GUIDE FOR

ENHANCED SHAFT ALIGNMENT

NOVEMBER 2016

American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

ABS Plaza
16855 Northchase Drive
Houston, TX 77060 USA

Foreword

The ABS *Guide for Enhanced Shaft Alignment* has been developed to address requests from owners and operators who wish to perform a more detailed shaft alignment analysis and installation assessment.

Vessels designed, constructed and operated in compliance with the requirements of this Guide may be assigned the Class Notation **ESA**.

Assignment of the **ESA** Notation requires the review of plans and calculations by an ABS Engineering Office and the attendance of an ABS Surveyor during additional shafting alignment efforts.

The intention of the Guide is to address shafting arrangements that may benefit from a more detailed analysis and a more accurate and structured procedure so as to optimize the shaft alignment and improve the service life of the vessel's powertrain. This Guide is intended to apply mainly to shaft alignment-sensitive vessels, as defined in this Guide, although it could apply to a wider range of powertrains including geared installations.

The main aspects that distinguish compliance with this Notation from the standard Rule application are:

- A final Shaft Alignment sighting is to be conducted after the engine or gearbox and other heavy machinery are installed on board and all major steel works are completed at the aft part of the vessel.
- Shaft alignment optimization calculations are required.
- Compulsory inclusion of hull deflections to be taken into account in the analysis.
- Requirement for Lateral Vibration (Whirling) analysis of the powertrain shafting system.
- Shaft alignment verification at more than one service condition.
- The vessel must be assigned the Tailshaft Condition Monitoring**TCM** Notation.

The ABS *Guide for Enhanced Shaft Alignment* is to be used in conjunction with all other applicable Rules, Guides and Guidelines published by ABS.

This Guide becomes effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of this Guide is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.

GUIDE FOR

ENHANCED SHAFT ALIGNMENT

CONTENTS

![ABS logo]

SECTION 1 General

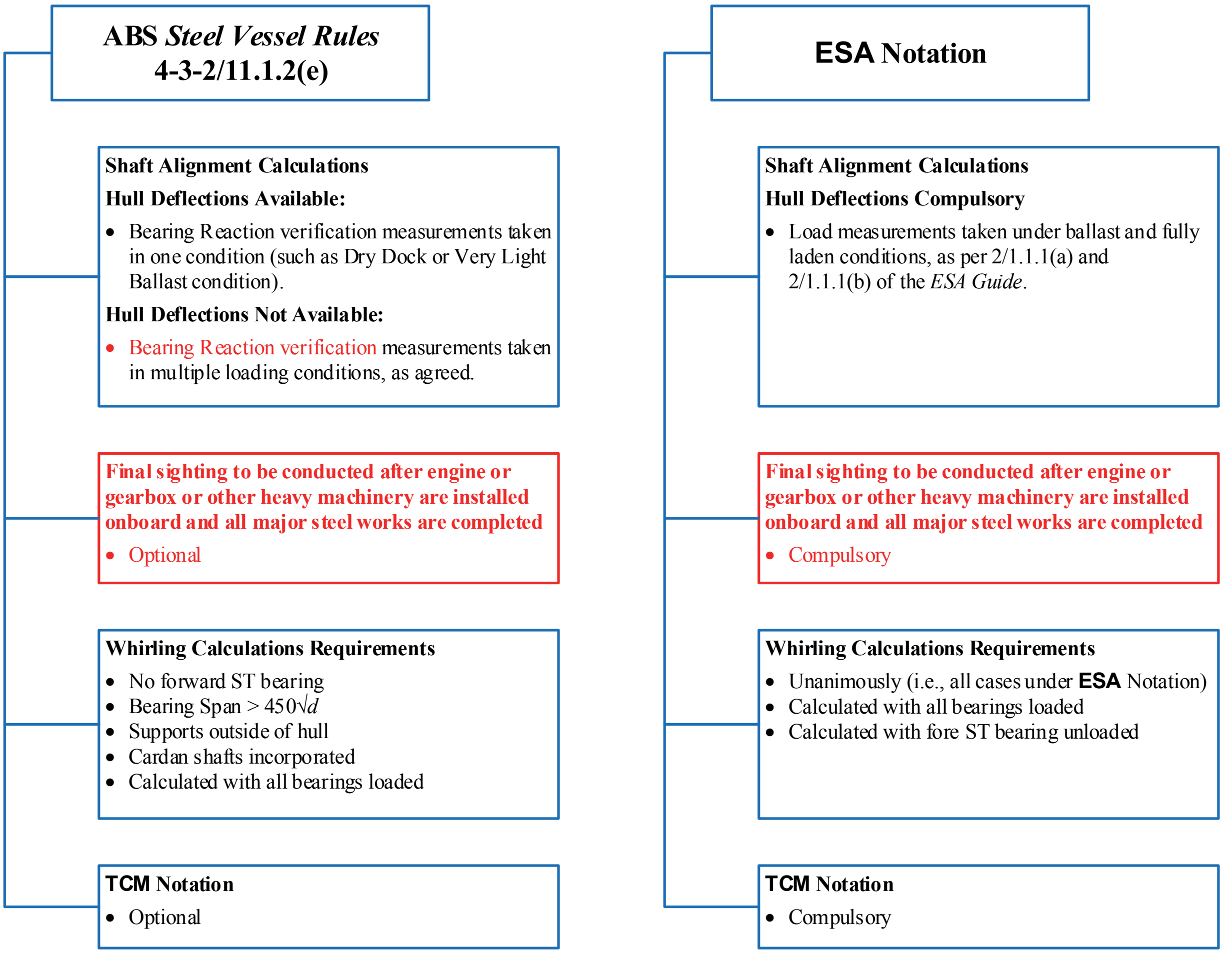
1 Introduction

1.1 ESA Notation

Requirements of this Guide are optional for classification purposes. However, where assignment of the optional notation **ESA** – Enhanced Shaft Alignment is being requested, provisions of this Guide are compulsory.

This Guide provides criteria for additional calculation requirements, such as design optimization, as well as more detailed requirements regarding the shaft alignment procedures in support of the optional notation **ESA** - Enhanced Shaft Alignment. Typical differences can be explained through the flowchart examples of Section 1, Figure 1.

FIGURE 1
Selected Differences between ESA Notation Requirements and ABS Rules *(1 November 2016)*



1.1.1 Objective

The objective of this Guide is to identify additional requirements and procedures beyond the minimum requirements currently specified in the ABS *Rules for Building and Classing Steel Vessels* so as to further enhance the shaft alignment. Vessels designed, constructed and operated in compliance with the requirements of this Guide may be assigned the Class Notation **ESA**.

1.1.2 General Requirements *(1 November 2016)*

The shaft alignment procedure for vessels with the **ESA** Notation requires that the final shaft alignment sighting is to be carried out after the vessel stern blocks are fully welded and all of the heavy stern structure is in place, such as any stern accommodation block, including the main engine and/or gearbox. This is to be verified by the attending Surveyor.

1.3 Definitions

1.3.1 ABS Rules

The ABS *Rules for Building and Classing Steel Vessels* is hereafter referred to as "*Steel Vessel Rules*".

1.3.2 **ESA** Notation

The notation granted based upon compliance with the requirements described in this Guide.

1.3.3 FEA

Finite Element Analysis.

1.3.4 MCR

Maximum Continuous Rating.

1.3.5 Very Light Ballast Condition

The condition in which the vessel is either in dry-dock or afloat at a quay with minimum ballast nearing a "lightship" condition. This condition is expected to have the least influence in the calculations with hull deflections that would affect the shaft alignment and therefore, it is considered as a condition without hull deflections.

1.3.6 Global Reference Line

In the shaft alignment sighting, the global reference line is the 0 (zero) datum used as the reference for all bearing offsets. All bearing offsets values are recorded based on this datum.

1.3.7 Shaft Alignment

The configuration of the shafts and bearings relative to the centerlines of the bearings from the theoretical straight line condition, so as to achieve an acceptable bearing load distribution.

1.3.8 Alignment Optimization

Alignment optimization is a condition where a mathematically predicted set of bearing offsets produces a satisfactory bearing load distribution for more than one alignment condition.

The shaft alignment optimization estimates the most possible uniform bearing load distribution for any given vessel loading case. It will produce an optimum set of bearing offsets, which will satisfy the vessel loading conditions from very light ballast to the fully-laden condition.

Knowing the hull deflections envelope together with the required operating conditions (e.g. fully loaded, hot dynamic), a bearing offsets range can be defined within which acceptable bearing load distribution.

Performing a reverse engineering calculation with the desired bearing load distribution as input and the bearing offsets range also as input, a specific set of bearing offsets can be calculated (usually more than one) as output, which is to be acceptable under all loading conditions.

This set of bearing offsets is said to be optimal and the shaftline is said to be optimum for alignment purposes, in accordance to the definition given to the alignment optimization.

1.3.9 M/E

Main Engine.

1.3.10 TCM

ABS Tailshaft Condition Monitoring Notation.

1.3.11 Shaft Alignment Sensitive Vessels

Large tank vessels such as Suezmax, VLCC, ULCC, LNGC, large bulk carriers, such as Capesize and VLOC, and large container vessels, i.e. above 9000 TEU are considered to be shaft alignment sensitive vessels.

In addition, the following propulsion systems are considered to be potentially shaft alignment-sensitive installations:

- Directly driven propeller installations
- Low speed diesel installations
- Systems with relatively short and rigid shafting
- Vessels with a relatively flexible hull structure
- Vessels with twin screw installations

3 Application

3.1 General *(1 November 2016)*

3.1.1 Notation Assignment

Vessels designed and constructed in compliance with the optional requirements of this Guide may be assigned the Class Notation **ESA**.

While the notation has been developed primarily for shaft alignment sensitive vessels and propulsion systems, other types of vessels and other types of powertrains may be granted the **ESA** Notation.

3.1.2 Survey

The Surveyor is to attend all stages of alignment as described herein.

The shipyard is to produce a log with the recordings of all the shaft alignment installation steps, including the sighting data recorded along with the manufacturers' acceptance criteria. The same is to be submitted to the ABS Engineering Office for review and for future reference.

3.1.3 Correlation with Calculations

The onboard shaft alignment is to be consistent with the system description and input parameters as listed in the approved calculations. Correlation between measurements and calculations for various shaft alignment conditions is to be verified at all times and stages of the process. The correlations criteria between calculations and measurements are defined in 3/3.5xxiv).

3.1.4 Other Powertrains

The Class Notation **ESA** is not applicable to ships designed with azimuthal thrusters or nonconventional shaft lines intended for main propulsion, or as otherwise deemed inappropriate by ABS.

3.1.5 Applicability Requirements

Class Notation **ESA** may be assigned to ships designed with one or more propulsion shaft lines that comply with the following:

i) Propulsion types of direct drives and geared drive installations, as shown in Section 1, Table 1 *ii)* The additional calculation requirements of Subsection 2/1 including hull deflections and shaft alignment optimization

iii) The shaft alignment processes described in Section 3 of this Guide.

iv) Possess the **TCM** Notation as per 4-3-2/13 of the *Steel Vessel Rules*

3.1.6 Geared Installations

For geared installations, as the low speed shaft will be stiffer than the high speed shaft, only the propeller to gearbox shaft alignment is required to be submitted to ABS for approval.

3.1.7 Alternative Shafting Arrangements

Shafting arrangements applicable for the **ESA** Notation are shown in Section 1, Table 1 below.

In cases of specific shafting arrangements not covered by this Guide, ABS may require additional calculations to verify compliance with the **ESA** Notation requirements.

TABLE 1
Propulsion Types and Shaft Alignment Systems that can be Covered by the ESA Notation

Propulsion Type	*Prime Mover*	*Alignment System*
Direct drive installation	Low-speed diesel/gas engine	from propeller to crankshaft
	Electric motor	from propeller to rotor shaft
Geared drive installation	Medium-speed diesel/gas engine	from propeller to main gearbox output shaft
	Steam/gas turbine	
	Electric motor	

5 Documentation

5.1 Documentation to be Submitted

5.1.1 Drawings

i) Shafting arrangement

ii) Intermediate shaft, propeller shaft drawings

iii) Couplings – integral, demountable, keyed, or shrink-fit, coupling bolts and keys' drawings

iv) Shaft bearing drawings

v) Shaft seals' drawings

vi) Propeller drawings

vii) Gearbox drawings, as applicable, as necessary

viii) Stern tube bearing and intermediate bearing drawings

5.1.2 Data *(1 November 2016)*

i) Rated power of main engine and shaft rpm

ii) Allowable bearing loads

iii) Actual Propeller mass and inertia

iv) Hull deflections data for light ballast, ballast and fully laden condition. Hull deflections data for light ballast, ballast and fully laden condition. In the ballast condition hull deflections are to be analyzed with the aft peak tanks full.

v) Crankshaft Deflection allowable limits

vi) All Bearing Stiffness values and information

vii) Propeller forces and moments for the following conditions:

a) Straight course, at full speed, in a fully laden condition

b) Straight course, at full speed, in the ballast condition

c) Full rudder starboard and port turns, at full speed, in a fully laden condition

d) Full rudder starboard and port turns, at full speed, in the ballast condition

5.1.3 Calculations *(1 November 2016)*

i) Details of shaft alignment calculation as required by the 4-3-2/7.3.2 of the *Steel Vessel Rules*

ii) Details of shaft alignment optimization calculation

iii) Aft Stern Tube Bearing Contact Analysis detailing the maximum remaining misalignment angle between the shaft and the bearing housing as well as the maximum estimated contact area and the calculated maximum contact pressure for the following conditions:

a) Hot static condition with propeller fully immersed

b) Hot running, straight course at full speed, in fully laden and ballast conditions

c) Hot running, full rudder starboard and port turns, at full speed, in a fully laden condition.

d) Hot running, full rudder starboard and port turns, at full speed, in the ballast condition.

iv) Lateral Vibration (Whirling) Calculations

v) Engine chock calculations

vi) For engine installations with resilient (flexible) mountings, the natural frequencies of the engine mounting system to be submitted in a form of a Campbell diagram.

5.1.4 Materials

i) Material properties of the shafts and bearings

5.1.5 Procedures

i) Details of shaft alignment procedure.

ii) Details of Bearing "Running in" procedure.

5.1.6 Measurements

i) Bearing temperature measurements and recording during "Running in" phase during sea trials

ii) Shaft Alignment Measurements including jack-up tests or strain gauge recordings and analyses

iii) Measurement report as per the **ESA** Notation requirements in 4/1.1

ABS may require additional drawings or documentation, as deemed necessary.

SECTION 2 Calculation Requirements for the ESA Notation

1 Calculations

1.1 General

1.1.1 Scope and Objective of Shaft Alignment Calculations

1.1.1(a) Calculations. The goal of the shaft alignment calculations is to provide data to the ship production personnel in order to determine satisfactory alignment under all intended operating conditions of the vessel (from ballast to full-load). Accordingly, the below calculations are to be conducted and verified for the following conditions:

i) Dry dock or waterborne at very light ballast at cold engine or gearbox and with propeller partially immersed

ii) Fully ballasted vessel with cold engine or gear box

iii) Fully ballasted vessel with hot engine or gear box

iv) Fully laden vessel with cold engine or gearbox, and

v) Fully laden vessel with hot engine or gearbox

Note: Conditions 2/1.1.1(a)ii) through 2/1.1.1(a)v) are to be analyzed with the propeller fully immersed.

1.1.1(b) Bearing Reactions. It is recognized that a fully ballasted vessel or a fully laden vessel may produce different bearing reaction results if the aft peak tank(s) is full or empty and when aft peak tanks are not void spaces. When hull deflection analysis such as FEA, may permit a level of resolution that enables to distinguish hull deflections with aft peak tanks full and with aft peak tank empty, then the below calculations are to be conducted and verified for the following conditions:

i) Dry dock or waterborne at very light ballast at cold engine or gearbox and with propeller partially immersed and aft peak tank empty

ii) Fully ballasted vessel with cold engine or gear box, and aft peak tank empty

iii) Fully ballasted vessel with hot engine or gear box and aft peak tank full or as filled up as permitted by the vessels' loading manual

iv) Fully laden vessel with cold engine or gearbox and aft peak tank empty

v) Fully laden vessel with hot engine or gearbox and aft peak tank full or as filled up as permitted by the vessels' loading manual

Note: Conditions 2/1.1.1(b)ii) through 2/1.1.1(b)v) are to be analyzed with the propeller fully immersed.

1.3 Additional Specialized Calculations

1.3.1 Requirements

All the design and installation criteria for shaft alignment calculations, as described in the *Steel Vessel Rules*, are to be applied.

In addition to the calculation requirements specified in 4-3-2/7.3.2 of the *Steel Vessel Rules*, there are additional requirements as follows:

1.3.1(a) Optimization of Bearing Offsets

i) Optimization of bearing offsets, as shown in 2/1.3.2 and in Appendix 1 of this Guide, is to be defined.

ii) If the optimization is not defined as per the ABS definition, a clear definition of the proposed objective function of the optimization, as well as the design and state variables used in the proposed optimization analysis, are to be submitted to ABS for special consideration.

1.3.1(b) Aft Stern Tube Bearing Contact Analysis Showing:

i) The calculated misalignment slope or the slope boring requirements before and after the application of the slope angle,

ii) The calculated actual contact area and

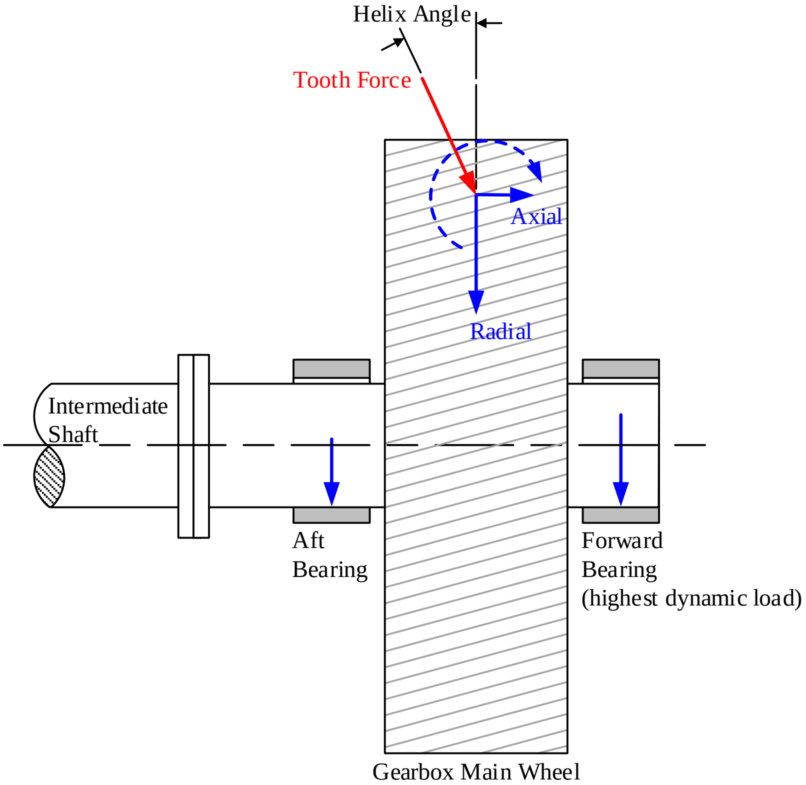
iii) Calculated actual contact pressure exerted by the shaft on the aft stern tube bearing bush.

Note: Alternative analyses based on finite element modeling or other acceptable methods which provide the above information and are determined to be acceptable to ABS may be considered on a case by case basis.

1.3.1(c) Lateral Vibration (Whirling) Calculations (1 November 2016). The requirements for Whirling Vibration Calculations, as addressed in 4-3-2/7.9.2 of the *Steel Vessel Rules*, are to be applied. For the **ESA** Notation, the whirling vibration calculation is to be submitted for all cases, even if not required by 4-3-2/7.9.1 of the *Steel Vessel Rules*.

1.3.1(d) Geared Installation Calculations. For shafting driven via a gearbox, the alignment analysis is to take account of the vertical and horizontal components of total forces applied by the pinion in the dynamic condition. Single helical gears will also result in applied moments due to unbalanced axial components of tooth force and these are to be included in the calculations.

FIGURE 1
Schematic Showing the Requirement of the Gearbox Forces Calculation in the Shaft Alignment Analysis Report



1.3.2 Shaft Alignment Optimization Calculation

The Shaft Alignment Optimization Calculation is to provide a set of bearing offsets at the drydock or very light ballast condition, which are regarded as optimal when considering the full range of vessel loading conditions (i.e., producing optimum bearing reactions for the conditions described in 2/1.1.1).

Alternative conditions will also be considered, such as:

i) Dynamic conditions including propeller loads due to influence from wakefield or bearing fluid film onto shaft (i.e., utilizing fluid structure interaction type of calculations), or

ii) As deemed appropriate by ABS with respect to the level of engineering assumptions, analysis and calculation simulation.

The ABS definition of Shaft Alignment Optimization as well as alternative Shaft Alignment Optimization definitions are outlined in Appendix 1 of this Guide.

ABS has developed the ABS Shaft Alignment software program that may be used to perform the shaft alignment optimization calculation. This program is available to ABS clients and interested parties are kindly requested to contact the nearest ABS plan approval office for more information. The definition of the ABS Shaft Alignment Optimization in this Guide is fully integrated into the ABS Shaft Alignment software program and thus utilizing this software program is an efficient way to perform this calculation. Alternative software programs utilizing alternative shaft alignment optimization definitions may be proposed.

1.3.3 Aft Stern Tube Bearing Contact Analysis

The slope angle between the shaft and the bearing is to be calculated and verified for the stern tube aft bush bearing in the hot static condition. The required calculated output quantities are:

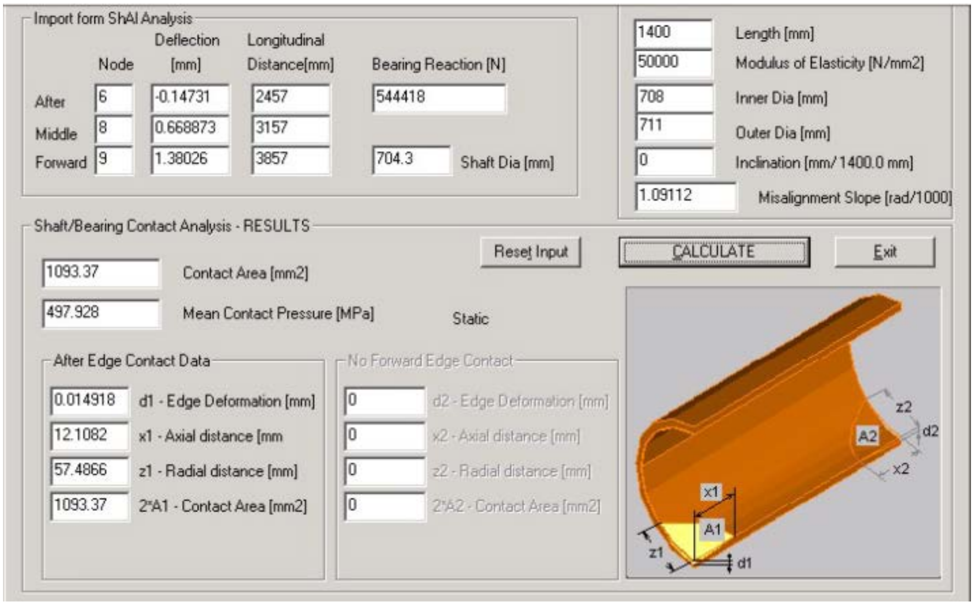
i) Slope angle between the shaft and aft stern tube bearing (misalignment angle) before and after the application of slope boring angle or inclination angle in the hot static condition.

ii) Estimated Contact Area between the shaft and the bearing bush.

iii) Estimated Mean Actual Contact Pressure between the shaft and the bearing bush.

The relevant calculation is to detail the calculation process and the assumptions made.

FIGURE 2
Stern Tube Bearing Contact Analysis Screenshot from the ABS Shaft Alignment Software



The ABS Shaft Alignment Optimization software may also be used in the required bearing contact investigation and analysis.

1.3.4 Lateral Vibration (Whirling) Calculations

Whirling Vibration calculations are to be submitted for all shafting systems for vessels and are to take into account the requirements explained in 4-3-2/7.9.2 of the *Steel Vessel Rules*.

In addition to the above Rule requirements, the bearing stiffness calculation including oil-film and bearing pedestal stiffness or other structural stiffness considerations are to be included in the calculations, clearly stating all the appropriate assumptions made.

The following cases are to be examined in terms of calculation of critical speeds' location within the operational speed range:

i) All bearings positively loaded as per the alignment calculation report results and with the appropriate bearing stiffness calculation for each bearing.

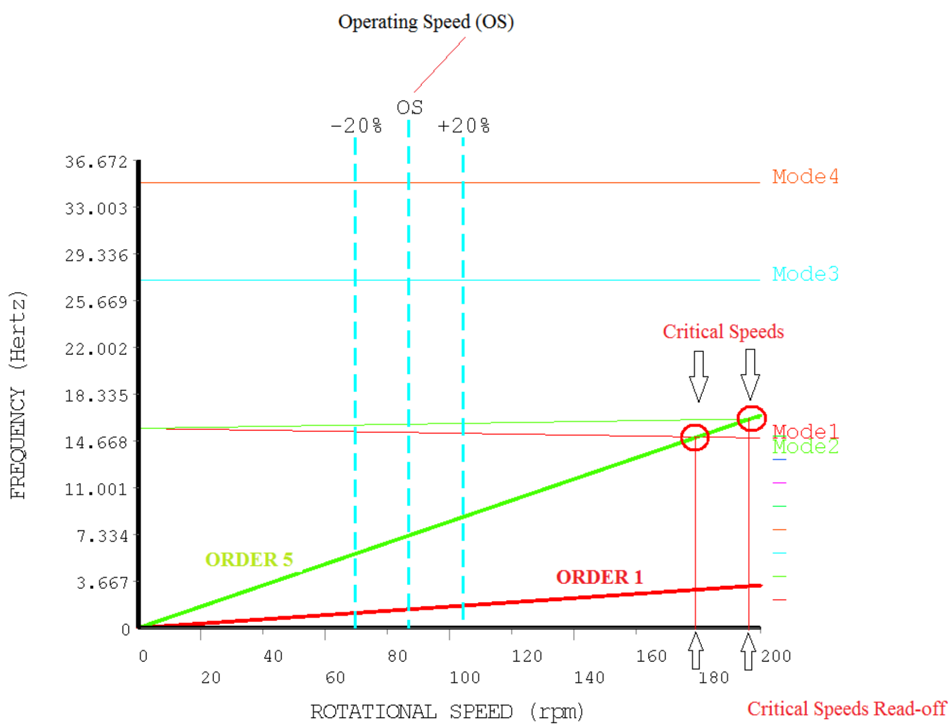
ii) As with 2/1.3.4i), but with unloaded forward stern tube bearing.

The following conditions are to apply:

- For 2/1.3.4i) and 2/1.3.4ii), the critical speeds are not to lie within ±20% of the MCR.

The preferred means of critical speed presentation for lateral-whirling vibration is through a Campbell diagram, with the X-axis representing the propeller shaft speed and the Y-axis representing the natural frequencies variation with propeller shaft speed. The influence of the gyroscopic effect is to be considered and possibly demonstrated in the Campbell diagram. The significant forcing orders, the first order (shaft unbalance) and the fourth or fifth order (Blade Passing Frequency for a five-bladed propeller, for example) is to be overlaid on the graph, clearly showing the critical speeds as intersections between the forcing orders and the natural frequency lines. The critical speeds in RPM are to then be listed preferably in a tabular format and those that lie inside the operating range of speeds are to be clearly highlighted.

FIGURE 3
Representation of Critical Speeds for a Whirling Calculation using a Campbell Diagram



3 Hull Girder Deflections

3.1 General

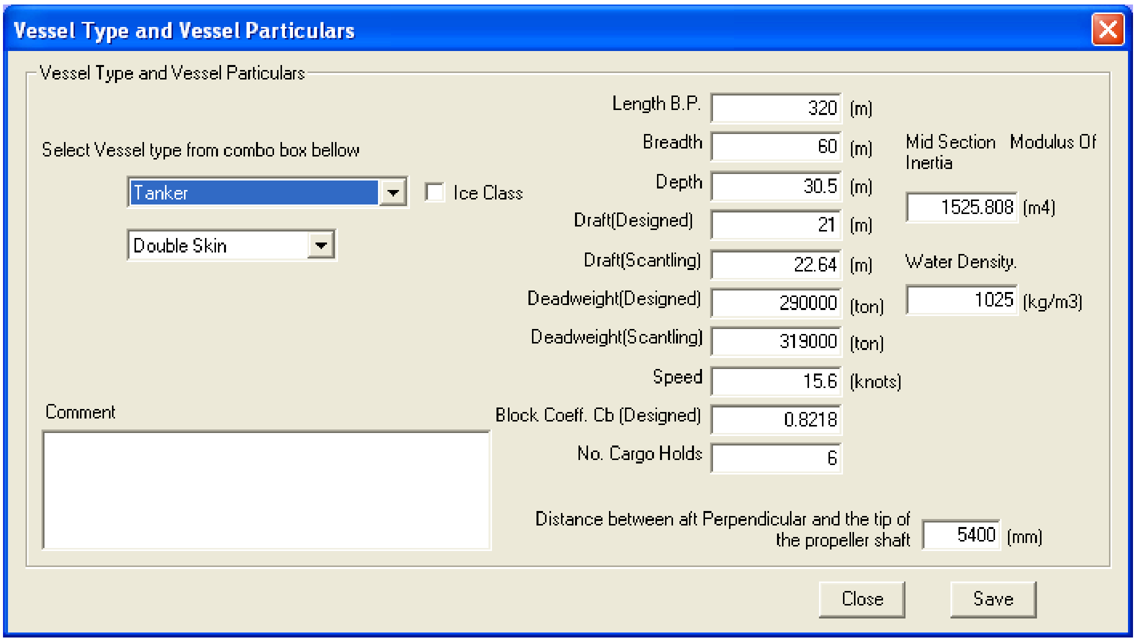
3.1.1 Hull Deflection Calculation

In order to evaluate the hull deflections for the ballast and the fully laden conditions, various computer programs and methodologies can be considered including the finite element model method. The hull displacements are to be obtained at each shaft supporting point or bearing, including the engine bearings. The set of the deflections may be provided, either using an absolute coordinate system or as relative displacement values through a transformation based on a reference line defined by the aftmost stern tube bearing and the most forward bearing of the shaft line including the engine, gearbox or any other prime mover machinery.

3.1.2 Hull deflection calculation using the ABS Software

The ABS Shaft Alignment software program referenced in 2/1.3.2 contains a module which estimates hull deflections for certain vessels for the purposes of shaft alignment optimization purposes. These include dry-dock or very light ballast condition, full ballast and fully laden condition.

FIGURE 4
Screenshot from the ABS Shaft Alignment Software Showing Typical Data Required for Fast Determination of Hull Deflection for Shaft Alignment Optimization Analysis



3.1.3 Alternative Hull Deflection Calculation and Data *(1 November 2016)*

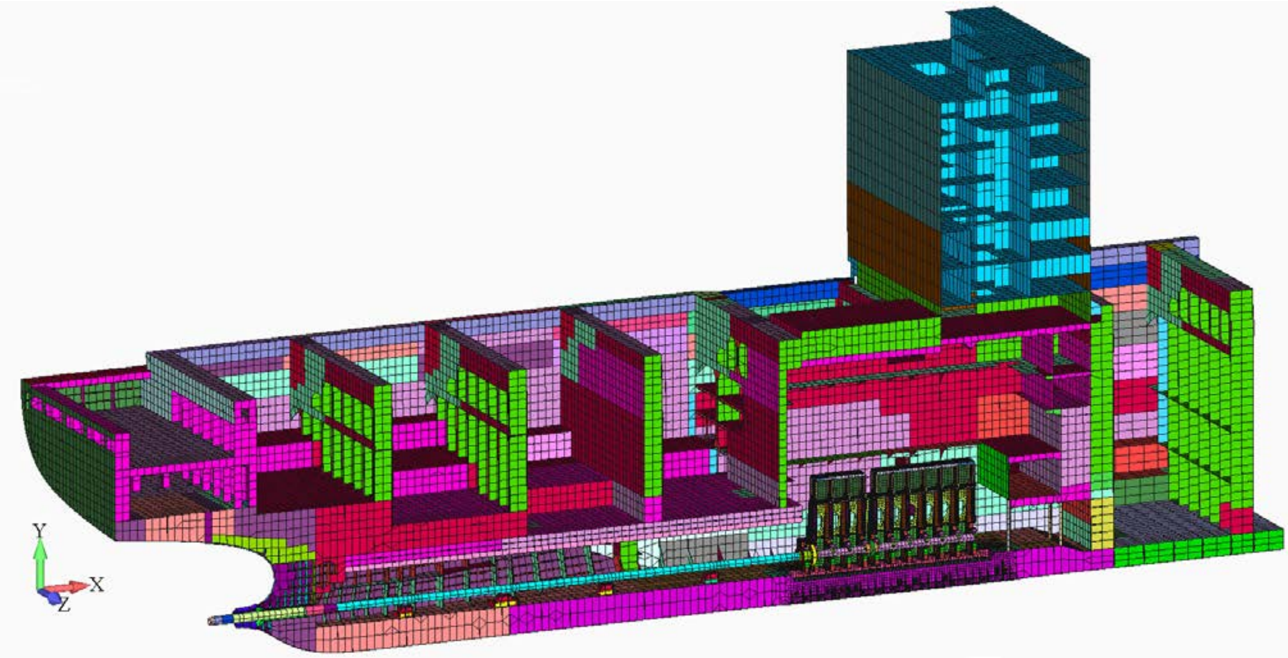
The submission report is to provide sufficient information in terms of data and calculations demonstrating that the hull deflection values are reliable. This applies particularly to the utilization of programs which make use of simple beam theory for the hull deflection calculation or other programs related to the vessel's stability and loading calculations.

Proven service experience and measurements from sister vessels can also be acceptable for the determination of hull deflections at the bearing location positions for the appropriate required loading cases.

For the cases where the finite element (FE) method is performed, the model is to include all structural parts and all steelwork of the engine room and the double bottom. Where an FE model is constructed, a reference to any modeling procedures such as element types, ratios of element sizes, material properties, elements warping ratio limits, etc., is to be included in the report.

In certain cases, ABS may request electronic submission of the actual FE model used for the hull deflection modeling for interactive model review purposes.

FIGURE 5
Typical Finite Element Model for the Purposes of Hull Deflection Calculations



SECTION 3 Alignment Procedure

1 General Requirements

1.1 Major Stages

The shaft alignment procedural steps are similar to those described in the requirements in 4-3-2/7.3.4 and 4-3-2/11.1 of the *Steel Vessel Rules* and in the ABS *Guidance Notes on Propulsion Shafting Alignment*. Further details for each of the following steps may be found in those Guidance Notes:

i) Sighting through (bore sighting)

ii) Engine bedplate pre-sagging

iii) Sag and gap

iv) Reactions measurements

v) Bearing-shaft misalignment evaluation

vi) Shaft eccentricity (run-out) verification

vii) Intermediate shaft bearing offset readjustment

viii) Crankshaft deflection measurements

ix) Engine bedplate deflections measurement

x) Gear contact evaluation (where applicable)

xi) Gear-shaft bearings reaction measurements

3 Shaft Alignment Installation Procedure *(1 November 2016)*

3.1 Conditions

In addition to the requirements in 4-3-2/7.3.4 and 4-3-2/11.1 of the *Steel Vessel Rules*, the following are to apply: The Shipyard is to produce a log with the recordings of all the shaft alignment installation steps, including sighting data recorded and this log is to be submitted to the ABS Engineering office for verification against approved limits or tolerances and for reference purposes.

i) The shaft alignment sighting is not to commence before the vessel stern blocks are fully welded and all of the heavy stern structure is in place including the main engine.

ii) Only then should the reference line for positioning the shafts, bearings, main engine and gear box be established.

iii) As far as possible, laser or optical centering checks are to be performed at night in order to avoid undesirable light or temperature disturbance.

3.3 Means of Bearing Reaction Measurement and Verification

Bearing reactions are to be measured using either:

i) Jack up testing method

ii) Strain gauge installation

iii) Laser techniques through shaft deflection

TABLE 1
Performance Characteristics of Typical Measurement Techniques

Jack-up tests	ADVANTAGES	DISADVANTAGES
	Easy to use – typical direct measurement technique	Shaft-bearings non-linearities limit accuracy of the measurement
	No special skills are needed to conduct the measurement	May need to be conducted a couple of times to ensure output data consistency
	Expensive equipment is not required	Can not be used to measure inaccessible bearings (e.g., aft sterntube bush)

Strain Gauge or laser techniques through shaft deflection measurement	ADVANTAGES	DISADVANTAGES
	Traditional method for enhanced measurement accuracy.	Specialized expert personnel is required to conduct this measurement.
	Through reverse calculation it can provide accurate information for the non-accessible bearings of the shaft.	Installation takes a long time (approximately one hour per strain gauge).
	Telemetric strain gauge provide most useful information data during vessel operation.	Generally flimsy equipment, which requires attention in order to operate reliably.
		Laser techniques require usage of expensive equipment.

3.5 Recordings

For the purposes of the **ESA** Notation, the shipyard is to record all related measurements listed in 3/3.3 above, in a suitably formatted log file for submission to the ABS for further review and filing. For the bearing reaction measurements, a record showing the all the accessible shaft bearings and the three aftmost main engine bearings or the gearbox bearing reaction values, as appropriate, are to be recorded for every hull condition measured. In addition, a record of the bearing reactions for every accessible shaft bearing compared to the calculated bearing reaction for the same condition is to be created for submission to ABS for further review and filing. Such records may be in tabular or bar chart format for facilitating the review.

FIGURE 1
Bearing Reaction Values During Sea Trials for Different Vessel Conditions for the Forward Sterntube Bearing (FWD), the Intermediate Bearing (IB) and the Aftmost Main Engine Bearing (ME)

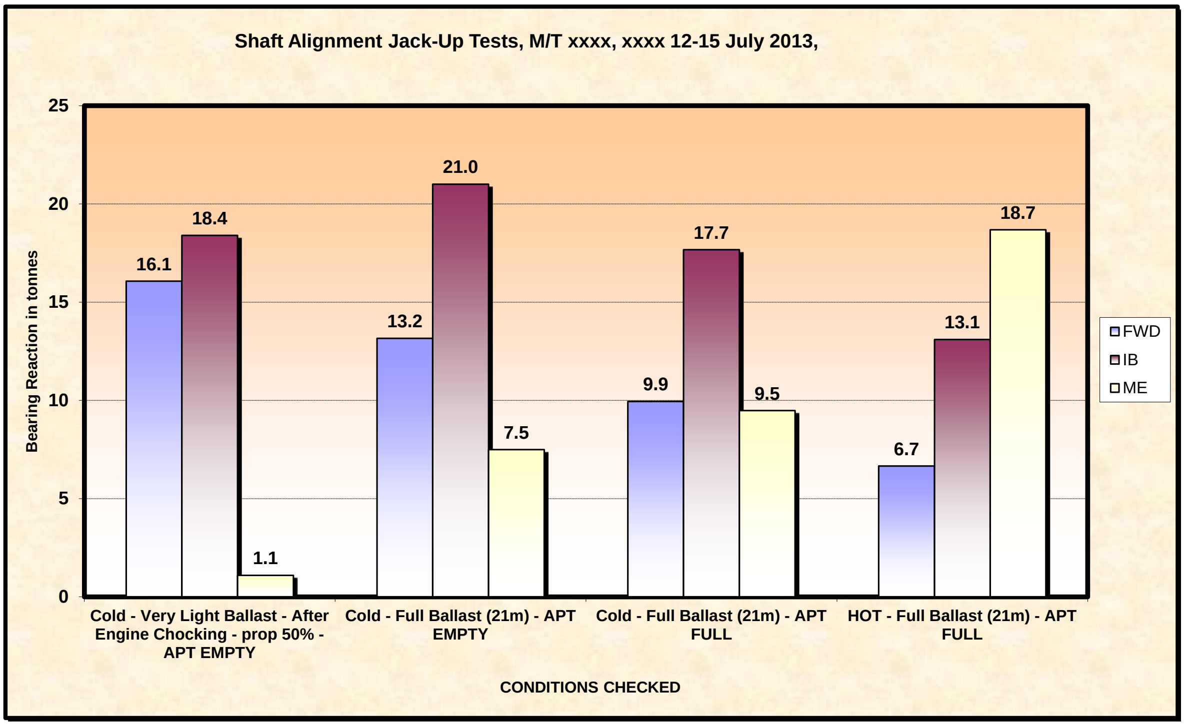
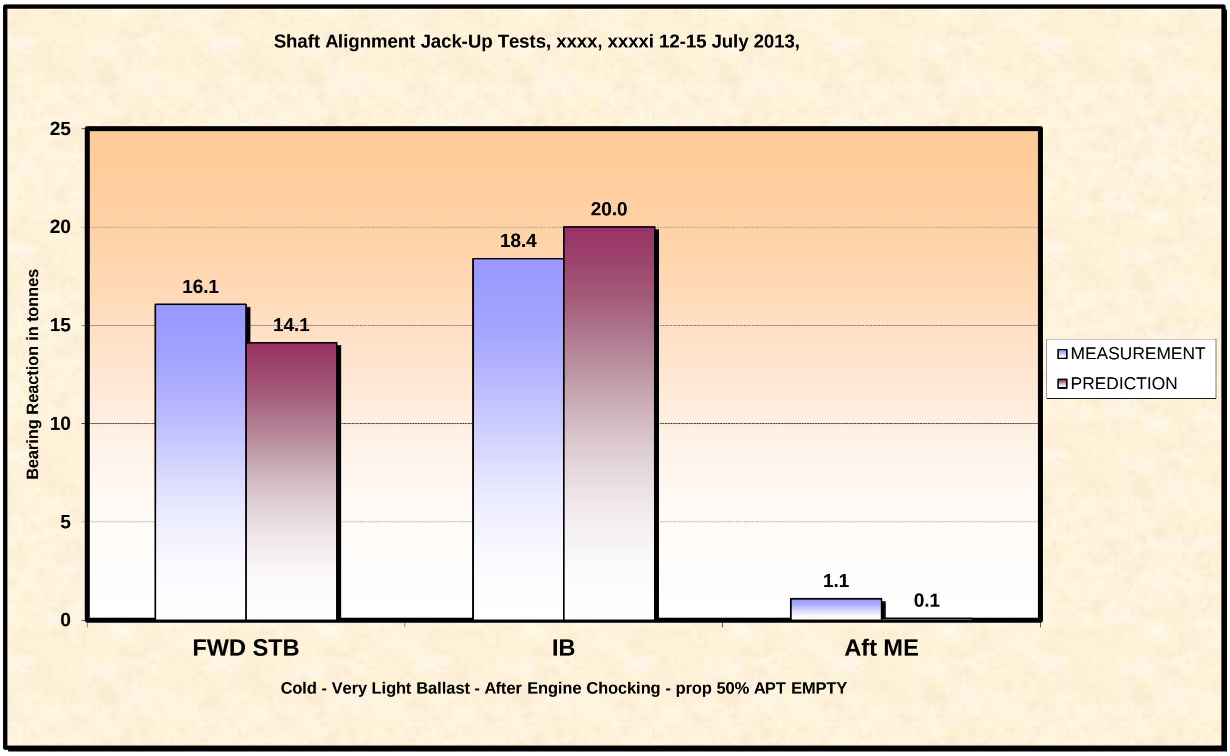


FIGURE 2
Correlation between Measured and Calculated Bearing Reaction Values for a Specific Vessel Condition



SECTION 4 Sea Trials

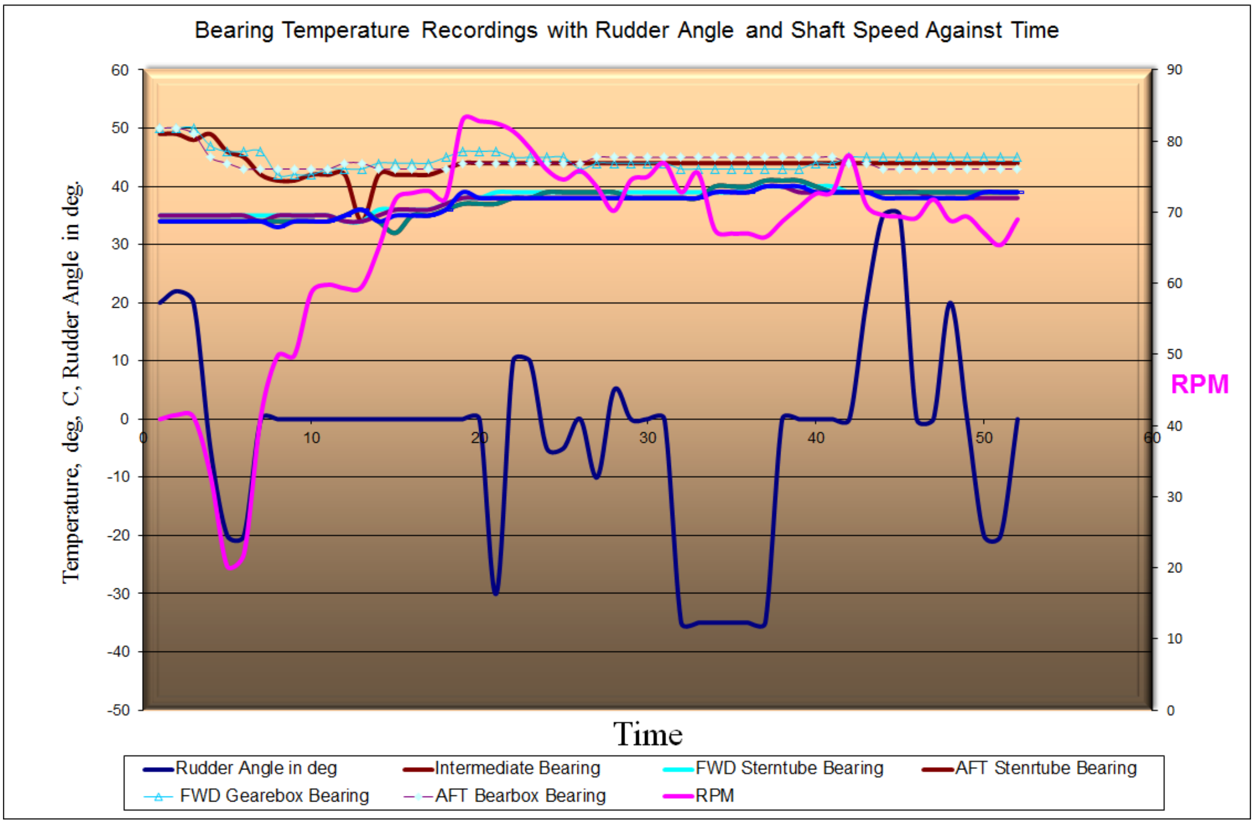
1 General Requirements

1.1. Test Procedure

In addition to the *Steel Vessel Rules* regarding the vessel's sea trial program, the following additional actions are required.

During trials, a number of parameters relating to the propulsion shaft bearing performance are to be recorded at about five-minute intervals by a competent member of the shipyard and/or ship's staff and reviewed periodically during the trials by the attending Surveyor. These data include all the shaft bearing temperatures including the aftmost three main engine bearings, gearbox bearings together with rudder angle in degrees and shaft RPM. The record is to be submitted to ABS for record purposes and future reference. If a bearing failure does occur during the trials, this data is to be available to the ensuing investigation. The data is to be trend plotted to provide an overview of the bearing temperatures. An example of bearing temperatures monitored during acceptance of sea trials are given below:

FIGURE 1
Bearing Temperatures Monitored during Acceptance Sea Trials



The “worst-case” operating conditions for the stern tube bearing, as identified by ABS and agreed with the shipyard and as applicable to the vessel type, are to be tested during sea trials by conducting full speed maneuvering turns and closely monitoring the stern tube bearing temperatures.

1.3 Running-in Procedure

A written procedure, as per 1/5.1.5, is to be supplied by the bearing manufacturer or shipyard and followed as closely as possible. Due to draught restrictions and navigation requirements, it is not always possible to follow the procedures exactly while leaving some ports. In such circumstances, continuous slow running (Slow Ahead) may be considered while navigating to open water where the running-in procedure can be commenced. A running-in procedure is to be conducted before any new sterntube bearing is exposed to an unrestricted service condition. Therefore, the running-in condition is recommended to be done immediately before the sea trials.

SECTION 5 Maintenance of ESA Notation

1 Maintenance of ESA Notation

If a modification or change is implemented onboard a ship granted the **ESA** Notation that may have an influence on the parameters or values of the requested results listed in Subsection 2/3, the **ESA** Notation may be withdrawn until a detailed description of the performed actions and an updated calculation report showing compliance with applicable requirements are submitted to ABS for approval. Such aspects may include, but not limited to, vessel incidents (e.g., grounding), which may affect the shaft alignment or modifications of any of the powertrain components either at the design stage at the time of assigning the **ESA** Notation or during of the life of the vessel. If any such event should occur, ABS is to be notified immediately.

If for whatever reason the main shaft of the vessel or part of the shaft such as tailshaft and/or intermediate shaft is withdrawn then the **ESA** Notation status is withdrawn. In order to reinstate the **ESA** Notation, the Shaft Alignment procedure as described in Subsection 3/3 of this Guide is to be followed.

SECTION 6 Surveys

1 Initial Survey

i) All systems required by the **ESA** Notation are to be examined in accordance with the approved plans to verify compliance.

ii) **ESA** Notation can be granted upon successful sea trial results.

3 Surveys after Construction

In order to maintain the **ESA** Notation, the survey requirements contained in the ABS *Rules for Survey After Construction (Part 7)* are to be complied with.

APPENDIX 1 Definitions of Shaft Alignment Optimization

The ABS Shaft Alignment Optimization software program involves an iteration process that is based on the genetic algorithm (GA) method, where a solution is sought by a parallel search throughout the solution space bounded by two "extreme" deflection curves, namely in this application, the ballast and the fully-laden condition. Within the defined solution space, the desired number of acceptable solutions that comply with the basic alignment requirements is extracted. It is then up to the designer to select the solution, which provides the most robust, practical and acceptable design.

In accordance with the ABS definition of shaft alignment optimization, the following definitions are observed:

i) *Objective Function (OF).* To minimize the difference of magnitude of the reaction forces among the bearing reaction forces rendering them as uniform as possible for all the bearings within the whole powertrain.

ii) *Design Variable (DV).* All selected bearing offsets.

iii) *State Variable (SV).* Two limit lines of bearing offset sets, or surfaces, describing the ballast and fully laden condition and based on the hull deflection data.

The above definitions are generic in design optimization problems and can be found in various literature survey related articles.

1 Shaft Alignment Optimization Alternative Definitions

Alternative definitions and analyses of shaft alignment optimization could be acceptable for the purposes of granting the **ESA** Notation; however, these are to be to the satisfaction of ABS and may be considered on a case-by-case basis. The report required in 1/5.1 is to detail the calculation process and the assumptions made. The submitted calculations are to include a clear definition of the shaft alignment optimization method including the relevant definitions of the design optimization such as the objective function, the state variables and the design variables (OF, SV, DV).

FIGURE 1
2D Design Optimization Mathematical Concept

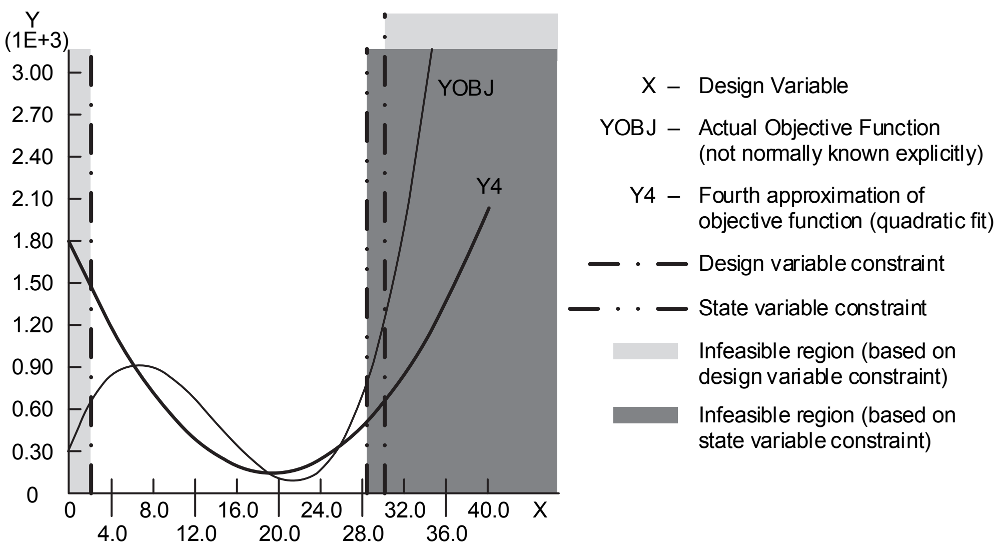
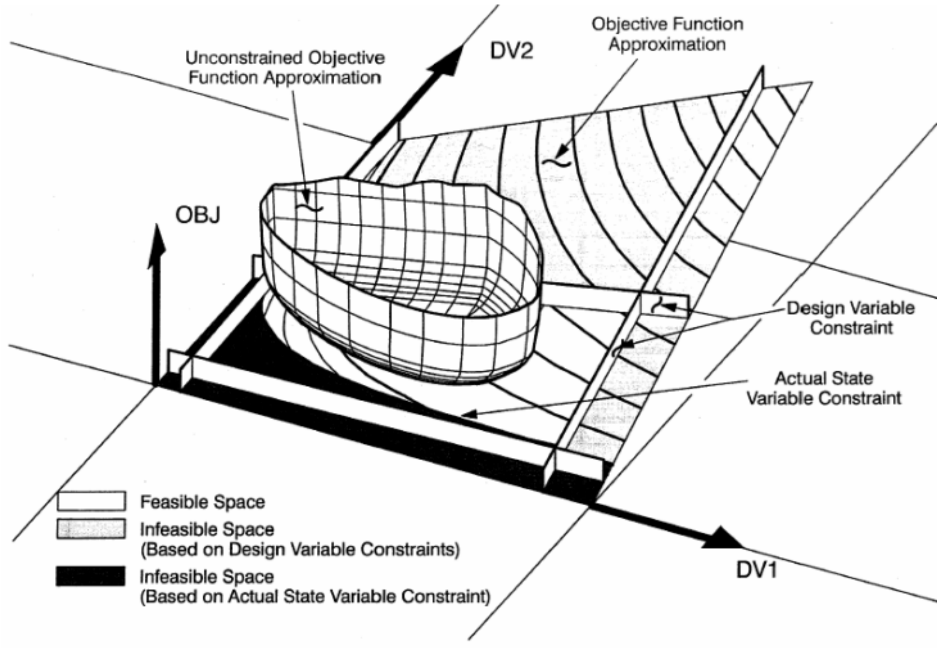


FIGURE 2
3D and higher Design Optimization Mathematical Concept



APPENDIX 2 References

1. ABS, *Guidance Notes on Propulsion Shafting Alignment*, 2014.
2. ABS Shaft Alignment and Alignment Optimization Software, Version 3.0, Users Manual, ABS, 2012.