Accurate Load Measurements in Marine Engines

To reduce emissions and increase efficiency

Beaho, Guy
Manager Business & Applications

Agenda

1. Introduction
2. Ship Engines
3. Relationship between pressure (BMEP) and Torque (Load)
4. Torque Measurement Methods
5. HBM Marine Solution
6. Calibration and Traceability

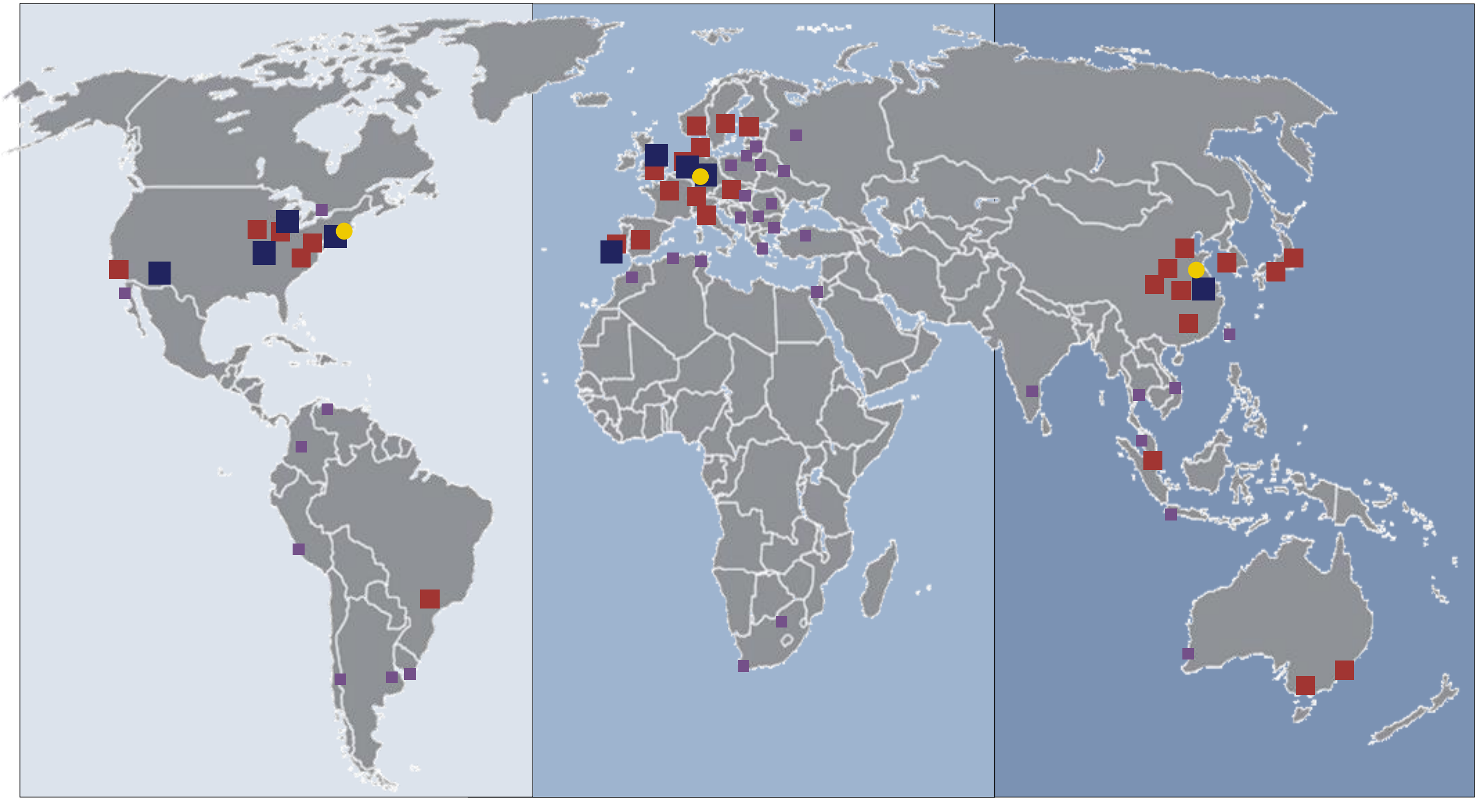
Presenter

Guy Beaho

- **Manager Business & Applications** with a focus on torque applications
- Graduate engineer & MBA
- 15 years of experience mechanical instrumentation
- **E-Mail:** guy.beaho@hbkworld.com

Guy Beaho

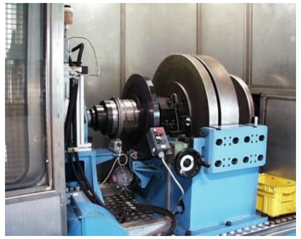
1- Introduction: HBM Global Footprint



- HBM development centers (9)
- HBM production facilities (3)
- sales and service centres (26)
- HBM representatives in over 50 countries (33)

1- Introduction: Torque Sensor Market: Segmentation

Automotive, Industrial Drives



Engine Testing, Load Unit
Drive Testing, Transmission
Brake, rotary switch testing…

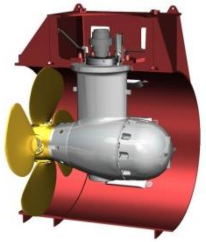
Medical, Chemical and Pharmacy

Viscosity in chemical liquids
Biomechanical actuation

Micromechanical Drives

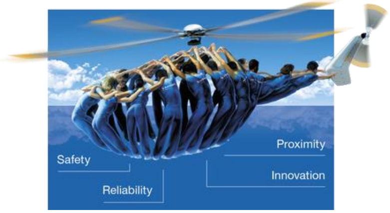
Micromechanical Testing
R&D
Labs

Offshore Application Ship Engine, Oil & Gas



Gas Engine Monitoring
Gas Compressor Efficiency

Aviation, Aerospace and High Speed



High speed engines incl.
power measurement

Power Generation & Renewable Energy

Wind Turbine Testing
GenSet

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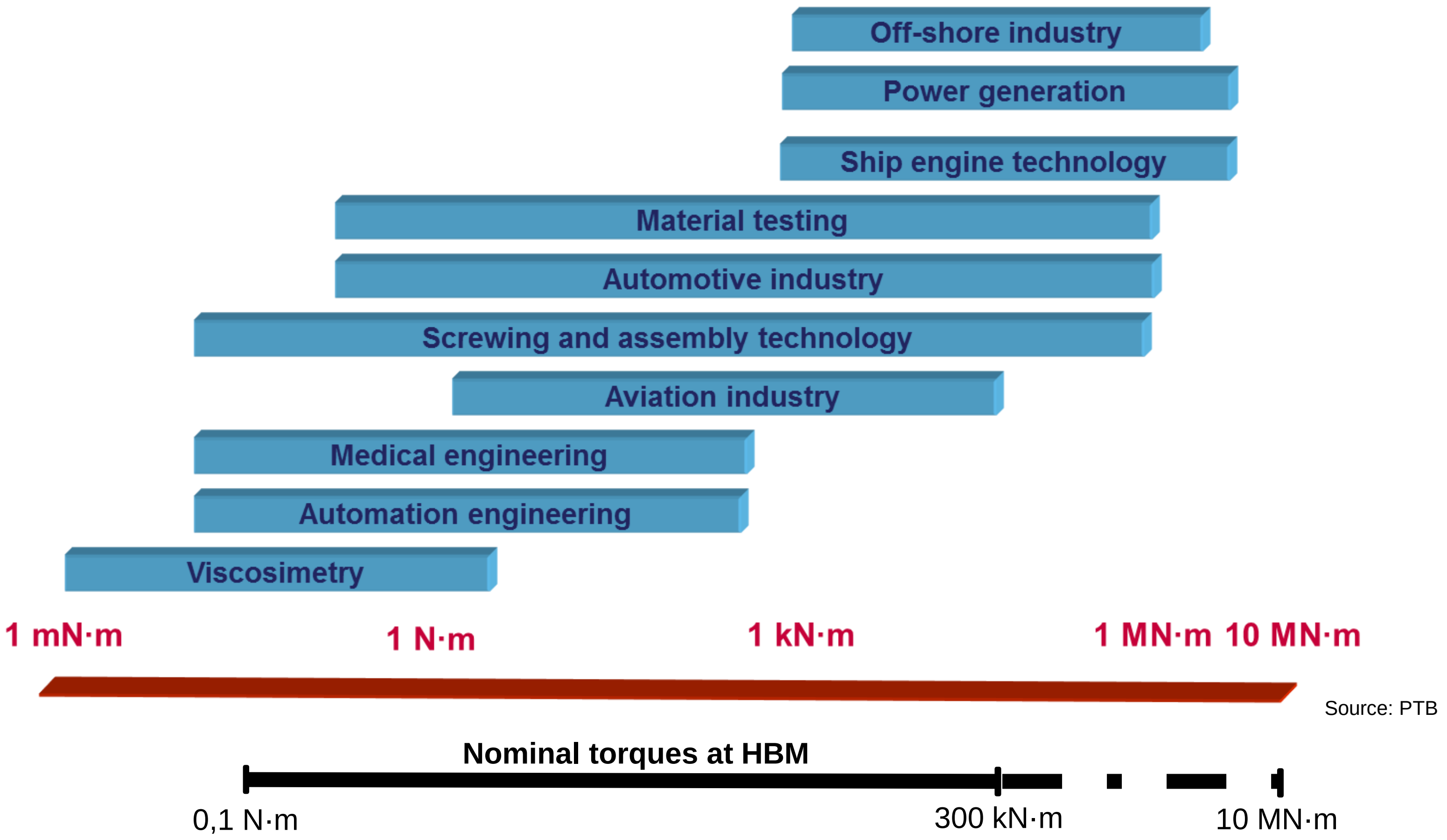
1- Introduction: Torque Sensor Market: Segmentation



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2- Ship Engines: Market Figures & Engines Segmentation

- Centered around; Ship construction (shipyards) / Marine equipment (shipyard supply industry)
- Major shipbuilding region are: Asia (South Korea, Japan, China, Singapore) / Europe (Germany, Italy, Netherlands, Romania)
- The last five years, India, Vietnam, the Philippines and Brazil have acquired substantial order books → become larger players than most European countries.
- The marine equipment → highly heterogeneous Subsector many relatively small companies→9,000 suppliers worldwide
  Total market value was estimated at € 57 billion (2005)

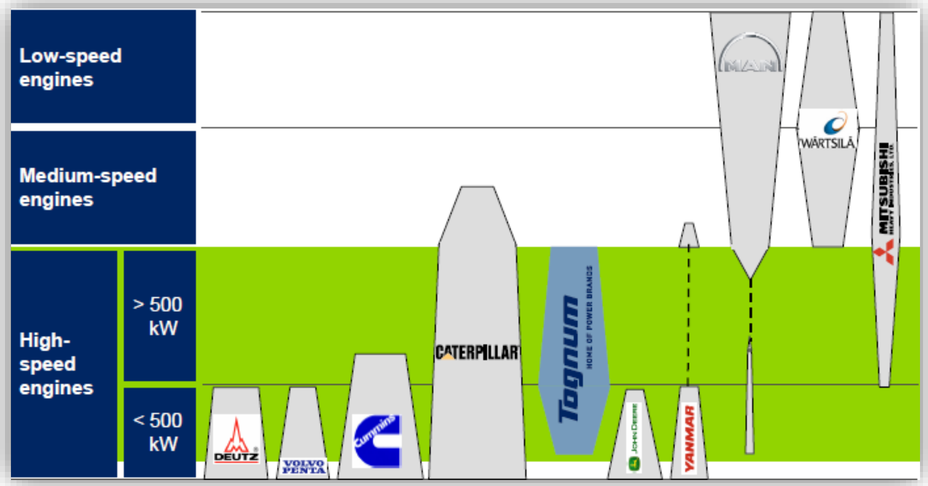
Ship Engine:

- Low-speed: <300 Rpm
- Medium-speed: 300 <Rpm < 1100
- High-speed: >1100Rpm

Low Speed: Wärtsilä, MAN Diesel and Mitsubishi Heavy Industries

Mid Speed: Wärtsilä, Caterpillar (MAK) and MAN Diesel
High Speed: Rolls-Royce, Caterpillar (MAK), Cummins, Volvo, MHI…

Wärtsilä
MAN
Rolls-Royce Marine (incl. MTU)
Caterpillar Marine
ZF Marine
Yanmar
Hyundai Heavy Industries (HHI) (South-Korea),
Doosan (HSD) (South-Korea) Manufacture for MAN & Wärtsilä
Mitsui (Japan) licensee of MAN B&W diesel
Mitsubishi (Japan): Joint venture with Wärtsilä
Hitachi Zosen(Japan) Licensee of Wärtsilä and MAN B&W.
Diesel United (Japan) Licensee of Wärtsilä and SEMT-Pielstick
Kawasaki (Japan)
Scania



Ship Engine Manufacturers

Source: Tognum

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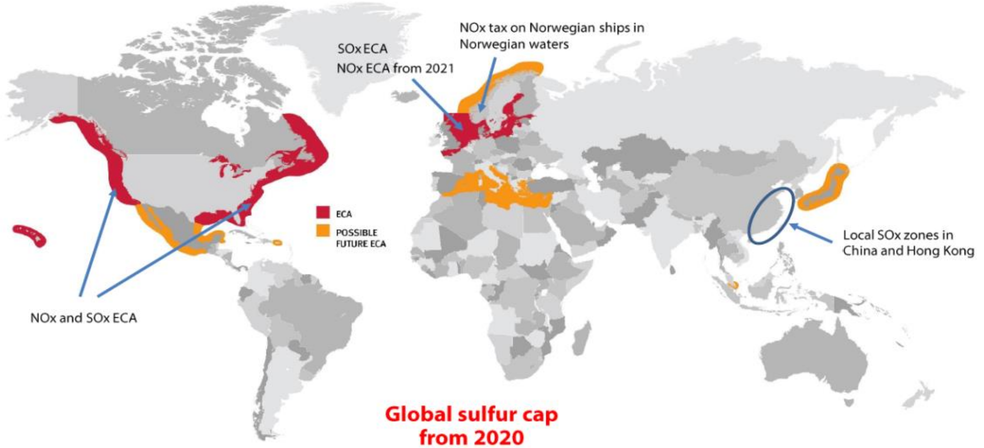
2- Ship Engines: Market Drivers & Challenges

Photo: Thomas Borberg/Polfoto/Arkiv

IMO agrees on global sulfur directive from 2020

CARRIERS: On Thursday, the IMO agreed that ships' fuel may not contain more than 0.5 percent sulfur starting in 2020. The agreement will reduce sulfur pollution from shipping by more than 80 percent, according to the Danish Ministry for Food and the Environment.

Ref.: Shipping Watch 27.10.16



Ref.: Dupont

The Netherlands looking to monitor sulfur use throughout journeys

CARRIERS: The Dutch authorities are working on a method to monitor whether ships co... journey. Project i... ShippingWatch a... measures.

Ref.: Shipping Watch 16.08.16

Home / Sector / Environment

Maersk official calls for greater enforcement of SOx rules

Ref.: Splash 24/7 05.10.16

Photo: MSC

MSC: Sulfur requirements will cost us more than USD 2 billion a year

CONTAINER: The decision to implement global sulfur requirements in 2020 will cost container carrier MSC more than USD 2 billion anually. The new environmental requirements put significant pressure on container carriers, says CEO Diego Aponte.

Ref.: Shipping Watch 28.10.16

Maersk Line expects billions in costs from new sulfur directive

CONTAINER: At Maersk's container carrier alone, the new IMO requirements for less sulfur in fuel from 2020 will results in costs totaling billions of dollars, Maersk Line tells ShippingWatch, calling for methods to enforce the global sulfur directive.

Robust Implementation is Key to Success of 2020 0.5% Global Sulfur Cap: Trident Alliance

Monday October 31, 2016

The Trident Alliance today has welcomed last week's decision by IMO to introduce a 0.5 percent global sulfur cap for marine fuel in 2020, but stresses the need for a robust implementation plan.

The group says that effective enforcement of the new global cap promises to be even more challenging than enforcing the current emissions control area (ECA) zones, and efforts there it has criticized as being "patchy".

Anna Larsson, Chair of the Trident Alliance

Ref.: Ship & Bunker 31.10.16

NOx zones will be reality by 2021

CARRIERS: The IMO has agreed on stricter requirements for vessel emissions of nitrogen (NOx). Starting in 2021, new vessels must trim 75 percent of their nitrogen emissions when sailing in the Baltic and North seas.

Ref.: Shipping Watch 28.10.16

No Delay to 2020 Sulfur Cap's Entrance into Force

Image Courtesy: IMO

The 2020 sulfur emissions legislation will enter into force without delay, Edmond Hughes, IMO's head of air pollution and energy efficiency (MEPC) said while speaking in Athens recently.

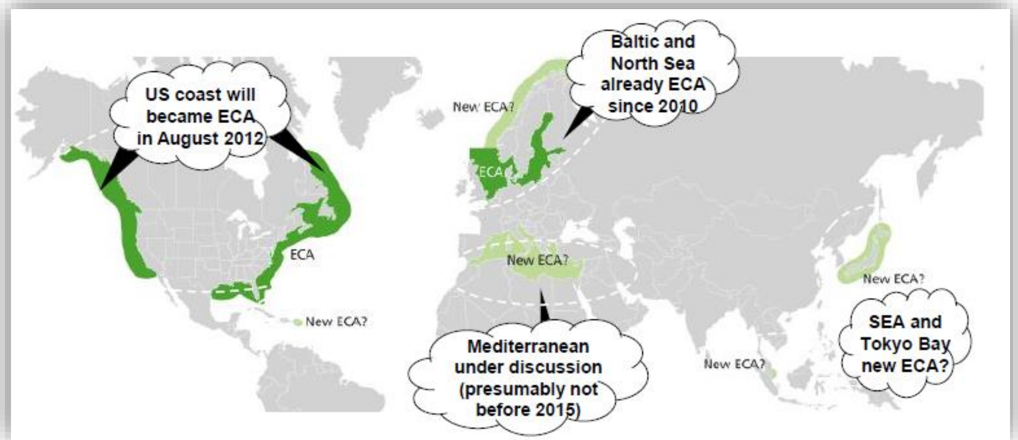
The reassurance was made to put an end to the overall confusion plaguing the industry amid rumored delays in the implementation and lack of preparedness of industry players to meet the requirement.

Ref.: World Maritime News 29.11.17

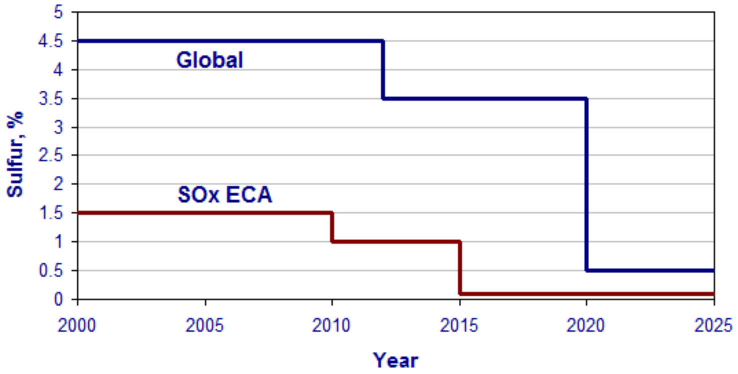
2- Ship Engines: Market Drivers & Challenges

Market Drivers

- **IMO Regulation** → NOx, Sox, GHG emissions < 70%
- **Costs efficiency** → Gas engines more efficient
- **Operational advantage** → More space



Emission Control Area



Solutions:
→ To install **SCR** (Selective Catalytic Reduction) and **EGR** (Exhaust Gas Recirculation) systems in engine systems to minimize emissions.
→ The second solution (namely LNG-fuelled engines) which can meet IMO TIER III standards without adding any auxiliaries. **Lean-burn** gas engine manufacturers mainly include Wärtsilä and Rolls-Royce.

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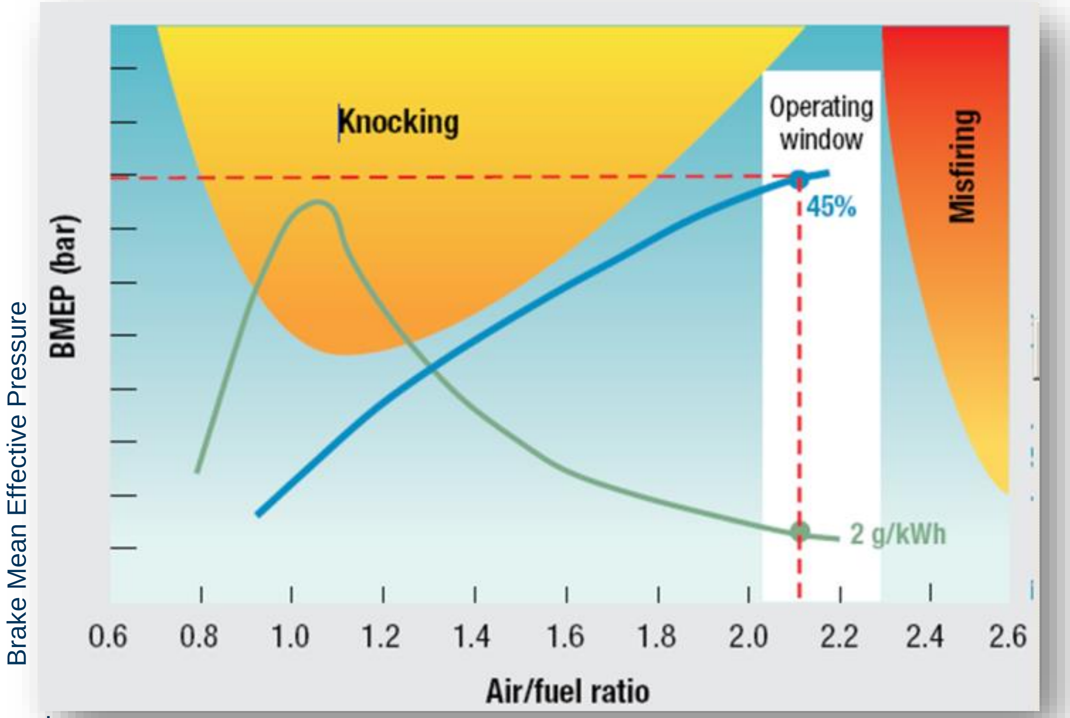
3- Correlation between Pressure and Torque

Lean burn Principle: High air to fuel ratio (about 2.1:1).
The heat energy released by the burning fuel is use to heat this extra air
Advantage → limiting combustion temperatures
→ Low NOx emissions (<1g/kWh)

Mixture Too Rich (below 1.9:1) → Knocking
when combustion of the air/fuel mixture in the cylinder does not start off correctly in response to ignition by the spark plug, but one or more pockets of air/fuel mixture explode outside the envelope of the normal combustion front.

Mixture Too Weak (above2.2:1) → Misfire:
an overly lean air-fuel mixture can lead to a failure to ignite in the combustion chamber,



Characteristics of a gas engine

W = work per cycle in joule
P = power output in watt
p_{me} = mean effective pressure in pascal
V_d = displacement volume in cubic metre
n_c = number of revolutions per power stroke (for a 4-stroke engine $n_c = 2$)
N = number of revolutions per second
T = torque in newton-metre

The power produced by the engine = (the work done per operating cycle) multiply by (the number of operating cycles per second.) →
P=W x n
If N is the number of revolutions per second, and is the number of revolutions per cycle, the number of cycles per second is just their ratio. So we can write

$$W = \frac{P n_c}{N}$$

By definition:

$$W = p_{me} V_d$$

$$p_{me} = \frac{P n_c}{V_d N}$$

Since the torque T is related to the angular speed & power produced by

$$P = T N 2\pi$$

$$p_{me} = \frac{T n_c 2\pi}{V_d}$$

3- Correlation between Pressure and Torque

INTERNATIONAL MARITIME ORGANIZATION

E

MARINE ENVIRONMENT PROTECTION COMMITTEE
66th session
Agenda item 4

MEPC 66/INF.7
17 December 2013
ENGLISH ONLY

AIR POLLUTION AND ENERGY EFFICIENCY

Additional information on revision of ISO 15016:2002

Submitted by the International Organization for Standardization (ISO) and the International Towing Tank Conference (ITTC)

Shaft torque shall be measured by means of permanent torque sensor or strain gauges on the shaft. The measurement system shall be certified for power measurements with a bias error smaller than 1% so that an overall bias error smaller than 2% (on board of the actual ship) can be achieved.

11.2.3 Evaluation based on Direct Power Method

To derive the speed/power performance of the ship from the measured speed over the ground V_G, power P_M and propeller frequency of revolutions η_M, the direct power method shall be used.

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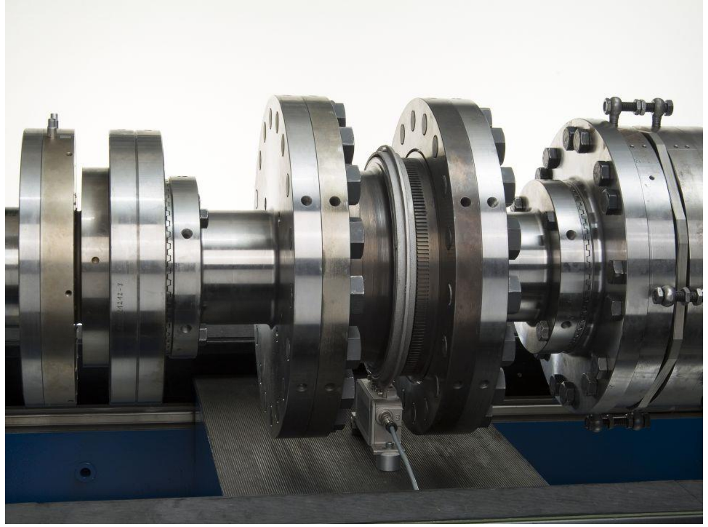
4- Torque / Load Measurement Methods

Indirect Methods

- strain gage on drive shaft
- torsional angle
- phase shift by encoder
- cylinder pressure

Direct Method

- - Inline torque transducer



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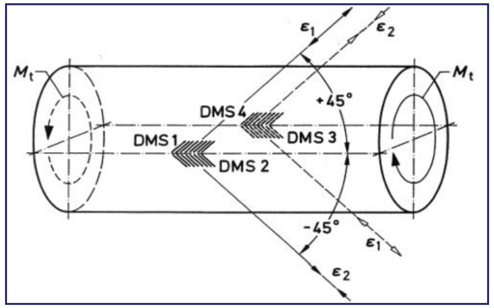
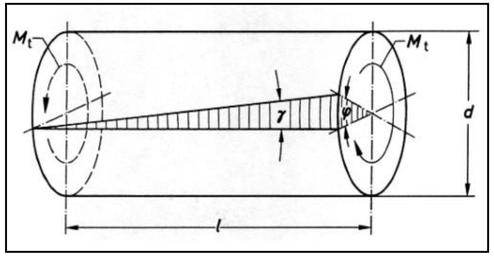
4- Torque / Load Measurement Methods: Indirect Measurement



strain gage on drive shaft

$$M_t = \varepsilon \cdot \frac{E}{(1+\upsilon)} \cdot \frac{\pi \cdot d^3}{64}$$



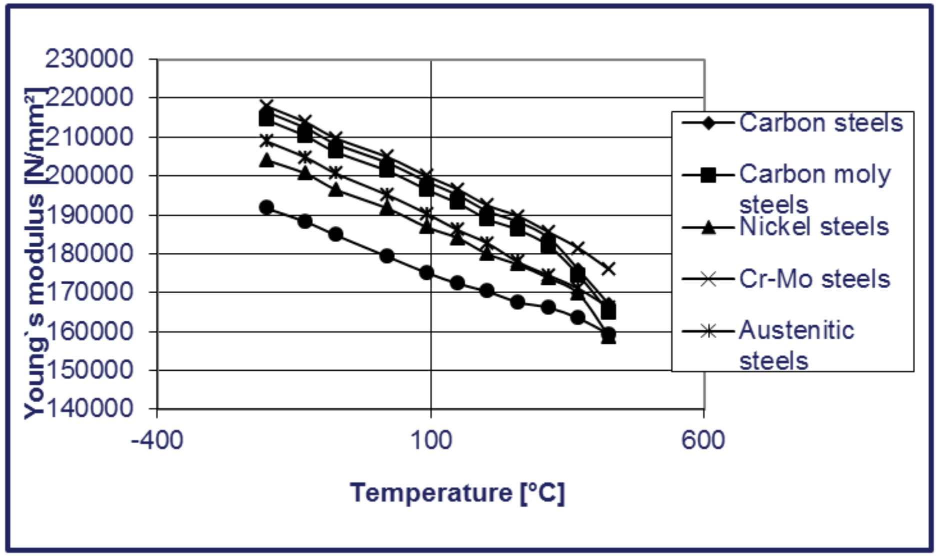
torsional angle

$$M_t = \frac{\varphi}{l} \cdot \frac{E}{(1+\upsilon)} \cdot \frac{\pi \cdot d^4}{64}$$

Concomitants Measurement Uncertainties:

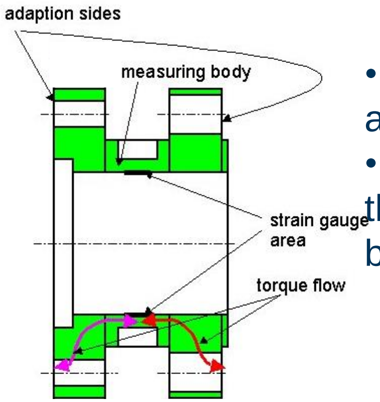
- Geometry
- Material properties

Parameter	Symbol	Approx. tolerances / %
Speed	n	**0.1**
Shaft diameter	d	**0.01**
Young's modulus	E	**5…10**
Poisson's ratio		**3…5**
Gauge factor	k	**1**
Torsional angle		**0.1**
Shaft lengtht	**l**	**0.01**

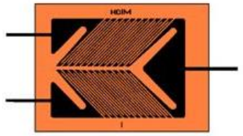


4- Torque / Load Measurement Methods: Direct Measurement

- **Torque Measurement**

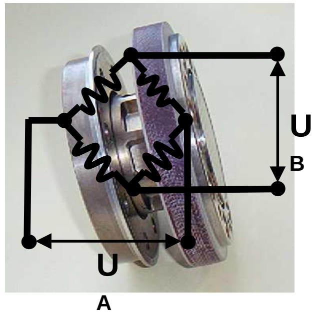


- Tensions are occuring under a angle of 45°
- Tensions creating a strain on the surface of the measurement body



$$\Delta R/R = k \cdot \varepsilon$$

Strain is converted into change of resistance



$$\frac{UA}{U_B} = \frac{k}{4}(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)$$

Resistance is proportional the introduced load (torque)

- **Temperature Effects**

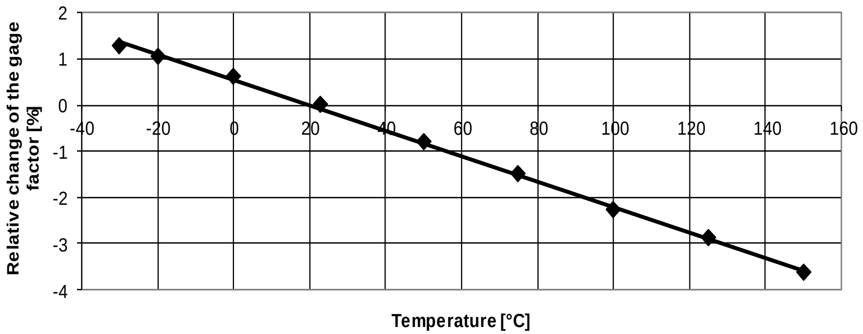
$$\left(\frac{\Delta R}{R}\right) = \left(\frac{\Delta R}{R}\right)_{therm} + \left(\frac{\Delta R}{R}\right)_{mech}$$

T° effect on the zero signal (*TC_0*)

T° effect on the sensitivity (*TC_S*)

$$\left(\frac{\Delta R_1}{R_1}\right)_{therm} = \left(\frac{\Delta R_2}{R_2}\right)_{therm} = \left(\frac{\Delta R_3}{R_3}\right)_{therm} = \left(\frac{\Delta R_4}{R_4}\right)_{therm}$$

$$\left(\frac{\Delta R}{R}\right)_{mech} = \sigma \frac{k_T}{E_T}$$



Relative change of the gage factor [%]

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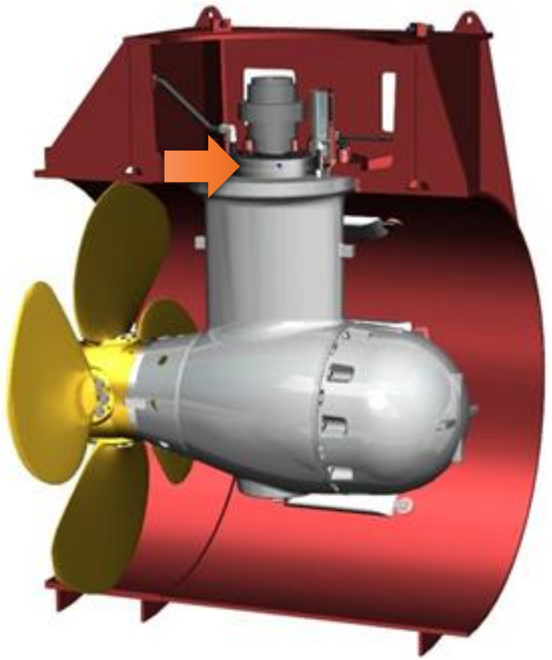
4- Torque / Load Measurement Methods: Comparison

Input variables	Tolerance of e.g. on site strain gage installation	Tolerance of torque transducer
Youngs modulus	2 … 5%	**~ 0%**
k - factor	~ 1%	**~ 0%**
Shaft geometry	~ 1%	**~ 0%**
Strain gage positioning	1 … 5%	**~ 0%**
Temperature impact	2 … 5%	**~ 0,1%**
Total	**5 … 7% , not detectable**	**~ 0,2 … 0,3% , detectable**



Source: Wärtsilä

Indirect method

- ⊕ Flexible installation
- ⊕ Low initial costs
- ⊕ No additional inertia
- ⊖ Fair to low accuracy
- ⊖ Auxiliary data
- ⊖ Downstream computation
- ⊖ No calibration certification

Direct method

- ⊕ Measurement of true torque (no calculations E, diameter, length, angle, …)
- ⊕ Measurement of high dynamic torque
- ⊕ Very high accuracy
- ⊕ Calibration certificate
- ⊖ For high-end measurements
- ⊖ Requires additional space
- ⊖ High initial investment

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4- Torque / Load Measurement Methods: Application & Solutions

- **Testing**

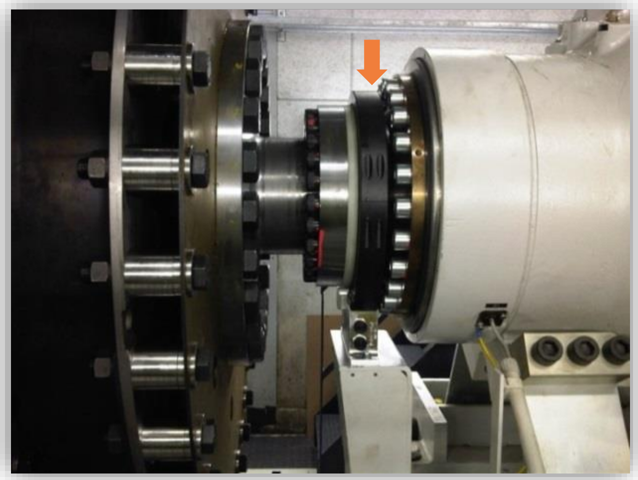
→Ship Engine Testing: Standard torque application.
→Thruster Testing
→Propeller Testing
→Gearboxes Testing, on board control and monitoring

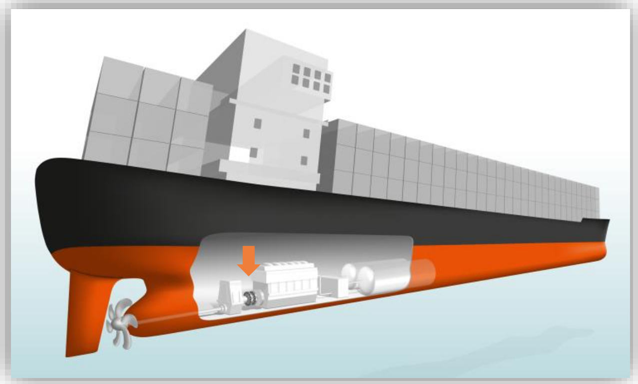
- **Control**

→Engine Load point control

- **Monitoring**

→Monitoring of gas engines with a direct drive mechanism
→Thruster Monitoring
→Winch Monitoring On-board load monitoring & control of cable tension on the winches e.g. Tugboat





Technology/Product advantages

- Measurement uncertainty
- Mechanical stability
- Directly torque measurement
- Real time data acquisition
- Maintenance free
- Certification for marine industry

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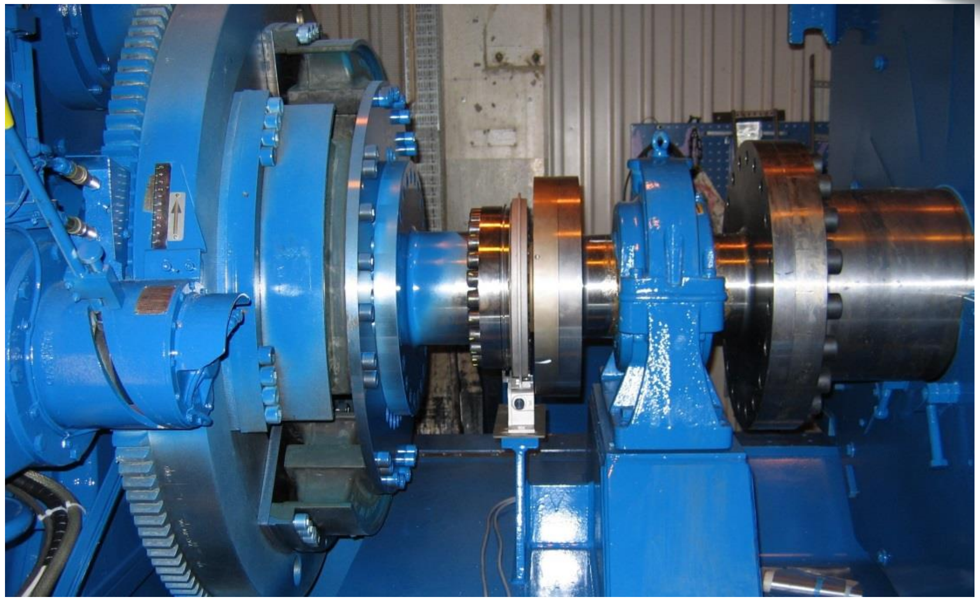
5- HBM Marine Solution: Applications



Engines Testing

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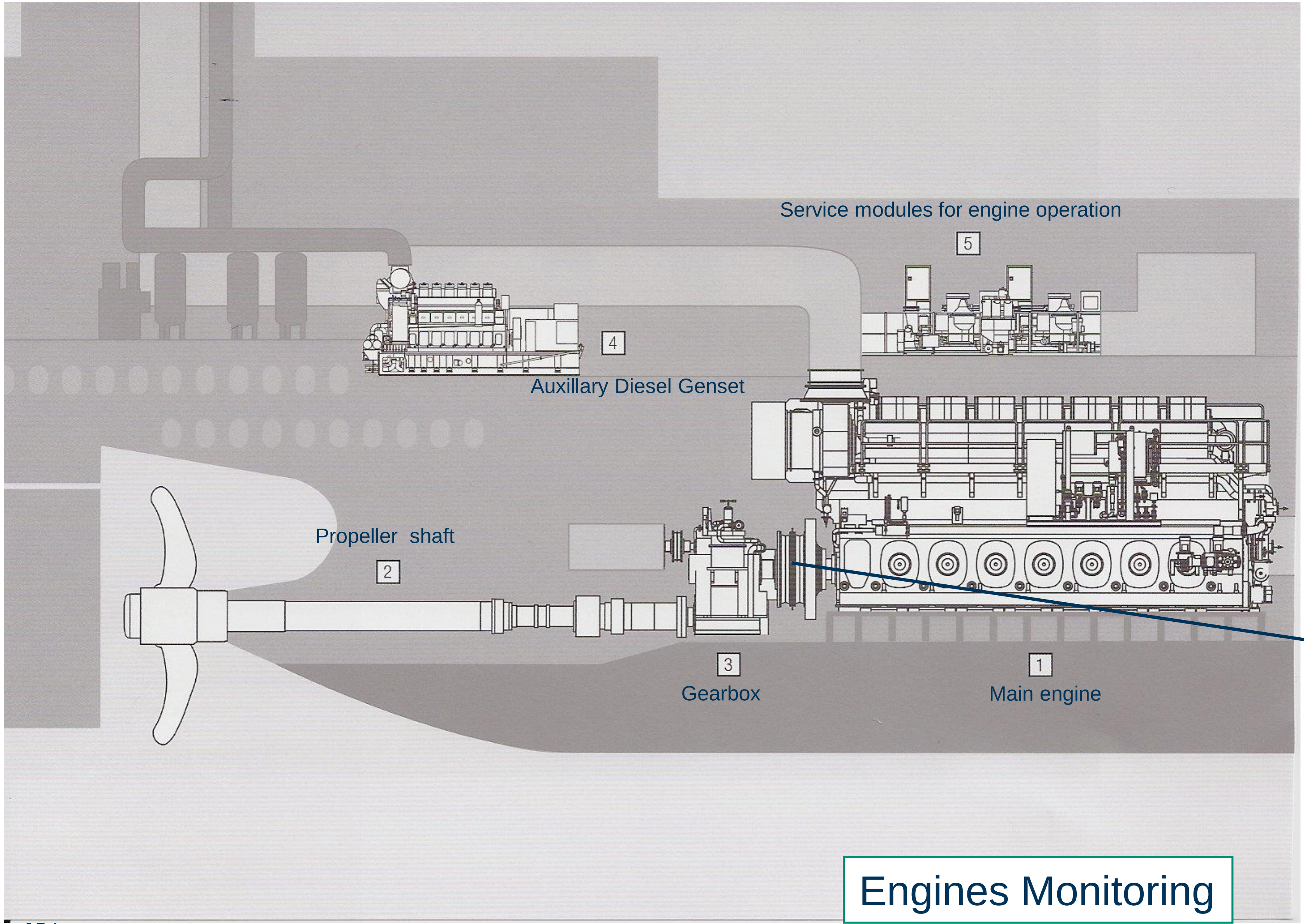
5- HBM Marine Solution: Applications



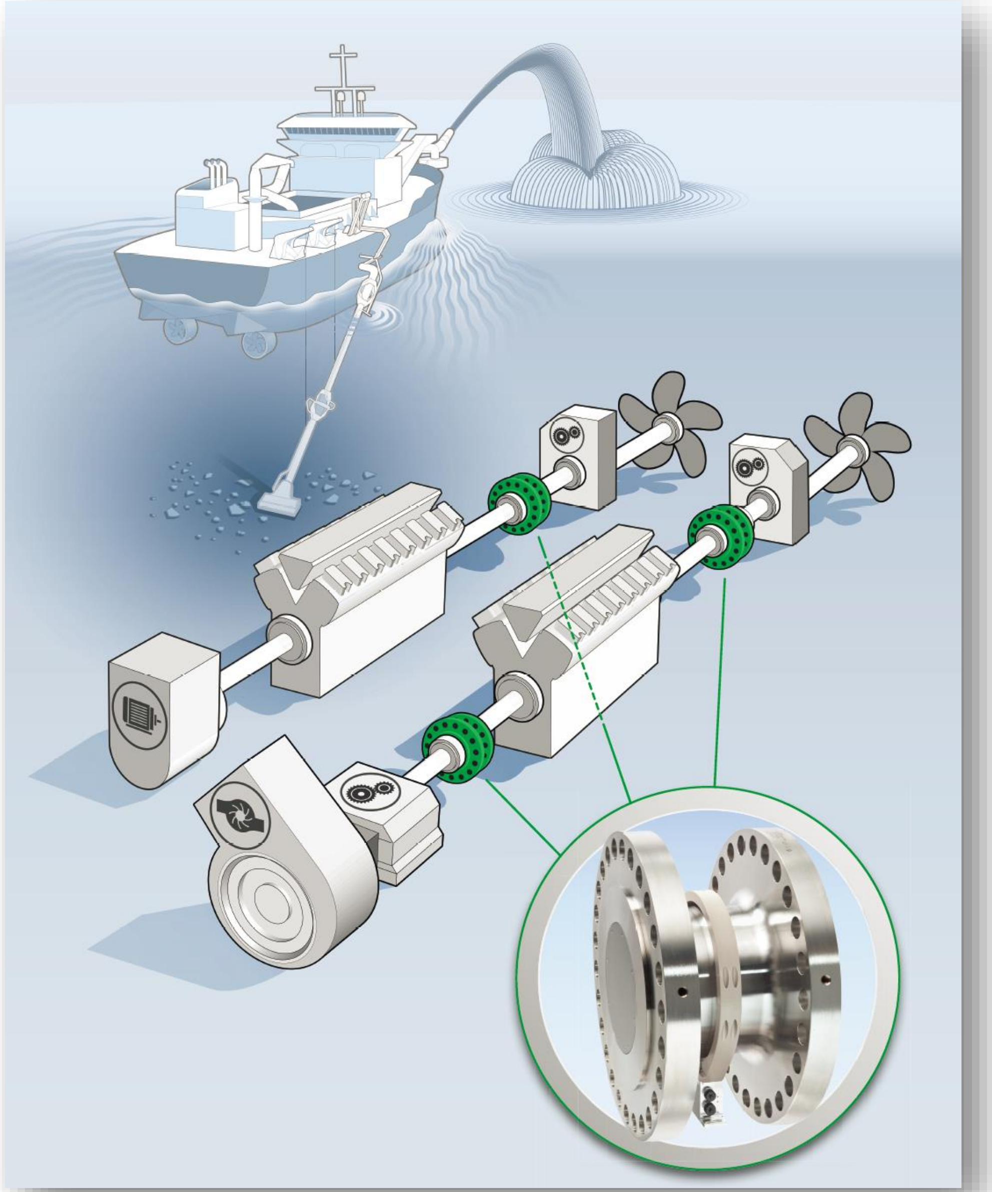
Engines Monitoring

HBM: business document

5- HBM Marine Solution: Applications

Engines Monitoring

5- HBM Marine Solution: Energy Management



Working vessels like dredgers or drilling boats, etc.

Accurate load measurement and real time monitoring

Efficient energy distribution

Overload Safe Operation

✓ **Safety**
✓ **Security**
✓ **Efficiency**

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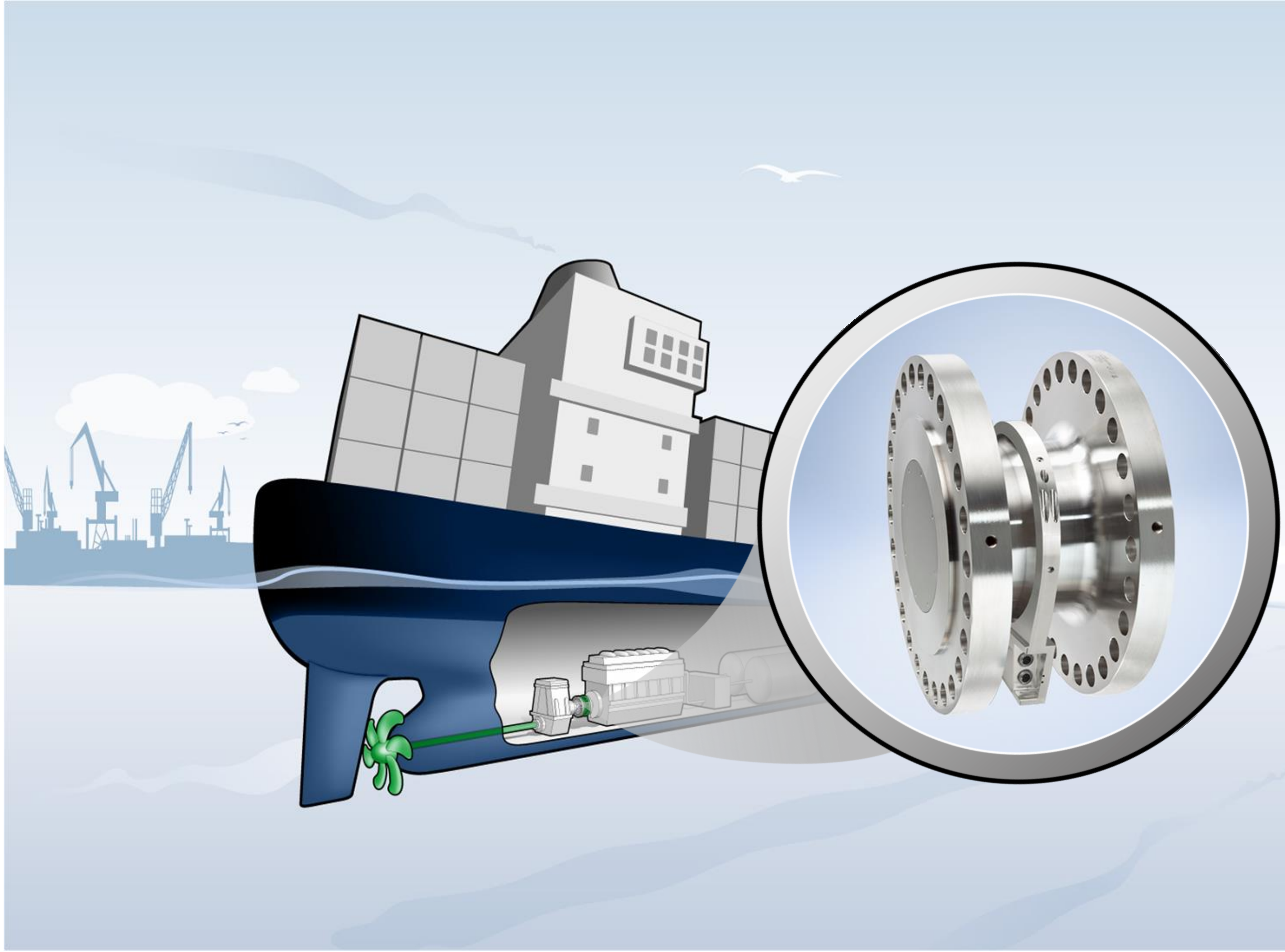
5- HBM Marine Solution: Applications

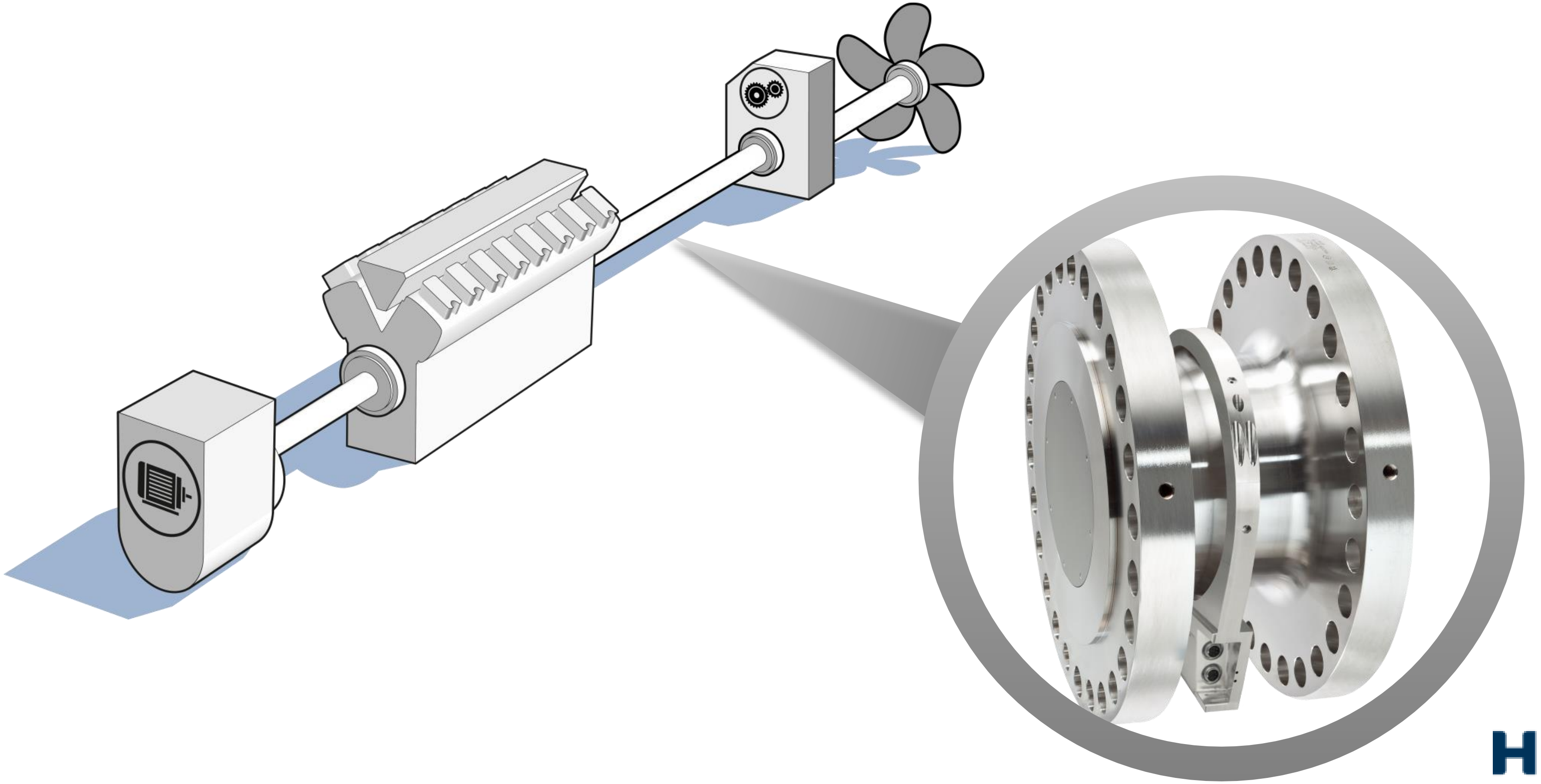


T40MAR

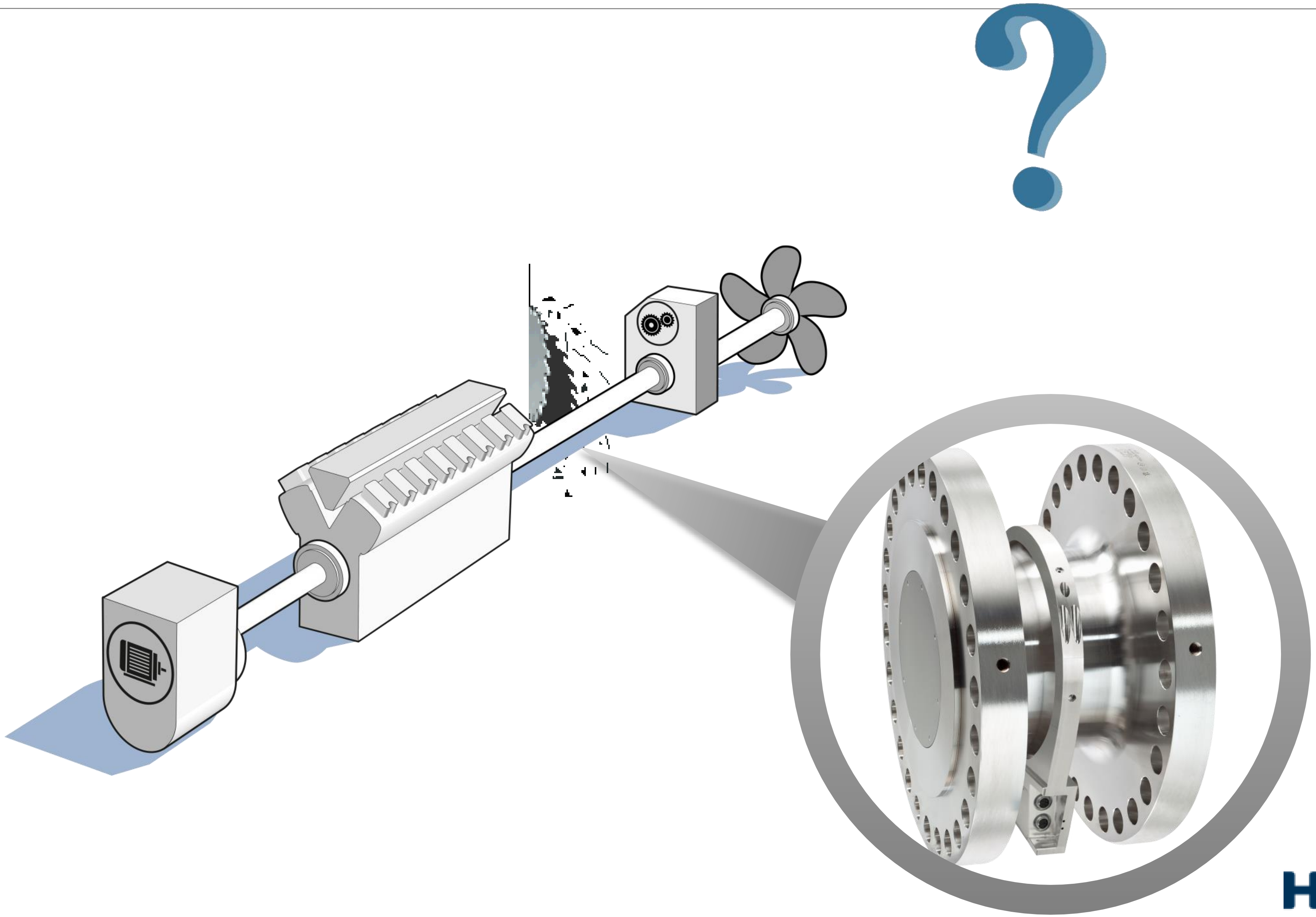
- Precise
- Robust
- Longlife

5- HBM Marine Solution:

How to integrate the transducer for existing ships



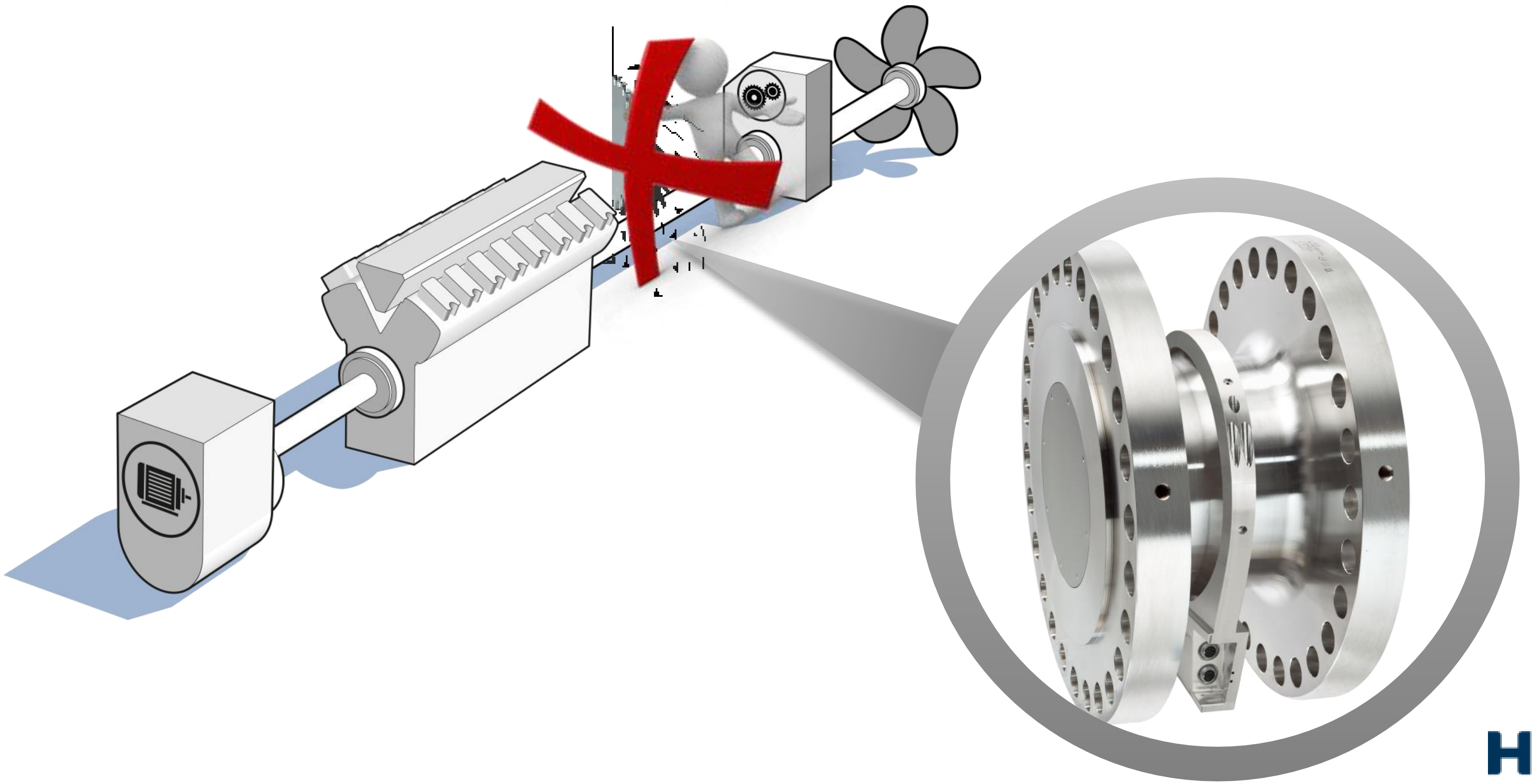
5- HBM Marine Solution:



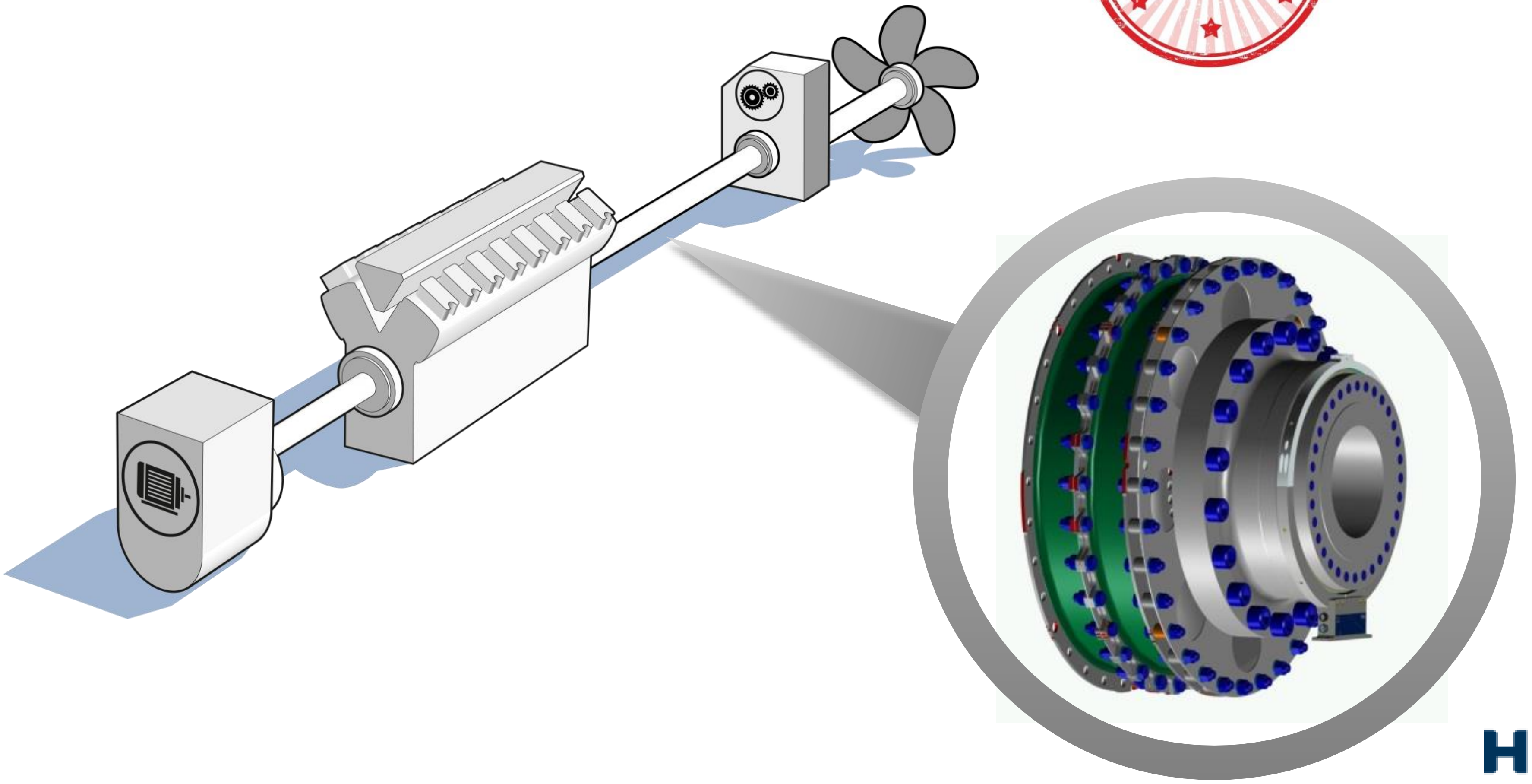
HBM: business document

5- HBM Marine Solution:

What if customer is not able to cut the driveshaft

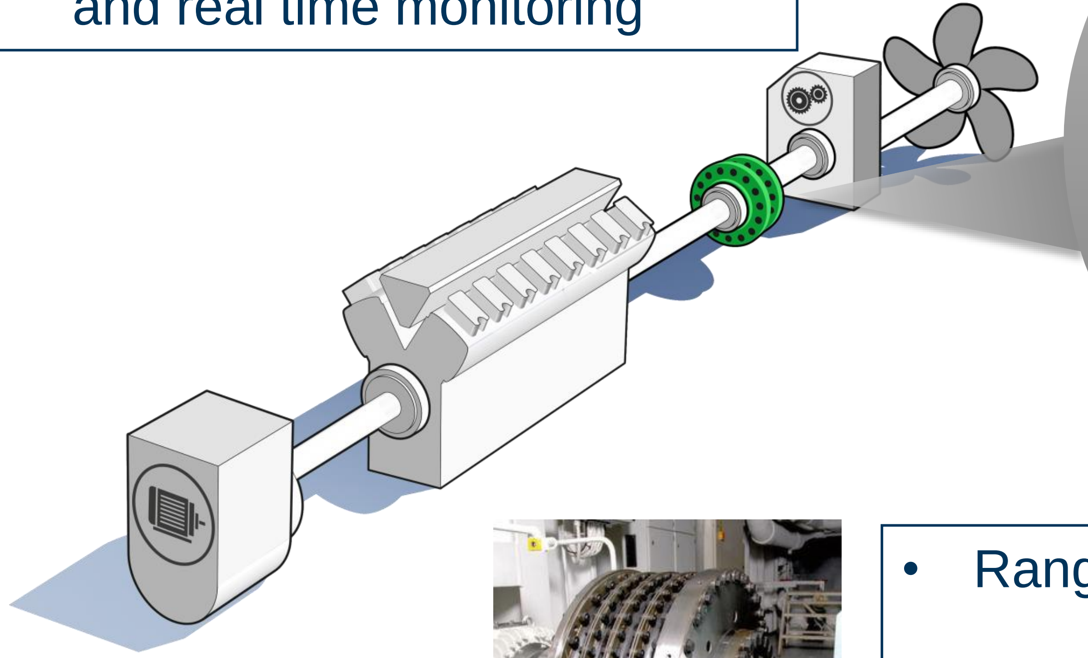


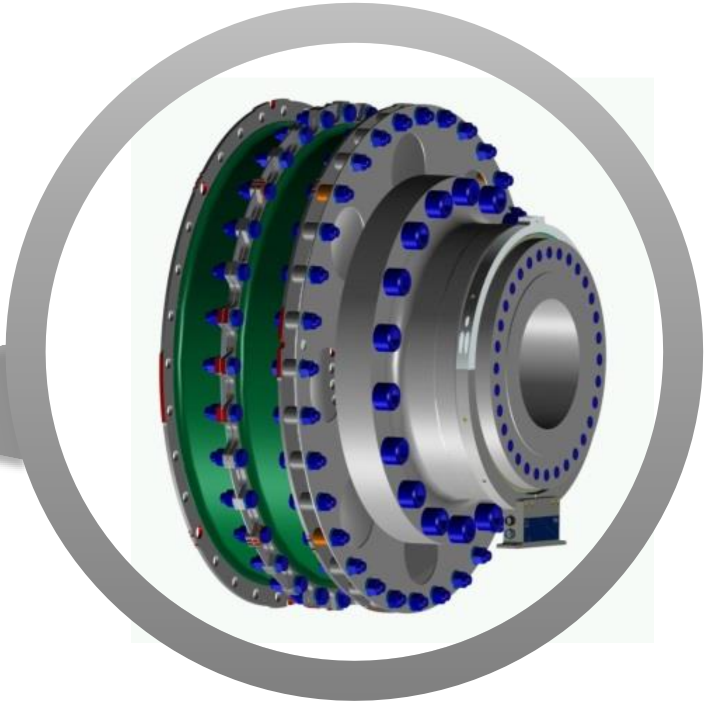
5- HBM Marine Solution: T40MC Measuring Coupling



5- HBM Marine Solution: Measuring Coupling for Load Monitoring

- ✓ For existing ship with our retrofit solution
- ✓ Neutral installation space requirements
- ✓ Accurate load measurement and real time monitoring





- Ranges: 10Knm to 400kNm
- Precision: 0,1% f.s.
- Marine certification

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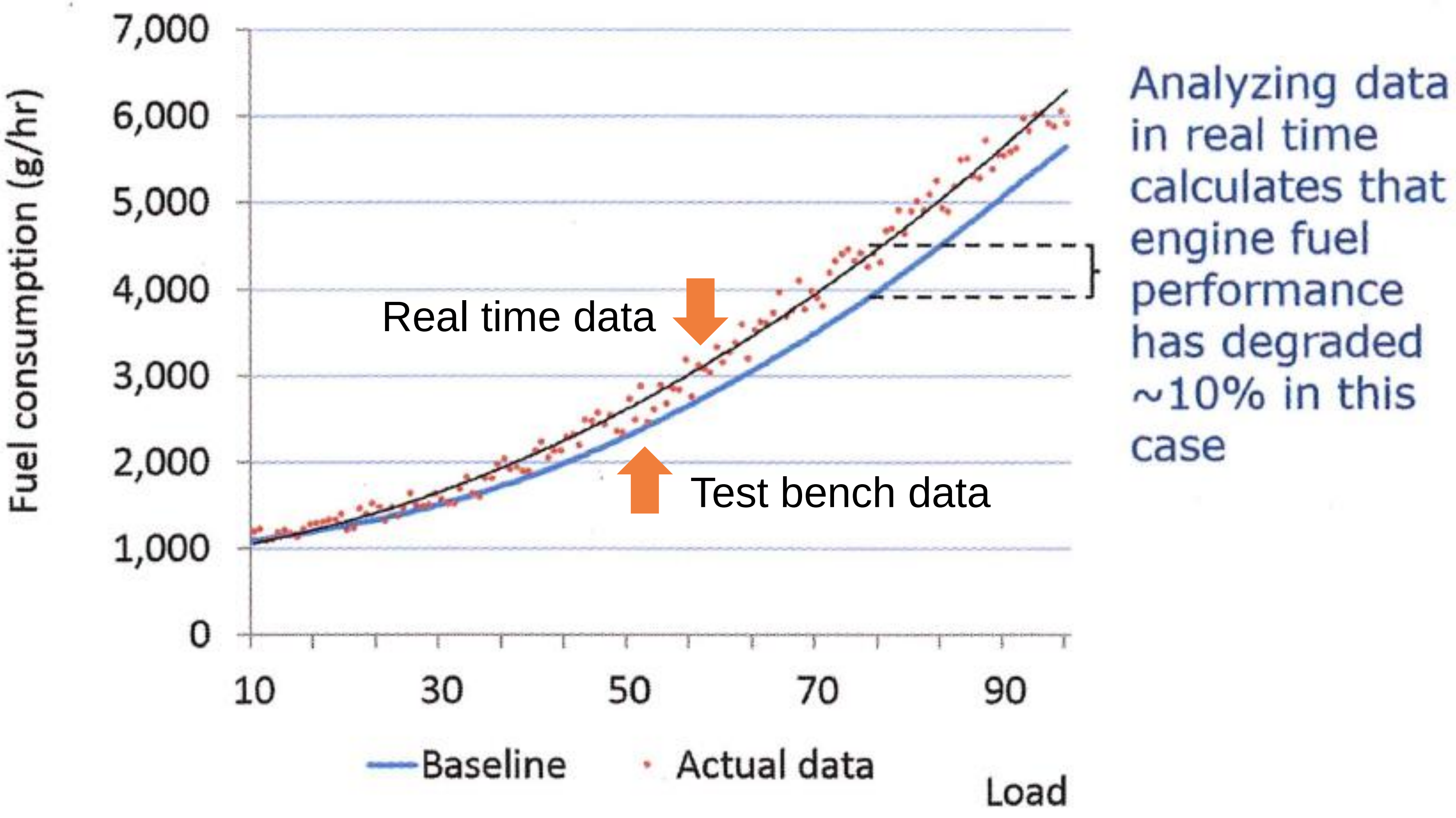
Applications of the Marine Industry - ship engine monitoring



Source: www.maritimeprofessional.com | Maritime Professional | 51 1Q 2014

5- Calibration and Traceability

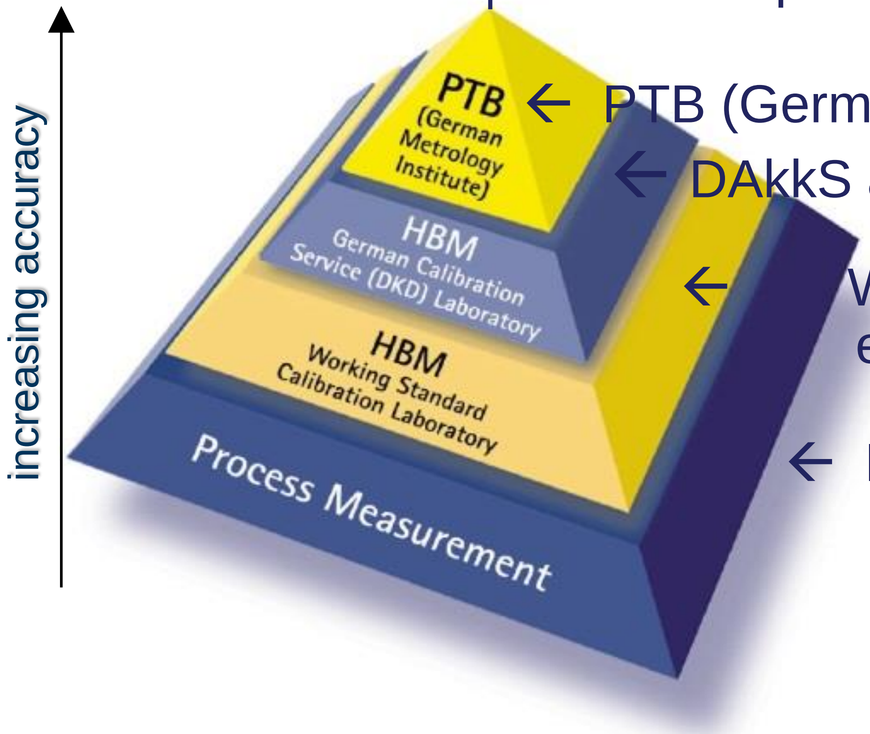
Hierarchy Levels of Calibration and Traceability

Mutual recognition of calibration certificates between 53 countries

ilac-MRA

DAkkS
Deutsche
Akkreditierungsstelle
D-K-12029-01-00

Intercomparison between National Institutes



← PTB (German National Metrology Institute)

← DAkkS accredited laboratories e.g. HBM

← Working standard calibration laboratory e.g. HBM

← Industrial applications

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5- Calibration and Traceability: Principles

Lever-arm/mass systems
Range 1 kN·m

A precisely defined torque is generated when the weight force of calibrated masses acts on the test specimen by means of a lever arm of known length.

- DAkkS
- Uncertainty 5 N·m - 1 kN·m: ±0,01 % (of measured value)

Reference force transducer
Range 50 kN·m

- Working standard calibration.
- Torque steps: 500 N·m to 50 kN·m
- Uncertainty 500 N·m - 50 kN·m: ±0,2 % (of measured value)
- C4 reference force transducer
- Powertrain calibration possible

Reference torque transducer
Range 400 kN·m

reference value

- DAkkS
- Uncertainty 3 kN·m - 400 kN·m: ±0,1 % (of measured value)

- In 1990, first and only torque calibration machine in Germany, a quasi National Standard over many years
- Lever-arm / mass principle
- Binary mass stacks
- 2 N•m up to 25 kN•m
- Very small uncertainty
- Calibrations acc. to DIN 51309, VDI2646

4 DKD-accredited machines:
2 N•m up to 25 kN•m
2 new machines in 2005

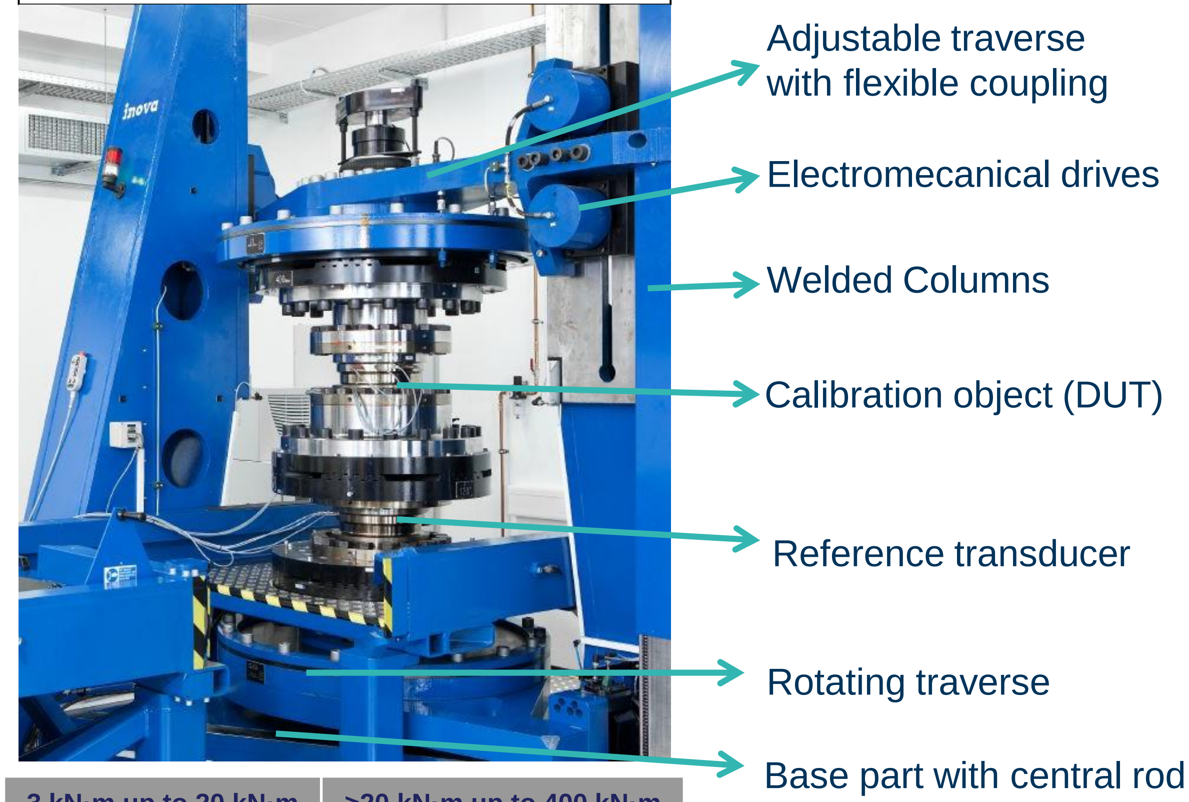
Best possible relative uncertainty
0.008%

Measuring Ranges	DAkkS	Measurement Uncertainty
0,2 N·m – 20 N·m		0,4 %
2 N·m – 200 N·m	X	0,04 %
5 N·m - 1000 N·m	X	0,01 %
100 N·m - 25 kN·m	X	0,008 %
250 N·m - 20 kN·m	X	0,02 %
2 kN·m - 60 kN·m		0,2 %
3 kN·m - 400 kN·m	X	0,1 %

5- Calibration and Traceability: 400 kN·m Calibration Machine

Torque calibration range up to 400 kN·m

- Reference calibration machine with 2 reference transducers: 150 kN·m and 400 kN·m (type: T10FH)
- Clockwise and counter-clockwise torque
- First step 3 kN·m
- Lowest calibration range 30 kN·m
- Steps of 1 kN·m



3 kN·m up to 20 kN·m	>20 kN·m up to 400 kN·m
0.15%	**0.1%**

Vertical layout

- Torque generated by two linear drives
- Toothed disk adapter
- Multi disk couplings on top and bottom
- Active weight compensation
- Vibration decoupled base plate

ilac-MRA
DAkkS Deutsche Akkreditierungsstelle D-K-12029-01-00

DAkkS calibration certificate according to DIN 51309 - **optimized accuracy** VDI2646 only HBM transducer
(**fix 6 steps**, **only full range)**

Working standard calibration (standard 6 steps, variable, up to 20 steps)

Tabelle 3 **Überprüfung der Einhaltung der Herstellerspezifikation anhand der Kalibrierergebnisse**
table 3 *Verification of compliance with manufacturer specification based on calibration results*

	Richtung *Direction*	Zulässiger Wert *Admissible value*	Berechneter Wert *Value determined*	Ergebnis *Result*
Linearitätsabweichung einschließlich Hysterese d_h in % von M_E *Linearity deviation including hysteresis d_h in % of M_E*	rechts *clockwise*	0,10	-0,009	ok
	links *anticlockwise*	0,10	-0,006	ok

All calibration certificates torque have a statement of conformity

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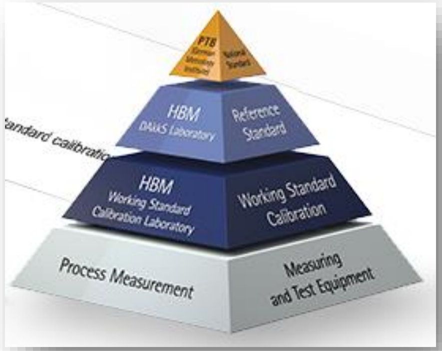
Summary

400KN.m with 0,1% M.U.



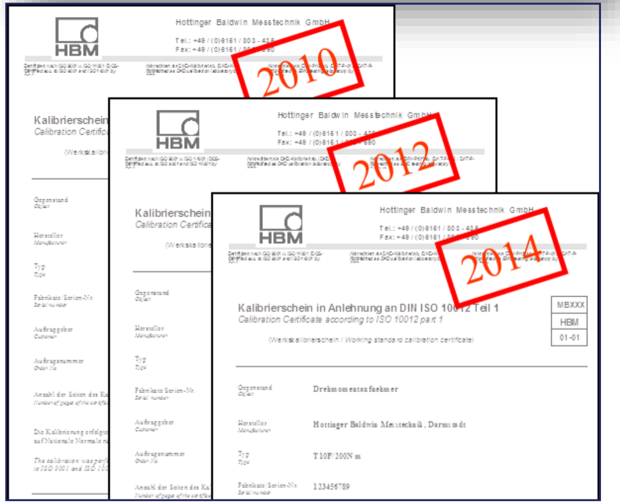
Unbroken chain of comparisons relating these torque transducers to the reference transducer of the German National Standard

This precision enables to measure the torque and calculate the power and the efficiency with accuracy at least 10 times better than the current environmental regulations requirement of the marine industry

- Best accuracy
- Traceability
- Transfer standard

Recommendation

- For electronic devices: recalibration after about one year
- For transducers: recalibration after max. two years
- Recalibration indispensable:
  - after overloading or inappropriate use
  - after repair



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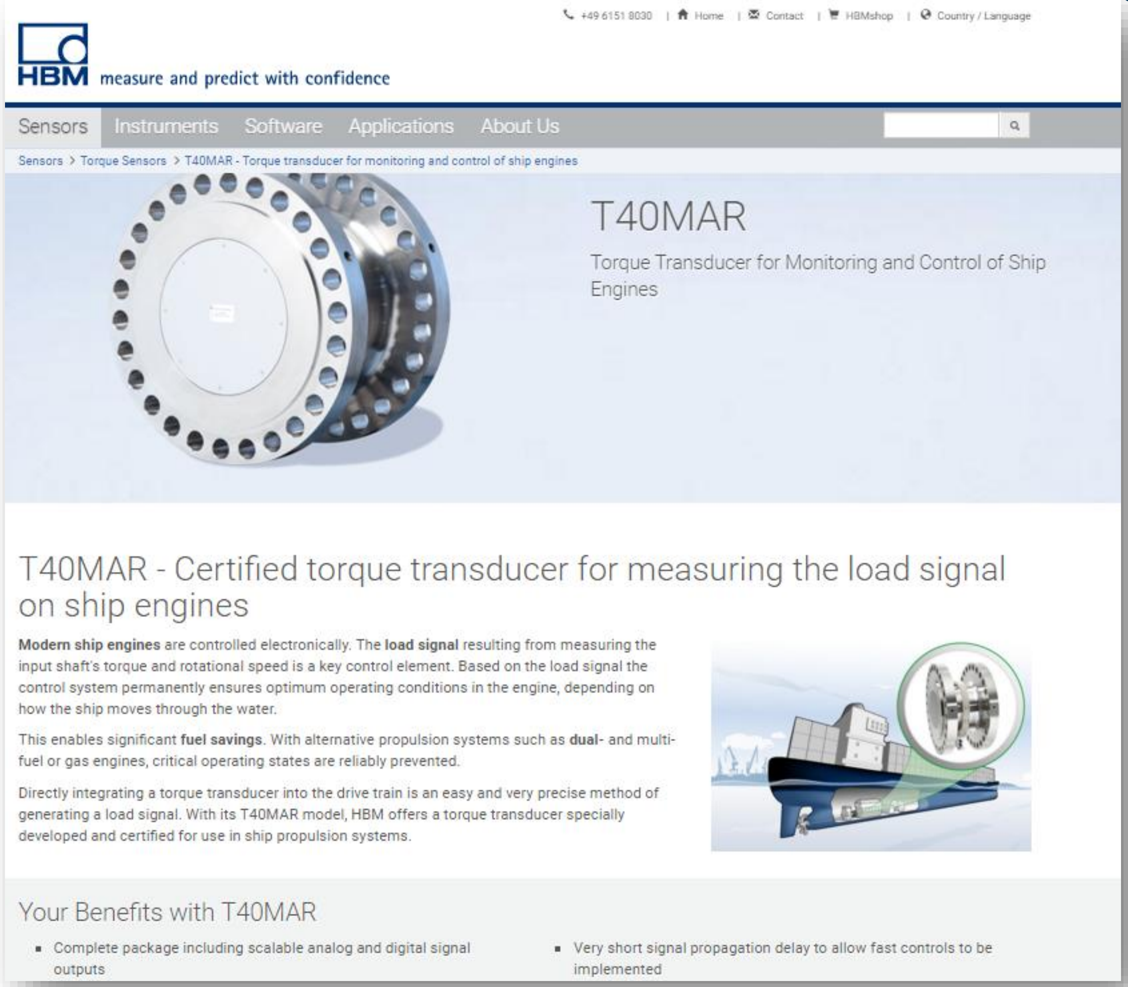
Additional informationen

More information on TOPIC can be found on our website:

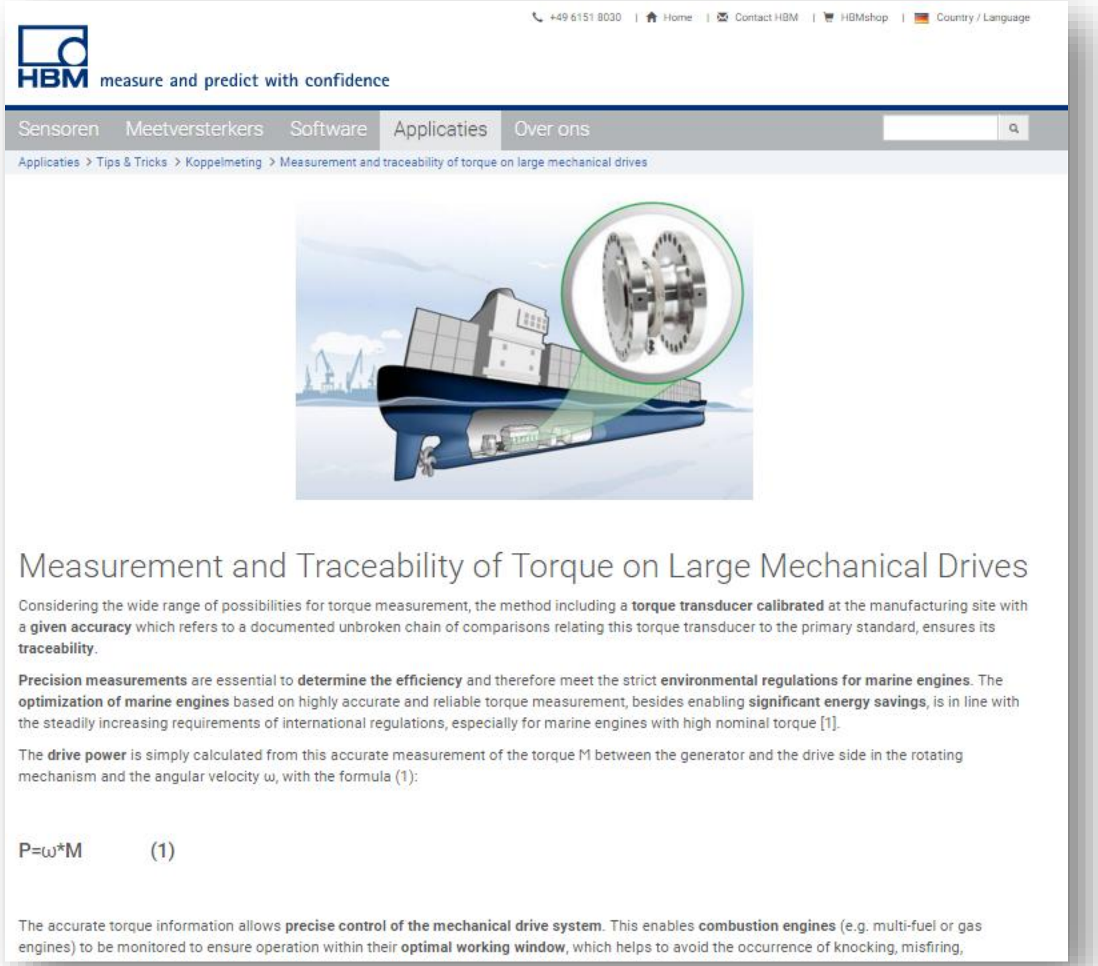
- **www.hbm.com/en/4207/t40mar-torque-transducer-with-maritime-certificate/**



Additional informationen

More information on TOPIC can be found on our website:

- **http://www.hbm.com/nl/4993/measurement-and-traceability-of-torque-on-large-mechanical-drives/**



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HBM measure and predict with confidence

Sensoren Meetversterkers Software Applicaties Over ons

Applicaties > Tips & Tricks > Koppelmeting > Measurement and traceability of torque on large mechanical drives

Measurement and Traceability of Torque on Large Mechanical Drives

Considering the wide range of possibilities for torque measurement, the method including a **torque transducer calibrated** at the manufacturing site with a **given accuracy** which refers to a documented unbroken chain of comparisons relating this torque transducer to the primary standard, ensures its **traceability**.

Precision measurements are essential to **determine the efficiency** and therefore meet the strict **environmental regulations for marine engines**. The **optimization of marine engines** based on highly accurate and reliable torque measurement, besides enabling **significant energy savings**, is in line with the steadily increasing requirements of international regulations, especially for marine engines with high nominal torque [1].

The **drive power** is simply calculated from this accurate measurement of the torque M between the generator and the drive side in the rotating mechanism and the angular velocity ω, with the formula (1):

$$P=\omega*M \qquad (1)$$

The accurate torque information allows **precise control of the mechanical drive system**. This enables **combustion engines** (e.g. multi-fuel or gas engines) to be monitored to ensure operation within their **optimal working window**, which helps to avoid the occurrence of knocking, misfiring,

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Thank you

Beaho, Guy
Manager Business & Applications

HBK PMMS-IMS
Tel. +4961518038879
guy.beaho@hbkworld.com

www.hbm.com

Beaho, Guy
Manager Business & Applications
HBK PMMS-IMS
Tel. +4961518038879
guy.beaho@hbkworld.com

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