

# Design concepts of propulsion and steering system for hotel unit of two-segment inland waterways ship

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## ABSTRACT

*This paper presents design assumptions and two conceptual design solutions of the propulsion and steering system for the hotel barge constituting a part of two-segment inland and coastal navigation ship. Both presented solutions are based on application of a small-power bow thruster with fixed propeller placed in a rotatable nozzle. In one of the solutions the propeller is driven by a hydraulic motor and in the other – by an electric motor. In both solutions the thruster's column rotating is driven by a hydraulic cylinder.*

**Keywords** : shipboard devices, hydraulic drives, electric drives

## INTRODUCTION

The designed two-segment inland waterways ship consisted of a pusher and hotel barge is intended for coastal and inland navigation on the route Berlin – Toruń – Kaliningrad.

A few design concepts of the propulsion and steering system for the ship were elaborated, including diesel-electric and diesel-hydraulic one, with application of two azimuthing propellers (rotatable thrusters).

Also, a design concept was prepared of an articulated joint connecting barge and pusher in a way which makes it possible to control pivoting both the segments against each other.

Both the above mentioned driving systems ensure relevant navigating and manoeuvring capabilities of the pusher and the entire push-train on the route. However still remains a troublesome problem of passing the train through many locks whose dimensions do not allow for accommodation of the whole train in them. Hence it is necessary to pass the pusher and barge separately. If the passing of the pusher which has its own propulsion system and good manoeuvrability would not constitute any problem, to ensure the safe and effective passing of the barge may be very troublesome if it is not equipped with suitable devices for realization of the operation.

The design conditions and assumptions as well as two concepts of solving the problem are presented below.

## DESIGN ASSUMPTIONS AND OUTLINE OF GENERAL DESIGN CONCEPT

To ensure passing the hotel segment through locks, to fit it with appropriate equipment was assumed to make it possible to realize the operation; such equipment will be characterized by the following features :

- ✱ ensuring high independence of the unit during locking operation
- ✱ providing good manoeuvrability of the unit and easiness of steering
- ✱ non-lowering voyage comfort, to a noticeable extent for passengers
- ✱ possibly low emission of vibrations, noise and polluting agents such as e.g. exhaust gas, during work of the devices
- ✱ versatility of the devices to make it possible to use them also to other operations or cooperation with other equipment
- ✱ possibly small dimensions
- ✱ relatively low cost.

Many possible solutions of the above stated problem were considered, a.o. the following systems :

- a thruster fitted with suitably formed ducts and two controllable flap valves intended for changing water jet appropriately
- a typical bow thruster and hoisting winches, e.g. mooring ones, which, after fastening the lines to quay bollards, would make it possible, in co-operation with the bow thruster, to move the barge during its entry to and exit out the lock
- a system of a few hoisting winches combined with the necessity of fastening the lines to both quays, that entails the need of appropriate outfitting the quays and makes the entire operation very complicated and troublesome
- a lowerable propulsion system consisted of a combustion engine, reduction gear and fixed screw propeller on a rotatable column
- a rotatable bow thruster with fixed screw propeller ducted in a suitably formed nozzle and driven directly by a hydraulic motor placed in an underwater pod
- a similar rotatable bow thruster but driven - through an intersecting axis toothed gear - by an electric motor vertically mounted in the barge hull; rotational speed of the motor has to be controlled by a frequency converter.

The above enumerated design concepts were subjected to a preliminary analysis consisting in defining the most important features of each of them in order to select the most favourable and focus further designing process on them. As a result it was concluded that the first of the design solutions, though improves manoeuvrability of the whole push train, makes the underwater part of the hull much more complicated and requires to install movable units, that increases hull resistance to motion and risk of failure, moreover it does not ensure an appropriately high manoeuvrability of the barge during passing through locks.

The second solution (point b) is much simpler but it lowers independence of the barge and makes locking operations longer and more complicated.

The third solution (point c) is the simplest out of all above enumerated, but it introduces many complications and lengthens the locking operations, moreover it requires suitable mooring bollards to be installed on both canal banks near the lock.

Moreover, it does not improve manoeuvrability of the whole push train during regular operation.

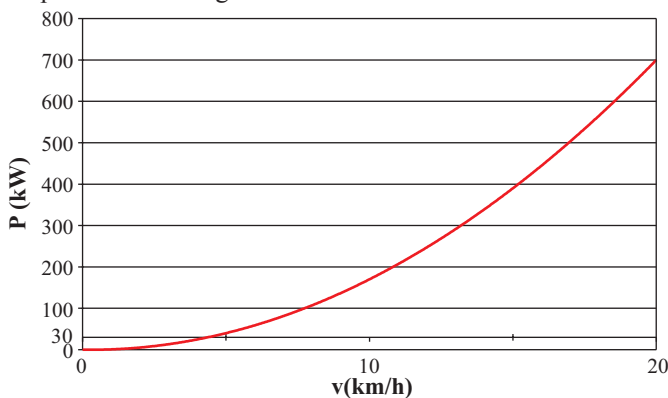
The application of the propulsion unit (point d) to be lowered to water during passing through locks requires to shape

appropriately the hull form and to ensure a required area, also on the deck of the barge. It should be also taken into account that such device and its control unit will be more complex and noise emitting during work. It may be also difficult to find a producer for such device of demanded power. It should be added that to use such unit to improve manoeuvrability of the push train during its regular operation is rather not viable because of noisy work of combustion engine and necessity of securing the propeller against failure resulting from catching on waterway bed.

Two last solutions (point e and f), where the use of rotatable bow thruster is proposed, can be considered as the most favourable out of the above enumerated ones. The rotatable thruster located on the bow ensures relatively good manoeuvrability of the barge, moreover, during ship's regular sailing especially in rough conditions it may be periodically used both for improving steering capabilities of the push train, by working as the thruster, and supporting the main propulsion system of the pusher.

As the solution based on the rotatable bow thruster was chosen for further considerations it is necessary to determine its power demand.

Also, it is necessary to take into account not only the need of bringing the barge slowly in and out the lock, but also of fulfilling the supporting function of the rotatable thruster in ship steering during voyage, as well as the function of a reserve energy source for hotel devices. To ease the task, was prepared the relationship between the power demand of the propeller and the barge speed, based on results of model tests, as presented in Diag. 1.



Diag. 1. The relationship between the power demand of the propeller and speed of the barge, for the barge draught of 1m.

After a broader analysis of both the above mentioned model tests and the propulsion-steering system of the ship as well as other technical and operational conditions it was assumed that the effective power of the propeller should be contained in the range of 20 ÷ 30 kW. For the so determined power the progressive speed of the barge may even reach the value of 3 ÷ 4 km/h.

The two design solutions of the propulsion system of the barge, based on application of the rotatable bow thruster, but differing to each other by a kind and power of propeller driving motor, are presented below.

### THE PROPULSION SYSTEM WITH THE ROTATABLE BOW THRUSTER DRIVEN BY HYDRAULIC MOTOR

In Fig. 1 the arrangement of main components of the barge propulsion and steering system in the version with the rotatable bow thruster driven by a hydraulic motor is shown in an simplified axonometric form.

From the figure it results that the system in question requires a relatively small area, of about 2,5 m in length, only; in spite

of that free access to particular devices is still maintained. The motor compartment has to be ventilated. The process will be realized by an ignition-proof exhaust fan.

During designing the system the principle of using catalogue devices or units of recognized producers was complied with, wherever it could be possible.

Tab.1. Specification of the devices and their mass.

| No.               | Name   | Mass [kg]     |
|-------------------|--|---------------|
| 1                 | GE 8065M12 IVECO electric generating set   | 1075          |
| 2                 | CELMA electric motor of 45 kW rated power and 50 rps rotational speed  | 335           |
| 3                 | A2FO4 REXROTH hydraulic pump of 50 rps rated rotational speed and 18 MPa working pressure                              | 13.5          |
| 4                 | VETUS hydraulic tank, fully equipped   | 100           |
| 5                 | Rotatable bow thruster : screw propeller and pod with hydraulic motor installed inside, being a unit of VETUS thruster | ??            |
| 6                 | Mechanism of rotation  | ??            |
| <b>Total mass</b> |  | <b>1523.5</b> |

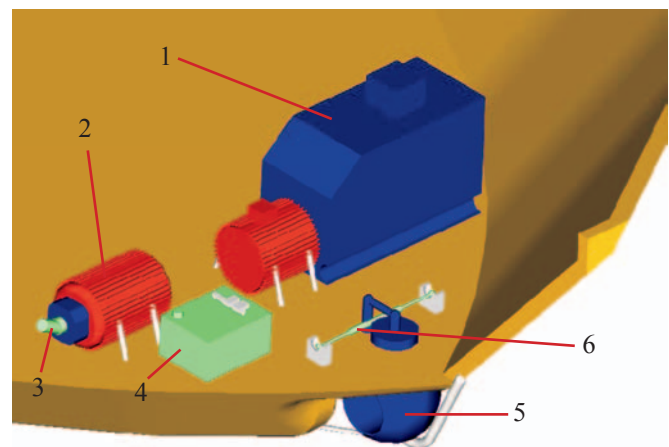


Fig. 1. The proposed arrangement of main components of the barge propulsion and steering system : 1 – electric generating set; 2 – electric motor; 3 – hydraulic pump; 4 – oil tank; 5 – rotatable bow thruster; 6 – rotating mechanism of bow thruster's column.

The rated power of the electric generating set (1) was determined with a large surplus with a view to make main hotel devices located on the barge working possible during operation of the rotatable bow thruster. Dimensions of the generating set allow to place it under the deck, near the rotatable bow thruster, that is very advantageous. The medium-speed electric generating set was chosen with a view to noise level moderating. Its estimated noisiness amounts to about 65 dBa. It may be supposed that when an appropriate acoustic insulation is installed in the bow part of the power plant the generated noise will be not troublesome for passengers. To additionally decrease noise emission by the generating set, an exhaust gas system fitted with water injection could be applied. An additional advantage of such solution is an effective limitation of unpleasant smell emission.

The rated power of the electric motor (2) driving the oil pump was chosen as large as to ensure oil supply not only to the hydraulic motor of the propeller but also to the rotating mechanism of the column of the rotatable bow thruster. In this case the high-speed motor of somewhat smaller weight and gabarites was chosen. It should be added that an alternative solution with a little less noisy medium-speed motor is also provided for. The selected oil pump (3) is of a constant capacity,

which highly simplifies the hydraulic system but somewhat limits possibility to continuously control working parameters of fed consumers. In the case when higher requirements from the side of ship owner would have to be complied with or supplying also other consumers from the system in question would be required, a multi-section pump or that of variable capacity can be applied.

To drive the screw propeller, was applied a special – directly coupled with it –hydraulic motor of small transverse dimensions, adjusted to be installed inside a pod for small-power thrusters, e.g. those produced by Vetus firm. In order to minimize hull resistance the outer surface of propeller nozzle is given the form of a sphere with pole parts cut at some parallel. In the position indicated in Fig.1 the propeller fulfils the function of a typical thruster. It should be stressed that the screw propellers used for thrusters are so shaped as to generate the same value of thrust in each of the opposite directions when direction of rotation is changed, that makes it possible to restrict the demanded rotation angle to 180° in the case of their application to the rotatable bow thrusters.

In the hydraulic system the oil tank with necessary equipment and valve block has to be applied. To assess its dimensions and mass one of the tanks offered by Vetus firm was chosen, depending on size of the system. The tanks are ribbed to ensure more effective heat transfer, that - in the case of short-lasting, short-term work of consumers - may eliminate necessity of applying an oil cooler, or reduce its dimensions.

The proposed rotating mechanism of the rotatable bow thruster's column is relatively simple and easy for realization. It will be driven by a two-piston-rod slidable cylinder to which a toothed bar is fixed. The bar will co-operate with a toothed wheel mounted on the rotatable bow thruster's column. To obtain low noisiness of that gear and to eliminate necessity of its lubrication, the toothed wheel will be made of a plastic material of good strength properties and a relatively low friction coefficient, such as. tarmamid.

The rotation angle of the column is limited to 180°, i.e. 90° both a-port and starboard. The mechanism in question ensures to reach any arbitrary direction of water jet within the whole round-angle range because the hydraulic drive of the propeller makes it possible to change direction of rotation of the propeller.

The rotatable bow thruster's column is supported by rolling bearings seated in the casing fixed to the hull in a relatively flexible way. As a result, a small inclination of the column casing against the hull is possible when significant load on the nozzle and propeller is exerted. To eliminate any excessive bending moment applied to the column, an additional slide bearing placed under the nozzle, along the column rotation axis, is used. The bearing's sleeve is seated in a special cage protecting the rotatable bow thruster against catching on waterway bed. The proposed form of the bow part of the ship hull and the above mentioned cage is shown in Fig.2 (side view) and 3 (view from below). The hull form allows for free operation of the rotatable bow thruster as a bow thruster but only within the



Fig. 2. Side view of the hull. The propulsion unit with the screw propeller of 400 mm diameter .



Fig. 3. Isometric view from below. The propulsion unit with the screw propeller of 400 mm diameter .

range of column rotation angle from 30° to 45° any effective action of water jet is not possible, that should not be of a great importance in the considered application.

### THE PROPULSION SYSTEM WITH THE ROTATABLE BOW THRUSTER DRIVEN BY ELECTRIC MOTOR

The barge propulsion and steering system with the rotatable bow thruster driven by electric motor was designed for somewhat smaller power than that given in the preceding chapter, in order to show a broader range of possible design solutions.

The arrangement of the main components of the system in question is shown in a simplified axonometric form in Fig.4.

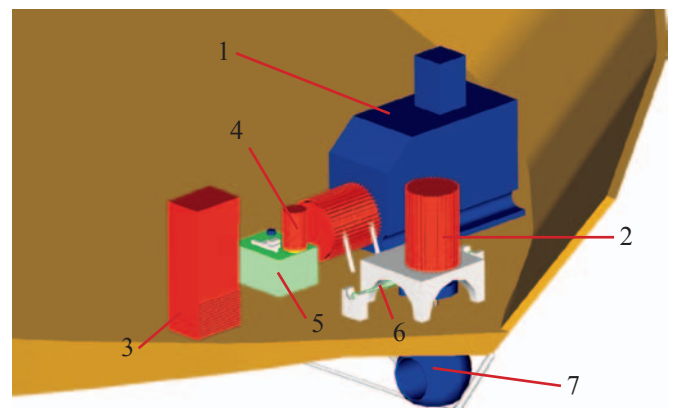


Fig. 4. The proposed arrangement of the main components of the barge propulsion and steering system : 1 – electric generating set; 2 – electric motor driving propeller; 3 – frequency converter; 4 – electric motor driving oil pump; 5 – oil tank; 6 – rotating mechanism of bow thruster's column.; 7 – rotatable bow thruster (screw propeller ducted in rotatable nozzle) .

The presented system (Fig. 4) is compact; it covers only 2,3 m in length and ensures easy access to all components. The motor's compartment is also ventilated in this case.

Like in the preceding solution also in this case the principle of applying catalogue devices or units of recognized producers was complied with, wherever it was possible.

The chosen components of the system are a little smaller and lighter than those in the preceding solution, despite a relatively large unit, the frequency converter, was added.

The propeller driving electric motor (2) is supplied from the frequency converter (3), that makes propeller rotational speed, thus thrust force, continuous changing possible.

The hydraulically driven rotating mechanism was applied to the column of rotatable bow thruster. Such decision was made after analysis of the solutions where an electric motor and either worm gear or planetary gear had to be applied; the solutions appeared more complex, larger and heavier. An additional

Tab. 2. Specification of the devices and their mass.

| No.               | Name   | Mass [kg]     |
|-------------------|--|---------------|
| 1                 | GE 8045M08 IVECO electric generating set   | 860           |
| 2                 | INDUKTA electric motor of 22kW power and 25 rps rotational speed class   | 175           |
| 3                 | VLT 5032 DANFOSS frequency converter in IP 54 casing   | 41            |
| 4                 | Sh 80-2A BESEL electric motor of 0,75W ? and 45,7 rps rotational speed class   | 7.8           |
| 5                 | Oil tank   | 55            |
| 6                 | Mechanism of rotation  |               |
| 7                 | Rotatable bow thruster : screw propeller fitted with intersecting axis toothed gear installed inside the pod, being a unit of VETUS thruster | ??            |
| <b>Total mass</b> |  | <b>1138.8</b> |

argument speaking for the hydraulic drive is the possible application of the hydraulic system to driving shipboard devices, e.g. mooring-anchoring winch. It should be added that during the regular sailing of both joined ship's segments the hydraulic system will not operate even if the rotatable bow thruster is used only as a typical bow thruster.

The relatively small dimensions of the nozzle of the rotatable bow thruster make it possible to shape much more simply the bow part of the hull, that can be observed in Fig.5 and 6. The hull form is simpler in manufacturing and ensures to make effective use of water jet in the whole range of possible angular positions of the column of the rotatable bow thruster.



Fig. 5. Side view of the hull. The propulsion unit with the screw propeller of 300 mm diameter.

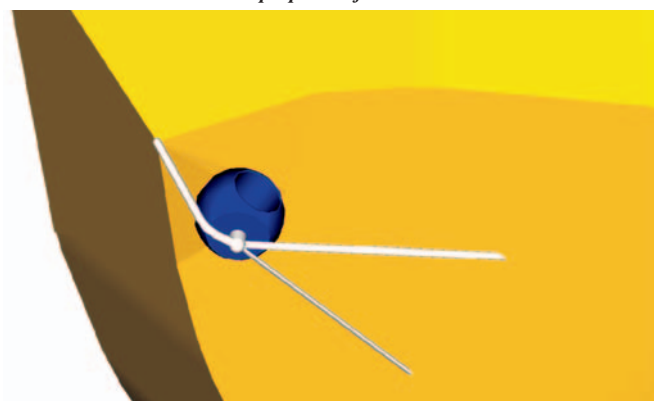


Fig. 6. Isometric view from below. The propulsion unit with the screw propeller of 300 mm diameter.

## CONCLUSIONS

- Both the described design solutions based on the rotatable bow thruster, in spite of the differences in ways of realizing propulsion and steering functions, do not differ much to each other in gabarites, however the solution with the electrically driven propeller demands a smaller power. Though

this solution occupies somewhat greater area, total mass of both systems is comparable

- The estimated efficiency of the system with the electrically driven propeller will be greater by a few percent than that of the system with the hydraulically driven propeller even if to take into account that the first system additionally contains the intersecting axis toothed gear and frequency converter. Both the additional units are of so high efficiency (abt. 98%) that the fact of their use does not change superiority of general efficiency of the first system. It should be stressed that the efficiency criterion is rather not decisive in selecting an optimum solution of the systems in question because of their rather small power values and small differences in total efficiency as well as an short-term and short-lasting character of work of such systems.
- A more important criterion is level of emission of noise, vibrations and pollution agents as well as reliability and simplicity of operation and maintenance of a system. Also from this point of view the system with the electrically driven propeller seems to be a little more favourable. The location of the power plant in a small compartment in the bow part of the barge makes it possible to lower noise level by applying a soundproof insulation to walls of the compartment. This is important as in its neighbourhood passenger cabins may be situated.
- In the case of staying the barge in an undeveloped site the electric generating set installed on the barge may serve as a reserve electric energy source to supply hotel equipment as well as shipboard devices such as : mooring - anchoring winches, collapsible aerial mast, various lifts and covers.
- One of the most important advantages of the system with the hydraulically driven propeller is providing, for the drive transmitting elements, a good protection against overload which may happen in the case of an increased resistance of the ship propeller to motion, or even its entire locking, due to entangling in nets, ropes or other garbage elements; this way risk of a serious failure of the rotatable bow thrusters may be greatly lowered.
- In the opinion of the authors the above presented design concepts constitute a good basis for selecting the most favourable solution of the propulsion and steering system for the barge, to be elaborated in the preliminary design phase.

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