Table of contents

Introduction **1**

Abbreviations **1**

1 Gap and sag of un-coupled flanges **2**

2 Crankweb deflection **3**

2.1 Preparation of crankweb deflection measurements 3

2.2 Judgement of crankweb deflection measurement results 8

2.3 Recording of crankweb deflection measurement results 9

2.4 Evaluation of vertical and horizontal crankweb deflection 10

3 Static bearing loads **11**

3.1 Preparation of static bearing load measurements 11

3.2 Measurement of static bearing loads 15

3.3 Recording of static bearing loads 18

3.4 Evaluation of static bearing load measurement results 19

Introduction

The purpose of this alignment practice guideline is to provide information and guidelines about the correct measurement, recording, judgement and evaluation of crankweb deflections and bearing loads. It is based on practical experience and aims to support the end user in achieving evaluable results.

Abbreviations

The following abbreviations are used in this document:

ALC	alignment layout calculation
BDC	Bottom dead centre
CA	crank angle
DG	design group (Wärtsilä drawing set structure)
EXH	Exhaust side
FPS	Fuel pump side
mb	engine main bearing
TDC	Top dead centre

1 Gap and sag of un-coupled flanges

This section provides information about measuring of gap and sag values for un-coupled flanges during the alignment of shafts and main engine. Details about this alignment procedure are provided in DG9709 - “Engine alignment – Procedure & measurements at shipyard” - section “Final alignment in floating condition”. The gap & sag data for the alignment process are provided by the case specific ALC. The gap and sag values shown in this section are provided as examples only.

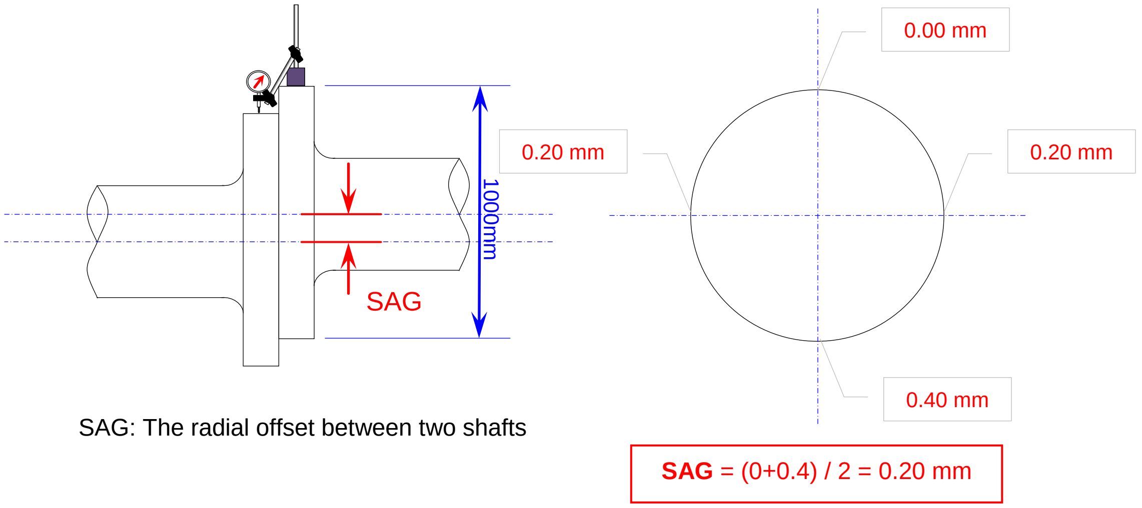

Figure 1: measurement of sag by means of a dial gauge

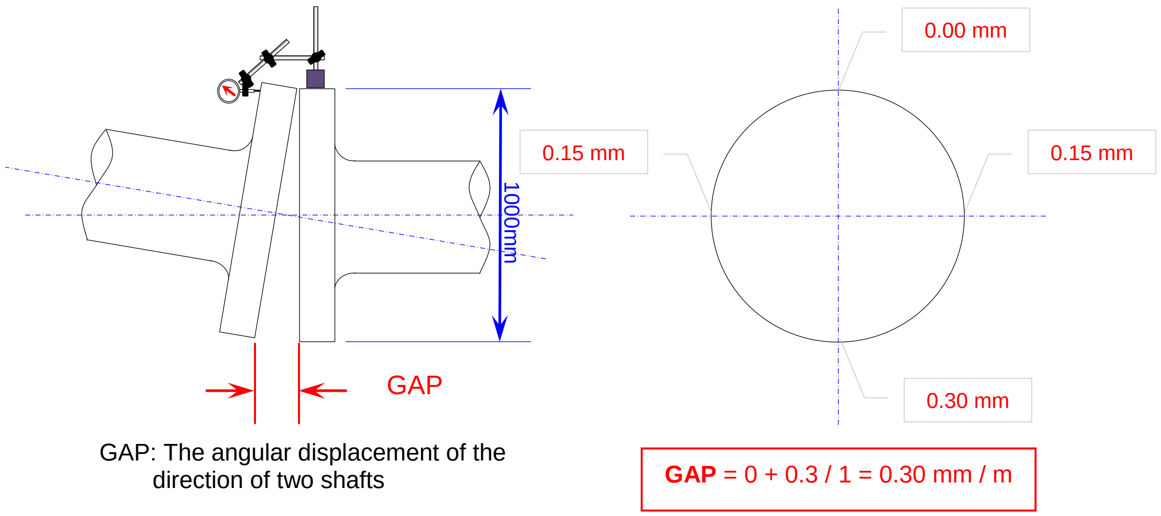

Figure 2: measurement of gap by means of a dial gauge

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2 Crankweb deflection

This section provides guideline for crankweb deflection measurement in addition to the contents provided by DG9709 - “Engine alignment – crankweb deflections - limits“ and DG9709 - “Engine alignment – Procedure & measurements at shipyard“.
Good experience and great care is crucial for measuring crankweb deflections.
The safety rules have to be strictly observed.
The engine is stopped and has to be reliably interlocked against starting for safety reasons until completion of the measurement and after all crank doors have been completely closed again.
In particular the safety advices provided in the Maintenance Manual (MM), e.g. the minimum delay between stopping of main engine and opening of crankcase doors, the oily surfaces inside the engine, etc.

2.1 Preparation of crankweb deflection measurements

2.1.1 Tools for crankweb deflection measurement

The crankshaft deflection gauge which is included in the set of engine tools or a similar one[1] with appropriate length and 1/100 mm scale should be used for the measurement of crankweb deflection see figure 3.

Figure 3: mechanical dial gauge kit (left), electronical measurement gauge (right)

Preparation of dial gauge

Before using the deflection gauge its functionality needs to be checked carefully:

- The indicator sliding rod has to move smoothly and free from any irregular friction or an abnormally high resistance during movement.
- The extension bar needs to be straight and selected in accordance with the engine specific distance “A” between the opposing crankwebs / main journals (see table 1 and figure 4).

1 Alternatively also an electronic measurement system using an inductive distance sensor as shown in figure 3 can be used.

Table 1	Distance "A" between cranks / journals *1 [mm]
W-X35	136
W-X40	156
W-X62	234
W-X72	270
W-X82	272
W-X92	320
RTA / RT-flex48T-D	150
RT-flex50 / -B / -D RT-flex50DF	150
RT-flex58T-D / -E RTA58T-D	183
RT-flex60C-B	186
RTA / RT-flex68-D	210
RTA / RT-flex82C	272
RTA / RT-flex82T-B/ -D	272
RTA / RT-flex84T-D	260
RTA / RT-flex96C-B	404

*1 without consideration of punch mark depths

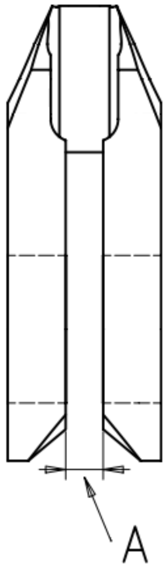

Figure 4: Distance between crankwebs / main journals.

2.1.2 Ambient conditions during crankweb deflection measurement

Switching-off heat sources in foundation

For measurements at cold condition, the following **heat sources have to be switched-off at least 8 hours before the measurement**:

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

For measurements **at warm conditions,** the above mentioned heat sources have to be switched-off **at least 4 hours before the measurements**.
For measurements **at hot conditions,** the above mentioned heat sources have to be switched-off **at least 1 hour before the measurements.**

Sea motion

For measurements in afloat conditions, flat water conditions are recommended. Measurements made at sea motion or heavy swell or even rough sea condition, may lead to scattered measurement results which might not be evaluable.

If such measurement conditions cannot be avoided (e.g. at sea trial), then we recommend to repeat the measurement as soon as more favorable conditions are present (e.g. after sea trial) – even if the draught or temperature has changed – and to include these additional measurements to those with scattered results.

Further influences

During the measurement, the influences onto alignment should be limited as far as possible:

- Measurements at covered sky or just after sunrise or at night should be preferred.
- Cargo operation or ballasting operation should be avoided.
- Measurements at strong sunshine onto one side of ship hull should be avoided.

2.1.3 Engine conditions during crankweb deflection measurement

- The electric motor driven **turning gear has to be ready** for use.
- The piston and cylinder liner including **all** other **moving parts should be lubricated well** before the measurement is taken to avoid any abnormal friction change while turning the crankshaft – in particular after a longer period of engine stand-still.
- **The engine is stopped and has to be reliably interlocked against starting.**
- The main **lubricating oil pumps** (incl. crosshead pumps, if exist) have **to be stopped as early as possible**.
- The **indicator** (test) **cocks at** all **cylinder covers** need **to be opened**.

2.1.4 Measuring crankweb deflections

The crankweb deflection is measured at five angular positions. The first and the last reading values need to be read when **the dial gauge is very close to the connecting rod** (details see figure 6).
A detailed step-by-step description for preparation and performance of reading crankweb deflections is provided in this section. The steps are indicated by numbered paragraphs.

Safety

Ensure that the safety advices mentioned in section 2 are fully adhered at any time and that the main engine is stopped and reliably interlocked against starting until completion of the measurement and after all crank doors have been completely closed again.

Turning direction during measurement

It is recommended to choose the turning direction based on location of turning gear (see figure 5):

- **Counter-clockwise** rotation for engines with **turning gear on fuel pump side:** e.g. RTA48T-D, RTA58T-D, RT-flex60C-B, RTA68-D, RTA82C, RTA82T/T-B, RTA/RT-flex84T-D, RTA/RT-flex96C-B.
- **Clockwise rotation** for engines with **turning gear on exhaust side:** e.g. W-X35, W-X40, W-X62, W-X72, W-X82, W-X92, RT-flex48T-D, RT-flex50-B/-D, RT-flex82C/T.

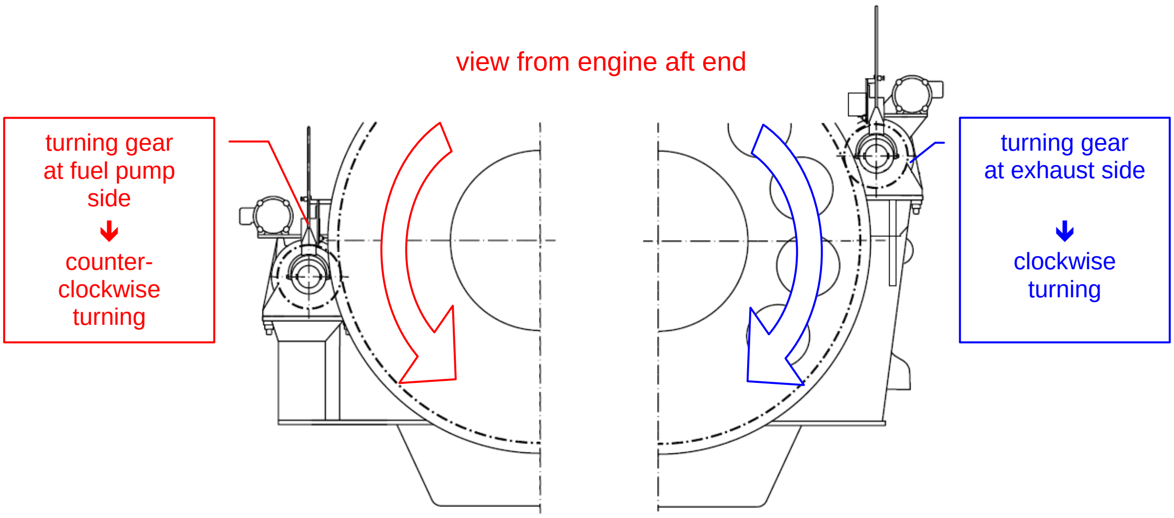

Figure 5: definition of turning directions (view from aft end)

During a measurement session, the crankweb deflections of all cranks have to be measured with the same turning direction, i.e.
- either clockwise for all cranks
- or counter-clockwise for all cranks.

All measurements must be read under the same condition, i.e.
- either all are read during turning of the crankshaft
- or all are read at stopped condition.

That means in case all measurements were taken while the crankshaft continued turning, also the last measurement has to be taken during turning and just before stopping.

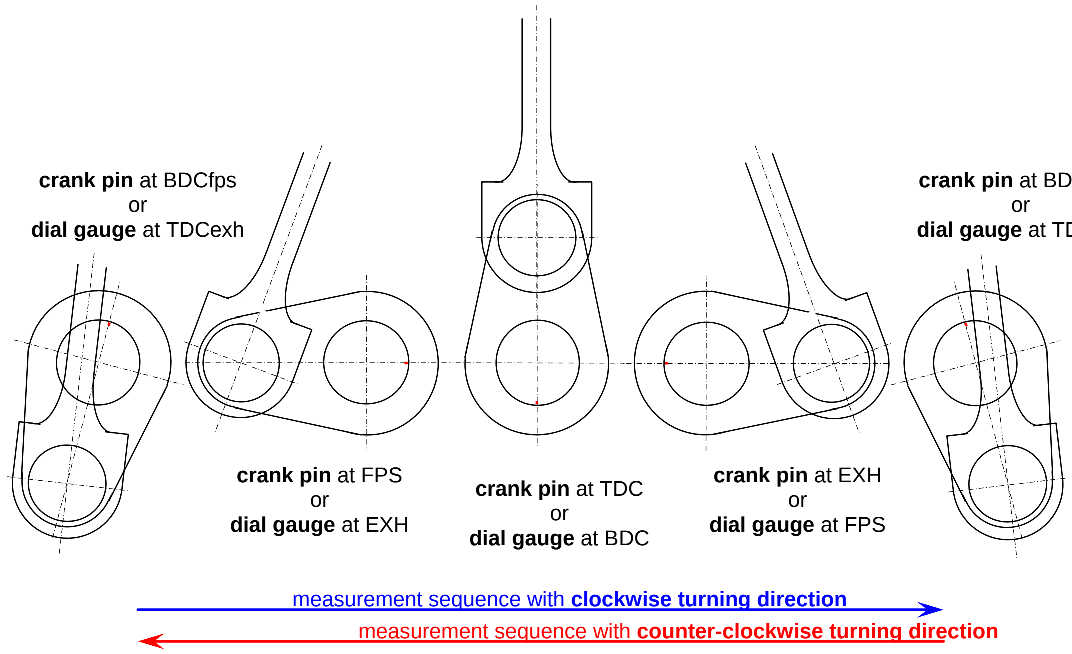

Figure 6: reading positions for crankweb deflections (view from aft end)

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Inserting and resetting the dial gauge

High attention needs to be paid for the correct setting of the deflection gauge:

1) Engage the turning gear.

2) Turn the crankshaft at least one revolution in order to ensure that all moving engine components are free and get properly lubricated and thus reduce the resistance to a minimum, especially after a longer period of stand-still.

3) Turn relevant crank pin into the bottom dead centre (BDC)[2].

4) Then just turn the crankshaft out of the bottom dead centre into the first of the five reading positions[2] using the same turning direction like for all subsequent measurements, i.e. turn the crank
   - either into bottom dead centre – exhaust side for counter-clockwise measurement;
   - or into bottom dead centre – fuel pump side for clockwise measurement

   This position needs to be as close as possible to the bottom dead centre position so that the dial gauge can just safely be inserted and turned around its axis (see step 6).

5) Insert the dial gauge carefully into the round centre punch marks which are stamped into each of the two opposing main journals of relevant crank as shown in figure 7 and figure 8.
   Do not insert the gauge into the crank - journal slip indication marks on the outer side of the round centre punch marks[3].

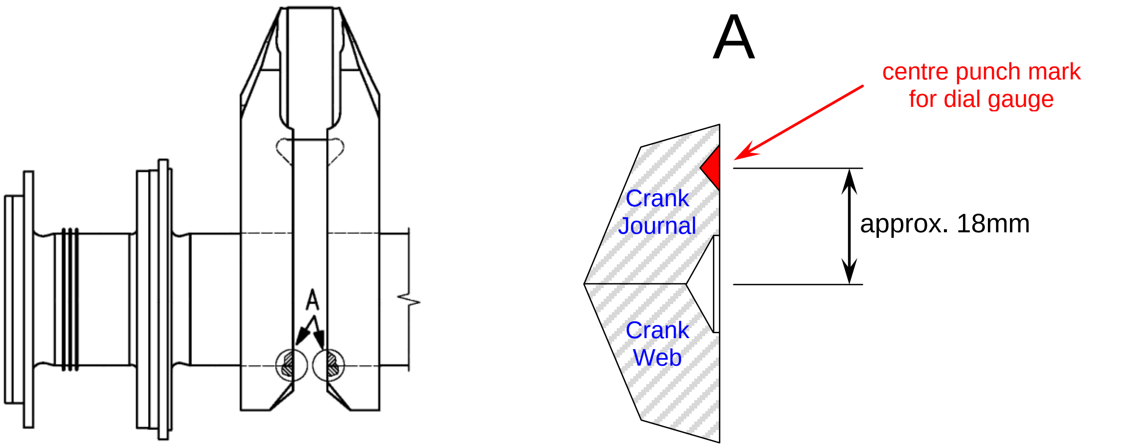

Figure 7: positions of round centre punch mark dedicated for inserting the crankweb deflection measurement gauge

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2 Turning the crankweb into bottom dead centre completely and then use the turning direction for measurement to turn the crank into the first of the five reading positions close to the connecting rod is crucial to achieve the required low difference between the first and the fifth reading value – see section 2.2 .

3 The indicated distance (18mm) between the centre punch mark for crankweb deflection gauge and the crank - journal slip indication marks may differ, depending on engine type and version.

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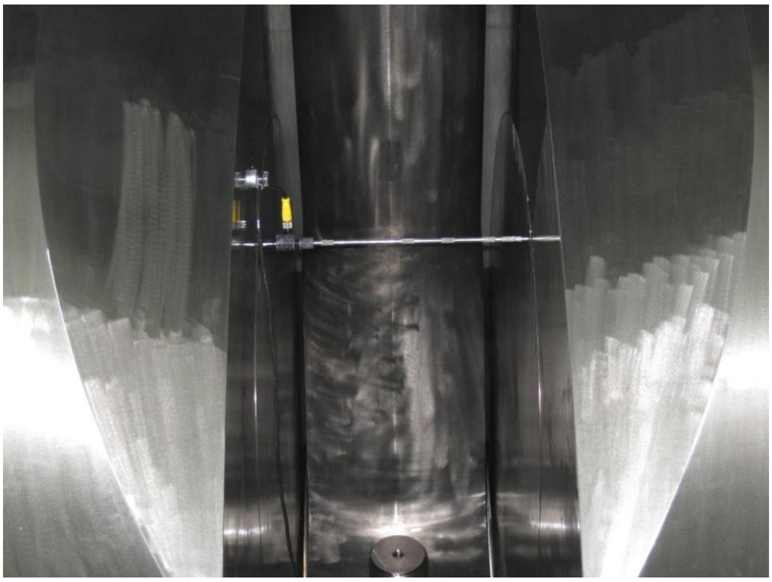

Figure 8: dial gauge installed for crankweb deflection measurement

6) Ensure a complete settlement of dial gauge into the round centre punch marks by numerous turns around its measuring axis until the gauge indicates a steady value.

7) Finally reset the dial gauge to zero.

Reading and noting the crankweb deflections

8) Turn the crankshaft in the chosen turning direction and read and record the deflection changes when the crank pin reaches relevant reading positions shown in figure 6.

9) Right after reading the fifth deflection value, check the difference between the first and the last reading value: It has to comply with the permissible deviation as explained in section 2.2 . If the permissible deviation is exceeded, then repeat the complete measurement of the relevant crank. In case of sea motion causing excessive deviations see section 2.1.2 - subsection “Sea motion”.

10) Repeat steps 3) to 9) for each crank to be measured.

2.2 Judgement of crankweb deflection measurement results

The permissible deviation between the first and the last crankweb deflection reading value is limited as listed in table 2 for each engine type.
If the permissible deviation is exceeded, then the complete measurement of the relevant crank needs to be repeated – otherwise it might not be possible to judge the measurement results.
Possible reasons for exceeding the permissible deviation can be

- change of turning direction when turning from the first to the second reading position
- incomplete settlement of dial gauge into the centre punch marks
- either the first or the last reading position was too far away from bottom dead centre – see figure 6.

Table 2	Permissible deviation between first and last deflection reading value of a crankweb [mm]
W-X35 **W-X40**	0.03
W-X62	0.04
W-X72	0.05
W-X82 **W-X92**	0.06
RT-flex48T-D & RTA48T-D **RT-flex50-B / -D & RT-flex50DF** **RT-flex58T-D / -E & RTA58T-D** **RT-flex60C-B**	0.04
RT-flex68-D & RTA68-D	0.05
RT-flex82C & RTA82C **RT-flex82T & RTA82T** **RT-flex84T-D & RTA84T-D** **RT-flex96C-B & RTA96C-B**	0.06

2.3 Recording of crankweb deflection measurement results

A careful recording of crankweb deflection measurement results is essential for a reliable analysis 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.

We recommend using the Wärtsilä data record sheets. They are provided free of charge in Microsoft Excel file format. 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.

2.3.1 Additional information about measurement

General information

- date of measurement
- engine type, incl. number of cylinders
- engine builder and his manufacturing number (refer to name plate at engine)
- for ship newbuilding: shipyard name, hull number and IMO number
  for ships in service: ship name and IMO number
- for ship newbuilding: current engine and shaft installation progress, e.g. before or after chocking, before or during or after sea trial
  for ships in service: operating hours

Information about ship condition

- current fore and aft ship draught
- approx. temperatures of crankshaft, main lubricating oil and cylinder cooling water

Information about reading details

- units of crankweb deflection reading values (e.g. 1/100 mm)
- turning direction during the measurement, i.e. either “counter-clockwise” or “clockwise” [4]
- the referred measurement positions[4]:

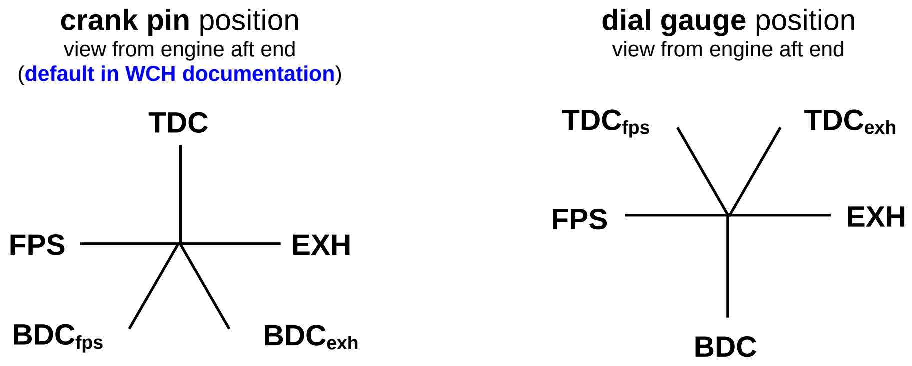

Figure 9: definitions of crankweb deflection reading conventions

- The reading convention of the dial gauge[4] which is defined as follows:
  - ➢ 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 higher 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)

2.4 Evaluation of vertical and horizontal crankweb deflection

It is recommended to use Wärtsilä´s recording sheet in DG9707 – “Engine Alignment Record Sheets”. If evaluation sheets of 3rd party are used or if the readings are evaluated manually, then the vertical and horizontal deflections for each crankweb are calculated from the five reading values per crank as shown in table 3, depending on the reading positions which refer either to crank pin positions or dial gauge position:

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4 Record all measurements as read, i.e. in accordance to the actual turning directions, measurement positions and reading convention. The Wärtsilä´s recording sheet in DG9707 - "Engine Alignment Record Sheets") contain input fields to report also these conditions and reading details.

Table 3	Calculation of vertical and horizontal crankweb deflections	
	crank pin position readings (default in WCH documentation)	**dial gauge position** readings
vertical deflection:	$TDC - \frac{BDC_{exh} + BDC_{fps}}{2}$	$BDC - \frac{TDC_{exh} + TDC_{fps}}{2}$
horizontal deflection:	$FPS - EXH$	$EXH - FPS$

2.4.1 Crankweb deflection max. deviation indicator

If the crankweb deflection measurement refers to ship newbuilding or engine re-alignment, then the difference of vertical crankweb deflections needs to be checked. If it exceeds the related maximum deviation indicator[5], then additional jack-up tests for other main bearings become required (see DG9709 – "Crankweb deflection - limits" - section - "Crankweb deflection max. deviation indicator").

3 Static bearing loads

This section provides guideline for static bearing load measurement in addition to the contents provided by DG 9709 - "Engine alignment – Main bearing loads – recommendations & limits" and DG9709 - "Engine alignment – Procedure & measurements at shipyard"
The measurement of static bearing loads (also called 'jack-up test') is the common method to determine actual static bearing loads for engine main bearings, intermediate shaft bearings and forward stern tube bearing. The data is needed for the verification whether the real static load distribution meets the requirements which were defined within the layout calculation.

3.1 Preparation of static bearing load measurements

3.1.1 Ambient condition during static bearing load measurement

Switching-off heat sources in foundation

For measurements at cold condition, the following **heat sources have to be switched-off at least 8 hours before the measurement**:

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

For measurements **at warm conditions,** the above mentioned heat sources have to be switched-off **at least 4 hours before the measurements**.

5 This usually applies for the two foremost crankweb deflections in case a heavy external mass such as a TV damper, front disc or free end PTO gear drive is installed.
If this applies for other main bearings, i.e. mb #3 to the second foremost, then Wärtsilä needs to be contacted.

For measurements **at hot conditions,** the above mentioned heat sources have to be switched-off **at least 1 hour before the measurements.**

Sea motion

For measurements in afloat conditions, flat water conditions are recommended.
Measurements made at sea motion or heavy swell or even rough sea condition, may lead to scattered measurement results which might not be evaluable.
If such measurement conditions cannot be avoided (e.g. at sea trial), then we recommend to repeat the measurement as soon as more favorable conditions are present (e.g. after sea trial) – even if the draught or temperature has changed – and to include these additional measurements to those with scattered results.

Further influences

During the measurement, the influences onto alignment should be limited as far as possible:

- Measurements at covered sky or just after sunrise or at night should be preferred.
- Cargo operation or ballasting operation should be avoided.
- Measurements at strong sunshine onto one side of ship hull should be avoided.

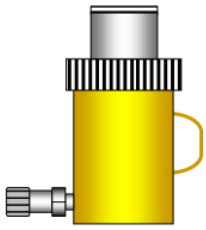
3.1.2 Engine condition during static bearing load measurement

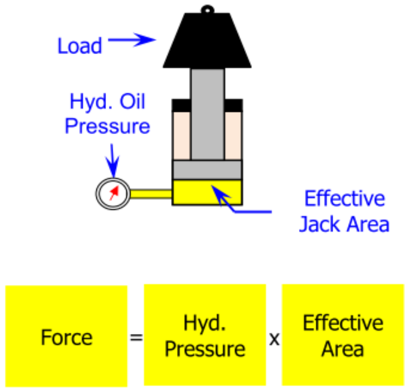
The electric motor driven **turning gear has to be ready** for use.
The piston and cylinder liner including **all** other **moving parts should be lubricated well** before the measurement is taken to avoid any abnormal friction change while turning the crankshaft – in particular after a longer period of engine stand-still.
The engine is stopped and has to be reliably interlocked against starting.
The main **lubricating oil pumps** (incl. crosshead pumps, if exist) have **to be stopped as early as possible**.
The **indicator** (test) **cocks at** all **cylinder covers** need **to be opened**.

3.1.3 Tools for static bearing load measurement

- Appropriate hydraulic jacks which have to be chosen according to the following criteria:
  - ➢ Jacks for jacking up engine main bearings need to have a sufficient size, whose engine specific guidance values are provided in table 4.

Table 4	Recommended Jack capacity [ton]
W-X35	25 – 50
W-X40	25 – 50
W-X62	70 – 100
W-X72	100 - 150
W-X82	100 - 150
W-X92	100 - 150
RTA / RT-flex48T-D	50 - 70
RT-flex50 / -B / -D RT-flex50DF	50 - 70
RT-flex58T-D / -E RTA58T-D	70 – 100
RT-flex60C-B	70 – 100
RTA / RT-flex68-D	70 – 100
RTA / RT-flex82C	100 - 150
RTA / RT-flex82T-B/D	100 - 150
RTA / RT-flex84T-D	100 - 150
RTA / RT-flex96C-B	100 - 150





- Jacks for jacking up shaft line bearings need to be selected according to the expected bearing loads which are provided in the alignment layout calculation for referred condition. As guidance, the jack capacity for jacking up shaft line bearings is usually about half in size as the jack capacity needed for jacking up engine main bearings.
- It is not recommended to increase the total capacity by operating two jacks in parallel, side by side below one jack up point, since the results can be hardly evaluated.
- To avoid increased friction by twisting: It has to be avoided, in reference to figure 10 that the jack's plunger is too much extended in the maximum position. As countermeasure the adjustment of a parallel and even machined steel block under the jack can be considered.

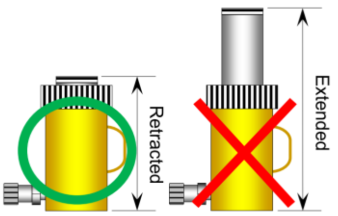


Figure 10: jack extension

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Appd	21.10.2013	B.Haag			

➢ To keep hysteresis small transversal angular misalignment and transversal parallelism between shaft and bearing shell (figure 11) has to be equalized by positioning of the jack exactly below the transversal shaft centre as it is shown in figure 12.

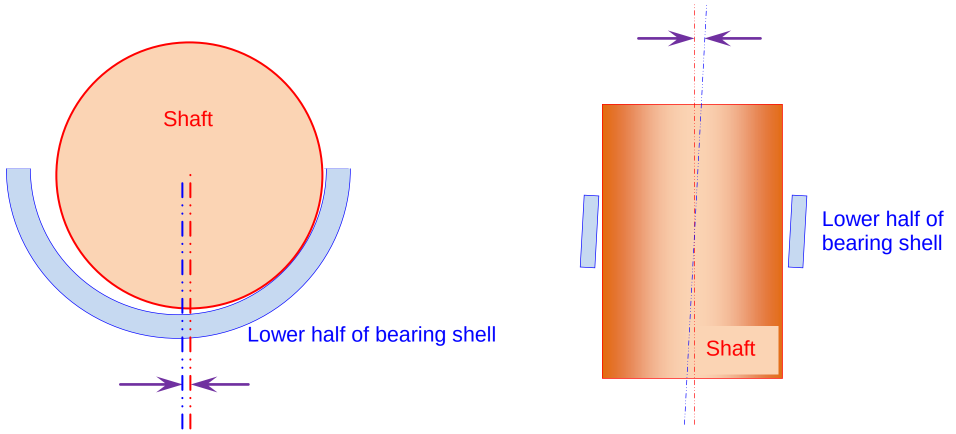

Figure 11: Transversal angular misalignment and transversal parallelism between shaft and bearing shell

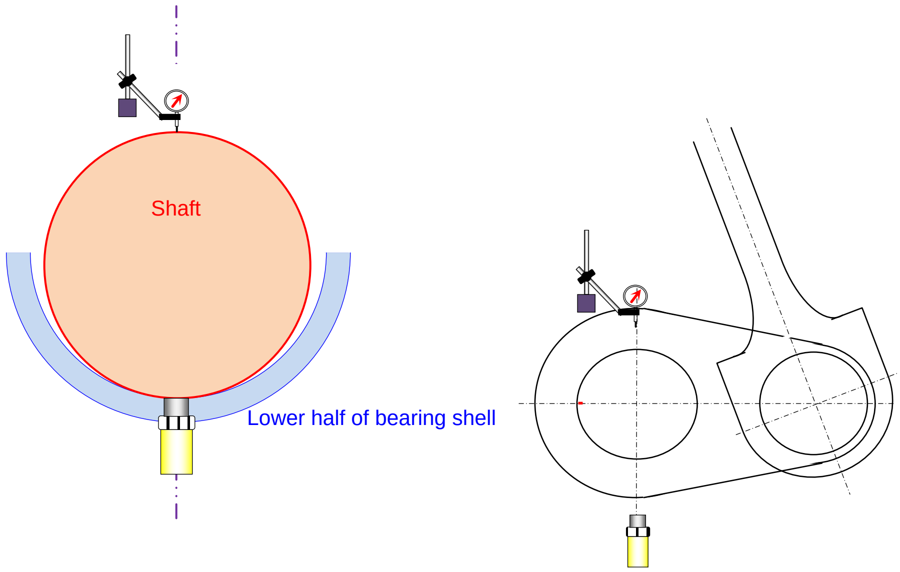

Figure 12: Correct positioning of hyd. jack and measurement gauge exactly above/below of transversal shaft centre

- Hydraulic pressure gauge, range acc. to jack size (fine scale 10, 20 or 25bar), or electronic load cell.
- Hydraulic pump, capacity acc. to jack size.
- Adequate hydraulic hoses and stop valves.
- Dial gauge (e.g. with 0.01mm scale) with magnetic stand.
- Steel plate(s) for distribution of jack load onto tank top (or foundation) below flywheel.

- Steel plate between hydraulic jack and flywheel to protect flywheel turning teeth.
- Girder (see figure 13) provided for crankweb lifting during lower half main bearing shell inspection or replacement.

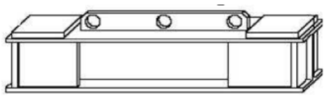

Figure 13: Girder for placing the hydraulic jacks below cranks

3.2 Measurement of static bearing loads

The following description provides a step by step instruction for the systematic measurement of static bearing loads.

1) Engage the turning gear to the flywheel.
2) Turn the crankshaft at least one revolution in order to ensure that all moving engine components are free and get properly lubricated and thus reduce the resistance to a minimum, especially after a longer period of stand-still.
3) Turn the crankshaft to the required position e.g. cyl. 1 at top dead centre for measuring of mb #1 and shaft line bearings loads or cyl. 1 at exhaust gas side for measuring of mb #2 and mb #3 load.
4) Arrange the measurement tools (jacks and dial gauges) according to following descriptions, referring to figure 14 to figure 17.
5) Ensure that there are no personnel inside the crankcase. Then disengage the turning gear from the flywheel.

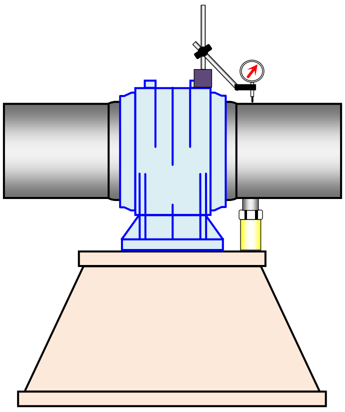

Figure 14: Arrangement for jack-up test with hydraulic jack and mechanical dial gauge.

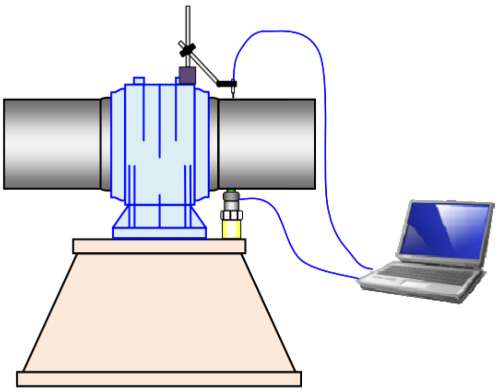

Figure 15: Arrangement for jack-up test with load cell and electronic displacement gauge.

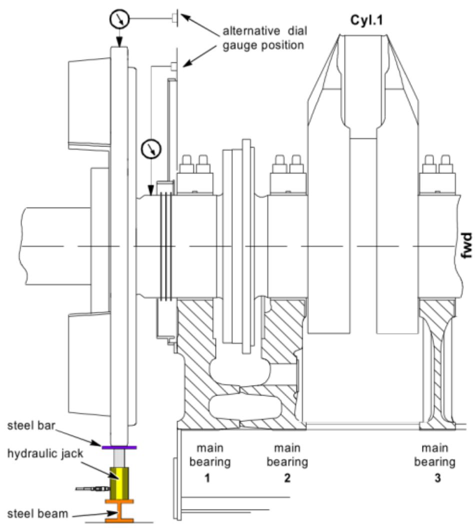

Figure 16: Jack-up test of aftmost mb #1

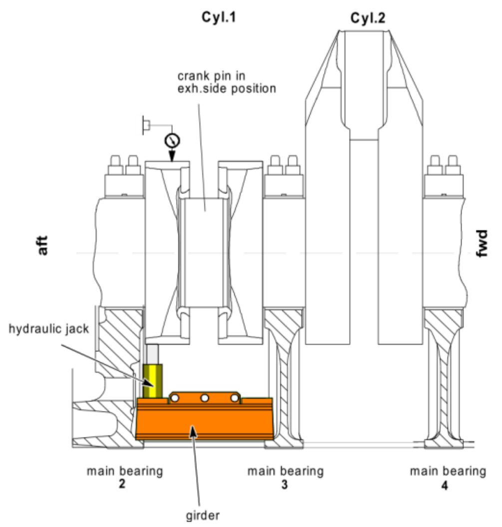

Figure 17: Jack-up test of mb #2

Aft most mb #1 should be jacked up below the flywheel. A steel beam or steel plates are required to distribute the jack load to the tank top plate. A steel bar arranged between jack and flywheel is required to prevent damage of flywheel turning gear teeth.

Mb #2 up to foremost mb should be jacked up below the crankweb next to the relevant bearing supported by a girder. The dial gauge to measure the vertical lifting of the crankshaft in relation to bearing housing has to be placed above or at least as close as possible to the jack with the magnet stand placed either on top of the mb cap or on the engine housing.

6) Before taking the measurement, lift up and lower down the shaft at least once and check the jack and hoses concerning leakages of hydraulic oil during the arrangement.

7) Lift up the crankshaft at the relevant bearings under consideration of the following points:

- The lifting up of the crankshaft at the relevant bearing should be done steadily (step by step) and slowly in order to avoid an exceeded hysteresis.
- For each step the vertical shaft position (lifting height) and the related jack pressure has to be recorded. The recorded results are illustrated as jack up curve in the evaluation sheet.
- For the whole jack up test, a pressure range from 10-50 bar should be covered and include as much as possible measurement points (at least 15), especially for the lifting height range from 0 to 0.2 mm.

T_PC-Drawing_portrait | Author: Y. Keel, S. Knecht | Released by: K. Moor | First released: 29.07.2010 | Release: 1.2 (06.09.2010)

- In case the bearing load is very low resp. close to zero load it is recommended to use 3 dial gauges (potentially with a finer calibration) in parallel, i.e. one on the crankweb housing, two on each side of the adjacent crankwebs, to achieve by reference measurements evaluable results.
- The shaft at the corresponding bearing has to be lifted up as much as possible to receive evaluable results. The max. lifting height for the main bearings is **restricted by the minimum bearing clearance plus 0,05 mm** for taking into account the elastic deflection. For the min. lifting height refer to table 5 which provides engine specific guidance values.
  The max. lifting height for the shaft line bearings is **restricted by the minimum bearing clearance plus 0,5 mm** for taking into account the elastic deflection. For the clearance of the shaft line bearings refer to the data provided by the bearing supplier.
- To avoid overstretching of bearing tie rods or provoking a deformation of the upper bearing shell, the lifting up has to be stopped immediately as soon as an irregular resistance is observed, i.e. the lifting height stagnates although the load increased significantly.

Table 5	Recommended minimum lifting height (mm)
W-X35	0.2
W-X40	0.2
W-X62	0.3
W-X72	0.4
W-X82	0.4
W-X92	0.4
RTA / RT-flex48T-D	0.3
RT-flex50 / -B / -D RT-flex50DF	0.2
RTA / RT-flex58T-D / -E RTA58T-D	0.3
RT-flex60C-B	0.3
RTA / RT-flex68-D	0.3
RTA / RT-flex82C	0.4
RTA / RT-flex82T-B/D	0.4
RTA / RT-flex84T-D	0.4
RTA / RT-flex96C-B	0.4

8) Lower down the crankshaft at the relevant bearings under consideration of the following points:

- The lowering down of the crankshaft at the relevant bearing should be done steadily (step by step) and slowly in order to avoid exceeded hysteresis.
- For each step the vertical shaft position (lifting height) and the related jack pressure has to be recorded. The recorded results are illustrated as lowering down curve in the evaluation sheet.

9) Repeat step 3 to 8 for the static load measurement of each bearing.

3.3 Recording of static bearing loads

To make a clear evaluation and to issue a confirmation letter, if the results met the requirements, the following information are requested by Wärtsilä (if available, Wärtsilä`s record sheet provided in DG9707 – "Engine Alignment Record Sheets" should be always used):

- Date of measurement
- Engine type.
- Engine builder and their manufacturing number. (refer to name plate at engine)
- Ship name, shipyard and hull number.
- Operating hours of the engine

- Engine and shaft installation progress status, e.g. before/after chocking, before/during/after sea trial.
- Actual fore and aft ship draught
- Approx. temperature of crankshaft, lubricating oil and cylinder cooling water.
- Scale unit of the measurement devise used for the recording of shaft lifting height.
- Scale unit of the measurement devise used for the recording of jack pressure, respectively jack load (e.g. bar, kg/cm2 or ton).
- If only the jack pressure is recorded, exact effective pressure area of the used hydraulic jack.
- Exact position of each hydraulic jack and dial gauge
- Crankshaft position, e.g. aftmost crank #1 at TDC or EXH side for each measurement.
- The jack up test measurement results (lifting heights with corresponding loads) for all relevant bearings, i.e. at least for the three aftmost engine main bearings and all shaftline bearings, except the aft sterntube bearing (see DG9709 - “Engine alignment – Main bearing loads – recommendations & limits”).
- The corresponding crankweb deflection measurement results, which were taken under the same engine and ambient conditions and are needed for the evaluation and verification of the recorded jack up curves by reverse calculation.

3.4 Evaluation of static bearing load measurement results

3.4.1 Calculation of static bearing loads

With the jack pressure recorded during the jack up test, the jack load can be calculated with the corresponding effective jack area according to the following formula 1.

$$Jack\ load\ [N] = Jack\ pressure\ [MPa] \cdot Jack\ area\ [mm^2]$$

Formula 1: calculation of jack load

The actual static bearing load is influenced by several factors which are taken into account within the calculation as follows:

- **Jack position in correlation to the dial gauge position:**
  Since the hydraulic jack during jack up test is in most cases not exactly in the same longitudinal position as the dial gauge for measuring of the lifting height a jack correction factor needs to be applied to calculate the bearing load in the corresponding position as described by formula 2:

$$Bearing\ load\ [N] = Jack\ load\ [N] \cdot Jack\ correction\ factor$$

Formula 2: calculation of bearing load

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Appd	21.10.2013	B.Haag	

Page	Material ID	Drawing ID	Rev
19 / 31	PAAD128849	DAAD040468	

Basically, the jack correction factors depend on the project specific layout of the propulsion shaft, i.e. shaft diameter, bearing distances and actual bearing load distribution. For the evaluation of shaft bearings' jack-up test results, the jack correction factors provided by the ALC should be applied. For further information refer to DG9709 - "Engine alignment – Main bearing loads – recommendations & limits" - section "Jack correction factors"

- **Influence by friction of the hydraulic jack:**
  Due to the unavoidable friction in the hydraulic jack, the hydraulic pressure corresponding to a specific load is during lifting up higher than during lowering down. The real (frictionless) load can be achieved by the analysis as line between the lifting up and lowering down curve.

- **Influence by the crank angle in actual measurement position:**
  The main bearing loads vary depending on the crank angle (CA). The reason for this can be found in the geometry of the cranks which causes non-rotary symmetrical stiffness of the cranks, i.e. the crankshaft stiffness between the bearings is different for different crank angles and consequently the bearing load distribution is different. **Therefore, a reference condition is defined which refers to zero crank angle, i.e. cylinder #1 in top dead centre position**.
  The total extent of each bearing's load range within one 360° rotation is indicated on the EnDyn calculation output graphics (refer to figure 18) by a grey load range field. The cylinder #1 top dead centre position (TDC) which refers to zero crank angle (0°CA) is marked by the longer red centre line. The shorter red lines on the left and right sides in the grey box mark the main bearing loads at jack-up test condition, i.e. on the left side for jack-up test from the main bearing's aft side and on the right side for the jack-up test from the main bearing's forward side. As main bearing #1 can only be measured from aft side, the line on the right side is omitted, and the left line accordingly for main bearing #2, as this bearing can only be measured from forward side.
  The following figure 18 shows an example of the vertical bearing load graphic as provided by EnDyn, but reduced to just the aft main bearings #1 to #3.

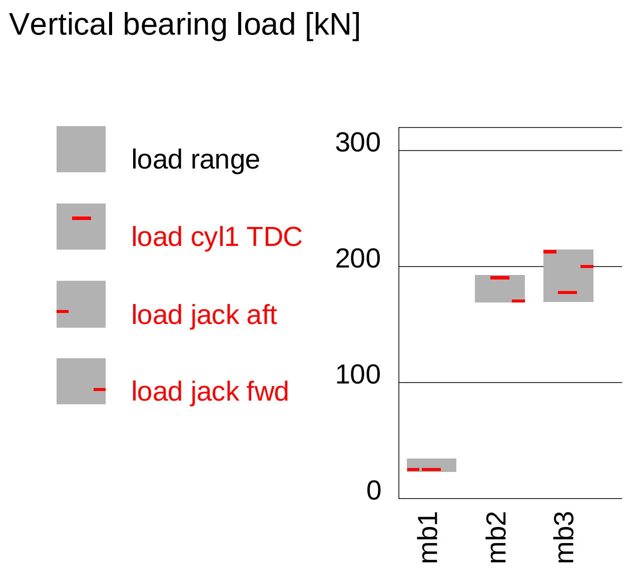

Figure 18: example of RT-flex58T-D main bearing #1 to #3 loads as plotted by the EnDyn alignment calculation program.

The static load variation within one complete turn of main bearing #2 is shown in figure 19 ; that of main bearing #3 is shown in figure 20.

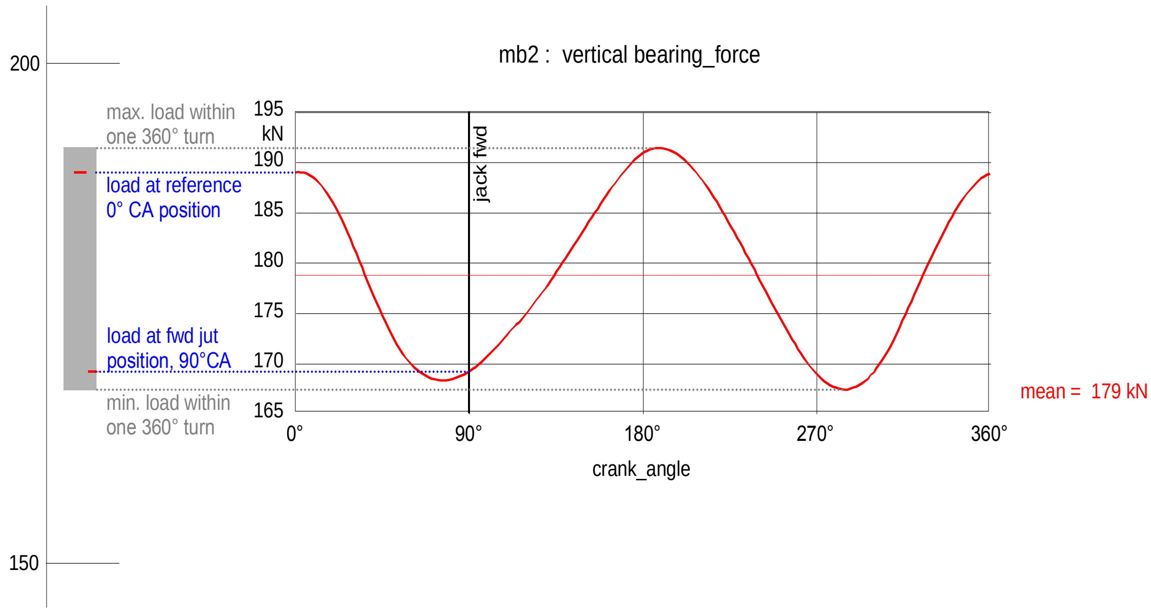

Figure 19: Main bearing #2 load and the corresponding bearing loads within one 360° rotation.

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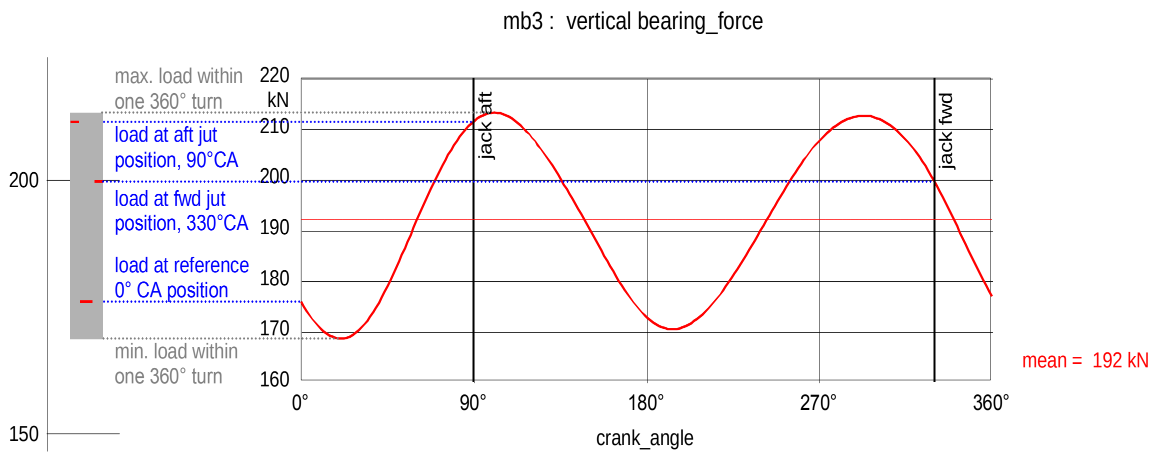

Figure 20: Main bearing #3 load and the corresponding bearing loads within one 360° rotation.

The loads calculated by applying the two-dimensional crankshaft model refer to the reference condition, while the measured bearing loads refer to the crank angle which is adjusted for carrying out the load measurements. Applying the EnDyn calculation program makes information about the bearing loads at measurement condition and any other crank angle condition available.
Main bearing #1 load is measured at zero crank angle (0° CA, reference condition) position and therefore the measured load refers directly to the calculated load. However, the jack-up tests for main bearings #2 and #3 are usually carried out with the aftmost crankpin on exhaust side, as indicated in the bearing load graphics. For these jack-up test conditions the bearing loads generally deviate compared to zero crank angle (0°CA) as follows:
Mb #2: lower[6] static bearing load[7], close to the minimum of the one-revolution load range.
Mb #3: higher[8] static bearing load[7], close to the maximum of the one-revolution load range.
The extent of the bearing load change depends on the engine type as well as the current situation (bending moments in the crankshaft). In general the range of expected load change within one 360° rotation is less for main bearing #2 than for main bearing #3.

---

6 In most cases between 80% and 90% of reference load for high-loaded bearing #2 as requested for the layout condition. In case of low-loaded main bearing #2, the load might be reduced to 0%, i.e. unloaded.

7 Static bearing load = jack load multiplied by the jack correction factor.

8 Depending on engine type and current situation (bending moments in the crankshaft), usually a variation within the range of 15% to 70% can be expected, as long as main bearing #3 is loaded as recommended. EnDyn alignment layout calculation helps at least to know the influence of the engine type. Advanced analyses support is provided on request by Wärtsilä.

3.4.2 Graphical analysis of static bearing loads - basics

This chapter provides the description how to judge and evaluate static bearing load measurement results by means of graphical analysis.

The following graph (figure 21) shows a typical jack up test result plotting the lifting height in correlation to the corresponding jack load.

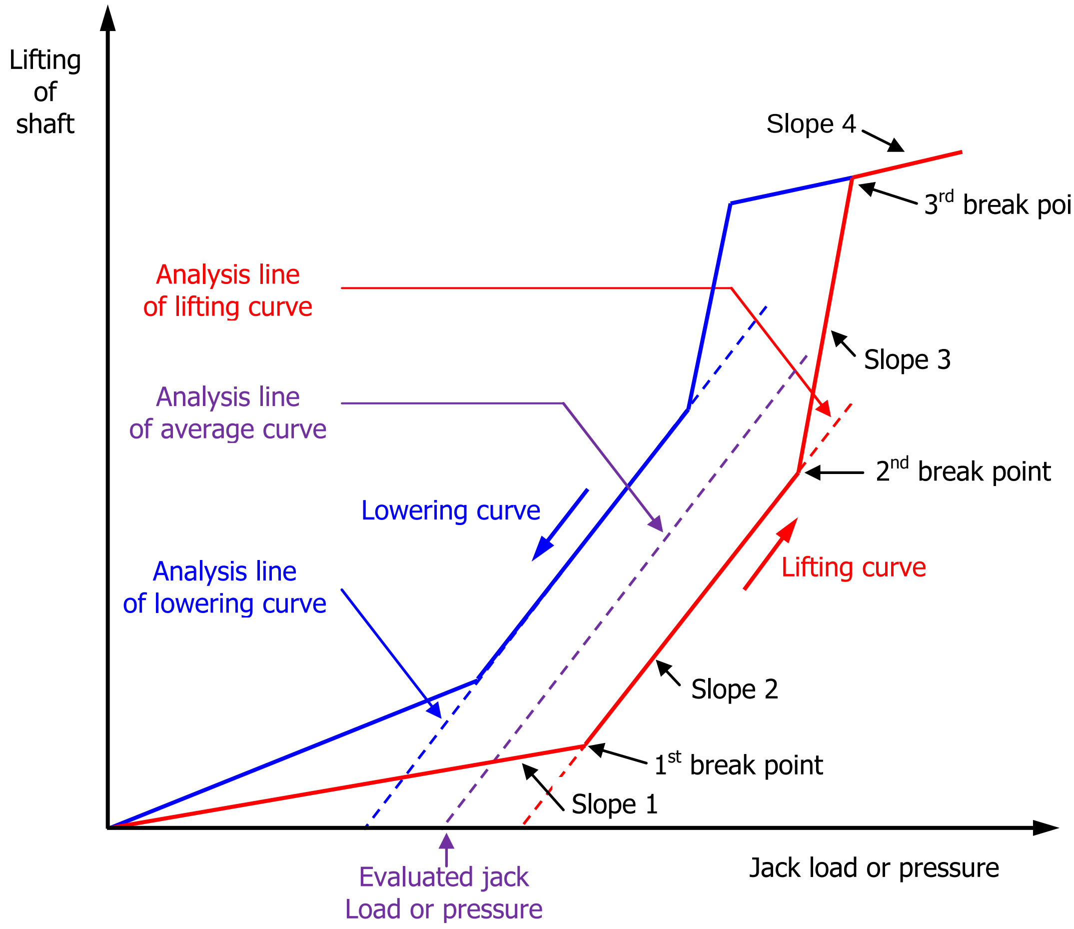

Figure 21: Plotted jack-up test results (solid line) with analyses lines (dashed line)

Explanation of the graph in figure 21:

The following description refers to the jack-up tests results which are measured during lifting of the shaft, shown in figure 21 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 "$\Delta F_{jack} / \Delta h_{journal}$".

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 DG9709 – "Procedure & measurement at shipyard" - section - "Evaluation of static bearing loads".

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.

3.4.3 Graphical analysis of static bearing loads - examples

In this chapter there are real examples of in practise recorded jack up test results shown to make the end-user aware how the analysis lines should look like to enable a clear evaluation. Therefore, in the following there are examples provided which fully meet Wärtsiläs´ requirements as well as examples of jack up test results that can be hardly evaluated. To avoid achieving of such undesired results as it is shown by figure 24, figure 25, figure 29 and figure 33, the recommendation for the jack up procedure provided in section 3.2 of this document should be followed.

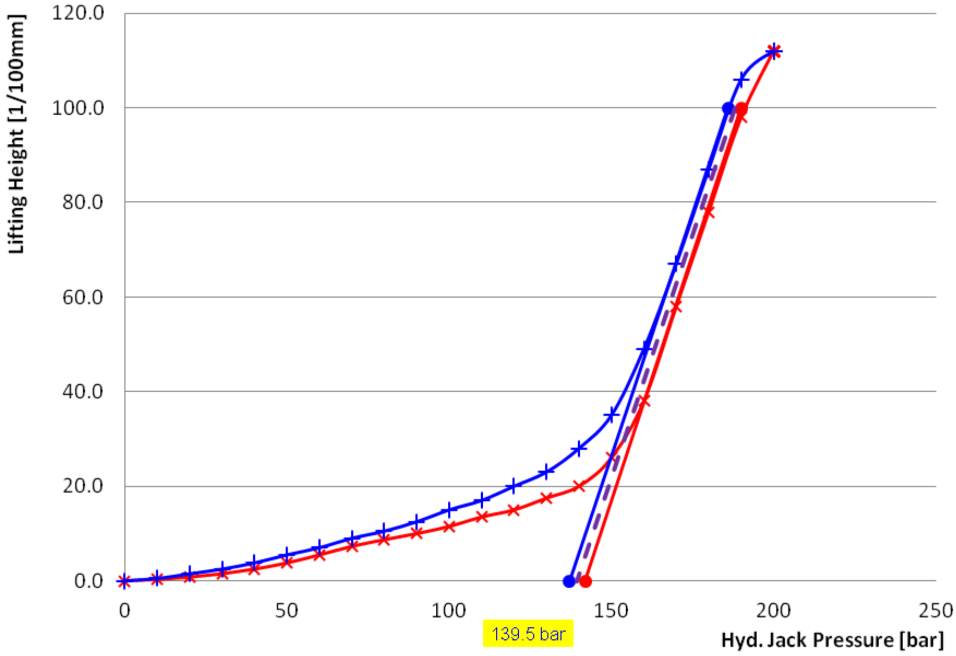

Figure 22: Jack up curve of a shaft line bearing
Judgement: measurement quality is very good

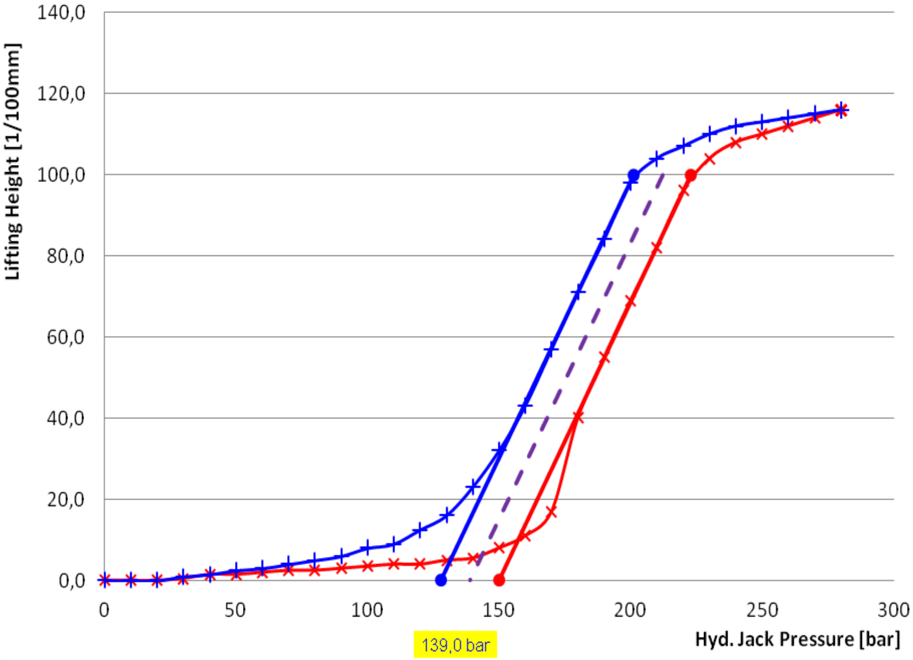

Figure 23: Jack up curve of a shaft line bearing
Judgement: measurement quality is good, but the shaft was lifted up too much.

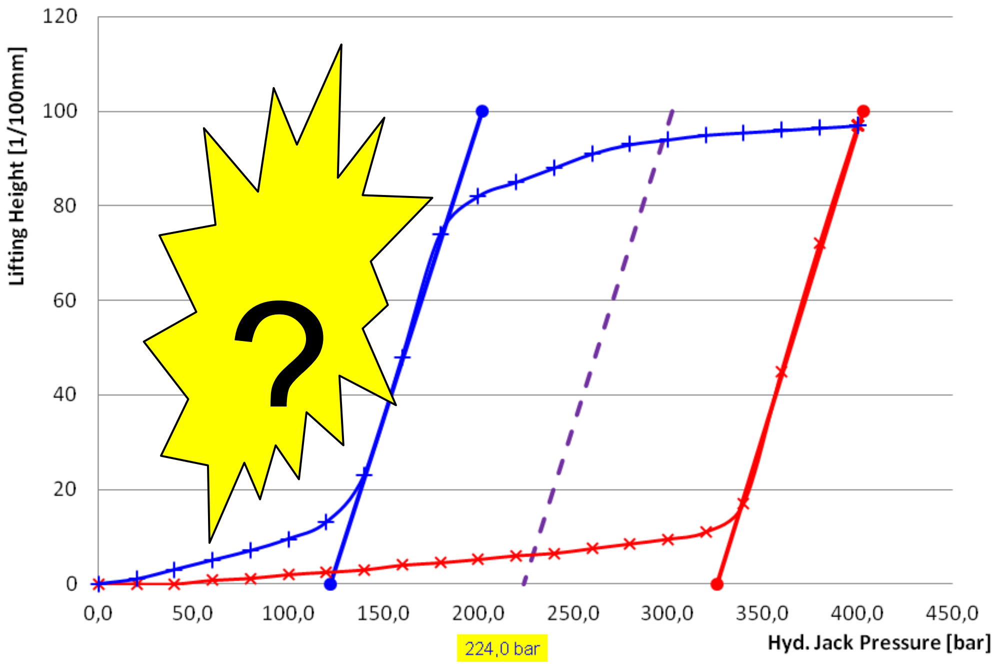

Figure 24: Jack up curve of a shaft line bearing
Judgement: measurement quality is bad due to huge hysteresis

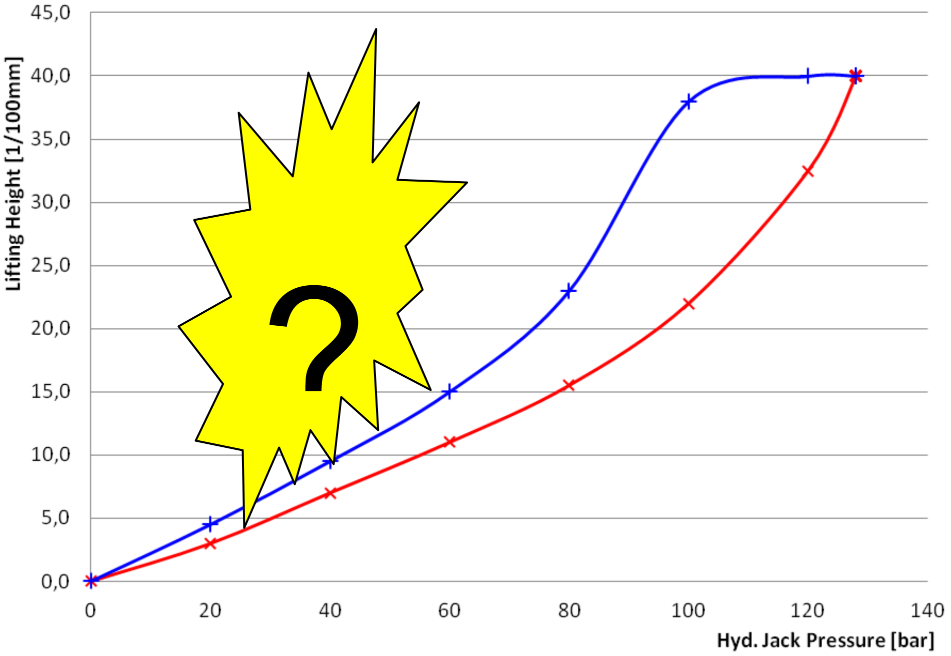

Figure 25: Jack up curve of a shaft line bearing
Judgement: measurement quality is bad due to a too small lifting height

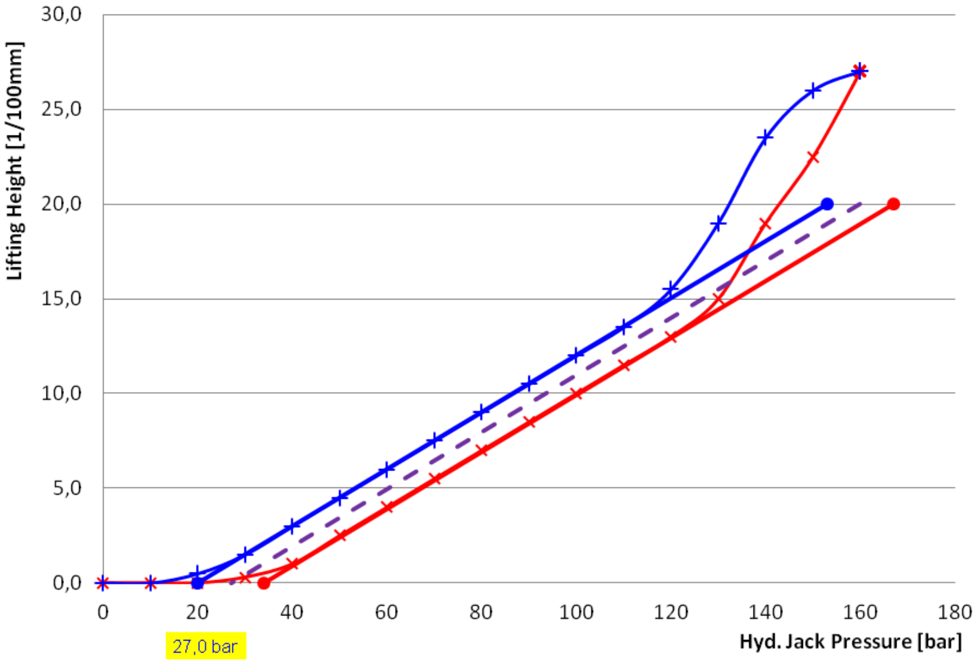

Figure 26: Jack up curve of a main bearing #1, low loaded
Judgement: measurement quality is good

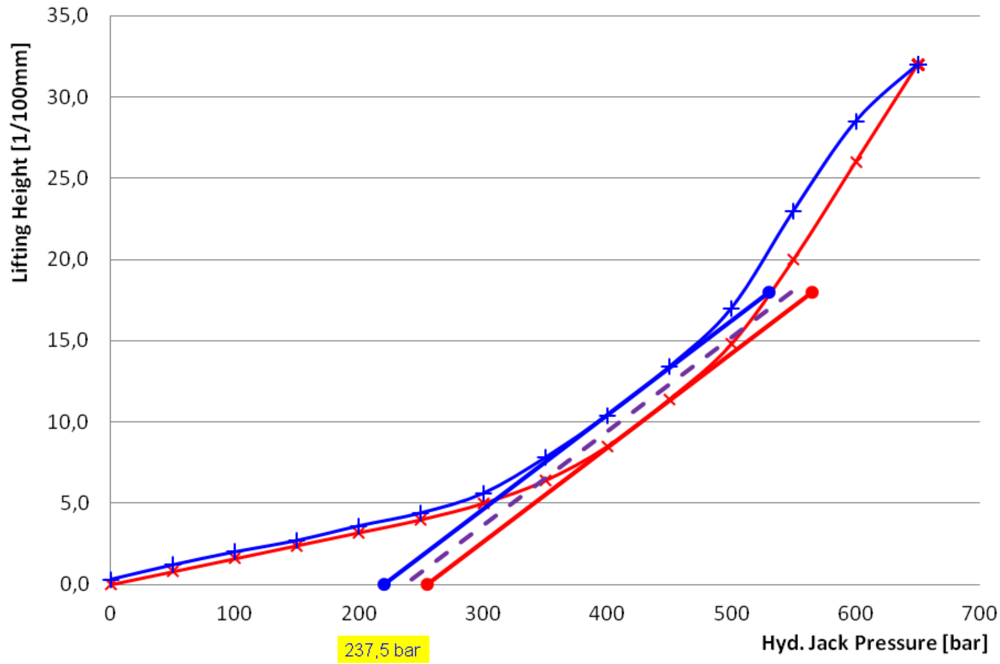

Figure 27: Jack up curve of a main bearing #1, high loaded
Judgement: measurement quality is good

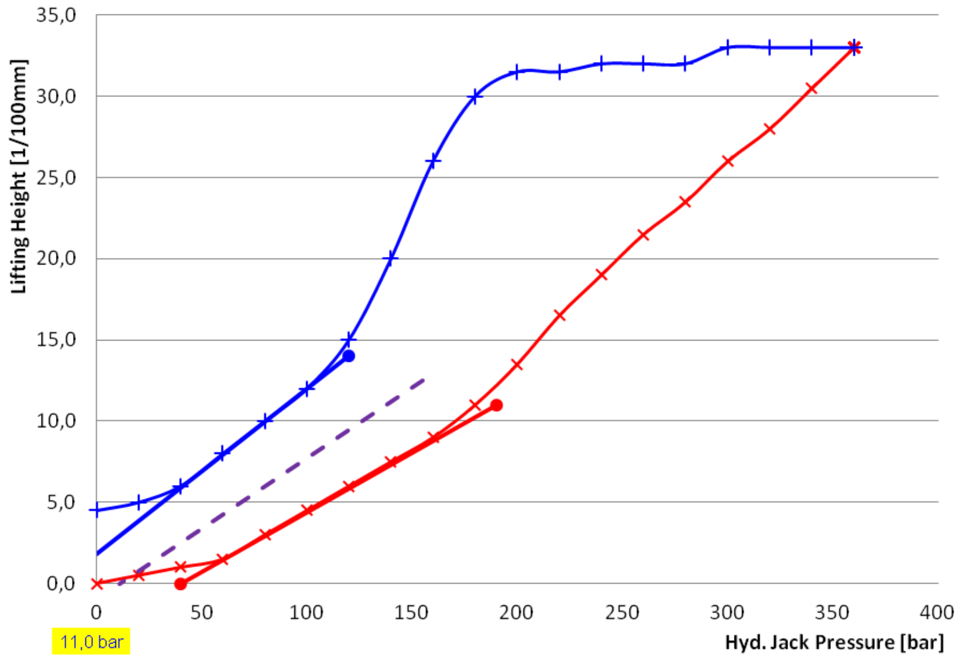

Figure 28: Jack up curve of a main bearing #1, low loaded
Judgement: measurement quality is not perfect but still acceptable

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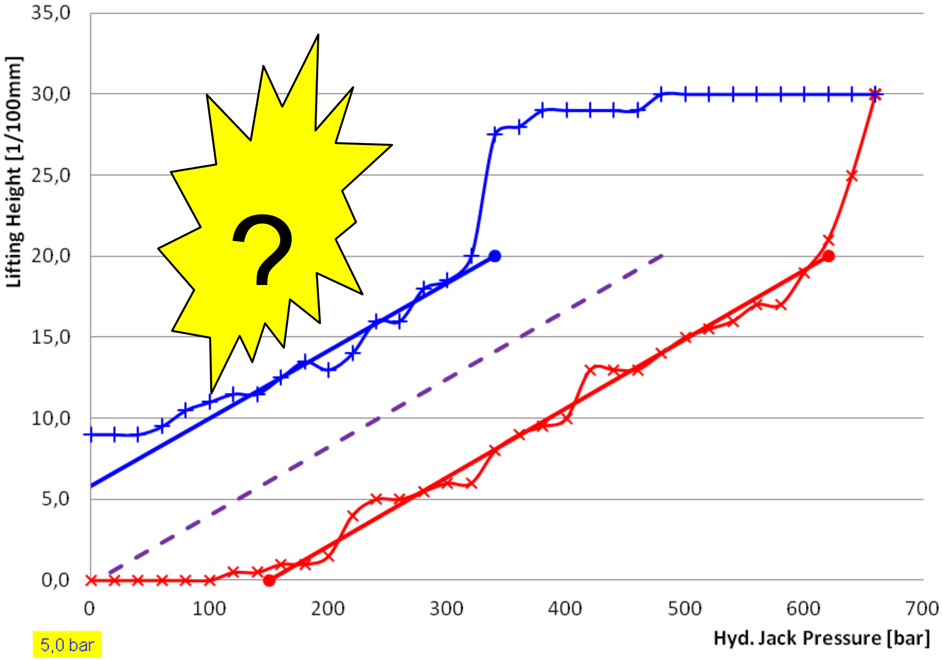

Figure 29: Jack up curve of a main bearing #1
Judgement: measurement quality is bad due to huge hysteresis, jack up/down with un-even speed or leakage of hydraulic oil could be a reason

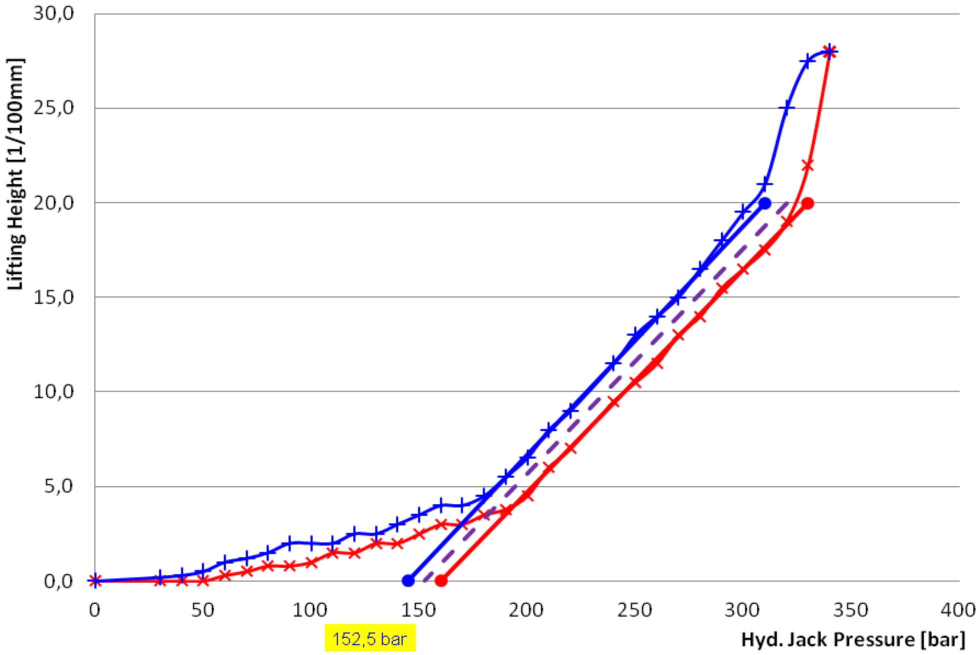

Figure 30: Jack up curve of another main bearing, high loaded
Judgement: measurement quality is good

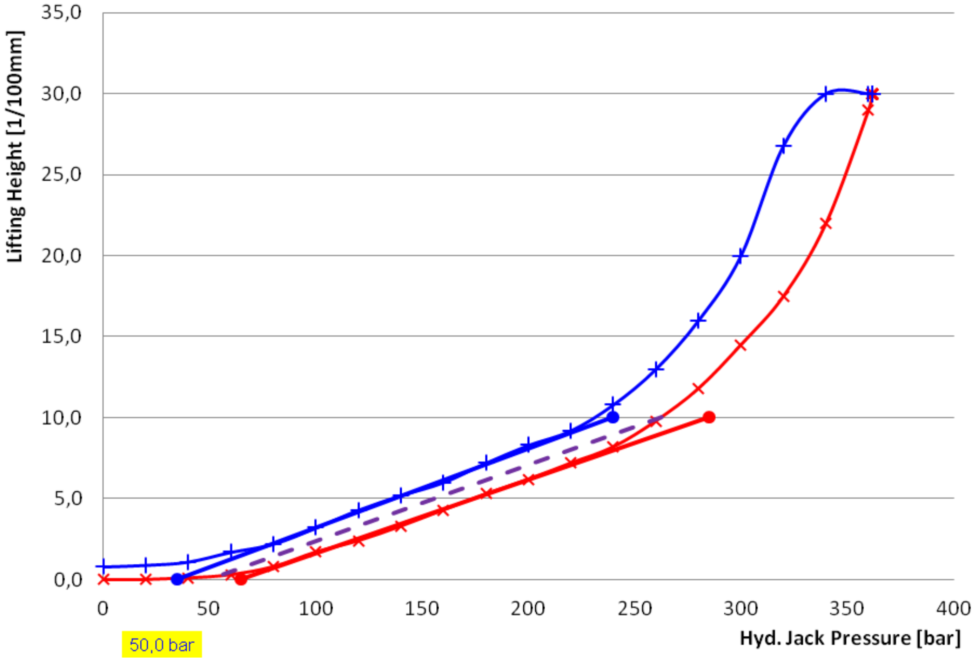

Figure 31: Jack up curve of another main bearing, low loaded
Judgement: measurement quality is good

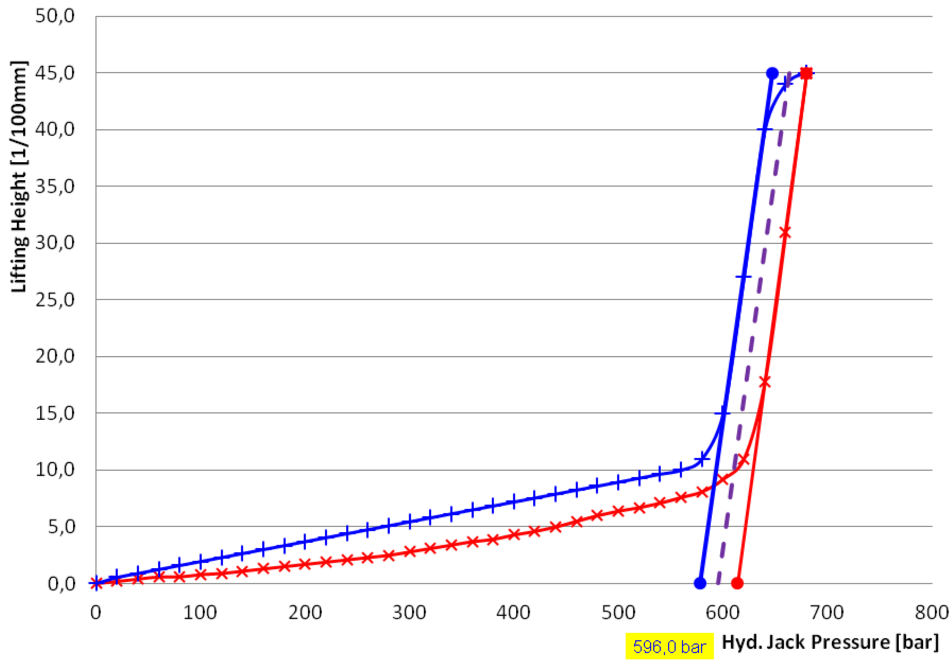

Figure 32: Jack up curve of a foremost main bearing with heavy mass installation at crank shaft free end
Judgement: the measurement quality is good

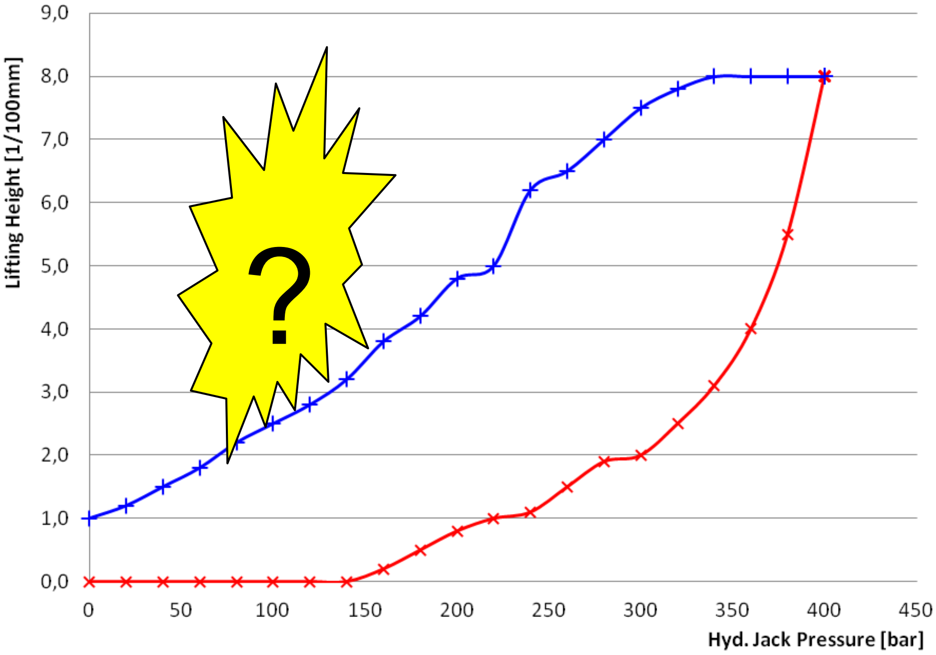

Figure 33: Jack up curve of another main bearing,
Judgement: measurement quality is bad due to high hysteresis and a too small lifting height

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WinGD-2S - Guidelines for measurements

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