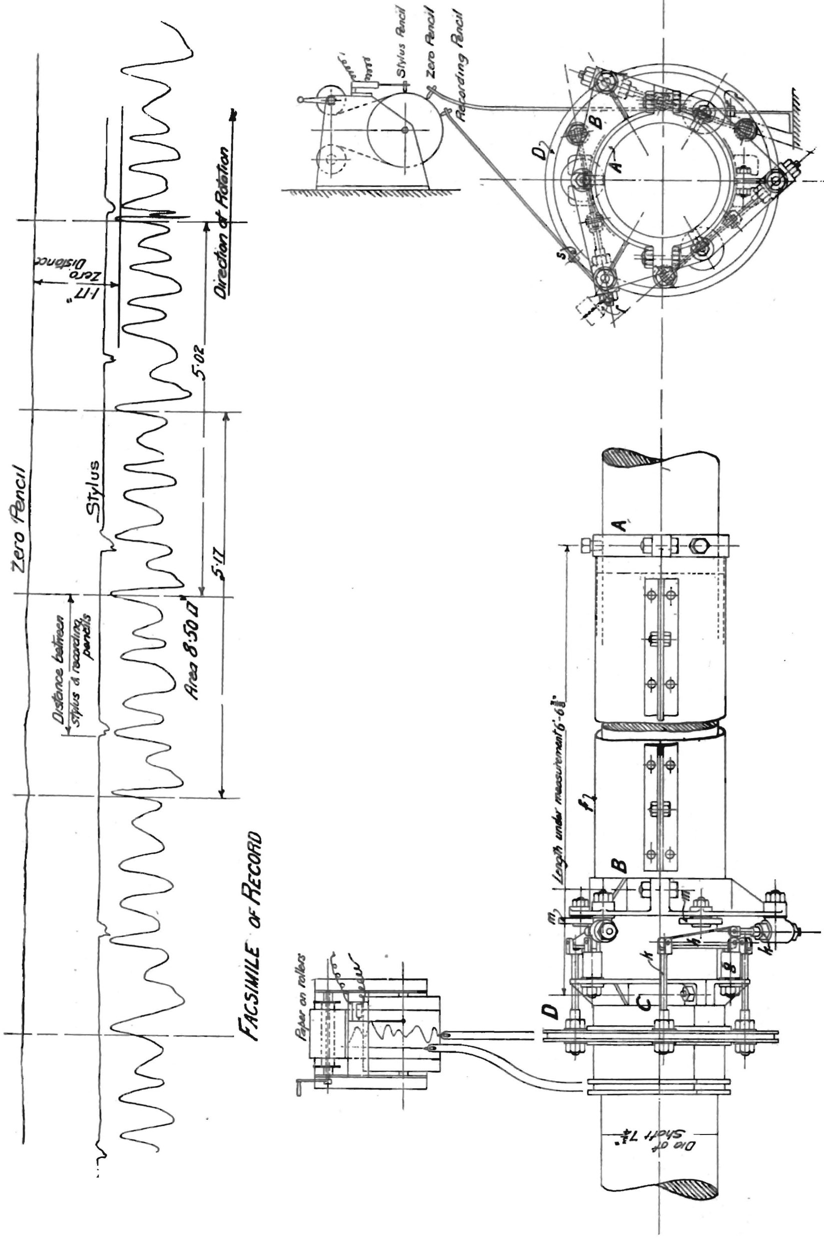

Fig. A

— Torsion Meter —

Figs. A & B.

of the sleeve F. This sleeve is of rigid yet light construction, so that there may be no sensible twist throughout its length.

The object is to measure the relative displacement or twist, between the centres of the set screws on discs A and C—as disc B is rigidly connected to A, it suffices to measure the twist between discs C and B.

On disc C, are fixed three studs (g), each carrying a bell-crank lever (h). At each end of the arms of these levers is attached a rod (k), fixed to disc B and disc D respectively. Thus, if there is any movement in a transverse direction (that is to say, a twist) between discs A and C, there will be a corresponding relative movement transmitted through the levers in an axial direction (that is, parallel to the shaft) between discs C and D, the disc D sliding axially on disc C.

To keep the weight of the sleeve and disc B off the levers and studs, disc B is supported on three rollers (m), which can be adjusted to run on the surface of the shaft.

The amount of twist can thus be measured by the displacement of the disc D in an axial direction, from a zero position.

To record the movement, two pencil levers are used, having their fulcrums (r) fixed to the hull of the vessel (or its equivalent) and operated by means of cod-pieces (s) pivoted to them but sliding in grooves cut respectively in discs C and D. The leverages of these pencils are such as to give the same movement to the pencil ends, for equal movements relative to discs C and D. The pencil for disc C, registers the zero (approximately a straight line) and that for disc D records the amount of movement out of the zero position. By this arrangement of pencils, the hull vibrations are cut out, and the distance recorded between the two pencils, will be that due to the twist of the shaft.

The records are taken on a continuous roll of paper, the movement of which is obtained by hand, enabling the records to be spread out as required. It was not found difficult to maintain a sufficiently uniform rate of movement by the means shown.

To co-relate the torque records with the engine and with each other (there being in this case, two sets of apparatus, one forward and one aft, to deal with the two propellers simultaneously) a third pencil is used, controlled by an elctro-magnet. The circuit in this magnet is closed once in every revolution by means of a one piece commutator attached to the shaft, thus causing a kick to be made by the pencil once every revolution. This commutator controls the pencils on both instruments, the electro-magnets being placed in series so that the kicks forward and aft are given at the same time. It was also so arranged on the shaft, that the circuit was closed when the H.P. piston of the engine was on the top centre, and so the torque diagrams from each end could be directly connected with each other, and also with the indicator cards taken off the engine cylinders.

MULTIPLICATION OBTAINED WITH THE APPARATUS.

1. The first multiplication of the actual movement of the surface of the shaft, is obtained by placing the points in disc B, to which the levers are attached, at a distance from the centre of the shaft of 7¾ inches. The radius of the shaft being 3·875 inches, the ratio is 7·75 to 3·875, and therefore the multiplication is 2.

2. The ratio of the levers is 5·875 inches to 0·75 inches, giving a multiplication of 7·84.

The direct multiplication is therefore $7\cdot84 \times 2 = 15\cdot68$, but this does not represent the actual total multiplication for it may be noticed that the levers do not lie tangentially to the surface of the shaft, at their points of attachment to disc B, and are therefore not directly in the line of the twist, but are set at an angle to that direction. This angle, as taken from the apparatus, has a mean value of $48\cdot5^\circ$

3. The actual total multiplication is therefore,

$$15\cdot68 \text{ Cos } 48\cdot5 = 15\cdot68 \times 0\cdot663 = 10\cdot4.$$

Note.—It was necessary to incline these levers to make the apparatus compact, and the size of the discs was such that they could be machined at the University.

4. A further multiplication is obtained through the pencil levers. This was slightly different at each end of the vessel, being—

3·738 to 1 for the after end,
3·654 to 1 for the forward end.

The final multiplication at the record was therefore,

After end—$10\cdot4 \times 3\cdot738 = 38\cdot8$.
Forward end—$10\cdot4 \times 3\cdot654 = 38\cdot0$.

CALCULATION OF HORSE POWER TRANSMITTED.

The formula is:—

$$\text{Horse Power} = \frac{2 \quad G\ I\ N\ X}{12 \times 33{,}000\ L\ R}$$

in which:—

I—Polar Moment of Inertia in inch units.
L—Length of shaft under measurement, in inches.
R—Radius of shaft in inches.
N—Number of revolutions per minute.
X—Distance through which the shaft is twisted.

G—Shear modulus of elasticity in pounds.

For the case under consideration, the diameter of the shaft is 7·75 inches, and the length between set screws on discs A and C is 78·375 inches.

G is taken at 11,250,000. (This value is assumed, as it was not possible to test the shaft).

Therefore, inserting the known values in the above, we have Horse Power—

$$\frac{2 \times 3.14 \times 7.75 \times 7.75 \times 7.75 \times 7.75 \times 11{,}250{,}000 \times N \times X}{12 \times 33{,}000 \times 78.375 \times 3.875 \times 32} = 208\ N\ X.$$

Now if X^1 = the mean torque as obtained from the record $X^1 = kX$, where k is equal to the amount of multiplication in the apparatus.

Therefore the Horse Power transmitted:—

$$\text{After end} \quad \frac{208\ N\ X^1}{38 \cdot 8} = 5 \cdot 36\ N\ X^1$$

$$\text{Forward end} \quad \frac{208\ N\ X^1}{38 \cdot 0} = 5 \cdot 48\ N\ X^1$$

These numbers were used in finding the B.H.P. from the records. X^1 being obtained in the manner now to be described, and N, the revolutions corresponding to the faired trial results, obtained from the curves shown later.

INTERPRETATION OF RECORDS.

It will be seen from Figure A (reproduction of facsimile of Record) that on each record there are three lines. One is due to the recording pencil, another to the zero pencil, and the third (which draws an approximately straight line, except here and there) is due to the stylus pencil. These pencils were never in the same plane, at right angles to the direction of the paper, so as to avoid interference. Each pencil is therefore in front of, or behind one or both of the other pencils, that is, while one pencil is drawing a line at one spot on the paper, the other pencils are drawing corresponding lines at points so many inches before or behind it. This distance between the pencils is the first thing to be measured, and this is very easily done by noticing, when the record is stopped, the position of each pencil, marking the place on the record accordingly, and measuring the distance between the marks. To fix the zero, the distance between the zero line and the recording line is measured in several places, from the record taken while the boat is at the wharf. The mean of these measurements is taken as the true zero distance between the two pencils. Notice must be taken as to whether the recording line is to the right or left of the zero line.

The torque at any point on a record taken during a run, will be the distance between the zero and recording pencil at that point, minus or plus the zero distance, according as to whether the recording pencil is on the same or opposite side of the zero pencil, as it was when the zero distance was measured.

In order to measure the mean torque, a point is taken on the recording line, and a corresponding point is taken two or three revolutions ahead. The distance between these points divided into the area between the zero and recording lines, for these points, will be a measure of the mean height between the zero and recording lines, and this is either added to, or taken from the zero distance to obtain the mean torque.

The distance between the stylus pencil and the recording pencil, must be taken as before stated. By setting off this distance, either before or behind the recording pencil as required, the position of the H.P. piston at its top centre can be obtained, and so any other point of the cycle can be referred to the recording line as desired.

Referring to Figure B an example will make this clear.

Record No. 5B, from after end.

Direction of run, ahead, propeller pushing.

In the ahead direction, the recording pencil would have to move to the right to give a positive twist to the shaft. Distances between zero and recording lines when the vessel is at the wharf, are 1·19 inches, 1·18 inches, 1·15 inches, and therefore the mean distance is 1·17 inches, and the recording line is to the right of the zero line. Two corresponding points are taken, two revolutions apart. The distance between these points is 5·17 inches. The area between the zero and recording line under these points is 8·5 square inches.

Therefore, the mean distance between lines is $\frac{8 \cdot 5}{5 \cdot 17}$ equal to 1·642 inches to the right.

The zero distance is 1·17 inches to the right.

The mean torque is 1·642 — 1·17 equals 0·472 to the right, and is therefore positive.

This is done two or three times for each run, and the mean taken (as is also done for the M.E.P. obtained from the indicator cards). The revolutions are taken from the faired curves of speed and revolutions, and the B.H.P. so obtained for each end of the vessel is plotted against the observed speed.

It is not claimed that the instrument is perfectly accurate, but after a critical examination of the possible sources of error, the writer is of opinion that the limits of error are within 5 per cent., which is sufficiently close to enable practical deductions to be made. Also, as will be seen later, some difficulty is experienced in fairing up the curves of B.H.P. and speed, but by careful judgment mean lines can be obtained which may be justifiably considered to lie within the limits of error stated.

METHOD OF CONDUCTING THE TRIALS.

The trials were carried out on the s.s. "Bingarra," of the Port Jackson Steam Navigation Coy.'s fleet of ferry steamers. The particulars of this vessel which were available are as follow:—

Length, L.W.L. .... 190ft.
Breadth, L.W.L. .... 30ft. 6in.
Draft, loaded with full complement of passengers .... 11ft. 4in.
Displacement, loaded .... 630 tons.
Displacement, light .... 560 tons.

The engines are of the triple expansion type, the diameter of the cylinders being 17¾in., 27½in., and 45in., and the stroke is 27 inches. They are supposed to develop 1,200 I.H.P. at 150 revolutions per minute, with steam at a pressure of 160 pounds per square inch.

The propellers are of gunmetal:—

Diameter .... 7ft. 9in.
Pitch .... 12ft. 3in.
Surface of each blade .... 5·7 sq. ft.
Number of blades 4

In working out the various results, the mean displacement of the vessel was taken at 600 tons on a mean draft of 10ft. 10in., and the wetted surface at 5,300 sq. feet.

Two sets of trials were made, the first from November 14 to November 19, 1907, and the second from February 5 to February 10, 1908. The apparatus was not found to be working satisfactorily during the first series of trials, and the data obtained were therefore very incomplete. Sufficient data were however got from them to enable quantities in the second series of trials to be satisfactorily computed, as in the first series the condition of the ship's hull was known, the vessel having just come out of dock after undergoing the periodical overhaul, being therefore quite clean. In the second series, the apparatus gave very satisfactory results, and from these and the data of the first series, the writer has attempted an analysis, which, although imperfect, throws some light on the question of economically driving these double-ended vessels.

The course taken was the measured mile from Pinchgut to Bradley's Head, and allowance was made for the difference in length of run according to direction of travel. The distance from Pinchgut to Bradley's is taken as a true knot, but that from Bradley's to Pinchgut is taken as 60 feet short of a knot, in accordance with the chart in the offices of the Sydney Harbour Trust.

Shortly before coming on to the measured course, the engines were set to run as nearly as possible at the required number of revolutions, and in this way a progressive set of results from about 5 knots to 12 knots per hour was obtained. Indicator cards were taken simultaneously off the three cylinders, and at the same time the records from the shaft were obtained. An electric bell was placed in each hold where the torsion-meters were, and these were connected in parallel off the same switch. This switch was in the engine room, and when a set of cards was being taken, notice was given to the men at the torsion-meters, who then took off a record. The total number of revolutions for the whole mile was taken by means of a counter fixed on top of the engines and worked off one of the indicator levers. The times of passing the landmarks were taken with a stop watch, and a note was made of the state and direction of the wind and tide.

Four trials were run each night, and six men were required as observers, who were apportioned as follows:—

1. Timekeeper.
2. Man working H.P. and M.P. indicators.
3. Man working L.P. indicator, and reading the number of revolutions.
4. Man below for reading gauges and working bells.

5 and 6. Man for each torsion-meter.

The arrangements were found to work very satisfactorily, and only a few of the records were spoilt.

METHOD ADOPTED IN WORKING UP THE RESULTS.

Of the data obtained, the most reliable results are those of speed of vessel and the revolutions per minute. These are taken as the basis on which the other results are plotted.

The M.E.P. obtained from each card is referred to the L.P. cylinder, and the mean of these adopted for any particular run. These M.E.P. are then plotted on revolutions, as shown on Figs. 1 and 2, and a fair curve run through the spots. To obtain a check for the M.E.P. required to overcome initial friction, the logs of the M.E.P. are also plotted, a fair curve being run through the spots and continued down till it

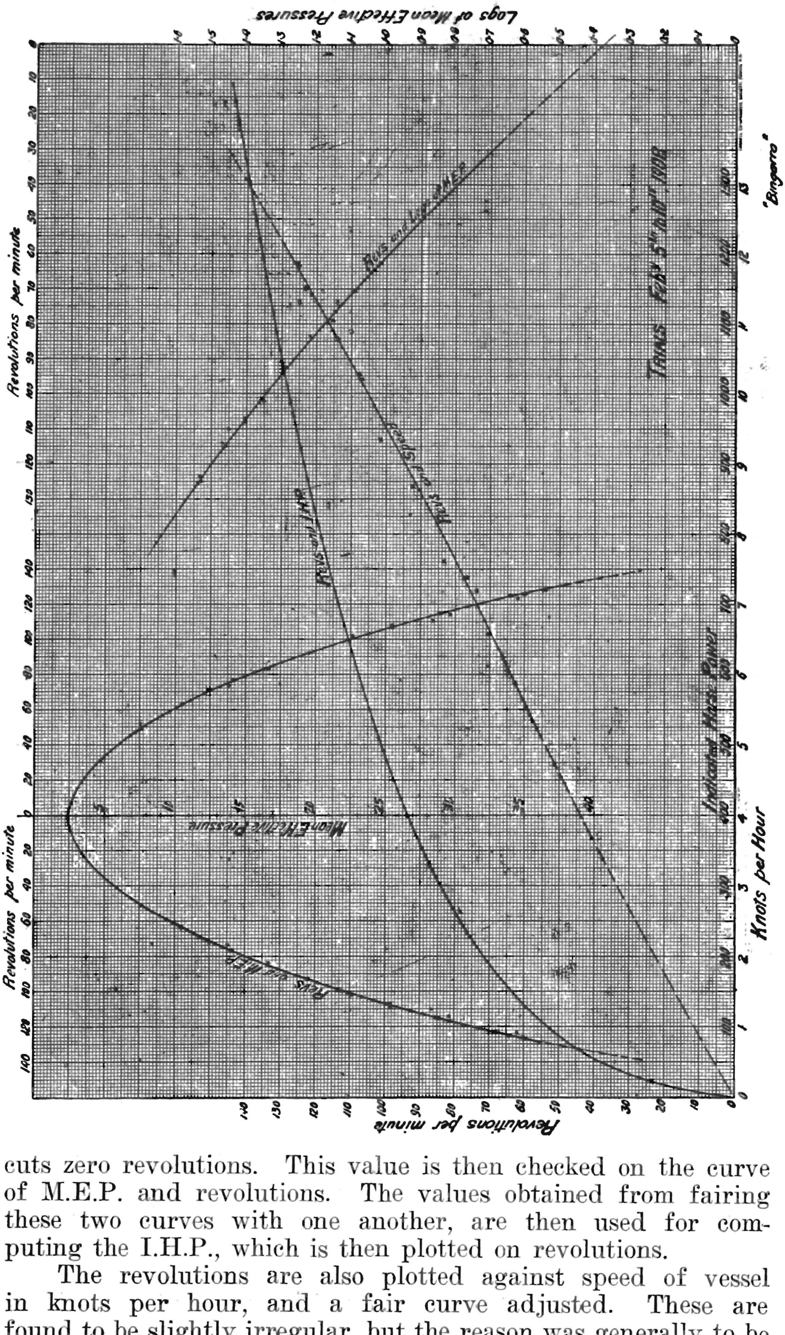

FIG. 1.

cuts zero revolutions. This value is then checked on the curve of M.E.P. and revolutions. The values obtained from fairing these two curves with one another, are then used for computing the I.H.P., which is then plotted on revolutions.

The revolutions are also plotted against speed of vessel in knots per hour, and a fair curve adjusted. These are found to be slightly irregular, but the reason was generally to be

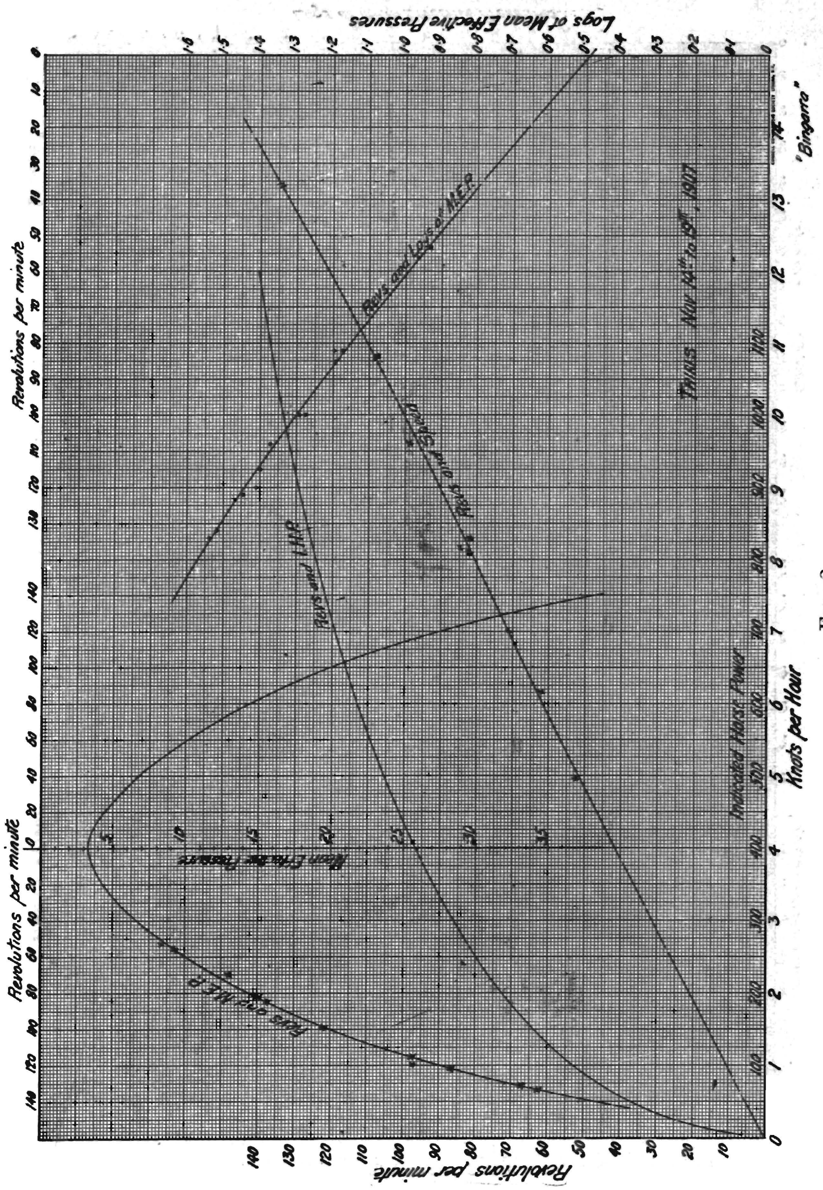

FIG. 2.

found by a reference to the state of the load, wind, or tide, for the particular observation in question, and so allowance made for the value of each spot. A fair curve being obtained, the I.H.P. for the speed can be readily taken off the curve of revolutions and I.H.P.