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ADVANCED FEATURES OF THE RECONSTRUCTED SPECIAL PURPOSE RIVER SHIP *KOZARA* WITH A DIESEL ELECTRIC DRIVE (DED)

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Professional paper

Summary

The paper presents the reasons for the reconstruction of the special purpose river ship *BPN-30 Kozara* as well as some of the vessel's characteristics. The modified ship is equipped with two diesel generator sets, 400 kW each, which drive two electric motors, 250 kW each, the bow thruster of 90kW, and supply the ship with electrical power of 90 kW. The main diesel electric generators can operate independently or in parallel. An auxiliary diesel generator set, output power of 70 kW, is installed onboard to supply the ship with electricity when connected to shore. The tests performed show a significant improvement of the manoeuvring and propulsion characteristics of the ship compared to the former conventional diesel-powered two engines, rated power 294.4 kW each. The paper outlines other advantages of the ship with electric propulsion such as increased comfort for everyone onboard and the possibility of downstream economical cruising with a single diesel engine in operation. It can be concluded that the diesel electric drive presented in the paper shows a number of advantages for the operation of river ships that can be recommended for different river ships.

Keywords: *electric drive; electric propulsion; special purpose ship; Kozara; Kriemhild; manoeuvring characteristics*

1. Introduction

The ship named *Kozara*, the former *Kriemhild* [1], was built in 1939 in the Linz Shipyard, Austria. After the completion, the ship joined the Black Sea fleet of the German Navy where it stayed until the year 1945. The sole purpose of the ship was to serve as a command ship for the commander of the naval and river forces in the sectors of the Danube, the Black Sea and the Dnieper, and as a depot ship for a division of minesweepers. For a while the ship was navigated in Odessa (Ukraine), northwest of Sevastopol and later in Constanta (Romania). In 1945 the ship was captured by USA and was used to accommodate a part of division headquarters of the US Army in Regensburg. During this period, according to data from the shipping museum in Regensburg [2], the name of the ship was changed to *USS Oregon*. During that period, the ship had a couple of short navigations. Already in 1948 the ship was handed over to the shipping company Bavarian Lloyd, Regensburg, which renamed her back to *Kriemhild* and converted her into a hotel-restaurant. The ship *Kriemhild* was used as a restaurant until 1954, when it was closed down due to unprofitability. After that the ship was towed to a branch of the Danube and given to two families to take care of it.

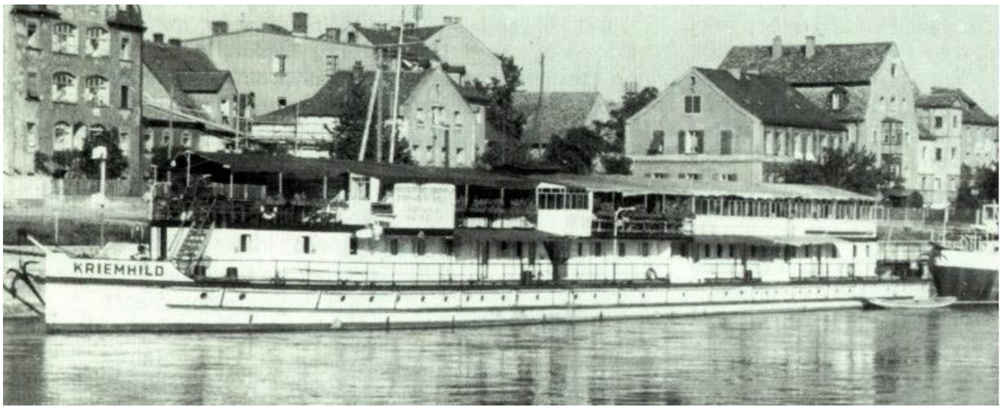


Figure 1 Ship *Kriemhild* in the port Regensburg in 1948

Figure 2 Special purpose ship *BPN-30 Kozara* after reconstruction in Apatin shipyard in 2013

At the same time, the negotiations on mutual ship exchange between the shipping companies Danube Lloyd from Sisak and Bavarian Lloyd from Regensburg were started. The owners of the former military ship *Kriemhild*, which was not suitable for commercial use, were willing to cede her to the Yugoslav shipping company Danube Lloyd from Sisak in exchange for a new tow cargo barge. Having in mind the tactical and technical characteristics of the vessel, the director of Danube Lloyd offered to the command of the River Flotilla of the Yugoslav Navy the possibility to purchase the *Kriemhild*. This resulted in the final decision to replace the ship *Fruška Gora* with the *Kriemhild*. Thus, the *Kriemhild* in 1961 became part of the River Flotilla of the Yugoslav Navy, while the ship *Fruška Gora* was removed from the fleet list [3]. The vessel was renamed *Kozara* as it is still called today.

2. Specifications of the ship with diesel drives

From 1961 to 2010, the ship was constantly in use. The propulsion system of the ship consisted of the main propulsion engines, related fuel systems, lubricants, power transmissions, propellers and equipment for engines' operation control. The original main propulsion diesel motors date back to the year 1939. The main drive motors on the ship were built with two four-stroke diesel engines, Klöckner Humboldt Deutz AG, of 400 HP (294.4 kW), 400 min^{-1}, 6-cylinder engine type RV6-M-345. The engines were directly connected to the propeller shaft in such manner that the change of propeller rotation direction was performed by for moving bumps forward, or aft. This change was done manually using a lever.

Testing the propulsion characteristics and manoeuvrability of the ship *Kozara* with the diesel drive was done on 19/09/1963 [5]. Tests were performed on the Danube on the part of the waterway from 1,274 km to 1,279 km, the wind speed was between 6 and 8 m/s and the speed of the river flow was 6.3 km/h. Displacement of the ship was 601 t and the mean draught of the ship was 1.24 m.

At the propeller speed of rotation of 100 min^{-1}, average speed of the ship was 1.8 km/h, and at the propeller speed of rotation of 200 min^{-1}, average speed of the ship was 7.63 km/h and at 300 min^{-1}, average speed was 12.8 km/h. When the speed of rotation of the propeller was 350 min^{-1}, average speed of the ship was 17.2 km/h, and at 400 min^{-1}, average speed was 21.0 km/h.

Testing of stopping path of the ship with diesel drive was carried out in similar environmental conditions and with both engines operating at 360 min^{-1}. Time to start astern navigation in downstream sailing was 95 s and distance travelled from the beginning of the regime of navigation astern was 300 m or 4.47 lengths of the ship. In case of upstream sailing, the time was 62 s and the distance travelled from the beginning of the regime of navigation astern was 105 m or 1.56 lengths of the ship.

Table 1 The basic technical characteristics of the ship *BPN-30 Kozara* with diesel engines [4]

Purpose	Command ship of the River Flotilla of the Serbian Army
Crew	47
Capable of carrying	250 soldiers with equipment
Type of construction	Steel
Dimensions	
Length overall	68.75 m
Breadth	9.55 m
Depth	2.7 m
Draught	1.10 - 1.30 m
Displacement standard	550 t
Full displacement	601 t
Power plant	
Two diesel engines	2x400 HP (294.4 kW)
Fuel consumption	170 gr/HPhour
Downstream speed	25 km/h
Upstream speed	15 km/h
Marine supplies	
Water	40 t
Fuel	45 t

3. Reconstruction of the ship

Over time, the existing devices and systems became obsolete and reconstruction of the ship was necessary. For the purpose of reconstruction, different variants of propulsion systems presented in literature were considered [6] and considerations given in [7-10] were also analyzed. However, further criteria were dominant for choosing electric propulsion.

The reconstruction of the ship was carried out in the period from June 2010 to September 2013 in Apatin shipyard [11].

Reasons for the reconstruction of the ship were as follows:

• The drive motors were old, without technological resources, and there were no spare parts for necessary repairs,

• There were very big problems with alignment of shaft lines after long period of inactivity on the slipway,

• Marine generators were direct current powered, low potent and unable to meet the needs of outfitting modern devices and systems,

• Due to poor maintenance of the main engines the ship had poor propulsive and manoeuvring characteristics

• Low standards of crew comfort.

The following was required from the drive of the propulsion system [12]:

- *Greater speed of ship.* Since the old engine lost power, it was necessary to restore ship back to the original features, and to increase the ship speed, if possible;
- *Better manoeuvrability characteristics.* Installing a bow thruster, and independent regulation of propeller rotation;
- *Greater toughness drive.* The possibility of a lower power operation as well as in case of a power train fault;
- *Higher quality of electric power supply.* Electrical sources onboard required a transition to a system of 3 x 380V and the related supply of new electrical appliances;
- *Endurance.* All drive train components had to be made by reputable manufacturers. In addition, it was necessary to operate in an optimal mode, that is, to the extent to ensure their long service life;
- *Maintenance.* Maintenance had to be minimal. This means that the drive had to be simply designed and made of quality components so that routine maintenance could be reduced to a small extent;
- *The optimal amount of total investment.* Given the desired performance, the investment cost of the power train had to be optimal.

To incorporate the new diesel electric propulsion it was necessary to reconstruct the hull, which was reflected in the following:

- Construction of a new engine room on the stern of the ship to install the drive electric motors and frequency inverters,

- Installation of new foundations for the electric motors from NP18 to NP32,

- Installation of new foundations for diesel generator sets from R60 to R65 in a way that the structure of the existing foundations of the main drive motor is adapted to the foundations of the diesel generator sets,

- Shortening the existing shaft lines i.e. construction of three intermediate shafts at each shaft line and installation (reconstruction) of one intermediate shaft for connecting gear with propeller shafts.

Assembled diesel electric propulsion (DED) (Fig. 2), consists of diesel generating sets (2 pieces), drive motors (2 pieces), gears (2 pieces), shaft lines (2 units), bow thruster, electric distribution system (propulsion and general ship consumption), propulsion control systems (voltage frequency converter) and remote control of propulsion [13].

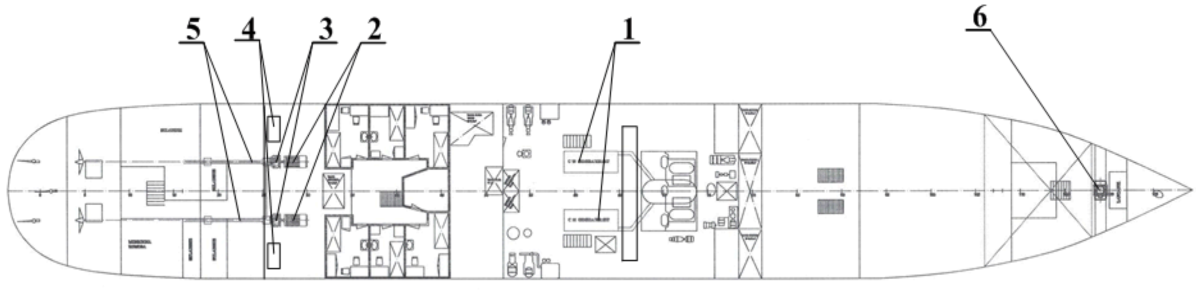


Figure 3 Power train of diesel electric propulsion
1 - diesel electric generators, 2 - electric motors, 3 – gear boxes, 4 - voltage frequency converters, 5 - shaft lines, 6 - bow thruster

After considering the advantages and disadvantages of the ship propulsion, two asynchronous electric motors, 3 x 400 V, 50 Hz, 250 kW each, were built in [14]. The speed of rotation of electric motors at 100 % rated power is 1,490 min^{-1}. The transfer of power from the electric motor to the propeller is done through the gears. Regulation of rotation speed and torque of electric motors is done through the U/f (voltage frequency converters). Gearboxes have the transmission ratio 1:3.968 and the speed of rotation of the propeller at 100 % rated power is 375.5 min^{-1}.

Two generators 3 x 400 V, 50 Hz, 500 kVA (400 kW) were installed as the main source of electrical power onboard. There is also an auxiliary (port) generator 3 x 400 V, 50 Hz, 88 kVA (70 kW).

Voltage frequency converters for propulsion are designed for four quadrant operation, so this allows operation in both directions of rotation and regenerative braking. Diesel electric generators are located in the engine room, while the electric motors and controls for their operation are in the stern engine room.

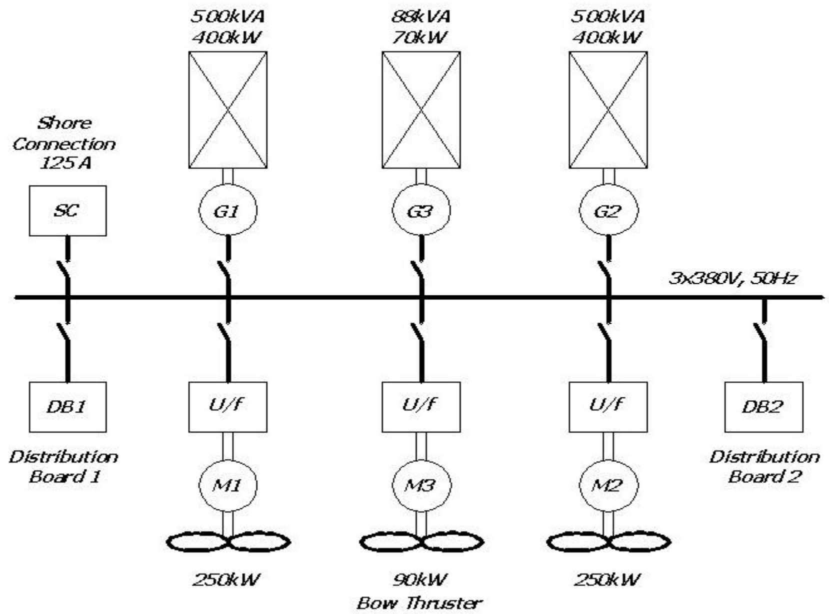


Figure 4 Single line diagram of diesel electric propulsion on ship *Kozara*

For managing the ship, the manual hydraulic steering gear of Orbitrol type was built in, located at the stern of the ship, with three rudder flags from the year 1939. In order to improve manoeuvrability, a bow thruster (propeller in a tunnel) is built into the bow. It is regulated over voltage frequency converters, power of 90 kW, and maximum propeller thrust is 13.1 kN. In addition to the drive electric motors as part of the new form of propulsion, for the first time a modern system of propulsion was incorporated using a voltage frequency converter, a system for the distribution of electric energy, and a system for automatic control of generators, with a modern alarm system.

The implementation of the diesel electric drive resulted in the following improvements:

1) The drive motors were mounted in the aft engine room. In this way, the earlier experienced vibrations were avoided,
2) The components of the original drive with diesel engines and systems, with an estimated weight of about 40 tons, were dismounted from the middle of the ship, which caused the "relaxation" of the ship’s structure. The installation of the new foundations and their connection with the foundations of the old diesel engines improved the longitudinal strength of the ship,
3) By removing the intermediate shaft that went through the crew cabin, above the floor, the cabin comfort was increased,
4) Installation of two diesel generators of 400 KW each, and the new main switchboard solved the entire energy balance of the ship because there is enough electric energy to supply devices, which enables increased crew comfort.

4. Results of testing the propulsion and manoeuvring characteristics of the ship

Testing of propulsion and manoeuvring characteristics of the ship with the new, diesel electric drive was carried out twice on the Danube River in different parts of the waterway in line with similar tests carried out worldwide [15] and in our country [16] as well. The first measurements of the speed and stopping distance were made in May 2012, on the part of the waterway from Novi Sad to Belgrade, where the water depth was up to 10 m. The tests were performed in conditions of sailing without wind and waves. Displacement of the ship was 530 t, and the average draught of the ship was 1.11 m. The second measurements of the speed, stopping distance and turning manoeuvres were performed in October 2013 on the part of the waterway in the region of Veliko Gradište and Donji Milanovac where the water depth was up to 15 m. The tests were performed in conditions of sailing without wind and waves. Displacement of the ship was 564 t, and draught of the ship was 1.17 m.

4.1. Ship speed measurements

For the measurement of the ship′s speed, a GPS (Global Positioning System) device was used. The length route for acceleration of the ship was about 3 nautical miles (5.6 km) before starting the measurements at a constant speed of rotation of the main motor and with a minimum steering, and the total length of the course required for carrying out the measurements was 7 nautical miles (13 km).

The ship′s speed measurements were done during a single pass in the downstream navigation as well as during a single pass in the upstream navigation. The speed of rotation of the drive motors was pre-defined, and it roughly corresponded to the regimes of 50 %, 75 %, 100 % and 110 % of the rated power of the drive motors.

Figure 5 shows a diagram of the mean speed of the ship with the diesel electric propulsion, measured in May 2012 on the part of the waterway from Novi Sad to Belgrade (line 1) and in October 2013 in the region of Veliko Gradište (line 3). The mean speed of the ship with the original diesel propulsion measured in September 1963 is presented by line 2 in Figure 5.

Table 2 Results of the speed measurements of the ship *Kozara* with DED made in May 2012 on the part of the waterway from Novi Sad to Belgrade

The speed of rotation of the electric motors [min^{-1}]	The speed of rotation of the propeller [min^{-1}]	Speed of the ship [km/h]		
		downstream	upstream	mean
750	189	16		
1125	283.5	21.1	15.2	18.15
1490	375.5	25.56	18.71	22.14
1550	390.6	26.1	19.63	22.87

Table 3 Results of the speed measurements of the ship *Kozara* with DED made in October 2013 on the part of the waterway in the region of the Veliko Gradište

The speed of rotation of the electric motors [min^{-1}]	The speed of rotation of the propeller [min^{-1}]	Speed of the ship [km/h]		
		downstream	upstream	mean
750	189	12.6	12	12.3
1125	283.5	17.0	15.4	16.2
1490	375.5	24.5	20.0	22.25
1550	390.6	26	20.4	23.2

Results of the speed measurements of the ship *Kozara* with DED made in May 2012 and October 2013 are given in Tables 2 and 3.

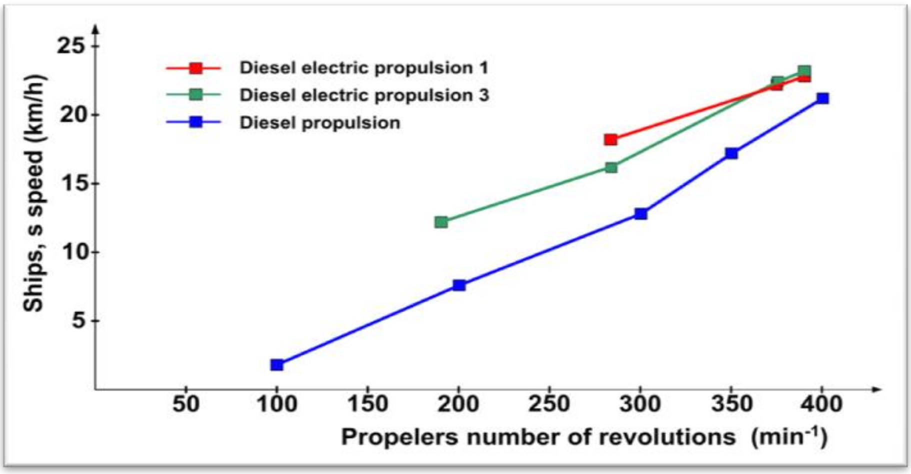


Figure 5 - Diagram of the mean speed of the ship *Kozara* versus the speed of rotation of the propeller with the diesel electric drive and the former diesel drive

4.2. Measurement of stopping manoeuvres

The characteristics of the ship were tested during the stopping manoeuvre after switching the electric motors from some initial manoeuvring speed to defined manoeuvring speed. Crash-stop manoeuvres were tested by switching to full power astern.

Testing began when the ship was brought in steady linear motion with a constant speed at 100 % of the rated drive; the navigation course was chosen so that the ship was sailing downstream, in the middle of the waterway. The test was terminated when the ship had a speed of 0.25 m/s backwards.

Table 4 Measurement results of stopping manoeuvre of the ship *Kozara* with DED performed in May 2012 on the part of the waterway from Novi Sad to Belgrade

Engines running in previous regime (propeller number of revolutions) [min^{-1}]	Commanded regime	Time to start navigation astern [s]	Distance travelled		Remark
			in meters [m]	in lengths of ship	
374	Astern	54	150	2.23	Downstream

Table 5 Measurement results of stopping manoeuvre of the ship *Kozara* with DED performed in October 2013 on the part of the waterway in the region of Veliko Gradište

Engines running in previous regime (propeller number of revolutions) [min^{-1}]	Commanded regime	Time to start navigation astern [s]	Distance travelled		Remark
			in meters [m]	in lengths of ship	
374	Astern	59	191	2.8	Downstream
374	Astern	43	95	1.6	Upstream

The ship's course and speed, the speed of rotation of the propeller and the rudder angle were measured using GPS during the tests path. The results of the CRASH-STOP manoeuvre on the part of the waterway from Novi Sad to Belgrade performed in May 2012 as well as the results of the CRASH-STOP manoeuvre performed in the region of Veliko Gradište in October 2013 are given in Tables 4 and 5 respectively.

It can be seen that the shortest stopping manoeuvre was in the upstream navigation in the region of Veliko Gradište. The stopping distance was only 95 m, or 1.6 lengths of the ship and it lasted 43 seconds. In the downstream navigation, on the part of the waterway from Novi Sad to Belgrade, where the speed of the river was lower, the stopping manoeuvre was about 58 % longer, and the time until the navigating astern was about 25.8 % longer. The longest stopping manoeuvre was in Veliko Gradište in the downstream navigation, where the speed of the river was the highest. The stopping manoeuvre was 101 % longer than in the upstream navigation and lasted 37.2 % longer than in the case of upstream navigation.

4.3. Measuring ship’s turning-circle diameter

The paper presents some results of the ship’s turning-circle manoeuvres at full ship’s draught in both operating modes of propelled EM 1000 min^{-1} forward, in the following cases of drive use:

1. Maximum position of the rudder to the left or right, without changing regime of engines at full speed ahead
2. Use of feedback and rudder to one side or the other
3. Use of feedback and rudder to one side or the other and use the use bow thruster
4. Use of feedback and use of bow thruster without using the rudder
5. Using the feedback without using the rudder and the bow thruster

Table 6 presents the results of the measurements of ship's turning-circle diameter in the case of the diesel electric propulsion.

Figures 6 to 10 show the ship's trace recorded on ship's navigation information system, when testing of the radius of turns.

Table 6 Turning circle measurement results for the ship *Kozara* with diesel electric drive

Number of the main engines in operation	Number of revolutions of the main engines [min^{-1}]	Number of revolutions of the bow thruster [min^{-1}]	Rudder direction	Rudder angle [^{O}]	The driving time in a full circle [s]	Turning circle diameter [m]
a - Turn manoeuvre mode for both propeller forward and rudder entirely to the right						
2	1000	-	Right	Max.	4.17	234
b - The manoeuvre turns in feedback mode right propeller to the back, left to the front and rudder entirely to the right						
2 Feedback	1000	-	Right	Max.	7.51	102
v - The manoeuvre turns in feedback mode right propeller forward, left with astern, bow thruster to the left and the rudder entirely to the left						
2 Feedback	1000	98	Left	Max.	m	
g - The manoeuvre turns in feedback mode with right propeller forward, left astern, bow thruster to the left and steering wheel in the middle						
2 Feedback	1000	98	Left	0	5.07	0
d - The manoeuvre turns in feedback mode, right propeller forward, left astern and rudder in the middle						
2 Feedback	1000	-	Left and Right	0	The turn of the ship was not achieved	

5. Analysis of results

Testing of the driving and manoeuvring characteristics of the ship was carried out according to the test plan [17] and presented in the test report [18].

5.1. Ship speed measurements

The speed of the ship, on 530 t displacement and 1.11 m draught, measured on the part of the waterway from Novi Sad to Belgrade at the mode of 100 % rated power was 25.56 km/h in downstream navigation and 18.71 km/h in upstream navigation. The average speed of the ship was 22.14 km/h. We concluded that the speed of the river in that part of the waterway was 3.43 km/h.

On the part of the waterway in the region of Veliko Gradište the speed of the ship on a displacement of 564 t and a draught of 1.17 m, measured at the mode of 100 % rated power was 24.5 km/h in downstream navigation and 20.0 km/h in upstream navigation. The average speed was 22.25 km/h. We concluded that the speed of the river in that part of the waterway was 2.24 km/h.

The average ship's speed measured at the two above-mentioned parts of the waterway at 100 % rated power of the diesel electric propulsion, and at the propeller speed of 375.5

min^{-1} was 22.14 km/h and 22.25 km/h respectively, whereas in the case of the former diesel propulsion the average speed was 21 km/h at the propeller speed of 400 min^{-1}.

In both cases, the measured speed of the ship with diesel electric propulsion is about 5 % higher compared to the speed of the ship with the original diesel propulsion at the mode of 100 % of the rated power. As the ship propellers were not changed, and as the speed of rotation of the electric motor to drive through the gearbox reduces the engine speed of the propeller shaft, which is slightly smaller than the speed of the old diesel engines that were directly connected to the shaft lines, the increased speed of the ship can be attributed to the attached drive equipment significantly lighter than the old operation equipment, and therefore to the smaller displacement of the ship as well. During the ship's speed measurements performed in 2012, the displacement was less than 71t from the full displacement of the ship with the original diesel drive. The speed measurements conducted during 2013 were carried out with full ballast tanks, which are built into the ship for the efficient functioning of the bow thruster (it is necessary for the tunnel to be immersed in water), thus the displacement of the ship was increased, but was still less than 37 t form the full displacement of the old diesel-powered ship. Analyzing the results of the speed measurements in case of the diesel electric drive, it can be concluded that the speed of the ship is influenced by ship's displacement and velocity of the river flow. This is best illustrated in the diagram of average speeds (line 3 in Figure 5).

The results of the measured speed of the ship indicate in the best way the influence of displacement on ship's speed. It is important to note that the average speed with the diesel electric drive on a smaller displacement is higher for lower speeds while the peak power drive is lower than for the ship on a greater displacement. The results can be interpreted by the fact that the displacement is related to the propeller immersion in water (propellers are fitted so that they are not completely submerged in water). In other words, the displacement of the ship depends on the resistance of the ship and on the thrust generated by the propellers. The effect of these two factors obviously varies with the increasing speed of the ship. The ship with a smaller displacement has greater acceleration. The ship speed is higher at a lower number of propeller revolutions in that case.

5.2. Measurement of stopping distance

While comparing the stopping distance test results it is evident that the length of the stopping distance of the ship with the diesel electric drive is considerably shorter than the length of the stopping distance of the ship with the original diesel drive. The measured stopping distance of the ship with the original diesel drive, in the mode of 100 % of the rated power, was 300 m and the stopping time was 1 min 35 s, while the measured stopping distance of the ship with the diesel electric drive was 150 m and the stopping time was 54 s with 530 t displacement of the ship, and 191 m with the stopping time of 59 s on a displacement of 564 t. Such a great improvement of stopping manoeuvres is contributed to the possibility of rapid changes in direction of the rotation of shaft lines, which was not possible with the original diesel drive.

In fact, with the original diesel drive, the rotation of the propeller was changed in a way that the drive was firstly stopped, then the direction of rotation of the motor was changed and finally the motor was started again. This was necessary because the engines were directly connected to shaft lines without gears.

With the diesel electric propulsion, where the electric motor is controlled via a frequency inverter, reversing of the propeller is done simply by moving the control lever from one direction to another drive, which significantly reduces the reversing time and results in a significant improvement of the ship's manoeuvring characteristics.

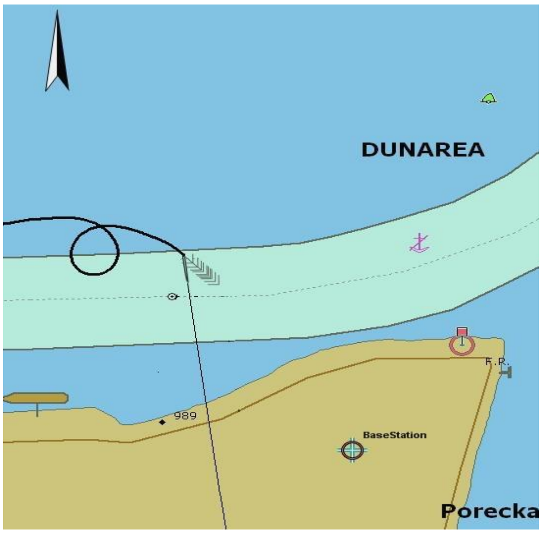


Figure 6 The turning circle manoeuvre in the mode both EM forward 1000 min^{-1} and rudder right completely

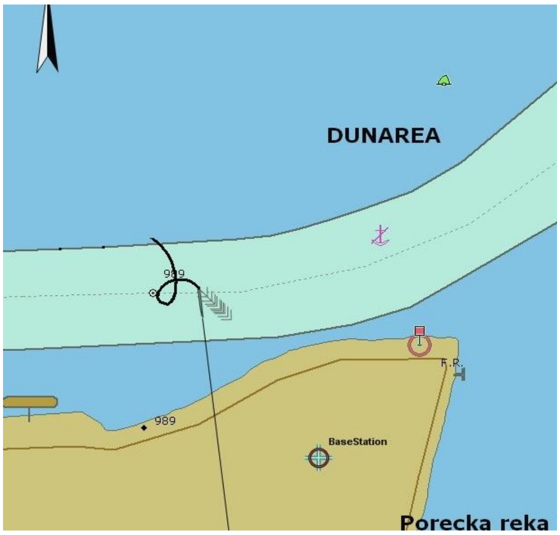


Figure 7 The turning circle manoeuvre in the mode coupling right EM astern 1000 min^{-1}, the left EM forward 1000 min^{-1} and rudder right completely

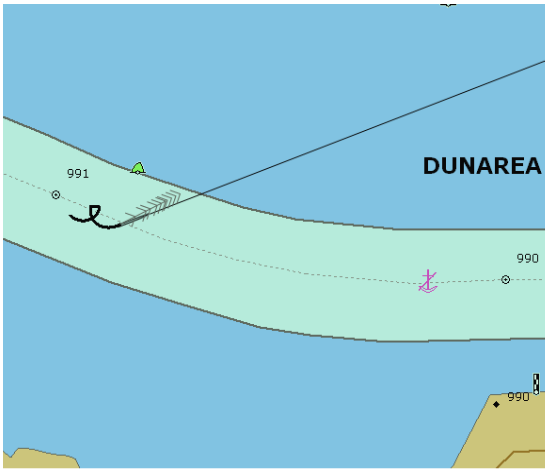


Figure 8 The turning circle manoeuvre in the mode coupling right EM ahead of 1000 min^{-1}, the left EM astern of 1000 min^{-1}, bow thruster left 98 min^{-1} and rudder left entirely

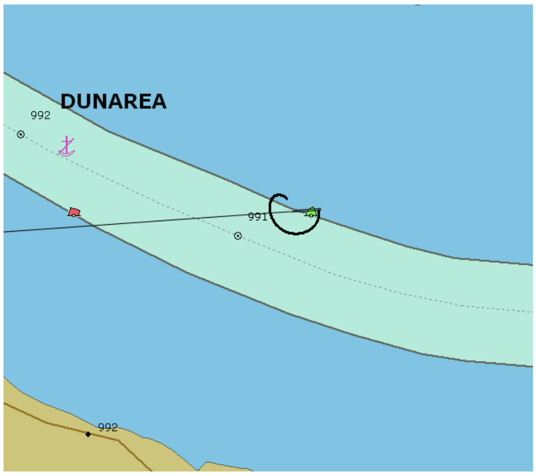


Figure 9 The turning circle manoeuvre in the coupling mode right EM ahead of 1000 min^{-1}, the left EM astern of 1000 min^{-1}, bow thruster left 98 min^{-1} and rudder in the middle

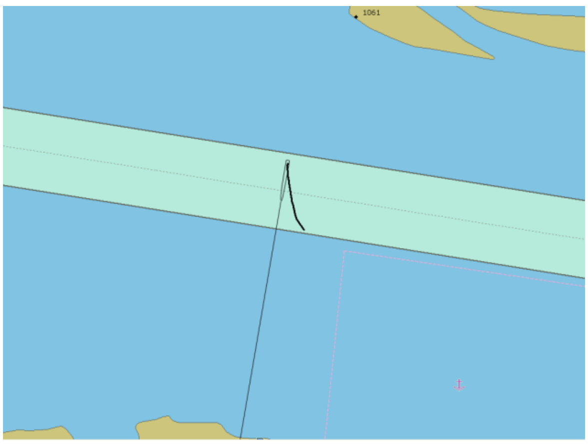


Figure 10 The manoeuvre of the turns in the mode coupling right EM ahead of 1000 min^{-1}, the left EM astern 1000 min^{-1} and rudder in the middle

It is also evident from the stopping manoeuvre test results for the ship with DED that the impact of inertia of the ship depends on the ship's displacement. The ship with a greater displacement has a larger inertia, and therefore has a longer stopping distance (150 m at a displacement of 530 t and 191 m at a displacement of 564 t).

5.3. Measuring ship's turning-circle diameter

Testing of turning circles shows a significant advantage of the diesel electric drives compared to the classical diesel-powered drive.

As we had no data of the earlier measurements of the turning circles of the ship with the original diesel drive, we assumed that the measurement results were similar to the results of the measurement of turning circles of the ship with both electric drive forward at 1000 min^{-1} and the maximal shifting of the rudder to the left or right as shown in Figure 3. In this mode, the measured radius of the circle is 234 m.

The ship's new drive allows quick change of the direction of rotation of the EM drive which allows efficient use of coupling the drive motors. Figure 4 shows the result of the manoeuvre turns at EM and with rudder position maximal to one side. The measured turn radius is 102 m, which is about 56% less than the assumed radius turns with the conventional diesel powered drive.

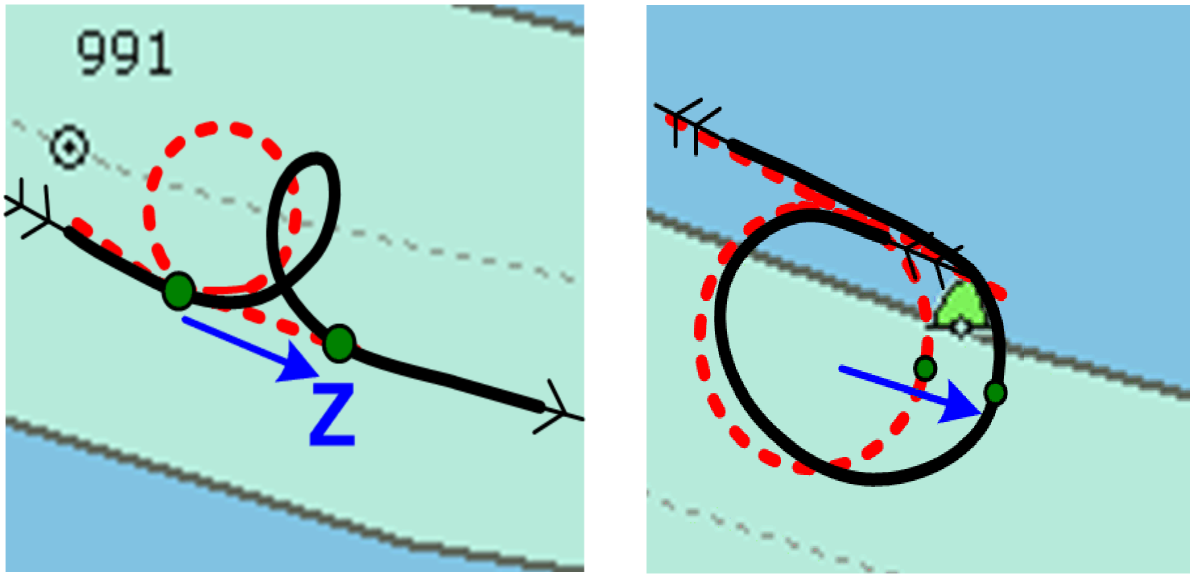
The installation of the bow thruster further improved the manoeuvrability characteristics of the ship.

Figure 5 shows the result of measuring the radius of the turn with the use of EM coupling drive, maximal rudder position to one side and the bow thruster at maximal mode in the required direction. The measured turning circle diameter is 73 m, which is about 69% less than the assumed turning circle diameter with the conventional diesel powered drive.

Figure 6 shows the result of measuring the turning circle diameter with the use of EM coupling drive, the bow thruster at the maximal mode in the required direction and the rudder in the neutral position. The measured resulting turning circle diameter is 170 m, which is about 37% less than the assumed radius turns with the conventional diesel powered drive.

For the analysis of the manoeuvring characteristics of the ship interesting is the result of testing the radius of the turn. The turning circle manoeuvre which was carried out only with the EM loop drive with the wheel in position 0 and without the use of the bow thruster is presented in Figure 7. The turning manoeuvre transverse to the river stream in the opposite direction of the river flow was achieved. The ship kept more or less rectilinear motion. This is explained by the fact that the drive propellers are located close to each other, due to which the coupling of forces is too small to achieve rotation of the ship to overcome the power of the river flow.

In order to facilitate consideration of the specifics of navigation on the river, the influence of the river flow on the turning circle manoeuvre is examined. Figure 11 shows the turn manoeuvres shown in Figures 5 and 6, compared with the theoretical circle turn of the ship in calm water. Figure 11a shows the comparison of the path of the ship to the manoeuvre turns in the downstream navigation. Figure 11b shows the comparison of the path of the ship to the manoeuvre turns in the upstream navigation. During the turn when the ship navigates downstream, the ship moves relatively slowly from the moment of the beginning of turning until the direction that is higher or lower than 90˚ from the initial course. The ship continues to move while being approximately perpendicular to the river flow, after which the turn finishes rapidly. The completion of the turn (point Z in Figure 11a) is downstream compared to endpoint turns in calm water. At the turn of the ship in the upstream driving the turning period is similar to the turning in calm water, while the circle proceeding the turn has tendency of downstream movement.



a) b)

Figure 11 Comparison of the ship's turning path in the river stream and in calm water
a) turn in the downstream navigation, b) turn in the upstream navigation

Actually, instead of the circle shape of the ship's turning path, we obtained an ellipse whose elongation depends on the speed of the river, and on whether the manoeuvre was performed downstream, upstream, or from the shore or in the stream of water, or vice versa. The distance of the tangents of the ellipse parallel to the river bank is taken as the diameter of the turning circle.

6. Other advantages of electric propulsion

The electric propulsion of the ship has a number of other, significant advantages over the conventional diesel powered drive.

6.1. Better manoeuvrability and performance

1. high-power electrical generators and high availability driving force
2. the possibility of continuous control of the rotation speed of the propellers
3. the ability to use the entire speed range from full speed ahead to full speed back
4. the possibility of independent speed control of each propeller
5. easily and quickly reversing drive
6. the work of driving the diesel engine at a constant speed of rotation
7. the simple installation of a strong bow propulsion machinery

6.2. Reduction of fuel consumption

Although the electric drive has higher losses in the transmission of power to the propeller it still saves fuel because it allows:

1. the work of driving the diesel engine at a constant speed of rotation in the area around the optimal load at all speeds navigation
2. the possibility of using optimal number of units in the upstream and downstream navigation.

6.3. Increased reliability

Electric propulsion increases the reliability of the ship:

1. there is an increased reliability of navigation because there are more diesel generators, and if one is not in use the other allows you to work at less power
2. there is always a possibility of the ship's power grid supply with at least one diesel generator,
3. there is less risk of large-scale fires due to spatial distribution of power sources.

6.4. Environmental benefits

One of the important advantages of the diesel electric drive is a significant reduction of fuel consumption, which means better preservation of energy resources and lower emissions at the same effect. In addition, high-speed diesel engines, which are designed to drive the ship's generator with diesel electric drive, operate at a constant speed of rotation, and have significantly lower emissions than the engine in the diesel mechanical drive.

Diesel electric drive successfully reduces noise and vibration:

1. the use of small high-speed diesel engines,
2. the favourable placement of the diesel engine so that it does not disturb the crew,
3. the reduction of torsional vibration for smooth operation of the drive motors.

6.5. Increase and better arrangement of the useful ship space:

1. The use of small, high-speed engines with high efficiency.
2. Diesel generator can be installed in the most suitable place inside the ship within one or more ship's spaces.
3. There is no need to place diesel engines in line with the central axis of the ship, which increases the load space.
4. Electricity for the general purposes onboard is obtained from marine generators used to supply power equipment.
5. Auxiliary generators are eliminated.
6. The possibility of optimal placements of the diesel engine.
7. Elimination of long shafts.

6.6. Increased crew comfort

By increasing the usable space and reducing the weight of the ship, an improvement in the quality of crew housing was achieved. By removing the intermediate shaft that went through the floor of the cabin, crew comfort was also increased. Modernization of marine toilets was done and the number of showers and toilets was increased. Complete overhaul of the heating system onboard was performed, and all windows and doors were replaced, which contributed to the effectiveness of heating and air conditioning. Also, 10 external air conditioning units and 22 indoor air conditioning units were installed. In addition to the air conditioning system, a new ventilation system was built in, which considerably improved the working conditions onboard. Reconstruction of the engine room and the removal of the old diesel drive equipment enabled the installation of new non-structural drinking water tanks with a total capacity of 21,100 l.

6.7. Other

Although there was a risk of problems with THD distortion of the supply voltage [19] interference that U/f converters could create, it turned out that it was not necessary to apply any filters or serial inductance to reduce harmonics in the network.

7. Conclusion

The replacement of the conventional, diesel unit with the diesel electric drive onboard the command ship *BPN -30 Kozara* was performed in 2012 in Apatin shipyard, but the complete reconstruction of the ship was completed in 2013 year.

The tests which were carried out [18, 20] have shown that the average speed of the ship in free navigation is 22.25 km/h, which is an increase of 5 % in relation to the measured average speed of navigation with the former diesel-powered drive. Thus, we can conclude that the ship with the new diesel electric drive has retained the average speed achieved with the diesel powered drive.

The stopping distance is reduced to 191 m or for 47 % in comparison to the conventional navigation actuator. The radius of the turn has been reduced from 234 m in DED regime to 73 m with the use of EM coupling drive, transferring the rudder to one side and using the bow thruster that is by up to 3 times.

With a better quality power supply, the crew comfort has been also increased. There is a possibility of navigation with one or both drive motors, as well as the ability of one diesel generator to work at lower operating regimes, which results in fuel savings.

On the basis of the results of performed tests it can be concluded that the project of the diesel electric-powered ship has fully met the task. The River Flotilla received the ship with extraordinary characteristics.

Given the fact that electricity is probably the highest quality energy that can be easily transferred and managed, and that there are devices which can work only when supplied with electric energy, the conducted tests have shown that the electric drive has features that fulfil the project task of reconstruction the ship *Kozara*. It can be concluded that we should strive for a comprehensive implementation of electricity (Project: All Electric Ship - AES) on military river ships.

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