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STERN EQUIPMENT FOR SMALL FISHING BOATS

Compiled by

Shinzo Yamamoto

Training Department

Southeast Asian Fisheries Development Center

PREFACE

This textbook on Stern Equipment for Small Fishing Boats is compiled from the lecture notes for the Fisheries and Marine Engineering Training Course during the 1980-81 academic year at the SEAFDEC Training Department. It is intended as a general introduction to aspects of stern equipment (propeller) pertaining to small wooden fishing boats.

This text deals with three main topics: stern equipment, especially propeller shaft; small wooden fishing boats which are popular for Japanese coastal fisheries; and basic explanation of propeller equipment.

The discussion on stern equipment has been based on Japanese standards of safety and regulations for fishing boats.

Finally, the choice of the propeller in relation to the tugging force and desired speed of the boat, has been discussed only briefly in this textbook. For further study of this subject, I should recommend another book in the SEAFDEC text series, "Simplified estimation method of the speed of fishing boat" (TRB/No. 23) by the same compiler, or other advanced reference books.

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Shinzo Yamamoto
SHINZO YAMAMOTO

SEAFDEC
Training Department

CONTENTS

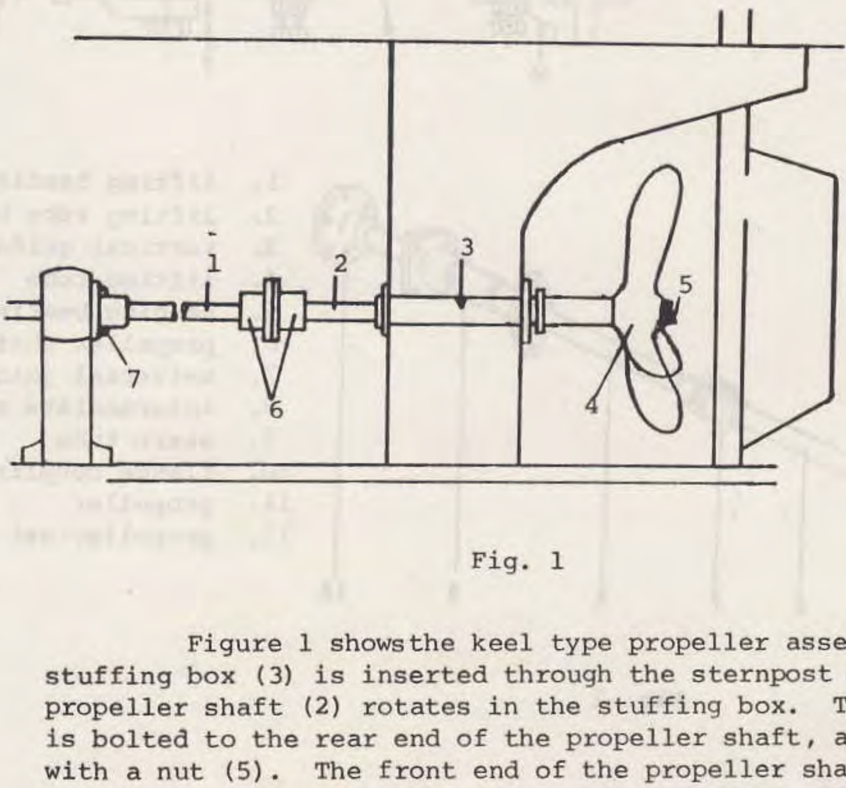
Stern Equipment for Small Fishing Boats

1. GENERAL

The main engine for marine use is mainly a power source for advancing and backing ships. A propeller assembly consists of a propeller shaft and a screw propeller. One end of the propeller shaft is connected to the output shaft of the engine and the propulsion power is transmitted from the engine to the propeller through the engine output shaft and the propeller shaft.

There are three kinds of stern equipment: the keel type, the lifting type and the bracket type.

Keel type



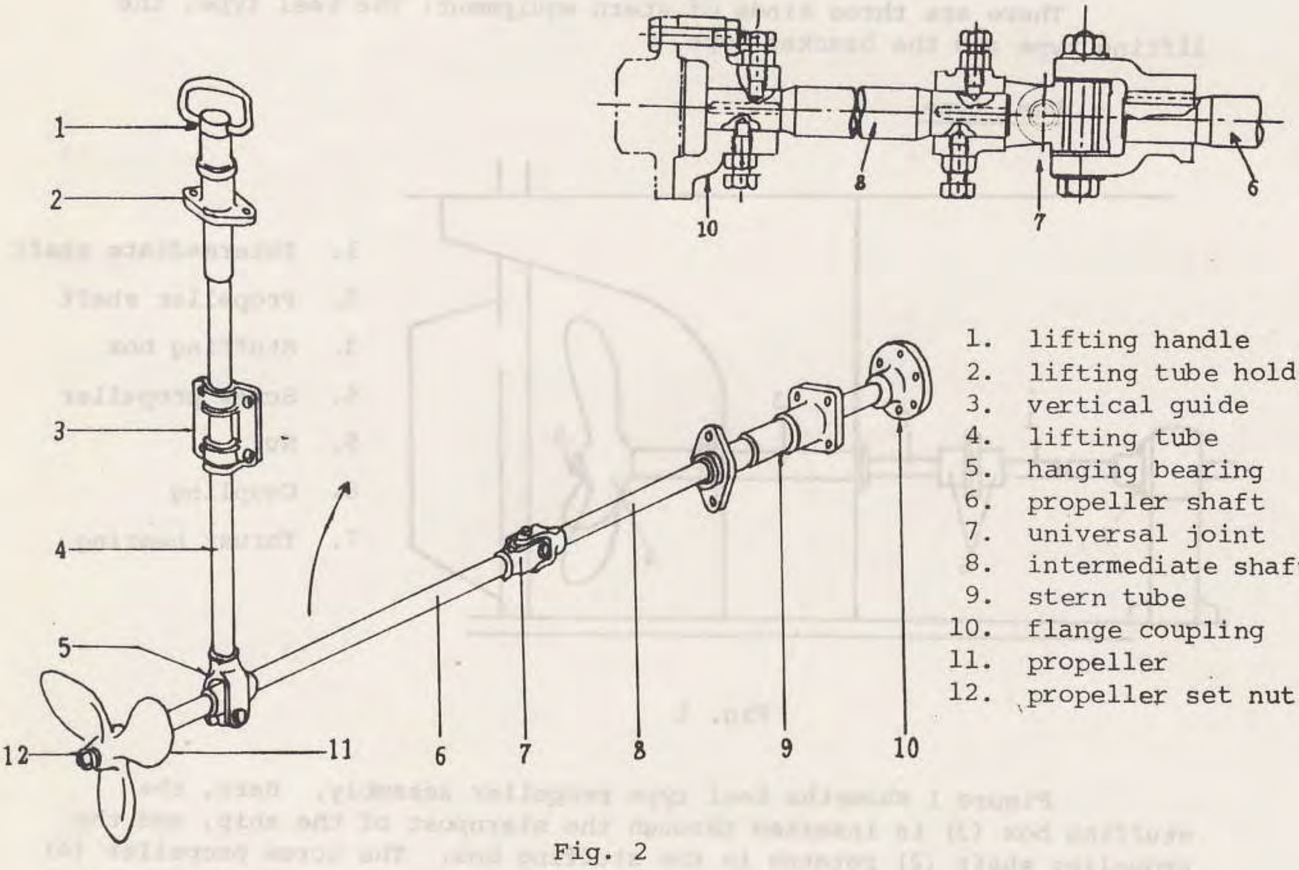
1. Intermediate shaft
2. Propeller shaft
3. Stuffing box
4. Screw propeller
5. Nut
6. Coupling
7. Thrust bearing

Fig. 1

Figure 1 showsthe keel type propeller assembly. Here, the stuffing box (3) is inserted through the sternpost of the ship, and the propeller shaft (2) rotates in the stuffing box. The screw propeller (4) is bolted to the rear end of the propeller shaft, and securely tightened with a nut (5). The front end of the propeller shaft (2) is connected to the intermediate shaft (1) by means of the coupling (6). The front end of the intermediate shaft is connected with the engine output shaft by means of the coupling (7). In some specific applications, the propeller shaft may be connected directly with an engine output shaft without the intermediate shaft. The thrust bearing block is sometimes replaced by a reduction gear box bearing in small fishing boats.

Lifting type: Small fishing boats under 30 HP sometimes use lifting type propeller assembly shown in Fig. 2.

Propeller lifting device



1. lifting handle
2. lifting tube holder
3. vertical guide
4. lifting tube
5. hanging bearing
6. propeller shaft
7. universal joint
8. intermediate shaft
9. stern tube
10. flange coupling
11. propeller
12. propeller set nut

Fig. 2

Bracket type: The bracket type propeller assembly (Fig. 3) is similar to the keel type propeller assembly and is used for small fiberglass reinforced plastic (FRP) boats.

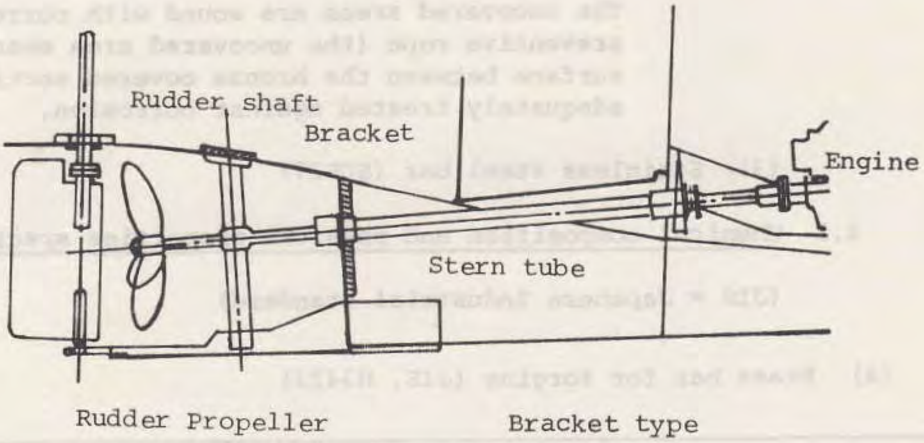


Fig. 3

2. MATERIAL OF PROPELLER SHAFT

The main materials used for the propeller shaft are brass or stainless steel.

(1) Brass bar

Brass bar for forging .... (BsBf)
Naval brass bar .... (NBsB1)
High strength brass bar .... (NBsB1, NBsB2, NBsB3)

(2) Brass wrapping

There are three kinds of brass wrapping:

(a) The brass wrapping of propeller shaft is carbon steel for machine structure (S35C, S45C), covered with bronze casting by shrinkage fitting.

(b) The main material of propeller shaft is carbon steel for machine structure (S45C, S45C), covered with bronze casting (BC3) in more than 2 divisions by shrinkage fitting. Each division is fitted by welding.

(c) The main material of propeller shaft is carbon steel for machine structure (S35C, S45C) which is partially covered with bronze casting (BC3) in more than 2 divisions by shrinkage fitting. The uncovered areas are wound with corrosion preventive rope (the uncovered area means the surface between the bronze covered sections) or adequately treated against corrosion.

(3) Stainless steel bar (SUS27)

2.1 Chemical composition and physical properties specified by JIS

(JIS = Japanese Industrial Standard)

(a) Brass bar for forging (JIS, H3423)

Symbol	Chemical composition %				Physical properties (Tension test)	
	Cu	Pb	Impurity Fe + Sn	Zn	Tensile strength Kg/mm^2	Elongation %
BsBF	53.0 - 62.0	Under 2.0	Under 1.5	Remainder	Above 32	Above 15

(b) Naval brass bar (JIS, H3424)

Symbol	Chemical composition %				Physical properties (Tension test)	
	Cu	Sn	Impurity Fe +	Zn	Tensile Strength Kg/mm^2	Elongation %
NBsB1	61.0-64.0	0.7-1.5	Under 0.8	Remain-der	Above 35	Above 20
NBsB2	59.0-62.0	0.5-1.0	" 0.8		" 35	" 20

(c) High strength brass bar (JIS, H3425)

Symbol	Chemical composition %								Physical properties (Tension test)	
	Cu	Al	Fe	Mn	Sn	Si	Impurity Pb	Zn	Tensile kg/mm^2	Elongation %
HBsB1	56.0-61.0	Under 1.0	Under 1.0	Under 1.0	Under 1.0	-	Under 0.8	Remainder	Above 45	Above 20
HBsB2	56.0-60.0	Under 2.0	Under 1.0	Under 2.5	Under 1.5	-	Under 0.8	"	Above 50	Above 15
HBsB3	55.0-59.0	Under 2.0	Under 1.5	Under 3.0	Under 1.0	Under 0.8	Under	"	Above 55	Above 12

(d) High strength brass casting (JIS, H5102)

Symbol	Chemical composition %								Physical properties (Tension test)	
	Cu	Zn	Mn	Fe	Al	Sn	Ni	Impurity Pb+Si	Tensile kg/mm^2	Elongation %
HBsC1	52.0-60.0	Remainder	Under 4.0	Under 2.0	Under 1.2	Under 1.0	Under 1.0	Under 0.5	Above 44	Above 20
HBsC2	52.0-59.0	"	Under 4.0	Under 2.0	Under 1.2	Under 1.0	Under 1.0	Under 0.5	Above 48	Above 18

(e) Bronze casting (JIS, H5111)

Symbol	Chemical composition %					Tensile kg/mm2	Elongation %
	Cu	Sn	Zn	Pb	Impurity		
BC3	86.5-89.5	9.0-11.0	1.0-3.0	-	Under 1.5	Above 25	Above 15

(f) Stainless steel bar (JIS, G4303)

Symbol	Chemical composition %						
	C	Si	Mn	P	S	Ni	Cr
SUS 27B	Under 0.08	Under 1.00	Under 2.00	Under 0.040	Under 0.030	8.00-11.00	18.00-20.00

The mechanical properties of the shaft bar (hardened by heat treatment), such as tensile strength, yielding point, elongation, contraction and impact strength, are standardized as tabulated below.

Symbol	Mechanical properties					Impact test	Hardness test	
	Tensile strength kg/mm^2	Yielding point kg/mm^2	Elong. #4	Elong. #5	Contraction %	Check value (Charpy) kg/mm^2	Hardening or tempering H	Hardening or tempering HB
SUS 27B	Above 52	-	Above 50	Above 60	Above 60	-	Under 185	Under 90

2.2 Materials specified in Marine Engine Regulations

Article 5 of the Marine Engine Regulations in Japan classifies the propeller shafts into two categories:

Category 1: Includes all propeller shafts which have monoblock sleeve; those which have equivalent anti-corrosion value and those which have an adequate device to lubricate the stern assembly (propeller assembly).

Category 2: Includes all propeller shafts other than those specified in Category 1.

The application of these two kinds of propeller shaft for fishing boats is regulated by Art. 196 of the Marine Engine Regulations, but it is to be understood that the invariable number for calculating the diameter of propeller shafts is "144" for Category 1 and "100" for Category 2. The diameter of Category 1 shaft is smaller than that of Category 2. (See Appendix 1). Explained below are some details concerning propeller shafts, extracted from the Marine Engine Regulations.

(1) Propeller shaft with monoblock sleeve

The steel propeller shaft in Fig. 4 belongs to Category 1. It is protected from corrosion by being covered with corrosion-resistant alloys such as brass. The fitting is done by shrinkage.

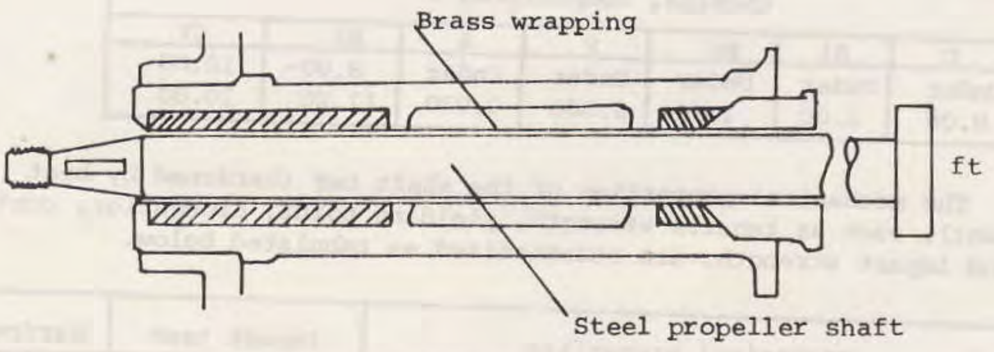


Fig. 4

(2) <u>Propeller shaft whose corrosion resistibility is higher than that of monoblock sleeve shaft</u>

Figure 5 shows the propeller shaft whose corrosion resistibility is much higher than that of the monoblock sleeve shaft, but the difference is that it is used for comparatively smaller boats. This type of propeller shaft also belongs to Category 1.

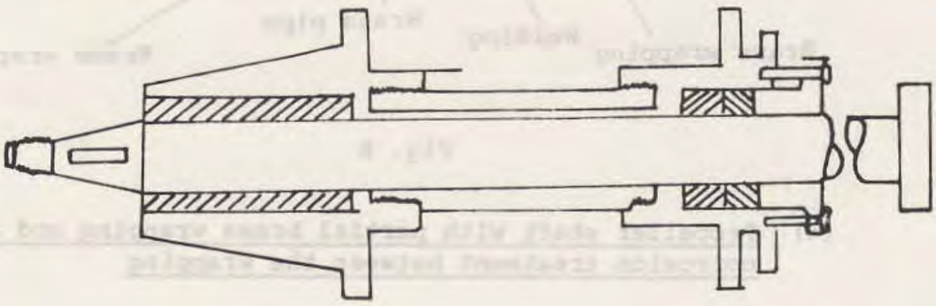


Fig. 5

For this type of propeller shaft Art. 34 of the Marine Engine Regulations designates that "The nonferrous material for the propeller shafting (except the screw propeller) is subject to the approval of the Regional Marine Authorities for the test standard on materials used". The high strength brass bar JIS HB425 satisfies this material standard designated in Art 34. Besides, the diameter of the shaft must be 1.05 times larger than the diameter of forged steel propeller shafts. We will explain later the full particulars of how to calculate the diameter of this kind of propeller shaft.

(3) <u>Propeller shaft partially wrapped with brass by shrinkage fitting (in more than 2 divisions) and fixed by welding or the propeller with lubrication system for stuffing box</u>

Figure 6 shows the propeller shaft covered with brass wrapping. The brass wrapping is made at two sections of the shaft; the same material (brass pipe) is welded in the mid-surface between these two brass wrappings and grease or red lead is packed in the space between the shaft surface and the welded brass pipe. Such a shaft is approved for Category 1. If the mid-brass pipe is connected by soldering instead of welding, the shaft belongs to Category 2.

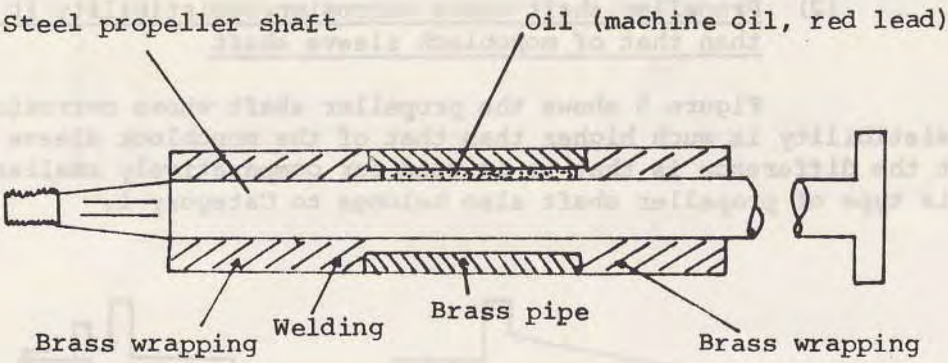


Fig. 6

(4) Propeller shaft with partial brass wrapping and anti-corrosion treatment between the wrapping

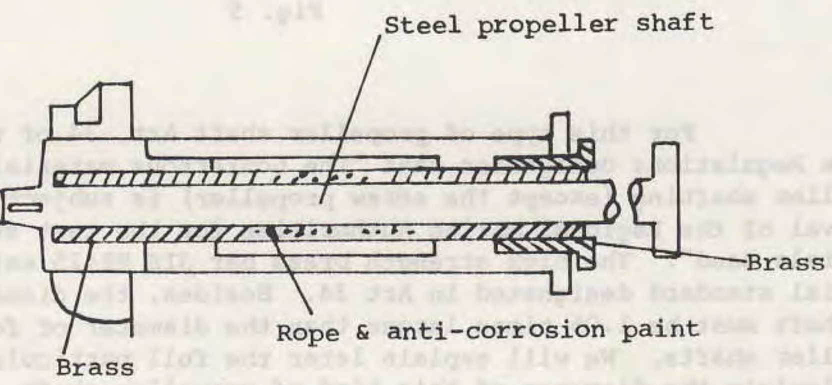


Fig. 7

Figure 7 shows the propeller shaft of Category 2. The brass wrappings are made in more than two divisions, and the space between these brass wrappings is wound up with rope or vinyl tape or rubber tape, and coated with anti-corrosion paint as shown in Fig. 8.

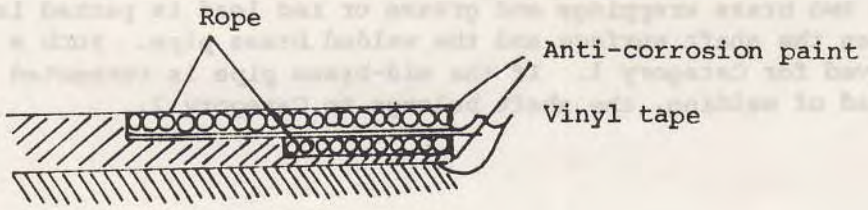


Fig. 8

(5) Propeller shaft made of stainless steel bar

The propeller shaft made of stainless steel bar (JIS G4303) belongs to Category 2.

3. WEAK POINTS OF PROPELLER SHAFT

3.1 Corrosion of propeller shaft boss

The propeller assembly is always submerged in sea water and is subject to corrosion unless well maintained, particularly around the fixing portion between the propeller boss and the shaft. The main trouble of propeller is always caused by fatigue due to corrosion and special attention should be given to the following points.

(1) The propeller must be properly fixed to the tapered shaft end.

(2) The nuts must be tightened to fit the blades to the boss and to the tapered end of the shaft securely.

(3) Waterproof rubber packing should be used as shown in Fig. 9 to prevent sea water from penetrating into the boss or into the tapered end of the shaft. Use as tight rubber packing as possible. If loosely packed, grooving corrosion will be generated by penetrating sea water.

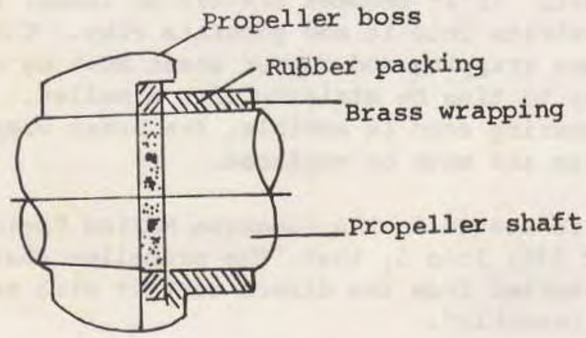


Fig. 9

(4) In the propeller shaft of Category 2, the non-wrapped portion between the brass wrappings is covered with sheet copper (see Fig. 10). This sheet copper is liable to come off and allow water into the shaft. This should be kept in mind when soldering is being done.

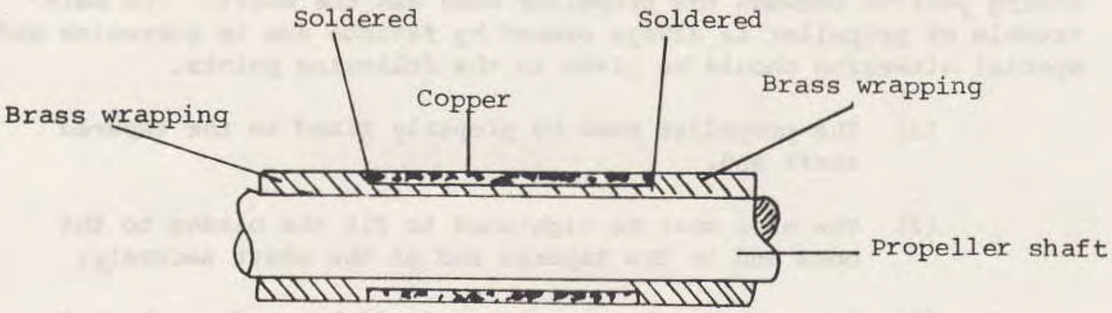


Fig. 10

(5) The brass wrapping is made tight by shrinkage fit. It can be assumed, however, that this shrinkage fit will become loose or cracked by engine vibration or vibration caused by wear of bearings or by twisting motion of the shaft. If it becomes cracked or loose, sea water will penetrate into it and generate rust. Therefore, the brass wrapping and copper sheet must be checked from time to time by striking with a mallet. If a dull hammering echo is audible, the brass wrapping might be loose and must be replaced.

(6) It is stated in the Japanese Marine Engine Regulations, Art 230, Item 5, that "The propeller shaft must be protected from the direct contact with sea water as much as possible".

3.2 Keyway of propeller shaft

The keyway is specified in the Marine Engine Regulations, Art 230, Items 6 and 7:

Item 6: The bottom corners of the propeller shaft keyway should be made round with an adequate R degree.

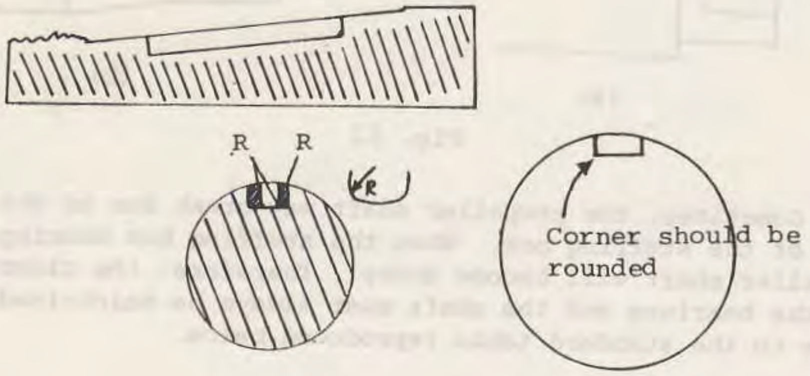


Fig. 11

Item 7: The cotter of propeller shaft must be inserted into its way securely.

Besides, items 6 and 7 specify that the "R" at the bottom corners of the cotter way is to avoid cracking and the key must be inserted into its way securely, allowing no shaking.

3.3 Misalignment of propeller shaft center

The propeller shaft must be aligned correctly on its center line. If misaligned, the bending stress will be created and the repeated stress will break the shaft. The shaft alignment is necessary especially when the engine has been installed before launching of the boat. In such a case, the boat center is deranged by water pressure after launching and in consequence the axial center of the propeller shaft will be deranged. Another cause of misalignment is a new engine bed which will become a little lower in practical use causing the propeller shaft center to shift. For this reason when a new engine is installed it is imperative to realign the propeller shaft center after the engine has been used for some time.

Fig. 12 shows two kinds of joints of propeller shafts. The experience has shown that the joint (a) is more likely to break than the joint of (b) form. Therefore, (b) form joints are now commonly used.

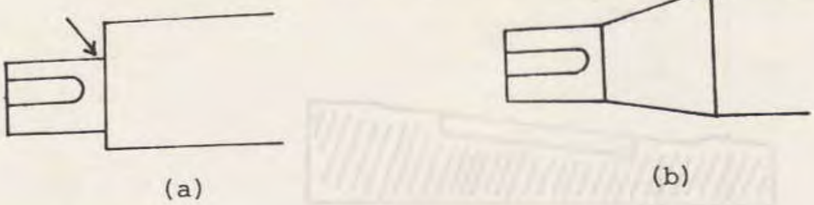


Fig. 12

Sometimes, the propeller shaft may break due to the worn out bearings of the stuffing box. When the stuffing box bearing is worn, the propeller shaft will become shaky. Therefore, the clearance between the bearings and the shaft must always be maintained normal in reference to the standard table reproduced below.

Clearance between bearing and shaft

Diameter of propeller	Standard clearance (mm)		Critical limit (mm)	
	Lignumvitae	White metal	Lignumvitae	White metal
(mm)				
Under 25	0.4	0.3	1.1	1.1
" 50	0.4	0.3	1.2	1.1
" 75	0.4	0.3	1.4	1.2
" 100	0.5	0.4	1.6	1.4
" 125	0.6	0.5	1.8	1.6
" 150	0.7	0.6	2.2	1.8

Note: For fishing boats the clearance limit may be 1.25 times of the standard values tabulated above.

4. PROPULSION POWER AND PROPELLER

4.1 Propulsion power

Ship:
- Man power .... oar, paddle, pole
- Wind force .... sail
- Mechanical power
  - Steam engine
  - Steam turbine
  - Internal-combustion engine
  - Nuclear power engine
  - Electrical system

  →
  - Outboard wheels
  - Jet propulsion
  - Voith-Schneider propeller
  - Screw propeller

(1) Man power

The man power is still used for advancing or backing small pleasure boats or small transportation boats. These small boats are usually moved with oars, poles or paddles.

(2) Wind power

The wind power is used for yachts, coastal fishing ships and some deep-sea fishing ships, but at present almost all the fishing ships are moved with engine power. However, in the times when the mechanical propulsion was not as advanced as in the modern days, all navigation had depended on wind force.

(3) Mechanical power (engine power)

The mechanical power is the main means of propulsion now used for ships and boats. The mechanical power means engine power which involves steam engines, steam turbines, internal-combustion engines (Diesel engine, hot valve engines, electrical ignition engines, nuclear engines and electrical system). These engines are mounted in ships or boats and propel them by means of various kinds of propellers involving outboard wheels, jet propulsion system and Voith-Schneider propeller.

4.2 Propellers

4.2.1 Classification of propellers by type

(a) Outboard wheels

The outboard paddle wheels were much used in the 19th century as a means of propelling ships. The wheels, which were mounted on both sides of the ship, were moved by a certain motor power and paddled the water to advance or back the ship. At present, however, these outboard wheels are found rarely in specific ships on lakes or in shallow river navigation.

(b) Jet propeller

A jet propeller is used for high-speed propulsion by means of a powerful pump which jets water or gas backward to advance the ship by the jet reaction force. It cannot display its full capacity unless used in superhigh speed. It is mainly used for aircraft, but not much used for ships yet.

(c) Voith-Schneider propeller

The Voith-Schneider propeller creates a propulsive force with several blades that oscillate in conformity with the rotation of a disc that is driven by a vertical shaft. This propeller is mainly used for tug boats in harbours. It is not used in deep sea navigation as its mechanism is not suitable for ocean-going ships.

(d) Screw propeller

Almost all propellers now used are the screw propellers. The screw propeller was developed in the late 19th century and has been modified to the present types in repeated improvements. The name "screw propeller" originates from the blade form of the screw and at present it is popularized and is usually called simply "propeller".

4.2.2 Screw propellers classified by form

There are three kinds of propellers if classified by form, namely, fixed pitch propeller, variable pitch propeller and nozzle propeller. We shall proceed by explaining the full details of these three kinds of propellers.

(a) Fixed pitch propeller

Almost all screw propellers now used are the fixed pitch propellers; their pitch and angle cannot be changed during operation. The stationary pitch propellers can be further sub-classified into two kinds: one is the uniform pitch propeller in which the rake angle of all blades is made with even radius, and the other is the vari-pitch propeller in which the pitching angle of blades is different. The classification may be summerized as follows:

Uniform pitch propeller:	Mainly used in comparatively smaller ships or in 2-shaft ships (2-propeller ships).
Vari-pitch propeller: (Increase pitch or decrease pitch)	Usually used in comparatively larger ships.

As mentioned above, the vari-pitch propeller can have an increase pitch or a decrease pitch. An increase pitch means that the blades spread wider at the blade top and are narrower at the root. A decrease pitch means the blade pitch is made just inversely from the increase pitch, i.e., gradually narrower at the top and comparatively wider at the root of the blades.

Which one is better suited to a ship depends on the kind of rudder which is always placed at the rear of the propeller. The increase pitch blade has effective propulsion power for streamline rudders and the decrease pitch blades is said to be effective for reaction type rudders or contra-rudders. For this reason, the uniform pitch propeller is usually used for small boats or 2-propeller ships and the vari-pitch propeller is used for larger ships.

(b) Controlable pitch propeller (C.P.P.)

The controlable pitch propeller means that the propeller pitch angle (rake) can be changed as necessary during operation. The specific feature of the vari-pitch propeller is that the ship's course can be changed as the circumstances require.

The ship can be advanced or backed freely with the engine and shaft revoluation at constant speed. The advantage of this is that the engine output power is fully utilized for tugging at high speed by propeller operation. For this reason, the controlable pitch propellers are suitable for tug boats and trawl boats that require large load variation, and also for boats with a gas turbine which cannot operate at reverse revolution. We cannot, however, deny some disadvantages of the controlable pitch propeller: the complicated structure of propeller shafts and boss, and its high cost.

(c) Nozzle propeller

The nozzle propeller operates in a cylinder called "Colt Nozzle".

4.2.3 Screw propellers classified by merchanical structure

By mechanical structure, the screw propellers may be classified into two kinds: the monoblock type and the assembly type.

(a) Monoblock propeller

The screw propellers used in Mitsubishi "DAIYA" diesel engines are of monoblock casting. "Monoblock" means that the screw and the propeller are in one piece.

(b) Assembly propeller

In the assembly type propellers, the screw blades and the boss are cast separately and the blades are bolted to the boss. The advantages of the assembly type are:-

i) The blade is replaceable when damaged by corrosion, and several blades may be prepared for replacement.

ii) The blade angle (rake) is adjustable within the slit of the bolting hole.

iii) The bolting hole may be made oval and pitch may be changed as intended within this oval hole.

iv) The blade can be cast easily without large casting equipment.

v) The boss can be made separately with harder material (cast iron) mixed with such materials as manganese or brass.

However, the assembly type propellers also have some disadvantages. It is inevitable to make the boss comparatively larger for the purpose of bolting the blades. A large boss means an increase in propeller weight, which in turn will cause the propulsion efficiency to decrease to a certain extent.

4.2.4 Screw propellers classified by revolving direction

Figure 13 shows the propeller front facing from the stern side. There are two revolving directions: clockwise and counter clockwise, as shown in Fig. 13.

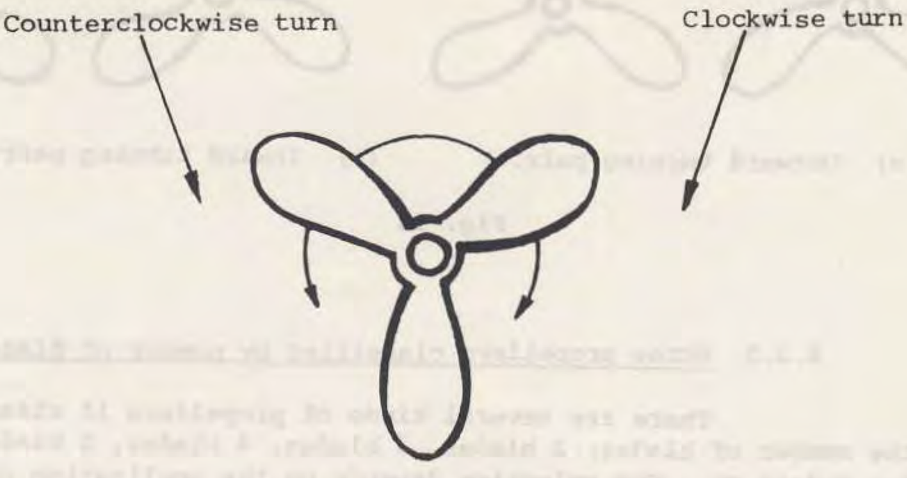


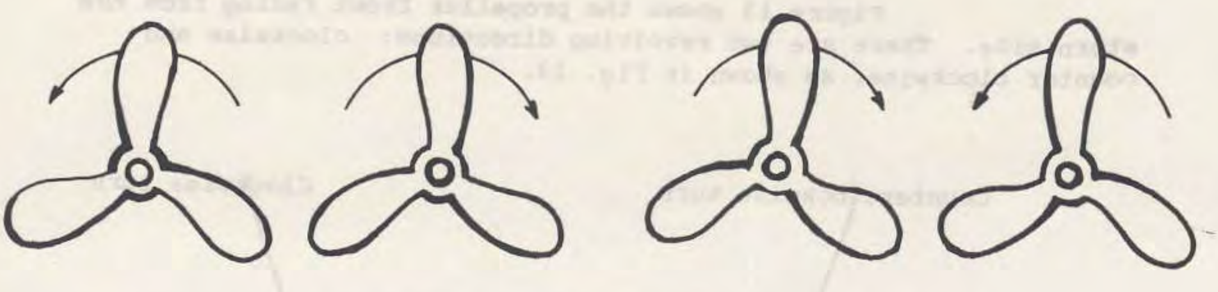
Fig. 13

(a) One-propeller shaft ship

In the ships with one shaft propeller, the clockwise turn propeller turns the ship stern in the starboard direction and the ship bow in the port side direction. On the contrary, the counterclockwise turn propeller turns the ship stern side in the port direction and the bow side in the starboard direction. This specific nature is appreciable in large class ships, but in small ships it is not so remarkable and may be negligible.

(b) Two-propeller shaft ship (Twin drive)

In two-propeller shaft ships, it is usual that the starboard side propeller revolves clockwise and the port side propell revolves counterclockwise. This is also called "outward turning". On the contrary, if the starboard side propeller is made to turn counterclockwise and the port side propeller turns clockwise, this is called "inward turning" (Fig. 14a, b).



(a) Outward turning pair. (b) Inward turning pair.

Fig. 14

4.2.5 Screw propellers classified by number of blades

There are several kinds of propellers if classified by the number of blades; 2 blades, 3 blades, 4 blades, 5 blades, 6 blades and so on. The selection depends on the application of propeller for ships as described below.

(a) Blade number in classification of application

Small motor boats .... 2 blades
Fishing ships and war ships ...... 3 blades
Cargo ships, passenger ships,
tankers and mercantile ships... 4 blades
Large freighters and tankers ..... 5 blades

Specific application for
eliminating vibration .... 6 blades.

(b) Propeller efficiency & vibration

Efficiency: Usually the propeller efficiency will decline, little by little, in proportion to the increase in the number of blades. But if the number of blades is increased, the optimum propeller diameter will decrease. Therefore, fewer blades mean better propulsion efficiency. This means that a 4-blade propeller is more effective than a 5-blade propeller and a 3-blade propeller is more effective than a 4-blade propeller.

Vibration: It is said that abnormally large vibration will occur by resonance created when the value of propeller speed (rpm) and blade number comes near the value of ship vibration.

The characteristics of propeller efficiency and vibration for 3-blade and 4-blade propellers which are now commonly used in ships are compared below:

Optimum diameter ....The diameter of a 3-blade propeller is larger than that of a 4-blade propeller.

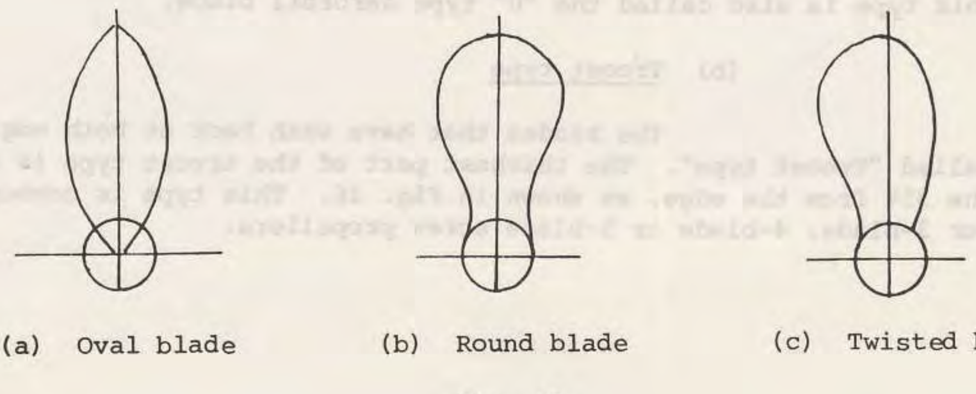
Propulsion efficiency.........A 3-blade propeller is a little better than a 4-blade propeller.

Vibration.....................A 3-blade propeller has a little larger vibration than a 4-blade propeller.

Price ....A 3-blade propeller is a little less expensive than a 4-blade propeller.

4.2.6 Screw propellers classified by blade form

There are three kinds of screw propeller if classified by form, as shown in Fig. 15.



(a) Oval blade (b) Round blade (c) Twisted blade

Fig. 15

Any one of these three propellers is applicable for any ship without much difference in performance. Generally, single propeller ships use either (b) or (c), and the oval form (a) is usually used for twin-propeller ships. The ships for deep-sea fishing are always subjected to waves dashing against the blades, which causes cavitation phenomenon on the propeller surface. Hence, the propellers will be damaged by unexpectedly quick corrosion. The round blade screw propeller (b) seems to be the most suitable for deep-sea fishing boats because the propeller with wide blade ends is effective in avoiding cavitation.

4.2.7 Screw propellers classified by sectional view

Aerofoil type .... TTRI type (leading edge wash back)
Troost type (leading edge and trailing edge wash back)

Ogival type .... (dome or segment type)

TTRI = Transport Technical Research Institute in Japan

Note: In the cross section the aerofoil type blade resembles the wing of birds or aircraft.

(a) TTRI type

Among the aerofoil type propellers, the one whose wash back is only at the leading adge is called the TTRI type. The thickest point of this blade is at the 35% from the leading edge. This type is also called the "U" type aerofoil blade.

(b) Troost type

The blades that have wash back at both edges are called "Troost type". The thickest part of the troost type is also at the 35% from the edge, as shown in Fig. 16. This type is commonly used for 3-blade, 4-blade or 5-blade screw propellers.

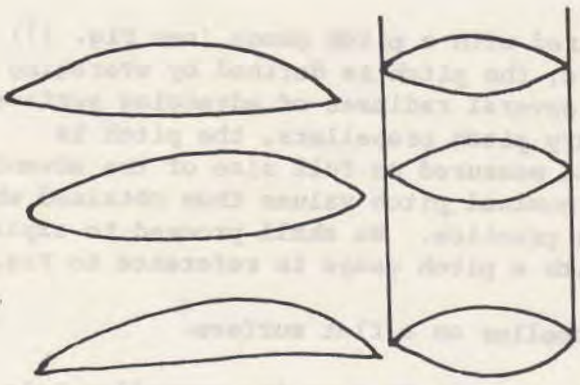


Fig. 16

(c) Ogival type

The acting surface of the ogival type propeller is plain and the thickest part is in the middle area of the total blade width. The back surface forms a dome of about one-quarter of the radius.

4.3 Diameter of propeller

The diameter of propeller means the diameter that a blade describes in revolution; it is just 2 times the radius of the blade. (Propeller blade radius x 2 = diameter)

4.4 Pitch

The pitch is the advancing distance of the acting surface of the blade by one turn of the propeller. The advancing surface of the propeller (item 3 in Fig. 18) forms a screw. In other words, the propeller pitch is the distance of the axial advance by one turn of the propeller blades, in the same way as a machine screw advances while rotating along a threaded hole. As explained before, the screw propellers are classified into two kinds by form and hence there are two kinds of pitch, the stationary pitch and the vari-pitch.

The stationary pitch propellers are comparatively simple in structure and are generally used for fishing ships, small freighters and tug boats. The vari-pitch propellers are more applicable for assembly type propellers and are appreciably more effective in propulsion power compared with the stationary ones, and are often used in large passenger ships and tankers.

The pitch is measured with a pitch gauge (see Fig. 17). In the vari-pitch propellers, the pitch is defined by averaging several values measured at several radiuses of advancing surfaces of blades. In the stationary pitch propellers, the pitch is defined by the average value measured on full size of the advance surface of the blade. The nominal pitch values thus obtained should be within permissible error in practice. We shall proceed to explain how to measure the pitch with a pitch gauge in reference to Fig. 17.

(a) Place the propeller on a flat surface.

(b) Fix the pitch gauge shaft into the propeller hole with the advance surface upward.

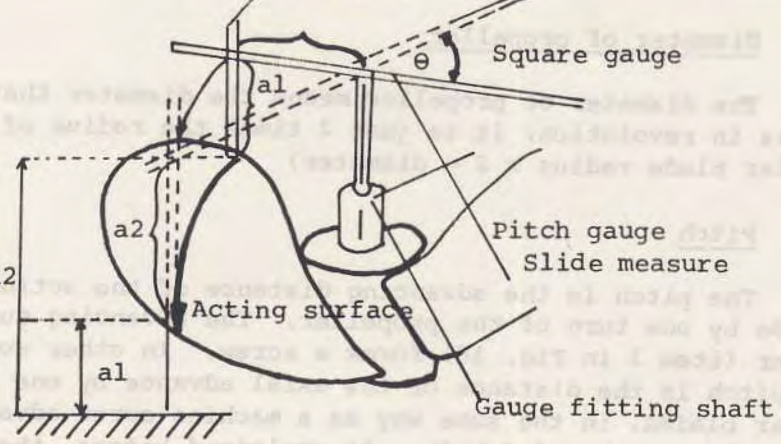
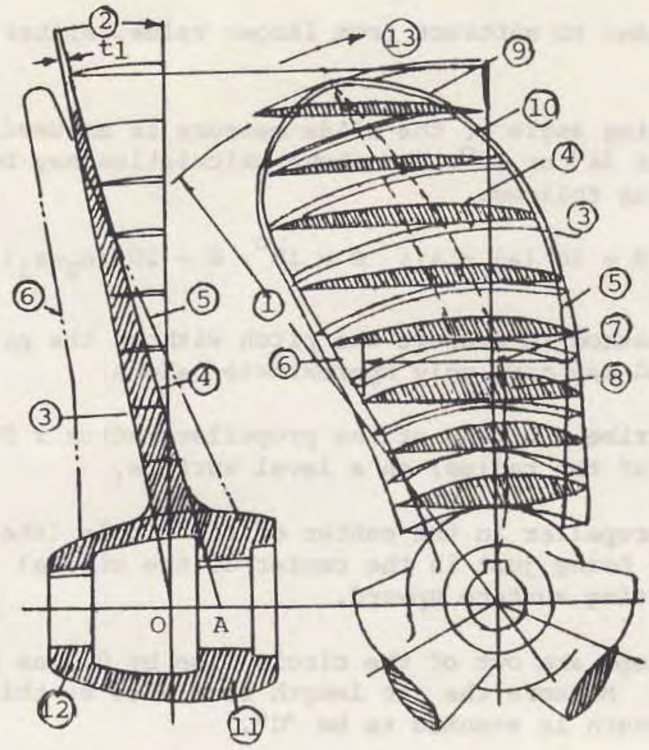


Fig. 17

NOMENCLATURE OF PROPELLER



(1) Diameter
(2) Rake
(3) Advancing surface
(4) Backing surface
(5) Leading edge
(6) Trailing edge
(7) Blade width
(8) Blade thickness
(9) Developed area line
(10) Projected area line
(11) Boss
(12) Cone part
(13) Revolving direction

Fig. 18

(c) Next, attach the pitch gauge to the pitch gauge shaft, and adjust the slide measure so that the end of the pitch measure bar slightly touches the "a" point of the advance surface of the propeller blade.

(d) Read the length "a" by means of the pitch measure bar.

(e) Turn the slide measure by θ angle, then the pitch measure bar end moves along the dotted line of the advance surface of the blade as shown in Fig. 17. At this point read the length of the pitch measure bar "a_2".

(f) Then reading the length of "a_1", the pitch "H" at the propeller radius "r" can be obtained by the following formula:

$$H = \frac{(a_2 - a_1) \times 360}{\theta}$$

in which the $(a_2 - a_1)$ means to subtract from larger value, either a_1 or a_2.

(g) If the turning angle of the slide measure is assumed to be either 36^o or 18^o, the above calculation may be simplified as follows:

$\theta = 36^o$, $H = 10\ (a_2 - a_1)$ $\theta = 18^o$, $H = 20\ (a_2 - a_1)$

There is another simple method to measure the pitch without the pitch gauge bar, but this method may give only approximate values:

(a) First, describe a circle of the propeller radius x 0.7 (0.7 times of the radius) on a level surface,

(b) Place the propeller in the center of the circle (the boss center being just in the center of the circle) with the acting surface upward.

(c) The blade tops are out of the circle line by 0.7 as shown in Fig. 19. Measure the arc length from A to B; this measured length is assumed to be "C".

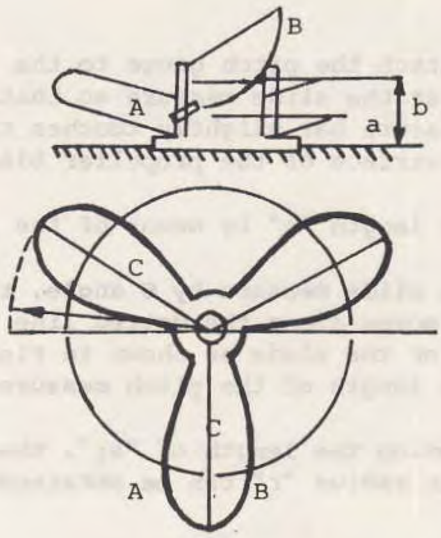


Fig. 19

(d) Apply a steel measure fitting it to the advance surface from A to B and read the value at the steel measure in intersecting with the carpenter's square. These values are assumed to be "a" and "b".

(e) With the values "a" and "b", the pitch H can be obtained by using the following formula:

$$H = \frac{2\pi \times 0.7R\ (b - a)}{C} \quad \text{or} \quad H = \frac{4.4R\ (b - 2)}{C}$$

(f) The pitch of each blade of the propeller is calculated in this way and then the approximate propeller pitch can be obtained by averaging the values of each blade.

4.5 Pitch ratio

The pitch ratio indicates the relationship between the pitch and the diameter of the propeller. Since the propeller diameter is restricted by the ship draft, the selection of pitch also depends on the ship draft. If a certain speed is required with a smaller diameter propeller, it is necessary to make the pitch ratio larger. In other words, if faster propeller revolution is required, it is necessary to make the pitch-ratio larger. Anyhow, an adequate pitch ratio depends on the ship's size and speed.

The following table shows the approximate pitch ratio used in classification of ship types. These values are an approximate standard for reference only and may be subject to some variation according to the number of blades.

Kind of ship	Approx. pitch ratio
Ocean tug ship	0.55
River tug ship	0.60
Mercantile ship (low speed)	0.70
" " (medium ")	0.80
" " (high ")	0.90
Pleasure boat (round bottom)	0.90
" "(V shape bottom)	1.00
High speed boat	1.20

Pitch ratio $P = \frac{H}{D}$ in which H ..... pitch and D.... propeller dia.

4.6 Blade angle (rake)

The blade inclination from the center line of the boss is called the "blade angle" or "rake" (see Fig. 20). It is usual that this angle is about $10^\circ - 15^\circ$ from the boss center line toward the stern side (backward). There are some specific propellers whose angle is 0° or which are inclined inversely frontward.

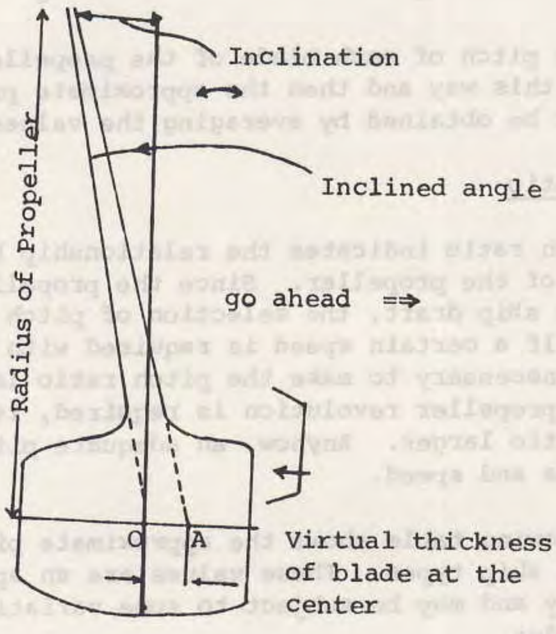


Fig. 20

4.7 Blade face

The stern side (back side) of the propeller blades is called advancing surface or acting surface and the bow side (front side) is called backing surface or "back".

4.8 Blade edge

The blade periphery is called the "blade edge". The front edge is the "leading edge", and the rear edge is called the "trailing edge", Fig. 21 shows the trailing edge wash back where the advance surface is slashed off from the dotted line.

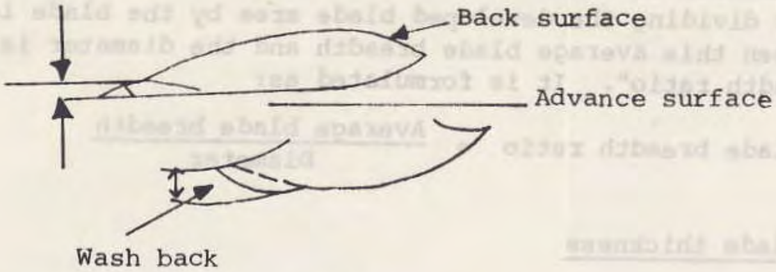


Fig. 21

4.9 Blade breadth

In the development drawings, the maximum position of a propeller blade is the widest area of a blade. The ratio of this maximum width and the blade diameter is called the maximum blade breadth ratio. It is formulated in the following way:

$$\text{Max. blade breadth ratio} = \frac{\text{Max blade breadth}}{\text{Diameter}}$$

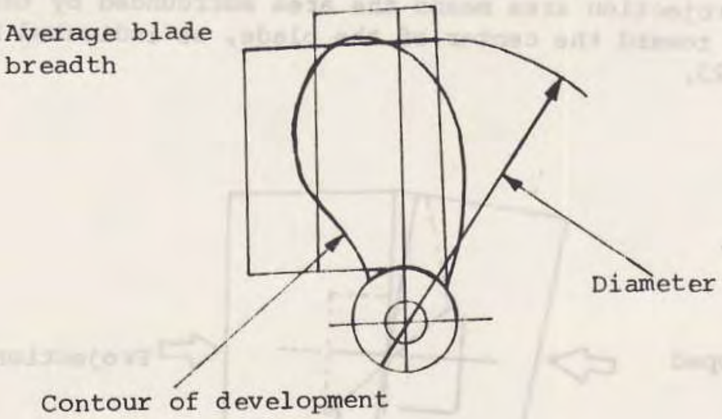


Fig. 22

Since the propeller blades always form an oval or a deformed oval, the breadth of a blade is indicated by virtual width that is obtained by dividing the developed blade area by the blade length. The ratio between this average blade breadth and the diameter is called the "blade breadth ratio". It is formulated as:

$$\text{Blade breadth ratio} = \frac{\text{Average blade breadth}}{\text{Diameter}}$$

4.10 Blade thickness

Item 8 in Fig. 18 is the sectional view of the blade to indicate its thickness. As shown in the figure, the thickest point is always nearer to the leading edge except in ogival type blade where the thickest point is in the middle position (refer to Fig. 16).

$$\text{Blade thickness} = \frac{\text{Vertical thickness of blade at center}}{\text{Propeller diameter}}$$

(Refer to Fig. 20)

4.11 Disc area

The disc area is the circle which a propeller describes in revolution.

4.12 Projection area

The projection area means the area surrounded by the blade contour facing toward the center of the blade, as indicated by the arrow in Fig. 23.

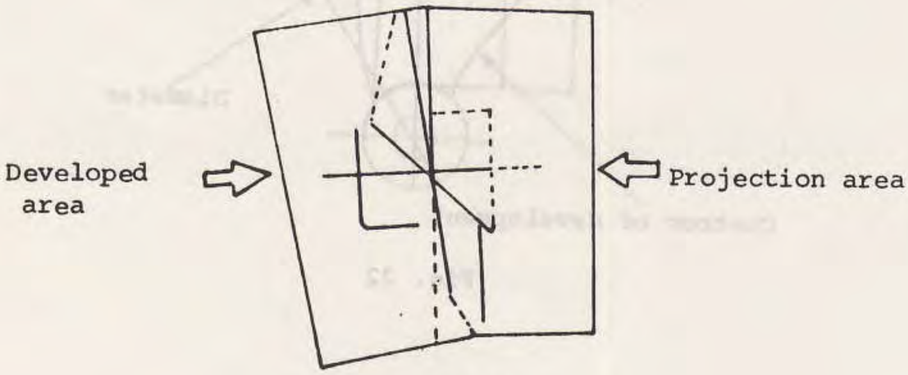


Fig. 23

4.13 Developed area

The developed area means the total area where all curves are developed flat on the drawing paper, as shown in Fig. 23.

4.14 Expanded area

The expanded area means the total plain area in which the curves of the developed area are expanded on a flat surface. In other words, the area is obtained by applying a sheet of paper on a blade; this area is measured and multiplied by the number of blades in order to obtain the total area.

4.15 Surface ratio

Usually the surface ratio (or disc area ratio) means the value obtained in dividing the expanded area by the disc area.

4.16 Boss ratio

The boss ratio means the ratio between the diameter of the propeller boss and the diameter of the propeller. Assuming these diameters to be B and R, the boss ratio can be obtained by the following formula.

$$\text{Boss ratio} = \frac{\text{Diameter of propeller boss}}{\text{Diameter of propeller}}$$

The boss ratio will differ according to the propeller structure, but usually the boss ratio may be determined approximately as below:

Monoblock propeller .... 0.16 - 0.20

Assembly propeller .... 0.23 - 0.25

5. PROPELLER SLIP

Like the bolts being screwed into nuts, the propeller assembly will advance revolving against water. The bolt, however, advances definitely along a solid threaded hole, whereas the propeller which revolves against water resistance is subjected to play by slipping and one turn of propeller does not always advance the ship exactly as the bolt pitch. Such play is called the "propeller slip" and the slip ratio may be represented by the following formula:

$$\text{Slip} = \frac{\text{(Propeller speed) - (Boat speed)}}{\text{Propeller speed}} \times 100\ (\%)$$

From the above formula, assuming that one turn of the propeller blades always advances the ship by H(m), like the bolt unless there is slipping, and if it runs N revolutions, the propeller revolution ought to be indicated by H.N (m/min).

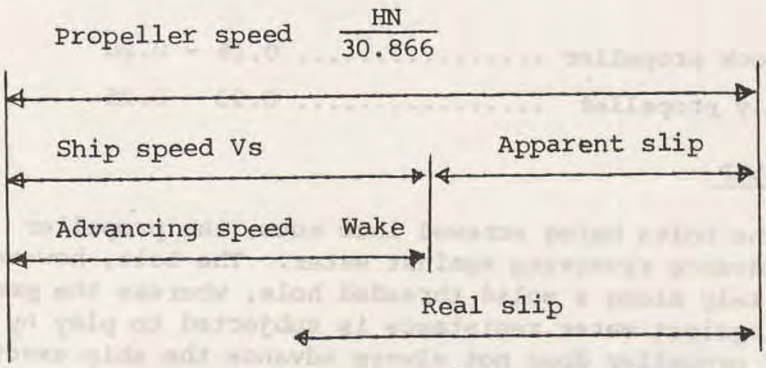
The propeller speed may be expressed in metric knots. Since a knot is a ship speed unit indicating 1852 m per hour (30.866 m per minute or 0.5144 m per second) the knot speed is obtained from the following formula:

$$\frac{60 \times N \times H}{1852} = \text{knot (propeller speed)}$$

Then, assuming the ship speed is Vs knots, the slip can be obtained with the following formula.

$$\text{Slip} = \frac{\frac{60NH}{1852} - Vs}{\frac{60NH}{1852}} \times 100\ (\%) = \frac{60NH - 1852Vs}{60NH} \times 100\ (\%)$$

Since the slip speed Vs is measured on the basis of the milepost on land, the slip calculated in the above formula is called "apparent slip". In contrast to this if water wake is anticipated for propeller speed, the Vs is substituted by Va in the above formula and the slip thus obtained is called "real slip". The following chart shows the standard speed in correlation with propeller speed, ship speed, apparent slip, real slip and wake.



As explained earlier, there are two kinds of propeller with regard to pitch: stationary pitch propeller and vari-pitch propeller. In the vari-pitch propeller, the speed or slip is usually calculated at the 0.7 point of blade radius. For example, assuming that:

Revolution of engine	850 rpm
Reduction ratio of engine	0.4
Propeller pitch	950 mm
Ship speed	9 knots

the slip may be obtained by applying the following formula:

$$\text{slip} = \frac{60 \times 0.95 \times 340 - 1852 \times 9}{60 \times 0.95 \times 340} = 14\ (\%)$$

6. TIP CLEARANCE OF PROPELLER

The propeller tip clearance is essential for propulsion efficiency. The propeller cannot display full efficiency unless there is sufficient clearance between the propeller tip and the hull. Too narrow tip clearance will create uneven water wake that flaps the ship hull and abnormal vibration will occur in the propeller assembly.

Note: The water wake means the average speed of water flow that follows the ship by surface friction caused in high speed navigation.

The wake is always at maximum at the stern side. It should be even at both sides of the hull; if uneven, it will cause vibration of the propeller shaft.

Figure 24 shows the standard tip clearance. This is a theoretical standard; in practice it is subject to variation depending on the ship size and form.

$a = (0.729 + \frac{t}{\quad} \times D$ in which the $(0.008 - 0.15)D$

$b = (0.15 - 0.20)\ D$

$c = (0.08 - 0.12)\ D$

$d = (0.02 - 0.03)\ D$

$e = (\ 64 - 74\ )$ mm

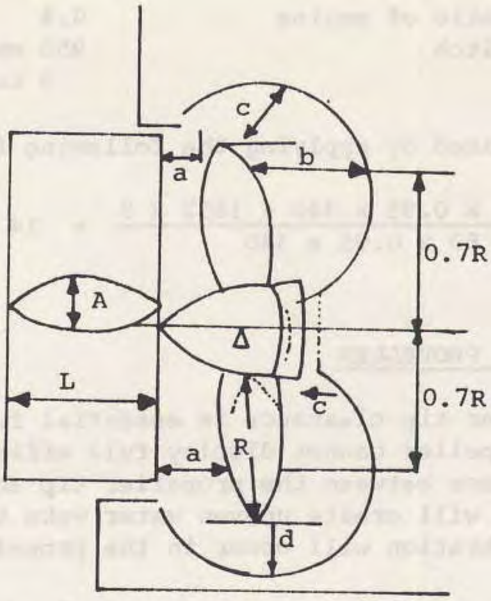


Fig. 24

7. CORROSION AND EROSION OF PROPELLER

7.1 Corrosion

Corrosion may be classified into two large groups; dry corrosion and wet corrosion. Dry corrosion will occur on parts which are not dipped in water or oil, while wet corrosion will be generated on such parts as cylinder liners and propellers, which are always dipped in oil or water. We shall concentrate here on wet corrosion which attacks propellers. Wet corrosion may be sub-classified into two kinds: general corrosion and local corrosion. General corrosion occurs when the overall area of a metal surface is evenly corroded.

There are four types of local corrosion:

Pitting (or grooving)

The metal surface is first corroded so as to form pits; then corrosion attacks the metal core and finally gets through to the opposite side and makes holes.

Intergranular corrosion

Intergranular corrosion is generated along the internal crystal line of an alloy and causes cracks.

Contact corrosion

Contact corrosion appears when one component in the alloy has a higher electric potential than the other components in the same alloy. The larger the electro-potential difference, the more likely it is that contact corrosion will develop.

Concentration cell corrosion

The concentration cell corrosion is generated due to differential ionization degree and density of gas.

7.1.1 Corrosion of propeller by dezincing phenomenon

As explained earlier, the propeller blades are made of a copper alloy whose main components are copper and zinc. Since the propeller is always dipped in water, zinc will dissolve in sea water by electrolyte phenomenon on the blade surface. This is called "Dezincing phenomenon" and can be recognized by the blackish colour of brittle copper. Dezincing will make the blade surface rough and in the long run cause a decrease of propulsion efficiency. If heavily dezinced, the blade may be broken by razing impact of sea water during navigation.

7.1.2 Electrolytic corrosion

Electrolytic corrosion is a little different from dezincing corrosion; it generates long, thin scars on both the advance side and the back of the blades. Electrolytic corrosion is caused by electrification due to stray current.

7.1.3 Preventive measures against corrosion

The electrical wiring should be well insulated in order to protect the propeller from dezincing and electrilitic corrosion. The most effective protection is to use zinc protectors as shown in Fig. 24.

Zinc protectors must be of high purity. The "ZAP" which is sold widely in Japan, is the most suitable for this purpose. The greater the quantity of protectors used, the more effective is the result. Zinc protectors are vital for the propellers used in wooden ships the zinc protectors should be connected with each other by means of a copper pipe and the end of the pipe must be connected to the propeller shaft as shown in Fig. 25. The shaft must always be connected to a carbon brush or a copper bar, and the copper wire should be connected to the stern tube.

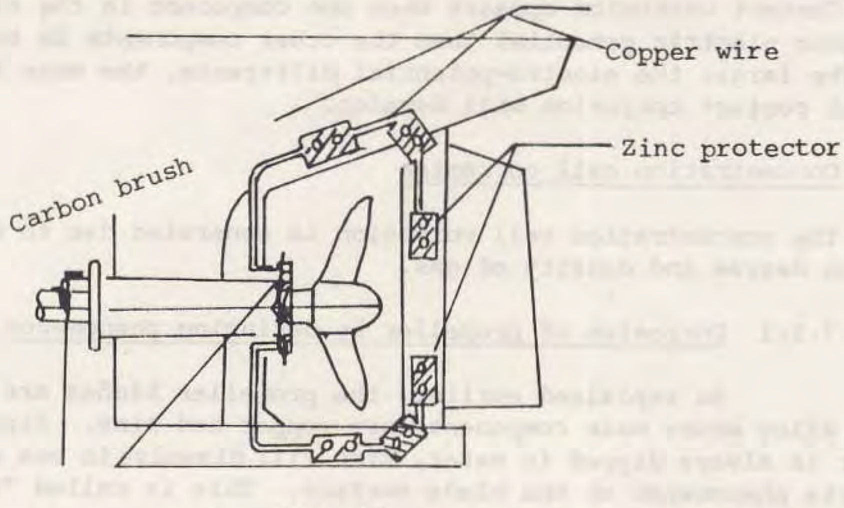


Fig. 25

7.1.4 Ships operating in coastal waters and in rivers

The propeller blade surfaces are vulnerable to acids and alkali. Chemical factories which are located on sea coasts and river banks drain waste solutions (acids or alkali) into the sea or rivers. The propellers used in ships for coastal river navigation are always damaged by these solutions drained from chemical factories. So far no conclusive preventive measure has been found. The experience has shown that if we coat a propeller all over with vinyl paint, the paint is soon damaged by the impact of floating matter such as sand, driftwood and so on, and the propeller blades are badly corroded by chemical waste drained from factories.

7.2 Erosion

Corrosion is chemically caused disintegration of material whereas erosion is physically or mechanically caused disintegration of material. In propellers erosion is mostly due to cavitation and is called "cavitation erosion". If simply explained, cavitation is due to a vacuum phenomenon which occurs on the propeller blade surface by action of dashing water. An impulse wave created in this void will strike against the blade surface and it is assumed to have the impact pressure of several hundred kilograms per cm^2. This repeated impact will erode the blade surface by turning it into a sponge-like state.

Every time the cavitation phenomenon occurs, the propeller plays and consequently fails to keep continuous revolution, fails to display its full capacity and the ship speed declines. The cavitation phenomenon inevitably occurs in the following circumstances:

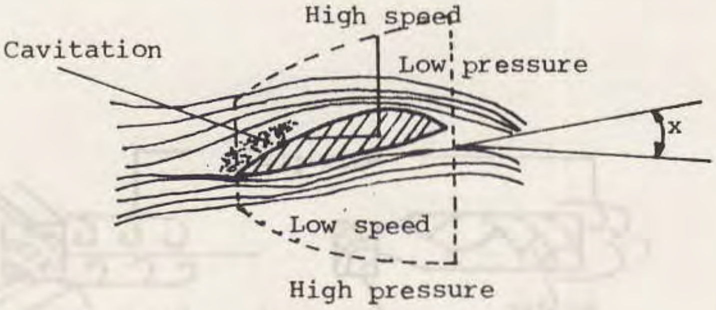


Fig. 26 Acting surface of propulsion

(1) When the incident angle is large. (The incident angle is the angle of water flow against the propeller blade; see Fig. 26.)

(2) When the circumferential speed of blades is large; in other words, when the speed of water current is too high.

(3) When the propeller position is not deep enough from the water surface.

(4) When the propulsion power is too large in relation to the projected area of the blades.

(5) When propeller slip is excessively frequent.

(6) When turbulent flow is frequent due to the stern form of the ship.

To avoid these causes of the cavitation phenomenon it is necessary to make the stern of ship in streamlined form and the propeller position as deep as possible with enough space between the propeller and the keel, so as to avoid creating turbulent flow around the propellers.

Note: For small fishing boats, it is imperative to make the propeller position as deep as the propeller diameter while the ship is standing still.

Sometimes, dezincing coincides with cavitation phenomenon and causes great damage on the propeller blades. Such damage is especially frequent on wooden boats for the following reason: stern and rudder are made of thick wood, which causes whirlpools as shown in Fig. 27.

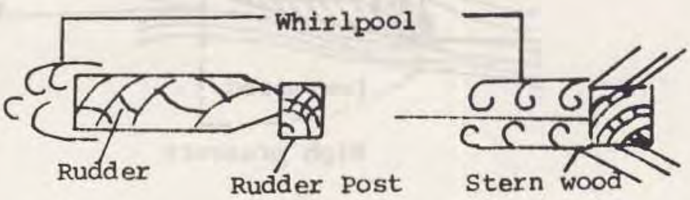


Fig. 27

These whirlpools cause cavitation on the blade surfaces. Also, thick wood makes the space between the propeller edge and the keel narrower, and in consequence, the blades slash the keel edge and the blade edges may be broken off during navigation.

8. BOAT TONNAGE AND DIMENSIONS

The size of ships is defined in terms of tonnage and dimensions. There are two kinds of tonnage: gross tonnage and net tonnage. The gross tonnage indicates the total load capacity including cabines, engine rooms, hatches and so on, while the net tonnage indicates a net loading capacity for commercial cargoes (mainly the loading capacity of hatches).

"Tonnage" is an international term to indicate ship capacity, and the ton used for ships indicates loading capacity, but not for weight. One (1) ton means 100 cubic feet. Namely, one (1) gross ton is a unit for the total loading capacity of a ship that can be obtained as below:

1 ton = 100 cubic feet (one cubic meter = 35.315 cft), and the total capacity counted by the metric system is multiplied by 0.353.

In Japan, tonnage of every boat is subject to a check by the government authorities and the Maritime Transportation Bureau of Japan. Ships larger than 5 gross tons are measured by officials from the Maritime Transportation Bureau, whereas boats under 5 gross tons have their tonnage checked by the local profectural office.

We shall proceed to explain the ship size in accordance with the "KANI SENPAKU SOKURYO KITEI" (Simple Ship Tonnage Measurement Regulations).

8.1 Gross tonnage

For small fishing boats measuring is not done exactly for each part of the inside space as in the large class ships; instead, the tonnage is calculated as follows:

The loading capacity (tonnage):

- Wooden ship...(length) X (width) X (depth) X 0.55 (approximately)
- Steel ship... (length) X (width) X (depth) X 0.62 (approximately)

The loading capacity on the upper deck is measured by totaling the length, width and depth but this is not as simple as the measurement under the upper deck. The gross tonnage is calculated by the following formula:

(1) Tonnage under upper deck

Wooden ship...(length) X (width) X (depth) X 0.19415..
Steel ship....(length) X (width) X (depth) X 0.21886.. (a)

The ship dimensions of length, width and depth are measured according to the metric system in Japan. A geometric mass is calculated down to the third decimal place, and the forth decimal is counted if it is 5 or more. For tonnage calculation the geometric mass is calculated down to the second decimal place, and the 3rd decimal is counted if it is 5 or more.

(2) Tonnage of upper deck compartments

Tonnage = 0.353 X (total capacity) .... (b)

In the above, the total capacity means a total of the relative products of length, width and height measured at each particular place in the ship. But the super-structure, deck houses and other compartments (whose inlet or outlet has no normal closing appliances, i.e. the closing appliances are less than 122 cm in height and 91 cm in width) are excluded from the counting of the total tonnage.

(3) The gross tonnage is thus obtained by adding (a) to (b):

gross tonnage = (a) + (b)

8.2 Net tonnage

The net tonnage is the net capacity for loading cargo; cabines, engine room etc. are excluded. The net tonnage can be measured by the following method.

(1) Ship without propulsion machinery

(net tonnage) = (gross tonnage) - (gross tonnage X 0.2)

(2) Ship with propulsion machinery

(net tonnage) = (gross tonnage) - [(gross tonnage X 0.2) + (tonnage of engine room X 1.75)].

If the value of the engine room X 1.75 is larger than the value of the gross tonnage X 0.44, the net tonnage is calculated by the following formula.

(net tonnage) = (gross tonnage) - [(gross tonnage X 0.2) + (gross tonnage X 0.44)] = (gross tonnage X 0.36).

8.3 Length, width and depth of small wooden boats in Japan (max. length 20m)

The nominal length is a little different for wooden boats and steel boats. The length of a wooden boat may be defined simply by the Structure Rule, but for steel boats the length is very complicated and regulated by the Ship Classification Measurement Regulations, in which it is designated as follows:

"The measurement should be done for straight distance at the deck beam from the front side of stem to the rear side of stern post."

The length of the steel boat is called the "Shipping Register Length" nominated in the "Certificate of Ship's Nationality". The boat length is also nominated in such shipping law as the "Marine Act", the "Detailed Enforcement Regulation" of the "Ship Safety Law" and so on.

(a) Boat length

The following figures from 28 to 36 show the dimensions (length, width and depth) of wooden boats.

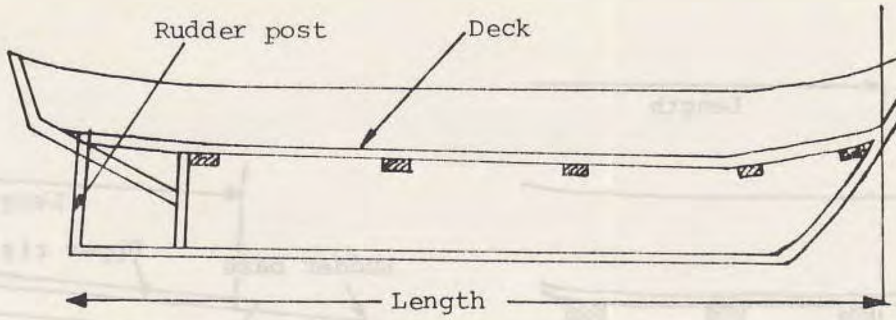


Fig. 28

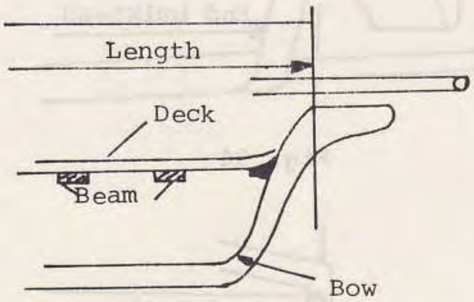


Fig. 29

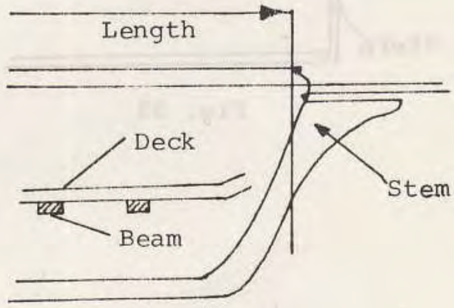


Fig. 30

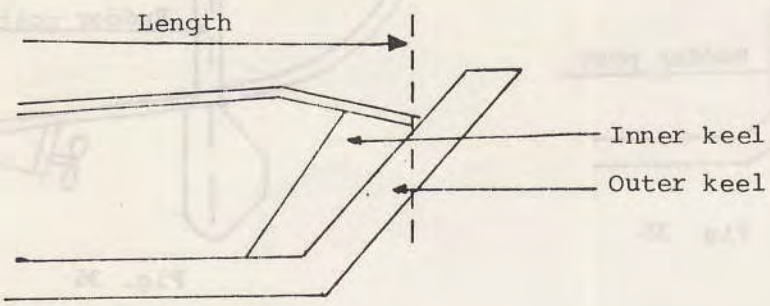


Fig. 31

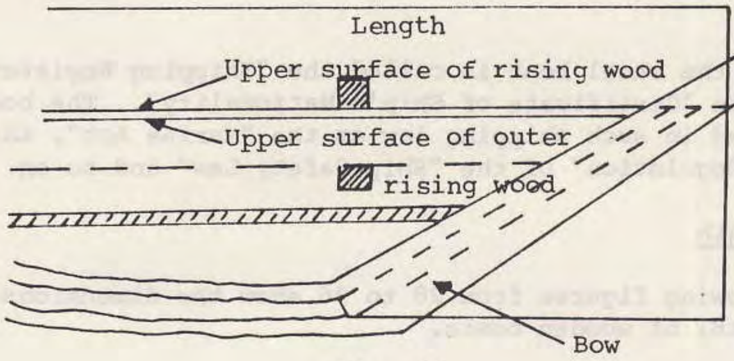


Fig. 32

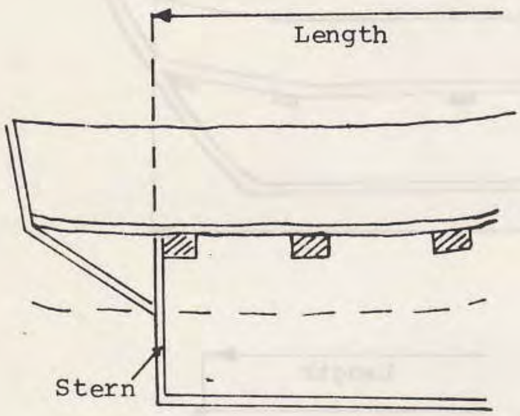


Fig. 33

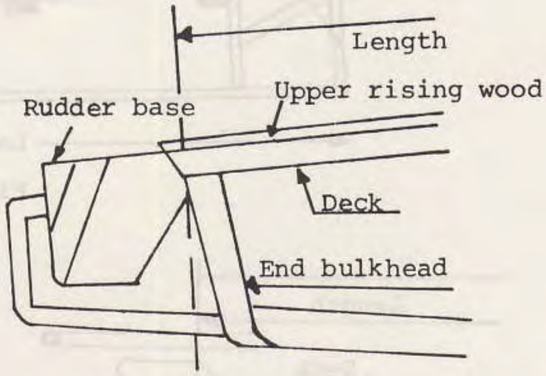


Fig. 34

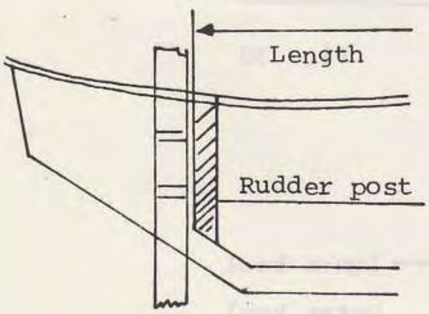


Fig. 35

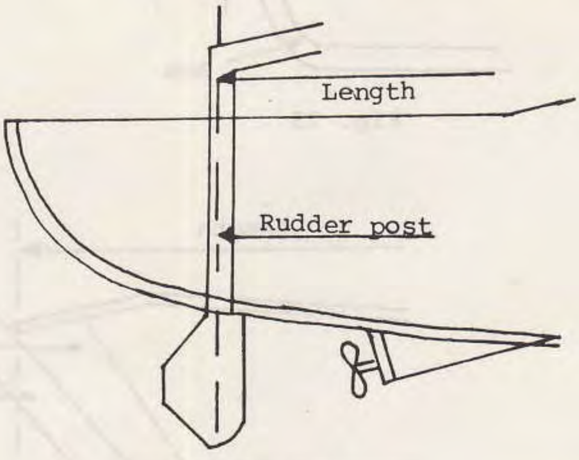


Fig. 36

(b) Boat width

The boat width is designated in the regulations as "the level distance from the outer surface to the outer surface at the widest point of the frame" as shown in the Figs. 37 - 39.

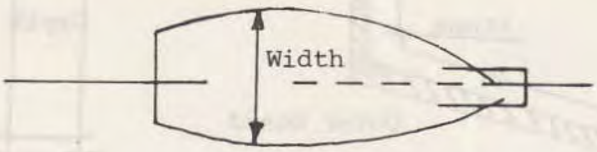


Fig. 37

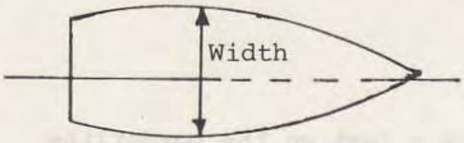


Fig. 38

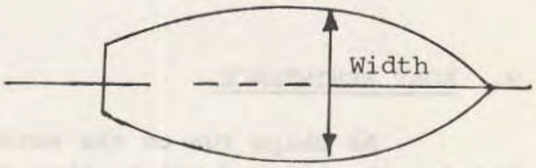


Fig. 39

(c) Boat depth

Figures 40 - 43 show the nominal depth of the boat. It is designated in the Japanese regulations that "The boat depth should be the perpendicular distance from the upper surface of the keel of the broadside to the top of upper deck beam at the center of the boat length".

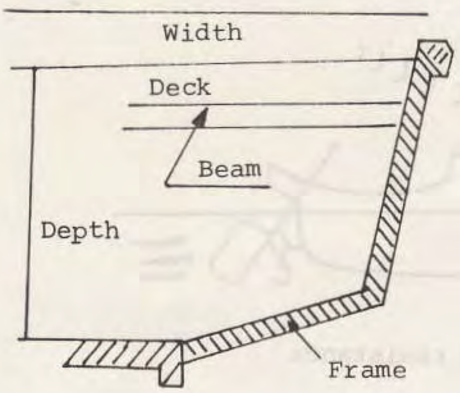


Fig. 40

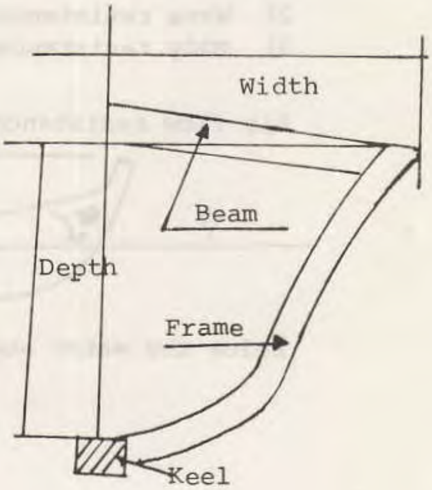


Fig. 41

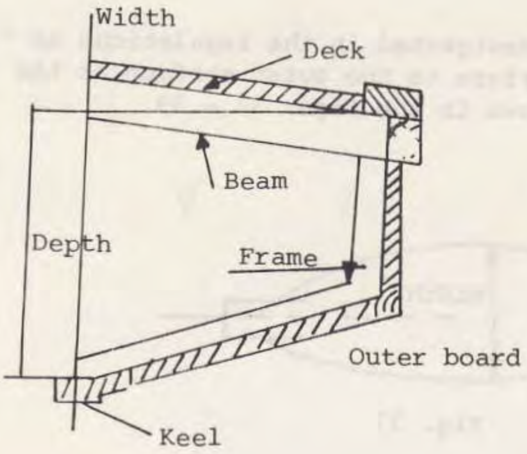


Fig. 42

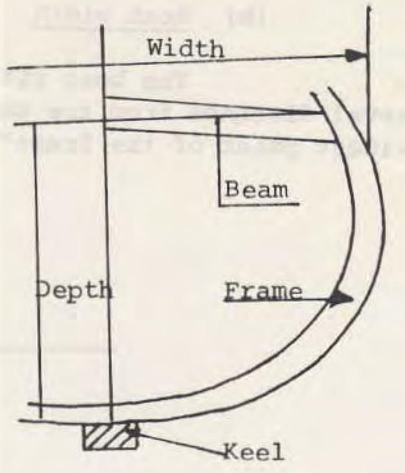


Fig. 43

9. BOAT RESISTANCE

As ships run on the water surface - just on the borderline between the air and water, they are subject to natural resistance of two kinds; water resistance and air resistance (see Fig. 44). When a ship is running against a strong wind or in a storm, the air flow resistance to it is very large, but in good weather the air flow resistance is small and may be negligible; the surplus power of the engine can overcome this resistance. Ships always have to run against water resistance and air resistance, but since the air flow resistance may be disregarded we shall proceed to explain only the resistance of water flow. The water flow resistance can be classified into several kinds as follows.

1) Frictional resistance
2) Wave resistance
3) Eddy resistance

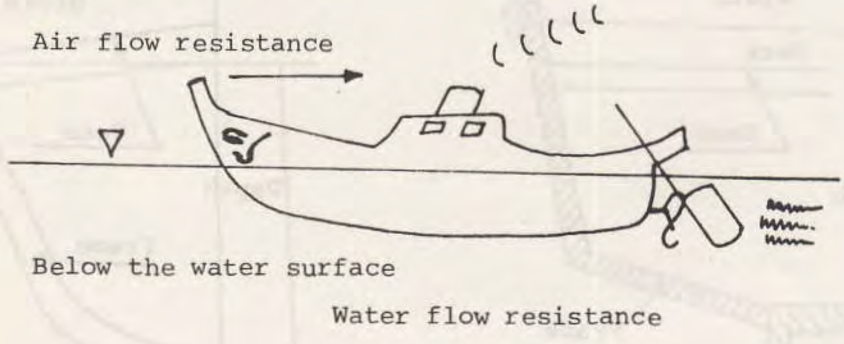


Fig. 44

9.1 Frictional resistance

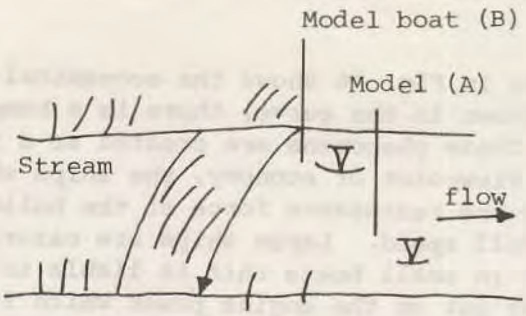


Fig. 45

Figure 45 illustrates a simple experiment by which one type of water flow resistance can be shown. Two model boats are set on the same starting line in a stream, model (B) near the bank, and model (A) in the stream center. As shown in the figure, the boat (A) in the stream center runs faster than the boat (B) which is set near the bank. This indicates that the stream flows faster at the center than at the sides. The water flow near the bank is slower than at the center due to the frictional resistance of the bank side, and it shows that this resistance gradually decreases toward the center. This phenomenon is true for real ships running on water. When a ship runs on water (sea or river), the hull surface is subjected to more or less resistance by the water flow. The force of the frictional resistance is the product of the square of the ship's speed and the wet surface of the ship. The frictional resistance force does not depend on the shape of the vessel even though there is a little less friction if the ship is longer. The frictional resistance will obviously affect the ship's speed by the hull condition when the hull surface becomes rough by adhered shells.

While running at normal speed, the ship is usually affected by frictional resistance more than by all the other kinds of resistance. However as the speed becomes higher, the wave resistance will become larger than the frictional resistance.

9.2 Wave resistance

A running ship raises high waves in its wake. In other words, a running ship creates motive energy in water and these energized waves provide resistance against its running speed. This is called "wave resistance". Two kinds of waves energized by ships may be distinguished: bow waves and stern waves. The high waves created in the ship's wake are the resultant waves of these bow waves and stern waves.

The curve in Fig. 46 shows the economical speed against resistance. As shown in the curve, there is a hump portion and a hollow portion. These phenomena are created as a result of energized waves. From the viewpoint of economy, the ships should be designed so as to decrease the resistance force at the hollow point to allow ships to run at full speed. Large ships are naturally designed with this in mind, but in small boats this is liable to be disregarded and emphasis is rather put on the engine power which is always comparatively high in proportion to the dimensions of the boat. Thus the boat is driven at an extremely uneconomical speed about 4 times higher than normal, which is an unwise attempt to overcome the problem. In conclusion, we can definitely say that the boat speed should be increased by improving the boat structure rather than increasing the engine horsepower.

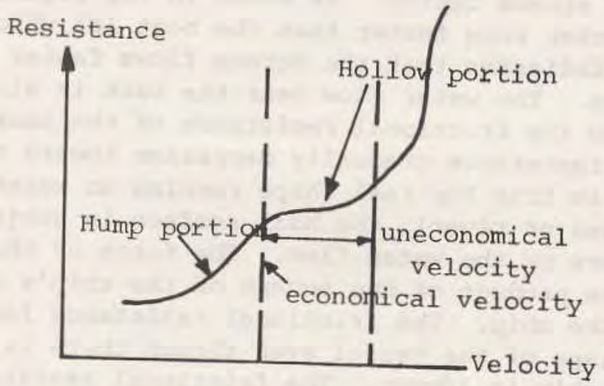


Fig. 46

9.3 Eddy resistance

Many eddies are created around and behind running ships. These eddies are also created and energized by the hull and they cause resistance against sea speed. This is called "eddy resistance". Eddy resistance affects especially wooden boats and it cannot be ignored. It is created usually by the angular shape of the hull; it is therefore necessary to streamline the hull form as much as possible.

As described above, there are three different kinds of resistance:

Frictional resistance ....X%

Wave resistance ....Y%

Eddy resistance....................Z%

Assuming that the total water resistance involves these three kinds of resistance, eddy resistance is the smallest in terms of percentage and usually is included in the wave resistance (Y). Wave resistance + eddy resistance together are called "overplus resistance". Thus of the two main types of resistance, frictional resistance and overplus resistance, frictional resistance does not much depend on the ship size, but overplus resistance hampers the ship speed depending on the shape and dimensions of the ship, and it is the streamline form that will best overcome ship resistance and increase the ship speed.

Assuming that the resistance (R) against the ship speed is 20,000 kg, and its sea speed is 15 knots, a ship being resisted by 20,000 kg should advance 7.7 meters per minute. This means that the ship will consume 154,000 kg-m energy that requires 2,050 PS power. In formulating the above resistance, energy and required horsepower, it may be understood that the ship resistance value is approximately similar to the horsepower except for the difference of unit. We may define that resistance is about ten times greater than the horsepower, as can be seen clearly from the following formula.

One (1) nautical mile .... 1.852 m

One (1) mile (land) .... 1.609 m

One (1) knot .... One sea mile per hour, or 1.151 land miles per hour (0.514 meters per second)

15 knots .... 15 X 0.514 ≑ 7.7 m/sec

Work = power X distance (kg-m).. 20,000 X 7.7

= 154,000 kg-m

Horsepower = $\frac{\text{Work}}{\text{Hour}}$ .... One horsepower being 75 kg-m/sec

$\frac{154,000}{75} \doteqdot 2.050$ PS

10. BOAT LENGTH AND SEA SPEED

Boat length is in close relation with the sea speed and this we call "speed - length ratio" in which the sea speed is divided by the square root of the boat length. The speed-length ratio may be formulated as below:

$$\text{Speed - length ratio} = \frac{V}{L}$$

V......boat speed.....1 knot = 1852 m/hr

L......boat length....1 meter = 3.2808 ft

For example, assuming boat of 36 foot length (about 11 meters) runs at the speed of 6 knots, the speed-length ratio can be calculated as follows:

$$\text{Speed - length ratio} = \frac{6}{\sqrt{36}} = \frac{6}{\sqrt{6}} \doteq 1.0$$

If the same boat is assumed to run at 7 knots, the speed-length ratio will be:

$$\text{Speed - length ratio} = \frac{7}{\sqrt{36}} \doteq 1.17$$

and if it the speed is 8 knots, the speed - length ratio will be:

$$\text{Speed - length ratio} = \frac{8}{\sqrt{36}} \doteq 1.33$$

When we say "boat speed or sea speed", it means the normal sea speed, and the normal sea speed means the speed at which speed-length ratio is about 1. Low speed or high speed is defined in relation to this normal point. Low speed means a sea speed lower than the square root of the boat length (in feet) X 0.8, while high speed equals or is higher than the square root of the length (in feet) X 1.2.

In the foregoing examples, the boat length is assumed to be 36 feet. The square root of 36 is 6 and the sea speed may be defined in the following way:

Low speed .... 6 X 0.8 = 4.8 knots or lower

Normal speed .... 6 X 1.0 = 6 knots

High speed .... 6 X 1.2 = 7.2 knots or higher

The question is then for a boat of this length (36 feet), how much can the speed be raised? The speed which is 1.5 times of the square root of the boat length may be possible by improving the shape of the hull or increasing the engine horsepower, but it is absolutely impossible to improve the speed to twice the square root of the boat length. In other words, the boat should be designed so that its length (in feet) is the square of the intended normal speed. For instance:

If the intended sea speed is 6 knots the boat length should be 36'

If the intended sea speed is 8 knots the boat length should be 64'

If the intended sea speed is 10 knots the boat length should be 100'

Of course, the above basic rule is for the normal standard, and some shorter boats may display surplus speed, but it is to be understood that an unreasonable speed increase will shorten the engine and propeller life quickly.

As described above, when the boat length is determined in the first design process, the reasonable maximum sea speed is also defined implicitly. If higher sea speed than originally planned is desired, the length must be increased, rather than making the engine horsepower larger as already explained in the section on "Wave Resistance".

In conclusion, the boat length or more precisely the draft length, should comply with the Construction Regulations for Wooden Vessels.

11. BOAT SPEED AND HORSEPOWER

It is natural that if the engine power is increased, the boat speed will increase in proportion to the power. There is, however, a limit in this relation. When the speed attains a certain limit, it can not be increased however much the engine power is raised.

Figure 47 shows gradually increasing horsepower of Mitsubishi "DAIYA" diesel engine installed in a boat of 14.66 meters length. According to the details give in the table below, the horsepower required

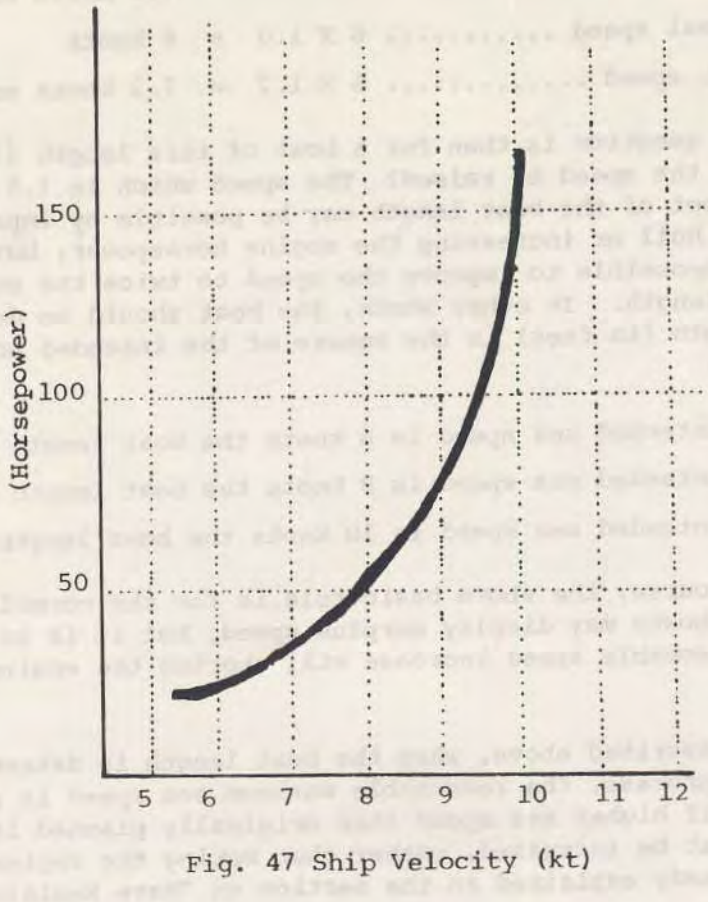


Fig. 47 Ship Velocity (kt)

for increasing the sea speed becomes gradually larger. Namely, an increase from 6.5 knots to 7.5 knots requires 15 horsepowers, a further increase from 7.5 knots to 8.5 knots requires 20 horsepowers, and from 8.5 knots to 9.5 knots requires 40 horsepowers. In the long run, about 33 horsepowers will be required to increase the sea speed by only 0.3 knots. This means that beyond a certain point a very large horsepower will have very little effect on increasing sea speed.

In the table below, the speed-length ratio is calculated as follows:

Boat length = 14.66 m, 1 meter = 3.2808 feet

14.66 X 3.28 = 48 feet $\sqrt{48}$ = 6.9282

Thus the normal speed of this boat (14.66 m) is 6.9 knots; any speed above 8.3 knots is high speed and its highest limit is 10.4 knots. As explained in the section on SHIP LENGTH AND SEA SPEED, the ship speed may be raised by 1.5 of the square root of the boat length by improving

Ship speed (knot)	HP	HP required for 1 knot increase	Speed length ratio
6.5	30	-	0.94
7.5	45	15	1.08
8.5	65	20	1.22
9.0	80	-	1.30
9.5	105	40	1.37
9.6	115	-	1.38
9.8	138	-	1.41

the shape of the hull or increasing engine horsepower, but it is absolutely impossible to raise the speed by twice the square root of the length. Since in our example the boat length is 48 feet, the approximate square root is 7 and the speed may be raised 1.5 times of this square root i.e., to 10.4 knots. This speed of 10.4 knots is the maximum and the speed cannot be increased unless the boat length is also increased.

12. DIAMETER AND PITCH OF PROPELLER

12.1 Selection of propeller diameter

Since high technical skill is required to define propeller dimensions, the selection should be carried out by a competent specialist who will do the necessary calculations. When ordering a propeller, it is necessary to supply the following information to enable a specialist to select the appropriate propeller diameter.

(For new installation)

Hull (a) Material: wood, steel etc.

(b) Newly built ship or old ship.

(c) Ship style: Europen, Japanese, etc.
In the case of a Japanese style ship it is necessary to specify whether it is the lift type or keel type.

(d) Ship kind: passenger ship, freighter, cargo-passenger ship, tug boat, high-speed boat, fishing boat. For the fishing boat, specify the type of fishery.

(e) Boat dimensions: Length x width x depth.

<u>Engine</u> (a) Manufacturer's name and type.

(b) Normal horsepower/revolution and maximum horsepower/revolution.

(c) Reduction equipment (whether it is provided). If provided it is necessary to specify its reduction ratio.

(d) Supercharger (whether it is provided).

<u>Propeller</u> (a) Revolving direction (facing toward the propeller at stern side clockwise or counter clockwise).

(b) Maximum diameter of propeller allowed.

(c) Diameter of propeller, length of boss, front outer diameter of boss, rear outer diameter of boss.

(For replacement installation)

(a) For the existing propeller to be replaced: diameter, pitch,blade number and manufacturer's name.

(b) Performance of existing propeller: revolution, speed, displacement, average draft.

(c) Reason for replacement and requirements for installation (additional requirements:- increased speed
- tugging).

12.2 <u>Simple calculation for approximate diameter of propeller</u>

A competent propeller specialist will calculate the most suitable propeller dimensions in accordance with the above particulars. Sometimes, however, an urgent need will occur to estimate the propeller diameter. For this reason we shall briefly explain a simple method of calculating the propeller diameter. It should be borne in mind, however, that this method will give only approximate value. The data required are:

Horsepower (PS), Revolution (N), Ship speed (Vs)

Let us take an example of a ship whose fully loaded maximum output is 430 PS, propeller revolution is 390 rpm, and ship speed 9.5 knots with the main engine.

Horsepower (PS) .... 430 PS

Revolution (N) .... 390 rpm

Speed (Vs) .... 9.5 knots

in which the .... $\frac{PS}{Vs} = 45.2$

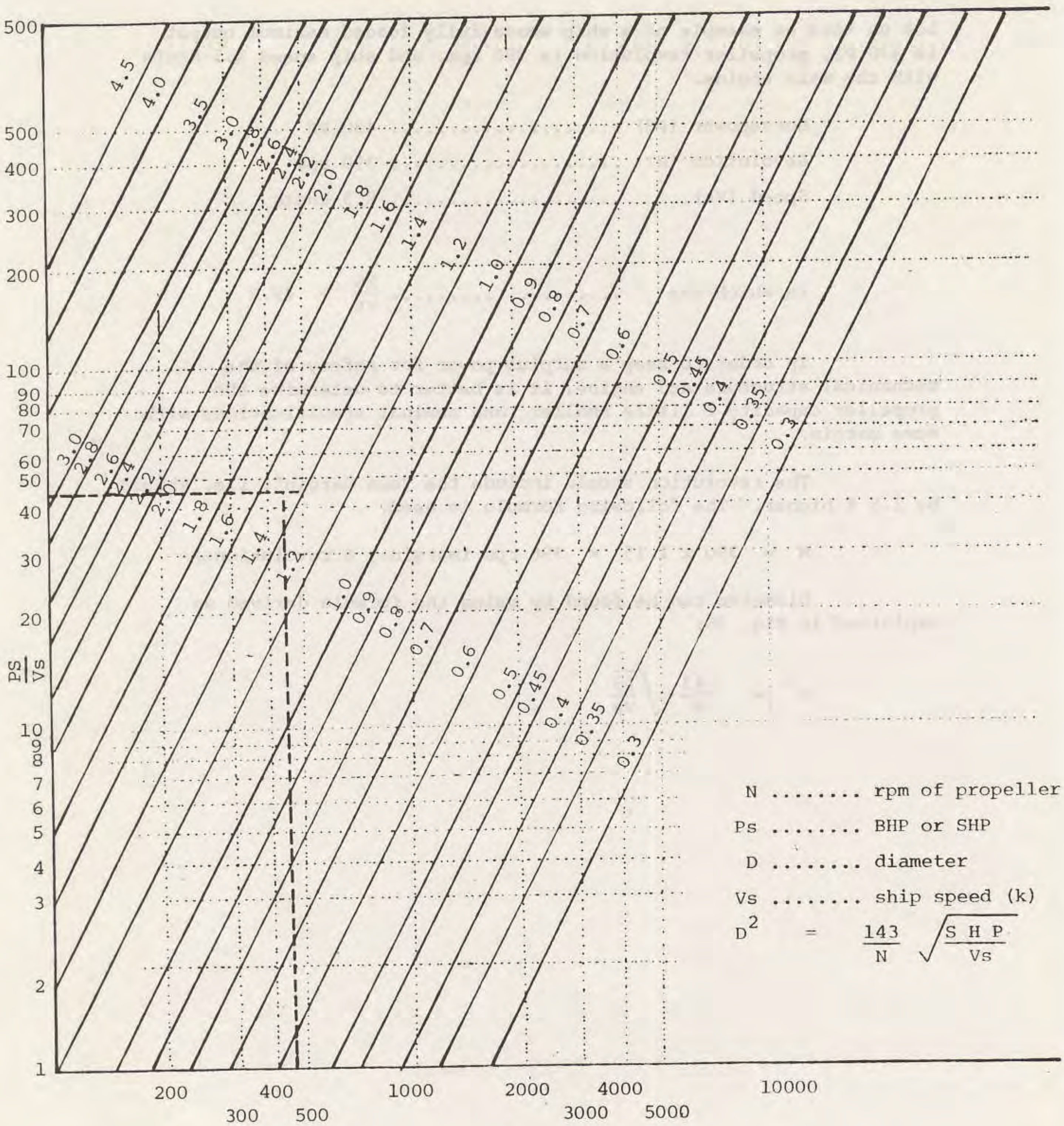
In order to keep a surplus power for safety of the mechanical structure and engine, it is better to determine the propeller capacity a little smaller than nominal specifications with some margin.

The revolution should include the "sea margin", i.e. should be 1.5 % higher. The following formula is used.

$$N = 390 \times 1.15 = 396 \text{ rpm (margin: 6 revolutions)}$$

Diameter can be found by using the formula derived as explained in Fig. 48:

$$D^2 = \frac{143}{N} \sqrt{\frac{PS}{Vs}}$$



$$D^2 = \frac{143}{N}\sqrt{\frac{S\ H\ P}{Vs}}$$

Fig. 48 The most suitable diameter for a 4-blade propeller.

In the diameter chart in Fig 48, N is on the horizontal axis, and $\frac{PS}{Vs}$ is on the vertical axis. First, we read the intersecting point i.e., the point where the horizontal 396 intersects with the vertical 45.2. At this point the value given is 1.56; that means that the adequate propeller diameter is 1.56 m. (This 1.56 m is for a 4-blade propeller, and if a 3-blade propeller is intended, "D" value must be increased by 4%). Assuming this diameter 1.56 m to be "D", $\frac{ND}{Vs}$ is obtained as follows:

$\frac{396 \times 1.56}{9.5} \doteq 65.0$ and this 65.0 means the slip

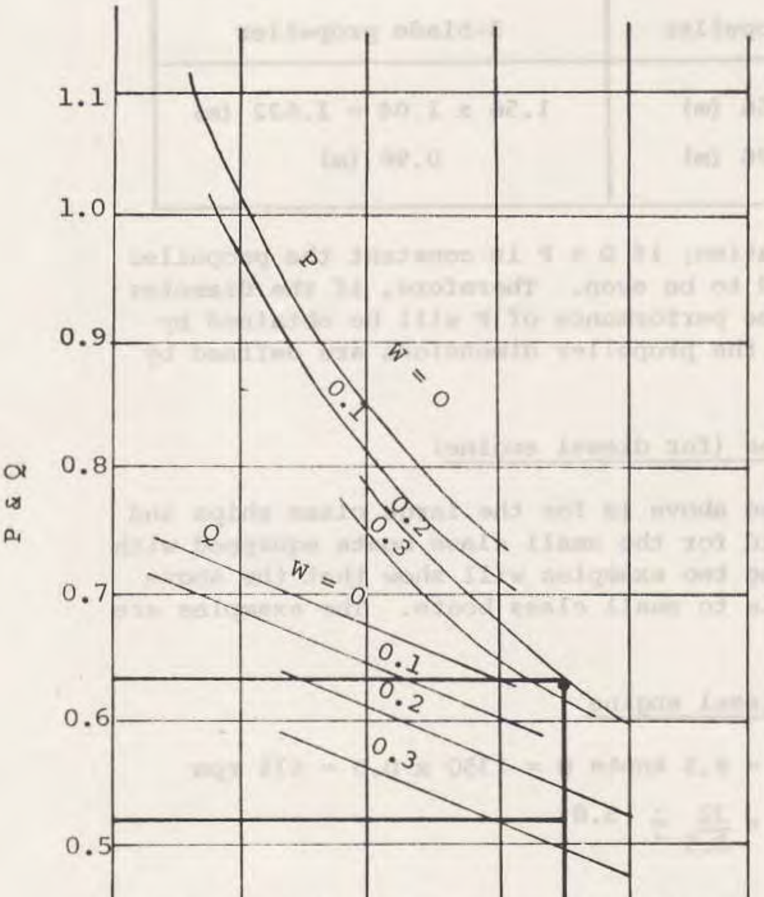


Table of W

	Single propeller	Twin propeller
A	0.25-0.33	-
B	0.25-0.33	-
C	0.15-0.25	0.07-0.11
D	0.20-0.30	-
E	0.25-0.30	-
E	0 -0.10	0

A = freighter

B = tanker

C = passenger ship

D = fishing boat

E = wooden ship

F = motor boat

Fig. 49 Pitch ratio of a 4-blade propeller

In Fig. 49, the wake factor (W) is assumed to be 0.25, and reading the 650 line, the ND/Vs values, the wake (W) value 0.25 is found at the intersecting point, then the pitch ratio is obtained as follows:

Pitch ratio $P = 0.615$

Efficiency $\eta = 0.515$

The pitch (P) is 1.56 m x 0.615 = 0.960 (m), and this pitch can be compared for 3-blade and 4-blade propellers as tabulated below:

4-blade propeller		3-blade propeller
Diameter	1.56 (m)	1.56 x 1.04 = 1.622 (m)
Pitch	0.96 (m)	0.96 (m)

In the above calculation, if D + P is constant the propeller performance may be considered to be even. Therefore, if the diameter is increased by 50 mm the same performance of P will be obtained by decreasing P by 50 mm. Thus the propeller dimensions are defined by D + P.

Experimental examples (for diesel engine)

The example described above is for the large class ships and engines, but the same is valid for the small class boats equipped with diesel engines. The following two examples will show that the above chart and table are applicable to small class boats. The examples are based on experimental data.

Example 1: 32 PS diesel engine

PS = 32 PS Vs = 8.5 knots N = 1350 x 0.5 = 675 rpm

$$\frac{PS}{Vs} = \frac{32}{8.5} \doteq 3.8$$

In Fig. 48, reading $\frac{PS}{Vs} = 3.8$, N = 675, the product is 0.66 which means the actual diameter is 0.66 m. Namely;

$$\frac{ND}{Vs} = \frac{0.66 \times 675}{8.5} \doteq 58.4$$

Assuming that the value of W in Fig. 49 is 0.2, the formula is found as below:

$$P = 0.75 \quad \eta - 0.58$$

$$D_3 = D_4 \times 1.04 = 066 \times 1.04 \doteqdot 0.69$$

$$P_3 = P_4\ 0.66 \times 0.75 \doteqdot 0.49$$

$$L + P = 1.15 \text{ (margin is 0)}$$

Then the propeller diameter and its speed is obtained from the above experimental data as follows:-

Propeller 600 x 480 ...... 8.5 knots/1350 rpm

Propeller 700 x 390 ...... 7.9 knots/1350 rpm

Example 2: 135 PS Diesel Engine

$$\frac{PS}{Vs} = \frac{138}{9.8} \doteqdot 14$$

In Fig. 48, $\frac{PS}{Vs} = 14$ The intersecting point of N = 400 is 1.18.

$$\frac{ND}{Vs} = \frac{1.18 \times 400}{9.8} \doteqdot 48$$

Assuming "W" in Fig. 49 is 0.25

$$P = 0.77 \quad \eta = 0.58$$

$$D_3 = D_4 \times 1.04 = 1.18 \times 1.04 = 1.23$$

$$P_3 = P_4 = 1.18 \times 0.77 = 0.91$$

$$D + P = 1.23 + 0.91 = 2.14$$

The propeller diameter and its speed are obtained in accordance with the above experimental data as follows:

Propeller 1200 x 950 ..... 9.8 knots/1000 rpm

As shown in the above examples (1) and (2), the said chart and table can also be applicable for estimating an approximate propeller diameter of diesel engines. However, the chart and the table are only applicable in the case of comparatively large type diesel engines. The weak point is that the exact propeller diameter and its speed for diesel engines of smaller type cannot be obtained unless as many practical data of ship resistance as possible are prepared beside the above chart.

13. PROPELLER REVOLUTION IN RELATION TO ENGINE OUTPUT

The shaft horsepower of the main engine is proportionate to the value of the third power of the propeller rpm. The table below shows how to calculate the load value by the cubic root of revolution.

Load	Cubic root by which to multiply full load
1/4	$\sqrt[3]{1/4} = \sqrt[3]{0.25} = 0.63$
1/2	$\sqrt[3]{1/2} = \sqrt[3]{0.5} = 0.79$
3/4	$\sqrt[3]{3/4} = \sqrt[3]{0.75} = 0.91$
4/4	$\sqrt[3]{4/4} = \sqrt[3]{1} = 1.00$
11/10	$\sqrt[3]{1.1} = \sqrt[3]{1.1} = 1.03$
12/10	$\sqrt[3]{1.2} = \sqrt[3]{1.2} = 1.06$

In the above table, the load 4/4, 3/4, 1/2, 1/4 and so on, indicates the percentage of the total load of a shaft horsepower, but not the propeller revolution. For example, the 1/2 load means:

Revolution of full load X cubic root $\div$ 2 = 1/2 load.

Questions

1. Calculate the gross tonnage of the wooden ship whose specifications are given below. The measurements should be in accordance with the Ship Classification Measurement Regulations.

   (a) Length .... 14.6 m

   (b) Width .... 3.3 m

   (c) Depth .... 1.3 m

2. Based on the shaft horsepower at full load (4/4), 30 PS/1200 rpm of the main engine to drive a propeller, find out the engine revolution at the time of 1/4, 1/2, 3/4, 11/10, 12/10 load and describe their intersecting points by making a graphic chart.

1/4 .... rpm

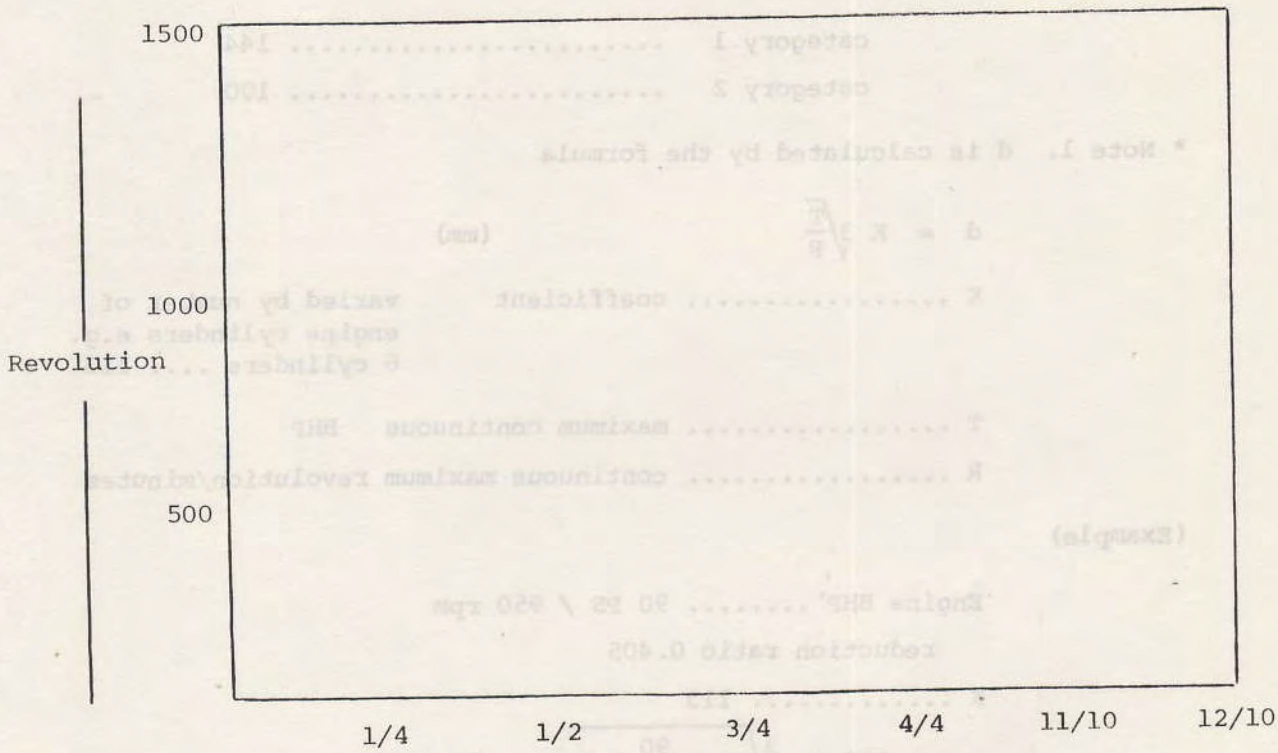
1/2 .... rpm

3/4 .... rpm

4/4 .... rpm

11/10 .... rpm

12/10 .... rpm



Appendix 1: <u>How to calculate the diameter of propeller shaft</u>

Calculation of the diameter of the propeller shaft (according to the Japanese government regulations)

$$ds = d^{*} + \frac{D}{c}$$

ds = diameter of propeller shaft (mm)

d = diameter of intermediate shaft (mm)

D = diameter of propeller

c = coefficient which varies according to the materials

category 1 144

category 2 100

* Note 1. d is calculated by the formula

$$d = K \sqrt[3]{\frac{T}{R}} \quad \text{(mm)}$$

K .... coefficient varied by number of engine cylinders e.g. 6 cylinders 113

T .... maximum continuous BHP

R .... continuous maximum revolution/minutes

(Example)

Engine BHP .... 90 PS / 950 rpm

reduction ratio 0.405

K 113

$$c = 113 \times \sqrt[3]{\frac{90}{950 \times 0.405}} = 69.63 \text{ (mm)}$$

Appendix 2: <u>Propulsion of small fishing boat</u>

Given below are the formulae for calculating different kinds of horsepower.

(1) Indicated horsepower (I.H.P.)

2-cycle single acting or 4-cycle double acting engine

$$I.H.P. = \frac{Pmi \times \frac{\pi}{4} \times D^2 \times S \times N}{75 \times 60}$$

where Pmi = indicates mean effective horsepower (kg/cm^2) which is calculated from an indicator diagram

D = diameter of cylinder (cm)

S = stroke of piston (m)

N = revolution/min

(2) Brake horsepower (B.H.P.)

$$B.H.P. = \frac{2\pi\ QN}{75 \times 60} \quad \text{or} \quad B.H.P. = I.H.P. \times \eta m$$

where Q = braking moment (torque) kg-m

ηm = mechanical efficiency measured from operating data at factory

(3) Shaft horsepower (S.H.P.) measured by torsion meter

$$S.H.P. = \frac{2\pi nQ}{75} \qquad Q = \frac{\pi D^4\ G\Theta}{32L}$$

Q = torque

n = revolution/sec

D = diameter of intermediate shaft

L = length of shaft / m

G = torsional modules (kg/m^2)

Θ = torsional angle

(4) Delivered horsepower (D.H.P.)

DHP = 1/1.05 x B.H.P.

DHP = 1/1/03 x B.H.P.

(5) Thrust horsepower (T.H.P.)

$$T.H.P. = \frac{T \times V}{175}$$

T = thrust of propeller (kg)

V = relative velocity of propeller (m/s)

(6) Effective horsepower

$$E.H.P. = \frac{R \times V}{75} = \frac{(Rw + Rf)}{75} \times \gamma$$

R = total resistance of boat

Rw = wave making resistance

Rf = frictional resistance