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O.O. Kanifolskyi, L.M. Krysyuk

THE CONCEPT OF SMALL HIGH-SPEED FERRY

В статті приведені рекомендації, щодо можливого розвитку суднобудівної промисловості в напрямку малих швидкісних суден. Одна з причин – це малі початкові витрати в порівнянні з будуванням великих суден. Витрати, що пов'язані з проектуванням будуть також меншими. Сектор швидкісних суден зазвичай пов'язують з пасажирськими та пасажирсько-вантажними поромами, суднами спеціального призначення (туристичними, спортивними та рятувальними). В цій статті запропонований варіант малого порому місткістю, що дорівнює параметрам туристичного автобусу, та здатного зробити автомобільно-пасажир-ські перевезення в напрямку Європи більш комфортабельними.

Ключові слова: *швидкісні судна, малий пором, перевезення пасажирів та автомобілів.*

В статье приведены рекомендации относительно возможного развития судостроительной промышленности в направлении малых скоростных судов. Одна из причин - это малые первоначальные затраты по сравнению со строительством крупных судов. Расходы, связанные с проектированием будут также меньше. Сектор скоростных судов обычно связывают с пассажирскими и пассажирско-грузовыми паромами, судами специального назначения (туристическими, спортивными и спасательными). В этой статье предложен вариант малого парома вместимостью, равной вместимости туристического автобуса, и способного сделать автомобильно-пассажирские перевозки в направлении Европы более комфортабельными.

Ключевые слова: *быстроходные суда, малый паром, перевозка пассажиров и автомобилей.*

For the effective development of the shipbuilding industry, the direction of the small high-speed vessels can choose. One of the reasons is small initial costs for constructing of small-vessel compared with the constructing of large ships. The cost of designing work will be less, also. The sector of fast ships has been always in the demand in the maritime complex, as passenger and cargo ferries, special purpose ships (tourism, sport and rescue). In this article, the variant of small ferry with a capacity equal to the capacity of tourist bus and able to make passenger and car transportation in the direction to Europe more comfortable is proposed.

Keywords: *high-speed vessels, small ferry, transportation of passengers and vehicles.*

The purpose of this work is a conceptual project of small ferry, which is created by using of modern methods of theory ship design, and some requirements of the International Maritime Conventions.

The period of the flight fast ferries, with aircraft type passenger cabin will be limited to a period of time, which a passenger can withstand without discomfort. Researcher Levi [1] proposes to limit this period to ten hours and space equal to one and a half square meters per passenger.

On the map there are many places suitable for high-speed cargo vessels with a short duration of time of flight. One of the possible directions for development of passenger ferry is Odessa port − port Balchik, the closest Bulgaria's port or Constanta (Romania). Such line served by small speed cargo-passenger ferry would be popular and effective because the state of Ukrainian roads in the direction to Romania there is bad and there are no effective crossings over Danube River. Passenger capacity of the ferry is about forty people, given that the average number of passengers in a passenger car − three people, auto capacity about twelve cars, travel time ten hours. Such passenger capacity corresponds to the passenger seating capacity of the bus. If ticket prices for passengers and transportation vehicles will be competitive compared to road transport, and also considering saving time spent on customs and border checks, this kind of traffic will be in demand. Possible scope of such vessels and passenger ships − is lines between the ports of the Black Sea coast and the marine sphere of urban and suburban transport. Such vessels could promote not only to discharge of urban and suburban highways, for example, in Odessa and its environs, but also to ensure environmental security in the region. New international requirements for the prevention of air pollution, for ships, lead to the fact that the new vessel, which satisfies these requirements, will bring less harm to the environment than a car engine, which can be transported on this ship.

In the Black Sea, waves are characterized as follows. Weak waves prevail in summer, wave height less than 1 m exists in 55-70 % of cases. In winter, the repeatability of such waves is reduced in the northeast region to 40 % in the rest of the sea up to 27 %. Waves of heights 2-3 meters are most often in the winter, their frequency in this period reaches 20%, in the rest of the year it is not more than 12 %. Wave height of 6 m or more are rare; their frequency does not exceed 1 % (December-February). From the experience of operating coastal passenger vessels, it is known, such vessels perform their functions at waves of 4 points (the height of waves up to two meters, distance to the port of refuge less than twenty nautical miles). These parameters correspond to the class of vessel R3-RSN in rough sea with wave height to 3.5 m, distance from places of refuge not more than 50 miles. The modern fast ferries are operated at waves up to 3 meters, while reducing the ship's speed by 12 %, for example «Guizzo» [2].

By type of cargo fast ferries are passenger and cargo-passenger. It ships with ro-ro cargo operations (Roll-on / Roll-off). Classifying fast ferries of the type of propulsion is possible to note ships, which used propellers or water jets, can be a combination of these two types of propulsors, «Isola di Stromboli». This option provides additional capabilities for varying the speed of the vessel during the operation.

From three options of movement: displacement, transitional and planing mode, the second mode of operation is typical for the fast monohull ferries.

International documents identify several categories of passenger high-speed craft. Ship Category A − Any high-speed passenger ship carrying not more than 450 passengers on the route operated, which was demonstrated by the high probability that in case of an evacuation, all the passengers and crew could be saved over the shorter of the following periods: a period of time, necessary to ensure that the people in the lifeboats or rafts, were not exposed to the environment, leading to hypothermia or 4 hours (HSC passenger-A). In the category of vessel B − high-speed passenger vessel, other than a vessel of category A, the vessel designed so that in case of damage or flooding of one compartment, the boat retains the ability to safely float (HSC passenger-B).

High-speed operation of fast ferries, with waves of more than 5 points, is usually not provided, due to the regulations of comfort («Guizzo»). Wave height 3.5 m, corresponding to 5 points, characterizes of the navigation area R3-RSN. It is, by definition [3] − river-sea navigation in rough seas with wave height to 3.5 m, with 3 percent probability, the maximum distance from a place of refuge not more than 50 miles. Below is a figure showing the relationship of wind and sea waves, table 1.

Rules GL, RINA and BV considered for high-speed vessels, the area «Restricted open sea», which is characterized by height «significant» waves and represent $2.5m<h_{1/3}<4.0m$. The average height of the largest third of waves $h_{3\%} = 1{,}33 h_{1/3}$.

Table 1

The relationship of wind and sea waves

Wind		Sea waves	
Points	Speed range, m / s	Points	The range of wave height 3% probability, m
0	0 – 0,5 (0)	0	0
1	0,6 – 1,7 (1)	1	to 0,25
2	1,8 – 3,3 (2,5)	2	0,25 - 0,75
3	3,4 – 5,2 (4,5)	3	0,75 – 1,25
4	5,3 – 7,4 (6,5)	4	1,25 – 2,0
5	7,5 – 9,8 (8,5)	4	1,25 – 2,1
6	9,9 – 12,4 (11)	5	2,0 – 3,5
7	12,5 – 15,2 (14)	6	3,5 – 6,0
8	15,3 – 18,2 (17)	6	6,0 – 8,5

Analysis of the materials of the hulls of modern high-speed ferries showed that the material of the hull can be used high-strength steel, aluminum alloys, as well as the combination of these two materials (hull - high-strength steel, superstructure - aluminum alloy).

The ships of the transitional mode occupy an intermediate position between displacement ships and planning. The designer does the work on the choice of values of relative dimensions, the coefficients of the hull and the shape of its contours, for reducing the resistance of water at relative velocities of the transitional mode. In the design of vessels of this mode, it is necessary to give attention to the weight of the hull and its strength, due to the emerging dynamic loads. The wetness, flooding, and the stability of these vessels should not be overlooked, which are associated with their high speeds and the appearance of additional hydrodynamic forces. All these seeakeaping qualities of the vessel are considered at different stages of the project. One of the variants of the main stages of the project described in the literature [4] and it is a syste-matic approach to the design process. In this paper, the design philosophy was considered and noted that the design of vessels − a specific process, see Figu- re 1. The first step of the design Concept Design consists two phases of the process: Concept Exploration and the Concept Development.

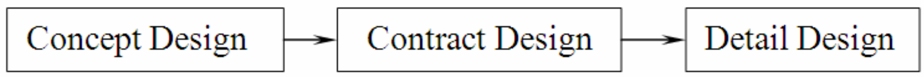

Figure 1. Main stages of the development of the project

The results of the first phase Concept Exploration are: a preliminary assessment of costs and efficiency; choice of technology; choice of the basic concept of the basic features, «one digit» estimate the weight and risks. The second phase (Concept Development) is a traditional spiral of the design. The result of this process − a more detailed study of the geometry of the vessel and the weights («two-digit» estimate), the main parts of the vessel, the body lines sketch, the preliminary study of the general arrangement, and the estimate of seeakeaping qualities. At this stage of the project, it is demonstrated that the results obtained in the Concept Exploration are balanced and workable. In this article, the Concept Development was selected for study.

The study of this article included the process of determining the main dimensions of the vessel based on the data of [5] and takes into account the seeakeaping, technical and operational quality of the future vessel. The calculations also include clarification vessel's stability in the transitional mode, taking into account the emerging hydrodynamic forces at hull [6]. Many calculation methods for the definition of hydrodynamic and hydrostatic forces in the planning mode are known, but information about values of these forces and their location on a ship's hull when operating in the transitional mode is absent. Such recommendations are given in paper [6].

The wetness of these vessels should not be overlooked. The requirements about of the minimum bow height of ship are included in the texts of International Convention on Load Lines (the old version and new). These requirements sometimes are differing. Besides, in these normative documents, at purpose of the minimum bow height of ship is not taken into account velocity ship. The need to compare new and old methods of the calculation appeared and after we can use this knowledge in process of the designing of ships.

Howard's formula, which takes into account the speed of the vessel, for assignment of freeboard at the bow, proposed in [7], $F_b = \frac{v}{3} \pm 1$, where v – the speed of the vessel, knots. For vessels with small length, it is better to use Howard's graph.

In the appointment of the bow height of a small vessel, a dominant value of the wave height must be selected. This may be the height of sea waves or formed wave, figure 2.

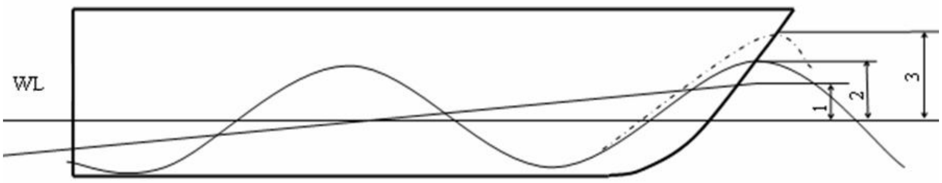

Figure 2. Three parts of submersions of the fore end of ship:
1 – pitch; 2 – sea waves; 3 – formed waves

Kent formula $h_{fw} = 0{,}94B\frac{Fr_L^2}{l_e}$ is designed to calculate height of the formed waves and proposed to apply for low-speed and medium-speed vessels. The height of formed waves will be depended on the relative velocity, the width of the hull and the relative entrance length $l_e = \frac{L_e}{L}$. Similar an empirical formula for estimating height of the formed waves is used in Regulation China Classification Society [8]. This formula Tasaki $h_{fw} = 0{,}75B\frac{Fr_L^2}{l_e}$ is a similar to Kent's formula.

On table 2, the heights of the formed wave are represented, for different values of the Froude number.

The second, but no less important factor influencing the choice of the desired value of the bow height is the amplitude of the pitching. For small passenger vessels, on a wave of up to 4 points, the amplitude of the pitching can reach 7 °, the minimum value is 3 ° [1]. Trim is calculated from the expression $\Delta = L \times tg\psi$. Immersion of the bow for concept ferry, as a result of pitching will be equal to 0,8 m.

Table 2

Formed wave height determined by different formulas

Froude number Fr_L	Formed wave height, m	
	Kent formula $h_{fw} = 0{,}94B\frac{Fr_L^2}{l_e}$	Tasaki formula (China Classification Society) $h_{fw} = 0{,}75B\frac{Fr_L^2}{l_e}$
0,4	0,9	0,7
0,71	2,8	2,2

The third component of immersion of bow is sea waves. This article covers ships of restricted area river-sea navigation R3-RSN, with the corresponding height of waves up to 3.5 m. Half of wave height is about 1.75 m.

Worst case, in terms of wetness, is variant, when waves that are created by the movement of the ship and sea waves are coherent and boat speed is unchanged. In this case, the summation wave heights are possible (method of summation)

$$F_b = h_{fw} + h_{pitch} + h_w = 2{,}2 + 0{,}8 + 1{,}75 = 4{,}75 \ m \ . \qquad (1)$$

The F_b defined by Howard's graph is 4,7 m.

In the calculations it is assumed that the sea waves and formed waves are coherent. In real terms this effect may not occur or the master can affect the event by changing the ship's speed and direction of motion. It should also be taking into account that in the waves the boat speed will be reduced. In the table below, two variants (still water, pitch and formed waves or rough water plus pitch) are presented.

The minimum bow height of ship defined on formula

$$F_b = 56L(1 \quad \frac{L}{500})1{,}36/(c_b + 0{,}68)\,,$$

for ships by length less than 250 m. This requirement was in old versions International Convention on Load Lines, which acted before 2005. In these formulas, the minimum bow height of ship depends on such parameters: length of ship and the block coefficient. The required minimum bow height of ship will decrease, with increase of the block coefficient. This convention's position, at first thought not logistical, because one of the amendments to minimum freeboard of ship is a correction for block coefficient. The freeboard must be increase, at growing of this coefficient. Really, the freeboard table were made for «base ship», with typical parameters (c_b = 0,68, $\frac{L}{D}$ =15, etc.). If the factor c_b increases, then displacement of ship $V = c_b LBd$ grows too, but relative reserve buoyancy $\frac{W}{V} = \frac{c_w LBF_b}{c_b LBd} = \frac{c_w F_b}{c_b d}$ decreases. Possible, in old convention's version, we expected that enlarging freeboard is sufficient.

The new version of the formula, for calculation of the minimum bow height of ship, is shown below.

$$F_b = (6075(\frac{L}{100}) - 1875(\frac{L}{100})^2 + 200(\frac{L}{100})^3)(2,08 + 0,609c_b - 1,603c_{wf} - 0,0129\frac{L}{d_1}), \quad (2)$$

where F_b – is the calculated minimum bow height, in mm;

L – is the length, in m;

B – is the moulded breadth, in m;

d_1 – is the draught at 85% of the depth D, in m;

c_b – is the block coefficient;

c_{wf} – is the waterplane area coefficient forward of L/2.

In new formula, it is taken to account else two parameters: c_{wf} – waterplane area coefficient forward of L/2 and parameter $\frac{L}{d_1}$.

With growing of the factor c_{wf}, required minimum bow height of ship will decrease (to account of the increase the volume of buoyancy in the fore end).

The parameter $\frac{L}{d_1}$ renders same influence to minimum bow height of ship as c_{wf}; with growing of this parameter required minimum height will decrease. At growing of relative length $\frac{L}{d_1}$ we can observe increase longitudinal metacentric height $H = \frac{M_h}{\Delta \sin\psi}$ and reduction of pitch ψ ($\frac{L}{d_1} \uparrow \rightarrow H \uparrow \rightarrow \psi \downarrow$).

On table 3 there are results of calculation for old and new convention's versions and by method of summation.

Table 3

Results of calculation for old and new convention's versions and by method of summation

Length ship L, m	New rules LL F_b, mm	Old rules LL F_b, mm	$h_w = 3{,}5$ m, pitch, F_b, mm	Still water, $Fr_L = 0{,}71$, pitch, F_b, mm
30	2049	1851	2536	2986
31	2111	1909	2562	3012

The results of the study of main dimensions of small high-speed vessel, figure 3.

Length	30.6 m
Width	5.1 m
Draught	1.0 m
Bow height	3.0 m
Speed	24 knots.
Number of passengers	40 persons.
Number of cars	12
Light weight ship	54 t
Main engine power	1100 kW

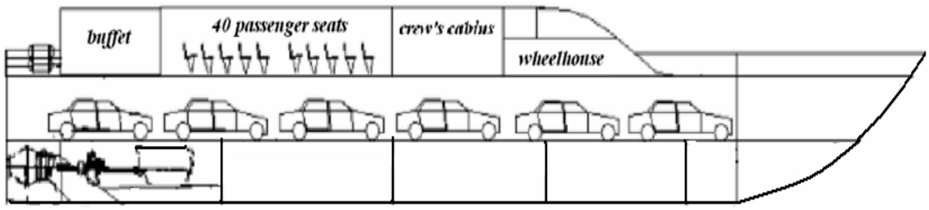

Figure 3. The sketch of the general arrangement of small fast ferry

The definition of price of the vessel is based on analyze of world prices for this type ships. The calculation showed that the ratio of the vessel prices in USD to the light weight ship LW is in the range 0,021- 0,024 million USD / t.

$$Price\ of\ the\ vessel = 0{,}021LW = 1{,}1 \quad million\ USD \tag{3}$$

The cost of works, on the Ukrainian shipyards, less than the European market by 30-40 %. Estimated price of the vessel in Ukraine is 0.7 million

USD. This ferry line can compete with auto roads. The journey time by ferry is 10 hours. During the day, the ferry carries two flights. For example, it was taken 20 days of exploitation. The ticket price is 50 \$ for a passenger, freight cost for auto place is 100 \$ per car. The revenue per flight will be 3200 \$. The costs per flight will be 2900 \$ (fuel 2300 \$; salary 400 \$; port charges and other 200 \$). The profit per flight is 300 \$ for the year 144000 \$.

The period of the recoupment $PP = \sum_{k=1}^{n} P_k \geq IC$ is one of the most common indicators to measure the effectiveness of investments. The cash flow in the k-th year is sum of two components $P_k = \Pi_c + A_k$: Π_c − net profit and A_k − amortization. This project will pay off for 5 years. The profitability of one flight will be 10 %. This project can be used in coastal ferry flights, after little changes and increase the number of passenger seats (for example, Odessa-Zatoka, journey time is 2 hours). Duration of this trip is comparable with the travel by car.

Figure 4. The possible directions for development of passenger ferry

Conclusion. One of the advantages of small vessels − small initial costs associated with the construction of a small craft. Approximate price of small fast ferries is 0.7 million USD. The project will pay off for 5 year. Short lines, with small duration of flight, are preferred, because the opportunity to design minimum areas for passengers exists. As a result of the study, the main dimensions, the weights, the sketch of the general arrangement of the vessel were obtained by using of modern methods of theory ship design, and some requirements of the International Maritime Conventions.

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Рецензенти:

кандидат технічних наук, завідувач кафедри «Теорія і проектування корабля ім. проф. Ю.Л. Воробйова» Одеського національного морського університету **О.В. Демідюк**

директор УЦПКБ «Стапель» **І.А. Карпенко**