International Standard

ISO 8933-1

Ships and marine technology — Energy efficiency —

Part 1: Energy efficiency of individual maritime components

Navires et technologie maritime — Éfficacité énergétique —

Partie 1: Efficacité énergétique des éléments maritimes individuels

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Foreword

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This document was prepared by Technical Committee ISO/TC 8, *Ship and marine technology.*

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Environmental concerns, emission regulations, fuel prices, and emission taxes are increasing the demand for greater energy efficiency in shipping. In 2013, the International Maritime Organization (IMO) adopted the Ship Energy Efficiency Management Plan (SEEMP)[1] to significantly decrease the amount of carbon dioxide (CO_2) emissions by 10 % to 50 % per transport work in international shipping. This strategy refers to a pathway of CO_2 emissions reduction which is consistent with the goals of the Paris Agreement,[14] alongside the United Nations 2030 Agenda for Sustainable Development.[15]

Standardizing methods to evaluate energy efficiency in the maritime sector interface is valuable for a range of different stakeholders, including:

— shipowners who are looking to buy maritime systems to comply with IMO SEEMP initiatives;

— maritime equipment and engine manufacturers who are responsible for the design and production of ship systems;

— governments that are committed to environmental regulations and environmental targets such as the “levels of ambition” adopted by IMO.

The purpose of this document is to improve energy efficiency in ships by providing more energy efficient options that can be considered when replacing malfunctioning components throughout the ship lifetime.

This document allows shipowners and shipyard workers to objectively identify the most energy-efficient components for retrofits, as well as newbuilds.

The document provides a method for comparing energy performance on an objective basis to prevent energy loss and to improve cost-efficiency and environmental conditions during maritime transport. This document makes it possible for users to compare the energy efficiency of different individual maritime components based on a standardized method to measure and calculate the values.

It is a widely established that the usual combination of best efficient single systems on board do not lead in sum to the most efficient ship. It is common practice that owners instruct shipyards to meet the criteria for an optimized operating point of the respective ship system during the design phase (new build or reconstruction).

Accordingly, a shipyard checks before installation that each single system or component meets good energy efficiency values. It is not possible to calculate the ship's overall efficiency if the operating conditions are not standardized.

An example of a system or component where the efficiency depends on the operational conditions is an engine room ventilation without a given fan speed control system. If fan is designed and optimized for the tropical zone and the ship is operated under North Atlantic conditions, less power is necessary during winter times. Owing to the absence of a controller, the fan rotation speed cannot be adjusted. In sum, every single fan can operate efficiently on a test bed. An efficient performance is questionable if the ship sails under different operational conditions than what it is designed for.

To raise the overall operational energy efficiency of a ship in different operational conditions, the overall ship-individual combined system efficiency check should be performed. In addition, manufacturers, and operators should take into account the possible variations between test bed conditions and onboard test conditions when developing individual components and systems.

Ships and marine technology — Energy efficiency —

Part 1: Energy efficiency of individual maritime components

1 Scope

This document specifies generic measuring and calculation methods to evaluate the energy efficiency of individual maritime components installed on board ships, vessels for inland navigation or offshore structures. This document only covers energy consuming components for which a "unit output" can be clearly defined and which require energy to function.

This document only covers the major energy consuming components of a typical ship. It does not cover the propulsion component of the ship (e.g. the propeller).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
energy efficiency
ratio or other quantitative relationship between an *output* (3.4) of performance, service, goods or energy, and an *input* (3.3) of energy

EXAMPLE Efficiency conversion energy; energy required/energy used; output/input; theoretical energy used to operate/energy used to operate.

Note 1 to entry: Both input and output shall be clearly specified in quantity and be measurable.

[SOURCE: ISO/IEC 13273-1:2015, 3.4.1]

3.2
component
element performing only one function whose efficiency is defined by the ratio between *input* (3.3)and *output* (3.4)

EXAMPLE Electric motor, water pump.

3.3
input
product, material or energy flow that enters a *component* (3.2)

Note 1 to entry: Products and materials include raw materials, intermediate products and co-products.

3.4
output
product, material or energy flow that leaves a *component* (3.2)

Note 1 to entry: Products and materials include raw materials, intermediate products, co-products and releases.

4 Symbols and abbreviated terms

The following symbols are used throughout the document:

EER	energy efficiency ratio used in the heating/cooling industry	non-dimensionless
E	energy consumption	J
P	power consumption	W
Q	thermal energy	J
T	temperature	K or °C
V	volume	m^3
q_V	volume flow rate	m^3/s
q_m	mass flow rate	kg/s
c_p	specific heat capacity at constant pressure	J/kg K
c_V	specific heat capacity at constant volume	J/kg K
H	enthalpy	J/kg
η	efficiency ratio	dimensionless
ρ	density of water	kg/m^3
τ	torque	N·m

5 Method to evaluate the energy efficiency of individual maritime components

5.1 General

This document focuses on the components responsible for the major energy consumption of a typical ship.

The component types are categorized into the following groups:

— pumps (Clause 6);

— fans (Clause 7);

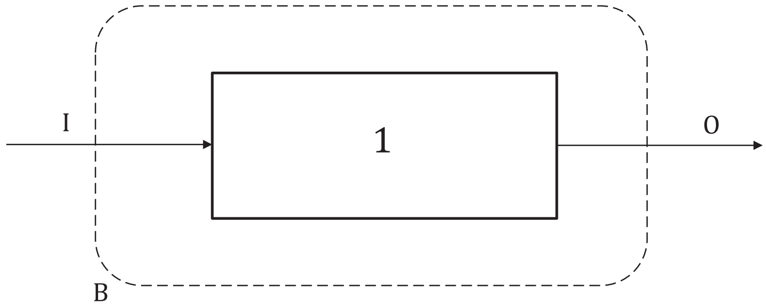
— gearboxes (mechanical power transmission) (Clause 8);

— heat exchanging (Clause 9);

— centrifuges (Clause 10).

The energy efficiency of the component is evaluated based on its expected operational purpose on board the ship and during its expected process operating window. This means that the boundary conditions on which the component is evaluated are defined to represent the normal operational pattern. This operational pattern can include the variations in ambient conditions or variations in the ship's operational pattern. This will be defined for each of the components.

The basic terminology of a maritime component is illustrated in Figure 5.1.



Key

B boundary

1 component

I input (energy, temperature, pressure, flow, concentration, force, velocity, torque, electricity)

O output (energy, temperature, pressure, flow, concentration, force, velocity, torque, electricity)

Figure 5.1 — Basic terminology of a maritime component

In relation to this document in the pursuit of simplifying the energy efficiency consideration of components, it is acknowledged that some influencing parameters are ignored, however such parameters will only have a minor impact on the result and are, hence, considered negligible unless otherwise addressed.

5.2 Measuring conditions

The actual conditions, such as ambient air temperature and shaft speed, etc. shall be recorded on the measuring report when the parameters for the energy efficiency are measured.

The parameters shall be measured by appropriately calibrated measuring instruments.

6 Pumps

6.1 General

Pumps have a wide variety of functions on a ship. For each purpose, several pump types can be used.

This document covers the energy efficiency for the following pump types.

— Positive displacement pumps:

  — reciprocating pump (piston pumps, plunger pumps etc.);

  — rotary pump (gear pump, screw pump, vane pump, lobe pump etc.).

— Dynamic pressure pumps:

  — centrifugal pump.

6.2 Definition of input and output

The definitions of the inputs and outputs are made generic for all the pump types. Each pump type has its own set of properties that affect the efficiency, but these are not accounted for in this document.

Clause 6 does not consider the efficiency of power production, such as electrical power, pneumatic power or hydraulic power.

The input and output of a pump component consists of the following:

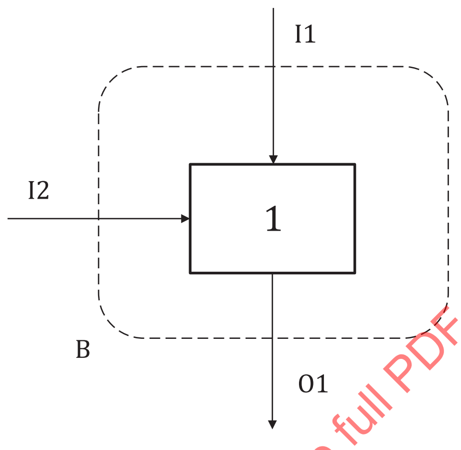
— input: liquid inlet (inlet pressure and flow), pump shaft power;

— output: liquid outlet (outlet pressure and flow).

6.3 Definitions of boundaries and media

The boundary of a pump is set to exclude the motor and any gear. These components form a complete working pump unit, and all of these elements are necessary for a functional pump unit. Any auxiliary devices, such as mechanical seal barrier systems, are also excluded from the energy efficiency consideration.

The pump component and its boundaries are shown in Figure 6.1.



Key

B boundary

I1 liquid inlet (pump suction)

I2 pump shaft power

1 pump

O1 liquid outlet (pump discharge)

Figure 6.1 — Boundaries of a pump component

6.4 Calculation method

The general formula for pump efficiency, valid for all pump types, is shown in Formula (6.1):

$$\eta_{pump} = \frac{q_V \cdot \Delta p}{P_{pump}} \quad (6.1)$$

where

q_V is the liquid flow of the pump, expressed in m^3/s;

Δp is the differential pressure – liquid outlet pressure minus liquid inlet pressure – of the pump, expressed in Pa;

P_{pump} is the pump shaft power, expressed in W.

A pump can state a liquid head (or column) height expressed in metres.

The relation between liquid head and pressure is shown in Formula (6.2):

$$p = \rho \cdot g \cdot h \quad (6.2)$$

where

p is the pressure, expressed in Pa;

ρ is the density of the liquid, expressed in kg/m^3;

g is the gravity constant 9,81 m/s^2;

h is the liquid head, expressed in m.

Combining Formulae (6.1) and (6.2), the formula for efficiency of a pump can be written as Formula (6.3):

$$\eta_{pump} = \frac{q_V \cdot \rho \cdot g \cdot \Delta h}{P_{pump}} \quad (6.3)$$

where

q_V is the liquid flow of the pump, expressed in m^3/s;

Δh is the differential head – liquid outlet head minus liquid inlet head – of the pump, expressed in m;

ρ is the density of the liquid, expressed in kg/m^3;

g is the gravity constant 9,81 m/s^2;

P_{pump} is the pump shaft power, expressed in W.

6.5 Measuring method

To measure the pump efficiency, it is most useful to use Formula (6.1), rather than Formula (6.3), as it is easier to measure the pressure instead of head. Formula (6.1) is suitable for any pump type.

As it is difficult to measure the pump shaft power directly, the motor power should be measured and adjusted for the motor efficiency η_{motor}. This relation is shown in Formula (6.4)

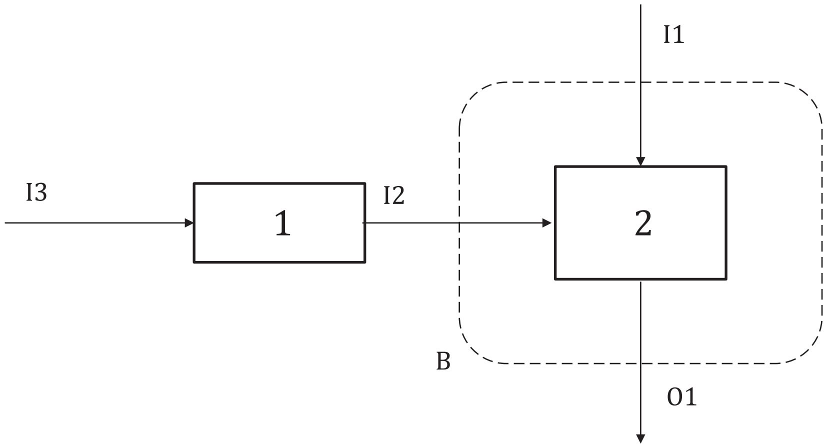
$$P_{pump} = P_{motor} \cdot \eta_{motor} \quad (6.4)$$

If shaft power is used as input, the efficiency can be found in IEC 60034-2-1[13].

Combining Formulae (6.1) and (6.4) gives an expression for pump efficiency that is easy to measure, as shown in Formula (6.5):

$$\eta_{pump} = \frac{q_V \cdot \Delta p}{P_{motor} \cdot \eta_{motor}} \quad (6.5)$$

The measuring method is illustrated in Figure 6.2.



Key

B boundary
I1 liquid inlet (pump suction)
I2 pump shaft power
I3 motor power in
1 motor
2 pump
O1 liquid outlet (pump discharge)

Figure 6.2 — Measuring method for pump energy efficiency

The process for determining the pump efficiency is:

a) measure the liquid flow in m^3/s;

b) measure the differential pressure, at the pump flanges, in Pa;

c) measure the motor input power in W;

d) determine η_{motor} relating to the type of motor and the operational profile;

e) use Formula (6.5) to calculate the pump efficiency.

7 Fans

7.1 General

Fans have different functions on a ship and for each purpose, a number of fan types can be used.

This document covers the energy efficiency for the following fan types:

— positive displacement fans.

— dynamic pressure fans:

  — centrifugal fans.

7.2 Definition of input and output

The definitions of the inputs and outputs are made generic for all fan types. Each fan type has its own set of properties that affect the efficiency, but these are not accounted for in this document.

Clause 7 in this document also does not take into account the efficiency of power production, such as electrical power, pneumatic power or hydraulic power.

The input and output of a pump component consists of the following:

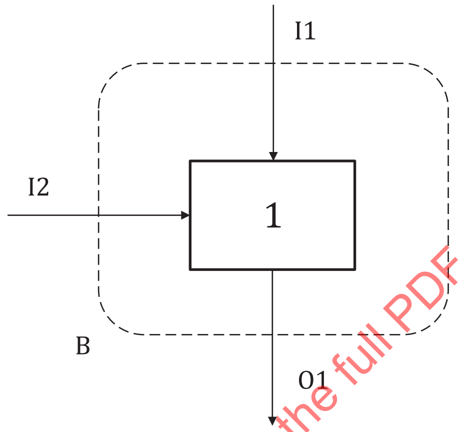
— input: gas inlet (inlet pressure and flow), fan shaft power;

— output: gas outlet (outlet pressure and flow).

7.3 Definitions of boundaries and media

The boundary of a fan is set to exclude the motor and eventual gear. These components form a complete working fan unit, and all of these elements are necessary for a functional fan unit.

The fan component and its boundaries are shown in Figure 7.1



Key

B boundary
I1 gas inlet (fan suction)
I2 fan shaft power
1 fan
O1 gas outlet (fan discharge)

Figure 7.1 — Boundaries of a fan component

7.4 Calculation method

The general formula for fan efficiency, valid for all fan types, is shown in Formula (7.1):

$$\eta_{fan} = \frac{q_V \cdot \Delta p}{P_{fan}} \tag{7.1}$$

where

q_v is the gas flow of the fan, expressed in m^3/s;

Δp is the differential pressure – discharge pressure minus suction pressure – of the fan, expressed in Pa;

P_{fan} is the fan shaft power – fan, expressed in W.

A centrifugal fan can state a head (or column) height expressed in metres.

The relation between head and pressure is shown in Formula (7.2):

$$p = \rho \cdot g \cdot h \tag{7.2}$$

where

p is the pressure, expressed in Pa;

ρ is the density of the gas, expressed in kg/m^3;

g is the gravity constant 9,81 m/s^2;

h is the head, expressed in m.

Combining Formulae (7.1) and (7.2), the formula for efficiency of a centrifugal fan can be written as shown in Formula (7.3):

$$\eta_{\text{fan}} = \frac{q_V \cdot \rho \cdot g \cdot \Delta h}{P_{\text{fan}}} \tag{7.3}$$

where

q_v is the flow of the fan, expressed in m^3/s;

Δh is the differential head – gas outlet head minus gas inlet head – of the fan, expressed in m;

ρ is the density of the gas, expressed in kg/m^3;

g is the gravity constant 9,81 m/s^2;

P_{fan} is the fan shaft power in, expressed in W.

Formula 7.3 is useful to relate the calculation of fan efficiency to the centrifugal fan curve, which in most cases is expressed with head and not pressure.

7.5 Measuring method

To measure the fan efficiency, it is most useful to use Formula (7.1), rather than Formula (7.3), as it is easier to measure the pressure instead of head. Formula (7.1) is suitable for any of fan type.

As it is difficult to measure the fan shaft power directly, the motor power should be measured and adjusted for the motor efficiency, η_{motor}. This relation is shown in Formula (7.4):

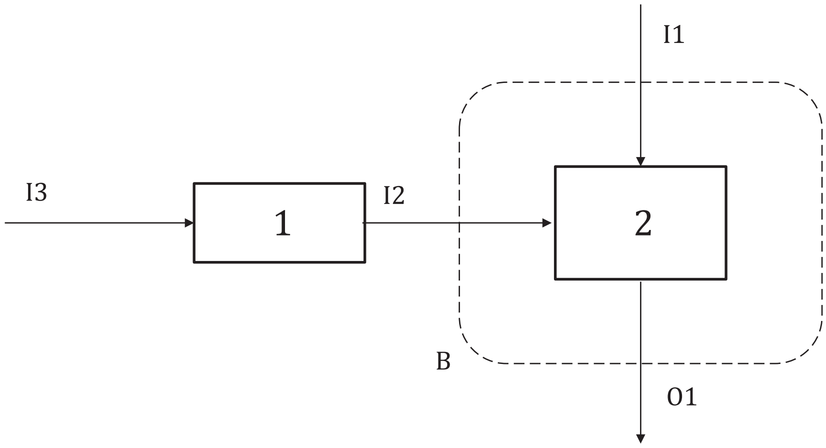
$$P_{\text{fan}} = P_{\text{motor}} \cdot \eta_{\text{motor}} \tag{7.4}$$

If shaft power is used as input, the efficiency can be found in IEC 60034-2-1[13].

Combining Formula (7.1) and (7.4) gives an expression for fan efficiency that is easy to measure, as shown in Formula (7.5):

$$\eta_{\text{fan}} = \frac{q_V \cdot \Delta p}{P_{\text{motor}} \cdot \eta_{\text{motor}}} \tag{7.5}$$

The measuring method is illustrated in Figure 7.2.



Key

B boundary
I1 gas inlet (fan suction)
I2 fan shaft power
I3 motor power
1 motor
2 fan
O1 gas outlet (fan discharge)

Figure 7.2 — Method for fan energy efficiency measurements

The measurement process of the fan efficiency is:

a) measure the gas flow in m^3/s;

b) measure the differential pressure, close to the fan, in Pa;

c) measure the motor power in W;

d) determine η_{motor} in relation to the type of motor and the operational profile;

e) use Formula (7.5) to calculate the fan efficiency.

8 Mechanical power transmission

8.1 Gearboxes

8.1.1 General

Marine gearboxes have various functions, such as:

— changing the rotational speed;

— rotating torque and the transmission direction;

— clutch;

— twin-input and one-out;

— distributing power;

— bearing propeller thrust.

Clause 8 applies to closed-line parallel shaft involute cylindrical gear transmission and conical gear transmission, which consists of an output shaft angle. The input power is from the prime mover.

The marine gearbox consists of a gear, shaft, bearing, case, oil pump, filter, cooler, valve, oil seal, wet friction clutch and other parts. The bearings may be rolling bearings or sliding bearings. The wet friction clutch is designed according to the functional requirements.

8.1.4 describes a method for calculating the efficiency of marine gearbox.

8.1.2 Definition of input and output

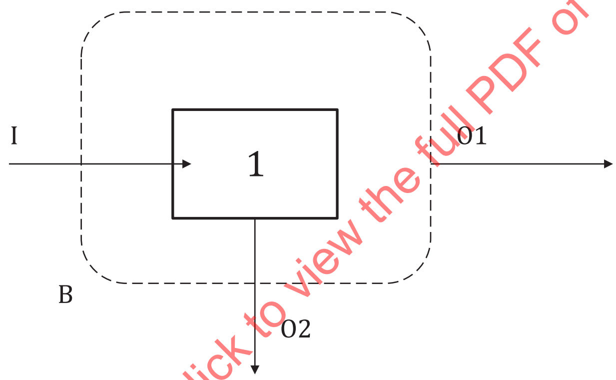
The input and output of a marine gearbox component consists of the following:

— input: power input is diesel engine and or electric motor;

— output: power output to the fixed pitch propeller (FPP), controllable pitch propeller (CPP) or shaft generator etc.

8.1.3 Definitions of boundaries and media

The energy efficiency calculation boundary of the gearbox is determined by the main engine input power (diesel engine or electric motor) and the load output (see Figure 8.1).



Key

B boundary

I input power

1 gearbox

01 output power

02 power loss (gear, bearing, oil pump, oil seal, clutch etc)

Figure 8.1 — Boundary of gearbox energy efficiency calculation

8.1.4 Calculation method

8.1.4.1 General

Power loss and efficiency are important indexes to evaluate economy in gear transmission.

It is estimated that the mechanical efficiency of the primary transmission of the gearbox without clutch should not be less than 0,98, and the mechanical efficiency of the secondary transmission should not be less than 0,975. For the gearbox with forward and reverse friction clutch, the mechanical efficiency of the primary transmission should not be less than 0,975, and the mechanical efficiency of the secondary transmission should not be less than 0,97.

The power loss of marine gearbox mainly includes meshing power loss, gear windage and churning power loss, bearing power loss, bearing windage and churning power loss, oil pump power loss, oil seal (contact type) power loss, clutch power loss. The overall efficiency of the marine gearbox, η, can be calculated according to Formula (8.1).

$$\eta = \left(1 - \frac{\sum P_{\mathrm{Mi}} + \sum P_{\mathrm{GWi}} + \sum P_{\mathrm{Bi}} + \sum P_{\mathrm{WBi}} + \sum P_{\mathrm{Pi}} + \sum P_{\mathrm{Si}} + \sum P_{\mathrm{Ci}}}{P}\right) \quad (8.1)$$

where

η	is the total efficiency of gearbox;
P	is the gearbox input power, expressed in kW;
P_{Mi}	is the meshing power loss, expressed in kW;
P_{GWi}	is the gear windage and churning power loss, expressed in kW;
P_{Bi}	is the bearing power loss, expressed in kW;
P_{WBi}	is the bearing windage and churning power loss, expressed in kW;
P_{Pi}	is the oil pump power loss, expressed in kW;
P_{Si}	is the oil seal (contact type) power loss, expressed in kW;
P_{Ci}	is the clutch power loss, expressed in kW.

8.1.4.2 Power loss of gears and bearings

The meshing power loss P_{Mi} is a function of gear tooth meshing and friction factor. It is related to gear geometric parameters, power, speed, speed ratio, lubricating oil and lubricating oil temperature. The calculation can be seen in ISO/TR 14179-1:2001, 7.4. In the preliminary estimation, the meshing power loss can be taken as $\frac{5P}{1\,000}$.

The gear windage and churning power loss P_{GWi} are related to gear geometric parameters, oil immersion depth, rotating speed, lubricating oil and lubricating oil temperature. The calculation can be seen in ISO/TR 14179-1:2001, 7.9.

The bearing power loss P_{Bi} is related to the bearing friction factor, load, rotating speed and geometric dimensions. The calculation can be seen in ISO/TR 14179-1:2001, 7.3. It can also be calculated according to the calculation method provided by the bearing manufacturer.

The bearing windage and churning power loss P_{WBi} are related to the bearing geometric size, oil immersion state, rotating speed, lubricating oil and lubricating oil temperature, etc. The calculation can be seen in ISO/TR 14179-1:2001, 7.10, and can also be calculated according to the calculation method provided by the bearing manufacturer.

The power loss of hydrodynamically lubricated radial and thrust bearings is calculated according to the statements in the relevant DIN standards (DIN 31652-1,[5] DIN 31657-1,[8] DIN 31653-1,[6] DIN 31654-1).[7] Radial journal bearings as fully and partially surrounding regular cylinder bearings are calculated according to DIN 31652-1,[5] and as sectioned surface and tilting pad bearings according to DIN 31657-1.[8] Calculation of journal thrust bearings as segmental thrust bearings is given in DIN 31653-1,[6] and as tilting pad thrust bearings in DIN 31654-1.[7]

The oil pump power loss P_{Pi} shall be checked or calculated in accordance with the sample provided by the oil pump manufacturer.

The oil seal (contact type) power loss P_{Si} is related to shaft speed, shaft diameter, lubricating oil, lubricating oil temperature, depth of oil seal immersed in oil and oil seal design. The calculation can be seen in

ISO/TR 14179-1:2001, 7.8[4], and can also be calculated according to the calculation method provided by the oil seal manufacturer. For non-contact seals, the power loss is negligible.

8.1.4.3 Power loss of wet friction clutch

The marine gearbox has one, two or more wet friction clutches. When the clutch is in the disengaged state, there is a large speed difference between the friction plate and the dual plate, and the oil is viscous. This causes the friction plate to produce a drag torque under the shear of the oil film, and the existence of the drag torque produces power loss. For the gearbox with single clutch, the friction plate and the dual plate are engaged during operation, and the power loss can be ignored. For the gearbox with forward and reverse clutches, the power loss due to the drag torque between the friction plate in the clutches shall be calculated.

The speed of the medium speed marine gearbox is low. When the clutch is disengaged, the lubricating oil between the friction pairs is usually in the state of pure oil film shearing. The drag torque is calculated according to Formula (8.2).

$$\tau_{\mathrm{d}} = N\frac{\pi\mu(t_{\mathrm{e}})(\omega_1-\omega_2)}{2}\left(r_{\mathrm{o}}{}^4-r_{\mathrm{i}}{}^4\right) \quad (8.2)$$

where

τ_{d} is the clutch drag torque, expressed in newton metres (Nm);

N is the number of friction pairs;

$\mu(t_{\mathrm{e}})$ is the kinetic viscosity of lubricating oil at equivalent temperature of oil film between friction pairs, expressed in pascal second (Pa s);

ω_1 is the angular velocity of friction plate rotation, expressed in radians per second (rad/s);

ω_2 is the angular velocity of dual plate rotation, expressed in radians per second (rad/s);

r_{o} is the outer circle radius of oil film of friction plate, expressed in metre (m);

r_{i} is the inner hole radius of friction plate oil film, expressed in metre (m).

When the clutch is disengaged, the clutch power loss is mainly oil film shear loss, which is calculated according to Formula (8.3).

$$P_{\mathrm{ci}} = \frac{\tau_{\mathrm{d}}(\omega_1-\omega_2)}{1\,000} \quad (8.3)$$

where P_{ci} is the power loss when the clutch is disengaged, expressed in kilowatts (kW).

The temperature increase of clutch lubricating oil at the inlet and outlet shall be calculated according to Formula (8.4).

$$\Delta T = \frac{1\,000\,P_{\mathrm{ci}}}{c\rho q_V} \quad (8.4)$$

where:

ΔT the temperature increase of lubricating oil at inlet and outlet, expressed in celsius (°C);

c the specific heat of lubricating oil, expressed in joule per kilogram celsius [J/(kg °C)];

ρ the lubricating oil density, expressed in kilogram per cubic meter (kg/m^3);

q_v the lubricating oil flow through clutch, expressed in cubic meter per second (m^3/s).

There are many factors that affect the clutch power loss. Computational Fluid Dynamic (CFD) software can be used for more accurate simulation calculation and experiments can be done to verify.

8.1.4.4 Simplified estimation method

Power loss and efficiency are important indexes to evaluate economy in gear transmission.

When selecting the type of marine gear box, its efficiency can be determined according to Table 8.1.

Table 8.1 — Marine gearbox efficiency selection table

Marine gearbox structure	Energy Efficiency %
One reduction stage, without clutch	≥98
One reduction stage with single friction clutch	≥98
One reduction stage with forward and reverse friction clutch	≥97,5
Two reduction stage without clutch	≥97,5
Two reduction stage with single friction clutch	≥97,5
Two reduction stage with forward and reverse friction clutch	≥97

8.1.5 Measuring method

8.1.5.1 Measuring conditions

The tested gearbox shall meet the following conditions during test.

a) The rotation direction of the input and output shafts of the tested gearbox shall meet the design requirements.

b) The tested gearbox shall use lubricating oil that meets the design requirements. When the electric pump is used for oil supply, the pump flow rate and pressure shall meet the design requirements.

c) The input power of the gearbox is maximum continuous rating (MCR) and continuous service rating (CSR), which is generally 85 % MCR. The input speed is the corresponding speed under MCR and CSR conditions. When the user has special requirements, the test conditions can be determined through negotiation.

d) During measurement, the ambient temperature and the temperature of cooling water for test shall meet the design requirements. The gearbox shall reach the thermal balance state. Generally, the change of oil inlet temperature and bearing temperature of the gearbox within 30 min shall not exceed 1 °C.

e) All test recording instruments, meters and their test elements of the test bench are qualified and within the validity period, and have been appropriately calibrated.

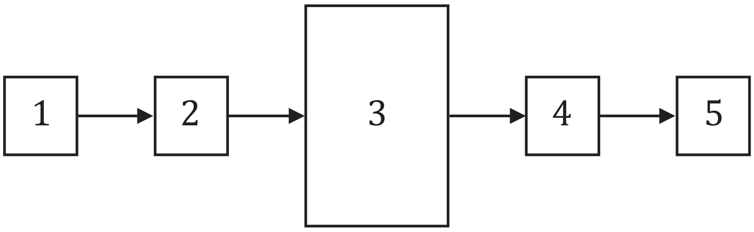
f) The actual ship of the gearbox generally shall bear the propeller thrust, but the test bench generally does not have the thrust loading function, and the measured efficiency does not include the efficiency loss of the thrust device.

g) For high-power gearbox, if the test bench is not capable of load test, the no-load power loss of the gearbox can be tested at the rated input speed and oil temperature in the range of 60 °C to 70 °C.

h) The design requirements specified by the client and/or the classification society.

8.1.5.2 Installation form and calculation formula of single gearbox

Installation consists of installing the gearbox between two torque speed sensors on the test bench (see Figure 8.2).



Key

1 drive device
2 input torque speed sensor
3 gearbox
4 output torque speed sensor
5 loading device

Figure 8.2 — Installation diagram of single gearbox test bench

The efficiency of the gearbox to be tested is calculated according to Formula (8.5).

$$\eta = \frac{\tau_o n_o}{\tau_i n_i} \tag{8.5}$$

where

η	is the efficiency of the gearbox to be tested;
τ_o	is the torque value measured by torque speed sensor at output end, expressed in newton metres (Nm);
τ_i	is the torque value measured by torque speed sensor at input end, expressed in newton metres (Nm);
n_o	is the speed value measured by the torque speed sensor at the output end, expressed in revolutions per minutes (r/min);
n_i	is the speed value measured by the torque speed sensor at the input end, expressed in revolutions per minutes (r/min).

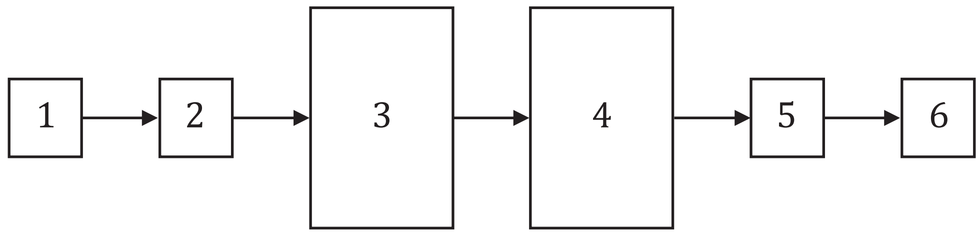
For high-power gearbox, if the test bench is not capable of load test, the no-load power loss of the gearbox can be tested at the rated input speed. For high-power gearboxes, steps 4, 5 and 6 in Figure 8.2 are not needed. The efficiency of the gearbox is calculated according to Formula (8.6).

$$\eta = \left(1 - \frac{\tau_i n_i}{9\,549P}\right) \tag{8.6}$$

where P is the gearbox rated input power, expressed in kilowatts (kW).

8.1.5.3 Installation form and calculation formula of two gearboxes

Installation consists of installing two gearboxes with the same specification, model and manufacturing level face to face or back to back between two torque and speed sensors on the test bench, as shown in Figure 8.3.



Key

1 drive device
2 input torque speed sensor
3 gearbox 1
4 gearbox 2
5 output torque speed sensor
6 loading device

Figure 8.3 — Installation diagram of two gearbox test benches

The efficiency of the gearboxes to be tested is calculated according to Formula 8.7.

$$\eta = \sqrt{\frac{\tau_o}{\tau_i}} \tag{8.7}$$

where

η is the efficiency of the gearboxes to be tested;

τ_o is the torque value measured by torque speed sensor at output end, expressed in newton metres (Nm);

τ_i is the torque value measured by torque speed sensor at input end, expressed in newton metres (Nm).

When a non-rigid coupling is installed between the tested gearbox 1 and the tested gearbox 2, the power loss of the coupling should be considered.

For high-power gearboxes, if the test bench is not capable of load test, the no-load power loss of the gearboxes can be tested at the rated input speed. Conduct the test in accordance with 8.1.5.2, and then calculate in accordance with Formula (8.6).

9 Heat exchanging

9.1 General

Heat exchanging covers a broad variety of heat exchanging device types, including boilers, fired heaters, heaters, electrical heaters, condensers, and plate heat exchangers. Despite them being very different by nature, the methodology for establishing the thermal energy efficiency is the same.

Heat exchanging are indispensable processes onboard ships used in relation to cargo pumping, cargo heating and cooling, engine cooling, fuel conditioning, condensing, tank cleaning, and hot water for accommodation.

Respectively, boilers and fired thermal-oil heaters generate steam and hot oil and are characterized by exchanging energy from a gaseous medium, flue gas or exhaust gas, to a liquid medium, water, or oil (normally addressed thermal-oil). Another characteristic is high enthalpy output, either owing to high pressure in the case of a steam boiler, or high temperature in the case of a thermal-oil heater.

Heaters, coolers and condensers which are not plate heat exchangers typically have a shell/tube construction and can therefore be used in high pressure applications. Specifically, 9.4.2 establishes that the energy efficiency of an electrical heater is always 100 %.

Plate heat exchangers are limited in their maximum operation gauge pressure; gasketed plate heat exchangers have an upper limit of approximately 2,5 MPa and brazed heat exchangers have an upper limit of approximately 5,0 MPa.

The flow directions of the two heat exchanging mediums impacts the efficiency of the device. Counterflow heat exchanging has a higher efficiency than crossflow and parallel flow. The materials used and the physical construction (e.g. fins, number of passes) also have an impact on a device's efficiency.

NOTE 1 The EN 12952 series[9] describes various aspects of water-tube boiler systems as pressurized devices and covers safety aspects to maintain. EN 12952-15[10] describes the energy efficiency verification of a complete system in its entire complexity.

NOTE 2 This document does not consider the heat exchanging cases where mixing of two streams occurs, all streams are considered to be isolated.

9.2 Definition of input and output

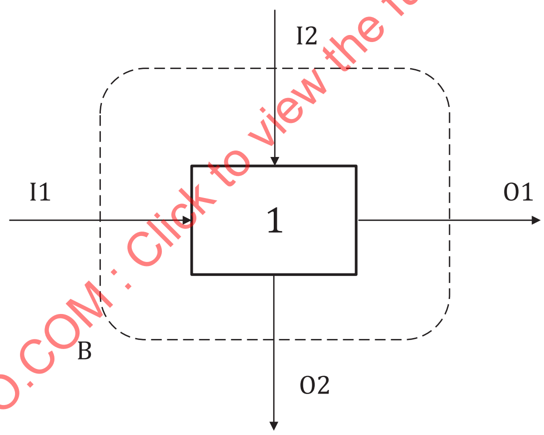
The input and output of a heat exchanging component consists of the following:

— input: heat or cooling source;

— output: heated or cooled media.

9.3 Definitions of boundaries and media

For the calculation of energy efficiency in 9.4, only the heat exchanging component is considered (see Figure 9.1).



Key

B boundary
I1 cold media in
I2 hot media in
1 heat exchanging component
O1 cold media out
O2 hot media out

Figure 9.1 — Boundaries for calculation of energy efficiency of heat exchanging components

9.4 Calculation method

9.4.1 General

Energy efficiency for heat exchanging devices should be calculated as shown in Formula (9.1):

$$\eta_{th} = \frac{Q_o}{Q_i} = \frac{q_{mc} \cdot \Delta h_c}{q_{mh} \cdot \Delta h_h} = \frac{q_{mc} \cdot c_{p,c} \cdot (T_{co} - T_{ci})}{q_{mh} \cdot c_{p,h} \cdot (T_{hi} - T_{ho})} \quad (9.1)$$

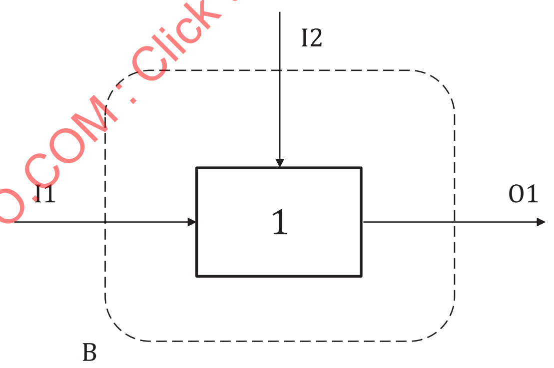
where

- q_{mc} is the mass flow of the hot media, expressed in kg/s;
- q_{mh} is the mass flow of the cold media, expressed in kg/s;
- T_{hi} is the input temperature of hot media, expressed in K;
- T_{ho} is the output temperature of hot media, expressed in K;
- T_{ci} is the input temperature of cold media, expressed in K;
- T_{co} is the output temperature of cold media, expressed in K;
- c_p is the specific heat capacity of the media, expressed in J/kg K.

The efficiency is with reference to an efficiency of 1 and not to a mathematical maximum less than 1.

9.4.2 Electrical heaters

An electric heater with the heating rods submerged into the media, will always have an efficiency of 1, because all incoming electric current is converted into heat when it passes through the resistance in the heating coil, and since no heat transfer is assumed to be ambient. See Figure 9.2.



Key

B boundary
I1 cold media in
I2 electrical input in
1 electrical heater
O1 cold media out

Figure 9.2 — Boundaries for calculation of energy efficiency of an electrical heater

Since it is assumed that the heat loss can be disregarded, the calculation of the maximum possible exchange of heat for an electrical heater can be expressed in Formula (9.2):

$$Q_{max} = Q_i = U \cdot I = Q_o \qquad (9.2)$$