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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 a multi-hull ship 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 and compared. In addition, some methods of shock pressure decreasing are shown too. As the results, some general and particular recommendations are proposed.

KEY WORDS: *multi-hull ship, catamaran, wet deck slamming, motion, mitigation*.

1.0 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 shock pressure intensity. Therefore, decreasing of wet deck slamming means the drops 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]:

$$NS = [(3600*\omega z)/2\pi]*exp - [(d2/2Dz) + (v02/2Dv)], \qquad (1)$$

here $\omega Z = (DV/DZ)1/2$, DV – dispersion of local velocity of the water level displacement, m2 / sec2; DZ – dispersion of the level, m2; d – local distance from design water-plane to wet deck, so named "vertical clearance", m; v0 – 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.

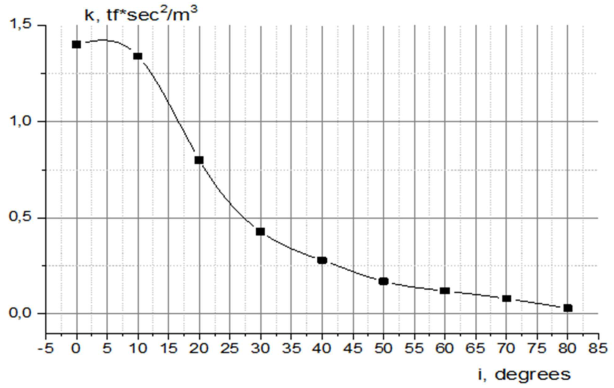

Figure 1: Empirical coefficient of shock pressure dependence from wet deck surface inclination to horizon [2]

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 Figure 1.

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.

2.0 LONGITUDINAL MOTION MITIGATION

2.1 Main dimension selection

Longitudinal motions can be decreased by various methods:

- changing of own frequency of motions for resonance avoiding at most often waves;
- 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.

A. 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.

Usually the relative area of water-plane is shown as a correlation of the area to hull displacement at the degree 2/3: AWP= L*B*CWP*/(V)2/3,

Here L,B – length, and beam of the hull water-plane, CWP - the coefficient of water-plane, V - the hull volume.

Relative area of water-plane of an usual high-speed mono-hull is about 5-6, the same coefficient of a SWA hulls is about 1 – 2.

Figure 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, relative area 1.35) in head waves [3].

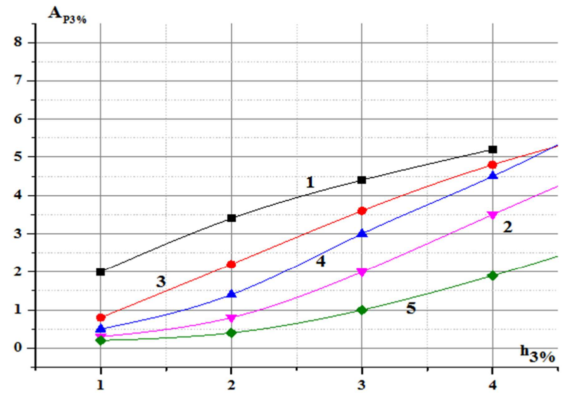

Figure 2: Pitch amplitudes in head waves: 1 – mono-hull battle ship, 1000 t, 15 knots; 2 – mono-hull, 3500 t, 15 knots; 3 – duplus, 600 t, following waves, 10 knots; 4 – the same, head waves, 10 knots; 5 – the same,18 knots.

Evidently, 600-t duplus has smaller pitch and, correspondently, bigger permissible speed in head waves in the comparison with 3500-t mono-hull. If the pitch amplitudes of a mono-hull are proportional to the cube root of displacement, the shown 600-t duplus has the same pitch, as a 20 000-t mono-hull - and at bigger Froude number by the hull length.

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.

B. The main dimension correlation, which acts strongly to motion and can be selected simple enough is relative beam of a hull, B1 / d, here B1 – a hull beam, d – the design draft. Some results of approximate calculations of the needed vertical clearance of two various hulls are shown by Figure 3 [3]. Here the selected number of slamming shock is no more, then 20, relative beam is B1 /d = 2 and 4, and wave intensity and relative speed (Froude number by a hull length) are varied ones.

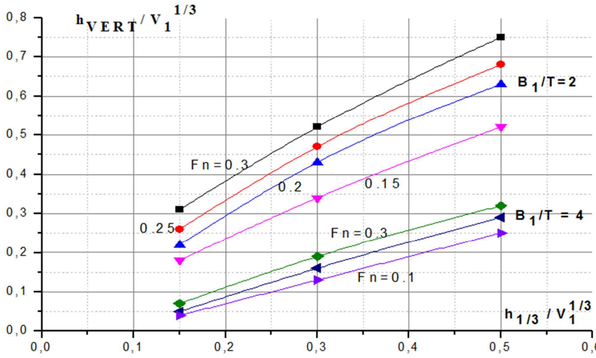

Figure 3: The needed vertical clearance estimation (for 20 shocks per a hour), here: hVERT – vertical clearance, m; h1/3 – height of wave, m; V1 - volume displacement of a hull, cub m; Fn – Froude number by a hull length.

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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 counteracted results of the beam selection.

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

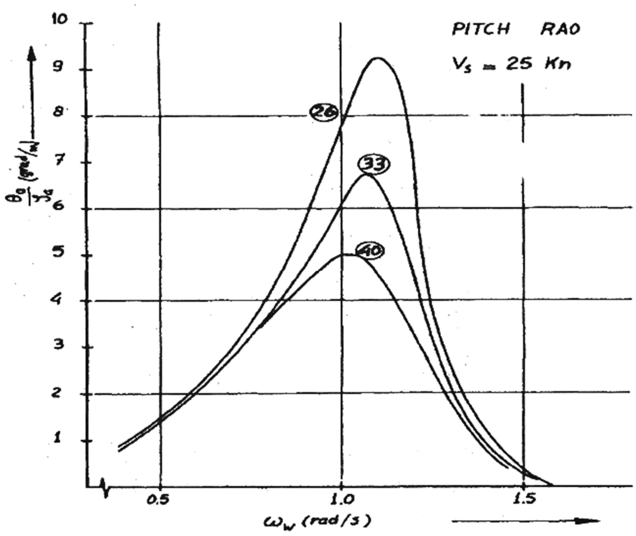

Figure 4: Root mean square of pitch single amplitudes [4] in the dependence of hull length.

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

D. Block coefficient of a hull as a whole and the fullness of bow are defined usually by needs of performance. And bigger fullness of hull is not used for motion mitigation. Moreover, the bigger fullness means bigger displacement; than the "pure" influence of fullness 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.

E. 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.

As a quality example, the Table 1 contains some results of pitch calculations of the catamarans with various distance between hulls (by linear wave theory). Pitch characteristics of the mono-hull of the same length and displacement are taken as the base of comparison.

Table 1: Catamaran characteristics relative to mono-hull ones [2]

Charact	$H_{3\%}$, m	Fn = 0				Fn=0.4			
		c/B_1=0.5	1.0	1.5	2.0	c/B_1=0.5	1.0	1.5	2.0
Heave amplitudes $A_{H3\%}$	1.5	105	128	136	128	260	142	133	125
	3.0	93	107	111	110	150	131	124	118
Pitch amplitudes $A_{P3\%}$	1.5	114	99	102	103	140	118	130	115
	3.0	93	96	98	100	93	108	125	117
Bow displacement $Z_{V3\%}$	1.5	108	103	108	106	150	127	134	118
	3.0	90	97	100	100	98	116	130	120
Bow accelerations $Z_{A3\%}$	1.5	85	115	123	117	175	144	137	113
	3.0	88	107	112	109	1156	130	135	117

Here c – the distance between inner boards, B_1 – a hull beam.

Not so defined in general, these 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.

2.2 Mitigation 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 motion decreasing because of bigger efficiency of

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mitigation systems.

A. 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 Figure 5 (pitch and roll amplitudes of an inhabited self-propelled model SM-14, the displacement about 7 t).

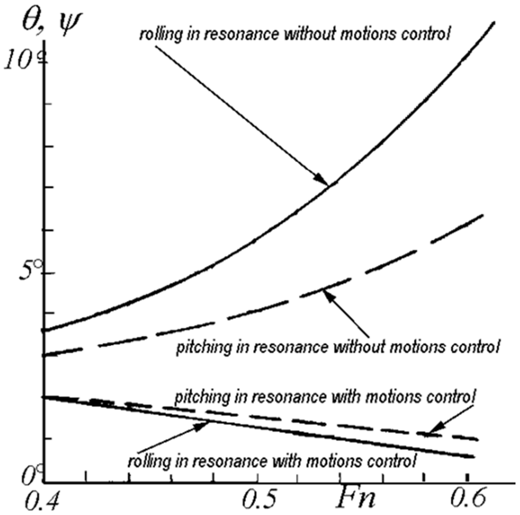

Figure 5: Resonance amplitudes of roll (upper line) and pitch (the second line from top) of self-propelled model SM-14 without mitigation; roll and pitch of the same model with foils, tow lower lines. Speed up to 14 knots, wave height 0.7 m, relative height 0.35 [2].

Evidently, the pitch can be mitigated at about 6 times at full speed, but if the foil area is comparable with water-plane area. For SWA ships, with their lower water-plane area and stability, approximate symmetrical arrangement of foils is desirable for maximal symmetry of motions. But for ensuring of longitudinal stability, the bow foils must be lesser, then stern ones, at 2-3 times. Figure 6 shows a model with bad option of foil-stabilizers: only bow foils. Very strong asymmetry of motion in head waves was the result of such option: stern had much bigger vertical displacement then bow. It was the main reason of option rejection.

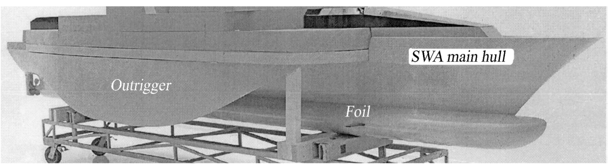

Figure 6: A bad option of foil arrangement [5].

The recommended option of foils for outrigger SWA ship is shown by Figure 7. The shown by Figure 7 option ensures essential mitigation of all kinds of motions.

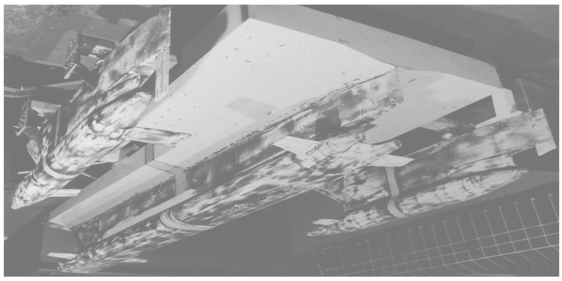

Figure 7: Recommended option of foil mitigation: two pair of foils at the ends of the mail hull (for pitch mitigation), one pair – on outriggers (for roll mitigation).

B. Activated by air water ballast tanks can be applied for SWA ship motion mitigation at stop and at slow speeds. Big enough volume of ballast tanks allows designing of SWA ships with minimal design draft (full displacement water-plane coincides with the top surface of the gondola(s) for more wide list of permissible harbors and sea straights. Such SWA ship can sail in smooth water with the minimal draft, and the not so big water ballast ensures bigger draft and high seakeeping. The needed ballast volume is equal about to half of inner volume of struts. Moreover, the controlled inlet of air to the ballast tanks ensures motion mitigation without a dependence from ship speed.

C. Some passive foils are used for longitudinal motion mitigation of ships with moderate full speed. The main problems of designing of such foils – area selection and avoiding of damage because of fatigue strength. For example, two UK frigates had bow foils at 50-ths years. The effect of motion mitigation was very notable, but the foils were cut because the fatigue cracks were a danger of hull surface. The inclined supports can be used for avoiding of fatigue damage, but they, of course, will increase the own resistance of foils. For an example, the influence of bow foil on pitch and vertical acceleration amplitudes of a small-sized catamaran is shown by Figure 8. The foil area was about 10% of water-plane area.

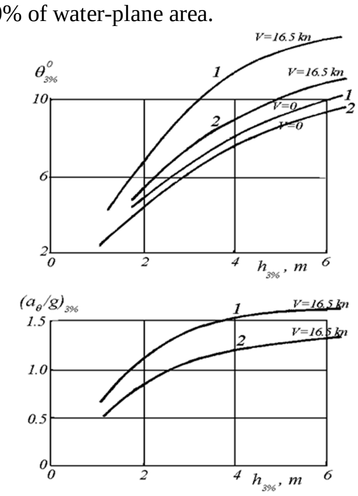

Figure 8: A comparison of pitch (upper graph) and acceleration (lower graph) of 50-t catamaran in head waves: 1 – without foil, 2 – with foil (tests of Eng. E. Boitsova,[2]).

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The effect is evident, especially at speed, but the effect is not so big in a comparison with foil action on SWA ship motion. It must be noted, the shown relative area of bow foil seems about optimal one, because bigger area leads to over-mitigation of bow vertical displacement, i.e. to growth of stern displacement in waves. For more simple repair and for avoiding of fatigue cracks, the foil must be connected with hulls by the hinges.

D. Flow interceptors on sterns and on middles of planning hulls can be used for motion mitigation. For example, the triple-hull super-planing vessel with air unloading must be equipped by three flow interceptors on sterns of hulls for decreasing of all kinds of motions, Figure 9.

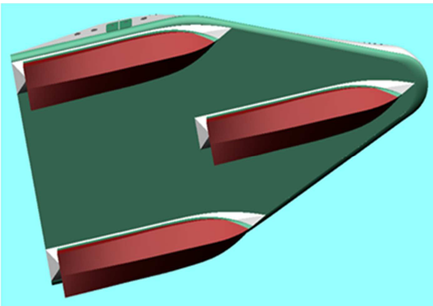

Figure 9: An example of hydrodynamic complex of "wave-piercing" trimaran (WPT) [6].

Evidently, stern interceptors are most simple and effective option of motion decreasing.

E. Big bow bulb, besides towing resistance decreasing, increases damping, i.e. decreases the longitudinal motion too. For example, Figure 10 contains a comparison of bow vertical accelerations of a 1000-t mono-hull without bulb, and with the big bulb (about 10% of volume displacement of the hull).

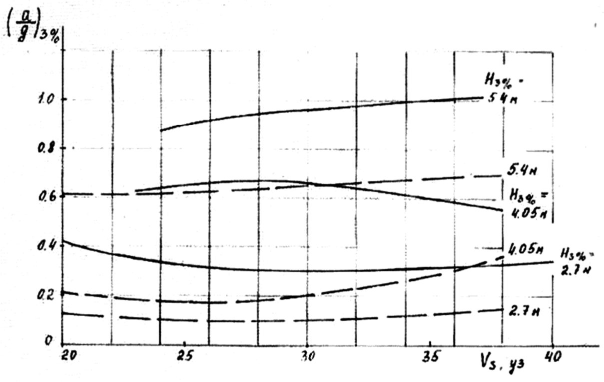

Figure 10: Relative vertical acceleration of bow of 1000-t mono-hull without bulb (solid lines) and with bulb (dotted lines), [7].

If the acceleration 0.15g is taken as a standard, as for a passenger vessel, the ship without bulb will ensure such level at wave height less, then 2.7 m, i.e. about Sea State 4. The bulb will increase permissible height of waves up to 4 m, i.e. more, then Sea State 5. It means notable wider limits of weather conditions for comfort sailing of the examined car-passenger ferry. Evidently, the same result will be for a catamaran from such hulls.

3.0 SHOCK PRESSURE DECREASING

As it was noted previously, one of the simplest and cheapest methods of shock decreasing is profiling of wet deck surface. As an example, Figure 11 shows the shape of wet deck of the trisec "Kaimalino", which was built and tested in USA.

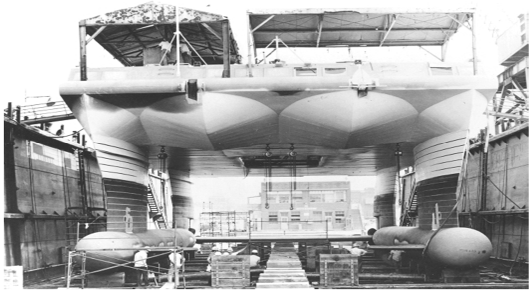

Figure 11: Wet deck profiling of the trisec "Kaimalino" [2].

It can be supposed, the shock decreasing is ensured not by surface inclination alone, but by local air cushions in the hollows of the surface. That profiling can be developed by various methods (for example, [8]).

Some options of measures for shock decreasing were researched by model tests at the earlier stages of fishery catamaran researching [2]. Figure 12 shows the main results of these tests.

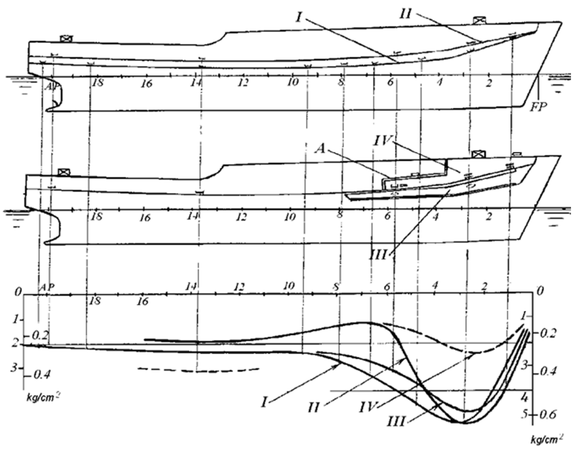

Figure 12: Some methods of shock decreasing of a catamaran wet deck:

I – initial clearance, flat surface; II – decreased clearance, III – initial clearance and perforated surface, IV – sell surface, A – perforated inner surface. The right scale at bow and stern – pressure on model, left scale – on full-scale ship.

It seems evident, the option, which ensure generation of local temporary air cushions, is most effective for shock pressure decreasing.

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One option of such measures was proposed for new type of a super-fast vessel ("wave-piercing" trimaran). The option scheme for a SWA structure is shown by Figure 13.

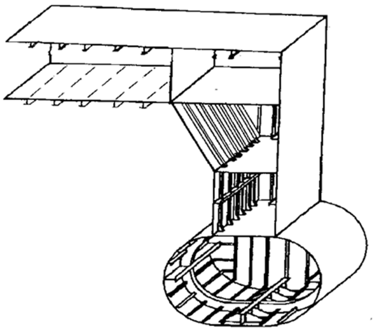

Figure 13: New structure of wet deck [3].

The new structure consists from longitudinal stiffeners are placed on outer surface of the wet deck (on the contrary to usual arrangement in the inner side). The stiffeners are supported by transverse frames through the wet deck plating. It means one deck plates instead of usual two ones, i.e. smaller structure mass, and ensures bigger vertical clearance at the same hull depth. Besides, the outer stiffeners destroy the wave surface at the moment of slam, and generate local temporary air cushions at the same moment.

4.0 CONCLUSIONS AND RECOMMENDATIONS

As it is noted previously, relative beam of a hull (B1/d) acts essentially to longitudinal motion, and slamming frequency; therefore, the recommended beam is no less, than 2. Some variation of the relative beam is desired at the design process of any multi-hull.

The same correlation of a gondola beam and height is recommended for SWA hulls – in spite of the contemporary trends of designing (round frames of the gondolas).

1. The vertical clearance, which defines the hull depth, must be varied at the design process too. Figures 14 (for traditional shape of hulls) and 15 (SWA hulls) contain the zero approximation recommendations for clearance selection [3].

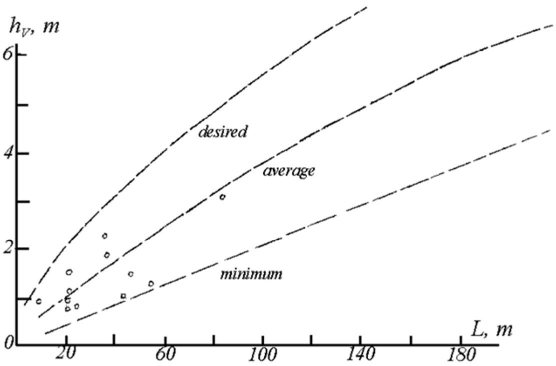

Figure 14: Recommended zero approximation of vertical clearance of multi-hulls with conventional hull shape; from top – desired, average, minimal values.

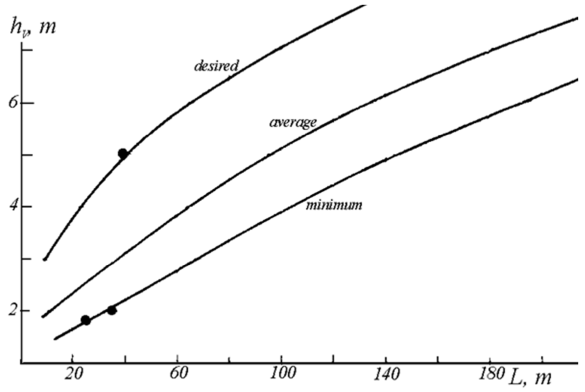

Figure 15: Recommended zero approximation of vertical clearance of SWA multi-hulls: from top – desired, average, minimal values.

2. Most based selection of vertical clearance is possible by calculations of slam number at a hour (see the previously formulae) with the base experimental or calculation data of water level displacement at the examined points. The corresponded model must be tested without the inter-hull structure, because it ensures most exact information on the displacement. By a way, on the contrary to the exist opinion, the level displacements must be measured separately at upper and lower directions from the design water-plane. (Because the full-scale measurements show a definite asymmetry of vertical accelerations [4])
3. As a rule, economical characteristics do not allow the selection of optimal clearance for any intensity of waves, especially – for small- and middle-sized vessels. Therefore, except the selection of big enough clearance, some measures of slam pressure decreasing must be realized. And some estimations of the effect of such structure options are very desired – on the base of added seakeeping tests. And it must be noted, the shock process of a wave to hull structure is not examined enough today, especially – if there are some temporary local air cushion (cavities). But it must be claimed a priory, the existence of such cavities will decrease the shock pressure.

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