SOME VAGARIES OF TORQUE

BY

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We normally think of torque as the quantity that has to be multiplied by the r.p.m. to find the s.h.p. that is being developed, and in general our interest is limited to full power trials, or the occasions when the full number of shafts is not in use and the torque on the remainder is, therefore, affected. This article deals with torques that are transiently experienced while turning or manoeuvring and it will be seen that some of them are alarmingly different from the steady torques referred to. The alarm will be tempered by the thought that these torques have been successfully sustained for many years before there were means to measure them.

The need to measure these torques has arisen from the desire to encroach on existing factors of safety in the interests of weight reduction in new construction and before this can be done it is obviously necessary to know what the present safety margins are. Some of the measurements which have been made are of general interest besides providing data for the designers.

H.M.S. " Savage "

The most valuable information has been obtained from instruments designed especially for the purpose and used in the Emergency Class Destroyer H.M.S. *Savage* during propeller trials which are being carried out to compare a number of different types of propeller.

Manoeuvring at Full Speeds

Besides the ordinary recording instruments for Siemen's " Ford " Torsionmeters and Michell Thrustmeters, pick-ups have been developed by the Admiralty Engineering Laboratory, West Drayton, that enable continuous reading of gauges to be mounted on a miniature gauge board which is photographed with 1/50 sec. exposures at one second intervals. The readings include torque and thrust, r.p.m. and turbine receiver pressures. By somewhat arduous analyses of the photographs, these readings can be plotted on a time base. Fig. 1 shows the results obtained when going from Full Ahead to Full Astern and from Full Astern to Full Ahead. The ship's speed obtained by Admiralty Experimental Works, Haslar, from sights on a mark-buoy is also plotted on the same base for the Full Ahead/Full Astern trial.

During the sea trials after completion and before acceptance of a new ship, it is specified that such a trial, *i.e.* Full Ahead/Full Astern/Full Ahead, should be carried out, and a practice has sometimes existed during these trials of limiting the Astern Receiver Pressure to about half of that finally required for the specified astern r.p.m. until the engines have started revolving astern. In the trials in *Savage* no such restriction was used, the full astern receiver pressure being applied as quickly as possible, whilst the ahead manoeuvring valves were being shut.

Six propellers have been subjected to this treatment and there was remarkable similarity in the shape of the transient curves of torque and thrust obtained

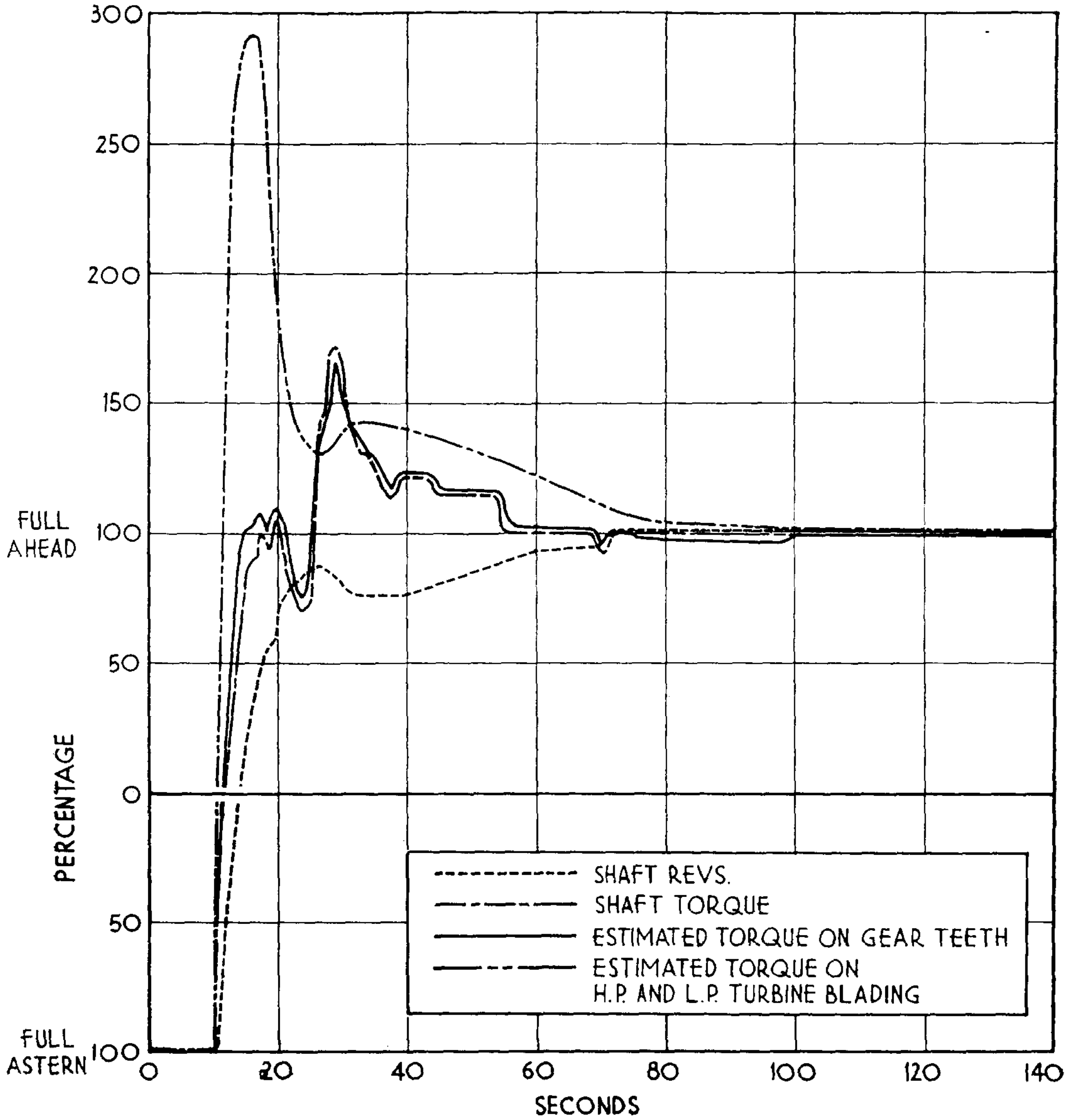

FIG. 2.— H.M.S. "SAVAGE" — TRIAL "F" — FULL ASTERN — FULL AHEAD

for each. The maximum values of torque and thrust measured in any of these trials (which it will be seen are a little higher than those shown in Fig. 1) were as follows :—

Maximum Ahead Thrust and Torque ... 175% of full power ahead steady speed values.

Maximum Astern Thrust and Torque ... 175% of full power astern steady speed values.

It is at once apparent that some of the existing factors of safety are serving a useful purpose and it is clear that propellers and propeller shafting must be made strong enough to withstand for a short time about 75% greater loads than their steady values at authorized full power.

In Fig. 1 it can be seen that the maximum values of both ahead and astern torque (and thrust follows the same pattern) occur after the propeller shafts have reversed and when they are revolving at nearly their full r.p.m. in the new direction. So much so, in fact, that there is insufficient power being supplied by the steam to provide the horsepower represented by the peak torque and the r.p.m. attained, and the system has to draw on its reservoir of kinetic energy to supply the deficit. This is shown by the falling off of r.p.m. that occurs when the peak torques are reached. It seems that at a certain stage the condition becomes such that the propellers can suddenly " get a bite on the water " to produce these peaks and as stated above there is remarkable consistency in the shape of these peaks and the time at which they occur with the different propellers tested. Since the engines are decelerated by this sudden increment in torque at the propellers, inertia is assisting the steam, and the turbine and gearing torques at this instant are less than the measured 175%, but the propeller torque is slightly greater.

Propellers of different blade thickness were used during the trials and by good fortune the thicknesses selected were such that a straddle was obtained, the thinnest blades tried being slightly bent when subjected to the maximum thrust and torque of about 175% of normal full power values. The other thicknesses successfully withstood these maxima, and as a result of these experiments future propellers can be made thinner than the present standard, thereby achieving an improvement in propulsive efficiency, particularly at the lower powers.

When the turbines are accelerating or decelerating, the turbines, and to a lesser extent the gearing, may be in a worse plight than the propellers and shafting for the value of maximum torque given above is that recorded at the torsionmeter sited at the normal position aft of the gearing, and additional inertia loads are taken by the gear teeth and the turbine blades when the engines are rapidly reversed.

Full Astern to Full Ahead (*Fig.* 2)

As is to be expected from the consideration that the torque tends to vary as the s.h.p. divided by r.p.m., the turbine blades and gear teeth are most highly stressed at an earlier period than that at which the torsionmeters record their highest values. When going from full astern to full ahead the teeth of the pinions and gear wheels have to provide not only the torque recorded at the torsionmeters but also that necessary to accelerate the turbine rotors and the pinions. Calculations indicate that if the load is shared equally between the H.P. and L.P. turbines the maximum torque at the gearing teeth is about 170% and at the turbine blading 290% of the steady torque at full ahead power (see Fig. 2). If during these transient conditions the load is not shared equally by the turbines the maximum torque at one or other will exceed these values.

Full Ahead to Full Astern (*Fig.* 3)

When going from full ahead to full astern, the astern turbine being incorporated in the L.P. turbine only, the L.P. pinion has not only to decelerate the gear wheel in addition to the torque recorded at the torsionmeter, but also has to decelerate the ahead turbine and overcome windage in the turbine when it starts revolving astern. As before the turbine blading has in addition to provide the decelerating torque for the L.P. turbine. Fig. 3 shows on a time basis the recorded torque in the shaft and estimates of the torque on the astern faces of the L.P. gear teeth and the torque at the astern blading. No reliable figure is available for the turbine windage effect which should be added to the maxima shown of 160% at the gear teeth and 250% at the turbine blading.

Manoeuvring at Lesser Speeds

Besides the trials in extreme conditions going from full ahead to full astern and back again to full ahead, further trials were carried out in *Savage* with full astern power at reduced speeds and with reduced astern power representing 10% and 20% of the full ahead power. These were carried out with initial

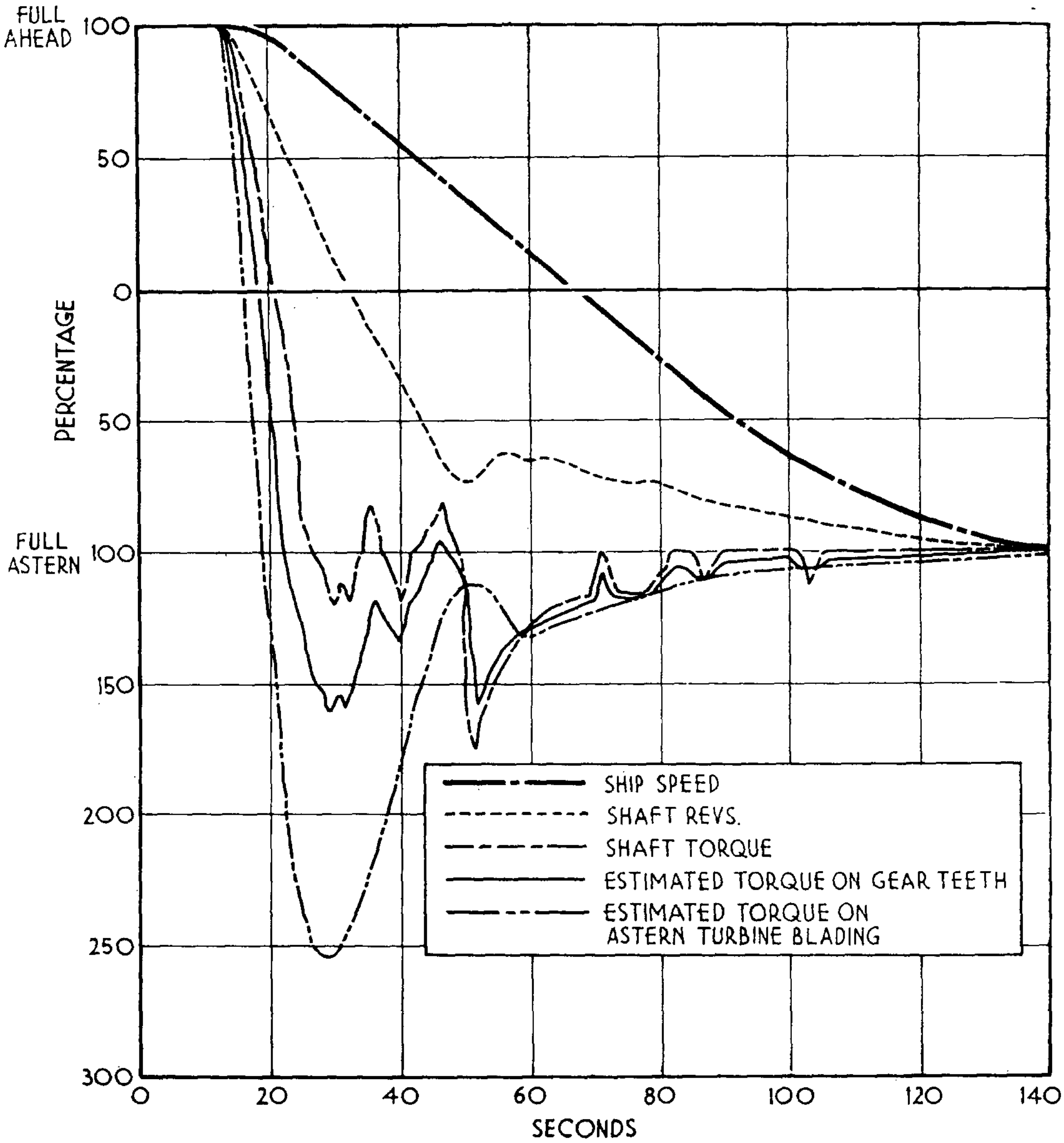

FIG. 3.—H.M.S. "SAVAGE"—TRIAL "F"—FULL AHEAD—FULL ASTERN

speeds of 32, 25, 20, 15, 10 and 5 knots. By the time the latter trials was reached the ship's company had become so well trained in manoeuvring that all sprayers were on, and the full astern receiver pressure was showing before the ship stopped, and, in fact, the sprayers in each boiler were increased from one to eight during this full astern trial at 5 knots in 15 seconds.

The results showed that the peak astern torques and thrusts measured were substantially independent of the initial speed and for practical purposes can be taken to vary almost directly with the astern receiver pressure, as one would expect. Fig. 4 shows the rough relationship of maximum thrusts and torques with astern power.

Cyclic Variations in Torque

During steady speed runs in *Savage* pen-recorders were used to measure the variations in torque during each revolution. The frequency of the main fluctuations was that of the propeller blades, *i.e.* three times the shaft speed and in general less than 10% of the mean torque. The fluctuations of thrust seem to be somewhat greater than those of torque.

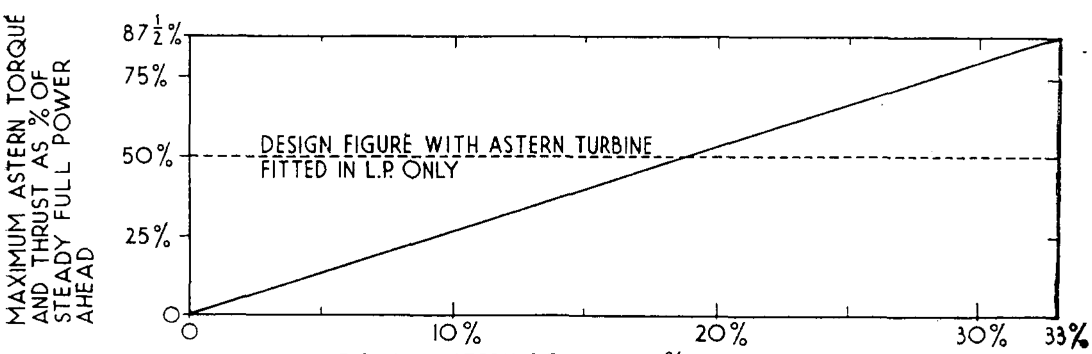

FIG. 4—ASTERN POWER AS % OF AHEAD POWER

It is not certain to what extent fluctuations in torque occur also during manoeuvring and whether their effects are additive to the maximum transient values given above. Instruments are being devised to check this point.

Turning at High Power

Measurements taken at full speed and full rudder showed both torque and thrust in the shaft on the inside of the turn reached maxima of just over 125% of their steady full power values. After some of the high percentages quoted above these may seem trivial, but whereas the very high torques and thrusts are seldom experienced during a ship's life and perhaps only during the initial sea trials, turns at high speed may be not infrequent, particularly in wartime. Moreover, the high values during manoeuvring last for at most a few seconds and those during the turns last considerably longer. It seems possible, therefore, that designers need only ensure that the yield strength of the materials used is sufficient to withstand the maximum stresses that occur during manoeuvring and that for the maxima that occur when turning fatigue limit criteria must be used.

H.M.S. " Vanguard " and H.M.S. " Eagle "

Turning at High Power

Although special instruments were not fitted it was found possible in H.M.S. *Vanguard* during high speed circle trials to take snap readings at 10 sec. intervals, while turning, of the torsionmeters and revolution indicators. These are shown plotted on a time basis in Fig. 5 which represents conditions when turning at full speed with 35° rudder. Similar readings taken in H.M.S. *Eagle* during sea trials confirm the maximum values of torque and r.p.m. to be approximately as follows :—

	Torque	*R.P.M.*
Outer shaft on outside of turn ...	—	103%
Inner shaft on outside of turn ...	—	120%
Inner shaft on inside of turn ...	130%	Taken with no reduction of receiver pressure in H.M.S. *Eagle*.
Outer shaft on inside of turn ...	118%	

At lower powers the percentages remain about the same if the throttles are not adjusted during the turn. For lower rudder angles down to 15° there is some, but not a proportional reduction in the maxima.

Axial Vibration of Shafting

There is yet another set of circumstances that may lead to high transient torsional stresses in the system. When ships with three or more shafts are turning there is a likelihood that the after propeller or propellers may have to work in the slip stream of one of the propellers further forward. The blades

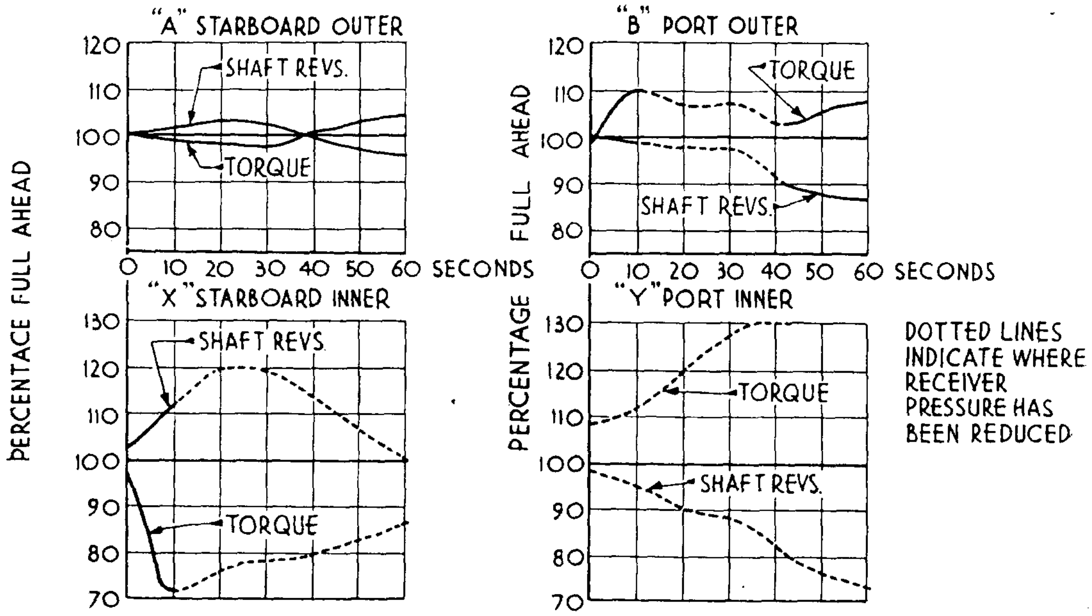

FIG. 5.— H.M.S. "VANGUARD"— FULL POWER TURN TO PORT—35 DEGREES OF RUDDER

of the propeller may then be subject to cyclic variations in the thrust and torque which they exert.

If the shaft is revolving at such speed that the frequency of the impulses from the propeller blades coincides with the natural frequency of longitudinal axial vibration of the shafting, dynamic magnification of the oscillation caused by these cyclic variations may occur to such an extent that there is actually a periodical reversal of thrust. H.M.S. *Warspite* was the classic case of this occurrence, but all multi-shafted large ships suffer to some extent from this trouble when turning at high speed. It was possible to alleviate the situation by reducing the power of the propeller causing the slip stream, and in some ships four or five bladed propellers have been fitted to the after shafts so that resonance occurs at a lower speed when the forces involved are in any case lower.

If periodic thrust reversal does take place it must presumably be accompanied by periodic doubling of the thrust and although this is not certain it is likely that the torque varies in sympathy from zero or a negative torque to at least double the average torque. It has been found from the results of the turning trials that at the times when this is likely to occur on the inner shafts, the average torque (and thrust) is some 20% less than the steady value appropriate to the ship's speed, so that doubling of it may only increase it to 160% of this steady value. Naturally this is most serious if resonance occurs at full power and if the resonance speed is lowered by fitting four or five bladed propellers the peak stresses can be reduced. However, until more is known of the maximum stresses occurring during resonant axial vibrations, it clearly will not be possible to reduce factors of safety very drastically.

Conclusion

Most of the readings of maximum transient torques given in this article have only recently been obtained and the results have been insufficiently digested for the design implication to be fully considered, but it appears that the maxima given below may in practice be reached. Fluctuations at blade frequency may possibly increase these figures :—

(1) When manoeuvring at full power. About 175% of steady full power ahead and astern thrusts and torques at the propeller, slightly less at the gearing wheel teeth, but considerably higher values at the turbine blading. These values are rarely reached in the life of a ship.

(2) When turning at full power. Nearly 130% of steady full power ahead thrusts and torques. About 120% of full power ahead r.p.m. may be reached, but while there is reduced torque.

(3) When resonant axial vibration of the shafting is occurring during turns at high power. Not fully investigated but say 160% of steady thrusts and torques.

After a ship has successfully undergone her acceptance trials, the worst should be over and it is not the intention of this article that seagoing engineers should modify practices which have proved safe in the past. These figures will, however, have to be taken into account by designers when determining margins of safety in weight saving endeavours in new construction.