MULTIPLE MEMBRANE COUPLINGS

BY

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Introduction

Although the Royal Navy uses a number of different types of flexible couplings in its main transmission systems, of which claw couplings, fine-tooth gear couplings, and multiple membranes are examples, this article deals only with our experience with the latter type; and concentrates on three areas:

(*a*) The Tribal Class frigates and County Class destroyers, which were the first classes of warships to be fitted with membrane couplings in their main transmission systems. In general this has been a satisfactory installation but has required careful *in-situ* balancing and there have been some problems with vibration in the high-speed line.

(*b*) The *Amazon* Class frigates and *Sheffield* Class destroyers, each of which have similar main machinery installations. Changes were made in the design and in the installation procedures to try to avoid the problems experienced in the earlier ships. To date, the couplings have been trouble free in service although some initial teething problems were experienced; these were related mainly to installation standards, especially at equipment interfaces.

(*c*) The measurement of coupling operating conditions: a coupling sited between a resiliently-mounted gas turbine and a solidly mounted gear-box has to cope both with steady-state and transient misalignment. An alignment meter, developed by Y-ARD Ltd. for the MOD(PE), is on trial in one of the Type 21 frigates. It gives a continuous indication of the position of a membrane coupling/torque tube assembly under operational conditions at sea, and is being used to check if the design limitations are exceeded in service.

The only design of multiple-membrane coupling in service in the R.N. is the 'Metastream', and the reasons for its adoption are partly historical and partly due to a desire for standardization. The history of the Navy's use of this coupling goes back to the mid 1950's when consideration was being given to the introduction of gas turbines for main propulsion. Metastream couplings were first used in the Pametrada shore machinery trials in 1956 and this led to their adoption for the COSAG machinery. This installation was fitted in the Tribal Class frigates and the County Class destroyers which came into service in the early 1960's. The Navy's experience with the couplings in these installations (reviewed later in this article) has, in general, been good.

Because of the Navy's policy for machinery standardization, when the next generation of warships after the COSAG ships came along, the coupling first considered for their main transmission was the Metastream. Although the engines for these ships—derived from aero gas turbines—set some new problems for the coupling designer in terms of steady and transient misalignments, maximum acceptable coupling weight, and operating temperatures, a satisfactory design was evolved and fitted in the COGOG machinery of the Type 21 frigates and Type 42 destroyers.

This policy of standardization means that this design will continue to be used in existing ships and would be given first consideration for future designs of ship, unless one or more of the following conditions arose:

(*a*) the design proves to be deficient in service and cannot satisfactorily be modified;

(*b*) the design ceases to be made and supported by a U.K. manufacturer;

(*c*) future design requirements are found to be beyond the capacity of the proven range of couplings.

COSAG Machinery

The twin-shaft County Class destroyer has four 3·7MW prime movers driving into each gearbox: H.P. and L.P. steam turbines forward, and two G6 gas turbines aft. Each prime mover has an M1800 spacer coupling in its output shaft line to allow for relative movement between the turbine and gearbox. For installation reasons, the spacer or torque tubes are of different lengths as shown in TABLE I. The L.P. steam turbine has an integral astern turbine, but the G6 gas turbine is uni-directional and its output has to be reversed for astern running by a system of fluid couplings in each gear-train.

The single-shaft Tribal Class frigates have one 9·6MW reversing steam turbine and one 3·7MW gas turbine driving into the front of their gearboxes through similar but shorter spacer couplings. The steam turbine uses an M4000 coupling with an overall length of 1140mm while the gas turbine has an M1800 coupling of 1060mm.

TABLE I—*COSAG coupling details*

		Steam Turbine	*Gas Turbine*
Coupling type		M1800	M1800
Speed	rev/min	6500	5000
Length	mm	2250	1800
Weight	kg	258	233
Running misalignment limits:			
Axial	mm	± 2	± 2
Lateral	mm	16	12
Angular per bank	degrees	$\frac{1}{2}$	$\frac{1}{2}$

Both types of coupling are manufactured in steel with a single membrane bank at each end of the torque tube. The membranes themselves are of the spoked type, stamped out from AISI301 stainless steel in the half hard condition. Each bank is made up from seventy-two membranes. Overload teeth or splines are provided at each bank across the interface between the torque tube and its driving or driven flange. If the membrane bank should fail, the teeth will carry the transmitted torque for a short period and so prevent the turbine from running away while the plant is shut down. They are not intended to be a 'get-you-home' device.

A total of 156 membrane units are fitted in the COSAG ships. The first ship came into service some eighteen years ago and, in that time and from that number of units, there has been only one case of membrane failure. In this instance, thirteen of the seventy-two membranes in one bank failed by cracking across the spokes a short distance away from the junction with the inner hub. The membranes had suffered some isolated pitting corrosion, but this was not associated with the cracks which were considered to have been caused by excessive axial misalignment.

The only general problem with the coupling is, in fact, one of installation, alignment, and overall balance of a high-speed rotating line made up from several components, and the symptoms of the problem are usually seen as high levels of vibration. Taking the Tribal Class steam turbine input line shown in FIG. 1 as an example, the line consists of the turbine rotor with its forward and after bearings, the Metastream coupling which is carried between the turbine after bearing and a coupling support bearing at the entry to the gearbox, a manual (sliding-spline type) clutch, and the input pinion. The input shaft continues as a quill shaft to an after support bearing, passing, on its way, through the centre of the output half of the manual clutch and the input pinion.

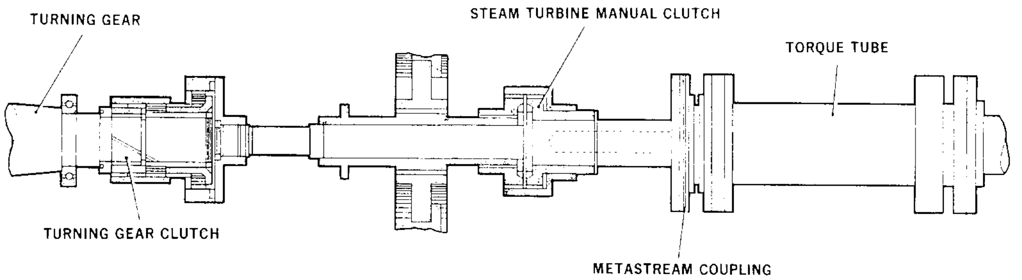


FIG. 1—TRIBAL CLASS HIGH-SPEED LINE

When the line was designed, reasonable tolerances were put on the positioning of bolt holes, concentricity and swash of flanges, etc., bearing in mind that the turbine, coupling, and gearbox were being made by different manufacturers, and by different combinations of manufacturers, as some of the turbines and gearboxes were made under licence. However, it has been found that, when the components are mated for the first time or a component is changed, *in-situ* balancing is almost always necessary and, as no 'built-in' system of adjustment is provided, correction to the balance involved weight removal by drilling radial holes in the coupling flanges.

The *in-situ* balancing procedure is normally carried out in two stages: first, in harbour, with the manual clutch disengaged, up to a turbine speed of 3200 rev/min; then, at sea, with the clutch engaged, up to the maximum speed of 5600 rev/min. The state of balance is checked by accelerometers temporarily fitted to each bearing cap, the maximum limits being set at 6·6mm/s peak velocity at once per revolution or fundamental frequency. FIG. 2 gives a typical set of vibration readings obtained from the coupling support bearing. (A) shows the initial readings which are above the acceptance limits. The curves for different clutch positions are obtained by stopping the turbine and disengaging the clutch and then re-engaging it in a different angular position. The variation between the curves indicates that there is some residual un-balance (in the input pinion itself) that is not removed by the balancing exercise on the coupling. (B) shows the interim stage when the out-of-balance of the input line has been corrected by fitting weights in the form of bolts screwed into tapped holes in the ends of the coupling flange bolts. (C) is the final result when the weights are taken off and an equivalent weight has been removed from the opposite side of the flange by drilling. The weight removed here was 37 grams but, in some cases, the correction may be as large as 58 grams.

Although an acceptably balanced line can be achieved by this method, the process itself is time consuming and requires some degree of expertise that may not always be available. Furthermore, when a coupling is exchanged, refurbished, and then re-used in another line, the correction of balance may be complicated by the presence of the 'old' balancing holes drilled in the flanges.

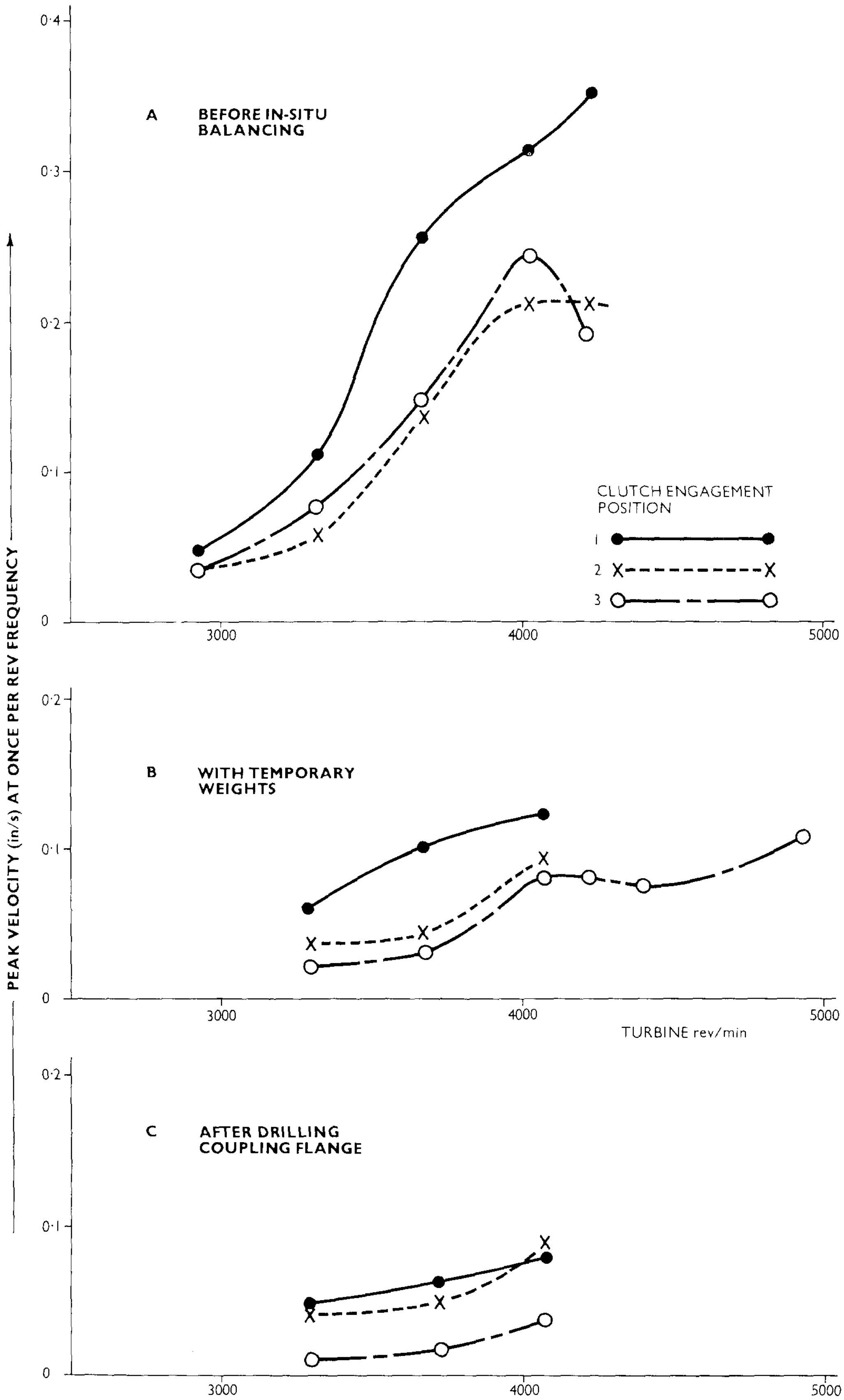


FIG. 2—COSAG STEAM TURBINE INPUT LINE—VIBRATION LEVELS AT COUPLING SUPPORT BEARING

COGOG Machinery

The general layout of one shaft of the COGOG machinery in the Type 21 frigates and the Type 42 destroyers is shown in FIG. 3. The power turbine of the 3·4MW Tyne cruise engine runs at up to 13 500 rev/min, and requires a primary gearbox to match its output to the input speed of the main gearbox. Three types of coupling are used as detailed in TABLE II.

TABLE II—*COGOG coupling details*

		Olympus	*Tyne*	
Coupling type		M4000	M1800	TS22
Speed	rev/min	5660	3560	13 000
Length	mm	2390	1180	940
Weight	kg	230		60
Running misalignment limits:				
Axial	mm	±2·80	±2·00	±1·65
Lateral	mm	12·8	12·8	4·00
Angular per bank	degrees	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{4}$

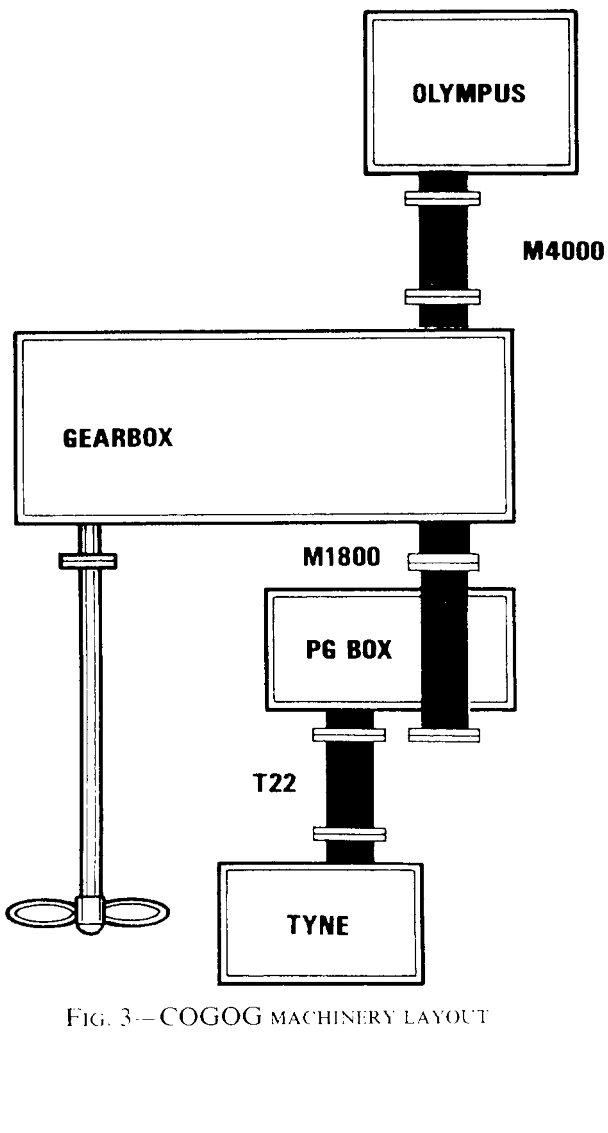


FIG. 3—COGOG MACHINERY LAYOUT

The M4000 membrane shown in FIG. 4 is the same type as that used in the COSAG ships but the coupling has been uprated by increasing the number of membranes in the bank to one hundred. As the gas turbines are resiliently mounted while the gearbox is on solid chocks, the spacer tube must have sufficient length to allow the membranes to accommodate the lateral misalignments that occur under start-up and other transient conditions. In practice the actual length is dictated by the installation requirements which are usually greater than the minimum required. Conflicting with this length criterion is a need to keep the load carried by the power turbine flange within certain limits, and this resulted in the M4000 torque tubes and coupling being manufactured from Hiduminium 54 instead of steel to reduce the coupling half weight.

The primary gearbox and the Tyne gas turbine module are mounted on a common base frame. To keep the distance between this unit and the main gear-

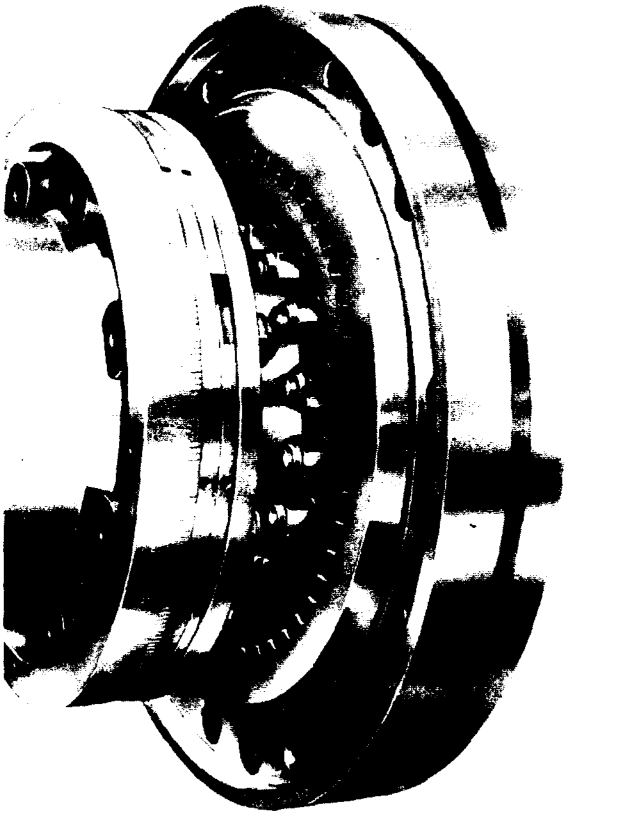


FIG. 4—M4000 MULTIPLE MEMBRANE COUPLING UNIT

box to a minimum while providing an adequate torque tube length, the steel spacer tube of the M1800 assembly passes through the centre of the primary gearbox output wheel to connect with a membrane unit on each side of the gearbox. From an engineering point of view, this is not an ideal arrangement as access for maintenance is restricted. It is one example of the penalties that have to be accepted when a high-power installation has to be fitted into the minimum space.

The coupling between the Tyne power turbine and the primary gearbox is also a difficult area for the designer. The rotational speed (13 500 rev/min) being higher than had been used in previous naval designs meant keeping coupling weight and diameter to a minimum. Also, the increased windage at the higher speed gives a high ambient temperature within the coupling covers. The size of the covers could not be increased as their diameter and the general access to this area is severely restricted by the exhaust duct from the power turbine. To overcome this restraint, a T-type membrane was developed and used. This is in the form of a ring and gives a considerable reduction in the outside diameter of the membrane bank. Both the coupling and the torque tube are manufactured in steel.

Following experience with the membrane coupling in the COSAG machinery where most of the difficulties arose in the mating of components and their initial installation, the following steps were taken at the design stage to try to alleviate the problems in the new COGOG ships:

(*a*) The coupling assembly was to be dynamically balanced and then installed as a complete unit. This was possible with the M4000 coupling, it was more difficult with the TS22, but it could not be done with the M1800. More attention was to be paid to the balance of the remaining components which go to make up the complete rotating line.

(*b*) The accuracy of the mating flanges between different components was to be improved by the use of better jigs and tighter tolerancing on bolt-hole position, bolt fit, flange concentricity and swash, etc.

(*c*) The installation procedures were revised and standardized, with tighter tolerances on the concentricities to be achieved along the complete rotating line.

(*d*) For the large M4000 coupling, balance rings were to be fitted at each end of the torque tube. These rings, which can be seen in FIG. 4, allow *in-situ* balancing without the need to drill the flanges, should balancing still be found to be necessary.

In general, these measures have been successful although there were some teething problems. The idea of fitting the coupling as a complete balanced

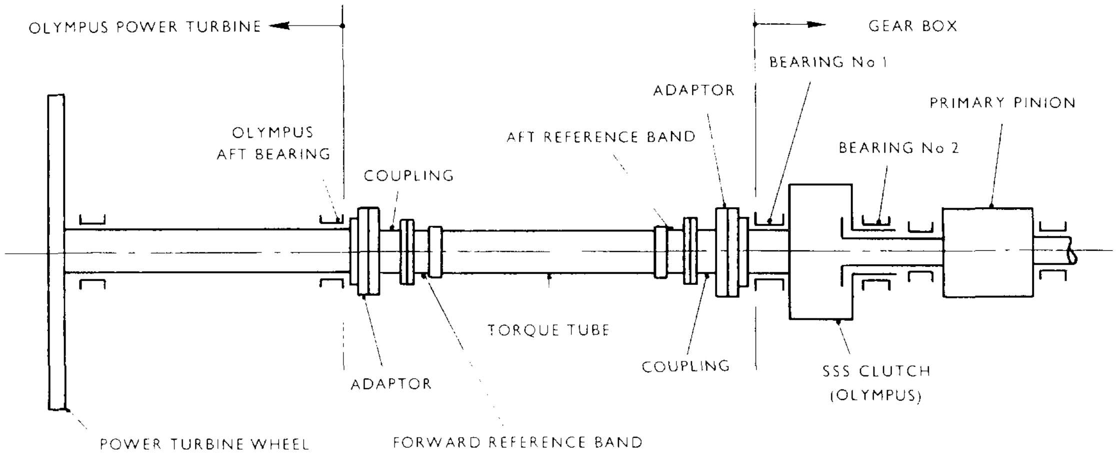


FIG. 5—TYPE 21 FRIGATE/TYPE 42 DESTROYER HIGH-SPEED LINE

assembly is fine in principle, but a M4000 coupling is large and it is usually one of the later items to be fitted in place. At that stage, the space allowed for manoeuvring it into place may have become partly obstructed thus requiring the assembly to be split and reassembled in place. Usually this has been successful but there have been occasions where the reassembly has not been accurate enough, and removal and rebalancing has been necessary to bring the vibration levels within limits.

The significance of the overall length of the coupling on the vibration characteristics of the high-speed line was not fully appreciated in the early days, and this did give some problems in the first Type 21 frigate. Here the Olympus M4000 coupling line was found to be outside the acceptance limits for vibration, which had been set at 3·8mm/s peak velocity at once per revolution frequency at any gearbox input line bearing. The layout of the Type 21 high-speed line is shown in Fig. 5 and it can be seen that the Metastream-coupling/torque-tube assembly is carried between the Olympus power turbine output flange and the SSS clutch input flange. Fig. 6A shows the readings taken on initial sea trials at No. 1 bearing. The readings were high and also unusual in that they 'stepped' from the level shown by the lower curve up to the upper level at irregular intervals, and maintained this higher level for periods of up to 60 seconds at a time.

Briefly, the following changes were made to try to improve this situation:

(*a*) The torque tube was made stiffer to raise its critical speed by increasing its diameter by 76mm to 304mm.

(*b*) The adaptors which connect the coupling flanges to the gearing and power turbine flanges were changed from steel to Hiduminium 54 to give a further weight reduction.

(*c*) The centre of gravity of each bank was moved slightly outwards by reducing the length of the overhang.

(*d*) The procedures for balancing and installing the couplings were reviewed and more strictly applied.

The first Type 21 frigate was already late on her building and trials programme, and so there was considerable pressure to rectify this high-speed line vibration problem to allow her to continue with her sea trials. Eventually the full package of improvements was applied and the problem was solved, as is shown by the readings in FIG. 6B. In retrospect, however, it is difficult to say which measure or combination of measures was responsible for the improvement.

Once these initial problems had been resolved, it was shown that accurate manufacture of all components to the specified standards and careful installation to the necessary limits will give a high-speed line that will run true within the fairly tight limits called for throughout the speed range and without the need for any balance correction *in situ*. The correction weights fitted for *in situ* balancing are held in reserve to allow the operators to correct any out of balance which may be generated during the life of the ship. Their use to compensate for any imperfections in a new installation is, if possible, to be avoided.

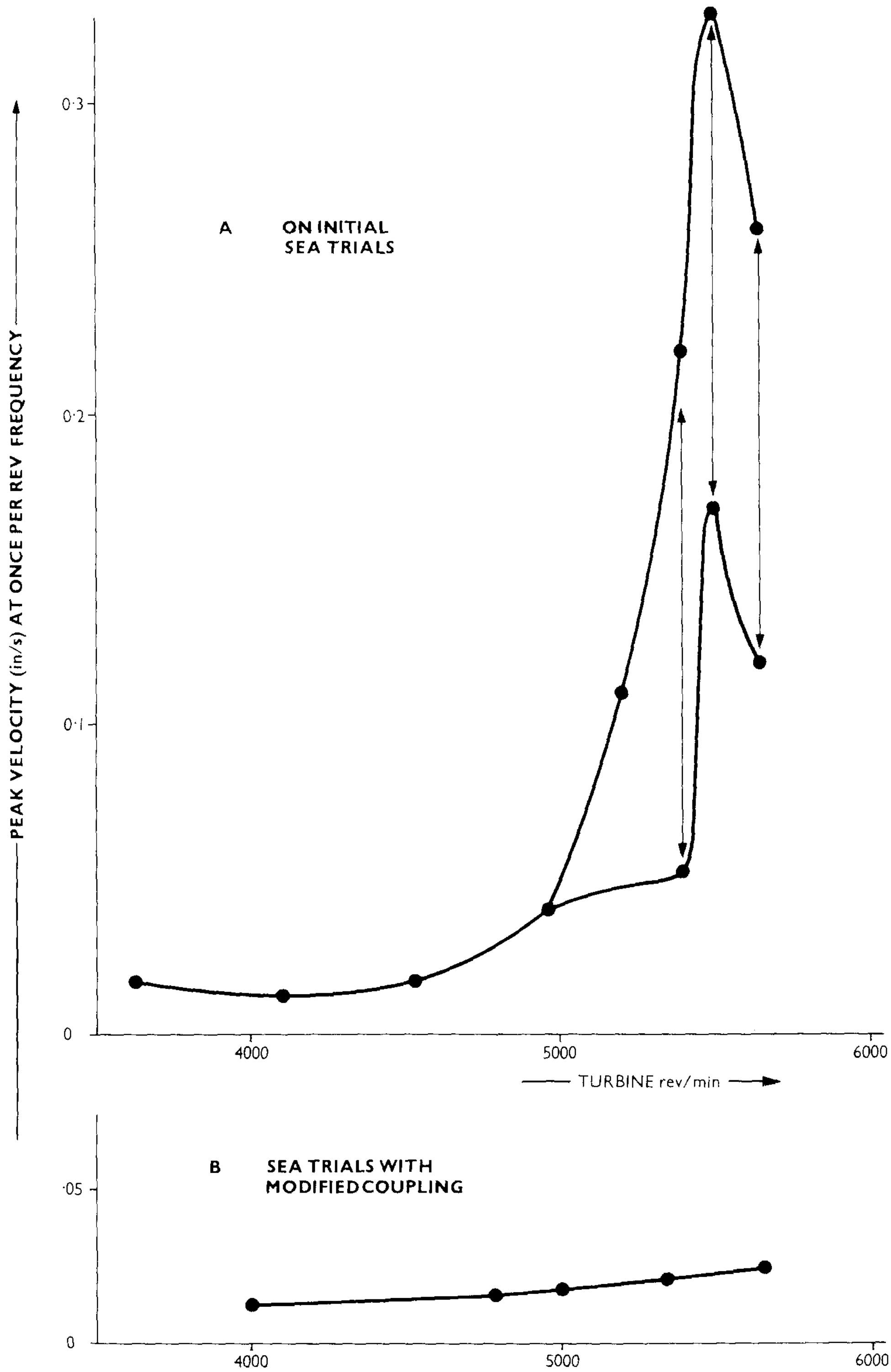
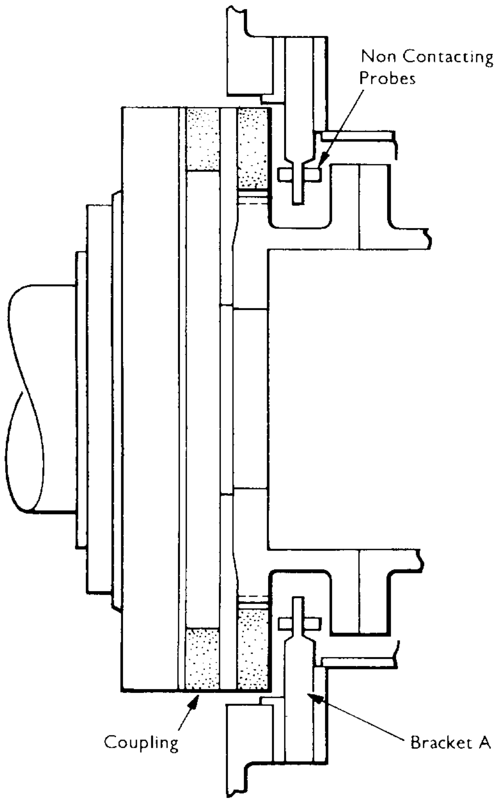


FIG. 6—COGOG OLYMPUS INPUT LINE—VIBRATION LEVELS AT COUPLING SUPPORT BEARING



TYPICAL PROBE MOUNTING BRACKET ASSEMBLY

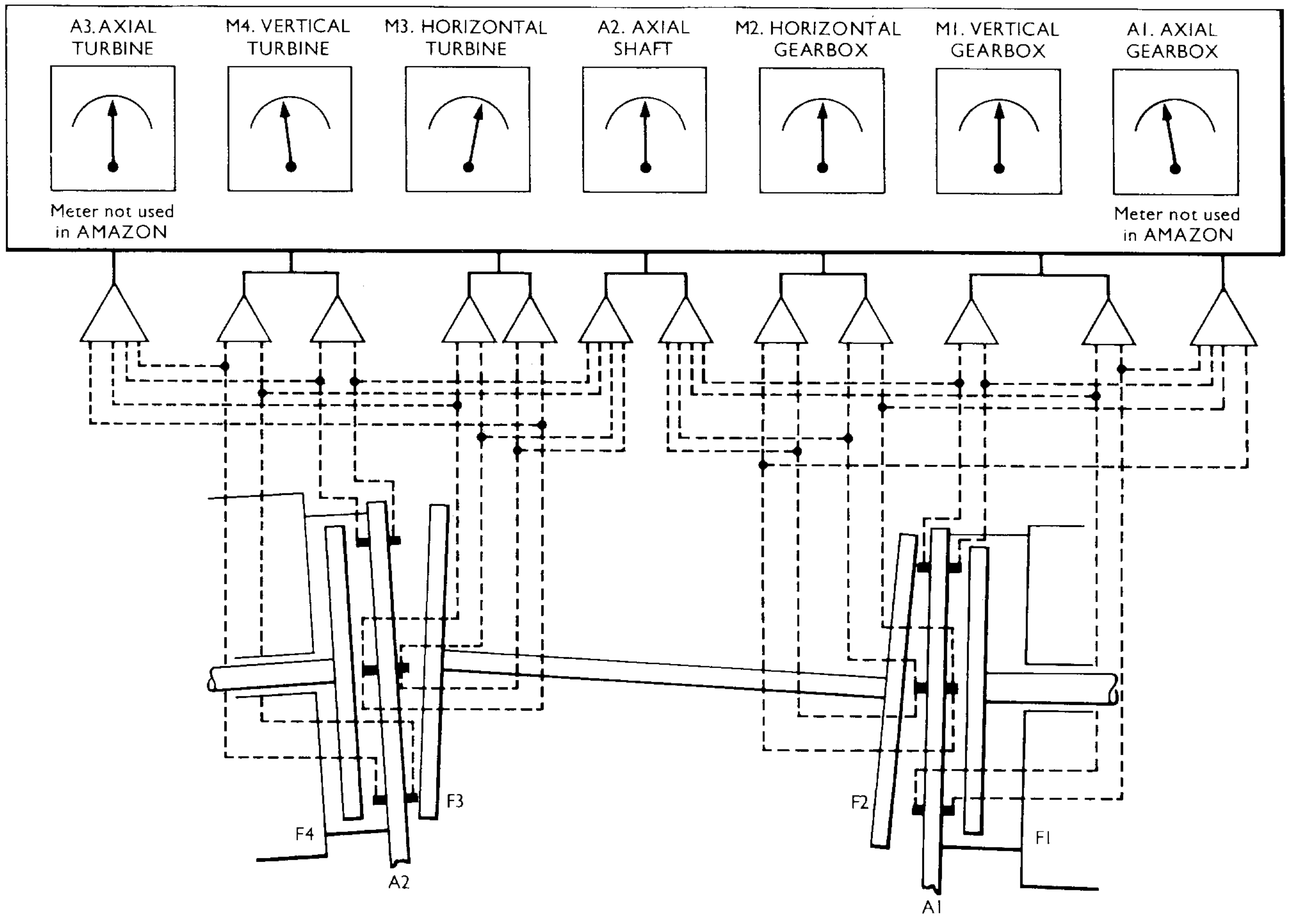


FIG. 7—SIMPLIFIED SCHEMATIC OF SHAFT ALIGNMENT METER SYSTEM

Other Applications

As already stated, membrane couplings are used in all R.N. gas-turbine ships. One application that is slightly different from those described above is in the ASW cruiser where, in addition to providing the coupling between the Olympus gas turbines and the main gearbox input flanges, membrane couplings are used, with and without spacer tubes, to provide articulation between gear elements within the main gearbox. The first of class, H.M.S. *Invincible*, has only recently been launched so there is no sea experience yet, but a main gearbox has been run on extensive shore trials and all the couplings have given satisfactory service despite being run near their alignment limits—in one case by design and in another by an unsuspected change in the alignment.

Satisfactory experience with this form of coupling led to its trial in place of a gear-tooth coupling in a *Leander* Class frigate in 1971–2. M-type membranes were used, but the overall length of the spacer coupling assembly was only 530mm between flanges. In the event, the experiment was a disaster that stressed again the need for careful and correct installation of these, or indeed any, couplings. In this case, the pedestal supporting the after steam-turbine bearing which was carrying the forward end of the coupling either worked loose or was left loose and, after operating for some eighteen months under conditions of gross misalignment, the turbine-end membrane bank failed completely with considerable consequential damage to the machinery installation. The subsequent investigation attributed the failure to the overstressing produced by this misalignment. Some corrosion of the membranes was found, in the form of stress corrosion towards the end of the spokes and fretting corrosion under the clamping rings. This prompted a review of the membrane material but it was finally considered that there was little to be gained from changing away from AISI301 stainless steel, especially as this would involve the Navy in using a different material from the usual commericial standard with all the consequent logistic problems.

This has been the Navy's only complete failure of these membranes, and the author is confident that, if they are treated correctly, it will remain the only one. Needless to say, that particular experiment was not repeated.

Measurement of Coupling Alignment and Attitude

A lesson learnt is that a membrane coupling will give good service if it is first correctly manufactured and correctly installed and then run within its designed alignment limits. For the latter, the MOD and Y-ARD Ltd. have developed a meter to indicate the running position taken up by the membrane banks of a M4000 spacer.

This meter utilizes small non-contacting displacement transducers to monitor the position of each membrane bank. FIG. 7 shows the mounting arrangements and a simplified schematic of the alignment monitoring system. Mounting brackets A_1 and A_2, usually in the form of rings, are located and fixed to suitable points on the power turbine and the main gearbox structure at each end of the coupling assembly. The brackets locate the position transducers between the flexible coupling flanges F_1, F_2 and F_3, F_4, the transducers being arranged to view the flanges in diametrically-opposed pairs in two mutually-perpendicular planes. Further transducers are mounted on the mounting brackets in mutually-perpendicular pairs to monitor and compensate for the movement of the power turbine and gearbox flanges.

The output from each transducer passes through an amplifier which also linearizes the output and allows adjustments to be made for different transducer target materials. As shown in FIG. 7, the meter system compares the output from complementary pairs of transducers and so displays the angular alignment of each membrane bank in two mutual planes on meters M_1, M_2, M_3, and M_4, and the axial position of the torque tube on meter A. After installation, the transducers are calibrated using slip gauges and a calibration facility is built into the system to standardize the meter display.

The system was first tried experimentally on a gas turbine shore-test rig, and a prototype version has now been installed to monitor a M4000 coupling on the Olympus high-speed line in a Type 21 frigate. This sea trial has two objectives: the firs is to evaluate the suitability of the system for ship board use, the second is to provide data on coupling transient alignment. If the meter operates successfully, then the data it gives will indicate whether the coupling is operating within its designed limits under all conditions. If it is, then no further action is needed, but, if it is not, then the possible actions could include changing the initial cold alignment, reviewing the declared life of membrane units, and possibly fitting a system of continuous alignment monitoring.

At the time of writing (August 1977), full results of this trial are not available. Unfortunately the system developed a fault during the first period at sea after installation but, for operational reasons, access could not be obtained to the equipment for some three months to rectify the fault; and shortly after the meter was made serviceable, the trial was again interrupted by the need for major gearing repairs. Initial trials showed that the thermal changes on start-up and shut-down produced quite large axial movements across the coupling (up to 2·5mm), while rapid changes of power resulted in changes in angular alignment of the order of 0·1 degree in each plane.

Acknowledgements

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