DEVELOPMENT OF THE TRAWL CONTROLLED SYSTEM WITH FLEXIBLE SPREADING DEVICES

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Abstract

The flexible spreading device for replacing the boards in the trawl fishing systems was developed at the beginning of the 1990s and, as a result, these devices could be used only during the coastal fishery, since the device was developed by means of experimental research. However, the flexible spreading devices failed to get a more widespread use because there were no calculation methodologies. So, this paper is aimed at developing the calculation methodologies of the flexible spreading devices and their control system. Two methodologies of calculating the flexible spreading devices are offered, the first methodology makes it possible, with the knowledge of an area and hydrodynamic characteristics of the trawl boards, to calculate the design characteristics of the flexible spreading devices, while the second methodology makes it possible, with the use of the aggregate trawl resistance with the specified design values, to calculate the design characteristics of the flexible spreading devices. The results of calculating the projected areas of the flexible spreading devices on two methodologies are coinciding with each other, which confirms the adequacy of the offered methodologies of calculating the projected areas of the flexible spreading devices, since the trawl developers took into account the tractive and speed characteristics of the vessels and the characteristics of the trawl boards as a whole. The results of calculating the control system of the flexible spreading devices on the methodology, which is offered in the paper, in comparison with the experimental research conducted are differing in 2%. As the methodologies are convenient, the factory workers were able to calculate and to make the flexible spreading devices according to these methodologies, and the fishery with those devices made it possible to increase the trawling speed by 1 knot and, as a consequence, to increase the takes by 10-15%.

Keywords: Flexible spreading devices, trawl system, trawl system control
I. Introduction

The trawl system is a complex that consists of a vessel having relevant fishing mechanisms, a trawl consisting of spreading devices for horizontal and vertical opening of the rope-net casing connected by dragropes with the vessel.

The trawl system control task consists in its aiming at a chosen aggregation of aquatic organisms (of the same species) and withdrawal of the trawl system from a fishing area of other aggregations of aquatic organisms. It is getting important to solve this control task in the Far East in fishing the sardine and mackerel aggregations, which can interchange with the vessel course and can be 80-100 m and more from each other (Figure 1). The fishery practice shows that in cases when the trawl casing is closed and it gets through the aquatic organisms aggregates, these objects fail to get into the trawl.

![Figure 1: Fragments of an echogram of the mixed sardine and mackerel aggregations with assessments of numbers and biomass of shoals, day time [IX]: 1 – Mackerel; 2 – Sardine](image)

In practice, when trawling, for the horizontal opening, the trawl boards are used, which are difficult to control and the trawl boards have a great weight up to 5 tons [VIII, X].

In order to solve this task, special flexible spreading devices [I] are developed, which, through the design flexibility, after forced or casual disturbing them from equilibrium, take up a steady position with an incoming water flow. However, methods of design calculation of the flexible spreading devices and the trawl complex control system were not developed at that stage.

This paper is aimed at developing the methods of the design calculation of the flexible spreading devices for horizontal opening of the trawl system and the control system of this complex. The research tasks to achieve the set goal were as follows:
- a detailed analysis of the previous research stages stated in the papers [I, II];
- development of methods of the design calculation of the flexible spreading devices for horizontal opening of the trawl system;
- development of the trawl complex control system with the flexible spreading devices.

II. Materials and Methods

The research to develop the flexible spreading devices were conducted by the Russian scientists jointly with the NRIFE institute (Japan) and the NICHIMO company (Japan) in the 1989-1994 period at the expense of the RF Government and the research was mainly experimental. This research gave rise to ideas to control this system, which, later on, was translated into reality and patented [II]. However, this system made it possible to work with the flexible spreading devices when the trawl casing was connected to the wing, but this diagram decreases the fishing area (Fig. 2) and requires the flexible spreading device’s adaptation to each specific trawl.

Fig. 2: Diagram the flexible spreading devices control:

1 – Flexible spreading device; 2 – Cable of the control action winch; 3 – Trawl; 4 – Control action winch; 5 – Closed cable to put the flexible spreading device into an unsteady condition; 6 – loads-depressors

Later on, a diagram of the flexible spreading device installation on the trawl wing was used on small coastal fishing vessels in Japan, but it was not widely developed during the fishery with medium- and large-capacity vessels. One of the reasons was an absence of methods of designing and theoretical description of the flexible spreading devices operation processes. Since 2009 Far Eastern State Technical Fisheries University resumed the work to develop the methods of designing the flexible spreading devices. An analysis of all the previous experimental work showed as follows:

– The flexible spreading device (Fig. 3) is a zero-torquesoft casing, which simplifies its numerical simulation and adjustment during the fishery [XI], although the authors [I] believe that it is very difficult to calculate this design;
– an angle of attack of the casing is specified structurally in designing the device (\( \alpha \approx \alpha_{cm} \)) and irrespective of the operation conditions it does not change practically. This was showed by the research conducted in marine condition sand in pools [I, II], which is typical of flexible casings and is connected with the condition \\
\[ R_x^{TPY} \rightarrow 0. \] (1)

**Fig. 3:** General view of the flexible spreading device: a – side elevation; b – top view; 
1 – longitudinal; 2 – inside surface; 
3 – working surface; 4 – “pockets” (confusers); 5 – gear

Thus, let’s describe the flexible spreading device with the following parameters: 
\[ R_x^{TPY}(\alpha) \] is hydrodynamic resistance; 
\[ R_y^{TPY}(\alpha) \] is a hydrodynamic spreading force; 
\[ F^{TPY}[S,M] \] are geometrical (\( S \) is the flexible spreading device area) and mass parameters of the device. When carrying out the Research and Development the most efficient construction angle of the flexible spreading device is 
\( \alpha_{cm} = 21^0 \), and the research of the trawl system movement with the flexible spreading device showed that the angle of attack of the shield working surface relative to the flow is 
\( \alpha_p = \left[ 20 \div 21^0 \right] \), the inside surface became deformed greatly (Fig. 4, a). The conducted experimental research with a model of the flexible spreading devices (scale 1:10) in the water flume [III], with observance of the
geometrical and hydrodynamic similarity showed (Fig. 4, b), that with $\alpha_p = 20^0$ the quality coefficient $K = 10,75$ $(C_x = 0,08, C_y = 0,86)$, with $\alpha_p = 25^0$ the quality coefficient $K = 6,4$ $(C_x = 0,15, C_y = 0,96)$, which is 1.8 times less. It is necessary to note that such a great difference of the quality coefficients, with the closed angles of attack ($\alpha_p = 20^0$ and $\alpha_p = 25^0$) explains why with the operation of the flexible spreading device in natural conditions $\alpha_p = \left[20 \div 21^0\right] \approx \alpha_{cm}$, which corresponds to the condition (1).

![Fig. 4: Forms of the flexible spreading devices: a – during the operation in the trawl system; b – the model in a water flume: 1 – inside surface; 2 – working surface](image)

The water flume research [III] and the previous experiments results [I] made it possible to determine the design parameters of the flexible spreading devices (Fig. 5) in the form of correlations of the shield elements, which made it possible, in manufacturing the flexible spreading devices, to determine the linear dimension $L$ as a basis.
Two methodologies are developed in order to calculate the flexible spreading device’s parameters. The first methodology makes it possible, with account taken of the trawl boards used during the fishery, to start using the flexible spreading device and it is based on the similarity methods [XII]. The second methodology is based on taking into account of the trawl casing resistance with the specified vertical and horizontal opening, and, in view of this, the methodology makes it possible to determine the flexible spreading device parameters.

The first methodology. With a correlation of hydrodynamic forces of the trawl board and the flexible spreading device the values of the hydrodynamic head \( \frac{\rho v^2}{2} \) of the trawl board and the flexible spreading device are equal, then, for convenience, let’s introduce relative magnitudes of the hydrodynamic forces

\[
\bar{R} = C_{s,x,y,z} S. \tag{2}
\]

Let’s impose the following restrictions while solving the task:
\[ \overline{R}_y^{\text{TPY}} (\alpha) \geq \overline{R}_y^B (\alpha_{\text{omn}}); \]  
\[ \overline{R}_x^{\text{TPY}} (\alpha) \leq \overline{R}_x^B (\alpha_{\text{omn}}); \]  
\[ S_{np}^{\text{TPY}} \geq S_p^{\text{TPY}}, \]  
where \( \overline{R}_y^B, \overline{R}_x^B \) are relative hydrodynamic forces of a trawl board with an optimum angle of attack \( \alpha_{\text{omn}} \); \( S_{np}^{\text{TPY}}, S_p^{\text{TPY}} \) - a projected and nominal area of the flexible spreading device is equal to:

\[ S_p^{\text{TPY}} = \frac{\overline{R}_y^B}{C_y^{\text{TPY}}}, \]

where \( C_y^{\text{TPY}} \) is a coefficient of the spreading force of the flexible spreading device with a shield angle of attack \( \alpha \approx 0 \).

The flexible spreading device’s gear is made of webbing with the square mesh, where a mesh bar has a correlation

\[ a = \frac{1}{30} L. \]

Calculation algorithm. Let’s introduce a set of boards \( B = \{ c_x, c_y, \{ s \} \} \), where \( c_x, c_y \) are hydrodynamic characteristics; \( s \) is areas of boards, with \( \alpha_{\text{omn}} \) and webbings \( D = \{ a, d \} \), where \( a \) is a mesh bar; \( d \) is diameter of the webbing thread.

1. Let’s choose a trawl board out of the set \( B \) and calculate \( \overline{R}_y^B, \overline{R}_x^B \);
2. Let’s compute the nominal area of the flexible spreading device \( S_p^{\text{TPY}} \);
3. Let’s compute the linear dimension \( L \) while choosing a projected mesh bar out of the set \( D \)

\[ a_n = \{ a \} \geq a, \]

let’s verify \( L \)

\[ L = 30 a_n. \]
4. Let’s compute $S^{TPY}_{np}$

$$S^{TPY}_{np} = L^2,$$  \hspace{1cm} (10)

On the basis of a correlation of the linear dimensions (Fig. 5) let’s compute the flexible spreading device characteristics.

The second methodology. As the flexible spreading device is a part of the trawl system, at present the following papers exist [IV-VII, XVI, XVII] that make it possible to compute an aggregate trawl resistance, which will be written as $T^A$, then the nominal area of the flexible spreading device is $S^{TPY}_\alpha$ let’s compute

$$S^{TPY}_\alpha = \frac{T^A \sin \alpha_T}{2C_{y}^{TPY}},$$  \hspace{1cm} (11)

where $C_{y}^{TPY}$ is a coefficient of the spreading force of the flexible spreading device with an operating angle of attack of the shield $\alpha_p = 20^0$; $\alpha_T$ is an attack angle of the net casing that is determined on the basis of these papers [4-7].

Then the design characteristics of the flexible spreading device are calculated starting with the third item of the previous methodology.

The main task of control of opening and closing of the trawl casing is to put the flexible spreading device into an unstable condition in order to close the casing, and while ceasing this control action the flexible spreading device is returned to an equilibrium condition and opens the trawl casing. The conducted research of hydrodynamic characteristics of the flexible spreading device [III] showed that a critical angle of attack is

$$\alpha^K \geq 55^0.$$  \hspace{1cm} (12)

Fig. 2 shows the control diagram of the flexible spreading device, which was used in practice during carrying out natural experiments that used the trawl IPT54.4/192, which was towed at a speed of 3.5 knots, and was equipped with the flexible spreading device 4.2 m$^2$ [I]. The flexible spreading device is put into an unstable condition through switching on of winch 4 to the selection of cable 2, which is connected with closed cable 5 in its upper part getting through rings fastened in the rear part of each flexible spreading device 1, when an angle of attack of the flexible spreading device overruns the critical values—the ceasing of trawl 3 is closed. Trawl 3 was opened through switching on winch 4 to the unwinding of cable 2, and closed cable 5 was unloaded and flexible spreading device 1 steadily returned to the subcritical angles of attack and opens the casing of trawl 3.
At present the task of control of trawl systems is solved in the following papers [V, VIII, X, XIII-XV, XVIII], a difference of the system, which is considered in the paper, from the existing ones consists in a markedly different design and way of the controlling action, which is stated in papers [I, II]. So, for a task of designing the control system, a methodology of calculating the necessary effort in the control element is developed, let’s consider the force diagram of the flexible spreading device control (Fig. 2), where the flexible spreading device characteristics are calculated according to the formulas:

\[ R_x^{TPY} = C_x \frac{\rho v^2}{2} S_x^{TPY} , \quad R_y^{TPY} = C_y \frac{\rho v^2}{2} S_y^{TPY} , \]

\[ (T^{TPY})^2 = (R_x^{TPY})^2 + (R_y^{TPY})^2 , \quad tg\alpha^{TPY} = \frac{-R_y^{TPY}}{R_x^{TPY}} , \quad (13) \]

where \( R_x^{TPY} \) is hydrodynamic resistance; \( R_y^{TPY} \) is a hydrodynamic spreading force; \( T^{TPY} \) is the flexible spreading device tension; \( \alpha^{TPY} \) is an angle \( T^{TPY} \).

The flexible spreading device (13) for the force diagram of its control is calculated with the attack angle of the flexible spreading device \( \alpha_p = 20^\circ \) [III].

The controlling action of \( T^\gamma \) is calculated according to the formulas

\[ tg\alpha_i^\gamma = \frac{T^\gamma \sin \alpha_i^\gamma - T^\gamma}{T^\gamma \cos \alpha_i^\gamma} , \quad T_i^\gamma = \frac{T^\gamma \cos \alpha_i^\gamma}{\cos \alpha_i^\gamma} , \quad (14) \]

where \( T_i^\gamma \) is the trawl tension with action of \( T^\gamma \); \( \alpha_i^\gamma \) is a vector angle of \( T_i^\gamma \).

In this case for the system (14) of \( T^\gamma \) let’s calculate the critical angle of attack \( \alpha^K \) according to the formula

\[ tg\alpha^K = \frac{T_i^\gamma \sin \alpha_i^\gamma + T_i^{TPY} \sin \alpha_i^{TPY}}{T_i^{TPY} \cos \alpha_i^{TPY} + T_i^\gamma \cos \alpha_i^\gamma} . \quad (15) \]

Values of \( T^\gamma \) are changed till the condition (12) is accomplished, or \( \alpha^K \geq 55^\circ \).
When carrying out the experiments with the trawl PT54.4/192, the controlling tension $T^y$ was 550 N \cite{I}. The calculated value according to the offered methodology is 539 N, and is a 2% deviation from the experimental value.

Solution to the task of the trawl system control during the fishery is connected with the tasks of closing the trawl casing and its opening, and a related trajectory of vessel movement during bringing the trawl to the aquatic organisms aggregation \cite{XX, XXI}.

The control action parameters in closing the trawl (Fig. 7) are computed:

$$L_y = \frac{H}{2} ; \quad t_y = L_y \nu_y,$$

where $L_y$ is a length of a rope, which must be chosen; $H$ is a distance between two flexible spreading devices; $t_y$ is a time, in which the trawl casing is closed; $\nu_y$ is a speed of a winch selection with a tension $T^y$.

In a time $t_y$ the trawl system covers a distance

$$L_{m.c.} = \nu_{m.c.} t_y,$$

where $\nu_{m.c.}$ is the trawl system speed.

In order to calculate the control action during the meeting of a shoal a distance $D_s$ is chosen from the flexible spreading device to a relevant aggregation, then it is necessary to fulfill a condition

\textit{Fig. 6:} Characteristics of the force diagram of the flexible spreading device control
\[ L_{\text{m.c.}} < D_n. \]  

(18)

The changing parameters in the control system are \( \nu \) and \( \nu_{\text{m.c.}} \), since the change of the trawl system speed is connected with the fuel consumption with the subsequent speed gathering, firstly, let’s fulfill the condition \( \nu(T') \rightarrow \max \) with fulfilling the condition (18), if this condition is not fulfilled, the speed is decreased \( \nu_{\text{m.c.}} \) to

\[ \nu_{\text{m.c.}} = \frac{D_n - 1}{t_y}. \]  

(19)

---

**Fig. 7:** Parameters of the trawl system with the controlled flexible spreading device: 1 – trawl casing; 2 – flexible spreading device; 3 – aquatic organisms aggregation; 4 – control action winch

The system during opening the flexible spreading device is calculated according to the formulas (16), (17) with account taken of the condition (18) only if \( \nu \approx \nu_{\text{m.c.}} \), so, the control, in case of opening of the trawl casing, is implemented only by the speed change of the whole trawl system. Here, to fulfill the condition (18) will be enough even if the trawl casing is not opened fully, as a result only a part of the shoal will be fished off.

**III. Results**

Fig. 8 shows the calculated values of the flexible spreading devices areas, which are computed according to the first methodology on the basis of characteristics of different types of trawl boards and their areas, which are made in Russia.
Fig. 8: Design cases of the areas (S) of the flexible spreading devices on the basis of the areas and the trawl board types: 1 – Oval-cylindrical board; 2 – Right-angled-cylindrical board; 3 – Flexible spreading device; 4 – Round spherical board.

Table 1 covers the projected areas of the flexible spreading devices, which are calculated according to the second methodology for the trawl types that are made in Russia.

**Table 1: Flexible spreading devices are as for the following trawl types**

<table>
<thead>
<tr>
<th>N</th>
<th>Type trawl</th>
<th>Projected openings of trawls</th>
<th>Flexible spreading device, m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>horizontal, m</td>
<td>vertical, m</td>
</tr>
<tr>
<td>1</td>
<td>149/786</td>
<td>90</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>113/480</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>118/620</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>130/810</td>
<td>70</td>
<td>65</td>
</tr>
<tr>
<td>5</td>
<td>108/450</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>54.4/192</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>7</td>
<td>80/396</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>119/450</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>
When using the methodology of designing of the system of the flexible spreading device control, tractive and speed characteristics of the control winch were calculated for several types of trawls, which are made in Russia, with different speed of the trawling, which are stated in Fig. 11.

The next task for the wide use of the flexible spreading devices during the fishery is to create the trawl system according to the scheme, when the flexible spreading devices, like the boards, are at a great distance from the trawl casing. This scheme makes it possible to use the unitized design of the flexible spreading device, like now the trawl board is used, and to connect it to different designs of trawl casings [1]. Figure 10 shows this diagram of the flexible spreading device gear. It differs from the previous versions in the fastening of the depressor loads to the flexible spreading devices. This scheme was tested in marine conditions in autumn 2018 during the coastal fishery in the Baltic Sea, and the scheme proved that it was efficient. Figure 11 shows the winding of the flexible spreading device on the cable-net drum during the setting up and selection of the trawl system, which was made by the tool factory workers on the basis of the first and second methodologies with the projected area $S_{np}^{TTV} = 2.3 \text{ m}^2$. Comparison with the existing trawl boards, with the same parameters of the trawl system opening, and the flexible spreading devices use made it possible to increase the trawling speed by 1 knot and to increase the takes by 10-15%, to significantly decrease a time of the trawl system selection (through exclusion of the operation to disconnect the trawl boards).

Fig. 9: Design loads on the control winch for different trawl types with different trawling speed

![Diagram showing design loads on the control winch for different trawl types with different trawling speed.](image-url)

<table>
<thead>
<tr>
<th>Trawl Type</th>
<th>Trawling Speed (kn)</th>
<th>Control Winch Tension (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>127/728</td>
<td>V=2 kn</td>
<td>149786 795 1805 3000 5000</td>
</tr>
<tr>
<td>118/620</td>
<td>V=3 kn</td>
<td>136650 950 2305 4120 6450</td>
</tr>
<tr>
<td>130/810</td>
<td>V=4 kn</td>
<td>103450 700 1250 1975 1975</td>
</tr>
<tr>
<td>144/192</td>
<td>V=5 kn</td>
<td>83396 717 1680 2905 4543</td>
</tr>
</tbody>
</table>

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IV. Discussion

It can be noted that the results of calculations of the projected areas of the flexible spreading devices on two methodologies are coinciding with each other (Fig. 8, Table 1), except for the trawl 113/480. This is explained by the fact that the trawls developers took into account the vessels tractive and speed characteristics and the trawl boards characteristics [XXII], which confirms the adequacy of the offered methodologies of calculations of the projected areas of the flexible spreading devices.

The calculated loads on the controlling winch for various types of trawls at different trawling speeds (Fig. 9) make it possible, if it is impossible to control the trawl system with the flexible spreading devices by means of the available authorized...
equipment on the vessel at a speed, to decrease the speed and to close the trawl system. It is possible to open the trawl system at any speed.

V. Conclusions

The long research developed two methodologies of designing the flexible spreading devices, which are based on the experimental research and the physics of the trawl system processes.

The first methodology makes it possible, with the availability of various types of the existing trawl boards recommended for the vessel operation on the trawl fishery, to calculate and to make the flexible spreading device.

The second methodology makes it possible, with the knowledge of the aggregate trawl resistance with the maximum parameters of its opening, to calculate and to make the flexible spreading device.

A mathematical model of the control system of opening the trawl system with the flexible spreading device was developed, which makes it possible to determine the controlling winch parameters: the tractive effort and the rope selection speed.

The practice of using the offered methodologies and the fishery schemes showed that the fishery tool factory workers calculated and made the flexible spreading devices easily, and now this device is used during the fishery successfully.

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