International Standard For Bollard Pull Trials

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Background

This standard has been developed by the 'Bollard Pull Joint Industry Project' members over a 3 year period. The Bollard Pull JIP consists of an international group of 31 industry representatives including ship yards, operators, design offices, classification societies, engine and propeller manufacturers and research institutes.

The standard has the purpose to ensure that the reported bollard pull figure represents the realistic performance of the vessel that can be met in service conditions at an acceptable level of accuracy, irrespective of the specific conditions met during the execution of the bollard pull trial that are known to affect the vessel's performance. This standard facilitates a repeatable performance figure in accordance with clear definitions. Based on the research carried out in the project the procedure expects to achieve an uncertainty of ±3% of the measured towline force.

The definitions, boundary conditions, environmental conditions, and analysis methodology for the recording of certified Bollard Pull of marine vessels have been derived based on model testing, CFD analysis, full scale validation campaigns and input from a team of specialists.

Validity

The issued Bollard Pull certificate is valid for 5 years.

1 Definitions

1.1 Bollard pull trial

A bollard pull trial is a full scale test with a vessel to determine the horizontal towline force which the main propulsion systems can generate at a vessel speed equal to zero knots. The bollard pull trial is executed in unrestricted and calm water, without external influences such as wind and current, whereby one end of the towline is attached to a dedicated towing point on the vessel (e.g. towing winch or hook) and the other end is attached to an external strongpoint (fixed bollard ashore, seabed secured anchor or otherwise). The towline force is measured by a calibrated load cell which is normally fitted between the towline and the external strongpoint. The engine power at which the bollard pull is executed is measured and reported in conjunction with the steady state line pull.

1.2 Vessel

The standard has been developed and is validated for harbour, escort, ocean and offshore tugs including Anchor Handling Towing Supply (AHTS) Vessels with multiple propulsors, with or without nozzles. This excludes vessel whereby propulsors are mounted under a large flat bottom (e.g. specialised ships with multiple thrusters for DP operation). For single propulsor towing vessels the standard is not validated. For these vessels the minimum water depth requirement is likely to be larger than stated in this standard.

1.3 Bollard Pull

1.3.1 The vessel's bollard pull is the towing force provided by the specified propulsors, recorded as being maintained in a steady state condition for a duration of not less than 5 minutes and performed at rated power as defined in 1.4.1 at a speed through water of zero knots.

1.3.2 The operating profile for the bollard pull trial condition shall represent normal service conditions, such that sufficient auxiliary power is available for normal and safe operation of the vessel.

1.3.3 Engine speed and brake power are to be measured simultaneously with towline force during the bollard pull trial and shall be reported on the certificate in accordance with Chapter 3.3.

1.3.4 Bollard pull trials conducted in hybrid mode, whereby batteries or other supplementary power devices are used to provide additional power for a limited period of time shall be separately listed as ‘Hybrid Bollard Pull (HBP)’, and must have an associated time of validity for each operational mode of such HBP.

1.4 Engine rating

1.4.1 The bollard pull trial is to be performed up to the maximum power of the engines which is available in service. Maximum power means:

1.4.1.1 For marine diesel -, and/or gas engines: The maximum brake power the engine can deliver in service that corresponds to the power recorded during 100% load testing at the Factory Acceptance Tests of the engine.

1.4.1.2 For electric propulsion machines the maximum brake power is the design power for normal service conditions defined at the electric motor, specified on the motor name plate.

1.4.1.3 For Hybrid propulsion systems (Diesel/Gas -mechanical with electrical Power Take In) the maximum power is the sum of the power defined in 1.4.1.1 and 1.4.1.2 for all propulsion machines.

1.4.1.4 In case the design power of the propeller is less than the maximum power of the engine(s), the maximum brake power is referred to the design power of the propeller.

1.4.2 The engine speed shall be within the Original Equipment Manufacturer (OEM) specified speed range, which shall be consistent with the type approval of the engine and the certification of the propulsion train (e.g. Torsional Vibration Calculations).

1.4.3 The available output power shall match the conditions stated in 1.3.2.

1.4.4 The propulsion and engine configuration used during the bollard pull trial is to be stated on the certificate. This includes a specification of the power generation systems (output of engines / fuel cells / battery banks etc.), propulsion motors (mechanical, electrical, hybrid) and propulsion systems (number of propellers, use of (retractable) thrusters etc.) used during the bollard pull trial.

1.5 Steady state phase

1.5.1 The steady state phase of the bollard pull trial is the time interval during which a steady towline force is measured. The steady state phase represents the highest consecutive 5 minute period, logged as per Chapter 3.4 during a 15 minute trial under effectively constant trial conditions stated in this trial test procedure. The definition of the highest consecutive 5 minute period shall be in accordance with Chapter 6.2.

1.5.2 The 15 minute trial window starts after the initial build up and subsidence in line tension of associated dynamic effects, as shown in Figure 1. During this period only small changes in steering angles associated with maintenance of vessel position are permitted. Strong sway motions are to be avoided.

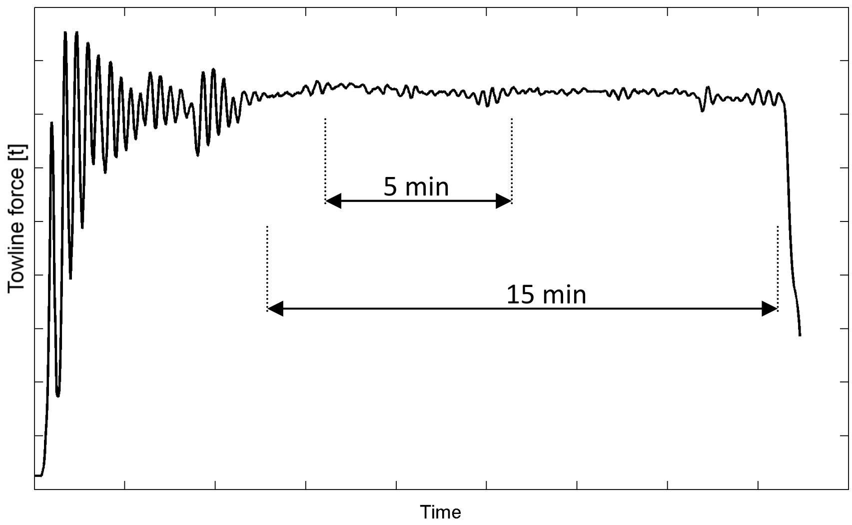

Figure 1: Schematic representation of towline force as function of time during bollard pull trial

1.5.3 In Hybrid mode (Diesel/Diesel-Electric power plus that available from the Batteries) the available battery power for propulsion might decrease during the execution of the bollard pull trial. In this case the reported bollard pull is to be defined by calculating the mean power and towline force over a period of 5 minutes as minimum, and noted down as a separate entry in the bollard pull certificate as 'Hybrid Bollard Pull (HBP)' with an associated maximum time for which that HBP rating is valid in service. The designed power availability duration is to be provided by the designer of the propulsion system

2 Trial site

2.1 Water depth and radius

The minimum total water depth, which shall be maintained at least in a radius of 2 times the ship's length around the towing vessel, is 4 times the propeller immersion depth (h_{imm}). The propeller immersion depth is defined as the distance between the water surface and the centre of the propulsion unit, as indicated in Figure 2. For Voith Schneider Propulsion (VSP) systems the centre line of the jet-stream is used, i.e. the middle of the VSP blades as indicated in Figure 3. The water depth during the trial is to be recorded on the bollard pull trial report.

2.2 Distance propeller to shore

The minimum distance between quay and centre of the propeller closest to shore, is 50 times the propeller diameter to avoid water circulation affecting the bollard pull.

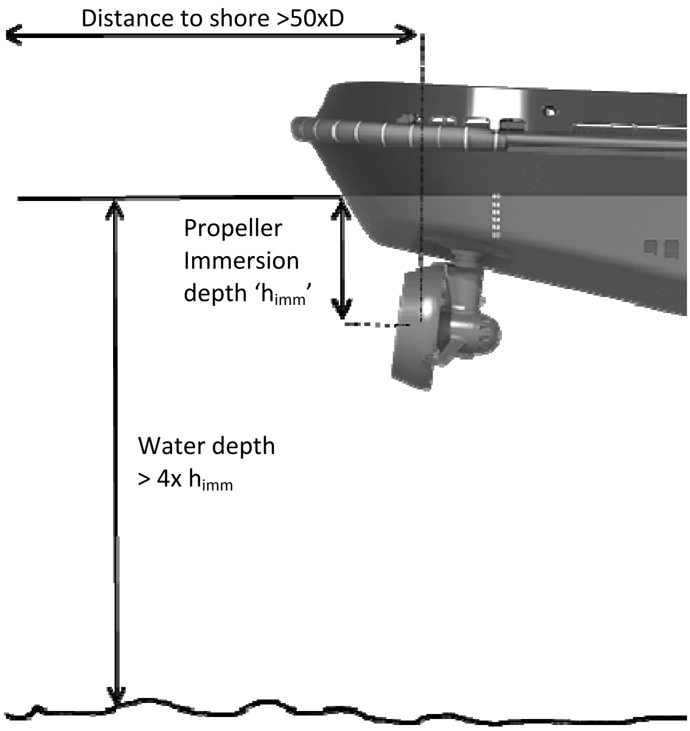

Figure 2: Definition of propeller immersion depth and distance ship to shore. D = propeller diameter

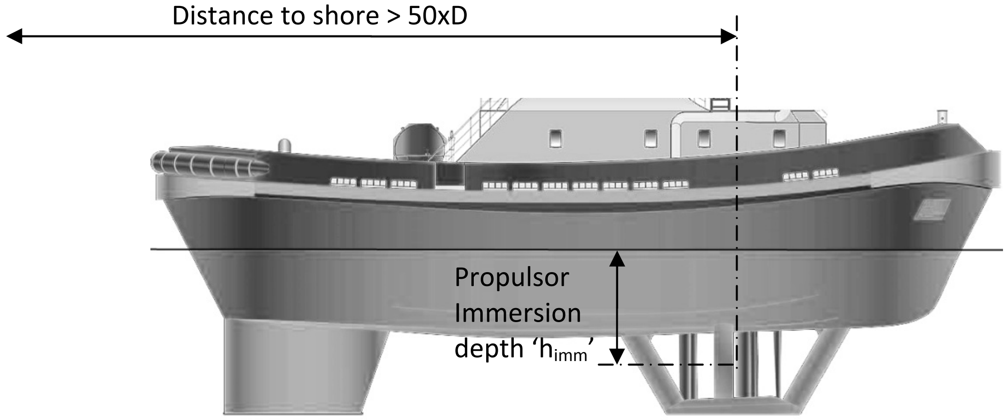

Figure 3: Definition of immersion depth and distance ship to shore for a VSP propulsor. D = propeller diameter

2.3 Current

The current speed is to be less than 0.5 knots from the bow or sides. If the current is approaching the vessel from the stern, the current shall be less than 0.3 knots. When the bollard pull trial is performed with side current, the towing vessel is to be allowed to shift position by letting it move with the current and not to steer against it, while maintaining heading relative to the towline. It is not allowed to fix the position of the towing vessel by cables, other vessels or other means. If the vessel is equipped with side thrusters, they may be used to hold position if this does not negatively affect the power available for main propulsion.

2.4 Water density

Water density shall be recorded on the bollard pull trial report. No corrections for water density shall be applied. In appendix 4 comments are made on the effect of water density on performance.

2.5 Waves

Ideally the BP trial should be conducted in calm water conditions. If not achievable, the maximum significant wave height encountered during the BP trial period is to be not more than 0.5m. No corrections for waves shall be applied.

2.6 Wind

Transverse wind may cause sway moments that must be compensated by applying rudder. This may degrade vessel bollard pull performance. Wind speed during the bollard pull trial shall be as low as possible but not more than 10m/s (BF5).

2.7 Outside temperature

No corrections for environmental conditions shall be applied. It is recommended to perform trials in non-tropic conditions (<45^{o}C air temperature, <32^{o}C water temperature) to avoid engine performance degradation. Appendix 4 lists an example for the effect of air temperature or engine performance.

2.8 Tow line

A torsion-free towline (e.g. synthetic) is recommended to ensure that the load cell measures, as intended, in direct tension.

2.9 Vessel orientation relative to the quay

The heading relative to the quay side (assuming solid quay sides) shall be chosen such that propeller wash can freely move without being re-directed in the direction of the vessel. Towing shall not be done in enclosed harbours, as recirculation is more likely to occur, resulting in unsteady performance. Minimum line length, water depth and associated radius shall be observed. Figure 4 presents examples of acceptable and unacceptable vessel orientations relative to the quay.

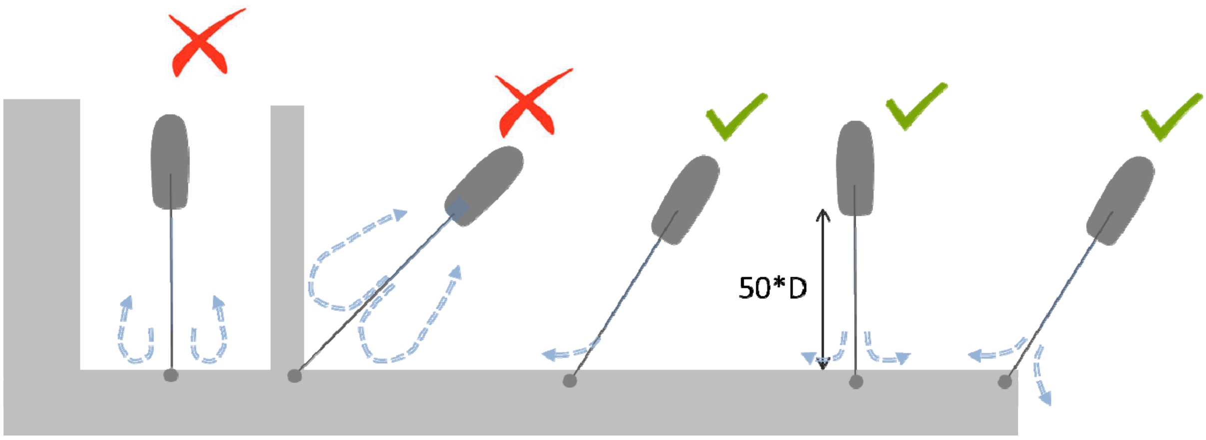

Figure 4: Positioning of the vessel during bollard pull trials. D = propeller diameter

3 Instrumentation

3.1 Load cell

The load cell is to be installed between the strongpoint and towline, either onboard or on shore. The load cell shall have a digital output and be capable of sampling at a rate of 1Hz or faster.

Systematic tests with different load cells indicated that they may be sensitive to drift over time, misalignment (see Figure 5), torsion, temperature and connection type, and accordingly can be considered the most inaccurate aspects of a bollard pull trial.

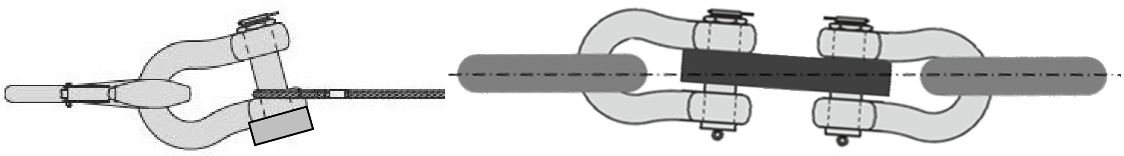

Figure 5: Load shackle and load cell misalignment

To maximise accuracy the following conditions shall be met:

3.1.1 The load cell calibration and certificate is not to be older than 12 months and shall be provided with the bollard pull certificate. The calibration procedure of the load cell shall be in accordance with the requirements stated in Appendix 2.1.

3.1.2 The load cell shall have an uncertainty in accordance with an ISO7500-1 Class 1 machine, which shall be stated on the load cell calibration certificate.

3.1.3 When a steel stranded wire is used during the bollard pull trial, the load cell shall be proven to be torsion insensitive in accordance to the requirements in Appendix 2.2.

3.1.4 Spacer rings shall be installed between load cell and shackle ears as indicated in Figure 6 to avoid misalignments during testing. Spacer rings are plastic rings specially made to fill the gaps between shackle ears and load cell, and thus centrally align the load cell.

3.1.5 Shackle pins are to be free from surface imperfections such as dents or bend

3.1.6 The towline shall be connected first to a shackle, which is consecutively connected to a second shackle that holds the load cell (Figure 6). This results in optimal alignment of the load cell with the towline.

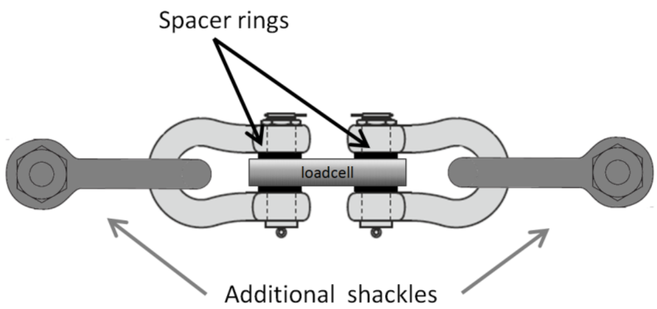

Figure 6: Recommended load cell arrangement with spacer rings and additional shackles

3.1.7 When a load pin shackle is used, a self-centring bobbin as indicated in Figure 7 is to be used in order to ensure correct alignment, in addition to additional shackles. The towline shall not be connected directly to the load shackle.

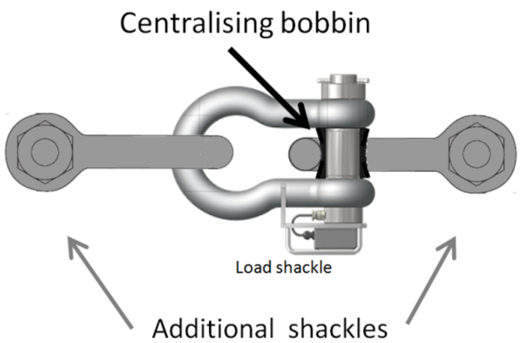

Figure 7: Recommended load shackle arrangement with centralising bobbin and shackles

3.1.8 The load cell / load shackle and connected shackles shall not touch the quayside edge or ground (Figure 8) to avoid misalignment, bending and corresponding offsets in measurements. The shackles denoted by 'Additional Shackles' in Figure 6 are allowed to touch the ground if not possible otherwise.

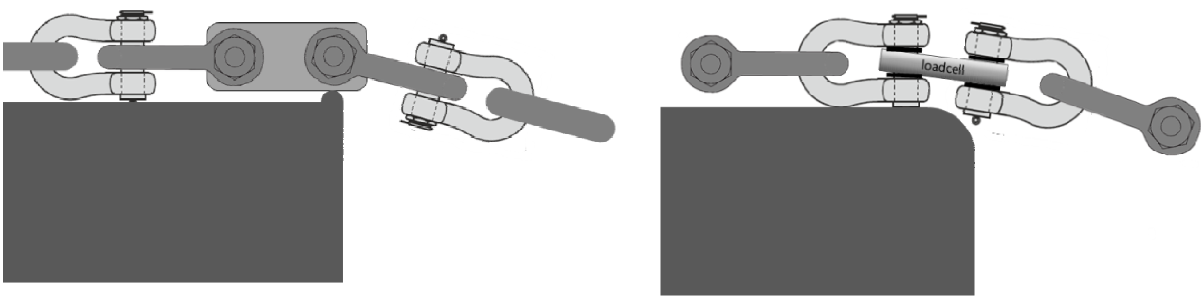

Figure 8: Load cell touching ground, causing bending moments and misalignment of the load cell

3.1.9 The test shall be conducted at the same temperature as during the calibration of the load cell, within a tolerance of ±10^{o}C. If this condition cannot be fulfilled, the load cell shall be certified to be suitable for the temperature during the trial.

3.1.10 The load cell shall be set to zero prior to the trial, when the tow line is not yet connected and free from any load. After the trial, when the load cell is free from any load, the reading shall be checked again.

3.2 Engine speed measurement

The engine speed shall be continuously measured using a pickup sensor or via the engine control system of the engine's manufacturer and recorded digitally during the trial.

3.3 Power measurement

3.3.1 Engine brake power shall be measured using a dedicated shaft torque / engine speed measurement system for first and second ships of a series. Torque measurement systems based on strain gauges are most common, but other techniques, e.g. using optical deflection measurement is also allowed. Engine speed can be measured using an optical or magnetic pickup sensor.

3.3.2 The power measurement shall represent engine brake power as tested during shop tests. For third and further of series the engine control system can be used that is verified based on the first two vessels of a series. The dedicated shaft torsion/engine speed sensor reading is leading for the engine power.

3.3.3 The uncertainty of the engine power measurement should be according to ITTC standard 7.5-04-01-01.1 (total bias uncertainty +/-2%).

3.3.4 Shaft material properties, i.e. the G-Modulus, shall be fully described and documented by the Shipbuilder. If no certificate based on an actual shaft torsional test is available, a G-Modulus of 82400 N/mm^2 shall be used for regular shaft steel.

3.3.5 If power cannot be measured directly on the engine's output shaft, it may be calculated by measuring power on the propeller shaft and correcting for power losses between engine flywheel and measurement point. These losses are to be confirmed by their respective manufacturer and stated in the trial report. Suggested measurement locations for various propulsion configurations are included in Appendix 4.

3.3.6 In case carbon shafts are used and no steel section is available for the installation of a power measurement system, the engine rating during the bollard pull (section 1.4) shall be determined on a case by case basis with the parties involved. Without a direct measurement of the shaft brake power, no power shall be reported on the trial certificate.

3.3.7 The power meter zero setting is to be done according to its maker's instructions prior to the trials.

3.4 Data logging

3.4.1 The readings of the towline force, engine speed and shaft torque shall be recorded continuously and automatically on a digital system with a sample frequency of at least 1Hz in order to capture the natural fluctuations in the forces. A higher sampling rate is recommended to identify measurement errors and dynamic effects more clearly. Each load cell reading shall be tagged with a time stamp and synchronised with the power measurements on the vessel.

3.4.2 Measurement shall commence prior to the bollard pull test, so that the steady state phase and no-load reading can be identified during post processing of the data. A real-time graphical presentation of time series during the trial is recommended so that the quality of the recording (see Figure 18 Appendix 4) and the behaviour of the vessel can be evaluated over real time.

3.4.3 Record the following (as per Appendix 1) at the beginning of the trial: Draft and trim, wind, waves, current, water depth, water density, distance to quay, fuel quality, towline diameter, length, and material. If conditions vary during the test, record variances which exist at completion of the trial.

4 Trial preparation

4.1 Draught and trim

The draught and trim of the towing vessel are to be representative for typical service conditions and shall be stated on the certificate.

4.2 Propellers

The propellers used during the trial are to be the same as used for service conditions. It is strongly recommended to clean/polish the propellers immediately before trials, as blade roughness and fouling negatively affects thrust and power efficiency.

4.3 Fuel

Fuel can have a significant effect on the available output power. The fuel used during the trial shall be representative for the normal service operation of the vessel. The fuel type and Calorific Value shall be stated on the certificate.

5 Trial execution

During the trial a visual observation of the load cell reading on the bridge is recommended, so that the commencement of the steady state phase can be judged. Minimal sway motion is recommended to avoid performance drops. The use of a bow thruster is allowed to maintain position during the trial, when this does not affect the power available to the main propulsion system. Stern side thrusters may affect the inflow velocity and should be used with caution.

At least four power settings shall be tested between 25% and 100% load: maximum power in accordance with section 1.4.1, 85%, 60% and 40% of the rated power are recommended. This allows a propeller efficiency curve to be made that can be used in future re-evaluation trials if no sufficiently strong bollard is available for bollard pull testing. The procedure for performing re-evaluation bollard pull tests at part load is included in Appendix 3.

The following steps shall be performed for the bollard pull trial:

1. Make sure the load cell, wireless indicator, test location and environmental conditions are according to the requirements stated in this document
2. Tare the load cell (set to zero) prior to the test when the load cell and shackles are not yet connected
3. Connect load cell and towline. Slowly put tension on the tow line. Ensure correct alignment of the load cell and shackles. Re-align when necessary
4. Increase tension on the tow line until the maximum power as defined in Chapter 1.4 is reached. Check power rating using the engine shaft power meter
5. When the vessel has a stable position and heading and line fluctuations are constant, start a 15 minute run recording the towline force, power and engine speed
6. Reduce power to other engine ratings (85%, 60% and 40% recommended as described in Appendix 3). When the vessel is stable and line fluctuations are constant, start measurement. The minimum measurement period is hereby 5 minutes. A longer period (15min) is recommended to capture a more stable performance
7. Repeat steps 2-7 for the other direction of towing (stern / bow) if applicable

Comments:

- Avoid conducting multiple runs at maximum throttle in confined conditions. This induces turbulent water circulation around the vessel, resulting in unsteady performance and sway motion and thus decreased pulling force
- If a slight current from the side is encountered, let the vessel drift with the water during the trial runs to avoid unstable performance.

During the test a log sheet shall be filled in. Minimum reporting requirements are listed in Chapter 7. An example log sheet is included in Appendix 1.

6 Data analysis

6.1 Validation of recorded data

The logged towline force shall be plotted on a time scale and evaluated for measurement errors, outliers and to identify the steady state period. The towline force shall have a smooth, sinusoidal character as a function of the mass-spring system behaviour of the towline and vessel. If the data quality is poor, indicated by stepwise data, missing data and large non-periodic fluctuations, the bollard pull trial shall be repeated.

6.2 Identification of steady state performance

The determination of the highest consecutive 5 minute period of stationary performance shall be performed after the trial using the logged data. The calculation of the average bollard pull over the 5 minute period is performed using a normal arithmetic average over the selected period (using at least: 1Hz sampled data x 5min = 300 consecutive data points). Clear outliers due to sensor errors shall be removed prior to calculation of the average. The average of the propulsion power and engine speed shall be determined over the same 5 minute data period.

7 Reporting

7.1 Reporting of test certificate

7.1.1 The bollard pull for tugs with conventional propulsion with no restrictions on power availability, shall be reported as following:

- *____ metric tonnes in ahead/astern pulling direction at a measured brake power of _____ kW and a mean engine speed of ____ RPM.*

7.1.2 For bollard pull for tugs with prime movers with diminishing supplementary power capacity the bollard pull shall be reported as 'Hybrid bollard pull' as following:

- *____ Metric tonnes in ahead/astern pulling direction at a measured propulsion power of _____ kW and a mean engine speed of ____ RPM. This pull is available for a designed minimal duration of ____ consecutive minutes.*

7.2 Trial report requirements

The bollard pull test certificate shall be accompanied with a trial report. The report shall contain at least the following information:

- Characteristics of the vessel, propulsion system and main engines / propulsion motors, including Original Equipment manufacturer (OEM)-defined consecutive periods of available maximum power
- The propulsion and engine configuration used during the bollard pull. This includes a specification of the power generation systems (output of engines / fuel cells / battery banks etc.), propulsion motors (mechanical, electrical, hybrid) and propulsion systems (number of propellers, use of retractable thrusters etc.) used during the bollard pull.
- Used method of power measurement and used mechanical/electrical efficiency if applicable
- Fuel characteristics
- Location, water depth, water depth and line length during the trial
- Environmental characteristics: ambient temperature, wave height, water density, wind and current speed and direction relative to the vessel
- Towline and load cell-shackle arrangement
- Calibration certificate of load cell
- Log sheet with test results of each 5-minute trial, including power, engine speed and line pull for all tested load cases
- Name and contact information for persons performing and witnessing the trial on behalf of shipyard, owner and main component manufacturers
- For re-evaluation trials at part-load operation: the original bollard pull – shaft power curve including the measured points at part load, and the calculation method to derive to the resulting extrapolated bollard pull at maximum power

The report shall provide the information stated in Appendix 1 as a minimum requirement.

Appendix 1: Bollard Pull test report example

Bollard Pull Trial report

Bollard pull tests were performed with the ”MV Example” in accordance to the *International Standard for Bollard Pull Trials*. This report provides details of the test conditions, used instrumentation and measured performance parameters.

Bollard pull tests have been performed at 100%, 85%, 60% and 40% load over the bow and over the stern. The tests at 100% load are summarized below:

Summary of trial results

Tested bollard pull

The bollard pull has been evaluated as:

- **____ metric tonnes in ahead pulling direction** at a measured brake power of _____ kW and a mean engine speed of ____ RPM.

- **____ metric tonnes in astern pulling direction** at a measured brake power of _____ kW and a mean engine speed of ____ RPM.

Hybrid bollard pull

The Hybrid bollard pull has been evaluated as:

- **____ metric tonnes in ahead pulling direction** at a measured propulsion power of _____ kW and a mean engine speed of ____ RPM. This pull is available in service for a designed minimal duration of ____ consecutive minutes.

- **____ metric tonnes in astern pulling direction** at a measured propulsion power of _____ kW and a mean engine speed of ____ RPM. This pull is available in service for a designed minimal duration of ____ consecutive minutes.

Vessel information

Main particulars	
Vessel Name	
IMO No.	
Builder	
Length between perpendiculars [m]	
Breadth at waterline [m]	
Design draught [m]	
Propulsion configuration *(E.g. diesel electric with 2 thrusters, 4 engines on 2 propellers, 2 main propellers + retractable thruster, etc.)*	

Main propulsion system	
Main Engines type	
Power and speed at 100% load according to FAT certificate	
For battery powered ships: OEM-defined consecutive periods for running at 100% load [minutes] *(E.g. unlimited, max 20 minutes etc.)*	
Electric propulsion motors	
Electric propulsion motors brand & type	
Design power and speed at 100% load	
Propulsor	
Type (thruster, open/nozzled, podded drive, VOITH etc)	
Propeller diameter [m]	
No. of blades	
Design Pitch	

Measurement information

Instrumentation	
Load cell type (Brand & range)	
Load cell serial number	
Load cell Calibration date	
Load cell / shackle arrangement (*e.g. steel towline - shackle – shackle - load cell – shackle – shackle - sling - bollard*)	
Towline type & diameter	
Power measurement system (PMS) type	
Measurement location of PMS *(e.g. engine shaft, propeller shaft, thruster drive shaft)*	
Used shear modulus of shaft for shaft power measurement [N/mm^2]	
Shaft / converter efficiencies used for engine power calculation (η_s)	
Reduction gear ratio	
Fuel type	
Fuel LCV (Lower Calorific Value) [MJ/kg]	

Conditions during bollard pull trial	
Trial date [dd-mm-yyyy]	
Trial location	
Draft Aft / Forward at marks [m]	
Minimum water depth (4 x propulsor immersion depth) [m]	
Actual water depth [m]	
Minimum distance to shore (50 x propeller diameter) [m]	
Actual distance to shore [m]	
Air temperature [deg C]	
Water density [kg/m^3]	

Mean values over 5min period of highest bollard pull

	Parameter	Unit	Test 1	Test 2	Test 3	Test 4
	Load set point	[%]				
	Test direction	Stern/Bow				
	Start time	[hh:mm]				
	Line pull	[metric tonnes]				
	Heading	[deg]				
	Engines / motors in operation	[-]				
	No. of propellers in operation	[-]				
PS	Propeller shaft power (P_{PS})	[kW]				
PS	Engine speed	[RPM]				
SB	Propeller shaft power (P_{SB})	[kW]				
SB	Engine speed	[RPM]				
	Total shaft power	[kW]				
	Gearbox & shaft losses	[kW]				
	Total engine power (P_{PS}+P_{SB})+Losses	[kW]				
	Average engine speed	[RPM]				
	Wind speed	[m/s]				
	Wind direction (rel. to bow)	[deg]				
	Current speed	[m/s]				
	Current direction (rel. to bow)	[deg]				
	Wave height	[m]				

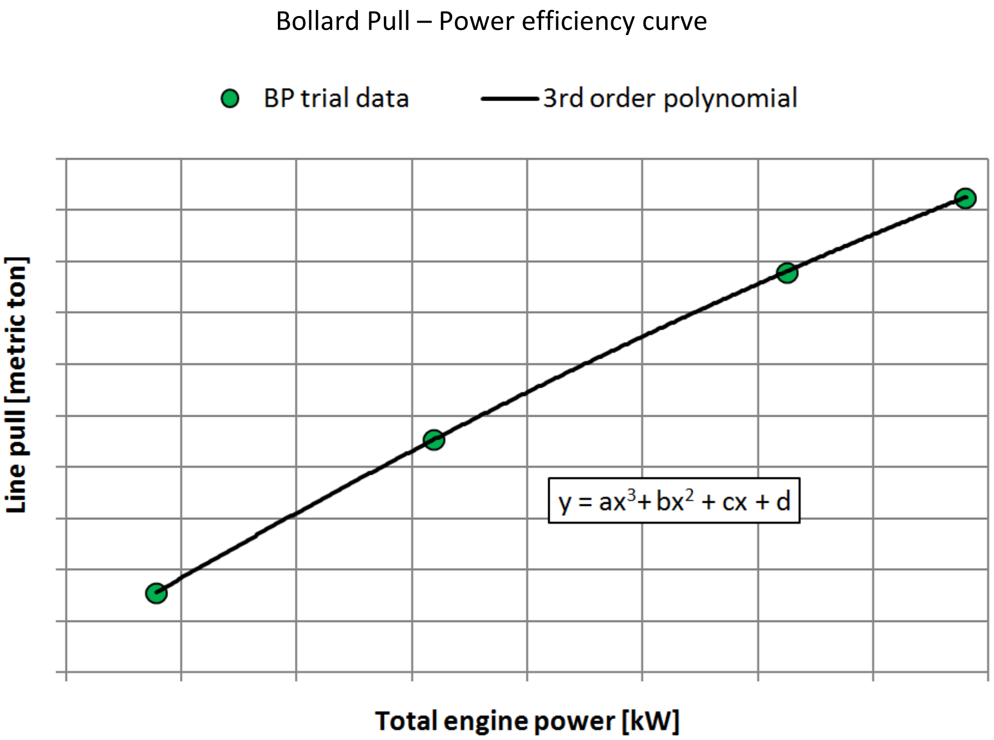

Figure 9: Summary of BP-trial results towing over the stern

Appendix 2: Load cell calibration requirements

A2.1 Load cells shall be calibrated according to ISO 7500-1 ('standard calibration'). This standard prescribes the conduct of three series of measurements with increasing force. To minimise random uncertainties, rotations of the load cell and shackle pins are added to the procedure to mimic a new installation of the load cell in the field. The load cell shall be calibrated with the same shackle pin diameter as it is used during bollard pull testing. If calibration is done on a horizontal calibration machine, spacer rings are to be used to improve alignment.

Figure 10 presents a schematic of the calibration procedure, which consists of the following steps in chronological order:

a) Pre-load to the maximum of the load cell's scale;
b) Pre-load to the maximum of the load cell's scale;
c) Pre-load to the maximum of the load cell's scale;
d) Stepwise load increase comprising at least five discrete force levels at equal intervals between 20 % and 100 % of the maximum range of the scale;
e) Rotation of the load cell by 180 degrees, around the X, Y or Z axis and a rotation of the shackle pins connected with the load cell by 30 degrees;
f) Repetition of steps c- e for two more times.

The repeated load sequences with rotation of the load cell and shackle pins in between each sequence of measurements minimize the random uncertainties from misalignments and seating deformations.

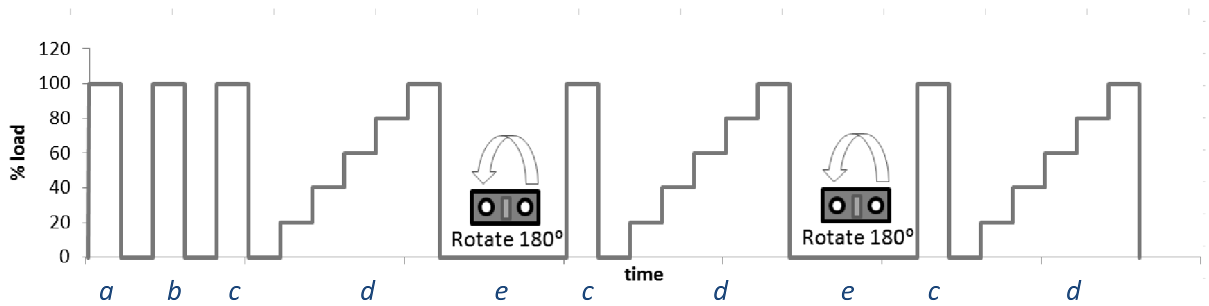

Figure 10: Schematic of calibration procedure according to ISO7500-1

For each discrete force, the arithmetic mean of the values obtained for each series of measurements shall be calculated. From these mean values, the relative accuracy error and the relative repeatability error shall be calculated. The preload runs shall be omitted.

A2.2 When a steel stranded wire is used during the bollard pull trial, the load cell shall be proven to be torsional insensitive to a value of at least:

$$T = c_1 * BP_{design} * D_{Line} \qquad \text{[kNm]}$$

Where c_1 is the towline wire torsion factor ($c_1 = 0.07$ for most 6/36 steel stranded wires), BP_{design} $[kN]$ is the vessel's (expected) bollard pull at 100% engine load, and D_{Line} [m] the diameter of the towline.

The insensitivity of the load cell is to be proven by the load cell manufacturer by means of systematic tests. When a rotation resistant rope is used (e.g. some synthetic ropes), this requirement is not relevant.

Calculation example:

*For a 80t design bollard pull and a steel stranded wire of 65mm, the load cell shall be proven to be insensitive to a torsion moment of at least 0.07 * (80 * 9.81) * 0.065 = 3.57 kNm.*

Appendix 3: Part load bollard pull re-evaluation trials

A3.1 Background

An issued bollard pull certificate has a limited validity. If the engines and/or propulsion system is overhauled or altered, or the certificate is outdated, a new bollard pull trial needs to be performed. In those cases where a suitable bollard is unavailable, e.g. because the available bollard has an insufficient safe working load, bollard pull trials may be performed at reduced load. These trials are no substitute for full bollard pull trials, but can be used to evaluate the validity of previous tests results performed at 100% load. This Appendix lists the requirements for such tests, the test and analysis procedure.

A3.2 Test overview

A full-range bollard pull as listed in Chapter 5 provides a bollard pull versus shaft power performance curve over the complete power range. This curve is evaluated in the performance re-evaluation trials at part load. The performance re-evaluation is done in three steps:

Step 1: The capabilities of the engines after overhaul are evaluated, by testing each individual prime mover separately at the highest power the engine can deliver (in compliance with Chapter 1.4). The engine power is hereby logged.

Step 2: A bollard pull test is performed at the maximum safe working load of the bollard with all prime movers in operation, but at part load.

Step 3: The measured bollard pull is compared with the original performance curve of the tug. If the measurement results are within ±3% the original curve, the original curve is still valid and can be intersected at the combined maximum power measured in step 1. If the deviations are larger the curve is shifted accordingly.

A3.3 Requirements

Bollard Pull Performance Re-evaluation Trials are only valid when the following conditions are met:

A3.3.1 Bollard pull trials have been performed in the past where a minimum of 4 power settings have been tested between 25% and 100% rated power according to this International standard, whereby delivered power is measured using a dedicated power measurement system on the drive shafts

A3.3.2 The maximum rated power of each prime mover can be tested separately. For ships with combinator mode and father/son arrangement a temporarily change in engine speed-pitch may be necessary to avoid overloading the engine when testing one engine per shaft

A3.3.3 The same propeller and nozzles are in place as tested under Chapter A3.3.1

A3.3.4 The propellers are re-conditioned (polished) to the same condition as tested under Chapter A3.3.1 according to the relevant ISO propeller class or similar

A3.3.5 The propeller nozzles have no surface damage and are in the same condition as tested under Chapter A3.3.1

A3.3.6 A bollard is available with at a safe working load that exceeds the power rating of each individual prime mover, so that the maximum power of each prime mover can be safely tested. For example, for tugs with a father/son engine arrangement, with two engines providing 60% / 40% of the total available power, the bollard shall be strong enough to hold the bollard pull obtained at 60% of the total available power.

If the above conditions cannot be met, normal bollard pull trials according to Chapter 5 shall be performed.

A3.4 Step 1: Evaluation of engine power

The engine capability of each prime mover is determined by loading the engine up to 100% load in a bollard pull setup (zero ship speed). The following procedure shall be followed:

1. Tare the shaft power measurement system according to manufacturer recommendations
2. Make sure the test location and environmental conditions are according to the requirements stated in this document
3. Slowly put tension on the tow line
   a. For vessels with multiple prime movers per propeller: engage one prime mover per shaft. Operate both shafts for symmetric operation (see Figure 11, left arrangement).
   b. For vessels with 2 propellers and two engines: disengage one propulsion unit so only one propeller is in operation. The other propeller may weather vane or stand still (see Figure 11, right arrangement)
   c. For vessels with multiple propellers: engage one prime mover

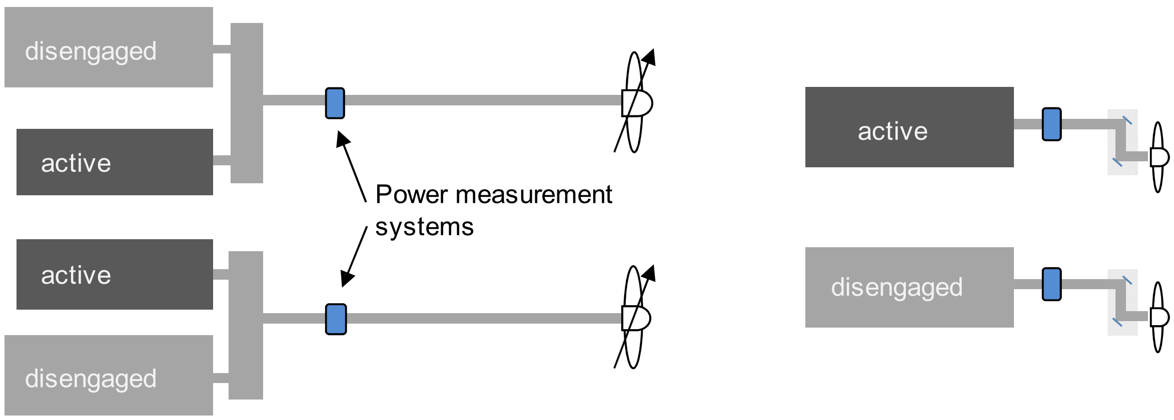

Figure 11: Propulsion configurations for individual engine performance testing

4. Increase power up to the power as stated Chapter 1.4.
5. Stabilise vessel and start a 5 minute power measurement. Bollard pull is not measured. For ships with one propeller in operation strong rudder usage may be necessary to stabilize vessel. It is assumed that this does not negatively affect the delivered power of the main engines
6. Repeat step (3) and (4) to test the other prime movers
7. Calculate the total power capacity, P_{Total}, of the main engines using:

$$P_{Total} = \frac{\sum_{i=1}^{n} P_{ME}(i)}{\eta_{gear}}$$

Where

P_{Total} : Total available power for all prime movers combined

P_{ME} : Engine power for each '*i*' prime mover as obtained in step (4) and (5)

η_{gear} : Gearbox efficiency ($\eta_{gear} = 1$ when there is no gearbox between measurement system and engine output shaft). The same gear box efficiency as used during the new-build bollard pull trials is to be used

A3.5 Step 2: Re-evaluation of propulsion efficiency

The propulsion efficiency curve (towline force versus shaft power) is evaluated at the maximum safe working load of the bollard. The following procedure shall be followed:

1. Make sure the load cell, wireless indicator, test location and environmental conditions are according to the requirements stated in this document
2. Tare the load cell prior to the test when the load cell and shackles are not yet connected
3. Ensure correct alignment of the load cell and shackles. Re-align when necessary.
4. Engage all engines and propellers and increase power until towline tension has reached maximum safe working load of bollard
5. When the vessel is stable and line fluctuations are constant, start a 15 minute run recording the bollard pull, power and engine speed in accordance with the procedure documented in Chapter 5
6. Reduce power to 40% of the total available power. When the vessel is stable and line fluctuations are constant, start a new 15 minute run recording the bollard pull, power and engine speed
7. Repeat above steps for astern operation if applicable
8. Plot measurement results in the original propulsion efficiency curve.

Steps 1-6 are performed in accordance with the normal procedures and environmental restrictions as documented in this standard.

A3.6 Step 3: Re-evaluation of bollard pull capability at available power

Due to uncertainties in the used load cell, power measurement system and wear of the propellers the data points found in Chapter A3.5 are likely to have an offset from the original performance curve, as depicted in Figure 12. The offset between the measured data points and the original performance is calculated by the towline pull ratio, α_{BP}:

$$\alpha_{BP} = \frac{BP_{Evaluate}}{BP_{Original}}$$

Where

$BP_{Evaluate}$: Bollard pull - power performance curve obtained during re-evaluation trials, Chapter A3.5

$BP_{Original}$: Original Bollard pull-Power performance curve from full power trials.

To obtain the bollard pull at P_{total} either the original performance curve is used, or the curve is first shifted:

a) If $0.97 < \alpha_{BP} < 1.03$, the original BP-Power curve is used to intersect the new bollard pull capability at P_{total}, as shown in Figure 12

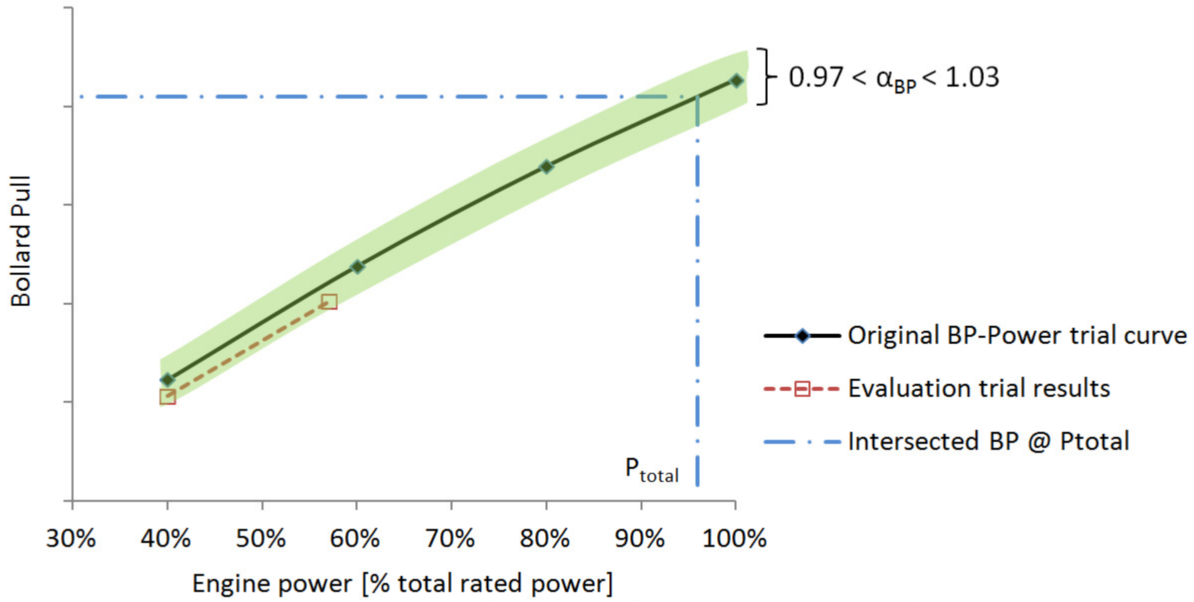

Figure 12: Procedure of estimating bollard pull at P_{total} from part load trials

b) If $\alpha_{BP} > 1.03$, classification societies may require new stability and strength calculations.
c) If $\alpha_{BP} < 0.97$, the curve is shifted vertically by multiplying the curve with α_{BP} to match the data points, as depicted in Figure 13

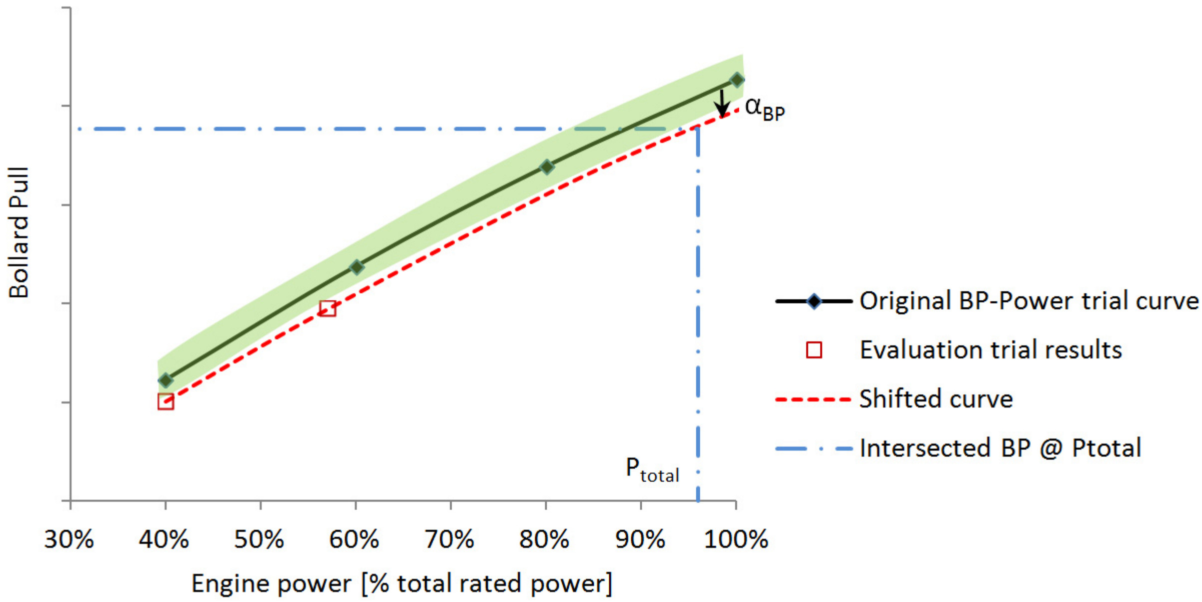

Figure 13: Procedure of estimating bollard pull at P_{total} when α_{BP} < 0.97

If P_{Total} is more than the highest power rating from the original BP-trial, the bollard pull is determined from the highest rating from the original BP-trial. No extrapolation beyond the original curve is allowed.

For tests in ahead direction the curve for ahead trials is to be used; for astern trials the curve for astern direction.

A3.7 Presentation of results

The original Shaft power – Bollard pull curve including its measurement points, and the method to derive to the resulting extrapolated bollard pull at rated power, is to be clearly documented. The extrapolated bollard will be documented as:

The bollard pull has been re-evaluated based on part-load tests as:

- *____ Metric tonnes in ahead/astern pulling direction at a brake power of _____ kW and a speed of ____ RPM.*

Appendix 4: Clarifying comments

2.4 Water density

The water density affects the developed thrust. In salt water, the propeller load increases with consequential slight increases to propeller efficiency and bollard pull. The drop in efficiency between salt (ρ=1025 kg/m^3) and fresh (ρ=1000 kg/m^3) water is approximately 0.8% at equal power. In fresh water the engine speed is approximately 0.8% higher to absorb the same amount of power as in salt water. While it is recommended to perform bollard pull trials in salt water, no corrections for water density shall be applied.

2.7 Outside temperature

Most engines feature no derating up to 45°C engine air intake temperature and 32°C coolant temperature. For higher temperatures engine performance may drop depending on engine characteristics. For example, according to ISO3046 one may see a 3.3% drop in power at 50°C compared to ISO conditions (20°C). Air pressure may also affect output power. It is therefore recommended to log relevant engine parameters during the trials in tropic climates.

3.3.4 Power measurement

The objective of the power measurement is to measure engine brake power. For ships with a diesel direct propulsion layout (Figure 14), the shaft power measurement system can be installed directly on the output shaft of the engine, as close to the engine as possible to avoid shaft losses.

For ships with multiple engines coupled to a gearbox (**Figure 15**), there is often insufficient space between main engine and gearbox to install a shaft power meter. In this case shaft power shall be measured on the propeller shaft. If a PTO is installed, it shall be declutched or unloaded. Auxiliaries connected to the gearbox or PTO that are necessary for the normal operation of the engine such as cooling or oil circulation pumps shall remain operational during the test. The main engine brake power shall be calculated by calculating the gearbox losses and adding them to the measured shaft power.

For ships with a Hybrid propulsion system (Figure 16), where both an electric motor and combustion engine provide power to a single shaft, the combined power shall be measured. Both the combustion engine and PTI shall not run at a rating higher than 100% load.

For diesel electric ships (**Figure 17**) the design power of the electric motor is the limiting factor for power output. The brake power of the electric motor shall be determined using a power measurement system on the output shaft. If this is not possible, the power to the electric motor shall be determined with a power spectrum analyser or other means.

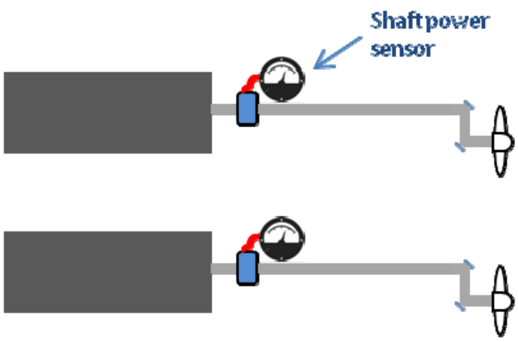

Figure 14: Power measurement on a diesel direct propulsion arrangement

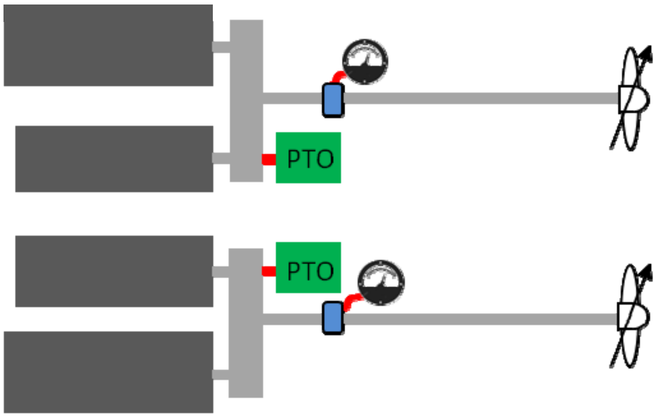

Figure 15: Power measurement on a geared diesel direct propulsion arrangement with PTO (declutched)

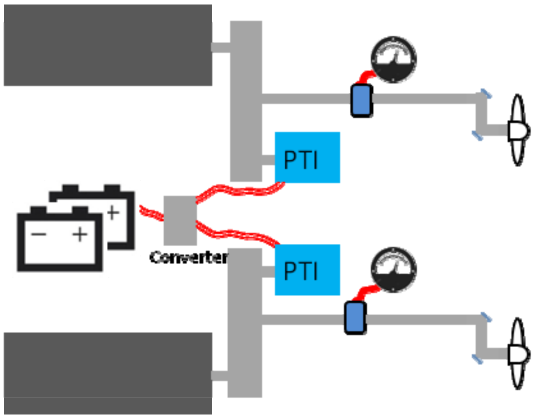

Figure 16: Power measurement on a Hybrid propulsion arrangement

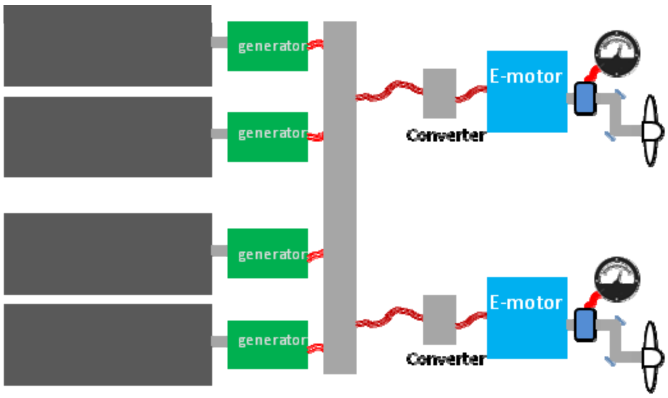

Figure 17: Power measurement on a Diesel-Electric propulsion arrangement

6.1 Validation of recorded data

A visual validation of the recorded towline force is necessary to identify reception errors, outliers and steady state periods. The ship and towline act as a mass/spring system. When sampled at sufficient rate, the line pull will show a sinusoidal pattern. Irregular, non-periodic step-wise behaviour may indicate poor performance of the wireless data transfer or other logging problems. Significant errors may be introduced when averages are derived from poor signals. Figure 18 shows an example time series of a line pull measurement with a poor performing telemetry system. The bottom line (red) shows the same line pull measurement from a redundant system with high quality data transfer. If the data quality is poor, indicated by many missing data points and large fluctuations, the bollard pull trial shall be repeated.

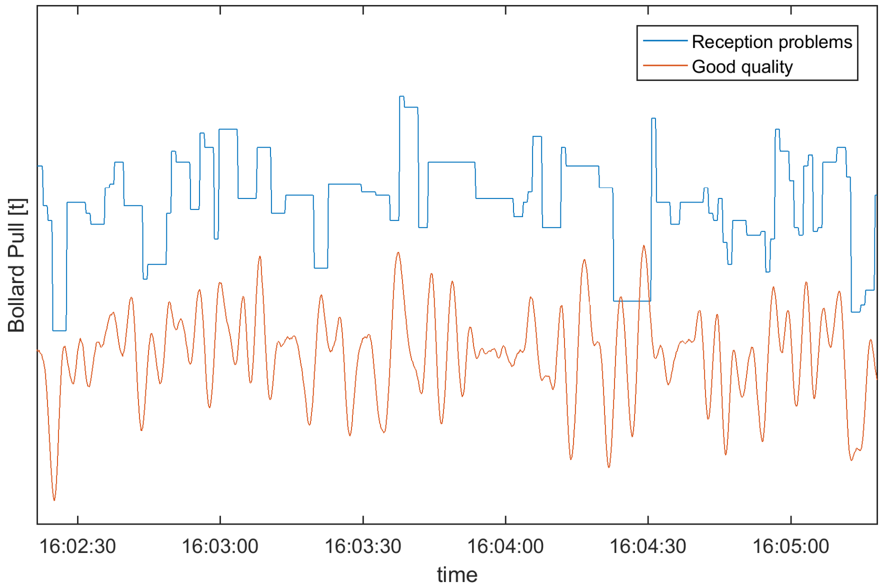

Figure 18: Example of a poor and good performing load cell measurement system