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Ship's Turning in the Navigational Practice

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ABSTRACT: The turning-basin is a special part of the port waters area. During every port's call ship need to be turned. The paper presents the analysis of the ship's turning in the navigational practice. The paper is based on the practical experience.

1 INTRODUCTION

The manoeuvre of ships turning is one of the most frequently executed port manoeuvres. It is executed every time during the ships port call. Simultaneously, it is comparatively little examined manoeuvre.

Place, where the ship's turning manoeuvres are executed, is called the turning basin. It can be understood as a two different meanings. First as the manoeuvring area appointed by the ships, place needed for a ship to execute turning. Second meaning is the hydro-technical building artificial or natural with suitable horizontal and vertical dimensions, where the considerable alterations of the course of the ship are executed. Shortly, it is the hydro-technical construction, part of the port waters. Certainly due to safety, the turning basin as the hydro technical building always has to be larger in all dimensions than the manoeuvre area to avoid the collision with bottom or bank (Kornacki & Galor 2007).

Figure 1. The ships turning manoeuvre with using of two tugboats.

The main parameter describing the turning basin is a size of the turning basin and size of manoeuvring area needed to execute manoeuvre. The influences on the size of turning basin during the manoeuvre have the large quantity of factors.

The ship's turning manoeuvres in a practice are „in the place". This should be understand as the changing (alternation) of the ship's course whose longitudinal velocities, during the manoeuvre, are close to zero (Kornacki 2007).

Turning the ship over the place is done on the turning basin as a result of the planned tactics of manoeuvring and can be done by the ships itself or in co-operation with tugs or use of anchors or lines (springs).

To be able to describe the practical realization of the manoeuvre in the quantitative way, the factors and the ways of the assessment of the manoeuvre will be introduced. The attempt at the exact assessment of manoeuvres will not be undertaken. The "operator" executing manoeuvre puts the actions to continuous evaluation of the correctness and the advisability of the next steps during of his work.

The acquaintance of the phenomenon of the instantaneous pivot point is important during executing the ship's turning manoeuvres. The existence of this phenomenon in ship manoeuvring is known to navigators. The recognizing of the instantaneous pivot point's location on a ship during ship's turning manoeuvres is causing some problems. It is important to be well-informed about location.

In the last part, the assay of the presentation of the practical view of the realization of the manoeuvres of the ship's turning will be undertaken. The attempt at presenting will be undertaken as the decision process proceeding and as the decision transfers on the realization of the manoeuvre.

2 THE ASSESSMENT OF THE SHIPS TURNING MANOEUVRE

Wanting to evaluate the realization of the manoeuvres of the turning, the methodologies of such assessment should be known.

The opinion, that the manoeuvre has to be executed effectively and safely, is repeated during the various conferences and discussion on the subject of the skill on shiphandling generally and shiphandling on the simulators. One can show on three elements which are very essential for the statement the correctness's of the realization of the manoeuvre on the basis of the convention STCW'78 with later corrections and experience from led trainings on the shiphandling simulator (Artyszuk 2002). The elements of assessment of such manoeuvres should be the statement that the manoeuvre was executed:

- safely
- effectively
- according to the principles of the manoeuvring practice

The assessment basis on this opinion can be proposed as the sum of these elements (Kornacki & Kozioł 2006):

$$O \approx B + E + Z \quad (1)$$

where:

O - the assessment of the manoeuvres,

B - safety of the manoeuvres,

E - effectiveness of the manoeuvres,

Z - compatibility with the principles of the manoeuvring practice.

One can propose the following division the criteria, which will have the influence on the assessment of the realization of the given element, and in the effect of the whole manoeuvre.

The element of the safety of the manoeuvre is estimated on the basis of following criteria:

- the size of the area of manoeuvring the ship during the of executing the manoeuvre,
- appearing the contact with different individual or navigational obstacle during the of executing the manoeuvre,
- the energy of the collision with bottom, underwater slope, bank (it is sometimes admissible such contact depending on the accepted tactics of the manoeuvre).

Criteria such as: the size of the manoeuvring area and the energy of impact (collision) they are applied in the investigations of Marine Traffic Engineering to the assessment of safety during port manoeuvres at present. Can, therefore also use these criteria as the criteria of the assessment of the skill of manoeuvring (Guziewicz & Ślączka 1997).

The element of the realization of the manoeuvre according to the principles of the manoeuvring practice should comply following criteria:

- the using of the rudder,
- the using of propulsion,
- the using of maximum sets of propulsion,
- the time of the realization of the manoeuvre,
- the using of the tugboats,
- the using of the anchors,
- the using of the lines.

The element of the effectiveness of the manoeuvre is estimated in the moment of the end of manoeuvre on the basis of following criteria:

- final ship's position on the end of manoeuvre,
- ship's heading on the end of manoeuvres,
- ship's speed and yaw velocity on the end of manoeuvres (if it is acceptable for continue with next manoeuvres),

All of these elements have to be acceptable for next manoeuvres. Turning manoeuvres are always between the others.

The element of effectiveness is the assessment of the last stage of the manoeuvres, when the ship is in the peaceable area with the aim of the given manoeuvre.

The very reliable criterion for the assessment the skill is the quantity of given commands in relation to the last element of the realization of the manoeuvre. The number of given commands in the reference to rudder, propulsion, using of the anchors or tugboats are the objective coefficient acquired the practice of ship's manoeuvring. Mostly, the persons manoeuvring worst are giving too much commands and so often and the manoeuvres become less controlled. The problem of the good manoeuvring practice as the good seamanship is not simple. The giving of emotional and incessant commands, often before the reaching the result of previous is the bad practice. The regard of the parameter relating pronouncement of maximum sets is important because of the fact of the influence of propeller's streams on the bottom of the reservoir and quay. However, leaving of the reserve of the power during the executing manoeuvres is the good practice in reference to the principles of manoeuvring, which can turn out indispensable in emergency situations or sudden influence unforeseen external conditions.

The assessment of individual elements is executed in the moment of the end of the manoeuvre.

Taking under considering above mentioned, it should be added that the assessment of these elements has to contain their weights.

Analysing the assessment, it can be introduce as follows (Kornacki & Kozioł 2006):

$$O = w_B * \sum_{i=1} b_i + w_E * \sum_{j=1} e_j + w_Z * \sum_{l=1} z_l \qquad (2)$$

where:

w_B - the safety elements' weight,

w_E - the effectiveness elements' weight,

w_Z - the weight of compatibility with the principles of the manoeuvring practice,

b_i - the criterions of safety,

e_j - the criterions of effectiveness,

z_l - the criterion of compatibility with the principles of the manoeuvring practice.

Economical is the additional element which in the practice will have the influence on the assessment of every manoeuvre. Also, the manoeuvre has to be optimum in relation to economic. For sure, the glaring abuse of the means will be disqualifying.

Summing up, the problem of the assessment of the skill of manoeuvring is complex. Executing the manoeuvre of the turning, the previously suitable tactics is accepted. During the executing of the manoeuvre of the turning and on the end, the manoeuvre is the subject to the assessment by performers on every stage to improve possible mistakes.

3 PIVOT POINT IN SHIP MANOEUVRING

The acquaintance of the phenomenon of the instantaneous pivot point is important during executing the manoeuvres of the ship's turning. This phenomenon existence in ship manoeuvring is well known to navigators. The recognizing of location of the instantaneous pivot point on a ship during various manoeuvres is causing problems for them. For a ship's operator is easier to control just a single motion and practical role of instantaneous pivot point increase. The navigators are familiar with apply the pivot point principles while making various kinds of manoeuvres, either at high or at low forward speed.

This is the essence of the kinematics of the turn of the ship that certain lateral velocity of the ship's centre of gravity always accompanies the angular velocity. It is directed in the external board in the relation to the centre of the circulation. During the turn, local lateral velocities on the stern and the bow of the ship are different from this existing in the centre of gravity. The lateral speed is larger on the stern, on the bow meanwhile smaller. It results from this, that on the stern the local lateral velocity coming from the rotational movement adds to the fine lateral movement, while it is on the bow inversely. The point in which the local lateral velocities reduce to zero is the instantaneous pivot point. The complex movement of the ship, being in the generality connection of three movements i.e. longitudinal, lateral and rotational movements in relation to the centre of gravity can replace with two movements consisting from the longitudinal and rotational movement in relation to the instantaneous pivot point.

At high speed applying the stern rudder will involve the rudder lateral force as developed on a constant arm. The ship's lateral motion strongly correlated with simultaneous turning is generated, consequently the instantaneous pivot point, in certain time, lies somewhere close to the bow and usually changes but in a rather narrow limit. Practically, the pivot point can be considered steady location.

3.1 *The position of instantaneous pivot point*

It is well known from rigid body mechanics that instantaneous arbitrary ship planar motions can be uniquely decomposed into a combination of translational motion of the point of origin and angular motion of the whole body around this origin. Both motions are defined by the linear velocity vector of the origin and the angular velocity vector. Such an instantaneous state of motion is equivalent to a sole angular motion around the instantaneous pivot point. The pivot point is a point on the body or can be even outside the body physical extents, in which the linear velocity disappears. The pivot point position instantaneously changes because of the ships linear and angular velocities are time dependent.

The position of instantaneous pivot point reference to the centre of gravity or amidships is qualified exact kinematic dependence (Artyszuk 2009):

$$x_{PP} = \frac{-v_y}{\omega_z} \text{ and } y_{PP} = \frac{v_x}{\omega_z} \qquad (3)$$

or non-dimensionally - divided by ship's length L:

$$x'_{PP} = \frac{-v_y}{\omega_z L} \text{ and } y'_{PP} = \frac{v_x}{\omega_z L} \quad (4)$$

where:

x_{PP} - the longitudinal coordinate of pivot point,

x'_{PP} - the longitudinal non-dimensional coordinate of pivot point,

y_{PP} - the lateral coordinate of pivot point,

y'_{PP} - the lateral non-dimensional coordinate of pivot point,

v_x - the longitudinal velocity,

v_y - the lateral velocity,

ω_z - the angular velocity,

L - the length of the ship.

The dimensionless values relating to any linear dimension of the ship is much more useful also in the shiphandling practice. The tips are universal for any ship size and ship visual positioning against external objects is also easier in relative units.

The instantaneous pivot point lies mostly opposite the side of the place of applying steering forces. During manoeuvres with the stern rudder or as a result of the lateral effect of the propeller during active stopping the ship, it is placed to the bow from amidships. The position of instantaneous pivot point is more-less steady for the given individual ship, although it is able to change in certain borders. The position of the instantaneous pivot point is comprises in range of 0.3 ÷ 0.5 L counted from amidships (or 0 ÷ 0.2 L counted from bow). Often, the literature tells about average values of this position for the ships in range of 0.25 ÷ 0.3 L counted from a bow, it should be treat rather for orientation and the current values should be accepted according to the parameters of the circulation settled e.g. (Artyszuk 2009).

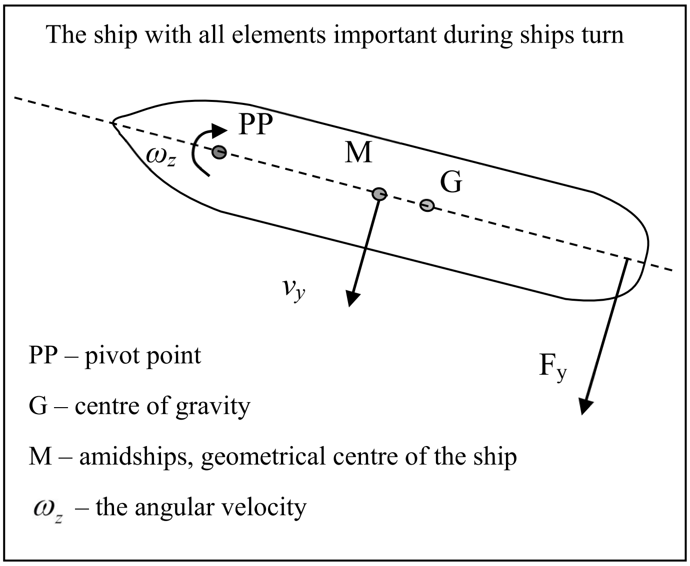

Figure 2. The ship with lateral force generating turn.

Often, it is very convenient for a short prediction period, as dominating in shiphandling practice, to disregard the lateral non-dimensional coordinate of pivot point and, instead of, to rotate a ship around the pivot point projected on the ship's centre line together with its simultaneous translation in the direction of heading according to the forward speed.

It is two other aspects of position of instantaneous pivot point. First is a position of it during turning of the ship in spot. Second is position of it during astern movement.

3.2 *The position of instantaneous pivot point during ship turning in spot*

Typical situation of ship turning at spot is while the longitudinal velocity is nearly zero, the instantaneous pivot point is located on the ship's centre line and the constant yaw velocity is requested. This kind of manoeuvres happens in turning basins.

To realize turning a ship at spot, the following steady phase motion equations shall be (Artyszuk 2010):

$$\begin{cases} (m + m_{11})\dfrac{dv_x}{dt} = F_x + (m + c_m m_{22})v_y\omega_z = 0 \\ (m + m_{22})\dfrac{dv_y}{dt} = F_y + F_{yH} = 0 \\ (J_z + m_{66})\dfrac{d\omega_z}{dt} = M_z + M_{zH} = 0 \end{cases} \quad (5)$$

where:

m_{11}, m_{22}, m_{66} - virtual masses [kg], [kg], [kg m^2],

v_x, v_y, ω_z - surge, sway and yaw velocity [m/s], [m/s], [1/s],

F_x, F_y, M_z - external total surge, sway forces and yaw moment [N], [N], [Nm],

F_{yH} , M_{zH} - hull sway forces and hull yaw moment [N], [Nm],

In case of application of two independent parallel forces, like using of two (or more) tugboats, such forces and moments can be defined by:

$$\begin{cases} F_y = F_{y1} + F_{y2} \\ M_z = F_{y1} x_{F1} + F_{y2} x_{F2} \end{cases} \quad (6)$$

This should solve the problem of discrete attachment points for tugs.

The turning with particular value of position of instantaneous pivot point can be completed with a single external force positioned between the ship's bow and stern (Artyszuk 2010):

$$x'_F = \frac{M_z}{LF_y} \quad (7)$$

The use of tugs (one or more) for large vessels as to generate the required external force is limiting the arms of external forces like technically possible contact points around the ship's hull for tugboats, like in pushing mode, where tugs are allowed in specially marked places contact with the hull or in pulling mode, where tug operation is restrained by the arrangement of ship's fairleads.

3.3 *The position of instantaneous pivot point during astern movement*

The ship's propeller working astern generates a side effect called also "wheel effect". This phenomenon is mainly joined with the inflow the reverted propeller race to the ship's stern and pressure characteristic of water medium generating lateral trust. Propeller generate twisted slipstream attacking various sections of ship's stern. As long as ship's positive speed is remaining the pivot point stay forward of amidships. It is proceeding independently from the astern throttle. While a ship starts a sternway the pivot point location changes astern of amidships. The pivot point location sign is changing from a positive to a negative one. This behaviour is not fully explained. Because of the propeller lateral force continues to keep its direction and generate the accompanied ship's lateral velocity, the ship's centrifugal force seems to be primarily reason of this behaviour. Anyway, this shifting of the pivot point from forward to stern because of continued propeller astern trust together with astern velocity and lateral velocity base on observation. For sure, the suitably large external force on the ship's hull will cause new moving the pivot point in dependence from the point of applying and size of the applied force.

4 THE TECHNIQUE OF MANOEUVRING

Turning manoeuvres of the ship could be systematized in relation to the aim of executed manoeuvres (which is not relevant), the conditions for manoeuvre (hydro-meteorological conditions, bathymetric conditions, legal aspect) that affect the realization of the manoeuvre, and most important, way of execution of manoeuvre, which can be further divided into independent manoeuvres and manoeuvres with tugboats assists. During the ship's turning manoeuvres is an important use of available propellers, anchors, ropes or tugs to manoeuvre was executed an manoeuvre area as small as possible while the use of the propellers, tugs, etc. was the most optimal in different ways.

In the practice, time of realization of such manoeuvre amounts from a few to more than ten minutes in dependence from accessible propellers and propulsions, the possibility of the use of the accepted tactics of manoeuvring, the ship's condition, hydro-metrological conditions and bathymetric conditions.

4.1 *The independent ship's turning maneuvers*

Independent manoeuvres can be executed using:

- only screw propeller and stern rudder,
- the bow thrusters and screw propeller and stern rudder,
- the bow and stern thrusters and screw propeller and stern rudder,
- anchor and the bow thrusters (if available) and screw propeller and stern rudder,
- lines (springs) and the bow thrusters (if available) and screw propeller and stern rudder.

The instantaneous pivot point moves from the extreme position in the bow area (during ahead propeller's mode) to the position in the stern area (while astern movement) during independent executing the turning manoeuvre (Rowe 1996). This changeability of the position of the instantaneous pivot point during the manoeuvre is effective on larger manoeuvring area of the ship's turning. The occurrence of the longitudinal velocity alternating forward and astern is additional factor influencing the increase of the manoeuvring area.

The use additionally anchors or lines (springs) does not cause considerable decrease of the sizes of the manoeuvring area. What is the aim of their applying? Simply, it would not be able to execute successfully such manoeuvre in many situations. It seems that use of anchors or lines should influence considerably of the size of the manoeuvring area. These elements, in practice, influence directly of the turning ability and their influence on the size of the manoeuvring area are not great and grow up together with the growth of the influence of external (hydro-meteorological) factors what simulating investigations confirm. The quantity of applied commands is significantly decreasing facilitating the realization and in others time of realization of such manoeuvre is significantly decreasing. Often, it is the large meaning on current narrow waters.

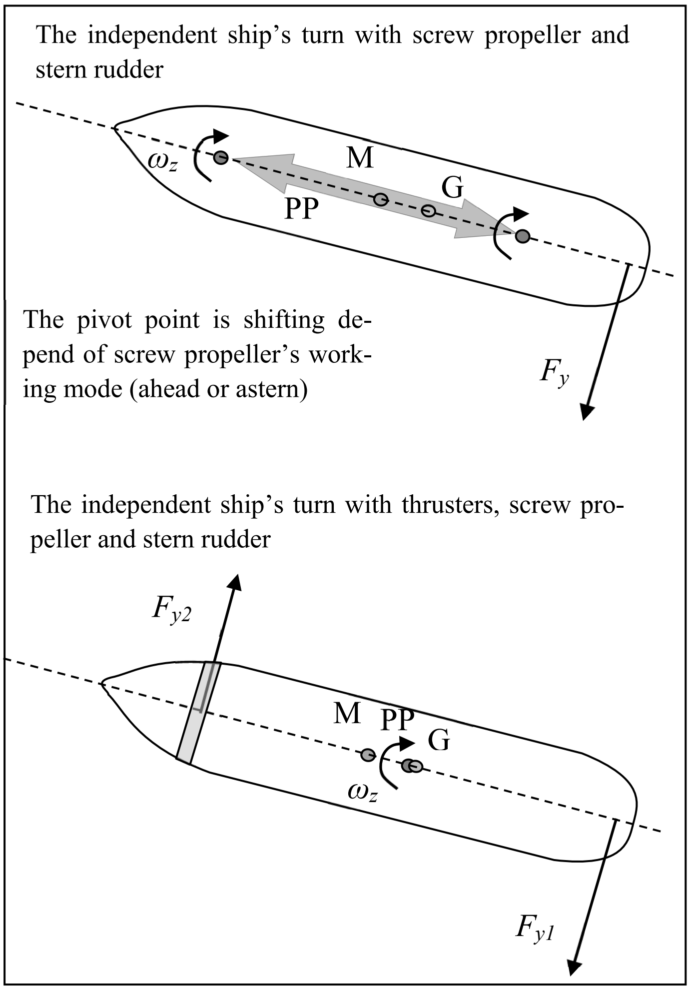

Figure 3. The independent ship's turning.

Thrusters are significant support for the ship's turning manoeuvres. They give the possibility the use constant forces apply in extreme points and affecting in opposite directions. The instantaneous pivot point does not change the position practically, and the yaw moment increase significantly. The additional using of thrusters helps significantly decrease the time, quantity of given commands and the sizes of the manoeuvring area.

4.2 *The ship's turning maneuvers with tugboats assists*

Tugboats, similarly as thrusters, are a significant support for the manoeuvres of the turning of the ship.

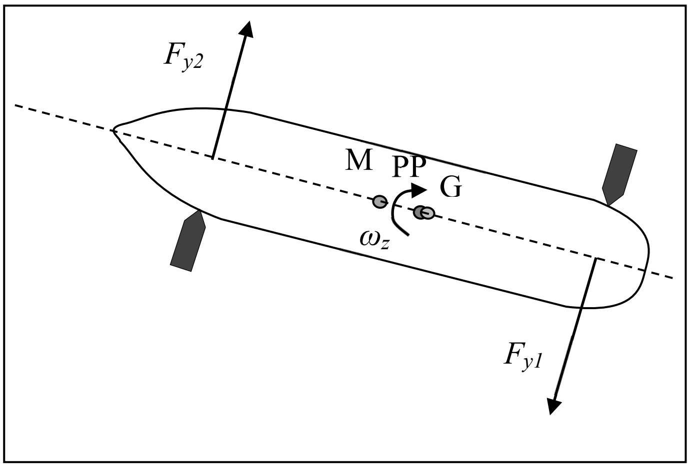

Figure 4. The ship's turning with tugboats assists.

They can work with long towing-hawsers, short towing-hawsers and as pushers. They give, in the principle, such advantages and the effects of working as in case of use of thrusters. The possibility of use of various directions of working tugboats is the additional advantage. The only deficiency can be the sizes of the manoeuvring area caused addition to the manoeuvring area of ship, the manoeuvring area of tugboats sometimes.

4.3 *The ship's turning maneuvers with other advanced propellers solutions*

Turning manoeuvres of ships with other advanced propellers solution signify:

- turning manoeuvres with twin screw propellers (with or without thrusters accompany),
- turning manoeuvres with advanced rudders,
- turning manoeuvres with azimuth drive,
- turning manoeuvres with Voiht-Schneider drive.

This advanced propellers solutions are applied mostly on smaller ships. This is the result of the aim of exploitation and costs. They are combining and increasing advantages of all independent ship's turning and ship's turning with tugboats assists, simultaneously decreasing deficiencies. The forces and yaw moments are enlarged by multiplying of different propellers and application more effective rudders. This kind of propulsions brings great decreasing of time consumption in ship's turning. Short time of manoeuvring transfers to safety of manoeuvring. It is minimizing the ship's manoeuvring area.

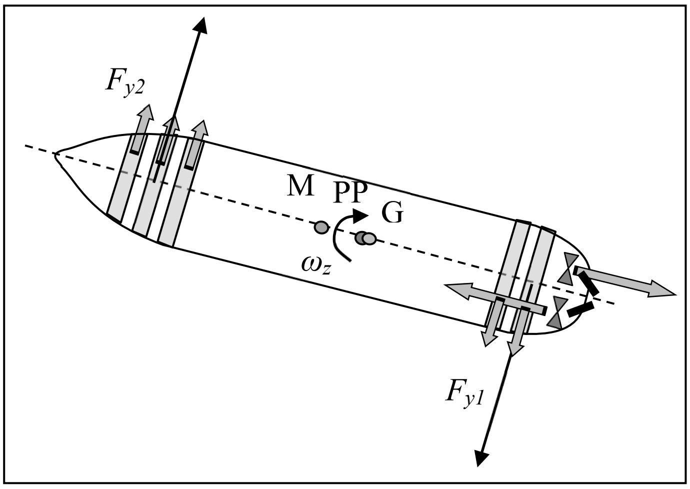

Figure 5. The ship’s turning with advanced propellers solution (twin screw propellers, five thrusters).

Appling of advanced propellers solutions brings some danger of human error in service. Some time, there are a lot of different elements that could be regulated. On some of them, to avoid any errors, advanced steering modules with consoles are installed. Then operator needs to declare direction and force of working of the propulsion.

5 CONCLUSIONS

The navigator manoeuvring the ship on the turning basin has concretely presented the problem which has to execute with the success. He has the ship with definite technical solutions and the accessible waters with known conditions where the task has to be made.

While executing the manoeuvre the process which he operates still assesses.

Many factors which concentrate in three groups consist on the assessment of the ship’s turning manoeuvre. All three elements have to be fulfilled in the minimum degree to recognise the ship’s turning manoeuvre correctly executed.

The variety of solutions carries with her the plurality of the possibility of their using.

The direct influence on the realization of the ship’s turning manoeuvre has position of the instantaneous pivot point. The instantaneous pivot point depends of the way how the operator steers propulsion and the accessible solutions of drives.

The techniques of manoeuvring influence the position of the instantaneous pivot point, longitudinal velocity and the time of the realization of the manoeuvre. These factors influence the size of the manoeuvring area. The manoeuvring area influences the safety of the executed manoeuvre. The operator can suitably influence the safe realization of the manoeuvre assessing the development of the situation and suitable action.

In practice, executing the manoeuvre of the ship’s turning all possible resources are used. This secures the development of the safety and the certainty of the realization of the manoeuvre. The plurality of steerable resources brings with them the development of the danger of the pronouncement of the human error.

The economics influences the manoeuvre of the turning significantly. For ships execute this manoeuvre seldom using of the tugboats assist is more justified. Better propulsion and steering equipment of the ship is more appropriate for ships executing this manoeuvre often.

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