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Decreasing of Wet Deck Slamming.

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Abstract-- **Shocks by waves, slamming, of the wet deck (the bottom of inter-hull structure) is a specific disadvantage of all multi-hull ships. It means the decreasing of such slamming is an important problem of multi-hull designing and creation.**

The problem is divided by two parts: motion mitigation and shock elimination. Some methods of longitudinal motion mitigation of various multi-hulls are examined. In addition, some methods of shock pressure decreasing are shown too. As the results, some general and particular recommendations are proposed.

Keywords-- **Slamming, multi-hulls, wet deck, vertical clearance, seaworthiness, motions, shock pressure.**

I. INTRODUCTION

Shocks by waves, slamming, of the wet deck (the bottom of inter-hull structure) is a specific disadvantage of all multi-hull ships. Usually there is the kind of slamming in head waves and at bow part of wet deck.

The slamming is defined by number of shocks per a hour and by intensity. Therefore, decreasing of wet deck slamming means drop of shock number and shock pressure. It must be noted usually the shock force drops with decreasing of shock number too.

Usually the triple-hull ships have wet deck at bigger distance from bow (in a comparison with twin-hull ones). It means, the problem of wet deck slamming is more important for twin-hull vessels.

Evidently, the slamming is defined by relative displacement of water level in waves, and by local velocity of the level displacement. Ships with small water-plane area, SWA ships, which have smaller longitudinal motions in waves (in a comparison with multi-hulls with traditional shape of hulls) have rarer and weaker slamming of the wet deck.

Wave shock generates, if the defined values of vertical displacement and its velocity coincide at the same moment. Number of shocks is defined by the following formulae [1]:

$$N_S = [(3600*\omega_z)/2\pi]*\exp - [(d^2/2D_z) + (v_0^2/2D_v)], \quad (1)$$

Here $\omega_Z = (D_V/D_Z)^{1/2}$, D_V – dispersion of local velocity of the water level displacement, m^2 / sec^2; D_Z – dispersion of the level , m^2; d – local distance from design water-plane to wet deck, so named "vertical clearance", m; v_0 – critical maximal vertical velocity, usually today supposed equal to 3.5 m/sec.

The dependences from local level displacement (i.e. longitudinal motion), its velocity and vertical clearance are evident. Usually today the permissible number of shocks is supposed equal to 20 per a hour.

But bigger vertical clearance means bigger height of boards, i.e. bigger building price of the ship; moreover, too big board height is not convenient for some purposes of a ship. It seems evident, the minimal permissible vertical clearance selection is an important part of a multi-hull vessel designing.

The problem of motion decreasing arises from the need of a minimal clearance selection. The problem is examined below.

Besides the shock number, the shock pressure is a very important characteristic of wet deck slamming. For the same other conditions, the pressure defines by the inclination of wet deck surface to horizon, see Fig. 1.

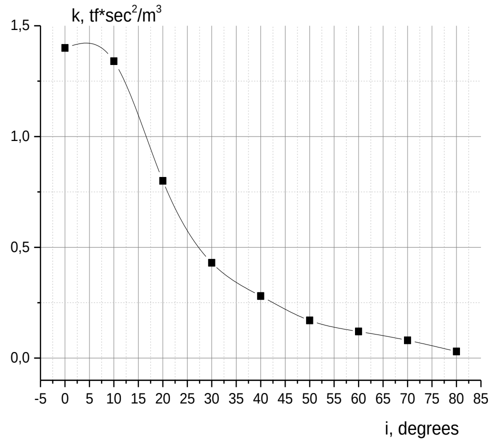

Fig. 1. Empirical coefficient of shock pressure dependence from wet deck surface inclination to horizon [2].

The coefficient can be decreased by some structural measures, see below.

Therefore, the problem of decreasing of wet deck slamming includes motion decreasing and shock pressure decreasing.

II. LONGITUDINAL MOTION MITIGATION.

A. Main dimension selection.

Longitudinal motions can be deceased by various methods:
- changing of own frequency of motions for resonance avoiding at most often waves;

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- decreasing of disturbing forces and moments from waves;
- increasing of dumping forces and moments for motion decreasing in all possible waves.

The methods are examined below from most to less effective ones. Besides, the existence of the needed initial data for such method realization and effect estimation is examined too.

(It must be noted, the big enough volume of data on mono-hull motions can be used for examination of the corresponded motions of multi-hulls with conventional hulls.)

Noted specificity of ship types shows the biggest importance of slamming decreasing of the catamarans as twin-hull ships with traditional shape of hulls. But examined below methods can be applied for any types of multi-hulls.

Maximal decreasing of **water-plane area** is a most effective method of longitudinal motion mitigation. The maximal decreasing of the area means a transition to the other type of hull shapes, to hulls with small water-plane area, to SWA ships. Each hull of such ship consists from the main under-water volume, a gondola, and usually one or two thin struts, which connect the gondola with the above-water structure.

Small area of water-plane means growth (up to two times) of own periods of motions, i.e. changing the resonance conditions in waves, and decreasing of disturbing action of waves, i.e. decreasing of corresponding forces and moments.

Fig. 2 presents pitch amplitudes of some various mono-hulls and a 600-t twin-hull SWA ship with one long strut at each hull (duplus) in head waves [3].

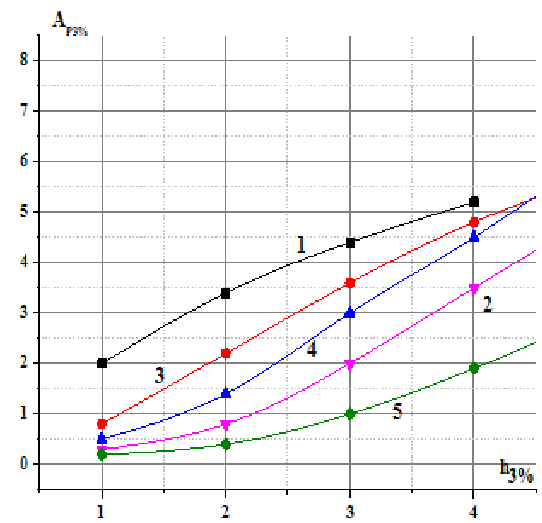

Fig.2. Pitch amplitudes in head waves: 1 – mono-hull battle ship, 1000 t, 15 knots; 2 – mono-hull, 3500 t, 15 knots; 3 – duplus, 600 t, following waves, 10 knots; 4 – the same, head waves, 10 knots; 5 – the same,18 knots.

Evidently, 600-t duplus has smaller pitch and bigger permissible speed in head waves in the comparison with 3500-t mono-hull. In general, head waves are more favorable option of sailing for all SWA ships, than following ones.

But a transition to small water-plane area is possible or convenient not at all cases, therefore motion mitigation of multi-hulls with traditional hull shapes is needed too and is examined below.

The main dimension correlation, which acts strongly to motion and can be selected simple enough, is **relative beam** of a hull, B_1 / d, here B_1 – a hull beam, d – the design draft. Some results of approximate calculations of the needed vertical clearance of two various hulls are shown by Fig. 3 [3]. Here the selected number of slamming shock is no more, then 20, relative beam is B_1 /d = 2 and 4, and wave intensity and relative speed (Froude number by a hull length) are varied ones.

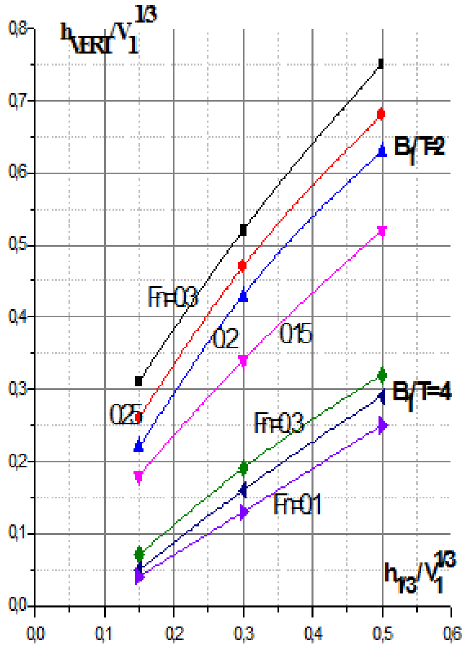

Fig. 3. The needed vertical clearance estimation (for 20 shocks per a hour), here: h_{VERT} – vertical clearance, m; $h_{1/3}$ – sufficient height of wave, m; V_1 - volume displacement of a hull, cub m; Fn – Froude number by a hull length.

Evidently, the needed clearance depends from the relative beam of a hull linearly, as a minimum.

But bigger relative beam of a hull means bigger relative wetted area, i.e. some growth of towing resistance. Therefore, the relative beam must be varied at the process of a multi-hull designing, for taking into account both results of the beam selection.

Length growth means decreasing of pitch motion resonance at the degree about 1.5, Fig. 4 [4].

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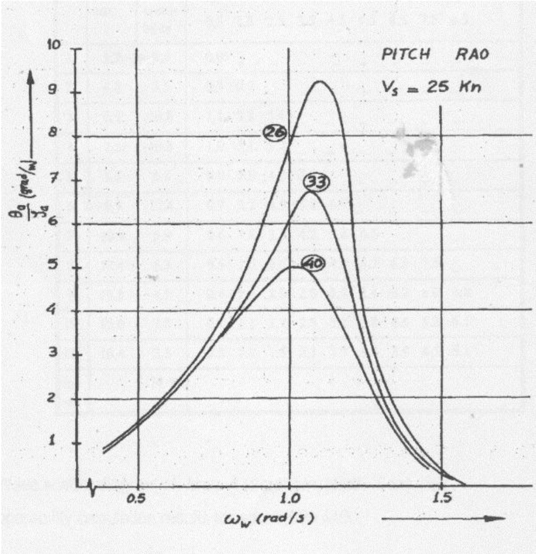

Fig.4. Root mean square of pitch single amplitudes [4] in the dependence of hull length.

But the length is most expensive dimension of a ship; for example, the longitudinal bending moment growths proportionally to length square – with growth of the hull structure mass. Therefore, usually the hull length is not enlarged for pitch decreasing only.

Block coefficient of a hull as a whole and **the prismatic coefficient** are defined usually by needs of performance. And the bigger block coefficient is not used for motion mitigation. Moreover, the bigger block coefficient means bigger displacement; than the "pure" influence of the coefficient to motion can`t be defined.

Besides, it is well known, an unusually big prismatic coefficient, i.e. bigger fullness of ends, ensures pitch decreasing in a comparison of pitch of hulls with usual (smaller) end fullness. Unlike block coefficient, the prismatic one can be varied without changing of the ship displacement, it ensures more logic comparison of options. But the author did not find some systematic data of experimental or digital results of such researching. The problem waits its researchers.

Usually **the mutual placement of hulls** is selected for the needed general arrangement, transverse stability, performance, but not for decreasing of longitudinal pitch. But it must be remembered, the hydrodynamic interaction of hull wave system affects to pitch amplitudes, especially – for small enough transverse distance between hulls. The definition of the influence is possible by seakeeping tests or corresponded calculations. Not so defined and general, the calculation results show the amplitude growth at big enough relative speed and wave height with bigger transverse clearance. On the other side, the dependence is reverse one for not so big waves…

In general the clearance changing acts to pitch, but the direction of such changing is not defined previously for any options of conditions.

B. Decreasing of longitudinal motion.

Usually some passive or active (automatically controlled) underwater foils are applied for longitudinal motion (pitch in main) decreasing. Besides, big enough bow bulbs generate added dumping, i.e. decrease pitch.

Planing (gliding) boats of all types can have active interceptors of flow for motion decreasing.

For displace and transient modes of relative speeds, the possible minimization of water-plane area is most effective measure of higher effectiveness of motion mitigation systems.

Decreasing of disturbing forces and moments does them nearer to achievable forces and moments are generated by motion moderation systems of various types. For example, the **active foils** are very effective at big enough speeds of ships with small-water-plane area, see Fig. 5 (pitch and roll amplitudes of a inhabited self-propelled model SM-14, the displacement about 7 t).

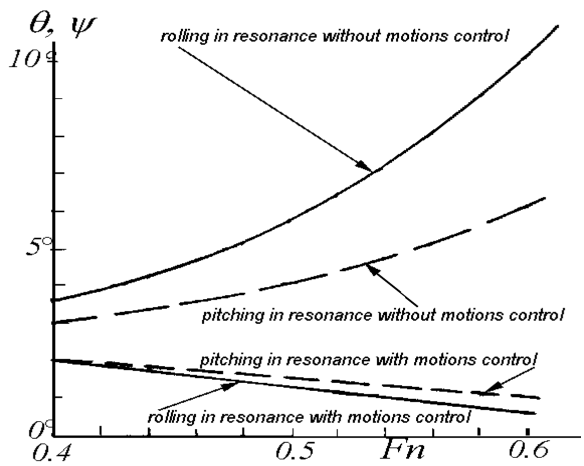

Fig. 5. Resonance amplitudes of roll (upper curve) and pitch (lower curve) of the self-propelled model SM-14 without foils; lowest curve – roll with foils, the second from bottom curve – pitch with foils. Speed about 14 knots, wave height 0.7 m, relative height 0.35 [2].

Evidently, pitch mitigation at full speed is about 6 times, but it correspond to big enough area of foils.

All SWA ships have decreased stability and water-plane area, therefore such ships need for about symmetrical placement of controllable foils; if not so, there is a big enough asymmetric vertical displacement of ends and bigger heave.

Stern foils must be no bigger, than bow ones, at 2 – 3 times. Fig. 6 shows bad option of mitigation foils: only bow ones. Not permissible asymmetry of pitch was defined: stern displacement was much more in the comparison with bow displacement. The general result – the ship option was rejected as a whole…

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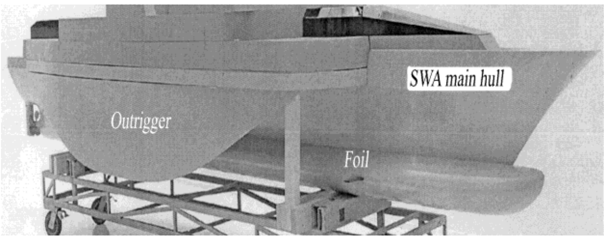

Fig. 6. Bad option of mitigation foils [5].

Fig. 7 presents the recommended option of mitigation foils of the outrigger SWA ship.

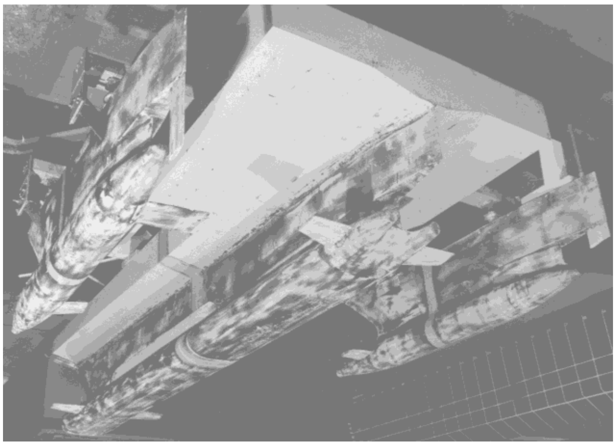

Fig. 8. The recommended option of mitigation foils: two pairs of foils at the ends (for pitch mitigation), one pair – at the outriggers (for roll mitigation).

The shown option ensures sufficient mitigation of all kinds of motions.

Activated by air **ballast tanks** can be applied for motion mitigation of SWA ships at rest and at small speeds. Besides, big enough volume of ballast tanks allows designing of SWA ships with minimal draft (the waterline without ballast must be at the horizontal connection line of the struts and the gondolas). SWA with minimal draft can be sail in smooth water, sailing at waves needs the ballast with the volume is equal to a half of strut inner volume for seakeeping growth. Controlled outlay of air allows compensating the immersed volume changing at motions, i.e. sufficiently decreasing of the motions.

Passive foils are used for ships with moderate speeds. Besides the selection of rational area of foils, ensuring the permissible fatigue strength of foils is the main problem. For example, two UK frigates have bow passive foils. The full-scale tests shown notable effectiveness by motion mitigation, but fatigue strength was not ensured, and the foils ware deleted form the ships.

Added supports of foils can be proposed for theirs strength growth. But it means bigger own resistance of such appendices…

Fig 9 shows a comparison of pitch of 25-m catamaran with and without bow passive foil (about 10% of water-plane area) between hulls.

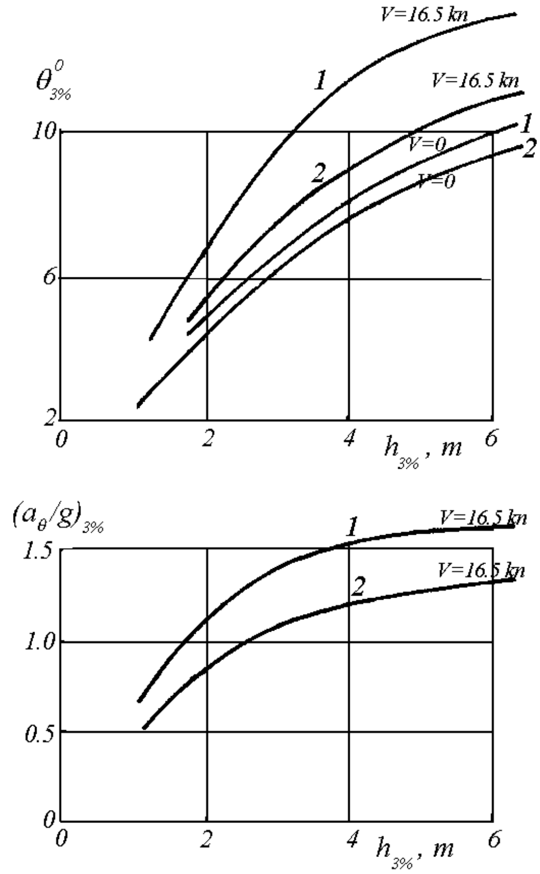

Fig. 9. Pitch amplitude comparison (upper curves) and pitch accelerations (lower curves) of 50-t catamaran at head waves, by Eng. E.Boitsova [2], 1 – without foil, 2 – with foil.

Evidently, the foil is more effective one at bigger speeds, but in main the motion mitigation is lesser, than of SWA ships.

It must be noted such area of the foil is about biggest from permissible ones, because bigger area will mean bigger vertical displacement of stern in a comparison with bow.

Flow interceptors can be applied for motion mitigation of gliding vessels. For example, the proposed by the author the triple-hull super-gliding boat with air-dynamic unloading (WPT) will have three flow interceptors at hull sterns. It allows a sufficient decreasing of pitch, roll and heave, Fig. 10.

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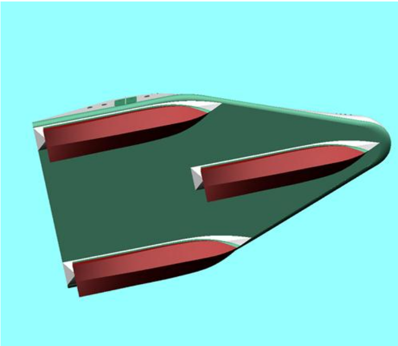

Fig.10. An example of wave-piercing trimaran, WPT, [6].

Big bow bulb, except towing resistance decreasing, decreases longitudinal motions too. For example, Fig. 11 shows the comparison of vertical accelerations at bow perpendicular of high-speed 1000-t mono-hull without and with such bulb; the volume of the bulb was about 10% of the ship displacement.

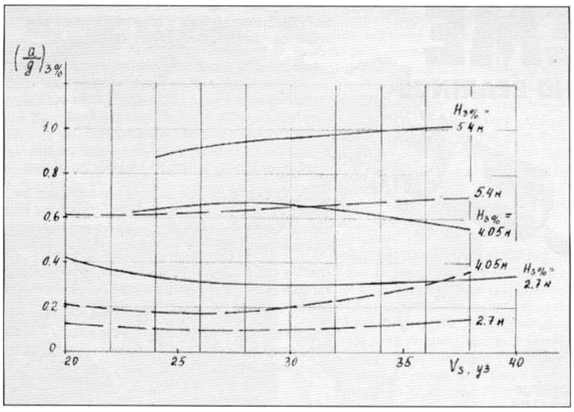

Fig. 11. Relative vertical accelerations at the bow perpendicular of the 1000-t high-speed monohull without bulb (solid curves) and with bulb (dotted lines), [7].

If the permissible standard of acceleration is 0.25g, as for a passenger ferry, the examined ship will have such level at wave height lesser, than 2.7 m/ i.e. about Sea State 4. The ship with bulb can ensure the same level of accelerations at wave height more, than 4 m, i.e. more, than Sea State 5. It means notable bigger time of comfortable sailing at any sea.

C. Decreasing of shock pressures.

As it was noted previously, some **profiling** of wet deck is one from the most simple and cheap methods of shock pressure decreasing. Fig. 12 shows wet deck profiling of "Kaimalino", American built trisec, which was tested in waves.

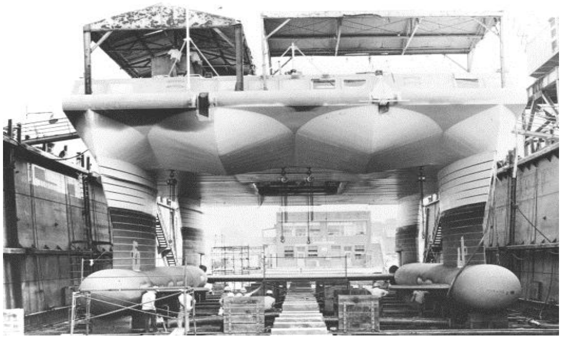

Fig. 12. Wet deck profiling of the trisec "Kaimalino", [2].

It can be supposed, decreasing of shock pressure is the result not only changing of surface inclination relative to horizon, but the temporary local air layers in the hollows of the surface.

Some options of the **special structures** for shock decreasing were proposed and tested by models at the early stages of creation of fishery catamarans [2]. Fig. 13 shows the main results of such investigations.

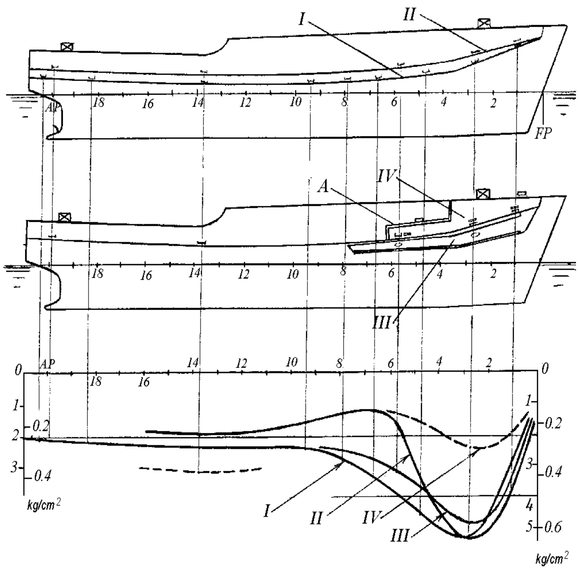

Fig.13. Some measures, which allow to decrease the wet deck slamming shocks:
I – initial vertical clearance, flat surface; II – smaller clearance, III – initial clearance and punched surface, IV – cell surface, A – punched inner surface. The right scale at bow and stern – model pressure, left one – full-scale pressure.

Evidently, the structure, which ensures temporary existence of local air layers, is most effective one from shock decreasing point of view.

One from such structures was proposed for shock decreasing on the wet deck of novel type of fast vessel, of "wave-piercing" trimaran, WPT. Such structure of a SWA ship is shown at Fig. 14.

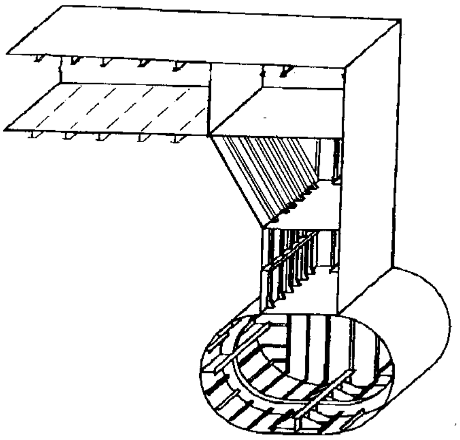

Fig. 14. Proposed new structure of a SWA ship wet deck [3].

The shown structure includes stiffeners are placed at the outer side of wet deck surface; the stiffeners are supported by floors at the inner side the wet deck plate. It allows change usual structure of wet deck (with two plates with floors and stiffeners between plates) by only one plate with floors up to it, and stiffeners below it, i.e. it means smaller mass of the wet deck and bigger vertical clearance for the same inter-hull structure height. The outer stiffeners, firstly, damage the surface of waves, and, secondly, generate temporary local air layers between stiffeners.

III. Conclusions, Recommendations.

1. As it was noted previously, relative beam of a hull acts to longitudinal motions sufficiently; it means big influence to wet deck slamming frequency; therefore, the relative beam values no less, than 2, is recommended. Variation of the relative beam is very desirable at the process of main dimension selection of any multi-hull ships. Besides, the SWA hull gondola beam must be twice bigger, than the gondola height (on the contrary with contemporary practice of round-frame gondolas of SWA ships).
2. The vertical clearance must be varied at the process of a multi-hull ship designing. The data of Figs. 15 (multi-hulls with traditional shape of hulls) and 16 (multi-hulls with small water-plane area) can be used as zero approximation values [3].

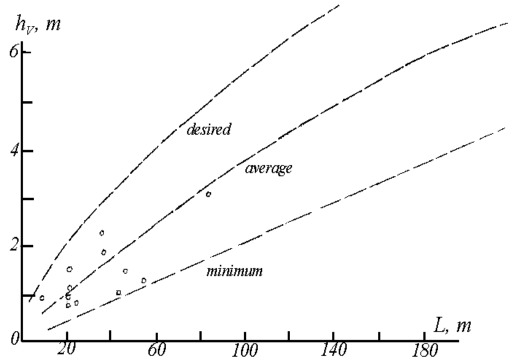

Fig. 15. Zero approximation of vertical clearance of multi-hulls with conventional shape of hulls: from top to bottom – desirable, average and minimal values.

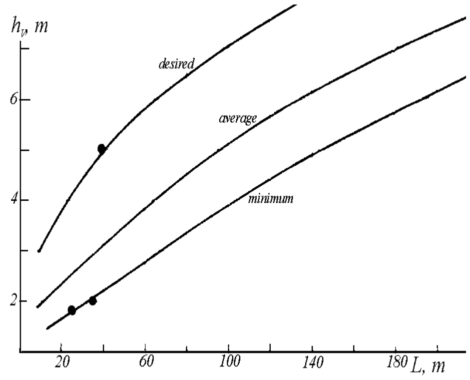

Fig16. Vertical clearance of multi-hulls with small water-plane area: from top to bottom – desired, average, minimal values.

3. Well-based selection of the vertical clearance is possible by calculation of shock frequency, see the formulae 1, and must be based on the experimental or calculated data of water level displacement relative the board surface. The corresponded model must be tested in waves without the wet deck, because that surface changes real water surface and decreases the exactness of measurements. Besides, in spite of today opinion, the displacements of level up and below the design waterline must be measured separately, because full-scale tests show their asymmetry [4].
4. As a rule, the economical restrictions do not allow selection of vertical clearance for any possible wave height, especially – of small- and medium-sized vessels. It means, except the clearance selection, some additional measurements must be carried out for decreasing of shock pressures at maximal possible height of waves. It must be noted the shock process is not so deep researched, especially – if there are air layers on the wet deck structure. It means some model tests are very desirable for based selection of the vertical clearance of any multi-hulls.

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