Two design concepts of power plant for an inland waterways passenger ship intended for operating on BERLIN – KALININGRAD route

Damian Bocheński, D.Sc., Eng.
Jacek Rudnicki, D.Sc., Eng.
Gdańsk University of Technology

ABSTRACT

This paper presents two most probable design solutions of power plant for a two-segment passenger ship intended for operating on inland waterways of Poland, Germany and Russia. Preliminary designs of the main power plant to be installed on the pusher are presented, as well as requirements for the auxiliary power plant to be placed on the barge are outlined.

Keywords : Inland waterways passenger ship, ship power plant, ship propulsion systems

INTRODUCTION

The passenger ship intended for operating on inland waterways of Poland, Germany and Russia is designed as a two-segment unit consisted of a pusher and barge. Such system is conditioned by characteristics of the waterway on Berlin-Kaliningrad route. Along the route are located 24 locks of the dimensions which make it possible to accommodate ships not longer than 55 m and not broader than 9 m [7].

With taking into account the assumptions concerning equipment and mode of operation of the ship the variant consisting in the idea of the main power plant to be installed on the pusher and the auxiliary power plant to be installed on the barge, was adopted.

The main power plant is intended for providing energy for ship propulsion as well as supplying all electric energy consumers (both on the pusher and barge) in all states of the ship's operation. In preliminary design phases it was assumed that the best solution of the ship's propulsion system would be a two-propeller system with two fixed screw propellers ducted in nozzles [6]. Among possible propeller driving systems the mechanical one with two high-speed diesel engines operating through reversing-reduction gears seems to be most economical [3,4]. An alternative solution is the diesel – electric drive.

The auxiliary power plant installed on the barge is first of all intended for providing energy to drive an auxiliary propeller located on the bow of the barge as well as for supplying electric energy consumers on the barge during locking operations when the two segments are disconnected.

Caterpillar and Volvo Penta engines are recommended as the main and auxiliary engines. The choice of the firms was preceded by the relevant analysis presented in [1,2].

In the preliminary design phase the Volvo Penta engines and electric generating sets were assumed [5]. Final selection of a producer of engines can be done during further design phase after consulting the ship owner. In the case of the diesel electric power plant, electric motors and frequency converters are additionally included into the main propulsion system. It was decided to apply EMIT electric motors and Danfoss converters [2,5].

POWER PLANT WITH MECHANICAL (DIESEL ENGINE) DRIVING SYSTEM OF SCREW PROPELLERS

Choice of a main propulsion system and electric plant is the crucial part of the preliminary design of the power plant. For the power plant with diesel-engine driving system of screw propellers the following elements of it were selected on the basis of the performed analysis [3,4] :

- ★ Two D9MH Volvo – Penta main diesel engines developing 261 kW each at the rotational speed of 1800 rpm
- ★ Two MG5114DC-E Twin Disc reversing-reduction gears installed directly on flywheel casings of main engines and fitted with thrust bearings. Gear reduction ratio equal to 3,2:1
- ★ Two D7A T/UCM274F Volvo – Penta electric generating sets of 108 kW output power each, 3×415 V voltage and 50 Hz frequency.

On the pusher the engine room of 8 m in length (between 4th and 12th abscissa), 8.5 m in breadth and 2.5 m in height,was provided [6,8]. However it should be added that due to the applied form of the stern the ship's hull bottom in the region of the engine room has not a rectangular shape of 68 m^2 area, but it has a trapezoid-like shape of the area of only about 50 m^2. The propeller shaft-line spacing has to be 6 m.

In order to satisfy the requirement concerning the propeller shaft-line spacing of 6m the main propulsion engines together with the reversing-reduction gears must be shifted fore. The coupling flange of the gear will be then located between 8^{th} and 9^{th} abscissa. The main engines should be placed on their foundations in such a way as to get the axes of output shafts of the reversing-reduction gears located at the height of 0.5 m above the ship's bottom. The propulsion shaft-line axes should be parallel to the base plane and plane of symmetry of the ship.

The electric generating sets will be located closer to the stern, symmetrically on both sides of the ship's plane of symmetry. Auxiliary devices of the power plant will be arranged in two regions of the power plant : between the electric generating sets and between the main propulsion engines. In both the cases the arrangement of the engines and devices will be such as to ensure possible passage from their control and operation posts to escape routes.

All diesel engines (main and auxiliary) will be fresh-water cooled. Heat will be absorbed by outboard water within water-water coolers. Each of the engines will be fitted with the fresh-water and outboard-water circulating pumps driven by engines. Water coolers with thermostatic valves and expansion tanks will be also suspended on the engines.

An outboard-water pump driven by a separate electric motor will be installed to absorb heat from other devices (oil coolers of reversing-reduction gears, cooling medium condenser of air--conditioning control unit, reefer store cooler, possible cooling system of bearings etc).

The outboard-water main will be situated along 11th abscissa. Water intake will be arranged from two sea-inlet valves shifted to each other by one frame spacing.

Every diesel engine will be fitted with one lubricating oil circulating pump driven from the engine, double oil filter and oil cooler (cooled with outboard water) [10]. Lubricating oil purification process in centrifugal separators is not taken into account.

Waste oil will be pumped from engine oil sumps to waste oil tank by means of an oil transport pump. A fresh-oil storage tank will be also included in the system. To transport the oil inside the ship as well as to discharge the waste oil out of the ship, an oil transport pump driven by a separate electric motor will be installed (possible application of hand –operated pump is also taken into account because of low flow rates and sporadic use of the pump).

The reversing-reduction gears are equipped with a circulating pump, filter and oil cooler cooled with outboard water.

Every Volvo – Penta diesel engine will be fitted with a fuel supply pump driven from the engine. The fuel supply pumps will suck in the fuel directly from the storage tanks (placed just behind the engine room bulkhead).

As the application of Marine Gas Oil (MGO) is assumed no centrifugal separators are provided for fuel oil. An electrically-driven fuel transport pump is provided to pump fuel oil to and from the tanks (i.e. the storage tanks on the pusher and barge as well as overflow tank) and to discharge the fuel oil out of the ship if necessary.

Every diesel engine will have its separate exhaust gas duct leading outside the ship. Outlet of exhaust gases through the ship's stern is proposed. The gas exhausts will be so situated as not to allow to suck in the gas from an operating engine to those not operating at all or operating only under low load.

In all the exhaust gas ducts of diesel engine, 35 dBA silencers fitted with spark catchers and an appropriate number of thermal expansion compensators will be installed. The exhaust gas ducts will be appropriately insulated.

Start-up of all diesel engines will be electric one with the use of 24 V voltage supplied from an accumulator battery. The main engines will be equipped with alternators driven from the engines, serving to charge the battery with 60 A current.

In the engine room, apart from the devices of auxiliary systems of diesel engines, will be also installed other devices being elements of other systems: fresh-water (potable and sanitary), sewage discharge, bilge, ballast and fire extinguishing one.

It is proposed to equip the ship with a common fresh- water system intended simultaneously for the purposes of drinking, washing and washing-out fecal matter. The fresh-water storage tanks will be supplemented with fresh water from land every second day. Separate systems will be installed on the pusher and barge. The water supply system on the pusher will include : two fresh-water hydrophore pumps (one to stand by), hydrophore tank, circulating pump for hot sanitary water (for washing), sanitary-water electric heater, fresh-water storage tanks, filters and fresh-water disinfection devices (optionally).

It is proposed to equip the ship with a common sewage discharge system for „black" and „grey" sanitary water simultaneously. It would be a collecting system. Sewage and waste sanitary water will be discharged to tanks and there stored, and next pumped out to land. The sewage discharge system on the pusher will include : a sewage discharge pump and sewage collecting tanks (built-in the hull).

For the bilge system is proposed the solution without any retention tanks, with one bilge pump (self-sucking-in rotary pump driven by electric motor); the ballast pump (of the same characteristics as the bilge one) will serve as a stand-by pump. Bilge water is assumed to be discharged during stays in ports.

Besides, it was assumed to fit the power plant with an air compressor (of 8 bar pressure) for auxiliary purposes. It is electrically driven and built together with 110 dm^3 pressurized air tank as one unit. And, the following devices were preliminarily selected: ballast pump, fire pump, compressor in air conditioning control unit as well as the so-called "power pack" intended for supplying hydraulic motors installed on the pusher.

The arrangement plan of the devices in the engine room is presented in Fig.1.

Tab. 1 contains the preliminary specification of the power plant equipment. Numbers shown in Fig.1 correspond with those given in Tab.1.

Tab.1. *Preliminary specification of the devices for the power plant with mechanical (diesel engine) drive of screw propellers .*

No.	Name of device	Number of pieces	Characteristics
1	Main diesel engine	2	Volvo Penta D9MH N = 261 kW n = 1800 rpm
2	Reversing-reduction gear	2	MG5114DC-E N = 261 kW i = 3.2:1
3	Electric generating set	2	Volvo Penta D7A T/UCM274F N = 108 kW n = 1500 rpm
4	Main engine silencer	2	To be delivered by the engine's producer
5	Auxiliary engine silencer	2	To be delivered by the engine's producer
6	Fuel oil transport pump	1	Q = 2 m^3/h ; p = 2 bar
7	Lubricating oil transport pump	1	Q = 20 dm^3/min p = 2 bar
8	Outboard-water pump	1	
9	Fire pump	1	Q = 40 m^3/h ; p = 6 bar
10	Ballast pump	1	Q = 35 m^3/h p = 2.5 bar
11	Bilge pump	1	Q = 35 m^3/h p = 2.5 bar
12	Auxiliary compressor	1	Q = 20 m^3/h ; p = 8 bar
13	Compressor in air-conditioning control unit	1	
14	Fecal matter pump	1	Q = 36 m^3/h ; p = 1.5 bar
15	Potable and sanitary water pump	2	Q = 2 m^3/h ; p = 5 bar

16	Hydrophore tank	1	V = 500 dm^3
17	Hot water circulating pump	1	Q = 1.5 m^3/h ; p = 2 bar
18	Water electric heater	1	Q = 20 kW
19	Power pack	1	N = 25 kW
20	Main electric switchboard	1	

DIESEL-ELECTRIC POWER PLANT

An alternative variant of the power plant in question is the diesel-electric design solution. The main propulsion system and electric power plant consist of the following elements :

- Three D9MG/HCM434C Volvo – Penta main electric generating sets. Each of 216 kW output power and the electric parameters : 3×415 V, 50 Hz
- Two Sg 355 s2 EMIT main drive electric motors of 200 kW output power each at 1450rpm rotational speed
- Two VLT Danfoss frequency converters

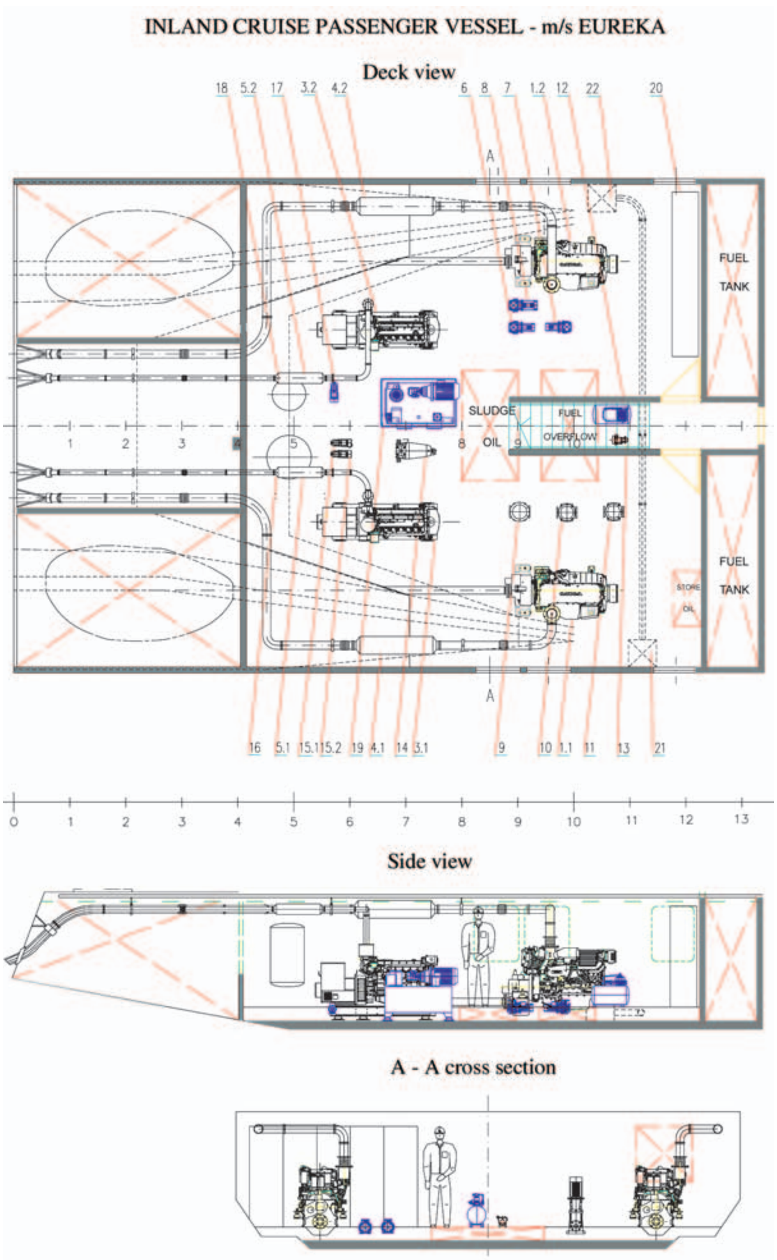

Fig.1. General arrangement plan of the power plant with mechanical (diesel engine) drive of screw propellers .

- Two NF 3 Renk-Tacke reduction gears of 2.5:1 reduction ratio.

The main drive electric motors together with the reduction gears will be shifted fore like in the case of the first solution of the power plant. The coupling flange of the gear should be located between 8th and 9th abscissa. The main drive electric motors should be placed on their foundations in such a way as to get the axes of output shafts of the reversing-reduction gears located at the height of 0.5 m above the ship's bottom. The axes of propulsion shaft-lines will be parallel to the base plane and symmetry plane of the ship [5].

Three main electric generating sets will be placed closer to the stern, symmetrically on both sides of the ship's plane of symmetry. Auxiliary devices of the power plant will be arranged between the propulsion systems containing electric motors. The minimum value of gangways between engines and devices should be not smaller than 600 mm [9].

In the case of the solution in question a greater concentration of machines and devices within the ship's engine room, hence a lower comfort level for operators of the power plant, is obtained. From the comparison of mass values of both the power plants (Tab.2) it reveals that the first variant is also a better solution as the diesel-electric power plant would be heavier by about 5 t [4].

***Tab. 2.** Mass of the main elements of two design variants of the ship's propulsion and energy supply systems [kg] .*

	Variant I	Variant II
Main diesel engines together with elastic couplings and reversing-reduction gears	4000	-
Electric generating sets	3000	7800
Main drive electric motors with gears and frequency converters	-	4100
Total	**7000**	**11900**

On all diesel engines, as in the case of the first solution, the pumps for fresh water, outboard water, lubricating oil and fuel oil supplying will be suspended (to be driven by the engines). The engines will be also fitted with fresh-water and lubricating oil coolers, oil and fuel filters, and surge tanks. The reduction gears will be equipped with an oil circulating pump, filter and oil cooler. Any centrifugal separating process of oil and fuel is not assumed, hence into the set of the auxiliary systems for diesel engines and propulsion system elements, which not will be delivered together with the engines or gears, will be included only the following: outboard-water pump, fuel oil transport pump and lubricating oil transport pump, like in the first variant of the power plant. Similarly, the outlet of exhaust gases from diesel engines will be also arranged through the ship's stern. However, as the main electric generating sets will be placed within the engine room it is proposed to place only their silencers outside the engine room. (see Fig.2).

The remaining auxiliary devices will be installed within the engine room, like in the case of the first solution, however in a different arrangement. The arrangement plan of all machines and devices within the engine room is presented in Fig.2. The preliminary specification of the devices of the diesel-electric power plant is given in Tab.3. The numbers shown in Fig.2 correspond with those given in Tab.3.

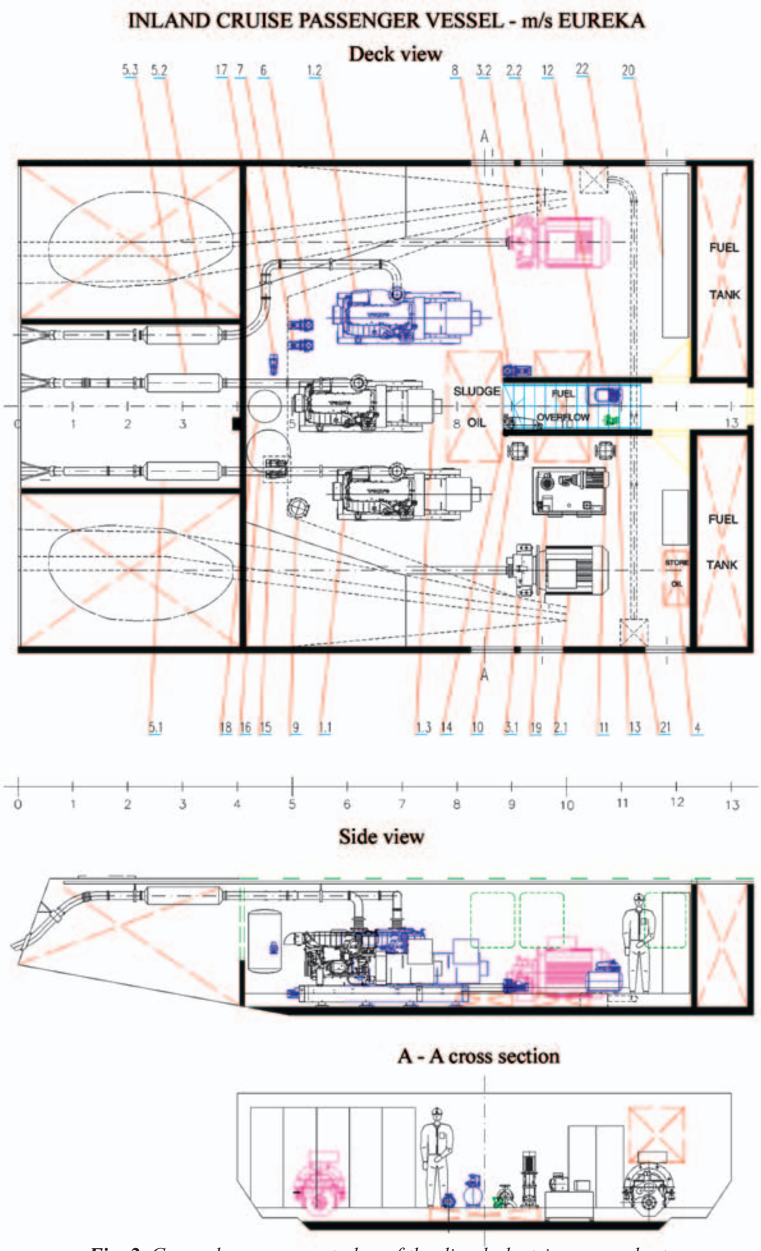

Fig. 2. *General arrangement plan of the diesel-electric power plant .*

ENGINE ROOM ON THE BARGE

A small electric generating set of about 40 – 50 kW output power will be the main device installed in the barge's engine room. Its task will be to satisfy electric energy demand in the following situations:

- ⇨ During disjoining the pusher and barge when the ship starts its locking process. The electric generating set would then cover electric energy demand of the barge. The demand would be associated a.o. with operation of a small propeller installed on the bow of the barge and intended for moving the barge out of the lock, lighting as well as with operation of the devices then necessary
- ⇨ During the maximum demand for electric energy, then the electric generating set on the barge would work in parallel with the electric generating sets installed on the pusher
- ⇨ During lying the barge along quay and its functioning as a hotel, in the case of lack of energy supply from land.

The electric generating set would be fitted with all auxiliary devices necessary for its operation (the devices suspended on the engine and driven by it will be the following : water pumps, oil pump and fuel pump). The barge should be provided with one fuel storage tank at least. Its capacity should be not greater than 100 dm^3 (or 2×50 dm^3). Unfortunately, discharging the exhaust gases is possible only through one of the barge sides. The exhaust gas duct will be fitted with a 35 dBA silencer and a spark catcher. The (L×B×H) dimensions of the electric generating set will be approximately equal to1400×800×1200 mm, and its mass to 600 – 800 kg (mean unit mass of 14 kg/kW).

The remaining devices which should be installed in the engine room of the barge are the following : outboard-water pump, sewage discharge pump, two pumps for potable and sanitary water, hydrophore tank, hot water circulating pump, water electric heater, fire pump, ballast pump, compressor in air-conditioning central unit, power pack, electric switchboard [5].

Tab.3. *Preliminary specification of the devices for the diesel-electric power plant .*

No.	Name of device	Number of pieces	Characteristics
1	Mian electric generating set	3	Volvo Penta D9MG/HCM434C N = 216 kW n = 1500 rpm
2	Main drive electric motor	2	EMIT Sg 355 s2 N = 200 kW ; n = 1450 rpm
3	Reduction gear	2	NF 3 N = 200 kW ; i = 2.5:1
4	Frequency converter	2	Danfoss VLT 6000
5	Engine silencer	3	To be delivered by the engine's producer
6	Fuel-oil transport pump	1	Q = 2 m^3/h ; p = 2 bar
7	Lubricating-oil transport pump	1	Q = 20 dm^3/min ; p = 2 bar
8	Outboard-water pump	1	
9	Fire pump	1	Q = 40 m^3/h ; p = 6 bar
10	Ballast pump	1	Q = 35 m^3/h ; p = 2.5 bar
11	Bilge pump	1	Q = 35 m^3/h ; p = 2.5 bar
12	Auxiliary compressor	1	Q = 20 m^3/h p = 8 bar
13	Compressor in air-conditioning control unit	1	
14	Fecal matter pump	1	Q = 36 m^3/h ; p = 1.5 bar
15	Potable and sanitary water pump	2	Q = 2 m^3/h p = 5 bar

16	Hydrophore tank	1	V = 500 dm^3
17	Hot-water circulating pump	1	Q = 1,5 m^3/h ; p = 2 bar
18	Water electric heater	1	Q = 20 kW
19	Power pack	1	N = 25 kW
20	Main electric switchboard	1	

In order to satisfy the requirements for proper maintenance of devices as well as for necessary width of gangways the minimum area of the engine room on the barge should be equal to about 25-30 m^2 [5].

FINAL REMARKS

- Out of the two presented variants of the power plant for inland waterways passenger ship the best solution seems to be the power plant with mechanical (diesel engine) drive of screw propellers. Firstly, such solution is the most economical [3,4], secondly, it is also better as regards mass and dimensions of the power plant.
- The diesel-electric power plant is an alternative solution which may appear more favourable in the case of yearlong operation of the ship on European waterways and a sudden rise of fuel prices in the years to come.

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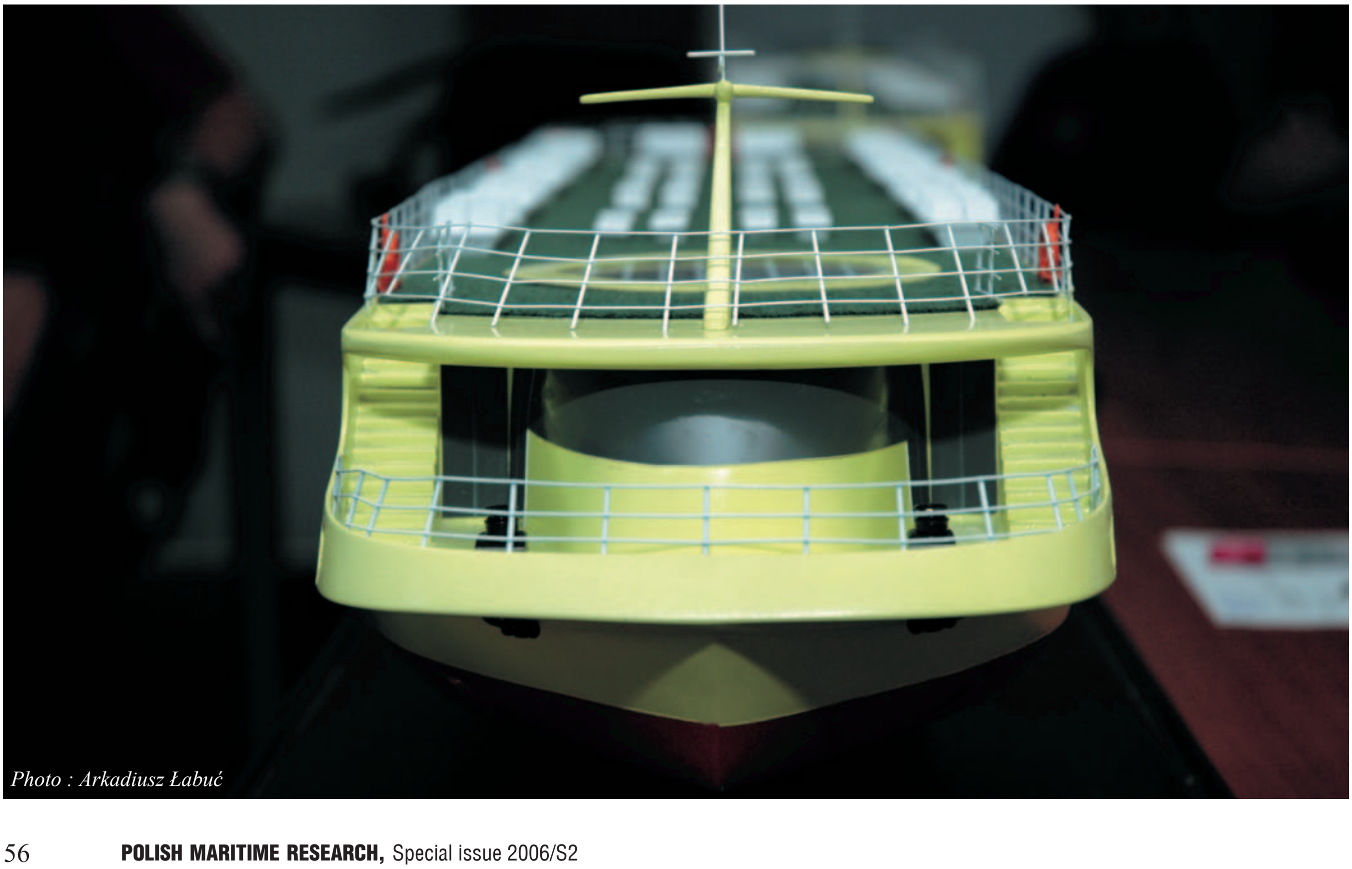

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