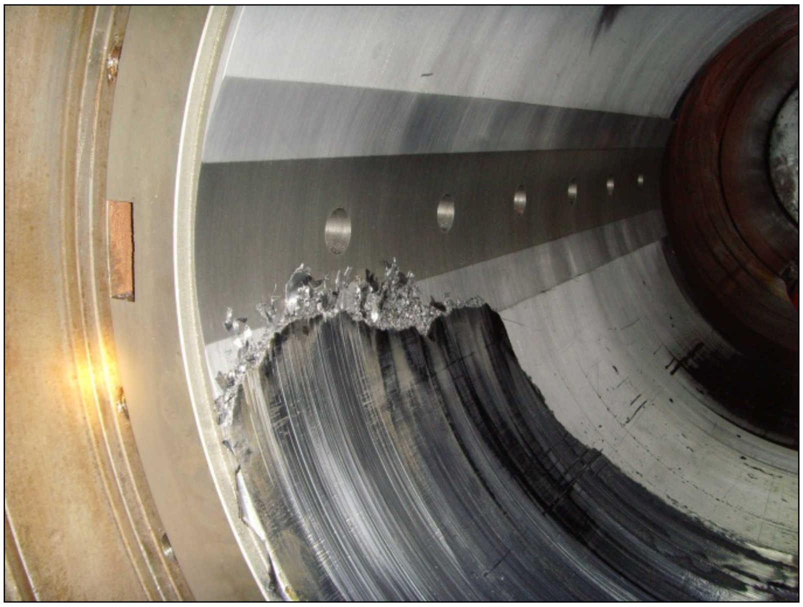
Shafting Systems without a Forward Stern Tube Bearing: Advantages and Prevention of Failures

Bruce Cowper, (FL), LamaLo Technology Inc.
Zachary Schramm, (M), Consultant to LamaLo Technology Inc.



Abstract

In recent years shafting systems, particularly those powered by slow-speed diesel engines, have been designed with only one bearing supporting the propeller shaft (typically an aft stern tube bearing). Designs with only one stern tube bearing provide for a system with more flexibility, easier installation, and a reduction in cost. With no forward stern tube bearing, there are different alignment characteristics that must be considered. Of importance is the significant effect of the aft intermediate shaft bearing position on the relative shaft slope in-way-of the aft stern tube bearing. The lineshaft bearing can be offset sufficiently to cause excessive relative shaft slope in the bearing, resulting in poor load distribution, excessive bearing pressure and subsequent failure. To provide more assurance that this relative shaft slope is acceptable with the vessel afloat and the shafting completely assembled, the strain gauge alignment measurement technique can be used. This paper describes the advantages of having only one propeller shaft bearing, the measurement technique used to reduce the risk of bearing failure due to excessive pressures, and examples of the application of this technique.

KEY WORDS

Alignment; Bearing; Propulsion Shafting; Stern Tube

INTRODUCTION

Some propulsion shafting designs have the propeller shaft supported by only one sterntube bearing, rather than the more traditional two sterntube bearing arrangement. This configuration has several advantages. The shafting system is more flexible, yielding ease of alignment and lower sensitivity to hull deflections and thermal growth. There is a reduction in material and labor costs. There is also the ability to adjust the relative shaft slope in way of the stern tube bearing without dry-docking, by proper positioning of the aft intermediate shaft bearing. However, this also means that excessive shaft slopes can result by improper positioning of this intermediate bearing. As evidenced by bearing failures, the impacts to traditional alignment processes when only one propeller shaft bearing is used, are not well understood. Fortunately, the strain gauge alignment technique can be used to mitigate the risk of these failures.

PROPULSION SHAFTING WITH TWO STERN TUBE BEARINGS

Conventional ship design has two stern tube bearings supporting the propeller shaft. It is common for these vessels to have shafting with a span to diameter ratio between the forward and aft stern tube bearings in the range of seven to ten. This generally results in a relatively stiff shafting system with corresponding disadvantages for alignment and maintaining acceptable bearing loads throughout the operating conditions.

Typical propulsion shaft deflection and slope curves, for a slow-speed diesel driven propeller, are shown in Figures 1 and 2, respectively. For this arrangement, the aft stern tube bearing is sloped (down going aft) to reduce the relative shaft slope in-way-of the bearing due to the overhanging mass of the propeller. This provides for a more equal pressure distribution across the bearing. In this example, the intermediate shaft bearing and main engine were required to be offset lower than the stern tube bearings by 2.6 and 4.4 mm, respectively. These lower offsets are required to ensure that the forward stern tube bearing is down-loaded and the shear force / bending moment combination at the thrust shaft flange are acceptable. During installation, the forward end of the propeller shaft is commonly required to be pulled down to load the forward stern tube bearing, prior to connecting the propeller shaft to the intermediate shaft. The procedure can be cumbersome and time consuming.

The forward stern tube bearing is normally aligned straight (no relative slope), yet the relative shaft slope can also be high in-way-of this bearing. There are cases where this slope results in high local pressure, as shown in Photo 1. This photo shows two wear patterns, one at the forward end and one on the bottom down the length of the bearing. The latter was likely due to installation of the propeller shaft before the propeller was installed, or initial wear-in of the bearing. There can be difficulty installing the propeller shaft, when the aft stern tube bearing required slope is exceeds the bearing clearance. For example, if the propeller shaft is installed from the forward end of the stern tube, the propeller shaft contacts the top of the aft stern tube bearing. This can require high forces to insert the shaft and result in damage to the bearing. All the above can be avoided when only one stern tube bearing is fitted.

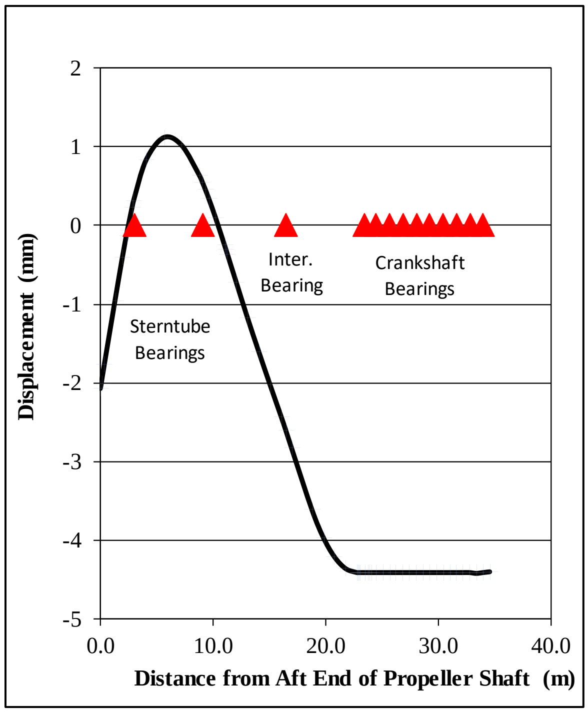


Figure 1. Shaft Deflection

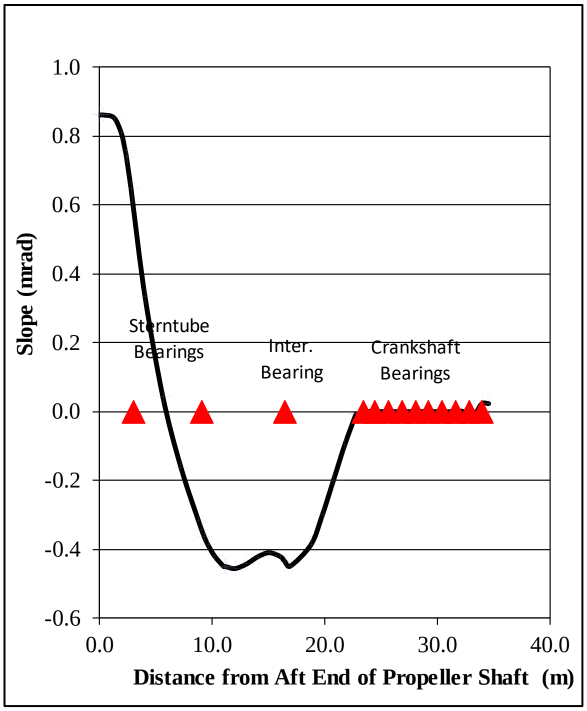


Figure 2. Shaft Slope

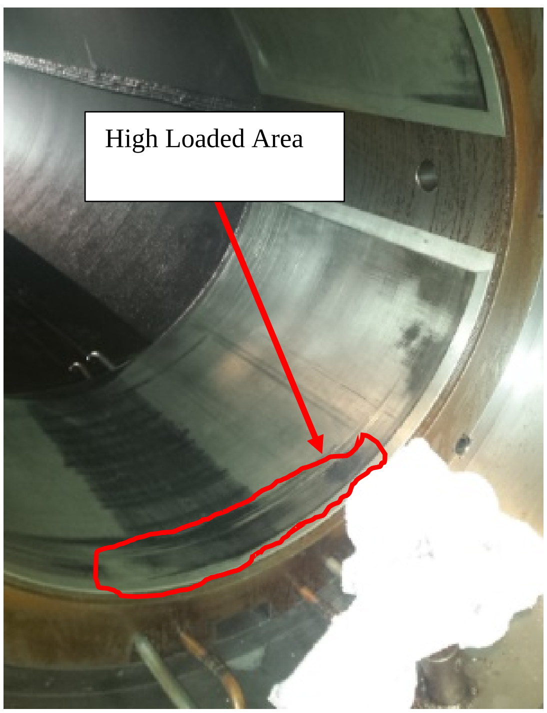


Photo 1. Forward Stern Tube Bearing Loading

ADVANTAGES AND CONSIDERATIONS OF SINGLE STERN TUBE BEARING CONFIGURATIONS

Shafting Flexibility

With no forward stern tube bearing, the spacing between the bearings increases resulting in increased shaftline flexibility. A recommended bearing spacing ratio for shafts diameters greater than 406 mm, is between 12 to 22 times the shaft diameter (Harrington, 1992). A more flexible system results in increased tolerance to changes in relative bearing offsets. Higher flexibility is also desirable during alignment, since the tolerances for bearing positioning are less restrictive. The intermediate shaft bearing(s) may need to be re-located to maintain acceptable bearing spacing and loads without a forward stern tube bearing.

Location of Center of Pressure

In a two-stern tube bearing configuration, the bearings are installed prior to launch and shaft installation, their orientation, and relative positioning remains fixed. A major advantage of single stern tube bearing systems is that the location of the center of pressure in the aft stern tube bearing, which is governed by the relative shaft slope, can be measured and adjusted with the vessel afloat. This is conducted by movement of the aft most intermediation shaft bearing.

Schedule and Cost

With one less stern tube bearing, there is a reduction in costs associated with design, manufacture, transport, installation, alignment, and documentation. Savings in duration are important, since this allows a facility to decrease cycle time which can affect the build strategy critical path.

Stern Tube Seal Considerations

Review of the forward and aft stern tube seal configuration and operating characteristics are prudent prior to changes in an existing stern tube bearing arrangement. Changes in the aft stern tube bearing center of pressure due to aft intermediate shaft bearing positioning could exceed the range of the forward or aft stern tube seals. Lateral vibration displacements, especially at the forward end of the stern tube, should also be reviewed to ensure they remain within this range.

STRAIN GAUGE TECHNIQUE

Shaft alignment analysis and measurement continues to be a critical part of ship construction and maintenance. One of the most common, and expensive, failures due to misalignment occur to the aft stern tube bearing. When an aft stern tube bearing is damaged the vessel generally needs to be drydocked and the shafting removed, at great expense and delay in ship availability. Using modern strain gauge alignment measurement and analysis techniques the risk of bearing failure can be reduced considerably. Strain gauges are mounted directly to the shaft to measure shaft bending strains at appropriate locations. The measured strains, in combination with the geometry and material properties of the shaft, are used to determine the bearing loads (Forrest, 1981). One of the significant advantages of the strain gauge alignment technique is that it can be used to measure stern tube bearing loads with the vessel afloat and the shafting completely assembled, and in the case of systems with one stern tube bearing supporting the propeller shaft, the location of the center of pressure on the stern tube bearing.

MEASURMEENT OF CENTER OF PRESSURE WITH NO FORWARD STERN TUBE BEARING

The location of the center of pressure can be measured using the strain gauge alignment technique, thereby providing critical data on the risk of excessive pressures on the bearing. Strain gauges are mounted at four locations, two aft and two forward of the intermediate bearing. Figure 3 illustrates the free-body diagram of the aft section of the shafting arrangement shown in Figure 4. First, the shear at the aft gauge location (V_A) is calculated from the measured bending strains at the aft two (2) strain gauges. The effective point support load (R_1) and location of the point support (center of pressure) [X_{R1}], on the stern tube bearing can then be calculated using equations (1) and (2). Table 1 provides the nomenclature for Figure 3. If the location of the center of pressure is found to be near the aft end, or forward end, of the bearing then the relative shaft slope in way of the bearing can be considered excessive.

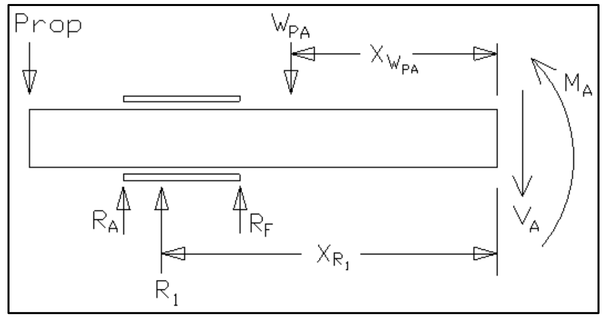


Figure 3. Freebody Diagram Aft Section

Table 1. Nomenclature for Figure 3

M_A	Bending Moment at section
R_1	Bearing load (1-Support Model)
R_A	Aft point load (2-Support Model)
R_F	Fwd. point load (2-Support Model)
V_A	Shear force at section A
W_{PA}	Weight of Section (with propeller)
X_{WPA}	Location of Center of Weight
X_{R1}	Location of center of pressure

$$\sum F_{PA} = 0 = R_1 - V_A - W_{PA}$$

$$\therefore \; R_1 = V_A + W_{PA} \qquad (1)$$

$$\sum M_A = 0 = -W_{PA}(X_{W_{PA}}) + R_1 X_{R_1} - M_A$$

$$\therefore \; X_{R_1} = \frac{W_{PA}\left(X_{W_{PA}}\right) + M_A}{R_1} \qquad (2)$$

A model with two (2) support points for the stern tube bearing can also be used to assess the bearing load distribution, one at the aft end and one at the forward end, (R_A & R_F), as shown in Figure 3. If one of the calculated loads is very low or negative, the bearing may not be loaded over its full length and the relative shaft slope may be excessive. However, using two support points forces the shaft to a specified offset at those support point locations. This results in unrealistic bearing load influence numbers, since the shaft is not free to bend along the length of the bearing, particularly forward of the center of pressure. Therefore, it is preferred to use the single support point model. Both models can be used and compared, with the single support being the preferred choice should there be a discrepancy between the two. Only the equations to calculate the center of pressure and a single-point support load are presented in this article.

APPLICATIONS

The measurement of the center of pressure in the aft stern tube bearing has been conducted with success on a number of vessels, both for new construction and troubleshooting. The following provides example results from three vessels, each with a single stern tube bearing.

Figure 4 is a schematic of a shafting system with only one stern tube bearing. Figure 5 illustrates the relative bearing pressure distributions that would correspond to the center of pressure measurements taken on an LPG Tanker and a Double-Hull Oil Tanker described below.

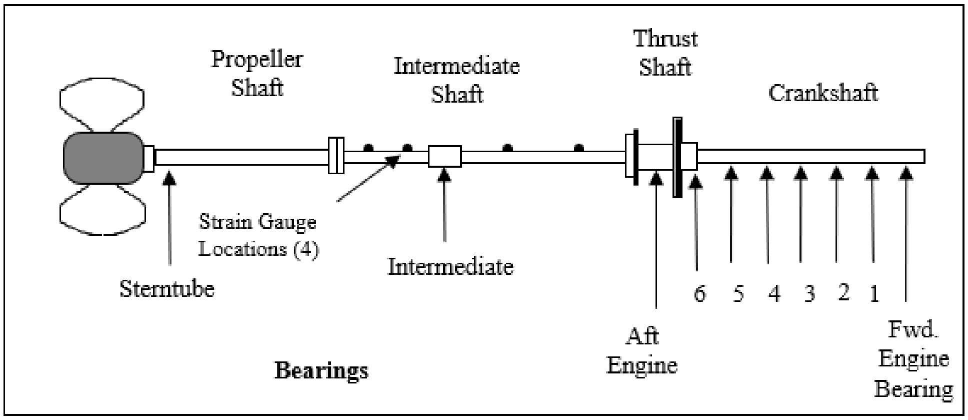


Figure 4. Schematic of a Propulsion Shaftline with One Stern Tube Bearing

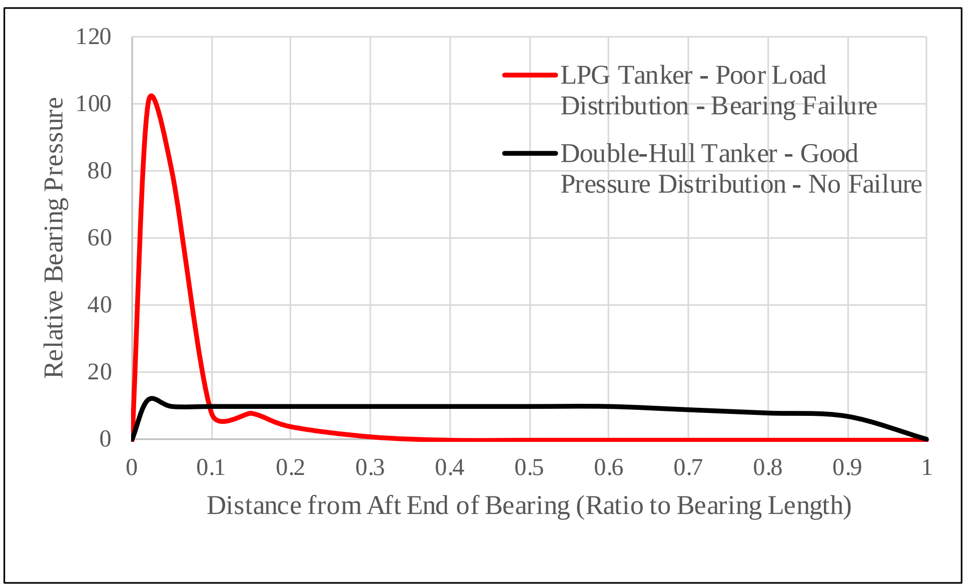


Figure 5. Estimated Relative Bearing Pressure Distribution in Aft Stern tube Bearing

Double-Hulled Oil Tanker

The center of pressure in the aft stern tube bearing was measured during construction of eight (8) 50,000 Tonne Double-Hulled Oil Tankers that were fitted with an arrangement similar to Figure 4. Table 2 lists the results of strain gauge alignment measurements from one of these tankers. After the initial measurement results were assessed, the intermediate shaft bearing was raised 1.8 mm to increase the load on the intermediate shaft bearing. Analysis indicated that the center of pressure moved from 65% of the bearing length from the aft end of the bearing to 44%. Both positions indicate an acceptable loading across the bearing with center of pressure near the middle of the bearing. All eight tankers have operated without any bearing incidents and with normal temperatures.

Table 2. Bearing Loads and Center of Pressure Location on a Double Hull Oil Tanker

Bearing	**Loads (kN)**			
	Initial Position		Interm. Bearing up 1.8 mm	
	Vert.	Horiz.	Vert.	Horiz.
Stern Tube	499	0	471	-2
Intermidate Shaft	6	4	51	-1
Stern Tube Bearing Center of Pressure Location				
Distance from Aft end of Bearing (mm)	805	NA	545	NA
Dist./Length	65%	NA	44%	NA

LPG Tanker

Table 3 lists the results from measurements taken on a shafting system on an LPG Tanker with an arrangement similar to Figure 4, but with the addition of a forward intermediate shaft bearing. The results indicated that the center of pressure was at the aft end of the stern tube bearing (2% of the bearing length from the aft end). This indicated a poor load distribution across the bearing and likely unacceptable bearing pressures at the aft end. During subsequent sea trials the stern tube bearing temperatures were excessive. The vessel was docked, and shafting removed for inspection. The aft end of the bearing was found to be damaged (wiped babbitt) as shown in Photo 3. The bearing was subsequently sloped aft to reduce the relative shaft slope and returned to service without any further issues.

Table 3. Measured Bearing Loads and Center of Pressure Location on LPG Tanker

Bearing	**Bearing Loads (kN)**	
	Vertical	**Horizontal**
Stern Tube	309	9
Aft Intermediate	59	-8
Fwd. Intermediate	117	-5
Stern Tube Bearing Center of Pressure		
Distance from Aft End (mm)		18
Distance / Bearing Length		2%

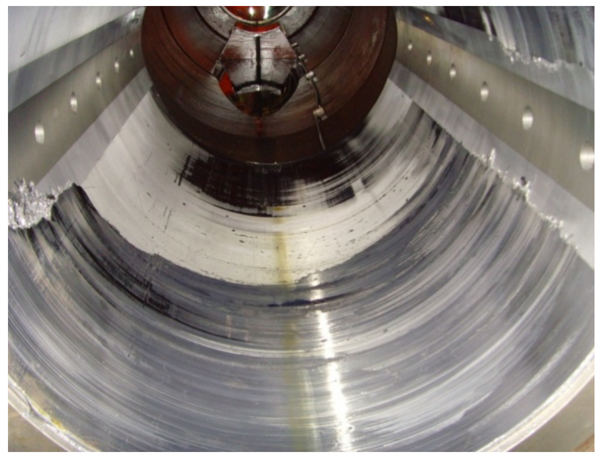


Photo 3. Damaged Stern tube Bearing – Center of Pressure at Aft End

Tanker Review / Analysis Before Construction

During the design review phase for a class of tankers with a shafting system similar to that shown in Figure 4, consideration was given to removal of the forward stern tube bearing. The factors discussed previously were reviewed. With a forward stern tube bearing fitted, the span to diameter ratio was 8 between the stern tube bearings, and 11 between the forward stern tube and intermediate shaft bearing. Without the forward stern tube bearing, the span to diameter ratio was 18 between the stern tube and intermediate shaft bearing. While span to diameter ratios of 25 or less generally do not have lateral vibration concerns, the natural frequencies were reviewed under both configurations and found acceptable.

The impact to shaftline flexibility is apparent when reviewing the bearing reaction influence numbers shown in Table 4 below. In the initial configuration, an offset of the intermediate shaft bearing down 0.36 mm results in a change in load of -35 kN, which is 100% of the theoretical aligned warm load. The corresponding load on the forward stern tube bearing was 30% of the theoretical aligned load.

With the forward stern tube bearing removed, bearing load influence numbers are reduced significantly. The influence of the intermediate bearing on itself is reduced by 226%. If the option was made available, movement of the intermediate shaft bearing aft was also recommended, since it would further reduce the influence on the main engine bearing loads and provide better control of the stern tube bearing center of pressure.

The shafting arrangement was satisfactory in both configurations and the decision was left to the design agent on final arrangement. The forward stern tube bearing was in fact installed and eight vessels were delivered. All operating without any shafting or bearing issues. *(On these vessels, the location of the center of pressure in the aft sterntube bearing was also estimated using similar techniques described above.)*

Table 4. Bearing Reaction Influence Number Comparison

Change in Bearing Load by Lowering Bearing 1 mm (kN/mm)				
Two Stern Tube Bearings				
	Aft Stern Tube	Fwd. Stern Tube	Interm. Shaft	Aft Engine
Aft Stern Tube	-9.1	20.2	-15.9	16.3
Fwd. Stern Tube	20.2	-50.6	52.5	-74.6
Interm. Shaft	-15.9	52.5	-97.9	279.6
Aft Engine	16.3	-74.6	279.6	-2211.0
One Stern Tube Bearing				
	Aft Stern Tube	N/A	Interm. Shaft	Aft Engine
Aft Stern Tube	-1.1	N/A	5.0	-12.8
N/A	N/A	N/A	N/A	N/A
Interm. Shaft	5.0	N/A	-43.3	191.7
Aft Engine	-12.8	N/A	191.7	-1870.0

CLASSIFICATION SOCIETY GUIDELINES

Classification societies have recently revised Guidelines in attempt to address continued failures of aft stern tube bearings on systems with no forward stern tube bearing (as well as systems with two stern tube bearings). For example, American Bureau of Shipping Steel Vessel Rules (2018) 4.3.2/7.3.4 (ii) states the following for systems with only one stern tube bearing:

- The aftmost intermediate shaft bearing is to serve as the second fixed point of reference when sighting is conducted.
- The intermediate shaft bearing is to be chocked and its offset not changed after the bore sighting is complete, except as agreed to by the attending Surveyor based on the clearance measurements identified in 4-3-2/7.3 4 iv) …

It is assumed that the above was to reduce the incidence of excessive relative shaft slope at the stern tube bearing, when the intermediate shaft bearing is adjusted. However, as described above, the intermediate shaft bearing can be adjusted without risk of stern tube bearing failure, which provides for more options during final alignment. For example, to provide acceptable loading on the aft most engine bearing, it is less time consuming to adjust the intermediate shaft bearing, rather than the main engine.

CONCLUSIONS

There are many advantages of designs with only one stern tube bearing, these include:

- Capital cost reduction
- Relative shaft slope in way of bearing can be adjusted after the vessel is launched.
- Reduction in installation and alignment time
- Increase in shaft flexibility

When properly employed, the strain gauge alignment technique can expedite propeller shaft installation and ultimately vessel construction or repair. Submission of these type of measurement results should also assist in obtaining approval of the installed alignment condition by Classification Societies, particularly regarding the concern the relative shaft slope at the stern tube bearing.

A similar technique described herein has been developed, and implemented with success, to estimate the center of pressure in the aft stern tube bearing for shafting systems with two stern tube bearings.

In the Author's experience implementing the methods described in this paper has resulted in a 100% success rate. This has included over 50 cargo vessels, and more than 7 different Classes *(vessels fitted with both single and two stern tube bearings).*

ACKNOWLEDGEMENTS

The authors acknowledge, with thanks, to the shipyard personnel for their hard work in properly implementing the alignment procedures and installation of shafting systems. Without their diligence, success would not be obtained. Also, thanks to the ship-owners and equipment suppliers for their cooperation and acceptance of these procedures.

REFERENCES

American Bureau of Shipping, "Rules for Building and Classing Steel Vessels, Part 4 Machinery Equipment and Systems", 2018.

Cowper, B., et. al., "Shaft Alignment Using Strain Gauges: Case Studies", Marine Technology, April 1999.

Cowper, B., et. al., Application of the Strain Gauge Alignment Technique on Slow-Speed Diesel Propulsion Shafting Installations , Presented at the World Maritime Technology Conference (WMTC), London, England March 2006

Forrest Jr., A.W., Labasky, R.F., Shaft Alignment Using Strain Gauges, SNAME Marine Technology, July 1981.

Harington, R., "Marine Engineering", SNAME, 1992.