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CALCULATION SCHEME AND ALGORITHMS FOR PLANNING THE PROCEEDING PLAN OF TRAJECTORY POINT DURING MANEUVERING FOR ANCHORING

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In confined waters, the water area for maneuvering is commensurate with the geometrical dimensions of the vessel and planning the trajectory of movement, and especially its curvilinear section, becomes of paramount importance.

Algorithms and computational schemes determine the procedure for increasing the accuracy of planning the route of movement to anchorage area, taking into account the water area for maneuvering, characteristics of braking and turnability and the use of methods for planning the route of movement by trajectory points, including curved sections.

To perform route planning, the following vessel data are required: permanent vessel data; two tables of characteristics of braking and turning ability [1-8]; a chart with an area for maneuvering and recommended paths of movement, determined by geodetic methods.

The further algorithm of the meaningful model will be as follows:

1. The coordinates of the anchoring point are plotted, which are agreed with the VTS.
2. The total vector of the wind and current direction is determined, and the approach line is drawn in its direction for releasing the anchor until it intersects the recommended path line on the chart or the water area of the beginning of maneuvering, free from hazards and suitable in depth, and determine the coordinates of the penultimate maneuvering point.

For this, the navigator must set the initial data in the computer, namely, the coordinates of the waypoints and the maneuvering characteristics of the vessel, which must be available on the vessel in electronic form in the form of tables. After that, the trajectory point's matrices will be automatically given to the skipper, along which the vessel will follow every 2 cables.

3. Make a table of waypoints and calculate the TC, the distance from the previous WP to the next one, the angle of rotation at each waypoint and the required rudder shift angle as follows.

When performing a turn automatically, the routine work of calculating the necessary data - the moment of the beginning of the turn, choosing an angle rudder shifting, determination of the coordinates of the current position, the onset of the moment of holding the vessel is performed by a computer. The navigator gives the necessary commands to the helmsman and controls on the computer screen the actual position of the vessel relative to the planned one and corrects its movement.

All the calculations performed are summarized in Table 1, and are necessary for planning the coordinates of the planned path by trajectory points (TP) and navigation control along it, including curved sections of the path, when anchored.

Table 1. Summary table of turnability parameters

WP	LAT	LON	Course	Distance, S, cables	θ	δ
0	46° 18,0' N	30° 53,5' E				
1	46° 17,2' N	30° 52,0' E	233	13,2	56	10
2	46° 18,5' N	30° 46,5' E	289	40,0	23,3	5
3	46° 18,0' N	30° 44,0' E	265,7	18,5	61,6	15
4	46° 15,5' N	30° 43,0' E	204,1	15,8	40,1	10
5	46° 14,0' N	30° 44,0' E	164	16,9		

With the automatic execution of the turn, the process of movement is planned and carried out by a computer without the participation of the navigator and the helmsman. The navigator exercises control over the normal operation of the control system and, if possible, visually evaluates the position of the vessel relative to the signs of the navigational situation.

The next task is to calculate the coordinates of the rotation matrices every 10 degrees by the method of segments. To do this, it is necessary, according to the method described above, to determine for each section the beginning, end of the turn and TP with a step of 10 degrees. These data for each turning angle when anchored in the port of Chornomorsk are given in Tables 2-13. It should be emphasized that the calculation takes place for small sections of the path. Therefore, in order to increase accuracy, it is necessary to leave 10 decimal places.

Table 2. Rotation elements of angle of rotation 1 as line segments

Angle	10°	20°	30°	40°	50°	56°
MC	1,081958282	1,408883289	1,746053028	2,099410462	2,476012182	2,71669
ME	0,328082488	0,661226178	1,004809472	1,364888378	1,748653718	1,99391

Table 3. Rotation elements of angle of rotation 2 as line segments

Angle	10°	23,3°
MC	1,121244311	1,835173414
ME	0,54855392	1,292749344

Table 4. Rotation elements of angle of rotation 3 as line segments

Angle	10°	20°	30°	40°	50°	61,6°
MC	0,031844958	0,267266499	0,51006536	0,764521121	1,035715294	1,37972
ME	0,230095185	0,463739959	0,704706376	0,957241716	1,226389141	1,56779

Table 5. Rotation elements of angle of rotation 4 as line segments

Angle	10°	20°	30°	40,1°
MC	1,081958282	1,408883289	1,746053028	2,103048453
ME	0,328082488	0,661226178	1,004809472	1,368595571

Having received the data of the lines for each parcel, you can determine the geographic points in which they will be located. These calculations are best done in tabular form. To do this, it is necessary to initially find the difference in latitude (DLat) and the difference in longitude (DLon) between each point, using formulas (1) and (2).

$$DLat = MC * cosTC \quad (1)$$

where TC is the heading before the turn.

$$DLon = DMP * tgTC \quad (2)$$

The difference between the meridional parts can be determined by the formula (4).

$$DMP = 3437{,}75 * \ln \left\{ \frac{tg\left(45° + \frac{\varphi_E}{2}\right)}{tg\left(45° + \frac{\varphi_C}{2}\right)} \right\} \quad (3)$$

It must be remembered that for the calculation of the first section, it is the coordinate of the turning point. For each section of the turn, the data of the difference in latitude and longitude between each segment of the MC and ME were calculated. Having received the segments of the difference in latitude and the difference in longitude, using simple navigation formulas (4) and (5), we determine the coordinates of these points.

$$_{C} = {}_{M} + DLat, \tag{4}$$

where $_{M}$ is the latitude of the turning point.

$$_{C} = {}_{M} + DLon, \tag{5}$$

where $_{M}$ is the longitude of the turning point.

Thus, having determined its coordinates for each point of the turning section, it is possible to construct the rotation matrices, which are given in Tables 6-9.

Table 6. Matrix of trajectory point for turning angle 1

	ϕ_{c1}	46° 17,29810' N	λ_{E1}	30° 52,3879' E
	ϕ_{E11}	46° 17,26745' N	λ_{E11}	30° 52,3532' E
	ϕ_{E12}	46° 17,23683' N	λ_{E12}	30° 52,3528' E
M_{t1}	ϕ_{E13}	46° 17,21277' N	λ_{E13}	30° 52,2773' E
	ϕ_{E14}	46° 17,20443' N	λ_{E14}	30° 51,9039' E
	ϕ_{E15}	46° 17,21461' N	λ_{E15}	30° 51,8827' E
	ϕ_{E1}	46° 17,23895' N	λ_{E1}	30° 51,7195' E

Table 7. Matrix of trajectory point for turning angle 2

	ϕ_{C2}	46° 18,46415' N	λ_{C2}	30° 46,8146' E
M_{t2}	ϕ_{E21}	46° 18,46738' N	λ_{E21}	30° 46,5507' E
	ϕ_{E2}	46° 18,44780' N	λ_{E2}	30° 46,313' E

Table 8. Matrix of trajectory point for turning angle 3

M_{t3}	ϕ_{C3}	46° 18,00621' N	λ_{C3}	30° 44,0808' E
	ϕ_{E31}	46° 17,98465' N	λ_{E31}	30° 44,0734' E

Table 9. Matrix of trajectory point for turning angle 4

	ϕ_{C4}	46° 15,61518' N	λ_{C4}	30° 43,04254' E
	ϕ_{E41}	46° 15,60160' N	λ_{E41}	30° 43,02962' E
M_{t4}	ϕ_{E42}	46° 15,58431' N	λ_{E42}	30° 43,01078' E
	ϕ_{E43}	46° 15,43542' N	λ_{E43}	30° 43,01337' E
	ϕ_{E4}	46° 15,42106' N	λ_{E4}	30° 43,03575' E

The next task is to determine the matrices of straight sections. It should be noted that the matrix for the first segment will start from the zero point and end with the turn start point 1. The second straight segment matrix will start from the turn end point 1 calculated above. It will end as the starting point of the turn at WP 2. Subsequent matrices of straight sections, except for the final one, will have the same construction principle. For the last leg, the straight matrix will start at turn end point 4 and end with waypoint 5.

Having received the DLat and DLon points for each trajectory point with a step of 2 cables, it is not difficult to construct matrices of straight sections using the segment method, remembered that the course remains unchanged.

Having determined the matrix of the final straight-line section of the path, it is necessary to find the braking start point. Let us resort to the assumption that the entire segment of the way to the approach to anchor, the vessel was moving at an average forward speed (the HA (half ahead) speed for this vessel is 10.3 knots). According to the maneuvering characteristics of the vessel, the active braking distance for HA is 14.59 cables.

We start the calculation from the final fifth point. The distance from it to the turning point will be 14.59 cables. To do this, replace the MC segment with a number equal to the active braking segment and then calculate using the formulas as usual.

Table 10. Braking start point coordinates

M_{BS}	ϕ_{BS}	46° 14,84149' N	λ_{BS}	30° 43,42921' E

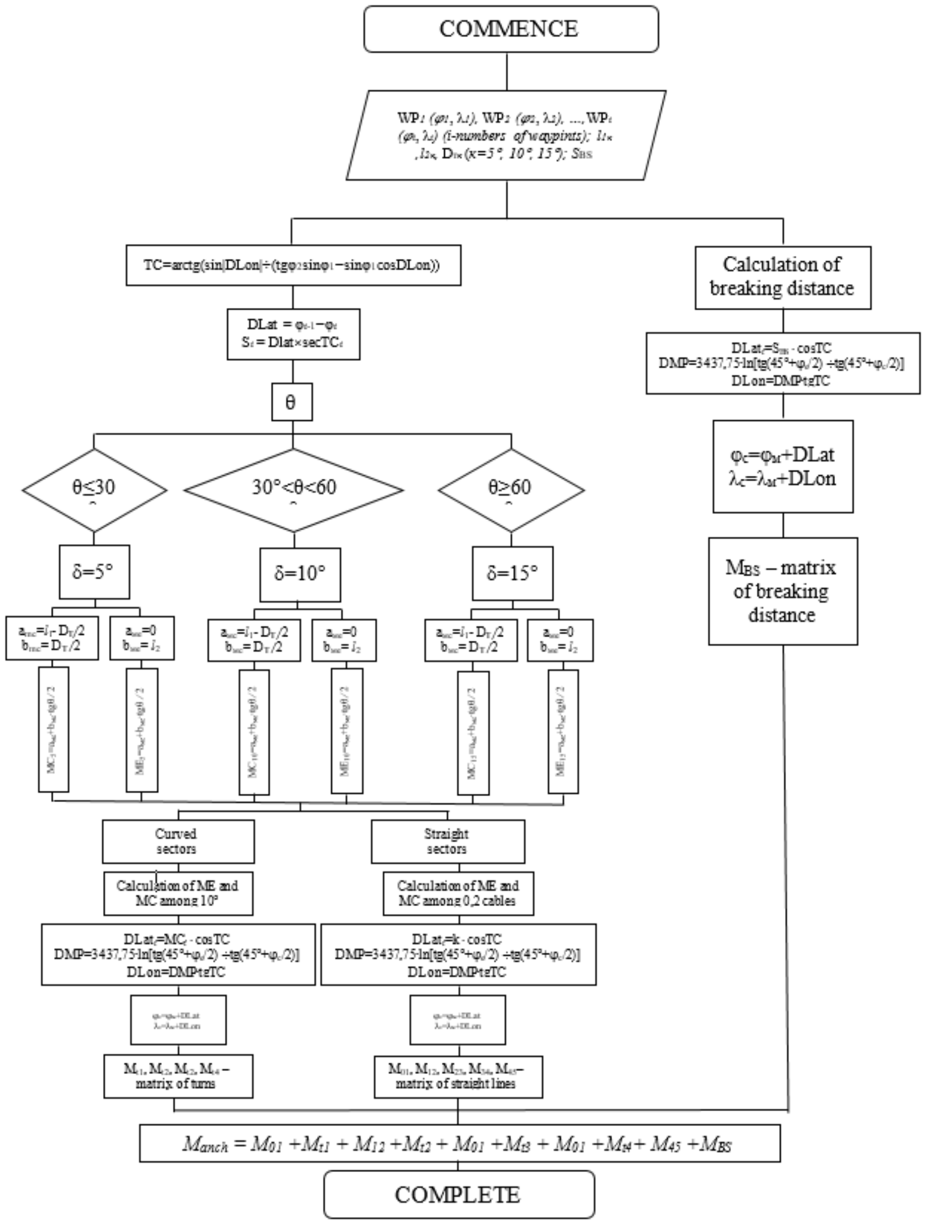

Fig. 1. Block diagram of the automation of calculations of a given algorithm for the operation of the control system in the form of an algorithm for calculating the coordinates of the trajectory points of anchoring, presented in the form of coordinate matrices of straight and curved track sections

Then the given algorithm for maneuvering control during anchoring Manch can be represented as a sum of matrices of straight and curved track sections.

$$M_{anch} = M_{01} + M_{t1} + M_{12} + M_{t2} + M_{23} + M_{t3} + M_{34} + M_{t4} + M_{45} + M_{BS}. \qquad (6)$$

The results of this calculation algorithm can be summarized in one flowchart for automating the calculations of a given algorithm for the functioning of the control system in the form of an algorithm for calculating the coordinates of the trajectory points of anchoring, presented in the form of coordinate matrices of straight and curved track sections, which is shown in Figure 1.

The developed navigation information and analytical complex "Planning the path trajectory using the waypoint matrices" contains modernized methods and techniques for creating the given algorithm for the operation of the ship control system and control over the process of moving along the trajectories, including curved and straight sections of the track when anchored. It automates the anchorage route planning process and controls safe maneuvering, including the use of motion control techniques using dynamic positioning.

The results of the developed navigation information-analytical complex can be used on unmanned ships, as well as on commercial and passenger ships during practical work, in order to accurately control the place of the vessel, in maritime educational institutions in the preparation of senior cadets for work on ships and in refresher courses.

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