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FUJI VOITH-SCHNEIDER PROPELLER

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I. FOREWORD

Our Company has made a contract for technical agreement on the Voith-Schneider propeller with J. M. Voith GmbH of West Germany with whom we have so far made technical cooperation on water turbine and already during last year, ships equipment with domestic manufactured Fuji Voith-Schneider propellers were put in service operation and through the favour of our customers, we are at present manufacturing about 10 sets of propeller. At the present occasion when various industrial areas have recently been expanded and modernized and accordingly new establishment and extension of their harbour equipment are being eagerly desired, we wish to introduce to our customers our Fuji Voith-Schneider propeller which enjoys popularity as the most suitable propeller for various kind of operating boats and moreover as a propeller for special multi-purpose ships.

II. PRINCIPLE AND PRACTICAL APPLICATION OF SCHNEIDER PROPELLER

The principle of Schneider propeller invented by the electrical engineer, Ernst Schneider of Vienna in 1925 was successfully applied for ships in 1931 by J.M. Voith GmbH of West Germany and since when, after carrying out continuous efforts and repeated researches and adding many improvements on points of hydraulics and construction, the present state of perfection has been attained.

In the following, how the principle of Schnider propeller was applied in practice will be explained.

In Fig. 1, when blade is made to stand vertically on periphery of radius r and rotated at angular velocity ω, forward velocity of propeller will be denoted by v, peripheral velocity of propeller by u, and relative velocity of water by w. In this case, if angle formed by u and w is taken as ϕ, and cross-point of vertical line to relative velocity w passing through any point on periphery of radius r with diameter AB at right angle to forward velocity v taken as N, velocity triangle PQR formed by u, v, w has following relation

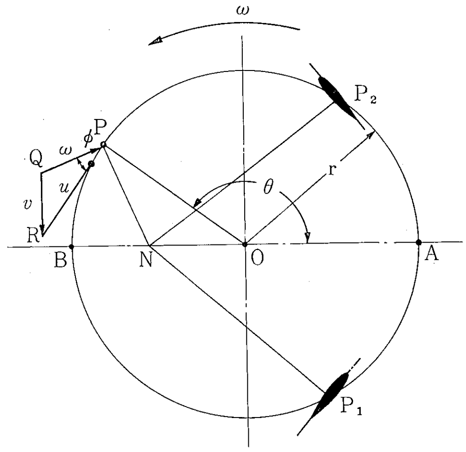

Fig. 1 Principle of Schneider propeller

$$\angle QPR = \angle NPO = \phi$$
$$\angle PRQ = \angle PON$$

and then,

$$\triangle PQR \backsim \triangle PNO \quad \cdots\cdots (1)$$

and then, when $ON = y$

$$\frac{v}{u} = \frac{ON}{OP} = \frac{y}{r} = e \quad \cdots\cdots (2)$$

that is, ON has a fixed length and length of ON indicates magnitude of forward velocity. Also, normally N is called steering point and e, *i.e.* ratio of ON and radius, is named pitch or eccentricity. In other word, if blade in relation to PN is rotated on the circle of radius r so that its blade chord will be at right angle, in its no-load operation state, it is possible to make it advance forward in right angle direction to ON at propeller modulus of $ON/OP = e$.

Now if angle formed by OP and OA is taken as θ, following formula will be obtained :

$$\phi = \cot^{-1}\frac{\frac{r}{y} + \cos\theta}{\sin\theta} = \cot^{-1}\frac{\frac{1}{e} + \cos\theta}{\sin\theta} \quad \cdots\cdots (3)$$

and maximum value ϕ_{max} of ϕ will be

$$\phi_{max} = \sin^{-1} e \quad \cdots\cdots (4)$$

and rotation angle $\theta_{\phi max}$ that produces ϕ_{max} will be

$$\theta_{\phi max} = \cos^{-1} - e \quad \cdots\cdots (5)$$

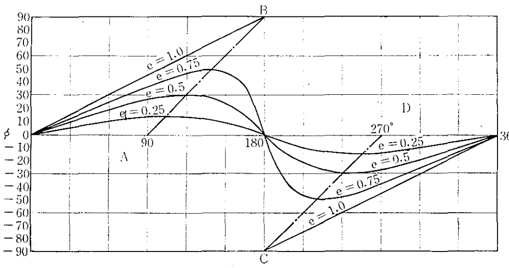

Fig. 2 Relation between θ and ϕ by Schneider theory.

Now, if e is taken as parameter and relation between θ and ϕ is shown diagrammatically, it will be as seen in Fig. 2. Also, $\theta_{\phi max}$ that gives ϕ_{max} as is clear from formula (5), comes on straight line tying AB and CD.

By principle of the Schneider theory variation of the blade angle will be equal to the variation of ϕ in Fig. 2. However, in order to actually to produce a certain thrust by the propeller and make it propel ship forward at speed v, necessary angle of attack α must be given for this to make it move. Judged from the result of various experiment, it cannot always be said that giving blade angle corresponding to ϕ in Fig. 2 will obtain the most suitable ability and it became known that in giving angle of attack α, the below mentioned 2 points should be considered.

1) In the case of ordinary screw propeller, in a certain operation state, flow is always constant at all positions of the blade and consequently its angle of attack α has constant value. In this case, limit of angle of attack where separation will not be produced is 10～15°. If it becomes above this, separation will be produced and necessary lift will not be produced. However, regarding propellers such as Schneider propeller where during one turn its angle of attack is gradually changed and operated, when, for instance, in Fig. 1 at A point and B point angle of attack is zero and between these, angles of attack are changed and operated, it has experimentally conformed that angle of attack in which separation will be produced becomes comparatively large.
2) As can be seen by Fig. 2, in the first half of propeller rotation, that is, between $\theta=0$～180°, increase of ϕ is slow but decrease rate from ϕ_{max} rapidly increases together with increase of e. In latter half of propeller rotation, it becomes reverse to this. Decrease rate of ϕ in first half of propeller rotation and increase rate of ϕ in latter half, or in other words, for giving change rate of blade angle in this range, it is necessary to give a large amount of work and at the same time there will be cases where by causing disturbance in water flow, efficiency will drop on the contrary. Because of this, changing velocity of blade angle in this range is reduced somewhat, that is, if point where blad angle becomes maximum is made fast in propeller first half and slow in latter half, moving mechanism of propeller can be designed easier and efficiency will be raised.

Fuji Voith-Schneider propeller moving mechanism is designed by carefully considering about 2 points and in the following this will be described in outline.

Fig. 3 is a drawing showing the moving mechanism.

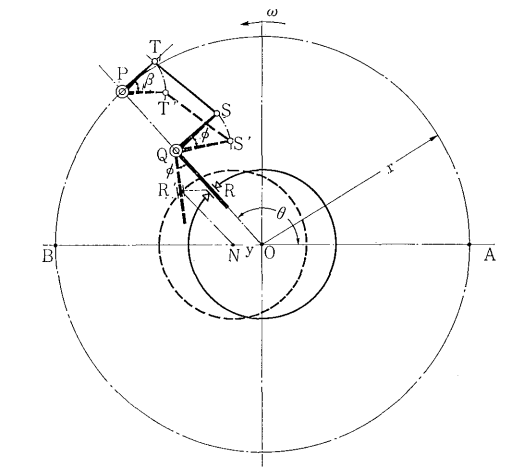

Fig. 3 Link mechanism of Voith-Schneider propeller

Point P is rotating center of blade and it rotates on periphery of radius r with O as center at angular velocity ω. Arm PT is taken out from point P and connected to arm QS from fixed point Q between point P and point O by link ST. Arm QS on the other hand is connected by arm QR to ring that can shift in parallel freely around point O.

In this mechanism, if ring is shifted in parallel by y in left direction of drawing, R shifts similarly to R' by y and QR rotates arm QS with point Q as fulcrum and gives blad angle β.

Now, if rotation angle of arm QR, that is, rotation angle of arm QS is taken as ϕ, length of QR as a and rotation angle of point P denoted by θ, following formula will be had.

$$\phi=\cot^{-1}\frac{\frac{y}{a}+\cos\theta}{\sin\theta} \quad \cdots\cdots\cdots\cdots(6)$$

This formula is quite same as formula (2) in form. This is, in place of radius r in formula (2), it becomes a form where it is replaced by a. This fact means that in contrast to moving mechanism as shown in Fig. 1 where link mechanism faithfully follows the Schneider theory and in which, in order to give necessary eccentricity, steering point N must be shifted to a point nearly equal to diameter, with this mechnism, by selecting distance of QR a suitably, great range of eccentricity can be given through only a slight shifting amount.

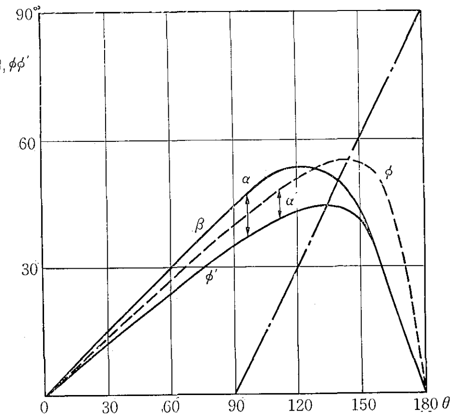

Fig. 4 Curves of blade angle

Further, in this mechnism, if it is selected as to give $QS=RT$, blade angle will become $\beta=\phi$ and it will be possible to give moving motion just in accordance with the so-called Schneider theory. However, as stated in previous clause, by large eccentricity change rate of blade becomes extremely large, large load will be required in mechanism and at the same time, favourable result in point of hydraulics also can not be hoped for. Regarding this point, our link mechanism has always following relation :

$$PT < QS \quad \text{......................................(7)}$$

which is kept, that is,

$$\beta > \phi \quad \text{..(7')}$$

it is mechanism of both giving equivalent eccentricity and if we compare rotation angle θ which makes blade angle maximum, it means that following relation will be kept :

$$\theta_{\beta\max} < \theta_{\phi\max} \quad \text{where } \theta=0\sim180° \text{ ....(8)}$$

$$\theta_{\beta\max} > \theta_{\phi\max} \quad \text{where } \theta=180\sim360° \text{ ....(8')}$$

Consequently, when this mechanism is adopted and operation done, blade angle of first half of propeller will be as shown in Fig. 4. Also, in the drawing, blade angle according to roughly equivalent Schneider theory is denoted by ϕ, angle formed by relative flow velocity and periphery velocity when it is operated at a certain propeller modulas by ϕ and angle of attack in this case by α, α' respectively.

As is clear from drawing, in steering mechanism adopted by our Company, angle of attack in first half of propeller is comparatively large in range of rotation angle $0\sim\theta_{\beta\max}$ and the state is that with this part most of the work is given and in decreasing range of blade angle β, it is made to give hardly any work by which smooth steering and good efficiency are obtained.

III. CONSTRUCTION

Fig. 5 shows appearance of Fuji Voith-Schneider propeller and Fig. 6 is a cross-section showing inside construction. In drawing, blade ① because it must work in sea water, as material 13% chrome-steel, which has high corrosion fatigue limit and shows good results against electrolytic corrosion, is used and its form is carefully selected so that it will keep good characteristics. Blade on its upper end shaft part is supported by 2 needle bearings and made so that steering motion can be carried out smoothly and is provided with special packing to prevent intrusion of sea water and leaking out of inside oil.

Thrust originated by blade passing through from rotor casing ② and bearing lantean piece ⑯ is transmitted to casing ③ united by flange boat hull.

Upward thrust produced by weight of rotating part and motion of boat body is supported by thrust bearing provided at lower part of bearing lantean piece. In this case, because thrust bearing is positioned just outside roller bearing, thrust weight load only will be borne and the other roller bearing will bear only radial weight load and construction is such that all load will always be supported by these two bearings.

Casing which transmits propeller thrust to boat body has welded construction and is designed and manufactured so weight is light but possesses ample strength and tenacity.

Power is transmitted to rotor casing ② supporting blade passing through driving sleeve ⑭ from driving shaft ⑪ by means of pinion ⑫ and bevel gear ⑬ and united to this. Driving shaft and pinion, according to driving engine speed are sometimes made as one forged pinion shaft. Pinion and bevel gear are

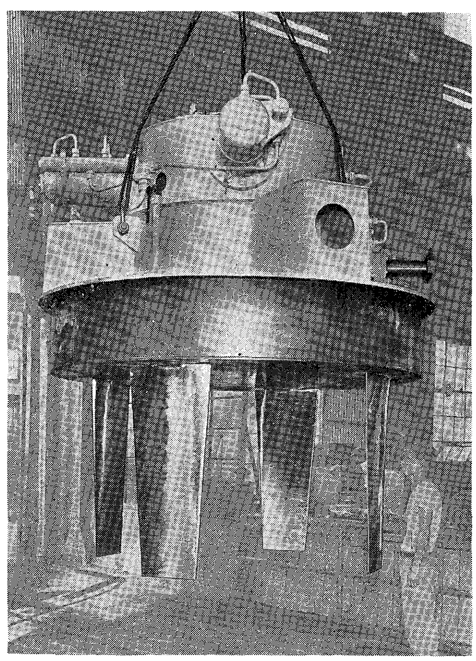

Fig. 5 Fuji Voith-Schneider propeller

made as spiral bevel which issues small noise and can obtain good engagement of gear and gear surface is nitrogen-hardenized in special nitrogenizing furnace to give ample strength and gear teeth hardness.

Shifting of operating point in order to change magnitude and direction of thrust is carried out by means of control rod ⑤ by two servomotors ⑥ crossing each other at right angles. Pilot valve for controlling servomotor by means of two levers provided on upmost tip of casing can be operated from bridge or any other desired place. This is, control stand installed on the bridge is provided with speed lever and steering handle which respectively are cnonected to two servomotor pilot valves. Consequently, speed lever adjusts lengthweise thrust of boat and steering handle adjusts thrust at right angle to this.

This if stated for the case of an automobile is quite the same as the relation between axle and handle and independently of engine room, ship can easily be navigated by one person. Also, if during navigation at high speed, steering handle is turned suddenly, a large sidewise thrust will be generated accompanied with danger of the ship capsizing and at the same time excessive load will be given to propeller and so it is designed that a limiter is attached between the two servomotors, that is, between speed controlling servomotor and steering servomotor pilot valves and so made that stroke of speed controlling servomotor will be automatically returned according to movement of steering servomotor.

Pressure oil used for servomotor is supplied by gear pump ⑱ attached to machine proper and further, this oil passing through a relief valve is supplied for lubrication of various parts.

Table 1 shows main dimension and weight for each type.

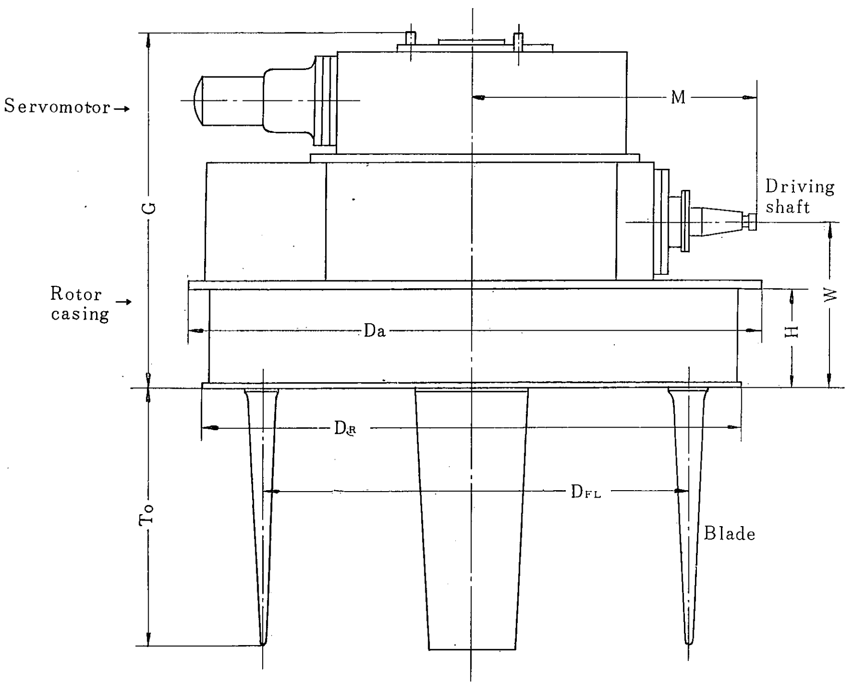

***Table 1* Main dimension and weight**

Propeller type	D_a	D_R	D_{FL}	G	T_O	M	W	H	Weight (t)
12 E	1,650	1,532	1,200	1,084	750	820	482	296	2.35
14 E	1,890	1,770	1,400	1,212	890	970	550	336	3.5
16 E	2,145	2,021	1,600	1,431	1,000	1,065	635	383	5.5
18 E	2,405	2,263	1,800	1,525	1,150	1,200	700	419	7.5
20 E	2,665	2,505	2,000	1,700	1,250	1,330	795	496	11.5
24 E	3,145	2,970	2,400	1,950	1,500	1,570	920	555	17.0
26 E	3,390	3,200	2,600	2,080	1,650	1,690	990	600	21.5
28 E	3,630	3,460	2,800	2,200	1,750	1,800	1,040	630	24.0
30 E	3,880	3,690	3,000	2,310	1,900	1,910	1,090	660	28.0

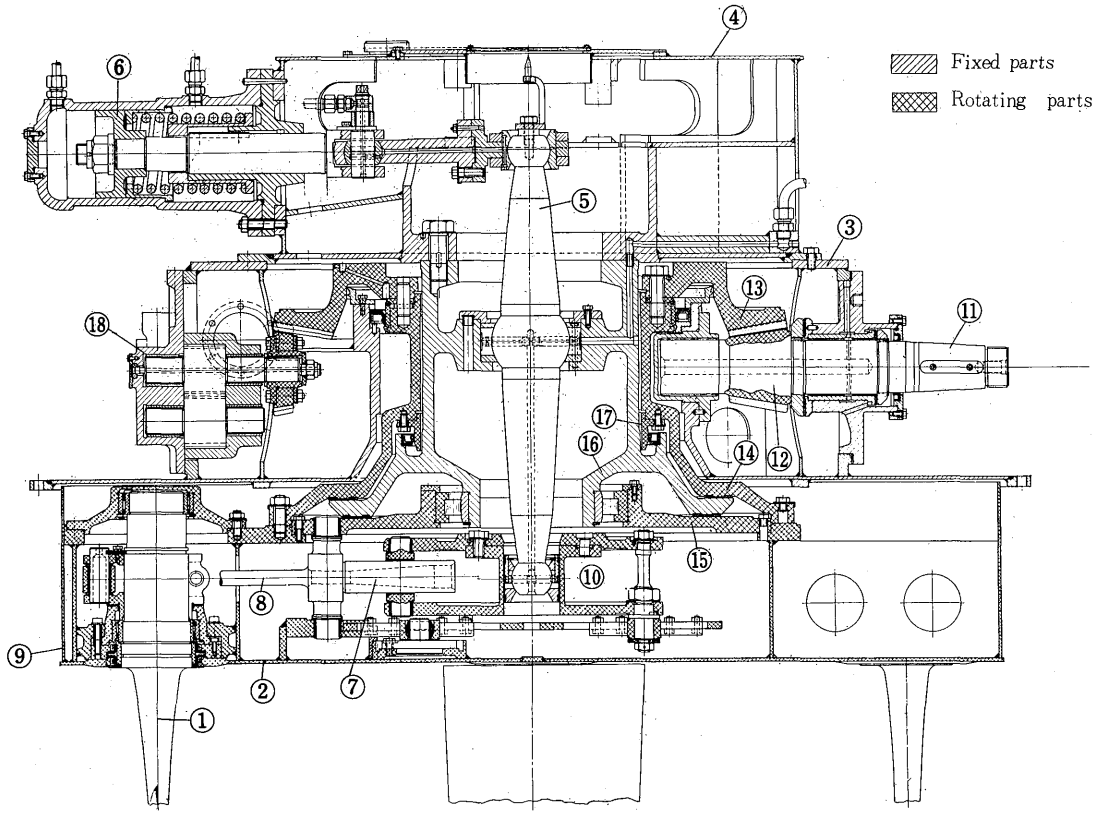

Fig. 6 Propeller section drawing

IV. SPECIAL FEATURES

Fuji Voith-Schneider propeller because of its large thrust and ability to be controlled to any direction at will, posseses the ability to perform the duty of very effective and powerful rudder beside propelling the ships and the many special features it contains are as described in the following.

1) Able to carry out quick and safe navigation, ahead and astern, by only one navigation on the bridge.

In general, with ships having ordinary screw propeller, steering can be done on the bridge but for ahead or astern navigation, the will of the bridge is transmitted to engine room by engine telegraph and main engine operating lever will have to be changed over in the engine room and therefore during full speed navigation ahead, if it is required to go astern from some reason or other, for these operations and confirmation, considerable number of persons and time are necessary and during this while, on account of its moment of inertia, the ship will be proceeding forward a considerable distance.

On the other hand, in ships having Fuji Voith-Schneider propeller, with only one crew member corresponding to the navigation in screw propeller ship, at the same time while steering, speed lever can be instantaneously changed over from ahead to astern and therefore there is absolutely no loss of time and proceeding distance due to inertia can be made very small and degree of safety of ship can be raised.

2) Conversion of direction is completely free.

Steering of ordinary screw propeller ship requires a high degree of skill and moreover considerable time and range of action are wanted but in ships with Fuji Voith-Schneider propeller, just like handling an oar in a Japanese junk for changing direction, it is possible to turn round 360 degrees in any desired direction within the diameter of length of the own

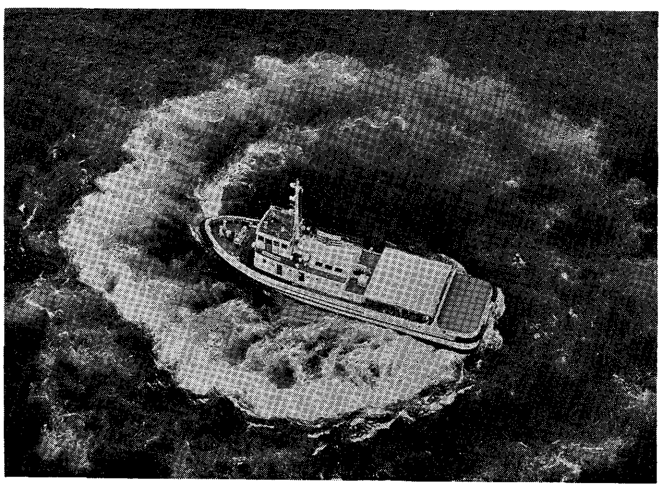

Fig. 7 Point turning operation

ship even during when the ship is at stop. That is, point turning is possible (see *Fig. 7*).

3) In the case where there is a tide current or river current and also even when wind is blowing, ship can be kept still at any desired position and moreover kept in any direction by its own power and also ship can be moved while maintaining any desired angle.

In an ordinary screw propeller, this is a thing that is absolutely impossible but in a Fuji Voith-Schneider propeller ship, this is quite a commonplace feat which it will always perform.

4) In the case where shift is made from high speed to low speed or vice versa, efficient navigation can be carried out.

In Fuji Voith-Schneider propeller ships, without changing speed of main engine, by making eccentricity of propeller smaller, low speed can be obtained and therefore their navigation efficiency is far higher than for screw propeller ships.

5) Durability in navigation compared with screw propeller ship is markedly higher.

According to reports of the German former navy, it was stated that: " Even when the sea was heavy, compared with ordinary screw ship, pitching and rolling of ship was quiet and activities were carried out smoothly. For instance, when navigating against the waves, even in heavy sea, our ship did not receive shocks and also at high speed, it was very rare that waves came over bridge on the bow. Further, even in the case navigation was done while being exposed to waves right from the side, not only inclination angle was small compared with other ships but frequency of tilting was less ".

This is in the case of screw propeller, if waves are high, screw propeller will be exposed in the air and motion will become unstable, but in Fuji Voith-Schneider propeller ship, because propeller is attached firmly to ship bottom, during operation pressure on the part to which propeller is attached is low and even in the case propeller is equipped at the stern, this part will not easily be separated from the water surface.

6) Able to navigate in shallows better than screw propeller boat of same output and can make damage of blade less.

It is possible to make draught for propeller part smaller than for screw propeller. That is, because length of propeller blade is shorter than diameter of screw propeller of same output.

7) When a towing rope coils round propeller it can be removed easily.

When a rope gets entangled with propeller, it requires generally a considerable amount of work to disengage this, but in the case it gets entangled with this propeller, by make its blade angle zero, it can reliably be made to slip off under the blades.

8) In the case of ferry boats where run and stop are comparatively frequent, compared with screw propeller boat, it is possible to reduce output of its main engine.

The Fuji Voith-Schneider propeller ship as described above compared with screw propeller ship is markedly superior and therefore compared with screw propeller ship, time required for arrival and departure at piers can be shortened and even with more or less sacrifice in navigating speed, it can be made to ply the same number of runs as a screw propeller ship. In addition, because output of a ship main engine is proportional to the third order multiple of speed, it is advantageous to increase number of runs by shortening navigating time without raising speed.

9) Number of crew can be cut down and moreover it is possible to give passengers a pleasant feeling and confidence to cargo owners.

As mentioned before, go-ahead or -astern and speed control can be carried out by one crew member and ship can be kept at any desired position and direction which all make out a clear reason for this.

10) If this is installed in the bow of a large size ship having ordinary screw propeller, its manipulation ability can be greatly increased.

By installing Fuji Voith-Schneider propeller in the canal on the bow side of a ship and making it so-called steering propeller, great extension of manipulation ability is possible. Voith Company has already executed such actual examples for over 30 ships as ferry boats and other purposes.

11) Construction cost of ship will not greatly differ from that for screw propeller ship.

Propeller apparatus itself certainly is higher in price than ordinary screw propeller but parts of ship mechanism such as rudder, steering gear, stern frame, bossing, shaft bracket, etc. can be omitted and also especially in tractor type tugboats, hull can be made smaller in size.

V. RELATION OF SCHNEIDER PROPELLER WITH SHIP HULL

The Schneider propeller differs from an ordinary propeller in that:

1) Direction of rotation in relation to water surface is in perpendicular direction.
2) It is a propeller combined also for steering rudder and rudder is not necessary and consequently position of this propeller while giving thrust to ship also steers it and so it is desirable to have a position suitable for both these points.
3) Direction of thrust can be generated freely in any direction of propeller and in almost the same magnitude. Consequently, it is important to consider how this force can be displayed to the maximum extent for any direction of ship.
4) Different from ordinary propeller, propeller jet of Schneider propeller has rectangular and

moreover its upper side coincides perfectly with ship bottom. On this account, suction force due to negative pressure generated in front part of propeller has a great effect on ship hull and at the same time, special care must be paid to hull friction resistance due to water flow accelerated in its rear part. On these special conditions, detailed explanation will be given by taking various examples.

1. Considerations on Direction of Rotation of Propeller

Fig. 8 shows an example of the case of tracter type tugboat with one propeller arranged in bow of ship.

In this case, if rotation direction of propeller is shown by ω, ship receives a reaction moment in reverse direction to ω. Especially, in tugboat equip-

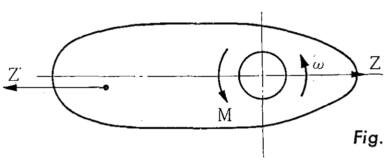

Fig. 8 Pusher type tugboat

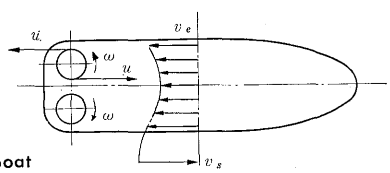

Fig. 9 Tractor type tugboat

ped with comparatively large capacity Schneider propeller for ship hull, there are cases where position of hook is somewhat deviated from center for making it roughly balance with this rotation moment.

Fig. 9 is an example of a pusher type tugboat carrying 2 Schneider propellers. If ship speed is taken as v_s, inlet speed w_e flowing into propeller due to wake is small and also its distribution as shown in the sketch is smallest at the center part of ship.

In this case, making rotation direction of the propellers the same will result in making rotation moment given to ship by 2 propellers two times and so it should always be selected that they are in opposite direction to each other.

On one hand, at the position of blade perpendicular to proceeding direction of propeller, blade without doing any work will always produce resistance due to drag. Consequently, it is necessary to consider how to reduce this drag as much as possible, for instance, as seen in Fig. 9 if both propellers are rotated, in center part of ship, it will mean that drag due to sum of relative flow speed of peripheral speed u and flowing in speed v_e will be produced.

Also, if it is rotated in opposite direction to sketch, at side wall part, it will receive reaction due to relative flow speed of sum of u and v_e.

By selecting rotation direction as seen in sketch, value of its drag will be smaller and better efficiency can be obtained.

Also, in the case 2 Schneider propellers are equipped, if distance between these propellers is made somewhat smaller, it will become a form as jet area just embraces both propellers and generated thrust will be increased. Also, on the other hand, if distance is shortened extremely, vibration occuring due to unbalance of left and right rotation or due to interference of jet from both propellers may arise and so normally taking center distance as L, we recommend to make

$$L = 1.35 \sim 1.5\,D \quad (9)$$

However, in floating cranes, ferry boats, etc., in the case importance is placed on navigating ability of ship, it needs no explanation that naturally it becomes more advantageous the longer the distance is made.

2. Position of Propeller and Towing Force Considered from Lengthwise Direction of Ship

In ordinary screw propellers, in order to increase propeller efficiency, propeller is arranged in stern of ship where wake is large and it is never mounted on the bow. However, in the case where towing force must be considered the most important factor such as with tugboats, by arranging propeller on the bow, an interesting merit can be displayed and for the best example of this, tractor type tugboat can be considered.

As has been already stated, in tractor type tugboat shown in Fig. 10, if keel of propeller front part is

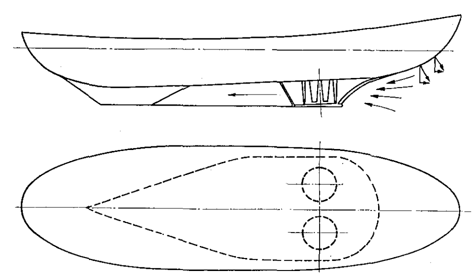

Fig. 10 Tractor type tugboat

made to incline upward, suction force due to negative pressure formed in this part will always have a component force that will propel ship in forward direction. Also, magnitude of this compared with the case where ordinary propeller is placed on the bow is larger. On this account, bollard-pull of a tractor type tugboat having bow construction of specially selected design, generally 10～15% increase is noted compared with simple body ability by water tank test.

In addition, in this case, in tractor type tugboats, because propeller comes to the lowest end during docking time, as protection of propeller, protecting plate is attached on its underside and by a few supporting pillars it is made to have enough strength to safely support hull.

This protecting plate, on the other hand in point of ability, acts just like a Kort-nozzle propeller and from experiment, an increase of thrust by 5～7% has be seen. That is, as increased part of pulling force due to arranging propeller on the bow only, at bollard-pull can be considered to attain 5～8%. Consequently, by placing Schneider propeller on bow in the case where speed of ship is not so fast even when drop of propeller efficiency due to wake is deduced, it becomes possible to generate large pulling force.

Compared with this, in the case of pusher type tugboat, generally for making disassembly and assembly easily carried out without docking and also including for the purpose of reducing wave making resistance with comparatively low speed ships of under 10 knots, it is desirable to take propeller draft as shallow as possible. Consequently, in this case, ship bottom of propeller front part has a downward sloping surface and attraction due to negative pressure of this part produces a component that pulls ship backwards. According to experimental data, bollard-pull in this case, compared with ability of unit body is generally seen to drop by 5～10%.

Fig. 11 shows comparison of bollard-pull for tractor type tugboat and for pusher type tugboat. As abscissa, PS per jet area is taken and bollard-pull per unit PS is shown.

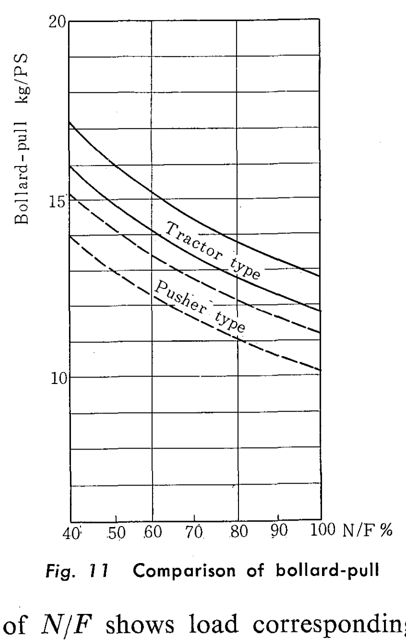

Fig. 11 Comparison of bollard-pull

100% of *N/F* shows load corresponding to about max. rating. As is clear from drawing, for 100% load, in the case of pusher type, it is 10.1～11.2 kg/PS and for tractor type, this becomes 11.8～12.8 kg/PS and there is a difference of about 20% between the two. Till the present, announcements on bollard-pull accurate values regarding Voith-Schneider propeller were few and also in this country only a part of values for pusher type has been shown and it has been reported that there is a great difference compared with variable pitch propeller or Kort-nozzle propeller. However, as is clear from Fig 11, for instance, in the case such as for tractor type, pull per PS is extremely large and if Voith-Schneider propeller is equipped, during goastern time or when sidewise thrust is generated, no great change will be produced in its value. Considering this together, for ships engaged in operation under various conditions such as tugboat, it can be said that there is no better propeller than the VoithSchneider propeller.

3. Arrangement and Speed of Propeller Considered from Lengthwise Direction of Ship

In construction with propeller arranged on the bow, due to aftercurrent of propeller it will be attended by increase of friction resistance of ship bottom which is especially marked when speed of ship is fast. This fact together with drop of efficiency due to having propeller attached to a part where accompanying current is small makes it not desirable for high speeds. On this account, it is important to contrive it so that propeller jet will not make contact with ship bottom as far as possible, for instance, as shown by sketch in tractor type tugboat of Fig. 10 by making ship bottom behind propeller in triangular form so that area of ship bottom contacting propeller jet is made as small as possible. However, it is a matter of course that with construction having propeller arranged on ship bow, ship speed cannot be desired, for instance, considering self navigating results in tractor type and pusher type, for ship speed of above 8 knots, pusher type is more advantageous.

The cases where arranging propeller on the bow is advantageous are as followings.

1) For various kind of tugboats operating normally at ship speeds of from zero to 4 or 5 knots.
2) For floating crane with standard ship speed of 5 to 6 knots. But in this case, propellers are arranged both on bow and stern.
3) For various kind of ships with ship speed of 7 to 8 knots, but in this case, more often 2 propellers are provided on bow and stern.

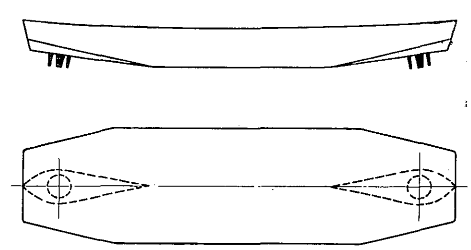

Fig. 12 Ferry boat

For designs for ship speed above 12 knots, propeller should always be arranged in the stern.

Fig. 12 shows ship bottom construction of a ferry boat provided with wedge on its bow and stern and designed so as to reduce friction resistance against propeller jet.

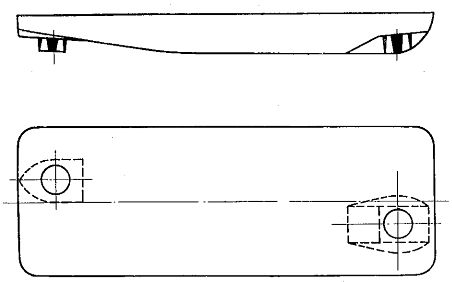

Fig. 13 Floating crane

Another merit of propeller arrangement of this case is that because there are steering positions on bow and stern, turning ability of ship is overwhelmingly superior and for cases where many number of to and fro trips have to be made, departure and arrival time of ship can be cut down immensely.

Fig. 13 shows one construction in the case of a floating crane where the propellers fore and after are not placed in the center but attached a little eccentrically.

This is for the purpose of preventing drop of efficiency in the behind propeller due to the propeller jet from the front propeller and at the same time by making distance between propellers large, it also has the merit of being advantageous in manipulating the ship.

Next, in the case of propeller arranged in the stern, if distance from propeller center to stern tip is too short, disturbance will be caused in propeller jet giving thrust but on the other hand, if made too long, because increase of friction resistance due to propeller jet will be caused, it is recommended to be selected by the following formula.

For ordinary ships

$$A=1.2\sim2.0\,D \qquad (10)$$

For the case as shown in Fig. 12 and Fig. 13 where projection is attached to ship bottom

$$A=2.0\sim2.5 \qquad (10')$$

Here D denotes propeller diameter, A distance to stern tip at water surface from propeller center.

Also regarding propeller draft of the case when propeller is attached on the stern.

1) In ships of ship speed under 10 knots, it is desirable to make it as shallow as possible or 50∼200 mm ordinarily from water surface to blade upper tip. This has the action of absorbing waves generated at ship side and because it will reduce wave-forming resistance, ability will be raised.
2) In the case draft is made shallow, when ship speed becomes about 13 knots, waves on ship side will develop greatly and suction phenomena of air in propeller will appear and at the same time stern waves will increase. Consequently, when ship speed is fast, it is best to select normal depth as 300∼600 mm.

Further, for ship speeds where Voith-Schneider propeller can be used, although there are actual cases of being applied for ships with above maximum 20 knots, as there is anxiety of cavitation phenomena, it is considered as normally 16 to 18 knots.

VI. OPERATING FEATURES AND METHOD OF OPERATION OF SCHNEIDER PROPELLER

Already in our country also the state has become such that over 40 vessels equipped with Voith-Schneider propeller are in service but as there are still many unclear points in selection of their PS and also on their method of operation, in the following, a few of these points will be described.

1. Eccentricity that makes Bollard-pull Maximum

Now if flow-in speed of propeller is taken as v_e (m/s), peripheral speed as u (m/s), radious of propeller as R (m), jet surface area of propeller as F (m^2), thrust coefficient K_s and moment coefficient will be respectively,

$$K_s=\frac{S}{\frac{\rho}{2}\cdot u^2\cdot F} \qquad (11)$$

where S shows thrust in kg, $\rho=r/g$.

$$K_d=\frac{M}{\frac{\rho}{2}\cdot u^2\cdot F\cdot R} \qquad (12)$$

where M shows moment kg-m around propeller rotation shaft.

Also, if propeller modulas is taken as λ, it will be:

$$\lambda=\frac{v_e}{u} \qquad (13)$$

propeller efficiency will be shown by,

$$\eta_p=\lambda\frac{K_s}{K_d} \qquad (14)$$

Also, on one hand, theoretical propeller efficiency η_{th} is,

$$\eta_{th}=\frac{2}{1+\sqrt{1+C_s}} \qquad (15)$$

where C_s is load coefficient and we have

$$C_s=\frac{S}{\frac{\sigma}{2}v_e^2\cdot F}=\frac{K_s}{\lambda^2} \qquad (16)$$

Consequently, we get

$$\eta_{th}=\frac{2}{1+\sqrt{1+\frac{K_s}{\lambda^2}}} \quad \text{.............................(17)}$$

If utilizing rate of propeller is taken as ξ, it will be shown by

$$\xi=\frac{\eta_p}{\eta_{th}}=\frac{\lambda \cdot K_s+K_s\sqrt{\lambda^2+K_s}}{2\,K_d} \quad \text{..............(18)}$$

If ship is not advancing forward, it will be sufficient to take $\lambda=0$ in formula 18.

That is, we get

$$\xi\,(\lambda=0)=\frac{K_s\sqrt{K_s}}{2\,K_d} \quad \text{.............................(19)}$$

If fraction in the case propeller is equipped is taken as Z and tractive coefficient shown by K_z, in above formula, it will be sufficient by replacing S with Z and K_s with K_z and utilizing rate $\xi'(\lambda=0)$ will shown by

$$\xi'\,(\lambda=0)\frac{K_z\sqrt{K_z}}{2\,K_d} \quad \text{................................(20)}$$

In free running condition, if eccentricity that produces maximum efficiency $\eta_{p\max}$ is taken as $e_{\max}$, value of $\xi'(\lambda=0)$ corresponding to any eccentricity e will be as shown in Fig. 14, As is clear from the drawing, for $e_{\max}$, eccentricity to make bollard-pull maximum is about 80% and if manipulating point is shifted over this, pull per PS rather diminishes. Also, if moment coefficient for $e_{\max}$ is

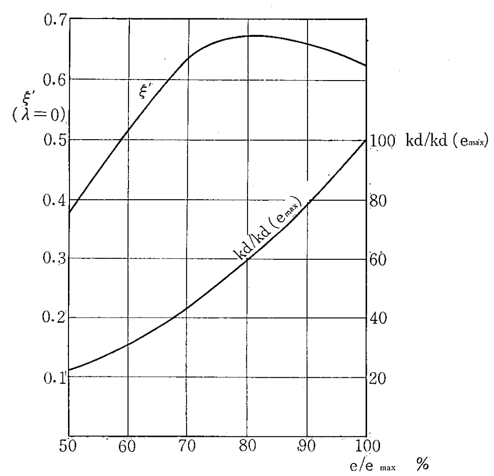

Fig. 14 Relation between eccentricity and $\xi\,(\lambda=0)$

taken as $K_d(e_{\max})$, pull coefficient $K_d(z_{\max})$ making utilizing rate $\xi'(\lambda=0)$ max. will be

$$K_d(z_{\max})\cong 0.6\,K_d(e_{\max}) \quad \text{.......................(21)}$$

Normally, design point for bollard-pull is set around $0.8\,e_{\max}$ and for such cases as tugboats, moment coefficient corresponding to maximum self-navigating speed is approximately equal to moment coefficient of $0.8\,e_{\max}$ in bollard-pull or somewhat greater in general.

2. Displacement of Steering Point

Fig. 15 shows relation of two servomotors that perform shifting of navigating point. In the drawing, if stroke of speed changing servomotor for controlling eccentricity in lengthwise direction of ship is taken as S_1 and stroke of steering servomotor for controlling eccentricity in sidewise direction is taken as S_2, range divided into rectangulars is shifting range of navigating point.

However, the part falling on its corner always is larger than $e_{\max}$ being an unneccessary part and at the same time it is impossible to be operated in this range. In navigating points selected by our Company,

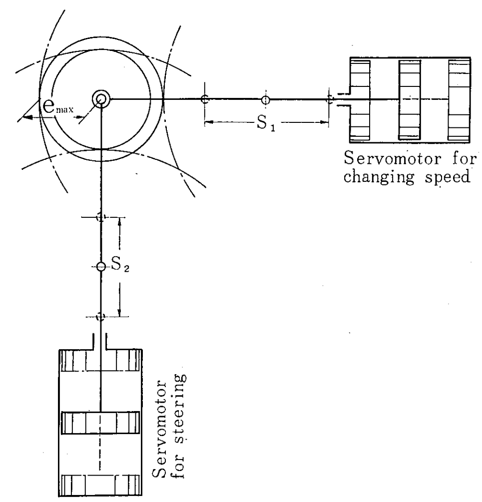

Fig. 15 Layout of servomotor

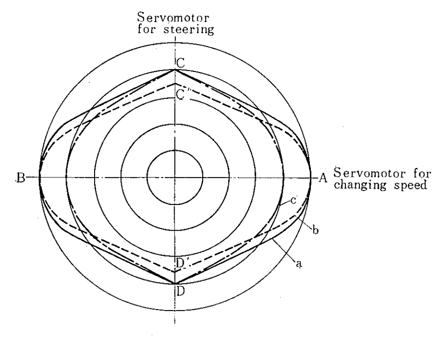

Fig. 16 Operation diagram

shifting amount is being limited by the form as shown in Fig. 16. That is in the motion of pilot valves that control stroke of both servomotors, by means of auxiliary link mechanism, it is designed so that various kinds of operation characteristics corresponding to various purposes of ships can be obtained.

As has been already explained by Fig. 14, if engine has too much capacity, when eccentricity is made to increase by condition of bollard-pull, thrust generated in vane will increase by about 1.5 times and naturally such a thing should be avoided. Also, Voith-Schneider propeller can act as a rudder at the same time and when turning ship, it is sufficient to change generating direction of this thrust only.

However, at the instant of starting steering, to this direction inlet speed of water is zero and it becomes just as if propeller is operated under condition such as bollard-pull.

By paying careful consideration to the above fact, shifting amount of navigating point should be decided. As shown in Fig. 16, shifting amount of navigating point in fore and after direction of ship which is necessary for obtaining $e_{\max}$ is given and shifting amount to give thrust in sidewise direction, in case of tugboat is designed normally so that it can give about 0.8 $e_{\max}$. (*a* in Fig. 16) During free running, when for making a quick turn steering handle is turned to its utmost, by compensating link mechanism it is so designed that regardless of position of speed changing servomotor, manipulating point will always come to *C* point or *D* point and propeller will generate thrust completely sidewise and at same time, made so that its magnitude also will only what will be sufficient for propeller. This fact is not only safe for propeller but at the same time prevents extreme sidewise force being applied to ship and eliminates danger of capsizing by limiting its inclination. In Fig. 16, *b* is the limiting range of steering point shifting amount for the case where Schneider propeller is used for high speed ship.

Efficiency of Voith-Schneider propeller roughly becomes highest for propeller modulas 0.7～0.75. Consequently, in case of high speed, its peripheral speed is somewhat increased so that necessary ship speed will be obtained and thrust will naturally increase in proportion to quadratic multiple of peripheral speed. Consequently, in order to suppress thrust produced in blade under a certain value, it is a matter of cause that it must be operated with a small eccentricity and shifting of steering servomotor should be limited to about 0.7 $e_{\max}$.

Next, if explanation be given about tug-time in tugboat, ordinarily tugboat operation is done at 0～5 knots and if eccentricity in lengthwise direction also is not limited when speed changing servomotor is fully opened, overload to propeller will happen as has already been stated. On this account, stoppers are separately provided which are arranged on the control stand and limit, during tug time stroke of speed lever that limit speed changing servomotor. Fig. 16 shows shifting range of steering point for this case and the crew can do the operation without anxiety.

3. Driving Engine for Schneider Propeller

Voith-Schneider propeller without changing rotating direction of engine, can generate large enough thrust as necessary in any desired direction by only controlling position of navigating point position from the bridge and so its driving engine may have extremely simple construction and moreover time for manipulating ship can be shortened to the utmost.

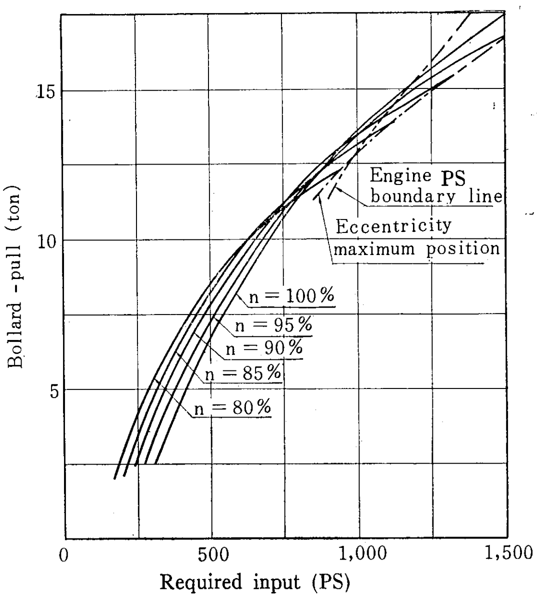

Fig. 17 **Relation between engine speed and bollard-pull**

However, in order to operate still more economically, explanation will be given on the case where an apparatus that makes it possible to change engine speed is added.

Eccentricity that makes bollard-pull maximum is normally at a position corresponding to 80% of e_{max}. and in tugboats during tug time if eccentricity is roughly fixed at this position and operated, as for propeller, pull per PS can be displayed to the maximum limit. Fig. 17 shows bollard-pull when engine speed is changed based upon actual measured results of a tractor type tugboat. In this case, propellers were 2, engine 600 PS at rated speed and permissible bollard-pull to engine is $2 \times 7\,t$. As is clear in drawing, if it is considered with propeller input 2×250 PS, pull of 6.6 *t* at rated speed and 8.5 *t* for 80% speed is being generated.

Bollard-pull per PS is respectively 13.7 kg and 17 kg showing difference of about 30%. Consequently, in tugboats, during operation time not requiring so much tugging force compared with its capacity, it is more advantageous to use it reducing speed of engine as can be seen from Fig. 17 also, if down to about 80% of rated speed engine speed is changed by steps or continuously, it is economical even when considering drop of engine efficiency due to decrease in speed.

Also on one hand, even in ships that carry out only self-navigation, according to maximum speed and regular navigating speed by changing engine speed, more often efficiency will rise and become economical. This fact is similar to speed control in variable pitch propeller and it is a point that our customers adopting the Voith-Schneider hereafter will do well to consider.

VII. CONCLUSION

In the above, on the Voith-Schneider propeller, points that from its merits and facts that hitherto have comparatively not been known have been picked up and enumerated and on this occasion, we request all our customers who have already adopted Voith-Schneider propellers to give us your opinion or views on unclear points in handling, on construction or on operating features, for which we would be very thankful. Also, we sincerely hope that all of our shipping business circles will give us your kind support and guidance.

ATTACHED TABLES

PS. and bollard-pull for each type are shown in Table 2 and 3 for the convenience of projection when using Fuji Voith-Schneider Propeller.

Table 2 **Propeller required PS**

Type	Length of blade (mm)	Number of blade	Continuous PS/30 minutes max. PS	
			When pull is taken as main factor	When speed is taken as main factor
12 E	750	4	190/210	240/265
14 E	890	4	265/290	335/370
16 E	1000	4	345/380	435/480
18 E	1150	4	440/485	565/620
18 E	1150	5	470/515	600/660
20 E	1250	5	575/625	740/810
24 E	1500	6	820/900	1080/1190
26 E	1650	6	975/1075	1270/1400
28 E	1750	6	1100/1225	1450/1600
30 E	1900	6	1300/1425	1680/1850

N.B. Value of PS numbers in above table is standard value. Actually, your operating condition put togather for both pulling power and speed determine engine PS and so please consult our Company in each case.

Table 3 **Bollard-pull**

Type	Length of blade (mm)	Number of blades	Comtinuous operation		30 minutes max. PS	
			for pusher	for tractor	for pusher	for tractor
12 E	750	4	1.95	2.25	2.1	2.4
14 E	890	4	2.7	3.15	2.9	3.3
16 E	1000	4	3.5	4.05	3.75	4.35
18 E	1150	4	4.55	5.25	4.85	5.6
18 E	1150	5	4.7	5.45	5.0	5.75
20 E	1250	5	5.65	6.6	6.2	7.0
24 E	1500	6	8.45	8.75	9.0	10.2
26 E	1650	6	10.1	11.6	10.5	12.0
28 E	1750	6	11.6	13.4	12.2	14.0
30 E	1900	6	13.3	15.2	14.2	16.3

N.B. According to good or bad form of ship, bollard-pull will vary somewhat.