TRAILING OF TURBINES.

The need for trailing a set of turbines is a somewhat infrequent occurrence, and therefore one which is all the more likely to raise doubts regarding the safety of the machinery on the rare occasions when this operation becomes desirable. It is of interest therefore to consider the extent to which the turbines may be endangered by trailing and to summarise the conclusions resulting from practical experiments in this direction.

The rotation of a turbine rotor in its casing by external means gives rise to heating due to windage and to churning losses in the blade channels. The energy appearing as heat due to these causes in a given turbine depends upon three main factors, namely, the density of the "atmosphere" in which the rotor revolves, the peripheral speed of the blading and whether or not the direction of motion is opposed to that in which the turbine is designed to be run. These facts may be expressed by the following relations in a given turbine :—

Disc Friction Losses.

H.P. dissipated varies as $u^3 \times \delta$

Vane Action Losses.

H.P. dissipated varies as $K \cdot u^3 \times \delta$. In the foregoing formulæ

u and δ represent the peripheral speed of the blading and the density of the medium respectively, while K is a coefficient which has a value of unity when the turbine is running in the designed direction and of about 7·0 when the direction of motion is reversed.

The conclusions to be drawn from these relations are that the heating effect depends chiefly upon the blade speed, but that it can be minimised by maintaining a low pressure in the turbine casing; further, that when trailing in the ahead direction, the maximum heating is to be anticipated in the astern stages.

Trailing is most commonly resorted to on account of the failure of condenser tubes or less frequently owing to the break-down of one of the units of the condensing plant. In any of these cases the turbine rotor is likely to be subjected to atmospheric pressure, a condition favourable to heating. The effect of blade speed is, however, so marked that it has been found safe to trail a turbine at low speeds under the foregoing conditions. It is evident that for every set of turbines there is likely to be a limiting blade speed above which heat is generated more rapidly than it can be dissipated, resulting therefore in a continuous rise of temperature which may become dangerous.

In view of the importance of this question under war conditions, when high average speeds may be expected to prevail, full-scale experiments have recently been carried out in order to provide authentic information. These experiments were further extended to ascertain whether any arrangements could be provided to enable trailing to be carried out for indefinite periods; the main body of this paper contains a brief account of these trials and of the conclusions arrived at.

Description of Trailing Trials.—The vessel selected for these trials was built with two sets of Parsons turbines of 1,800 S.H.P. per set, each of which consisted of an H.P. and an L.P. turbine connected to the propeller shafting by reduction gearing. The H.P. turbines were provided with an initial impulse stage, while the astern turbines, which were incorporated in the L.P. casing, were also of the impulse type.

Thermometer fittings and pressure gauges were provided at selected positions in the H.P. and L.P. turbines of the port set of main engines, and arrangements were also made whereby either air or a measured spray of water could be introduced into the turbines for cooling purposes.

I. Trials were first carried out to determine the relation between the working and trailing revolutions of the shafts. It was found that throughout the whole available range the trailed shaft revolved at exactly one half the speed of the working shaft, and further, that the revolutions of the latter under such conditions were approximately 20 per cent. higher than those obtaining when both sets of engines were in use to give the same speed of ship. Thus a speed of 17 knots was obtained at 254 revolutions when both shafts were working, or at 310 revolutions of the starboard shaft with that engine in use, the port shaft being trailed meanwhile at 155 revolutions per minute.

This relation between working and trailing speeds may be expected to hold good for any two-shaft installation, but in vessels with four shafts the conditions will be different for the inner and outer propellers respectively, since the former are affected by the stream of water delivered by the latter. It is estimated, from such data as are available, that the speed of an inner shaft when trailed will be about 25 per cent. below the revolutions corresponding to the speed of the vessel, but the actual figure will depend very greatly upon the relative positions of the propellers.

II. Trials were then carried out at different speeds and the temperature rise in the turbines was noted with various pressures in the casings. These trials lead to the following conclusions :—

(*a*) The heating effect at atmospheric pressure at any given point varies as u^3—the cube of the blade speed.

(*b*) That in trailing turbines without a vacuum the point at which unduly high temperatures are first likely to be developed is in the astern stages; it was established that the relative heating effects when trailing in the "normal" and the "reverse" directions are approximately as 1 is to 7.

(*c*) That Parsons reaction blading develops a considerable and positive pumping action, tending to circulate the surrounding medium in the direction of normal steam flow when the turbine is moving in its designed direction, the circulation being reversed when rotation is in the opposite direction.

Thus when trailing in the ahead direction a pressure gradient is formed in the turbines, having a point of maximum depression at the inlet to the H.P. turbine and a point of maximum pressure at the inlet to the astern turbine.

The pumping effect was observed to be a maximum in the L.P. turbine, very little being obtained from the H.P. reaction stages on account of the comparatively short blades and large tip clearances.

The Impulse blading (1st stage H.P. ahead, and all astern stages) did not appear to contribute greatly to the pumping effect, probably due to the fact that the " handing " of the blades is not so marked as in the case of reaction blading, while the nozzles exercise considerable damping.

(*d*) The temperature rise, even in the astern stages, at low speeds was not found to exceed about 100° F., the maximum temperature being attained after 2 to 2½ hours; the rate of rise is initially rapid, diminishing with time to zero.

At speeds above 200 ft./sec. in the astern stages temperatures of about 350°–400° F. were reached, while the initial rate of temperature rise had reached over 200° F. per hour.

(*e*) Investigation of the heating effect with air pressures exceeding atmospheric was hampered by an insufficient supply of air during these trials. Sufficient evidence was, however, obtained to indicate that an increased heating effect is to be expected under such conditions.

III. *Cooling Trials.*—A series of trials were then carried out to ascertain what means could be adopted in order to cool turbines while trailing. Two general methods were tested: (1) air cooling, and (2) water cooling.

(1) *Air cooling.*—The pressure gradient formed by the pumping action of the blading when trailing is in progress suggests that use might be made of this factor to circulate air through the turbine and thus prevent excessive temperatures from being reached.

Arrangements were therefore made to admit air through suitable orifices on the H.P. ahead nozzle box, exhausting it through others arranged on the astern nozzle box.

It was found that a cooling effect was obtained, the rate of temperature rise being considerably retarded, although not entirely prevented at high speeds.

(2) *Water cooling.*—Arrangements were made whereby a steady supply of fresh water could be provided at selected positions in the turbines.

In this case the cooling effect obtained, though large in amount, was very local, and it therefore appears that the use of this method alone is fraught with possible danger, especially if applied after any marked rise of temperature has taken place.

(3) *Air and Water cooling combined.*—In this case the water spray was applied at the inlet to the L.P. turbine, the air circulation being as before: the effect on the astern stages was very marked, while the local cooling at the point of application of the water was not more rapid than that obtaining in the remaining stages of the L.P. and astern turbines.

It will be noted that the water was supplied at a point where the temperature was low, and this probably accounts for the absence of the local cooling effect; had the spray been applied at the exhaust bend there is little doubt that the temperature fall in the astern stages would have been undesirably rapid.

The principal results obtained from the various trials are given on the accompanying curves. Fig. I shows the rise of temperature at the inlet to the astern stages when trailing at various speeds under atmospheric conditions. Figs. II and III indicate the effects of various methods of cooling. The sprayer used for the water-cooling trials consisted of a short length of $\frac{3}{8}$-in. copper pipe, closed at one end, drilled with twelve $\frac{1}{8}$-in. diameter holes.

General Conclusions to be drawn from Trailing Trials.

Limiting Blade Speed.—These trials definitely established the existence of a limiting blade speed above which the rise in temperature is progressive, and it remains to consider the practical application of this fact.

In reaction turbines of considerable output the minimum axial clearances are of the order of 0·16 in., and would necessitate a temperature difference of 200° F. between rotor and casing over a turbine length of 11 ft. 3 in. before these were absorbed. When a turbine is heated up by rotational effects, it is probable that little difference will exist between the temperatures of the rotor and casing at any given point, provided that the rate of heating is not rapid; if this supposition is true the absorption of the axial clearances from this cause is not greatly to be feared. Local heating of the turbine such as is liable to occur in the astern stages is, however, definitely dangerous, even when the resultant rise in temperature is small, as pronounced distortion may occur under such conditions. It is probable, therefore, that the mere attainment of a high temperature in a turbine is not in itself a source of danger, provided of course that the strength of the material used is not thereby prejudiced.

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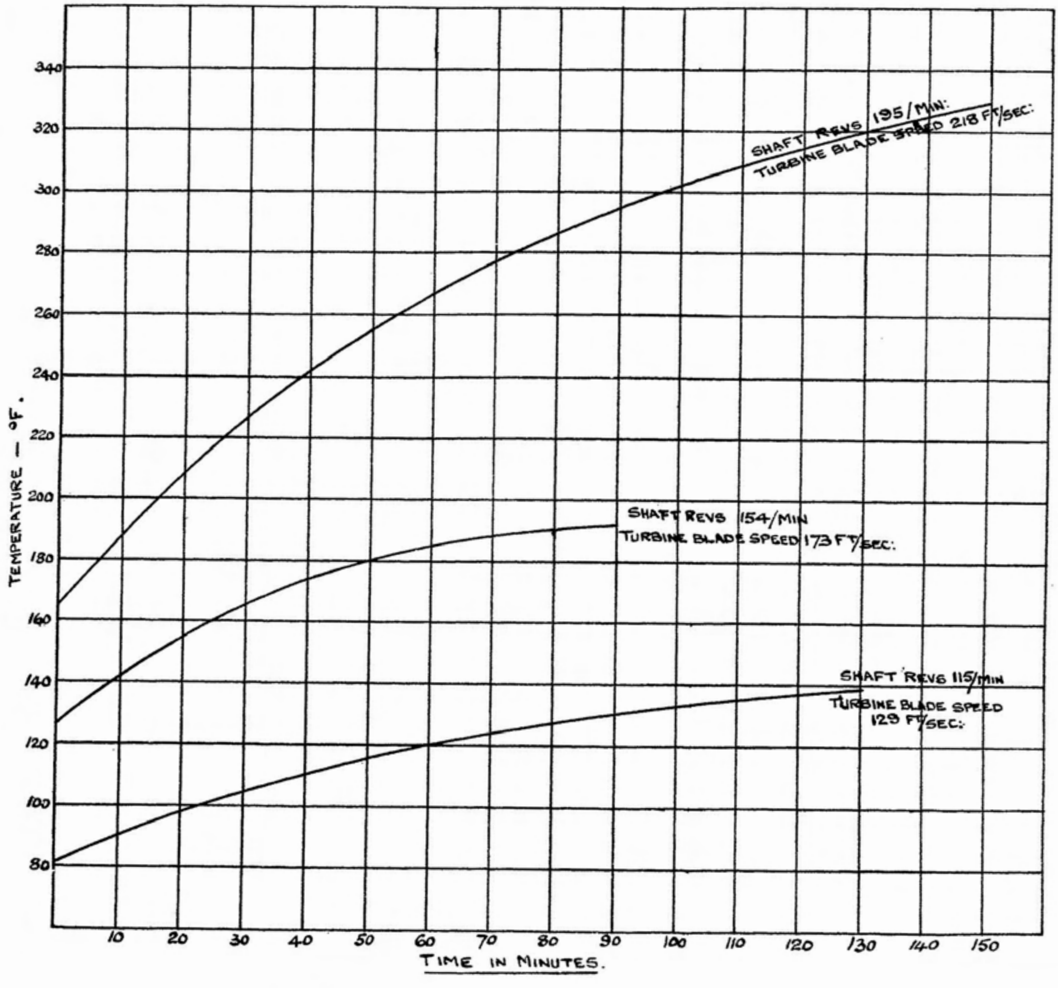

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HEATING TRIALS. — FIGURE 1.

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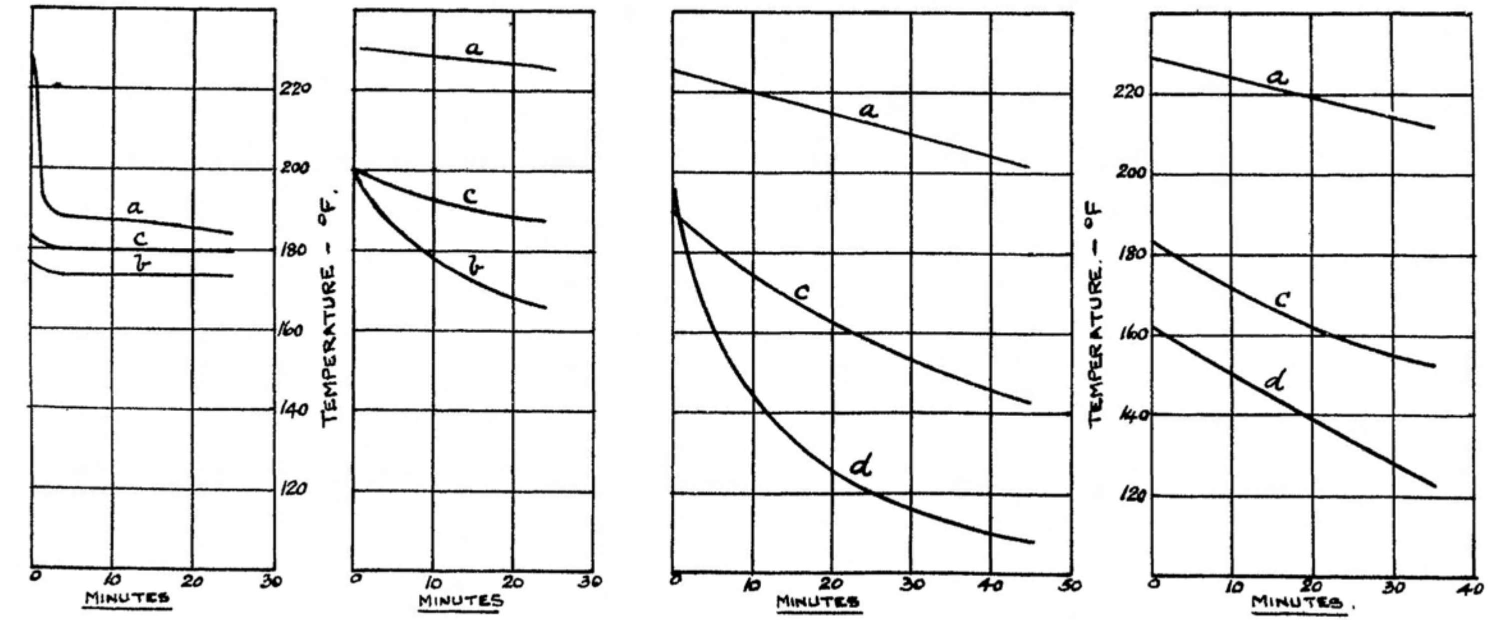

WATER COOLING TRIALS AT 154 REVS/MIN:

ONE GAL: OF WATER/MIN: ADMITTED AT ASTERN IMPULSE BLADING

ONE GAL: OF WATER/MIN: ADMITTED AT INLET TO L.P. TURBINE

a - ASTERN IMPULSE BLADES.
b - INLET TO L.P. TURBINE.
c - L.P. EDUCTION CHAMBER.

FIGURE 2.

AIR COOLING TRIALS AT 154 REVS/MIN:

THROUGH 3" DIAR HOLE.

THROUGH 2" DIAR HOLE.

AIR INLET HOLES IN H.P. STEAM STRAINER.

a - ASTERN IMPULSE BLADES.
c - L.P. EDUCTION CHAMBER.
d - H.P. INLET TO REACTION BLADES.

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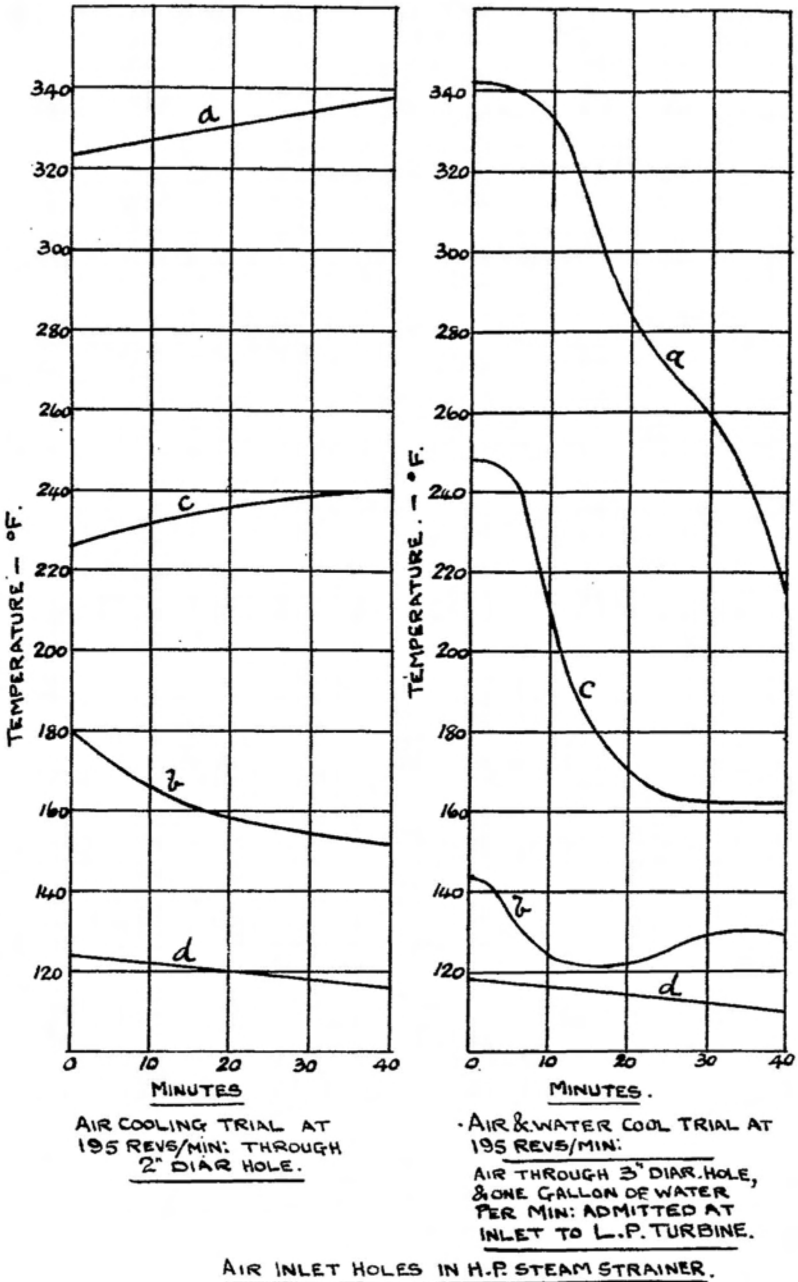

AIR INLET HOLES IN H.P. STEAM STRAINER.

a - ASTERN IMPULSE BLADES.
b - INLET TO L.P. TURBINE. (POINT OF APPLICATION OF WATER.
c - L.P. EDUCTION CHAMBER.
d - H.P. INLET TO REACTION BLADES.

FIGURE 3.

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The results of these trials suggest that a blade speed of 200 ft./sec. in the astern blading may usefully be employed as a danger limit, since at this speed the temperature rise is not only progressive but also is initially rapid; turbines should therefore not be trailed at speeds above this limit without special precautions being taken to observe and minimise the resulting rise of temperature.

In making use of this limit it should be noted that this figure was established from the trials of a set of turbines of small output (1,800 S.H.P.) and that in larger sets a somewhat greater rate of dissipation of heat is to be expected, resulting in a smaller temperature rise at blade speeds of the order mentioned above.

As a practical instance the case may be quoted of a cruising turbine in which damage occurred as the result of trailing at an unduly high speed without a vacuum. In this case the blade speed was of the order of 290 ft./sec. and stripping was observed after a period of about one hour's running under these conditions. The exact mechanism of this failure was not conclusively demonstrated, but it appears probable that the axial clearance must have been absorbed owing to temperature differences, possibly without any noticeably excessive temperature having been attained. Whatever the immediate cause of this accident, it points to the danger of trailing at high speeds under atmospheric pressure, and provides additional evidence in support of the limiting blade speed already suggested.

Safe Period for Trailing.—Regarding the length of time under which trailing may safely be carried out, in view of the danger to be anticipated from rapid local heating it appears probable that it will be unsafe to trail without a vacuum for even a period so short as half an hour if the suggested limiting conditions are exceeded, *unless* means of cooling are adopted.

Means of Cooling.—A combination of water and air cooling will provide adequate protection from damage, and the necessary arrangements can in general readily be extemporised in any existing set of machinery. In choosing the point of application of the water, due consideration must be given to the need for avoiding local cooling, and it is also preferable to apply the water spray when trailing is commenced rather than after a rise of temperature has been experienced. The experiments have indicated that adequate and safe cooling of the astern blading is obtained if the water spray is admitted at entry to the L.P. turbine, in conjunction with the provision of openings for the entry and discharge of air at the inlets to the H.P. ahead and the astern turbines respectively; this combined arrangement avoids any local cooling whatever.

In cases of derangement of the condensing plant not involving the air pumps, safety may be provided by the admission of small quantities of steam to the astern turbines. The beneficial effect of such action is twofold in that not only is the trailing speed reduced by the retarding action of the steam, but also its passage serves to carry away the heat generated by trailing and so to prevent the temperature rising greatly above that of the steam itself; trailing should be practicable at any speed under such conditions.

In turbines of the "Impulse" type, the positive pumping action of the blading, which makes air cooling a practical proposition, is likely to be somewhat smaller than that obtained from a reaction turbine; this point requires substantiation by trial. Owing to the greater clearances in "Impulse" turbines, the need for artificial cooling is not so vital as in those of the reaction type, but the possibility of undue local heating must nevertheless be borne in mind, particularly in velocity compounded stages.

Summing up then, whenever it becomes necessary or desirable to trail a set of turbines for prolonged periods, due consideration is required regarding the resulting blade speeds, especially in the astern turbine.

Blade speeds in excess of 200 feet per second appear to involve the possibility of danger to the turbines and should not be attempted, even for short periods, unless arrangements can be made to observe the temperature conditions in the turbine casings.

In the event of the necessity arising for trailing a set of turbines at speeds in excess of the figure quoted, safety may be ensured by allowing air to circulate through the turbines and by the provision of a spray of water at a position where high temperatures do not obtain.

When testing condensers by methods involving the maintenance of appreciable air pressures in the turbines, sight should not be lost of the increased heating effect (even at low speeds) due to the greater density of the medium in which the rotor is revolving. Further, when trailing, it is desirable that either the steam or sea sides of the condenser should be kept flooded with water in order to avoid drying the gromets.

Fuel Economy by Trailing.—The steam consumption per horse power of any set of turbines has, as is well known, a minimum value at one speed only, and under all other conditions a decreased efficiency will be experienced. The efficiency under conditions other than that designed for can be influenced to a limited extent by the employment of special cruising devices, but in general a considerable falling off is unavoidable at very low proportions of the full output of the set. It is evident therefore that if the power required to produce a given speed can be developed in (say) one unit instead of in two, then the steam requirements for the turbines only will be reduced since the percentage of full power required by the one unit will be thereby doubled; it is this possibility which constitutes one of the principal attractions of the so-called "Electric Drive."

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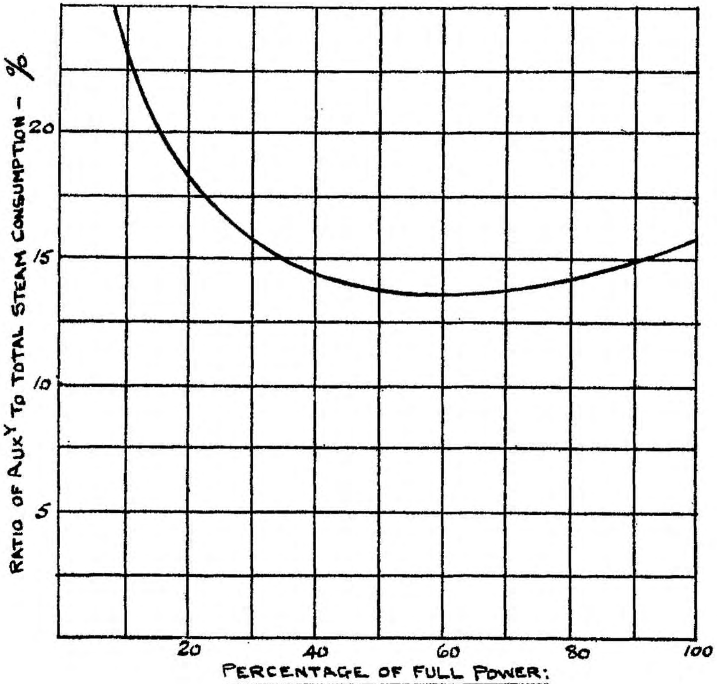

FIGURE 4.

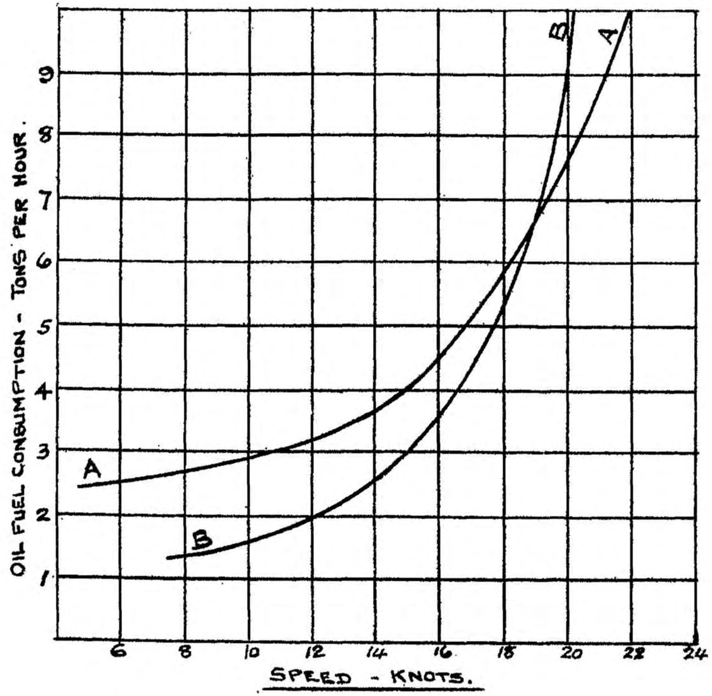

FIGURE 5.

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An obvious means of reducing the number of sets of turbines employed for propelling a ship at low speeds is to trail those units which it is not desired to use, and, provided that prolonged trailing is practicable, this method opens up possibilities of increased economy. Under these conditions the total S.H.P. required will be somewhat greater than that employed when all the turbines are in use, since not only do the propellers which are being trailed exercise a certain "drag" upon the ship, but also the propulsive efficiency of the working propellers will be changed in view of the altered relation between the relative speeds of the blades and the ship. Alternatively, the idle shafts may be prevented from turning by application of the brakes, but the resistance due to the propellers is thereby greatly increased over that which obtains when the shafts are trailed, and actual experiments have shown that it is more economical to permit the idle shafts to rotate. The third alternative of parting couplings of the propeller shafting, in order to prevent movement of the idle turbines while leaving the propellers free to turn, is not to be recommended, as the solidity of the couplings will inevitably be impaired if frequent removal of the bolts is permitted.

The degree of economy obtainable by trailing certain turbines in a ship cannot readily be predicted, since the results achieved depend not only upon the general characteristics of the turbines but also upon the loss in propulsive efficiency due to this operation; as regards the turbines themselves some economy is certain, but it may well happen in individual cases that the increased resistance to propulsion will outweigh the improved efficiency of the turbines.

There is, however, a secondary benefit to be derived from trailing, and one which is likely to be more than sufficient to turn the scale in favour of this method of operation. It has been pointed out in a previous Paper (No. 5, pp. 3–25) that as the power of the main turbines is reduced so the steam consumption of the auxiliary engines becomes an increasingly large proportion of the total steam evaporated. If, therefore, the idle turbines are trailed under atmospheric pressure and steam is entirely shut off from all the auxiliaries in connection with them, excepting only the lubrication system, then a substantial saving is to be anticipated. The curve of Fig. IV. indicates the relation between the total and the auxiliary steam consumptions at varying shaft horse powers in a particular case, the increase of consumption shown at high powers being accounted for by the comparatively high rate of forcing employed in the vessel under consideration.

Trials to ascertain the relative fuel consumptions of the two methods of operation were carried out in one of H.M. ships some years ago and the results indicated in Fig. V, where the curve *AA* shows the fuel consumption when all turbines were in use and the curve *BB* that obtained when the after sets of turbines were trailed. In the particular vessel in question the forward turbines were fitted with geared cruising turbines while the after sets were not so arranged, hence the improvement due to trailing the after set was somewhat exaggerated compared with that which would be obtained if all the sets of turbines had been similar. In this instance the economy obtainable by shutting off the auxiliaries in connection with the trailing turbines was not realised since the latter were maintained in a state of instant readiness.

These results, agreeing as they do with theoretical expectations, are sufficiently encouraging to warrant further experiments in this direction, especially when taken in conjunction with the information regarding the safety of turbines under trailing conditions as described in this paper. It is hoped that additional information on this subject will be available at a later date, when it will form the subject of a further article in these Papers.