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Improvement of Seakeeping Qualities of Small Fishing Vessels as One of the Ways to Increase Their Energy Efficiency

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Abstract – **The paper considers the status, parameters and prospects of small-size fishing vessels in Russia. A method for estimating the effect of seakeeping on the economic and energy efficiency of these vessels is described. The results of model and full-scale tests of these vessels are given.**

Keywords: seakeeping, small-size fishing vessels, energy efficiency, economic efficiency.

Abbreviations

SG shaft generator
ME main engine
DG diesel generator
GD geared diesel installation
DE diesel electric installation
SFV small-size fishing vessel
RMRS Russian Maritime Register of Shipping

I. INTRODUCTION

The Concept for development of the Russian fishery industry recognizes that the total fish yield has dropped by more than 50% over the period from 1991 to 2008 due to reduction in fish harvest in exclusive economic zones of foreign countries by 65% and open areas of the World Ocean by 75%. However, the share of fish proteins accounts for about 10% in the total consumption of animal proteins, and for about 25% in meat/fish balance (Concept, 2008).

It is explained by the fact that a significant part of the fishing fleet was relocated to the exclusive economic zone of the Russian Federation where small-size fishing vessels are actually operated.

The harvest of the main fish resources has exceeded the acceptable limits but many kinds of aquatic biological resources are still underdeveloped (herring, saury, squid, etc.).

Low-efficiency, obsolete and dilapidated vessels built in 1960s -1980s make up about 90% of the existing fishing fleet. These vessels have poor energy efficiency and their technical and economical characteristics are well below the modern requirements.

The strategic goal of the fisheries development in Russia is to achieve by the year 2020 the economic and social level in this industry that would be commensurate with the status of Russia as one of the leading fishing powers of the world.

For achieving this strategic goal it is planned to upgrade existing Russian fishing fleet and build new vessels, this program is broken down in three phases:

Phase 1 – 2008-2012;

Phase 2 – 2013-2017;

Phase 3– 2018-2020.

The first phase would feature:

- fast upgrading of Russian shipbuilding facilities;
- development of measures for state support to domestic shipyards to promote construction of modern fishing vessels.

The second phase is intended to raise the competitiveness of the Russian fisheries based on new technological principles, in particular:

- coastal fishing using small-size vessels would enhance recoverable fishery resources due to exploitation of underdeveloped aquatic biological resources and would become one of the most important components of the economy in the Russian Federation coastal areas;
- construction of newbuildings for the Russian fishing fleet at domestic shipyards.

The third phase of the Concept program would secure the Russian fisheries a leading position among the major fishing powers of the world and ensure sustainable social and economic growth based on innovations and integration in the world economy.

Table 1 gives the main data of small-size fishing vessels to be built in phase 1, and Figures 1-3 show outlines of these vessels.

TABLE 1. MAIN DATA AND PARTICULARS OF PROSPECTIVE SMALL-SIZE FISHING VESSELS. PHASE 1

Characteristic, unit of measurement	Design of Yaroslavsky Shipyard	Project 21060	Project 21890
Fishing gear	Purse-seine, trawl	Trawl, Danish seine	•
Production type	Chilled	Frozen	•
Length, m - overall L_{OA} - between perpendiculars L_{PP}, m	 28.4 24.0	 30.3 26.2	 32.0 28.2
Beam B, m	9.5	9.0	9.0
Depth D, m	4.3	3.6	4.0
Draft d, m	•	3.2	3.2
Cargo hold capacity, m^3	297	190	217
Speed, knots	•	10,0	•
Powerplant type and output N, kW	DE 1100 320 DG•	GD 895 SG 200 DG 2x160	• •
Endurance, days	•	20	•

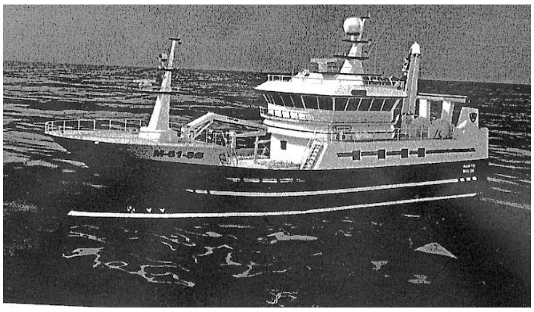


Figure 1. Fishing vessel for purse seining and ground angling built at Yaroslavsky Shipyard

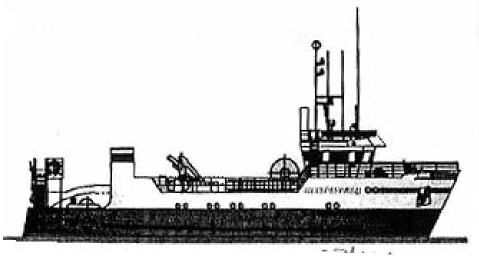


Figure 2. Small freezer trawler, Project 21060, Vostok Design Bureau

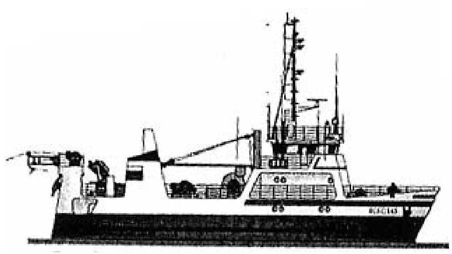


Figure 3. Fishing vessel with polymer composite hull, Project 21890, Vostok Design Bureau

II. MAIN DATA OF SMALL-SIZE FISHING VESSELS

The existing small-size fishing vessels (SFV) have the length between perpendiculars in the range of L_{PP} = 24-35 m, beam 5.5-9.5 m, main engine output 100-600 kW, speed 8.5-10.5 knots, gross registered tonnage 80-500 GRT (Figure 4). These vessels are broken down into 3 groups by GRT and main engine output, see Table 2. The main data of type SFV are given in Table 3.

As of 01.02.2009 the total number of SFVs in Russia is 365 units, i.e. 30% of the total fishing fleet. The vessels are distributed over 9 seas and 18 fishing ports (Table 4) with substantially different wave and wind conditions. Generally, these vessels are operated autonomously.

In accordance with the Rules (Safety rules, 1991) SFVs can perform fishing (depending on the fishing gear, ship design and displacement) in seas up to 4-5 sea state (significant wave height $H_S \leq 2.65$ m). Figure 5 shows the distribution of waves with wave heights $H_S > 3$ m by months in the areas of the major SFVs home ports as per the data of (RMRS, 2003), (Infomar Company, 2006), (RMRS,2006).

TABLE 2. MAIN CHARACTERISTICS OF TYPE SFVs

Main particulars	Group No.		
	I	II	III
Gross registered tonnage, GRT	100-200	201-350	351-500
Main engine output, kW	100-280	220-420	220-580

TABLE 3. MAIN CHARACTERISTICS OF TYPE SFVs

Characteristic, unit of measurement	Group No.		
	I	II	III
L_{PP}, m	24.09	29.6	35.0
B, m	6.72	8.87	7.30
D, m	3.70	5.95	3.49
d, m	2.90	3.50	3.24
Displacement ∇, m^3	244	536	449
Design speed V, knots	10.1	10.5	90.5
Endurance, days	14	20	32
No of berths	14	18	25
Navigation area	restricted	restricted	non-restricted
N, kW ME DG	 294 2x85	 425 2x165	 220 1x74 1x20
Gross registered tonnage, GRT	148	285	264
Trawling method	stern	stern	beam
Limiting sea states for fishing, sea state/H_S, m [2]	4 1.52	5 2.65	5 2.65

Downtime due to weather conditions reaches 20%, and downtime in harbour reaches 30% of the total operating time.

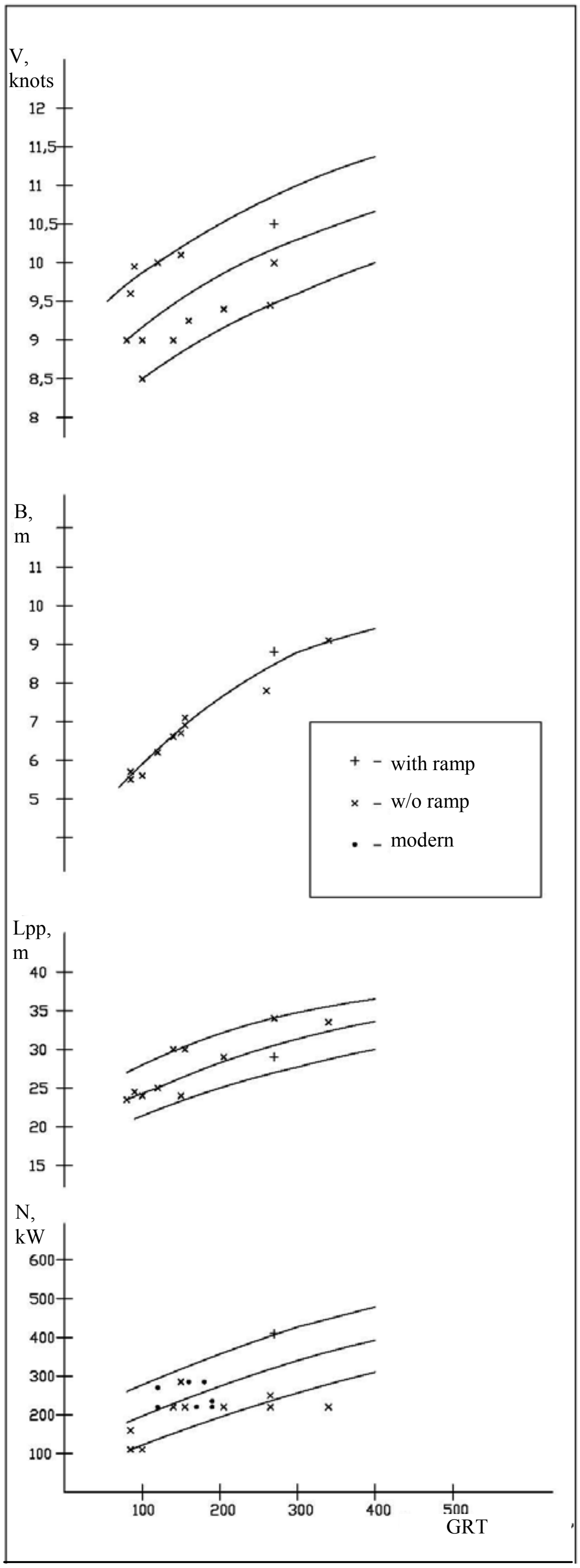


Figure 4. Relationships between the main parameters of SFVs

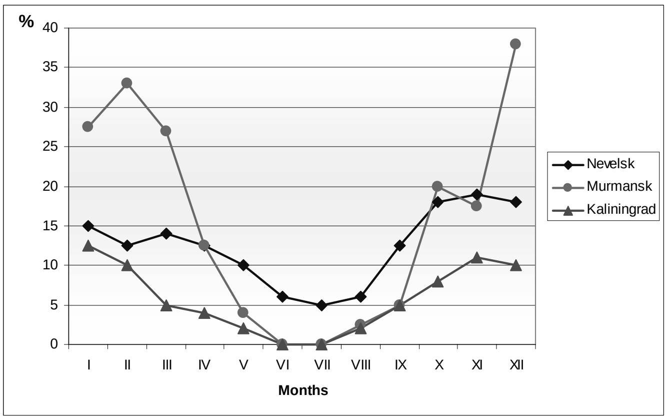


Figure 5. Percentage of waves with significant wave heights greater than 3 m in the areas of the major SFVs home ports

TABLE 4. SFVs DISTRIBUTION BY SEAS AND PORTS

Sea	Port	Total	Group No.		
			I	II	III
Sea of Azov	Taganrog Temryuk	11 1	11 1	-	-
Baltic Sea	Kaliningrad St.Petersburg	33 17	28 16	-	5 1
Barents Sea	Murmansk	68	55	-	13
Bering Sea	Petropavlovsk-Kamchatsky	75	49	7	19
Black Sea	Novorosiisk	9	8	1	-
Caspian Sea	Astrakhan Makhachkala	1 4	1 -	- 4	- -
Sea of Okhotsk	Magadan Okhotsk	9 3	- -	6 3	3 -
White Sea	Arkhangelsk	3	1	-	2
Sea of Japan	Vladivostok Nachodka Sovetskaya Gavan Kholmsk Nevelsk	22 23 9 26 51	13 - - 13 -	- 10 4 7 10	9 13 5 6 41
Total %	18	365 100	196 53.5	52 14.5	117 32

Because of the steep increase in fuel prices in the recent years the structure of operating costs has changed with a particular increase in the fuel cost component. This fact calls for careful consideration of speed loss due to wave and wind conditions during transit at sea and in the process of trawling. The SFV specific fuel consumption per ton of fish yield is also significantly increased due to interruption of fishing process because of unsafe working conditions for the crew.

Therefore, it is very important to provide the SFV designers and builders with additional information to help them in assessments of SFV economic and energy efficiency with proper account of seakeeping factors.

III. METHOD TO TAKE INTO ACCOUNG THE SEAKEEPING EFFECT ON ECONOMIC AND ENERGY EFFICIENCY OF SMALL-SIZE FISHING VESSELS

Figs 6 & 7 provide detailed flow charts for early design assessment of the seakeeping effect on the SFV economic and energy efficiency during transit at sea and in the process of trawling, respectively. For estimating how the calm-water operation efficiency of vessel will change in a specific area with its characteristic wind and wave conditions it is required to know the seakeeping characteristics and criteria.

In case of autonomous operating mode the following seakeeping criteria are applied:

- stern slamming;
- deck wetness in the bow, stern ramp and side work platforms;
- roll amplitudes;
- vertical and horizontal accelerations at work stations (weather deck, fish processing spaces, deck house, engine room, galley) causing sea sickness which degrades performance of the crew and, hence, delays in production processes;
- speed loss during transit at sea and trawling;
- propeller racing.

An important part in the assessment of seakeeping effect on vessel's efficiency is evaluation of regulated (critical) levels of relevant seakeeping criteria. When these are exceeded the crew's abilities to safely and efficiently perform their duties are degraded. The critical values used here are based on the analysis of studies by Denis (1976), Moiseeva (1976), Dubrovskiy (2000) and Makov (2007) as well as research done by the authors of this paper, specifically (Platonov et al, 1988).

The time losses during fishing are estimated using a numerical seakeeping parameter determined by means of polar diagrams.

Tables 5 & 6 give the range of parameters describing the above-water and underwater hull of fishing vessels covered in the study.

This methodology is intended for design of fishing vessels of various types with a length in the range of L_{PP} = 12-140 m and European hull lines. The authors appreciate contributions of D.G. Gryazin, V.M. Ilyin, K.D. Kornilov, I.P. Melkozerova, R.Ya Pershits, P.F. Pyryalin, Yu.M. Fishkis and M.V. Shmidt who took an active part in the creative development of this methodology as well as model and full-scale tests.

TABLE 5. MAIN PARAMETERS OF UNDERWATER HULL FORM OF FISHING VESSEL MODELS
(14 models tested)

Characteristic, unit of measurement	Range
L_{pp}, m	1.91÷3.13
B, m	0.498÷0.853
d, m	0.175÷0.306
C_B	0.406÷0.625
L_{PP}/B	2.50÷7.00
B/d	1.95÷3.81
L_{PP}/d	6.23÷17.5
Longitudinal radius of gyration r_y, 1/ L_{PP}	0.22÷0.28
d_{20}/d	0.85÷1.00
$(d_0-d_{20})/L_{PP}$	± 0.077
Frame shapes	V
Froude number Fn	0÷0.35
Regular wavelength, 1/ L_{PP}	0.5÷2.5

* d_0 и d_{20} –draft at stern and bow, respectively;
** One model was tested with V, U & VU-shaped frames, another model was tested at different flare angles of freeboard in bow using special-purpose dismountable attachments (-4° and +5°).
Nomenclature is given in Table 1.

TABLE 6. RELATIVE PARAMETERS OF ABOVE-WATER HULL FORM OF FISHING VESSELS
(120 options with L_{WL} = 1.5 m in model scale; L_{WL}/B = 5.0)

Characteristic	Symbol	Range
Freeboard at midship/ L_{WL}	$\overline{F} = \frac{F}{L_{WL}}$	0.021÷0.145
Side area of superstructure and deckhouses/total sail area	$\overline{S}_{SH} = \frac{S_{SH}}{S_{SA}}$	0.06÷0.63
Longitudinal center of sail area/ L_{WL}	$\overline{X}_{CA} = \frac{X_{CA}}{L_{WL}}$	-0.063÷0.122
Distance between superstructures along ship/ L_{WL}	$\overline{L}_p = \frac{L_p}{L_{WL}}$	0÷0.52
Side area of the smallest superstructure/side area of the largest superstructure	$\overline{S}_{SS} = \frac{S_{SS}}{S_{LS}}$	0÷0.56
Side sail area of bow visor/total sail area	$\overline{S}_{BV} = \frac{S_{BV}}{S_{SA}}$	0÷0.105
Trim by stern/ L_{WL}	$\psi = \frac{F_{20} - F_0}{L_{WL}}$	-0.021÷0.083
Draft	$\overline{d} = \frac{d_i}{d}$	0.80÷1.10

* L_{WL} – waterline length, m
** d_i –intermediate draft, m

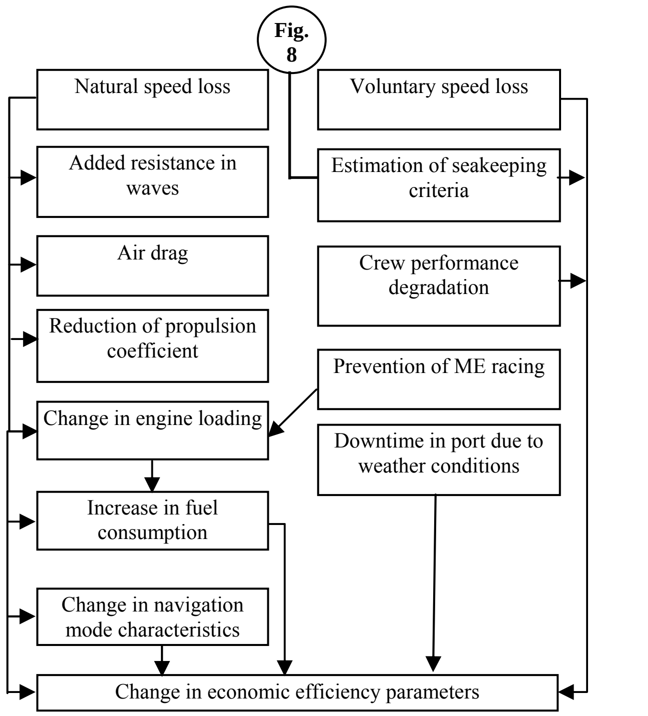


Figure 6. Flow chart for assessment of seakeeping effect on economic and energy efficiency of vessel during transit at sea

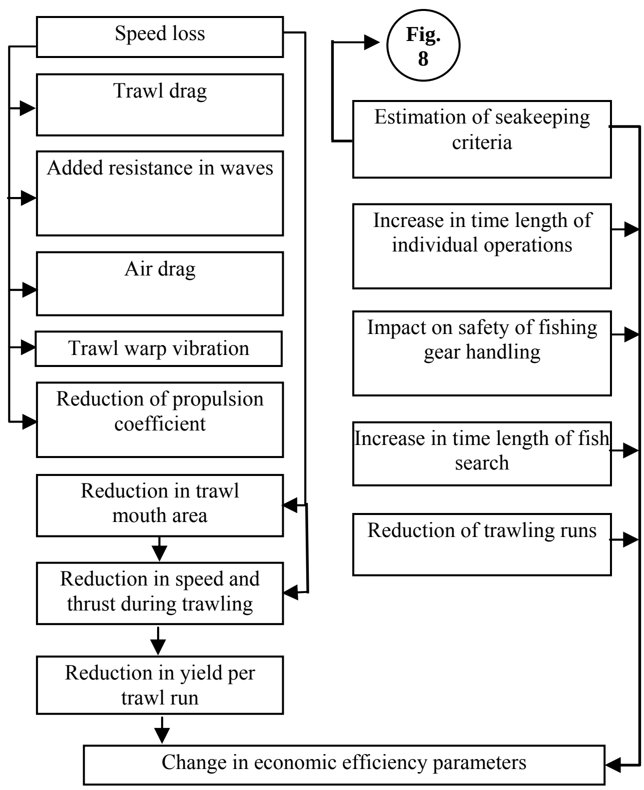


Figure 7. Flow chart for assessment of seakeeping effect on economic and energy efficiency of vessel during trawling

IV. ESTIMATION OF SEAKEEPING CRITERIA

The seakeeping criteria estimations according the flow chart given in Figure 8 are based on well-known formulae applicable to random processes whose amplitudes can be approximately assumed as distributed by Rayleigh law. For example, the probability P that the amplitude of random process U(t) exceeds some level F is calculated by the formula

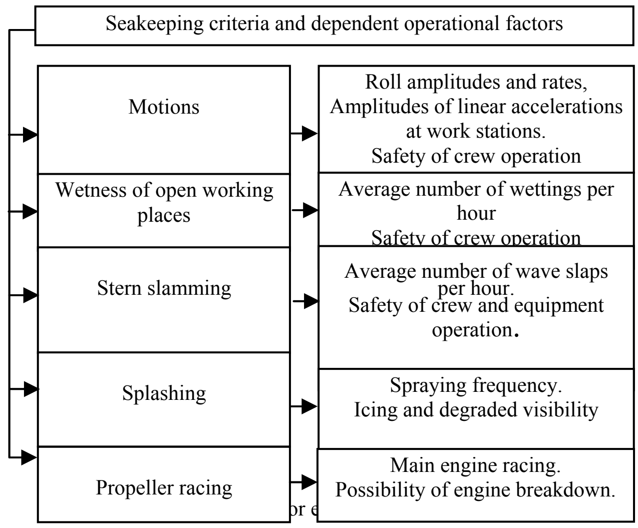
$$P = \exp(-\frac{F^2}{2D_U}), \qquad (1)$$

mean number of the level F exceeding cases per 1 hour of vessel operation N_U is calculated by the formula

$$N_U = \frac{3600}{\tau_U} \cdot P \text{, cases/hour,} \qquad (2)$$

where D_U – process variance U(t),

τ_U – mean period of process U(t), s.



Figuge 8. Flow chart for estimation of seakeeping criteria

Table 7 gives recommendations on how to choose F values for specific sections of SFVs and critical N_U values.

TABLE 7. RECOMMENDED F & N_U VALUES FOR SFVs

Mode	Values specified	Rated
Transit		
Emergence of fish search equipment	$F=F_d$-0,5, м F_d – depth of antenna	$N \leq 30$
Propeller racing	F– immersion of 1/3 propeller diameter below waterline, m	$N < 120$
Fishing ground		
Place of fishing gear recovery at vessel's side	$F=F_d + h_{sd}$, м F_d – vertical distance from waterline to work station; h_{sd} – allowable green water on deck.	$N \leq 15$ $h_{sd} \leq 0,4$ m
Upper edge of ramp	$F=H_ck_yk_lk_s+ h_c + h_{sd}$ ky, kl, ks – factors including the ramp angle of inclination, length and area of water draining openings; Hc – height of ramp upper edge above waterline, m; hc – height of ramp lower edge above waterline, m; h_{sd} – allowable green water on deck.	$N \leq 35$ $h_{sd} \leq 0,4$ m

The F level for the bow wetness is assumed to be the effective freeboard calculated taking into account the ship wave. The calculations of stern slamming take into account the threshold velocity of slamming, which depends on the stern overhang length and bottom shape. The experience with operation of small-size fishing vessels indicates that speed limitations in case of these vessels are generally imposed by bow wettings rather than slamming conditions. Therefore, bow wetting is considered to be one of the main criteria in estimations of the intentional speed reduction for SFVs during transit at sea.

The methodology also includes:

- differentiated regulation of pitch and roll on fishing ground and during transit depending on the requirements of equipment suppliers;

- differentiated regulation of accelerations in specific points depending on the function of the given vessel area.

- estimation of trawling cycle time length by the following formula

$$t_{tc} = t_{tc}^{cw} + p(H_S)H_S\sum_{i}^{n} a_i \qquad (3)$$

where t_{tc}^{cw} – time length of trawling cycle in calm water;

$P(H_S)$ – probability of seas with a wave height of H_S;

n – number of operations;

a_i – factors taking into account duration of individual operations in wave conditions;

as per the full-scale test data for SFV "Girulyay"

$a_1 = 4.2$ – trawl launch before trawl warp slacking, min/m;

$a_2 = 0.52$ –slacking of trawl warps, min/m;

$a_3 = 1.62$ – trawl warp slackening operation, min/m;

- estimation of the water volume trawled in function of the trawling speed;

- estimation of added resistance in head waves by the formula

$$R_{AW} = C_{AW}^{0} \rho g H_s (L_{pp}^{0})^2 K_m \left[1+\sum_{i=1}^{n}\Delta K(x_i)\right]10^{-3} \qquad (4)$$

where $C_{AW}^{0}(H_S, Fn)$ - - added resistance coefficient of the prototype vessel;

ρ - water mass density;

g - acceleration of gravity;

K_m – coefficient allowing for the difference of vessel length from the prototype vessel;

L_{pp}^{0} – length of prototype vessel;

$\Delta K(x_i)$ – coefficient allowing for the effect of the i-th vessel parameter given in Table 5.

Variance of vessel's motions and responses is estimated using generalized diagrams of SFVs motions in irregular waves obtained by calculations based on model series tests in head and following regular waves. These diagrams are rms values of the given type of motions versus non-dimensional frequency of irregular waves $\nu = (\omega_z / \omega_d)\cdot(\bar{r}_y / 0.24)^{1/2}$ (here ω_z – mean frequency of irregular waves, $\omega_d = (2\pi g)^{1/2} \cdot (L_{pp} d)^{1/4}$).

V. CONSIDERATION OF SEAKEEPING IN THE DESIGN OF SMALL-SIZE FISHING VESSEL: STUDY CASE

Table 8 gives an example of how the seakeeping is taken into account in estimations of the economic and energy efficiency of the Girulyay-type small-size fishing vessel. Specifically, the estimations indicate that an increase in vessel length improves the economic efficiency due to consideration of the seakeeping factor.

TABLE 8. MAIN PARAMETERS OF THE FISHING VESSEL SUBJECTED TO COMPREHENSIVE FULL-SCALE TRIALS; COMPARISON OF VESSEL OPTIONS

Characteristic, unit of measurement	”Girulyay”	Option 1	Option 2
Fishing method	Trawling		
L_{PP}, m	29.6	- 1.5	+ 0.4
B, m	8.87	+0.15	0.0
∇, m^3	535	- 15	+ 5
Solid ballast mass, t	16	- 16	+ 5
C_B	0.552	0.0	- 0.02
C_W	0.825	0.0	- 0.02
VCB, m	2.05	0.0	+ 0.01
VCG, m	3.81	+ 0.01	- 0.03
r_x, m	2.43	+ 0.01	- 0.03
GM, m	0.67	0.0	+0.01
GM/B	0.075	-0.001	+ 0.002
Natural roll period, s	8.7	+ 0.1	- 0.1
Ramp slope	0.500	+ 0.167	- 0.090
Propeller pitch ratio [2) 3)]	0.926 / 0.926	- 0.011 / - 0.011	+ 0.010 / + 0.010
Power take off [1) 3)], kW	589 / 520	0,0 / - 10	0,0 / - 10
ME speed [3)], rpm	345 / 305	0,0 / -5	0,0 / - 5
Vessel speed, knots design speed in calm water and service speed	11.15 8.83	- 0.15 - 0.13	+ 0.40 + 0.29
Thrust at trawling in calm water, kg	8502	- 53	- 137
Variation of annual yield, %	0.0	- 10.0	+ 2.16
Variation of specific costs per 1 t of product, %	0.0	+ 9.74	- 1.79

1) It is assumed that d = 3.41 m; LCB/ L_{PP} = - 0.0316;
$\bar{r}$ = 0.275;
2) high-speed four-bladed propeller with diameter 1.8 m in duct, blade area ration 0.58;
3) numerator refers to transit mode, denominator refers to trawling at 4 knots.
Nomenclature is given in Table 1.

CONCLUSIONS

1. The small-size fishing vessels make up a significant part of the Russian fishing fleet and have good potential for development.

2. The method elaborated for considering the seakeeping factors in the selection of fishing vessel parameters provides for improvement of their energy and economic efficiency early in the vessel design process.

3. Calculations by the developed method and numerous model tests make it possible to formulate the following recommendations to improve the energy and economic efficiency of small-size fishing vessels:

- increase in ship length;
- moderate block coefficient values characteristic of the European shipbuilding;
- increase in relative area of bilge keels up to 5-6%;
- use of passive anti-rolling tanks, if possible.

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