On Determination of the Head-on Situation Under Rule 14 of Colreg-72

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ABSTRACT: Analyzed one possible criteria of stating the fact of ships' meeting on reciprocal courses and proved that none of them can be judged with confidence of head-on situation. So, in fact Rule 14 of COLREG -1972 should be strictly adhered to: " …*When a vessel is in any doubt as to whether such a situation exists we shall assume that it does exist and act accordingly…*", i. e. alter the course to starboard.

1 INTRODUCTION

Rule 14 of International Regulations for Preventing Collisions of Sea-72 applies to the navigation of ships in sight of each other on reciprocal courses, when they are meeting head-on. "…When two power-driven vessels are meeting on reciprocal or nearly reciprocal courses so as to involve risk of collision each shall alter her course to starboard so that each shall pass on the port side of the other…" – this how Rule 14 of COLREG states. It seems to be simple and quite understandable! Statistics of ship collisions, however, shows that regardless of simplicity and clearness of the actions according to this Rule more than 50 percent of collisions precisely occur when vessels are meeting on reciprocal courses (Karapuzov, A. I. & Mironov, A. I. 2005. Maneuvering…). The points that on practice application of Rule 14 becomes complicated as it doesn't give exact quantitative criteria both for definition of "head-on situation" and minimum permissible "collision approach situation" to execute maneuvering safe passing clear of each other. As to the criteria of clearing up head-on situation, Rule 14 contains only the direction that "…Such a situation shall be deemed to exist when a vessel sees the other ahead or nearly ahead and by night she could see the masthead lights of the other in a line or nearly in a line and/or both sidelights and by day she observes the corresponding aspect of the other vessel…When a vessel is in any doubt as to whether such a situation exists, she shall assume that it does exist and act accordingly". The use of such inexact notations as "…nearly reciprocal courses…", "…nearly in a line…", "…nearly ahead…", "…corresponding aspect of the vessel…" as well as the absence of exact quantitative criteria in Rule 14 don't make it possi-

ble for navigators to judge the head-on situation in a unique manner. By virtue of navigators′ subjective perception of inexact notations, laid in Rule 14, some of them consider the head-on situation as falling under Rule 14, and the others – under Rule 15 applying crossing situation. The lack of agreement in navigators′ actions to different Rules of COLREG in the same situation often leads to collisions. It can be illustrated by some simple examples from practice (Snopkov, W. I. 2004. Ships′…). Fig. 1 shows the case in which one of the navigator (navigator C) has determined the situation as "head-on" falling within the jurisdiction of Rule 14 in accordance with which he changed the course to starboard and the other one (navigator A) has determined the situation as "crossing" falling within the jurisdiction of Rule 15 and considered it necessary to keep out of the way of the ship on her own starboard and changed the course to port. Further development of the situation doesn't require any commentaries.
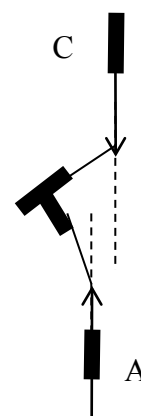

Figure 1. An example of dangerous situation development, when on navigator considers that he acts under Rule 14, and the other – under Rule 15

Russian commentaries to COLREG-72 don't at all consider the problem of quantitative criteria as applied to Rule 14, i.e. of minimum permissible aspect of oncoming vessel when it is to be considered as the vessel proceeding on reciprocal course head-on. In Russian commentaries to COLREG-72, complying with Rule 14, it is recommended in any doubt to use Rule 14 for altering the course "ahead of time and positively" to starboard.

Some foreign commentaries to COLREG-72, based on the materials of judicial arbitrary documents, assume that in the same case when the difference in courses doesn't fall outside the limit of $180°$ ± half a point, Rule 14 shall be applied. If the difference in courses falls outside the limit of $180°$ ± half a point, Rule 15 is recommended to apply (Karapuzov, A. I. & Mironov, A. I. 2005. Maneuvering…).

2 CLEARING UP THE HEAD-ON SITUATION ACCOUNTING MAST IN LINE

If the vessels are in sight of one another, then in day time a trivial criterion of their meeting on reciprocal courses might be an alignment of the oncoming vessel's masts, that can be seen with unaided eye or through the binocular. In this case let's consider this criterion. An observer is known to think that he is on a line of alignment (Fig. 2) until he deviates from it so that the formed angle a between the directions to leading beacons will not be larger than an angular perceptibility of the observer's eye. Then, Fig. 2 shows, that deviation W from the alignment axis will be (Kolomijchuck.1975. Hidrography…)
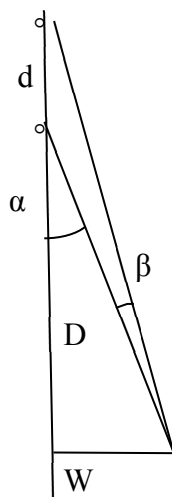

Figure 2. On calculating of angular perceptibility of linear alignment

$$W = \frac{D(D+d)}{d}\beta \qquad (1)$$

where d - the distance between leading beacons; D - the distance up to front leading beacons.

This, angle α determining an angular accuracy of the observer position in line will be:

$$tg\alpha = \frac{W}{D}$$

Or in view of (1) and accepting for an unaided eye of the observer that $\beta=\varepsilon=1'$ we record in writing

$$\alpha = arctg(\frac{D+d}{d}arc1') \qquad (2)$$

According to (2) with the oncoming vessel's masts displacement equals 100 m, at a distance $D = 4$ miles, we receive $\alpha = 12.3°$. For other values of d and D, the meanings of angle α are given in Table 1. As the table shows, to detect the movement of oncoming vessel proceeding on reciprocal course head-on by its masts alignment with unaided eye practically impossible. This is true even for very large vessels at close quarter distance as well. At least the accuracy to establish such fact will contradict with the accuracy the modern course indicatory can provide. The observer will assume that the vessels are proceeding on reciprocal courses head-on, though in reality their courses can differ by some degrees and even by some ten degrees (as to small ships they can be at a considerable distance from the observer). Probably, half a point difference in opposite courses, considering as a criterion for ships in head-on situation in the Foreign Commentaries to Rule 14, as it was mentioned above, when observing with an unaided eye is related to meeting distance in 1-2 miles with masts displacement of the oncoming ship by a factor of 60-120 m., as Table 1 shows. But they are closest point of approach close to last moment distances for maneuvering.

Table 1. Angular accuracy of defining oncoming masts alignment, *degrees*

Distance between masts d, *miles*	Distance up to front mast D, *miles*				
	1	2	3	4	5
20	15.2	28.4	39.0	47.2	53.4
40	7.8	15.2	22.1	28.4	34.0
60	5.3	10.3	15.2	19.8	24.2
80	4.0	7.8	11.5	15.2	18.7
100	3.2	6.3	9.3	12.3	15.2
120	2.7	5.3	7.8	10.3	11.0
140	2.4	4.6	6.7	8.9	9.7
160	2.1	4.0	5.9	7.8	8.6
180	1.9	3.6	5.3	7.0	8.6
200	1.7	3.2	4.8	6.3	7.8

Using a binocular or optical finding tube for observation can help to improve the situation and increase the eye resolution (in our case to increase angle β) in numbers equal to multiplicity of a binocular and finding tube increase (Kolomiychuck. 1975. Hidrography…). But even if angle β is reduced by a factor of 10 it will means according to (2), that the

angular accuracy of defining masts alignment is increased by a factor of 10, as Table 1 shows. But it doesn't solve the problem of small-sized vessels neither in the maneuvering zone (distance of 4-8 miles), nor in all the distances of close quarter (distance of 4 miles), to say nothing of the distances in the zone of situation appraisal (8-12 miles). As a result, the following situation is possible (Fig. 3): the navigator of a large ship observing the masts alignment of the oncoming small ship has come to the conclusion that it is proceeding on a reciprocal course head-on ($\beta<\varepsilon$) and decided to act according to Rule 14, altering the course to starboard. The navigator of a small ship, who has had the possibility to determine the masts alignment of a large ship, come to the conclusion that the masts of an oncoming ship are not in line ($\beta>\varepsilon$) and, accordingly, the ships are proceeding on reciprocal courses and he decided to take head-on maneuvering under Rule 15, altering the course to port and keeping out of the way of the ship on his own starboard. As a result, there was a situation schematically presented on (Fig. 1).
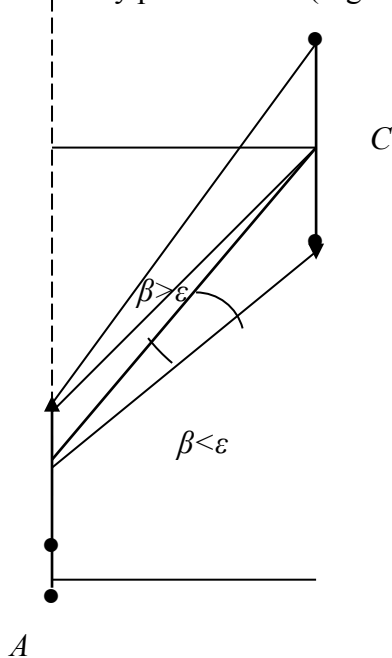

Figure 3. A navigator of small ship *A* sees the masts a large ship *C* not in line, and he think the ships are proceeding on reciprocal courses, and a navigator of large ship *C* sees the masts of small ship *A* in line and he thinks the ships are proceeding head-on

3 CLEARING UP THE HEAD-ON SITUATION ACCOUNTING MASTHEAD LIGHTS AND SIDELIGHTS

By night time the criteria for ships in head-on situation could be simultaneous visibility of sidelights or masthead lights in line. As to the criterion of determining head-on situation by the alignment of masthead lights, it is evidently that it is not better than the criterion of determining head-on situation by the alignment of the masts. Both of them have the same shortcomings. As to the criterion of clearing up the head-on situation by the visibility of sidelights, in our opinion, thought it is not perfect, it has some advantages in comparison with the criteria of clearing up the head-on situation by alignments of masts or masthead lights. The point is that in compliance with Rule 21 to COLREG-72 "… Each sidelight shows an unbroken light over an arc of the horizon of 112.5o and so fixed as to show the light from right ahead to 22.5o abaft the beam on its respective side. In Annex 1 to COLREG-72 it is defined more exactly that." In the forward direction, sidelights as fitted on the vessel shall show the minimum required intensities. The intensities must decrease to reach practical cut-off between 1 degree and 3 degrees outside the prescribed sectors." It means that having difference up to 180±3o in "nearly reciprocal courses" approaching vessels can observe the sidelights of one another: it will seem to them that they are proceeding on opposite courses, i.e. head-on. The same situation can arise when two ships are approaching each other "not head-on", but on opposite course (parallel course), in the case, when the course angle of observed ship in visibility of sidelights (3 miles) has the meaning up to 3o, i.e. when the distance between course lines is about 1,5 cables and there will arise the risk of collision because of the hydrodynamic interactions of the ships. These circumstances could have been taken as more precise definition of the notation "nearly reciprocal courses". They are supposed to be the courses, the differences of which, is within the limit of 180 ±3o. However, the substantial limitation, of criterion of the determination of head-on situation by the visibility of both sidelights is that it can be only applied at small distances between the ships because of their poor visibility.

As applied to clearing up the quantitative criteria of meeting of the ships proceeding on reciprocal (nearly reciprocal) courses head-on, we have put a special emphasis on the fact that the above-mentioned criteria could have been the same, that is they could have been implemented only under perfect conditions of navigation, when no external factors influence upon ships′ movement and when the ships could have been able to proceed without drifting and sheering along the course line (Fig. 1, Fig. 2). But the case it not often like this.

In practice in most cases of ship's navigation, any ship is exposed to winds and currents, and because of that, first the ship, is moving with drift angle, that is, not along the course line but on track line and, second, the ship lab ours yawing. As a result, the ships can move head-on (move on reciprocal track lines), though their courses difference can be other than 180°. Moreover, due to yawing it can be alternating, either larger or smaller than 180°. By daytime for the same reason, masts alignment of oncoming chip can't be observed, they can be either aligned or not

aligned, and at night time only one sidelight can be observed – if the ship is moving with constant drift angle and both sidelights can casually appear – if the ship is moving with yawing (Fig. 4).
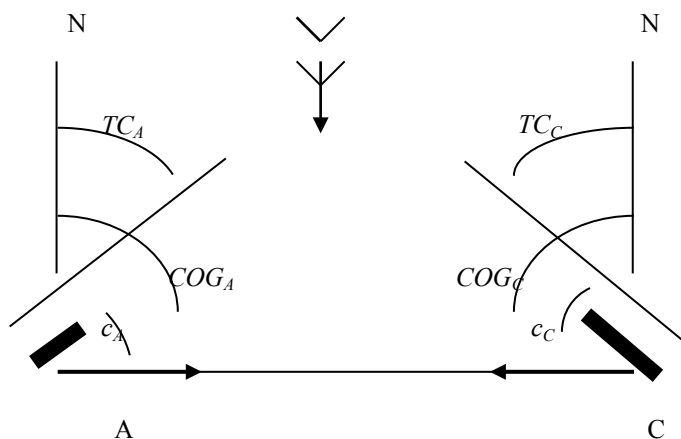

Figure 4. Ships proceeding on reciprocal course

In case, ships are proceeding with drift angle, it would be correctly to say, in our opinion that they are meeting on reciprocal track angle.

4 CLEARING UP THE HEAD-ON SITUATION WHEN USING RADAR

If the ships are proceeding with visual drift angle, instantaneously received criterion for clearing up head-on situation is not perceived at all. The only things to be undertaken in this case is to solve this problem in classic way, i.e. by relative plot ling method, observing the oncoming ship's alignment changes and distance to it by the radar. However, it should be implied that the question is about ships movement on nearly reciprocal route angles with relatively small course angles of each other and nearly equals to drift angle. That's why occasional errors of measuring, especially of bearings will greatly influence upon the results of relative plotting. Really, assume that the ships are preceding at speed of 10 knots on reciprocal courses with track angles and at a distance of 5 miles the navigators, observing with binocular or through optical finding tube, sight masthead lights supposedly not in line. In fact, it could be true, as under the condition of the problem, the ships are proceeding with drift angle. The navigator of A ship thinks that C ship is on his starboard side, and the navigator of C ship think, that A ship is on his portside. Nevertheless, the navigator of A ship decided to define more exactly head-on situation and he measured the bearing of C ship and distance to it by radar, and three minutes later he repeated his measuring again. Under the condition of a problem the C ship's bearing must not change, but due to occasional errors of gyrocompass (and with probability of 95% they can reach values $\pm0,5^o$ (Directions on…1987) it turned out that at a distance D_1=5 miles, bearing B_1 was $89,5^o$ in the first measur-

ing, and in the second measuring at a distance $D_2 = 4$ miles bearing was $B_2 = 90,5^o$. Calculation of closest point of approach by a formula:

$$d_{cpa} = \frac{D_1 D_2 \Delta B}{\Delta D}$$ (3)

where $\Delta B = B_2 - B_1$, $\Delta D = D_2 - D_1$, which gives it accurate to the component of 2nd order infinitesimal with minor values d_{cpa} (Luschnikov, E. M. 2007. Ships'...), and also relative plotting "made sure" the navigator of A ship that C ship would be on his reciprocal, but parallel course and pass his starboard at a closest point of approach (CPA) $d_{cpa} = 3.5$ cables (Fig. 5). It is not excluded, that the navigator of C ship also observed distance and bearings changes of A ship and his results were that at a distance of 5 miles A ship's bearing was equal to $270,5^o$ and at a distance of 4 miles it was equal to 269°, though, in fact A ship's bearing did not change and was equal to 270°. As a result of relative plotting and the above occasional errors in taking bearing, he "cleared up" that A ship was proceeding reciprocal but parallel course and it would pass on his port side at a close quarter distance of 3.5 cables sufficient for safe passing (Fig. 6). Both navigators could regard that ships would pass at a sufficient distance, but actually they were proceeding reciprocal track angles head-on.
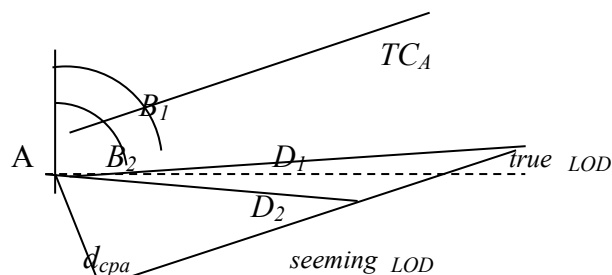

Figure 5. Possible result of relative plotting aboard A ship, when ships are proceeding on reciprocal track angles. The result was caused by random error in taking bearing
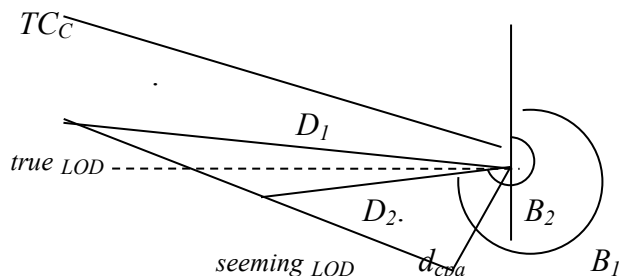

Figure 6. Possible result of relative plotting aboard B ship, when ships are proceeding on reciprocal track angles. The result was caused by random error in taking bearing closest point of approach

We cannot ignore one more situation, under which radar observation aboard A ship has showed that at a distance of 5 miles A ship's bearing is equal to 269.5^o, and at a distance of 4 miles it has changed to 270.5^o. In that case a relative plotting

showed that A ship was crossing C ship's course and would pass it at a closest point of approach of 3.5 cables (Fig. 7). A ship's navigator thinking that both ships, even if they are proceeding on reciprocal parallel courses, but at a short distance of closest point of approach d_{cpa}, and taking into consideration small bearing changes of C ship (even 1° is a sign of risk of collision) has decided to act in compliance with Rule 14, altering course to starboard. But C ship's navigator, computing the situation of meeting on crossing courses and A ship as being on his starboard has decided to act in compliance with Rule 15 and keeping out of the way of A ship, turned port side and as a result the situation of meeting has arisen which could lead to ships' collision of which we have mentioned earlier (Fig. 1) .
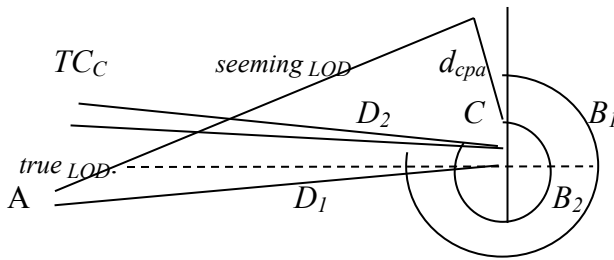

Figure 7. Possible result of the plotting on C ship when two ships are proceeding on reciprocal track angles. The result was caused by random errors in taking bearings

Thus, we have made sure that neither visual nor radar observation permit to determine with confidence the fact of ships' approaching on reciprocal courses (with track angles). That's why in this case of uncertainty, for want of something better, we should comply with Rule 14 of COLREG : "…When a vessel is in any doubt as to whether such a situation exists she shall assume that it does exist and acts accordingly…", i.e. alter course to starboard in due time. But the whole problem lies in that every navigator has his own degree of doubt…

5 CLEARING UP THE HEAD-ON SITUATION WHEN USING AUTOMATIC IDENTIFICATION SYSTEM

During the past few years many ships are being equipped with new technical aids to navigator, in particular, automatic information systems (AIS). They allow the ships' meeting within the range of VHF coastal station (about 20 miles) to exchange information about current positions of the ships, their speed, track angles, etc. That's why it is interesting to clear up their capabilities in order to determine head-on situations.

Ships' coordinates related to the same time and received from AIS allow determining the distance between ships and an oncoming vessel's bearing. Actually, if at some instant of time t_1 we received

coordinates φ_{o1} and λ_{o1} of our ship and coordinates φ_{b2} and λ_{b2} of the oncoming vessel, distances D_1 and D_2 between ships and the oncoming vessel's bearings B_1 and B_2 at those instants of time can be determined by formulae:

$$D_1 = \sqrt{\left(\varphi_{o1} - \varphi_{b1}\right)^2 + \left(\lambda_{o1} - \lambda_{b1}\right)^2 \cos^2 \varphi_m} \qquad (4)$$

$$B_1 = arctg \frac{(\lambda_{o1} - \lambda_{b1}) \cos \varphi_m}{\varphi_{o1} - \varphi_{b1}} \qquad (5)$$

$$D_2 = \sqrt{\left(\varphi_{o2} - \varphi_{b2}\right)^2 + \left(\lambda_{o2} - \lambda_{b2}\right)^2 \cos^2 \varphi_m} \qquad (6)$$

$$B_2 = arctg \frac{(\lambda_{o2} - \lambda_{b2}) \cos \varphi_m}{\varphi_{o2} - \varphi_{o2}} \qquad (7)$$

where φ_m - an average latitude between vessels .

To simplify these judgments, assume, that navigator takes place near Equator and $\varphi_m = 0$. In this case difference of distances and difference of bearings are:

$$\Delta D = \sqrt{\left(\varphi_{o1} - \varphi_{b1}\right)^2 + \left(\lambda_{o1} - \lambda_{b1}\right)^2} - $$
$$- \sqrt{\left(\varphi_{o2} - \varphi_{b2}\right)^2 + \left(\lambda_{o2} - \lambda_{b2}\right)^2} \qquad (8)$$

$$\Delta B = arctg \frac{(\lambda_{o2} - \lambda_{b2})}{\varphi_{o2} - \varphi_{o2}} - arctg \frac{(\lambda_{o1} - \lambda_{b1})}{\varphi_{o1} - \varphi_{b1}} \qquad (9)$$

Knowing the difference of distances and difference of bearings and taking info account the most interesting for practice the occurrence of small distances of close quarter approaching of ships we can use formula (3), to find the distance of close quarter approaching or we can determine it using method of relative plotting.

Root-mean-square errors of distances measuring m_D and measuring of bearings m_B can be found by formulae, following from equations (6) and (7) (Bukaty, V. M. 2005. Research…)

$$m_D = m_{\varphi\lambda} \sqrt{2} \qquad (10)$$

$$m_B = \frac{m_{\varphi\lambda} \sqrt{2}}{D} \qquad (11)$$

where $m_{\varphi\lambda}$ - a root-mean-square error of determining ships' coordinates (the errors is considered to be identical by latitude and longitude).

For larger simplicity of judgment, assume, the ship are approaching one another meridian so that longitudes difference will equal 0° and latitudes difference at the instant of time t_1, will be $5'$. Assume, that at the instant of time t_2 it will be $4'$, i.e. at the in-

stant of time t_1 the distances between ships are 5 miles and at some instant of time t_2 – 4 miles. Distances difference is 1 mile. Taking into account that AIS transmits the positions received from receiver-indicator NSS we calculate root-mean-square errors of determining distances and bearings by formulae (10) and (11). Assume NSS is working in the usual condition. Root-mean-square coordinates errors are a factor of $m_{\varphi\lambda} = \pm$ 20-25 m, and double errors (with probability 95%) will be a factor of $\pm$ 40-50 m (IMO Resolution A.953(23). 2003). According to (10) and (11) at instant of time t_1 with probability of 95% distance error between ships is $\pm$ 0.5°, and error of on-coming ship's bearing is $\pm$ 0.44°. At instant of time t_2 the error of bearing determination is $\pm$ 0.55°, and the error of distance determination is just the same. The errors of distance determination as above indicated are not great and they may be ignored. But the point is that bearings defining within the distances of maneuvering zone end practically the same whether we use AIS or radar observation. The relative plotting may show the same results and the same situations of approaching ships as we have considered above when writing about radar observations.

If necessary to consider an example when the distance differences between ships at the time of measuring is equal to 2 miles (measures are being done every 6 minutes at the same ships' speed), then for the distance of 5 miles (1st measure) the error of bearing measuring would be the same $\pm$ 0.44°, and for the distance of 3 miles (2nd measure) it would be $\pm$ 0.73° according to (11). It won't improve the situation, more than likely; deteriorate it i.e. the seeming approaching situation might happen not to be in accordance with the truth. In this example AIS fails to gain even to radar observation, where the error of taking bearing can be considered as independent of distances between ships.

It is of interest to examine AIS scope for much earlier ships' approaching situation. Suppose, that under the conditions of previous example ships started using the information of AIS at a distance of 20 miles. It means the errors of distance determination will not be changed and can as before be ignored because of their infinitesimal, and errors of bearing determination will reduce to one-quarter, adding a factor of $\pm$ 0.1° according to (11). But, in spite of the above, owing to distances increasing to one-fourth, closest point of approach will increase being equal to 6.6 cables as to (3). Owing to random errors of taking bearings we, as a matter of fact, receive the same variants of approaching situation from AIS, as we have considered them from radar observations.

Thus, the use of AIS, taking positions from SNS, funning in operation condition in order to clear up the situation when ships are meeting on nearly reciprocal courses cannot solve the problem. And we can repeat again and again the recommendations of Rule 14 that when the vessels are meeting on nearly reciprocal courses and if there is any doubt as to whether such a situation exists we shall assume that it does exists and other the course to starboard in due time.

If the information is entered into AIS from NSS, running in differential condition, the random error of ships' positions with arability of 95% could be taken as equal to 10 m (IMO Assembly Resolution. 2003). Here according to (11) root-mean-square of bearing error will equal to $\pm$ 0.1° when the distance between ships is 5 miles and about $\pm$ 0.25° when the distance is 20 miles.

6 CONCLUSION

Correspondingly, closest point of approach at the same distance difference of 1 mile, as in previous examples, will be equal to 0.7 cables in the first case and 3.3 cables in second one according to (3). Such a small closest point of approach of 5 miles at a starting distance would indoubtly indicate that the ships are meeting on reciprocal course (head-on situation). At a starting distance when the ships are 20 miles apart and the information about ships' position is entered info AIS from NSS, operating in differential condition, a seeming closest point of approach (3.3 cable) is such that it is able to lead a navigator into error as to the approaching situation. Thus, AIS, having received ships' positions from NSS, operating in the differential condition, allow a navigator to make proper judgment about the ships' meeting on reciprocal courses even at such a small distance difference between them at the time of measuring as 1 mile.

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