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Introduction

Installation of the propulsion machinery incl. its alignment is shipyard's responsibility.
The main engine and propulsion shafts are directly-coupled and thus form one propulsion shaft line which is supported by numerous bearings. The alignment of these bearings has to meet the following basic demands under all normal ship service conditions[1]:

- **All bearings[2] need to have a positive static load.**
- All crankweb deflections – engine stopped – need to be within the service limits.

However, the machinery foundation is exposed to elastic ship hull bending which depends on draught and trim and also on sea motion. **This varies the bearing offsets and thus their static loads.** Further influences are service forces and temperatures.
To ensure that the above mentioned demands are met, the following three principles have to be considered:

- **It is crucial that the shaft bearings are arranged at optimum long distances** in order to limit the effect of the influences which affect the static bearing loads and the crankweb deflections.
- **The bearing offset changes which are expected to occur between installation condition and any normal ship service condition need to be considered by an appropriate pre-compensation in relevant alignment layout calculation (ALC).**
- **A careful levelling of main engine bedplate by means of all jacking screws (or alignment wedges resp.) during installation is crucial for achieving proper static main bearing loads and crankweb deflections.**

1 Ship draught and trim within normal limits.

2 All shaft line bearings and all engine main bearings.

Alignment of a direct-coupled marine propulsion plant is based on a ship design specific alignment layout calculation (ALC) which needs to consider:

- the design of propulsion shaft line
- the design of the vessel
- the influence of ship hull bending
- rules and regulations of the governing bodies (e.g. class)

Before chocking and fixation of the main engine, alignment measurements are performed to proof that the alignment of the propulsion shaft line and the main engine complies with the referred ALC.
Further alignment measurements until ship delivery may follow, depending on specifications, rules and regulations, case specific class requirements, etc.
An overview of the alignment steps is provided by DG9709 - “Engine alignment – In Brief”.

Abbreviations

The following abbreviations are used in this document:

ALC	alignment layout calculation
CPP	controllable pitch propeller
cyl.	cylinder
cyl.(n-1)	second foremost cylinder
DG	design group (Wärtsilä drawing set structure)
mb	engine main bearing
PTI	power take in (shaft motor)
PTO	power take off (shaft generator)
TV	torsional vibration
TVC	torsional vibration calculation

1 Alignment at project stage

1.1 Check for shaft bearing distances

The shaft bearing arrangement needs to be checked for optimum long distances between the shaft bearings and to the main engine[3]. They are essential for limiting the influences which affect alignment, such as elastic ship hull bending, service forces and temperatures and also for an easy alignment process.
Wärtsilä offers support free of charge by reviewing relevant designs and proposing optimised shaft bearing arrangements if indicated.

1.2 Provision of input data for alignment layout calculation

The information listed below is required for creation of the alignment layout calculation (ALC). It is essential to provide the latest information. Updates of design need to be informed to the calculator immediately in order to ensure that the ALC is based on actual inputs:

1. **torsional vibration calculation (TVC)**, incl. flywheel inertial and mass of front disc (if exist) or TV damper (if exist)
2. **general propulsion shaft arrangement** (longitudinal section)
3. **stern tube assembly** (longitudinal section, incl. propeller shaft and propeller)
4. **propeller shaft drawing**
5. **intermediate shaft drawing(s)**
6. **drawing of aft stern tube bearing bush**, incl. overall length, the maximum permissible mean pressure and effective contact length of bearing bore (or maximum permissible static load), clearance of bearing bore and vertical offset of bearing bore in relation to bush outer diameter and bearing material type
7. **drawing of forward stern tube bearing bush (if exist)**, incl. overall length, the maximum permissible mean pressure and effective contact length of bearing bore (or maximum permissible static load), clearance of bearing bore and vertical offset of bearing bore in relation to bush outer diameter and bearing material type
8. **drawing of intermediate bearing(s)**, incl. the maximum permissible mean pressure and shell length (or maximum permissible static load)
9. **propeller drawing**, incl. propeller forces at design conditions, key design data like dry-mass, number of blades, outer diameter, mean pitch, expanded area ratio, inertia in air, inertia in water, position of propeller blades route and centre of gravity

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[3] Also required by class rules.
See also DG9709 - “Engine alignment – Bearing Arrangement & Layout Calculation“ - section “Shaft bearing arrangement / Optimum bearing distances”.

10. **propeller nut drawing** incl. dry-mass
11. **propeller cap drawing** incl. dry-mass
12. **longitudinal positions of hydraulic jacks** for measuring the static loads of each intermediate bearing and of the forward stern tube bearing (if exist)
13. **longitudinal positions of temporary supports** for the intermediate shaft(s) and for the propeller shaft (only for designs without forward stern tube bearing)
14. **longitudinal position of the jack-down force at** the forward end of **propeller shaft** when un-coupled (required in most cases)

Depending on the design, further information might be necessary such as

15. **drawing of sleeve coupling (if exist)**, incl. mass and required axial movement for opening/closing of the coupling sleeve
16. **drawing of servo shaft for controllable pitch propeller (CPP) (if exist)**, incl. the mass and longitudinal position of the oil distribution sleeve (or housing) attached on the servo oil shaft
17. **drawing of shaft generator (PTO) and/or shaft motor (PTI) (if exist)**, incl. the longitudinal position and the enhanced diameter onto which the pole shoes of the rotor are mounted and the total mass and inertia of the pole shoes
18. **drawing and data of flexible coupling for designs with tunnel gear driven PTO (if exist)**

1.2.1 Free end PTO

In case of free end PTO, Wärtsilä needs to be involved from the beginning of project phase.

1.3 Provision of Wärtsilä instruction for creation of ALC

We strongly recommend to ensure that those who are in charge for creating the ALC receive **all** parts of instruction DG9709 - “Engine alignment” from the beginning.

1.4 Checking the alignment layout calculation

The shipyard needs to check the ALC before sending it to classification for approval in order to ensure that

- **all ALC input data** extracted from the drawings and documents listed in section 1.2 **need to comply with the final design of components** which are purchased by the shipyard;
- **all ALC results comply with the specifications of relevant components**, e.g. slope machining of stern tube bearing bore(s) incl. the calculated angular mis-alignment of propeller shaft inside them, static loads of shaft bearings, bending stress in shafts, positions of temporary supports for un-coupled shafts, positions of hydraulic jacks for measuring the static bearing loads, etc.

2 Alignment before floating of the vessel

2.1 Propeller shaft installation

Before floating of the vessel, the propeller shaft incl. propeller nut and cap have to be installed.
The propeller shaft needs to be carefully aligned in relation to the long aft stern tube bearing.

2.2 Alignment of propeller shaft

2.2.1 Designs with forward stern tube bearing

For designs with a forward stern tube bearing, the alignment of propeller shaft is achieved by ensuring a positive static load at the forward stern tube bearing. For this purpose the ALC indicates if a jack-down force is required at the forward end of the un-coupled propeller shaft or not.

2.2.2 Designs without forward stern tube bearing

For designs without a forward stern tube bearing, the un-coupled propeller shaft has to be supported by a temporary support close to its forward end. The longitudinal position of the temporary support has to comply with the referred ALC. The requirement for a jack-down force at the forward end of the un-coupled propeller shaft needs to be checked with the referred ALC.

Alignment in relation to forward end of stern tube

Subsequently the temporary support is adjusted until the propeller shaft is aligned in relation to the forward end of stern tube (or the forward stern seal seat resp. if that is centred to the stern tube), i.e.:

- the horizontal position of the propeller shaft is adjusted by equal horizontal clearances between the propeller shaft and the forward end of stern tube (or the forward stern seal seat resp.)
- the vertical position in relation to the forward end of stern tube (or the forward stern seal seat resp.) is adjusted according to the ALC.

Reference measurements of propeller shaft position

Reference measurements need to be made in order to prepare the data for re-checking of the proper propeller shaft alignment after the stern seals are mounted and the ship has become afloat. In particular for designs without forward stern tube bearing, these reference measurements are essential to ensure the exact horizontal and the exact vertical position of the propeller shaft in relation to the forward end of stern tube (or the forward stern seal seat resp.).

2.3 Installation of stern seals

After the above mentioned reference measurements have been recorded, the stern seals are installed.

2.4 Securing shafts and main engine before floating of the vessel

Before floating of the vessel, the propeller shaft and intermediate shaft(s) and the main engine have to be firmly secured against possible movement which can be caused by the forces which are acting when the vessel is launched (slipway) or becomes afloat (dry-dock).

3 Final alignment in floating condition

3.1 Basic pre-requisites

The following basic pre-requisites need to be provided before the final alignment of the propulsion shafts and main engine is started:

- The manufacturing of the ship hull is completed and the ship's superstructure is in place.
- All major welding works of the ship building are completed.
- The main engine is completely assembled (i.e. its tie rods are fully tightened).
- The ship is in continuous afloat condition[4].

3.2 Ensuring propeller shaft alignment

At first the proper alignment of the propeller shaft in relation to the forward end of stern tube (or the forward stern seal seat resp.) needs to be ensured by repeating the measurements described in section 2.2.2 - re-adjust if indicated.
Subsequently the forward flange of the un-coupled propeller shaft[5] provides the reference for further alignment of intermediate shafts and main engine.

3.3 Alignment of un-coupled intermediate shaft(s) and main engine by gap and sag

3.3.1 Purpose

The purpose of the alignment by gap and sag values of the un-coupled shaft flanges is to adjust the height of bearings in *continuous fully afloat condition. Thus* the considerable changes of elastic ship hull deflection which occur when the ship becomes afloat are eliminated.

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[4] It is within the responsibility of the shipyard to carry out the final alignment including chocking of the engine according to their experience already gained at the dry dock. However, the risk of a possibly required re-chocking has to be born in mind.

[5] In case of designs with controllable pitch propeller (CPP), the servo oil shaft is already coupled to the propeller shaft first. Subsequently they are aligned in relation the stern tube bearings. The forward flange of the servo oil shaft is referred to for gap and sag alignment of the (aft) intermediate shaft.

3.3.2 Definition of gap and sag

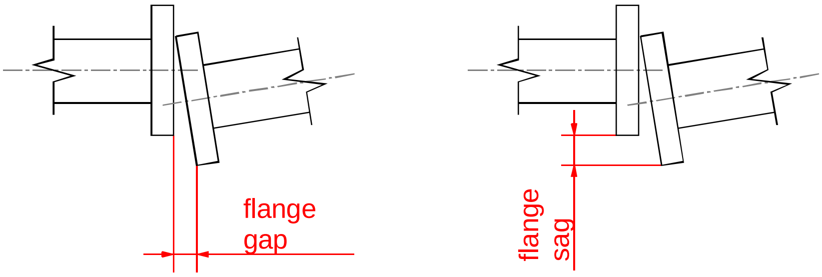

Figure 1: definition of flange gap & sag.

3.3.3 Tolerances for gap and sag

If not defined tighter by the referred class rules or ALC, then the following tolerances should be applied between the adjusted gap & sag values and the calculated vertical and the targeted zero horizontal values respectively:

- Gap tolerance: ±0.05 mm
- Sag tolerance: ±0.10 mm

3.3.4 Alignment of un-coupled intermediate shaft(s)

At first the intermediate shaft is aligned by gap and sag of its aft flange in relation to the propeller shaft forward flange[6].
If there are several intermediate shafts, then the aftmost intermediate shaft is aligned first. Subsequently the second aft intermediate shaft is aligned by gap and sag of its aft flange in relation to the forward flange of the aftmost intermediate shaft.
This is progressively repeated from aft to forward for each additional intermediate shaft until the gap and sag values at all intermediate shaft aft end flanges comply with the ALC.
Each un-coupled shaft is supported by just two supports points, i.e.

- either an intermediate bearing if arranged close to one end of the shaft
- or a temporary support which is arranged close to the opposite end of the shaft.

If the intermediate bearing is located near the middle of relevant shaft, then two temporary supports are required and each of them needs to be arranged near one of the shaft ends[7].

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6 In case of CPP: in relation to the forward flange of the servo oil shaft which is already coupled to the propeller shaft.

7 Indirect alignment of intermediate bearing: At first both temporary supports are adjusted until gap and sag at the aft flange complies with ALC. Then the intermediate bearing is lifted up from the lower side until its bottom shell just touches the intermediate shaft lower side. A positive static load of just 1kN is calculated for this intermediate bearing in un-coupled condition of the ALC.

These two support points are adjusted until the gaps and sags at the intermediate shaft aft end flange are adjusted as follows:

- If no horizontal gap & sag values are defined by the referred ALC, then the horizontal gap & sag values have to be the same on both sides of the un-coupled flanges[8].
- The vertical gap & sag values have to comply with the referred ALC.

It is crucial that each of the un-coupled shafts is supported by just two points[9].

3.3.5 Alignment of un-coupled main engine

Finally the un-coupled main engine is aligned by careful adjustment of its jacking screws (or alignment wedges resp.)[10] until the gaps and sags between the crankshaft aft end flange and the foremost intermediate shaft flange are adjusted as follows:

- If no horizontal gap & sag values are defined by the referred ALC, then the horizontal gap & sag values have to be the same on both sides of the un-coupled flanges.
- The vertical gap & sag values have to comply with those provided by the referred ALC.

When adjusting the main engine's jacking screws (or alignment wedges resp.) also the bedplate bending needs to be considered very carefully (see section 3.3.6)

3.3.6 Bedplate bending

Influence of bedplate bending on alignment

The bedplate bending influences the main bearing offsets and thus their static loads and the crankweb deflections.
A straight bedplate or a slight and smoothly overall bending of the bedplate – without kinks - is the pre-requisite for achieving proper main bearing loads and crankweb deflections.
It is not possible to measure the main bearing offsets directly in the completely assembled engine – but they can be concluded by analysing the crankweb deflection in combination with the bearing load measurement results by means of a reverse calculation e.g. made by Wärtsilä.
Due to this analyse, Wärtsilä does not require a measurement of the bedplate bending for alignment approval.

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8 Aiming for a straight alignment of the propulsion shaft line in the horizontal plane (top view).

9 In some cases two shafts are coupled together first and then they are supported also by just two points.

10 See DG9710-01 – “Tool engine alignment”.

Bedplate levelling at re-assembly

It is of utmost importance to carefully level the bedplate already at the beginning of engine re-assembly at the shipyard and it is mandatory to use the full number of jacking screws (or alignment wedges resp.) – otherwise distortions of the bedplate are caused which lead to complications and delays in final alignment.
Appropriate measurements as listed in DG0351 - “Assembly Instruction” are required to proof the proper levelling of bedplate during re-assembly at the shipyard.
However, measuring the crankweb deflections in the so called ‘open bedplate’ condition (just the crankshaft is installed in bedplate – but not the running gear) does not indicate a proper levelling of bedplate at re-assembly.

Bedplate bending of completely assembled engines

After completion of engine re-assembly, a slight sagging or a very slight hogging might be adjusted:

- A straight bedplate alignment is in most cases suitable for engines with 6 to 8 cylinders.
- A slight sagging bedplate alignment might be advisable for engines with 9 or more cylinders.
- A very slight hogging bedplate alignment is advisable for engines with 5 and 6 cylinders in case there is a heavy external mass at the forward end of crankshaft.

Influences on bedplate bending after engine fixation

After fixation of engine in the ship, the bedplate bending curve is influenced by service temperature of main engine and the bending shape of the engine foundation:

- The increase of ship draught causes an increase of bedplate hogging (or a reduction of bedplate pre-sag resp.).
- Also the change from cold to hot condition causes a slightly more hogging of the bedplate (or a slightly less pre-sagging resp.).

Engine pre-sag

As the bedplate bending shape will change to more hogging for hot condition, the engines may be installed with some pre-sag for pre-compensating the expected change. However, as long as all crankweb deflections are within the limits, no special care for engine pre-sag is required. More positive crankweb deflections[11] in way of cylinder #2 to second foremost cylinder, measured before chocking, give an indication that the engine is pre-sagged.
Experience has shown that more important than pre-sagging is that the bedplate bending is as smooth as possible, i.e. the variation from one main bearing measurement position to the next is as low as possible in relation to the actual sag curve.
It is not at all recommended to support the engine only in its four corner positions in order to adjust a pre-sag.

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[11] Sign definition: _/+_ _\-/_ (see section 3.5.2)

This causes irregular engine bending and thus leads to complications and delays in final alignment e.g. a lack of static load at mb #3. **It is therefore strongly recommended to have rather less or no pre-sag instead of distorting the bedplate.**

The engine has to be supported by all jacking screws (or alignment wedges resp.), as indicated on the engine installation drawings.

3.4 Coupling of all shafts and main engine

After all intermediate shafts and the main engine are aligned by gap and sag at their aft end flanges, all flanges will be coupled and all temporary supports and the jack-down force are removed.

3.5 Alignment measurements, before chocking condition

After coupling of all shafts and main engine, a full set of alignment data is measured, recorded and preferably sent to Wärtsilä for review – see section 3.5.4 sub-section "Wärtsilä evaluation – free of charge".

Wärtsilä will analyse the data and either confirm them if satisfactory – or advice corrective measures if indicated.

No further adjustments should be made after coupling and prior to the receipt of the evaluation of the alignment measurement results – even if some measurement results are not satisfactory. **Such intermittent re-adjustments often cause a very exhausting and time consuming continuation of alignment process.**

Before chocking and fixation of the main engine, alignment measurements are performed to proof that the alignment of the propulsion shaft line and the main engine complies with the referred ALC.

3.5.1 Constant conditions during alignment measurements

The alignment of the propulsion shafts and main engine is very sensitive to slightest changes of ship draught or local temperature differences in foundation.

Such influences seriously affect the consistency of alignment measurement results. The more these influences affect the measurement results, the more they may cause misleading results.

In order to achieve alignment measurement results with the necessary quality, it is essential to consider the following requirements:

At least 8 hours prior to alignment measurements in cold conditions (e.g. before chocking) the following heat sources have to be switched off:

- the tank heating in main lubricating oil sump tank
- the pre-heater of the main lubricating oil separator
- the tank heating in any other tank in the engine room double bottom

From beginning until completion of a set of alignment measurements (i.e. crankweb deflections and static bearing loads) the following has to be observed:

- no changes of ship draught or trim

- no ballasting operation
- no movement of heavy parts like hatch covers, etc.
- no welding works in vicinity of the propulsion system, etc.

The alignment measurements listed below need to be performed right after each other and without any intermittent re-adjustment:

- The crankweb deflections of all cylinders need to be measured.
- Jack-up tests of all shaft bearings (except the inaccessible aft stern tube bearing)
- Jack-up tests of aftmost mb #1 to mb #3
- Additional jack-up tests for other main bearings would become necessary, if the maximum deviation indicator for vertical crankweb deflections[12] between two adjacent cranks has been exceeded. It can be exceeded between the two foremost cranks if a heavy external load is attached at the crankshaft forward end[13]. In such a case the static loads for the two foremost main bearings need to be measured.
  However, if the maximum deviation indicator for vertical crankweb deflections between two adjacent cranks **is exceeded in way of cyl.2 to the second foremost cyl.(n-1), then Wärtsilä needs to be contacted.**

3.5.2 Recording of alignment measurement results incl. essential additional information

Careful recording of alignment measurement results is essential for a reliable analyse of the alignment condition. In addition to the measurement results, also further information about the measurement conditions and the measurement tools need to be included in the records for a clear understanding and a comprehensive judgement of the alignment measurement results.
See DG9709 - “Engine alignment – Guidelines for measurements” - sections “Recording of crankweb deflection measurements” and ”Recording of static bearing loads”.
Wärtsilä provides data record sheets in Microsoft Excel file format free of charge. See DG9707 - “Engine alignment – record sheets”. Please contact Wärtsilä, e.g. by email to: application.engineering.ch@wartsila.com or contact the local Wärtsilä office.

Two variants to designate the crankweb deflection reading positions

The deflection of each crankweb is measured in five turning positions (crank angle) as illustrated in figure 2. There are two variants for designating the so called ‘crankweb deflection reading positions’ (see table 1):

- either by the crank pin position (default in WCH documentation)
- or by the dial gauge position

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12 Details see DG9709 - “Engine alignment - Crankweb deflections - limits“ - section - “Crankweb deflection max. deviation indicator”.

13 E.g. a TV damper or a front disc or a free end PTO gear drive.

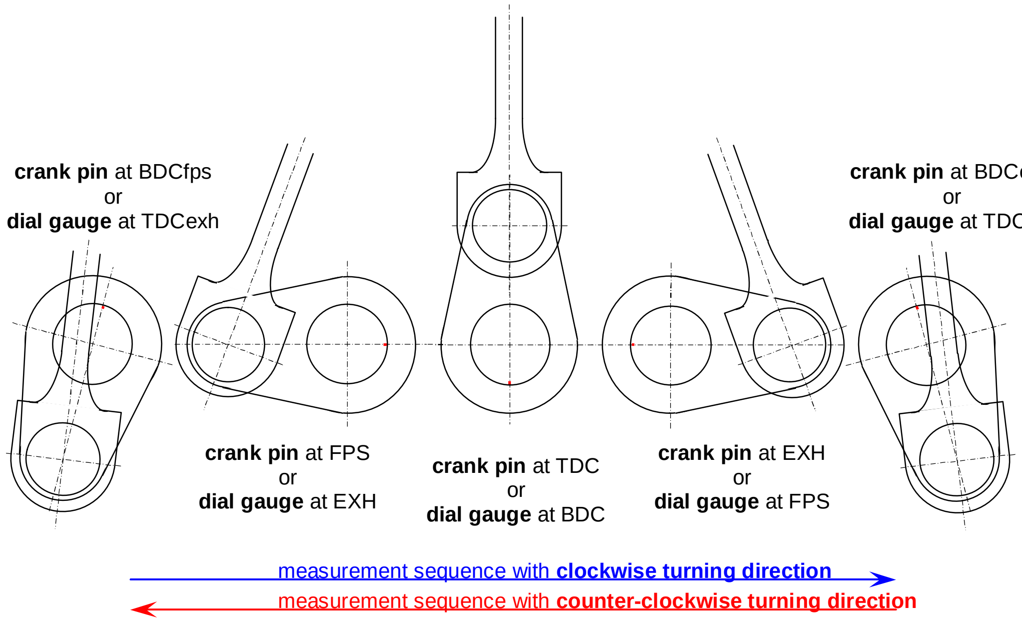

Figure 2: reading positions for crankweb deflections (view from engine aft end)

Table 1	**Crankweb deflection reading positions**		
crank pin positions (default in WCH documentation)		**dial gauge positions**	
BDCfps	bottom dead centre – fuel pump side	**TDCexh**	top dead centre – exhaust side
FPS	fuel pump side	**EXH**	exhaust side
TDC	top dead centre	**BDC**	bottom dead centre
EXH	exhaust side	**FPS**	fuel pump side
BDCexh	bottom dead centre – exhaust side	**TDCfps**	top dead centre – fuel pump side

Two variants of dial gauge indication

There are two variants how the dial gauge indicates varying distances and thus the crankweb deflections:

- If the measured **distance is reduced** and
  the dial gauge **indicates more negative values** (or lower positive values resp.),
  then the **reading convention complies with** the default in WCH documentation:
  \+ − (**default in WCH documentation**)

- If the measured **distance is reduced** and
  the dial gauge **indicates more positive values** (or less negative values resp.),
  then the **reading convention is opposite** to the default in WCH documentation.
  (e.g. Japanese dial gauges):
  − + (**opposite** to WCH documentation)

Substitute for:				PC	Q-Code	X	X	X	X	X
Modif	Number	Drawn Date	Number	Drawn Date	Number	Drawn Date	Number	Drawn Date		

WÄRTSILÄ	Product **W-2S**	**Engine Alignment** **Procedure & measurements at shipyard**	
Made 14.10.2013 J.Bergande	Main Drw.	Page 12 / 18	Material ID **PAAD128845**
Chkd 18.10.2013 W.Schiffer	Design Group **9709**	Drawing ID **DAAD040464**	Rev
Appd 21.10.2013 B.Haag			

3.5.3 Verification of crankweb deflections

Verification by Wärtsilä alignment measurement record file

The information provided in DG9709 - “Engine alignment – Crankweb deflections - Limits”, section “General” and section “Limits before chocking” need to be considered.
The crankweb deflection record sheet which is included in the above mentioned Wärtsilä alignment measurement record file (Microsoft Excel file format) includes an automated verification of relevant crankweb deflection limits and max. deviation indicator values, which - if exceeded – would require additional jack-up tests for other main bearings (see section 3.5.1)[12].

Calculation of crankweb deflections for manual verification

If the evaluation of crankweb deflections are not made with the above mentioned Wärtsilä crankweb deflection record sheet (included in the alignment measurement record file), then the vertical and horizontal deflections for each crankweb need to be calculated from the five reading values per crank as shown in table 2, depending if the reading positions refer to crank pin positions or to dial gauge positions:

Table 2	**Calculation of vertical and horizontal crankweb deflections**	
crankweb deflection reading position	**crank pin positions** (default in WCH documentation)	**dial gauge positions**
vertical deflection	$TDC - \frac{BDC_{exh} + BDC_{fps}}{2}$	$BDC - \frac{TDC_{exh} + TDC_{fps}}{2}$
horizontal deflection	$FPS - EXH$	$EXH - FPS$

3.5.4 Evaluation of static bearing loads

Wärtsilä evaluation – free of charge

We recommend to approach Wärtsilä for evaluation and review of alignment measurement results. This support is offered free of charge to shipyards and it is based on our long-term experience.
Wärtsilä evaluates static bearing loads by means of a so called ‘reverse calculations’. It is based on the calculation model of the ALC and processes all alignment measurement results in order to find the static bearing load distribution which fits best to all of the alignment measurement results.
If the ALC has not been made by Wärtsilä, then pls. provide the complete ALC to Wärtsilä as early as possible – and definitely before performing alignment measurements:

- If the ALC has been created by EnDyn program, ensure that Wärtsilä is in possess of the complete ALC – including the EnDyn input file (file name “*.ndi”).

- If the ALC has been created by another program, ensure that Wärtsilä is in possess of the complete ALC – including the complete listing of the calculation model.

Fill-in all measurement results including all additional information into the above mentioned Wärtsilä alignment measurement record file (Microsoft Excel) and transmit it to: application.engineering.ch@wartsila.com or to the local Wärtsilä office.

Explanation of jack-up test results

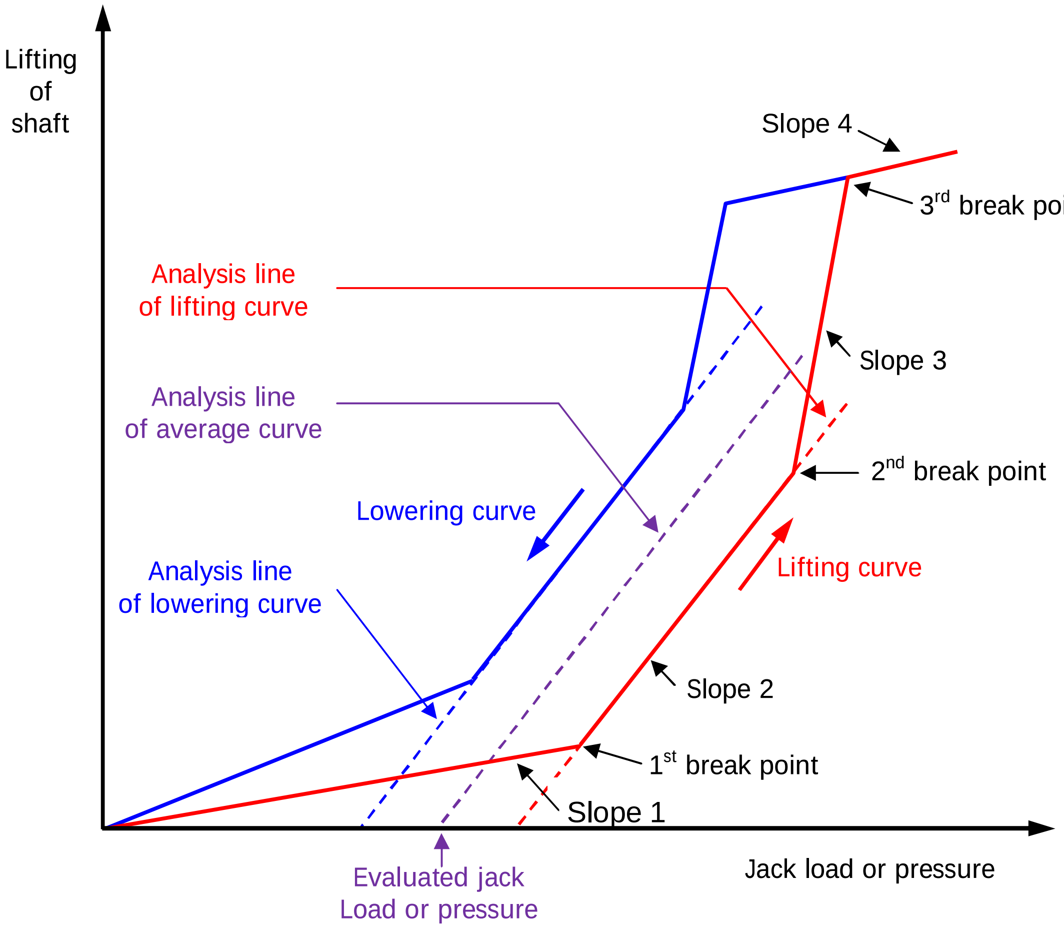

Figure 3: curves of plotted jack-up test results (solid lines) and analyse lines (dashed lines)

The following description refers to the jack-up tests results which are measured during lifting of the shaft, shown in figure 3 in red colour. The jack load mentioned in this description can also be understood as jack pressure.

Slope 1:

Initially all static load is in the bearing and no load is in the jack. By progressive increase of jack load, the static load of the bearing is progressively transferred to the jack. The slope 1 is rising moderately (low gradient). The bearing follows the lift of the shaft, i.e. there is no bottom clearance and thus no reduction of top clearance.

1st break point:

The transfer of static load from bearing to jack is completed.
The measured lift of shaft is related to bearing support stiffness and bearing load.

Slope 2:

This part of the plotted jack-up test results is required for evaluation of the bearing load. It needs to be long enough to allow a clear determination of the analyse line direction. Thus it needs to contain quite a number of readings which show the same increase of jack load "ΔF_{jack}" resulting in the same increase of lift "$\Delta h_{journal}$", i.e. the same ratio of "ΔF_{jack} / $\Delta h_{journal}$".
The further increase of jack load progressively transfers static load from the 2nd next bearing to the jack. Due to a larger distance (lever) between 2nd next bearing and jack, the slope 2 is rising more steeply (larger gradient).
The bearing next to the jack is not in contact with the journal anymore. Thus its bottom clearance increases and its top clearance reduces.

2nd break point:

The transfer of static load also from the 2nd next bearing to the jack is completed.

Slope 3:

The further increase of jack load progressively transfers static load from the 3rd next bearing to the jack. Due to an even more larger distance (lever) between 3rd next bearing and jack, the slope 3 is rising even more steeply (largest gradient).

3rd break point:

The shaft touches the upper shell of a bearing.

Slope 4:

The further increase of jack load "ΔF_{jack}" results in a significantly reduced lift of shaft "$\Delta h_{journal}$" (if any), i.e. in a much lower gradient of slope 4 for the curve of plotted jack-up test results.

Maximum lifting of shaft during jack-up test

If the inclination of the curve of plotted jack up test results is changed like above the '3rd break point' i.e. a further increase of jack load results in a significantly reduced lifting height, then the shaft touches an upper shell of a bearing and the jack pressure should not be further increased.

Shaft bearing loads

Evaluation of shaft bearing loads can be made manually. Further explanations to the above mentioned are provided in DG9709 - "Engine alignment – Guideline for Measurements", section "Evaluation of static bearing load measurement results".

Main bearing loads

Evaluation of main bearing loads is much more challenging due to their close distance in combination with the high bending stiffness of crankshaft and the higher stiffness of main bearing supports compared to the shaft bearings.
The most reliable evaluation is based on a reverse calculation – see section 3.5.4 sub-section "Wärtsilä evaluation – free of charge".

Evaluations without reverse calculations have an increased risk for errors. The following should be born in mind:

- The sum of evaluated static loads should be similar with the sum of relevant static loads in ALC.
- The evaluated static loads should be in an approximate relation to the elastic deflection of the bearing (height of 1st break point) and the stiffness of the bearing support.

3.5.5 Verification of evaluated static bearing loads

Evaluated shaft bearing loads

The static loads of shaft bearings must comply with the alignment layout calculation. A tolerance **according to class rules or according to ALC applies for them – whatever is tighter[14].**

The Wärtsilä evaluation and review of alignment measurement results includes also evaluation of the shaft bearing loads provided for reference only.

It lies within the responsibility of the shipyard to check, if the evaluated static loads of the shaft bearings are within specification.

Evaluated main bearing loads

The final alignment process needs to aim for achieving a static load distribution which is **very similar** to that which is provided by the cold – stopped condition of the ALC.

However, it is hardly possible to adjust the main bearing static loads exactly according to the referred loads of the ALC since the very close distance of the main bearings in relation to the crankshaft bending stiffness results in a very high sensitivity of main bearing static loads for offset variations. This is indicated by very high so called 'bearing influence numbers' [15].

The information provided in DG9709 - "Engine alignment – Main Bearing Loads – Recommendations & Limits", section "General" and section "Recommended static main bearing loads before chocking" need to be considered.

4 Chocking and fixation

4.1 Welding of main engine side stoppers

Before pouring the main engine resin chocks, the engine side stoppers have to be welded in their final positions[16]. Attention has to be paid for providing sufficient height for

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14 Usually a tolerance range of ±20% is considered.

15 Bearing influence numbers indicate the theoretical change of static bearing loads due to a change in vertical bearing offset. This information is provided by the ALC.

16 Welding the side stoppers before pouring the main engine resin chocks prevents possible damage of resin chocks caused by welding heat.

each of the side stopper wedges in order to meet the demand for the engine specific minimum vertical overlap. This information is provided in relevant side stopper drawing. The side stopper wedges are fitted after fixation of main engine (see section 4.4).

4.2 Chocking

The chocking of the engine has to be prepared as described in DG9710 – “Engine seating/foundation” [17].

The epoxy resin material for the chocks has to meet the defined properties as described in DG9710 – “Engine seating / foundation” – detail drawing “Epoxy resin”[17].

At next the main engine resin chocks can be poured according to the instructions of epoxy resin manufacturer.

Finally also the shaft bearings are chocked (e.g. epoxy resin chocks, metal chocks, etc.):

- either right after the chocking of the main engine
- or as a final installation step, after engine fixation and alignment measurements made after chocking have indicated satisfactory results.

The 2nd variant would allow very limited corrections in case some minor errors have occurred during the engine chocking and fixation process. However, the possible extent of such a correction is rather limited and should not counter-act any accurate working procedure.

Especially at designs without forward stern tube bearing, high attention has to be paid to the fact that a realignment of the (aft) intermediate bearing affects also the highly sensitive mis-alignment of the propeller shaft inside the aft stern tube bearing bore as well as its position at the forward stern seal.

4.3 Fixation of main engine

After the hardening of resin chocks is completed, the engine holding-down bolts have to be tightened according to DG9710 – “Engine seating / foundation” – detail drawing “Fitting instruction to engine seating with epoxy resin chocks” [17].

4.4 Installing of side stopper wedges

After chocking and tightening of main engine holding-down bolts the side stopper wedges are installed.

[17] This information is also provided by the engine specific Marine Installation Manual (MIM).

5 Alignment checks for commissioning / ship delivery

5.1 Pre-requisites

The draught and trim is within the normal ship operation limits.
The measurements can be taken at hot or cold main engine. However, general safety rules incl. the safety advices provided in the Maintenance Manual (MM) have to be strictly observed, e.g. the minimum delay between stopping of main engine and opening of its crankcase doors, the oily surfaces inside the engine, etc.
If the measurements are taken at warm or cold engine, then any heat supply to the engine room double bottom **has to be out of operation at least 4 hours prior to the measurement, i.e. the heating of the main lubricating oil sump tank below the main engine, the pre-heater of the main lubricating oil separator, etc.** Disregarding this aspect can cause inacceptable main bearing load distribution[18].
The information provided in section 3.5.2 has to be considered for recording of the measurement results.

5.2 Crankweb deflections

Crankweb deflections which are measured at commissioning / ship delivery[19] need to comply with the limits provided in DG9709 - “Engine alignment – Crankweb deflections - limits” - section “Limits for commissioning / ship delivery”.

5.3 Requirements for static main bearing loads at approx. ballast draught

For alignment measurements at ship delivery which refer to ballast draught and a trim which is within normal ship operation limits, the static main bearing loads need to comply with the requirements provided in DG9709 - “Engine alignment – Main bearing loads – recommendations & limits” - section “Required static main bearing loads before ship delivery”.

5.4 Limits for static main bearing loads at approx. design draught or maximum draught

For alignment measurements at ship delivery which refer to design draught or maximum draught (so called ‘scantling draught’) and a trim which is within normal ship operation limits, the static main bearing loads need to comply with the limits for normal ship service, provided in DG9709 - “Engine alignment – Main Bearing Loads – Recommendations & Limits”, section “Minimum limits for normal ship service”.

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18 Caused by an unequal temperature distribution which leads to an unequal thermal rise of main bearings.

19 Just before, during or after sea trial, when the ship is afloat and ready for operation.

WinGD-2S - Guidelines for alignment process

TRACK CHANGES

DATE	SUBJECT	DESCRIPTION
2016-10-25	DOCUMENT	First web upload