DESIGN CONCEPT OF DIESEL-ELECTRIC POWER PLANT OF A TWO-SEGMENT PASSENGER SHIP INTENDED FOR OPERATING ON EAST-WEST INLAND WATERWAYS OF POLAND

Damian Bocheński
Jacek Rudnicki

Gdańsk University of Technology
Ul. Narutowicza 11/12, 80-952 Gdańsk, Poland
Tel.: +48 58 3472773, fax: +48 58 3472430
e-mail: daboch@pg.gda.pl , jacekrud@pg.gda.pl

Abstract

This paper presents a concept of diesel- electric power plant of a two-segment passenger ship intended for operating on inland waterways. The conceptual design was elaborated in the frame of the EUREKA InCoWaTrans E!3065 project which concerns a new generation of environment-friendly ships for inland waterways and coastal service on east-west routes of Polish waterways system.

Keywords: *inland waterways passenger ship, ship power plants, ship power systems*

1. Introduction

The EU project called *EUREKA 3065! InCoWaTrans* concerned a new generation of environment-friendly ships for inland waterways and coastal service on east-west routes of Polish waterways system. Within the frame of the project it was the task for Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology, to elaborate a design concept of an inland waterways passenger (tourist hotel) ship intended for operating on extremely shallow and narrow inland waterways of Poland, Germany and Russia, mainly on Berlin-Kaliningrad route there and back.

The passenger ship in question (whose overall view is presented in Fig.1), is designed as a two-segment unit composed of a pusher and barge. Such system is conditioned by characteristics of the waterway on Berlin-Kaliningrad route. Along the route are located 26 locks of the dimensions which make it possible to accommodate ships not longer than 55 m and not broader than 9 m [7].

The depth of 4,8 m is assumed for the ship, which results from values of clearance under bridges located along the shipping route in question. The designed ship draught of 1,0 m is assumed with possible increasing it to 1,2 m by taking water into ship's ballast tanks. The increased draught is necessary for passing under the bridge at Łęgowo. Summing up, the main dimensions of the designed ship are as follows:

- Overall length of a single segment $L = 55{,}00\,m$
- Breadth $B = 9{,}00\,m$
- Maximum depth $H = 4{,}90\,m$
- Design draught $T = 1{,}00\,m$
- Total length of the push- train $L_C = 110{,}00\,m$

a) b)

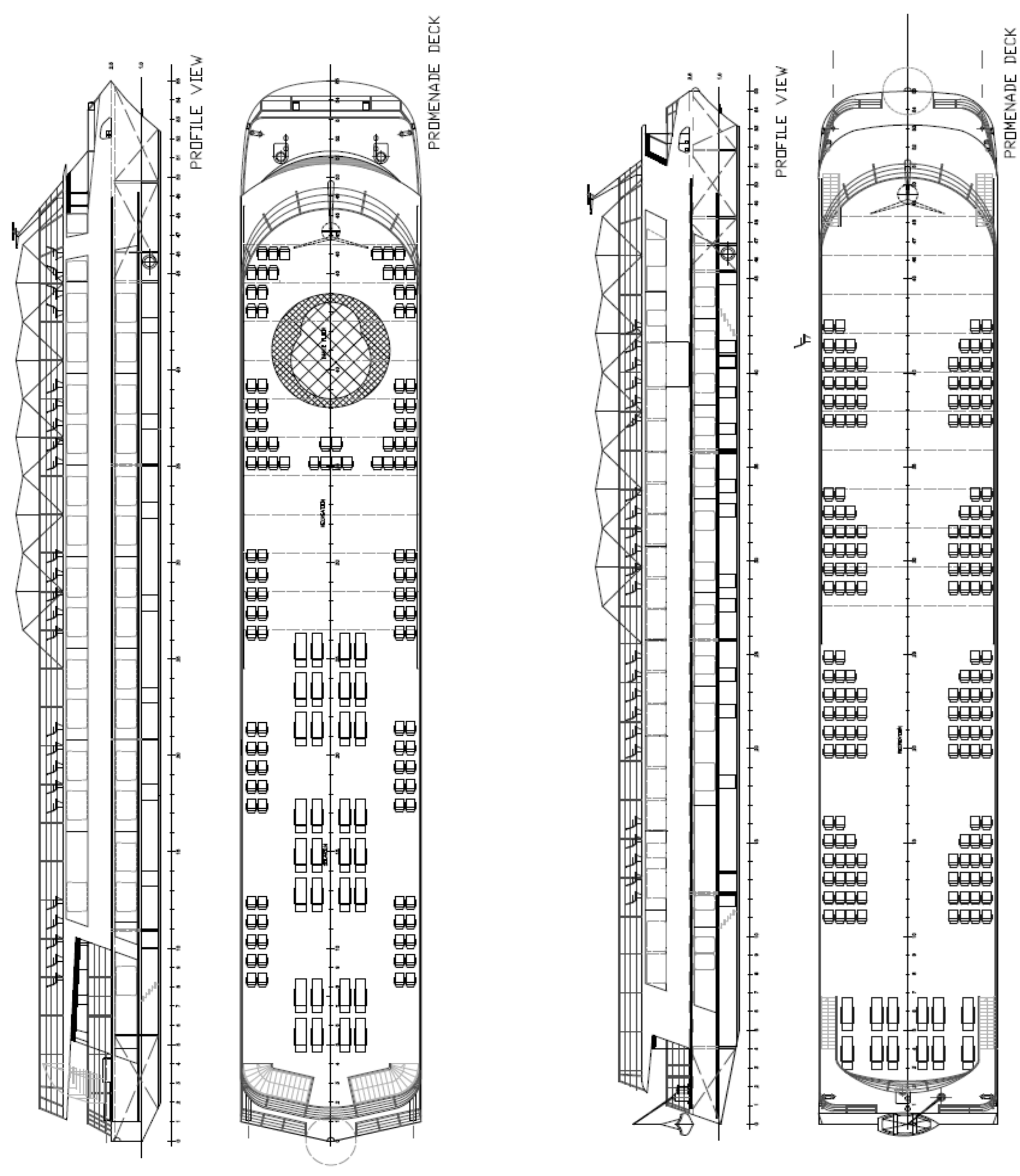

Fig.1. Overall view of the barge: (a), and of the pusher : (b)

2. Design assumptions

On the basis of comparative analyses of various propulsors it was assumed that the ship's propulsion will be consisted of two azimuthing fixed screw propellers ducted in nozzles. The propellers will be installed in the stern part of the pusher. Additionally, in the bow part of the barge will be installed an auxiliary, electrically (or hydraulically) driven propeller of about 30 kW output power. The propeller would serve as a bow thruster for the whole push-train, as well as provide - for the barge - capability to motion with the speed of about 2–3 km/h during the locking of the ship when to disconnect the train is necessary [5].

For the two assumed maximum speeds: 15 km/h in deep waters (ship delivery trials), 10 km/h in shallow and extremely shallow waters, as well as the speed of 6,5 km/h in canals, and canalized rivers, the power at the propeller cone equal to 2×150 kW, at the propeller rated speed of 600 min^{-1} [6,7], was determined. On the basis of the performed analyses [1,2,5] it was assumed that the ship in question will be equipped with a diesel-electric or diesel-hydraulic propulsion system. For electric (or hydraulic) main propulsion motors the output power of about 200 kW was determined from the analysis of service conditions of the diesel engines driving fixed screw propellers of the designed passenger ship [2].

With taking into account the assumptions concerning the equipment and mode of operation of the ship the variant consisting in the idea that the main power plant will be installed on the pusher and the auxiliary power plant - on the barge, was adopted. The main power plant is intended for delivering power for ship propulsion as well as feeding all electric energy consumers (both on the pusher and barge) in all states of the ship's operation.

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

Volvo Penta (and alternatively *Caterpillar*) engines were selected as main and auxiliary engines. The choice of the firms was preceded by the relevant analysis presented in [1]. Final selection of a producer of engines can be done during further design phases, after possible consulting the ship owner. In the case of the diesel-electric power plant, electric motors and frequency converters are additionally included in the main propulsion system. It was decided to apply *Cantoni* electric motors and *Danfoss* frequency converters [2,4].

In the opinion of the design team of the Department of Ship Power Plants, regardless of a ship propulsion variant, the main power plant should be composed of diesel engines of the same type, size and number. As far as the diesel-electric propulsion system is concerned the power plant will consist of three main electric generating sets driven by D9 MG *Volvo Penta* diesel engines of 239 kW rated power (216 kW output of one set). In the case of the diesel –hydraulic propulsion system also three D9 MG diesel engines will be installed, two of them to drive the hydraulic pumps of 200 kW power and additionally 50 kW electric generator, whereas one of them to drive the electric generating set of 216 kW output power.

During design process of the ship's power plant were made several decisions aimed at minimizing emission of pollutants, to the environment, resulting from power plant operation. The decisions consisted in:

– choice of diesel - electric propulsion system for the ship (or diesel-hydraulic one) that seems the most favourable for inland waterways ships from the point of view of environmental protection [9];
– choice of D9 MG *Volvo Penta* diesel engines (alternatively C9 *Caterpillar* engines) which can satisfy the strict requirements for emission of gaseous pollutants from combustion engines, contained in the so called Rhine Rules - stage II, established by the Central Commission for Shipping on the Rhine, which have to come in force in all EU countries beginning from 1 July 2007 [10];
– as to apply gas fuel was not possible – it was recommended to use distilled oil fuels of ISO-F-DMX category , as - light - as - possible;
– to apply wet exhaust gas outlet systems which are able a.o. to limit level of noise emitted from ship power plant to the environment;
– choice of an appropriate arrangement of tanks for fuel, lubricating and waste oil by separating them from side and bottom plating with the use of cofferdams;
– to store bilge water in a special tank so as to then discharge it to land-based receipt points in the time intervals precluding the tank from overflowing.

3. Main power plant on the pusher

On the pusher was provided the engine room of 8 m in length (between 4th and 12th abscissa), 8,5 m in breadth and 2,5 m in height. 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 a trapezoidal shape of the area of only about 50 m^2.

The main devices of the pusher's power plant will be the following:

- three D9 MG/HCM434C *Volvo – Penta* electric generating sets developing 216 kW (270 kVA) each. Each of them consists of a supercharged diesel engine assembled with an electric generator together, both fixed to a common steel foundation seated on elastic pads connected with hull structure by screw bolts. The diesel engines are of KC (keel cooling) version which makes it possible to use box coolers for fresh water cooling the engines. The engines will be equipped with a special knee duct to let exhaust gas from the engine to go together with outboard water to exhaust gas duct.
- Two main electric drive systems which can be made in two variants. The first - fitted with SEEK 315 M4C *Celma* vertical electric motors. The motors will be directly coupled with the shaft of the azimuthing propeller of "L" design (having one intersecting axis gear). The second - with SCe 315 M2 *Emit* horizontal electric motors. The motors will be connected - through a short cardan shaft – with the input shaft of the azimuthing propeller of "Z"design (having two intersecting axis gears). All the electric motors will develop 200 kW output power each. The rotational speed of motors: 1483 min^{-1}- in the first variant, and 2971 min^{-1} in the second one. The speed will be controlled by frequency changing. To this end VLT 6275 *Danfoss* frequency converters will be used.

All diesel engines of electric generating sets will be fresh-water cooled. The produced heat will be absorbed by outboard water within box coolers located in the left- and right –side Kingston valves. Each of the engines will be fitted with the high- temperature fresh-water pump, low-temperature fresh-water pump as well as the outboard-water circulating pump belonging to the wet gas exhaust system [3], all of them - driven by the engines. Expansion tanks and thermostatic valves 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).

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

Waste oil will be pumped from engine oil sumps to a waste oil tank by means of an oil transport pump. A fresh-oil storage tank will be also included in the system. An oil transport pump driven by a separate electric motor will be installed to transport the oil inside the ship as well as to discharge the waste oil out of the ship (possible application of hand – operated pump is also taken into account because of low flow rates and sporadic use of the pump) [3].

Every *Volvo – Penta* diesel engine will be fitted with *Bosch* combined pumping injectors, a double precise fuel-oil filter as well as fuel supply pump driven by the engine. The fuel supply pumps will suck in the fuel from the day tank placed in one of the storage tanks (or directly from the storage tanks).

As the application of the fuel oils of *ISO-F-DMX* category is assumed no centrifugal separators are provided for. An electrically-driven fuel transport pump is provided to pump fuel oil to and from the tanks. Fuel oil leaks which may occur during bunkering operations as well as those from pots under fuel devices, will be discharged to a leak oil tank and next to a separate free-standing tank or through an elastic pipe to land [3].

The wet exhaust gas outlet through ship sides is applied. Each diesel engine will have a separate duct for discharging the exhaust gas outboard. The system will be composed of an aqua-lift silencer (which serves also as a water blockade), rubber exhaust gas pipes as well as an outlet pipe connector fitted with a flap check valve. The exhaust gas outlets will be placed at least 50 mm over water line [3].

All diesel engines will be electrically started-up with the use of 24 V voltage supplied from an accumulator battery. In the pusher's power plant altogether 6 start-up batteries of 225 Ah and one 400 Ah emergency battery will be installed. They all will be acid-gel batteries chargeable from the electric network [4].

In the engine room will be also installed: the devices belonging to the water supply system on the pusher (hydrophore tank, two hydrophore pumps, hot-water circulating pump and electric heater), general-purpose outboard-water pump, auxiliary compressor, emergency drainage pump for compartments beyond the power plant, sewage discharging, bilge, ballast and fire extinguishing pumps as well as a power pack for feeding hydraulic motors on the pusher [4].

In the designed power plant of the pusher main electric generating sets, switchboards, electric motors driving azimuthing propellers as well as box coolers placed in kingston valves are the main elements to be dimensioned.

The electric generating sets will be seated on elastic pads with taking into consideration a rational route of exhaust gas ducts, location of silencers, routes of electric cables from generators, as well as structural design of foundations.

The kingston boxes are so located as to take into account that the box coolers have to be placed in them. The main which connects the kingston boxes to each other, of DN 125 diameter, will be located along 11th abscissa. Nearby will be located the outboard water pumps (ballast, fire, and general purpose pump etc) [3].

The main switchboards are placed in parallel to ship's plane of symmetry (on both side walls of the staircase leading to the main deck). The remaining auxiliary devices will be located between two electric generating sets situated port side and the transverse bulkhead at 4th abscissa and the starboard electric generating set. The devices and mechanisms are so arranged as to ensure free passage from their control and maintenance spots to emergency gangways. The main entrance to the machinery room – by the doors from the corridor that goes along the pusher on the floor level. The emergency exit - through the vertical stairs on the transverse bulkhead (at 4th abscissa) and the hatchway – up to the main deck [4].

The electric motors which drive azimuthing propellers will be located in separate compartments in the stern part of the pusher. Two variants of solving the propeller drive are possible: by using either vertical motors (of „L" design) or horizontal motors (of „Z" design). In the first case it would be necessary to shift the deck up - by about 30 cm - over the compartments of main electric motors.

The arrangement plan of the pusher's engine room is presented in Fig. 2. In Tab.1 the preliminary specification of power plant devices is given. The numbers shown in Fig. 2 correspond with those given in Tab. 1.

Tab.1. Preliminary specification of the devices of the pusher's power plant

No.	Name of device	Number of pieces	Mass [kg]	Characteristic
1	2	3	4	5
1	Main electric generating set Volvo Penta D(MG KE/HCM 434C	3	2660	N = 216 kW n = 1500 rpm
2	Main driver electric motor EMIT SCe 315M	2	1350	N = 200 kW n = 2980 rpm
3	Frequency converter DANFOSS VTL 6000	2	200	
4	Engine silencer VETUS	3		
5	Fuel – oil transport pump	1	50	Q = 2 m^3/h p = 4 bar
6	Lubricating – oil transport pump	1	20	Q = 20 dm^3/min p = 2 bar
7	Outboard water pump	1		Q = 10 m^3/h p = 2,5 bar
8	Cooling box	3		
9	Fire pump	1	400	Q = 40 m^3/h p = 6 bar
10	Ballast pump	1	180	Q = 35 m^3/h p = 2,5 bar
11	Bilge pump	1	180	Q = 35 m^3/h p = 2,5 bar
12	Auxiliary compressor	1		Q = 20 m^3/h p = 8 bar
13	Fecal matter pump	1	135	Q = 36 m^3/h p = 1,5 bar
14	Potable and sanitary water pump	2	30	Q = 2 m^3/h p = 5 bar
15	Hydrophore tank	1	400	V = 1 m^3
16	Hot – water circulating pump	1	15	Q = 1,5 m^3/h p = 2 bar
17	Water electric heater	1	150	Q = 20 kW
18	Emergency drying pump	1	180	Q = 50 m^3/h p = 2,5 bar
19	Power Pack	1	200	N = 10 kW
20	Main electric switchboard no. 1	1		
21	Main electric switchboard no. 2	1		
22	Hand operated fuel – oil pump	1	20	
23	Batteries	8	500	

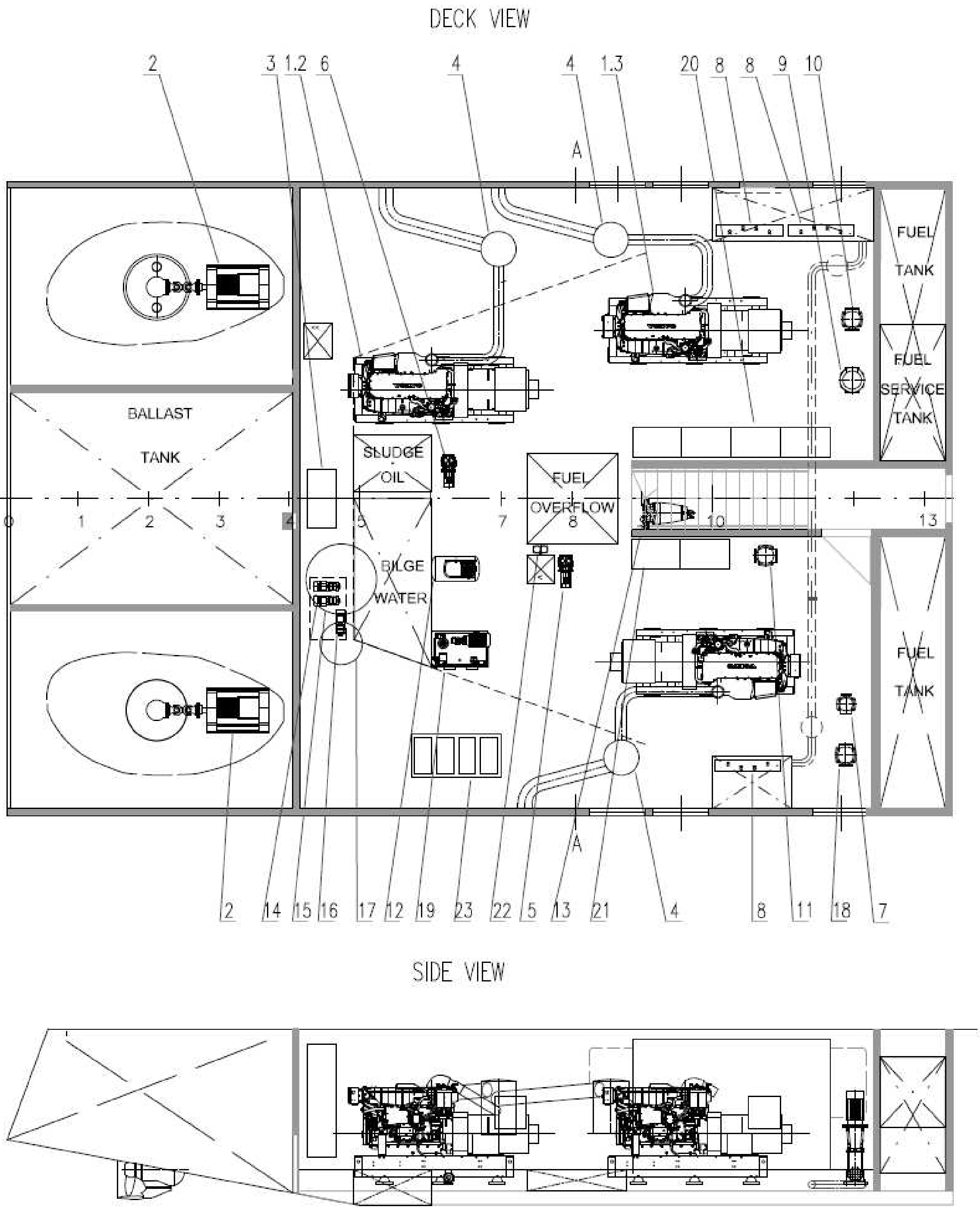

Fig.2. Arrangement plan of the devices located in the pusher's engine room

4. Auxiliary power plant located on the barge

A WCM42/5 small electric generating set of 42 kW (56 kVA) output power will be the main device installed in the barge's engine room. The auxiliary screw propeller will be located beyond the engine room, on the bow of the barge. Its electric drive will consist of Sg 180 L4 *Indukta* electric motor of 22 kW output power. Rotational speed control – by frequency changing with the use of VLT 5032 *Danfoss* frequency converter.

The diesel engine driving electric generating set is fresh-water cooled. The produced heat will be taken by outboard water in a water-water cooler. The engine will be fitted with the pumps suspended on it: fresh-water circulating, outboard water, lubricating oil and fuel supply pump. The fuel supply pump will suck-in the fuel oil from the day spare tank. The engine will be fitted with a separate pipe to discharge exhaust gas outside the ship. A dry system to exhaust gas above the promenade deck (alternatively through ship's stern) will be applied. Start-up of the engine – electric one [4].

In the barge's engine room will be also located the water supply system for the barge (containing two hydrophore tanks, two hydrophore pumps, one hot water circulating pump and electric water heater), emergency drainage pump for the compartments outside the power plant, sewage pump, ballast pump, fire pump, bilge pump as well as the power pack for feeding the hydraulic cylinders installed on the barge.

The barge's engine room will be located between the aft ballast tanks (the abscissae "0" and "5,5"). The gabarites of the engine room are the following: 5,5 m in length, 3 m in breadth, 2,5 m in height. The kingston main of DN 100 diameter, connecting the bottom kingston valve (under engine room's floor) with the side kingston valve will go along *2nd* abscissa. The electric switchboard will be fixed on the ballast tank bulkhead (port side) and in parallel the electric generating set will be placed on the other side. The remaining devices will be so arranged as to make free passage from their control and maintenance spots to emergency gangways, possible [4].

The main entrance to the machinery room– through the doors on the platform of the stairs connecting the corridor which goes on the floor level along the pusher, with the main deck. The emergency exit - through the vertical stairs and hatchway –up to the main deck.

The arrangement plan of the barge's machinery room is presented in Fig. 3. The preliminary specification of power plant devices is given in Tab. 2. The numbers shown in Fig. 3 correspond with those in Tab. 2.

Tab.2. Preliminary specification of the devices of the auxiliary power plant on *the barge*

No.	Name of device	Number of pieces	Mass [kg]	Characteristic
1	2	3	4	5
1	Auxiliary electric generating set WCM 42/5 – 60/6	1	1000	N = 42 kW n = 1500 rpm
2	Engine silencer	1		
3	Outboard – water pump	1	20	Q = 10 m^3/h p = 2,5 bar
4	Fire pump	1	300	Q = 40 m^3/h p = 6 bar
5	Ballast pump	1	180	Q = 35 m^3/h p = 2,5 bar
6	Hand operated bilge pump	1	20	Q = 7 m^3/h
7	Fecal mater pump	1	135	Q = 36 m^3/h p = 1,5 bar
8	Potable and sanitary water pump	2	30	Q = 2 m^3/h p = 5 bar
9	Hydrophore tank	1	400	V = 1 m^3
10	Hot – water circulating pump	1	15	Q = 1,5 m^3/h p = 2 bar
11	Water electric heater	1	150	Q = 20 kW
12	Emergency drying pump	1	180	Q = 50 m^3/h p = 2,5 bar
13	Power Pack	1	200	N = 10 kW
14	Main electric switchboard	1		
15	Batteries	1	120	

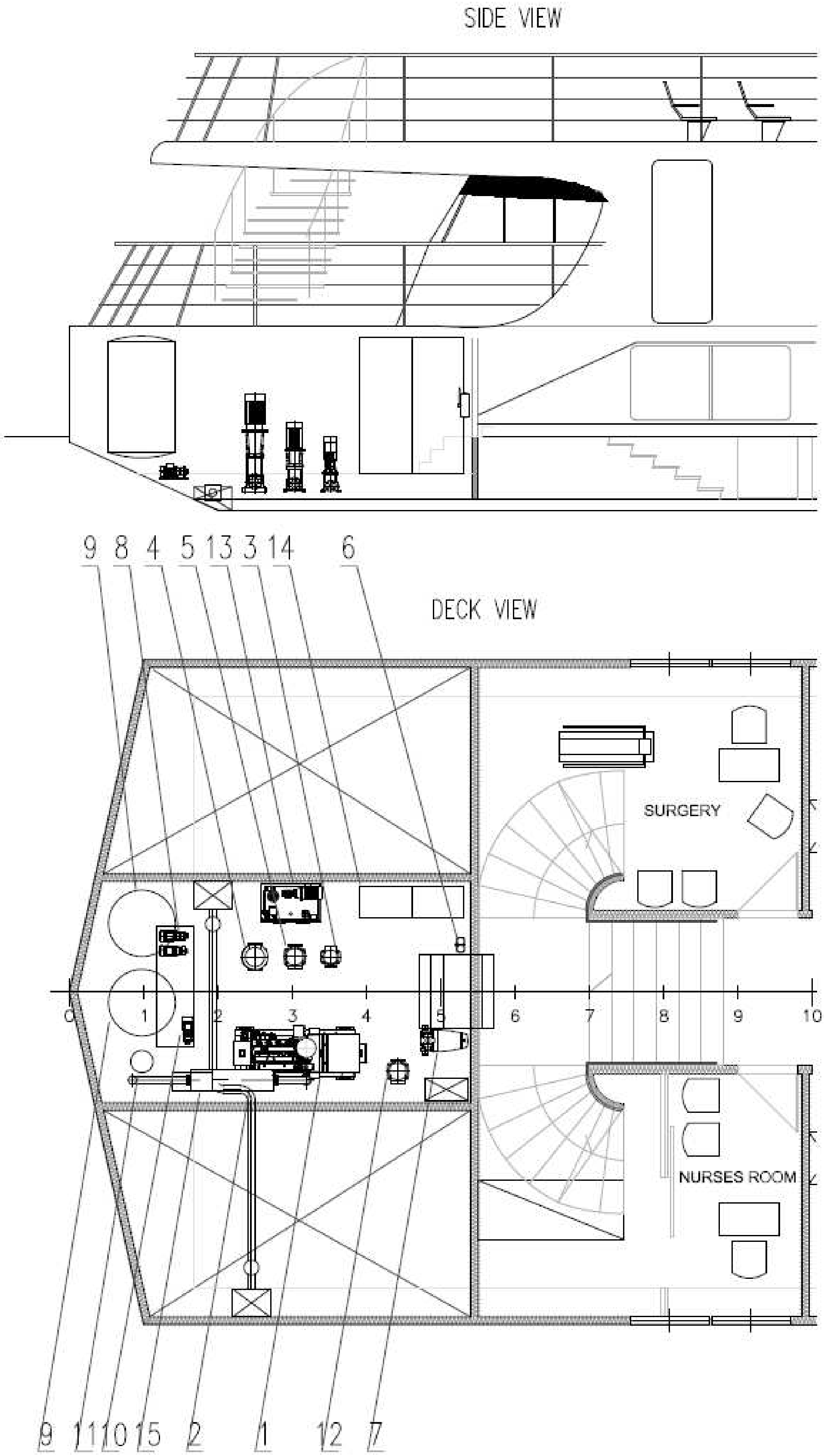

Fig. 3. Arrangement plan of the devices located in the barge's machinery room

References

[1] Bocheński, D., Kubiak, A., *Analiza i synteza warunków ruchu statku i ustalenie mocy efektywnych napędu głównego oraz propozycja rozwiązań konstrukcyjnych układu napędowego i siłowni z uwzględnieniem zapotrzebowania na energię elektryczną,* Research reports no. 94/SPB, Eureka/ 2004, Gdańsk 2004.

[2] Bocheński, D., Kubiak, A., Rudnicki, J., *Identyfikacja problemów wykonania projektu wstępnego siłowni śródlądowego statku pasażerskiego z uwzględnieniem zapotrzebowania energii do napędu głównego i odbiorników elektrycznych,* Research reports WOiO PG no. 221/SPB, Eureka/ 2005, Gdańsk 2005.

[3] Bocheński, D., Kubiak, A., Rudnicki, J., *Projekt i opis techniczny instalacji obsługujących silniki spalinowe siłowni spalinowo-elektrycznej śródlądowego statku pasażerskiego,* Research reports WOiO PG no. 241/SPB, Eureka/ 2006, Gdańsk 2006.

[4] Bocheński, D., Kubiak, A., Rudnicki, J., *Projekt siłowni spalinowo-elektrycznej śródlądowego statku pasażerskiego z napędem pędnikami azymutalnymi,* Research reports WOiO PG no. 242/SPB, Eureka/ 2006, Gdańsk 2006.

[5] Dymarski, Cz. Rolbiecki, R., *Opracowanie założeń i ogólnej koncepcji układu napędu i sterowania członu pchanego zestawu statku śródlądowego,* Research reports WOiO PG no. 196/SPB, Eureka/ 2005, Gdańsk 2004.

[6] Michalski, J., *Wstępne wyznaczenie głównych parametrów projektowych statku – prognozy oporowe kadłuba,* Research reports WOiO PG no. 96/SPB, Eureka/ 2004, Gdańsk 2004.

[7] Michalski, J., *Model matematyczny doboru optymalnych parametrów układu napędowego statków śródlądowych – aproksymacja eksperymentalnych charakterystyk oporowych kadłuba,* Research reports WOiO PG no. 182/SPB, Eureka/ 2005, Gdańsk 2005.

[8] Rosochowicz, K., *Ramowe założenia projektowe dla członowego śródlądowego statku pasażerskiego,* Projekt *Eureka INCOWATRANS E13065,* Gdańsk 2003.

[9] Wieszczeczyński, T., *Technical aspects of environmental protection concerning a small inland waterways passenger ship* (in Polish*),* Seminar on "Environmental protection in ship building and operating on inland and coastal waterways", Bydgoszcz, 21 June 2006.

[10] *Decree of Ministry of Economy and Labour, issued on 19-08-2005, on the detail requirements for combustion engines concerning limitation of emission of gaseous contamination and solid particles from the engines* (in Polish), Dz. U. (Bulletin of Legal Acts) no. 2005.202.1681.