Automatic Ship Lockage Based on Magnetic Mooring

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Abstract: To improve the efficiency and security of traditional ship lock, automatic ship lockage based magnetic mooring can replace twisted ropes and tugs to ship lock. In the dynamic design of the device, meeting requirements of Ship Lock, we take advantage of tug resistance and cable strength allowed by ship to calculate the power which the device need. The ship mooring device is designed to magnetic ship lock sucker that a part of the automatic berthing device, using rail traction motor to provide a way to ship traction. The calculation of the power required for different types of vessels to pass the lock is analyzed, and the relationship between different breadth and power is also listed, which provides a reference for the ship lock construction and motor optimum selection. The device changes the traditional mode and concept of ship lockage, it makes the ship more automatic, safe and efficient through the lock, which is a key step in unmanned or automation of ship lockage.
Key words: power device; magnetic mooring; magnetic lock; force relation

1. Introduction

For thousands of years, although the material from the original plant fiber has developed to the modern high-tech materials, and the tug has also been more and more automated, but in the aspects of safety and efficiency, the still can’t completely guarantee the ship into the gate The ship, especially when the environment is harsh, or ship's own manipulation is poor, safety coefficient of direct access had declined sharply, thus increasing the likelihood of collision between the ship and the lock. In the current level of science and technology, to realize automatic ship through lock, so as to realize the full unmanned (or automatic) driving mode is feasible, namely through the magnetic sucker, elastic shock absorber device, without the use of cables and the case, which help the ship reach the purpose of automatic lock. The related research at home and abroad, on the ship magnetic mooring research is more, but it rarely involved in magnetic lock. In this paper, according to the current mature magnetic mooring system device, the magnetic ship automatic lockage device is designed, to improve the existing problem of traditional way of ship lockage. In order to verify the feasibility of the device, the paper carries out a calculation example and use software Origin to obtained their mutual relations which is involved in forces, providing strong support to ensure the smooth development of the device. The validity of the proposed method was verified with the numerical example of a practical system.

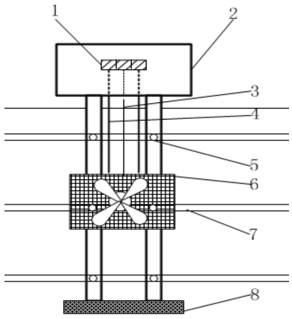
2. Constructions and Operating Principle

2.1 Primary structure

The overall design of the main structure diagram as shown in Fig. 1 and 2, which is mainly rail part and the body part.

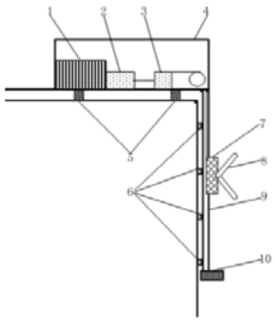
Rail part: Lying of two classes of orbit. Above the ground track and wall lateral orbital. Mainly provide the longitudinal traction tracks, which can make ship along the orbit direction traction.

Frame and moving parts: Sucker device, power plant, connecting device, stabilizing device, remote control device. Which mainly provide transverse magnetic adsorption and longitudinal traction.



1-follow-up drum,2-engine body,3-wire,4-link chain, 5-sheave,6-sucker,7-strong side rail, 8-the prominent chassis

Fig. 1: The front view of magnetic lock device



1-ballast,2-electrical machine,3-windlass,4-engine body,5-top rail, 6-wall lateral orbital, 7-sucker, 8-elastic shock absorber,9-connecting device,10-the prominent bottom

Fig. 2: The lateral view of magnetic lock device

2.2 Fundamental principles

The key component of this device is magnetic sucker. Suckers have electromagnetic and permanent magnet and other various types. When used on ships, due to the need of magnetic chuck power to produce magnetic force[1]. When the ship docked, electricity for a long time is needed to keep the magnetic to fulfill the requirements of mooring. Therefore, this is not economic, and reliability is not good. The device would lose her function when no power ,so that cannot be used on ships. Considering the safety of the ship, we shall adopt the mechanical composite power demagnetization of permanent magnet magnetic sucker. This kind of magnetic sucker has rated suction when no electricity to ensure the normal order of the ship mooring. When the lock in berthing of the ship, in special situations, for example, the sucker suction to fixed shipping rating, we can ensure the safety by reversing power control equipment and increase the suction. When the positive electricity suction disappear, it could make the ship away from the parking brake.

3. Structural Designs

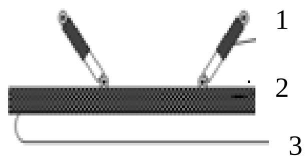
According to the size of the ship lock by different biggest tonnage and daily difference of throughput, these design devices can be made to satisfy the corresponding adjustment. This device is based on the magnetic mooring technology, This section has been relatively mature technology, so we do not repeat it again here[2]. The important part is structure and function of each part.

3.1 Each module functions introduction

3.1.1 Sucker device

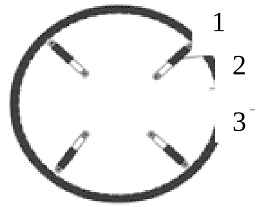
Currently, magnetic sucker has been widely used in metallurgy, lifting, mechanical processing and other industries, this technology has been already quite mature, magnetic chuck of many manufacturers design and manufacture could produce 600~1200 kn/m^2 of suction. Most magnetic sucker internal has many poles to in a certain order. S and N pole distanceare small, the lines of magnetic force is short.

When using mechanical composite power demagnetization of permanent magnet magnetic sucker magnetic chuck has rated suction when no electricity, which could ensure the normal berthing of ships. When in the gateway of the ships, In special situations, rating attraction force of sucker cannot secure the ships, we can reverse power by controlling equipment and increase suction to ensure the safety. When the positive electricity, Suction disappear, which can make the ship away from the area of reasonable selection of mooring sucker, for example, specification requirements such as a ship equipped with tolerance of 200kn cable is using magnetic suction that can choice 60cm in diameter suction cups that could meet the requirements in theory. And like this sucker, the diameter is smaller than a life buoy.



1- elastic shock,2- magnetic chucks,3- rubber protectivering

Fig. 3: The side face of magnetic sucker



1- elastic shock,2- rubber protectivering,3- magnetic chucks

Fig. 4:The right side of magnetic sucker

1) Elastic half a stable structure

As shown in Fig.3 and Fig.4, in order to reduce the suction cups and other objects directly the impact of the collision, we use the four groups of elastic shock absorber, and that The ends of the elastic shock absorber in each group respectively by spherical head connected to the suction cups, hull connection. According to the former, four groups of elastic shock absorber, upper and lower even after installation, it is of elastic half a stable structure[3]. So, the sucker can not only on the front and back, and lower part can have certain mobile space, can also and hull in arbitrary direction angle of deflection (similar to a “tumbler”toy movement).

2) The magnetic chuck crash-proof noise reduction measures

Outside the suction cup side (i.e. near the suction surface) on the cylinder of setting up a protective rubber ring, whose purpose is to prevent large Angle sucker, direct contact with fixed on the dock plate and prevent other objects collision chuck directly. In the suction cups and plate and instant, we can reduce noise in the maximum.

3) The sealing cover

The parts coated in magnetic mooring device appearance, which have certain elasticity (or scaling), have the effect of sealing protection, to make whole magnetic mooring device in addition to the suction surface all sealed, and prevent the spring shock absorber, the spherical connectors and other components are directly exposed and erosion by air, dust, water, etc, so as to prolong the service life of these artifacts.

3. 1. 2 Connection Device

Power Device sticks out the long arms in the direction of up and down, and the arms are connected with a track. Then the track is fixed on the body of the machine and cannot move by itself, enabling the Sucker Device move up and down, and it is also equipped with wire track. The track is divided into two parts to enhance stability and to make it more stable when the sucker slides up and down.

In order to enable the sucker move up and down in the control of people, two chains are set paralleled to the track. The ledge at the end of the track can hold the sucker when the sucker is not at work and won’t waste any other power. So sufficient strength is required to provide enough support. There is also Stabilizing Device at the end of the track.

The contact between the track and the sucker is mosaic, which enhances the stability and reliability, to some extent.

The top of the track is connected to the power device, enabling the track move forward and after together with the body of the machine, form which the chains go into the body of machine and are connected to the motor inside. The contact between the track and the body of the machine also should be very strong, for very large power will be produced here. Because the power varies from vessel to vessel, the largest vessel which can pass the ship lock should be taken into account.

There are cables at the middle of the track, which can provide electric power to the Sucker Device. The cables can stretch out and withdraw together with the Sucker Device so as not to be stuck or fouled, etc.

3. 1. 3 Power Device

The Power Device is mainly made up of high power electric motor, leads, shell and ballast.

Outer motor rotates to provide power to make the whole machine move along the track, and here the power of the motor should be chosen according to the power that the largest size of vessel needs, and the power provided by motor should not be less than the resistance calculated from chapter 3.1 below. Motor drives the wheels directly. Wheels are fixed on the track, so two tracks and four wheels not only enhance the stability, but also provide enough power (mosaic), enabling the whole machine keep stable on ground and preventing the body of machine being lifted from ground.

3. 1. 4 Stabilizing Device

There is a track inside the connection device, and the track is also mosaic. On the one hand,it can ensure the device run regularly. On the other hand,it enable the connection device be stable so as not to be dragged out. The intensity of this device can meet the requirement, meanwhile, it is convenient to be repaired.

3. 1. 5 Telecontrol Device

Telecontrol device aims mainly at three systems below:

Sucker device, which is set on three state that positive-going electricity, reversed electricity, and no electricity.

Inner motor, which is set on three state that positive-going rotation, reversed rotation and no electricity.

Outer motor, which is set on three state that positive-going rotation, reversed rotation and no electricity.

3. 2 Process of Passing Ship Lock

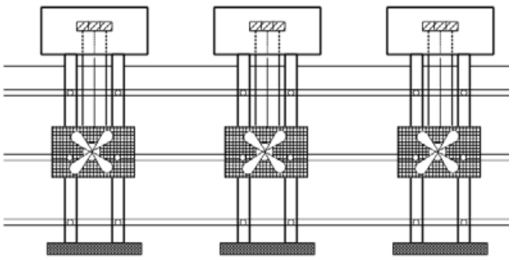


Fig.5:Distribution of magnetic power device

1) Sucker Device is located at the bottom of Connection Device freely, to begin with. After vessel arrives, two or three suckers(according to the size of the vessel) are selected and are driven to the bow, midship and stern in turn.

2) Vessel can be leant on two position accurately by automatic magnetic mooring system, and springs will stretch outside because of the extrusion of plate and hull. It is feasible that we just adjust sucker’s height in the former process and then turn on Magnetic Power Device.

3) After mooring is finished, just keeping magnetic power is ok, and other devices cannot be at work. After the doors of ship lock are closed and water is let out,vessel rises with water going up,making suckers move up. At this time, it’s practicable as long as winch keeps up with the speed of suckers. In this process, shocks(rolling, pitching, heaving) can’t be avoided. Owing to the spring system between suckers and hull, the shocks can be reduced greatly.

4) After water surface calms down, outer motor runs, driving the whole machine go forward. Meanwhile, suckers drive vessel move forward. When arriving at the end, magnetic power is withdrawn immediately, and springs recover to their original state, and bow deviates from the wall. Driven by officer or towed by tugs,vessel can leave lock road.

When vessel goes into ship lock, main operations include traction and making fast mooring,and we make detailed design on the basis of former people’s research. As for traction, it can make the same effect as being towed by tugs as long as the traction power, which is adopted in our design, isn’t less than the resistance of tugs, or it can make the same effect as the traction of heaving away lines as long as the traction, which is adopted in our design, is stronger than the strength which can just right cut the lines. And as for making fast mooring,It can make the same effect as making fast as long as the magnetic power, which is used in our design, is stronger than the strength which can just right cut the lines. So we need to research the resistance when vessel passes ship lock and the required power of lines used for mooring.

4. The Power Calculation of the Device

The main operation of the ship into the lock is traction and mooring, which is designed on the basis of previous research. As to the traction, the existing ship principally uses the method that artificial replacement of cable pile, twisting cable or tug towing. Traction adopted by the designed device is expected to be greater than or equal to the resistance of tugboat towing or breaking strength, which replaces the rope twisting. As to the mooring, the usual way is to use a cable to tie tightness, by artificial adjustment of the tightness of the rope, to make the ship tied up at lock. The magnetic force is expected to be greater than or equal to the breaking strength to achieve the purpose. So we need to study the ship resistance and mooring lines forced.

4.1 Towing Resistance Calculation

Towing ship in process, shell be affected by wind, current and other factors, the direction of whose force is opposite to the direction of the ship forward, namely the ship resistance. For the general ships, the ship itself can provide the rudder force to overcome the friction, but for unpowered ships, tugboat provide thrust to overcome the friction [3]. For different kinds of ships with different speed, the towing force is different and for tugboats, in the different speed, under different sea conditions the real-time drag force provided by them is not the same. In general, when the towing speed is "0", the tug offers maximum towing force that the column tugboat towing force, with the increasing of the speed, the tug available drag force decreases linearly [4].

Towing resistance calculation based on the empirical formula:

In the towing process, according to the nature of towing resistance, it can be divided into two parts: the basic resistance R_0 and additional resistance R . The total resistance of towing system is the total resistance of the tugboat and the ship towed. The following describes the calculation of the total resistance of the ship towed. Tugboat resistance is calculated with reference to the calculation of the total resistance of the ship towed[5].

1.The basic resistance

Basic resistance R_0 is divided into frictional resistance R_f and residual resistance R_b , the calculation formula is as follows:

$$R_f = 1.67 A_1 V^{1.83} \times 10^{-3} \tag{1}$$

$$R_b = R_t + R_x = 0.147 \delta A_2 V^{1.74+0.15V} \tag{2}$$

Note:

A_1 -surface area ship wetted, it can be available in the ship's materials according to the ship's draft ,

V -the towing speed,

C_b - ship square coefficient,

A_2 - the maximum cross-sectional area below the waterline.

2. Additional resistance

$$R_\Delta = R_W + R_1 + R_2 + R_3 \tag{3}$$

$$R_w = 1.64884 A_3 \left(V_w + V\right)^2 \times 10^{-4} \tag{4}$$

Note:

R_w - air resistance,

R_1 -additional resistance,

R_2 -fouling resistance,

R_3 -rough water resistance.

3. Calculate the towing resistance based on wind and water dynamic model Fig. The calculation of the wind resistance:

$$F_w = \delta q A \tag{5}$$

Note:

q - relation, after the air density and wind speed $q = 0.613 \times 10^{-3} V_W{}^2$ after conversion,

C_b - ship square coefficient,

A - the wind of projected area,

V_w - the design wind speed.

Beam wind force:

$$F_{yw} = \delta q A_y$$

Vertical wind force:

$$F_{yx} = \delta q A_x$$

Calculation of water flow force:

$$F_c = \tfrac{1}{2} C_d \rho A V_2 \quad (6)$$

Note:

C_d -water resistance coefficient,

ρ - seawater density,

A - the current projected area,

V -the calculation of flow velocity.

Lateral water force:

$$F_{yc} = \tfrac{1}{2} C_d \rho A_y V_y^2$$

Vertical water force:

$$F_{xc} = \tfrac{1}{2} C_d \rho A_x V_x^2$$

4. The calculation of calculation towing resistance

Beam wind and water force:

$$\sum F_y = F_{yw} + F_{yc} = cqA_y + \tfrac{1}{2} C_d \rho A_y V_y^2 \quad (7)$$

Vertical wind and water force:

$$\sum F_x = F_{xw} + F_{xc} = cqA_x + \tfrac{1}{2} C_d \rho A_x^2 \quad (8)$$

4.2 Rope Mooring Allowable Force in the Lock

Force value in the direction of the mooring of vessels in the lock, can be calculated by the cable breaking force divided by the safety coefficient[6]. The relationship between the boat outfitting number and the rope allowable force in the Table 2, is calculated according to theTable 1. In the Table 2 outfitting number more than 330 and not more than 3030 of the allowable stress of steel wire rope stress value, is determined according to the data in page 92 to 93 pages of book “ninety-second Yangtze River steel ship construction norms”. With the determine of the allowable stress of steel wire rope stress value, the transverse and longitudinal component values are determined by the angle between mooring rope and the longitudinal axis of the lock, which is general 20-40 degree meaning that the horizontal force is less than the longitudinal force 2 ~ 2.5 times. In Table 2 and Table 3, the angle used is 30 degree. As the following formula:

Longitudinal force:

$$P_L = P \bullet \cos 30^\circ = 0.866P \quad (9)$$

Beam force:

$$P_B = P \bullet \sin 30^\circ = 0.5P \quad (10)$$

When the angle between mooring rope and the longitudinal axis of the lock is A, and the direction and the horizontal surface with a tilt angle β , the relationship is as follows:

$$P_L = \cos A \bullet \cos \beta \bullet P \quad (11)$$

$$P_B = \sin A \bullet \cos \beta \bullet P \quad (12)$$

When the ship outfitting number is 300 ~ 500 and the rope is hemp rope, the allowable force is determined according to the Table 2, while the wire rope to the Table 2 and Table 3.

Combined with the actual situation in China, according to the specification of our current shipbuilding and the mooring equipment strength, put forward the allowable mooring force value P_y , based on equipment number[7-9] .

It’s more convenient to obtain the allowable force value from the table than by calculating with the formula.

Table 1 Mooring cable diameter and outfitting number table

Outfitting number N	<100	125	150	175	200	250	300	350	400	450	500
Cable Diameter (mm)	8.5	9.5	11	11	12	12	13	13	15	15	16.5
Hemp rope Diameter (mm)	25	27	29	29	31	31	33	33	37	37	41

Table 2 The boat outfitting number and rope allowable force relationship value

The relationship value between the boat (equipped with rope or twine) equipment number and rope allows the force

The number of ship outfitting N	Steel wire rope					Hemp rope				
	Diameter(mm)	Breaking force(kg)	Allowable force(kg)			Diameter(m-m)	Breaking Force(kg)	Allowable force(kg)		
			Join Force	Longitudinal Force	Beam Force	Join Force	Join Force	Join Force	Longitudinal Force	Beam Force
<100	8.5	2720	680	589	340	25	2936	734	636	367
125	9.5	3350	838	726	419	27	3598	899	779	450
150	11	4700	1180	1022	590	29	4037	1009	874	505
175	11	4700	1180	1022	590	29	4037	1009	874	505
200	12	5600	1400	1212	700	31	4916	1229	1064	615
250	12	5600	1400	1212	700	31	4916	1229	1064	615
300	13	6500	1630	1412	815	33	5322	1331	1153	666
350	13	6500	1630	1412	815	33	5322	1331	1153	666
400	15	8400	2100	1819	1050	37	6133	1533	1328	767
450	15	8400	2100	1819	1050	37	6133	1533	1328	767
500	16.5	10700	2680	2321	1340	41	7159	1789	1549	895

Table 3 The ship outfitting number and wire rope allowable force relationship value

Equipment Number N		Steel Wire Rope				
				Allowable(kg)		
Exceed	Unexceed	Diameter(mm)	Minimum breaking force(kg)	Join forces	longitudinal force	Transverse force
330	410	13	6500	1630	1412	815
410	540	15	8400	2100	1810	1050
540	710	17	10700	2680	2321	1540
710	920	18.5	13200	3300	2858	1810
920	1410	20.5	16000	4000	3464	2000
1410	1710	22.5	19100	4780	4140	2390
1710	2300	24.5	22400	5600	4850	2810
2300	3030	26	26000	6500	5620	3450

4.3 The Power Calculation of the Device

At first, calculate the devices traction force. Relying on the motor on the shore, traction force should be greater than the resistance of the tow[10-12]. By Table 3.1, the ship resistance force formula should be:

$$R_y = R_f + R_b + F_{yw} + F_{yc} \tag{13}$$

When the ship is towed by tightening rope, according to the table 3.2, the power of the device should be greater than the allowable mooring force value, that:

$$P \geq \quad Py$$

To sum up, the power of the device should be:

$$P \geq \quad R_y \text{ or } P \geq \quad Py$$

And the adsorption force should be greater than the mooring line tension values, that:

$$W \geq Py$$

5. Practical example

Taken 3000 tons container ship lock and permanent magnet type magnetic sucker device using mechanical power composite demagnetization as an example, the calculation of the force of the ship's traction and tied firmly adsorption magnetic is listed. The main data of the ship: Lbp 106 m, beam 17.1 m, the design draft 5.8 m.

The towing speed 3.0 m/s, the maximum velocity speed 5.0 m/s, wind speed 10 m/s , taken the relevant data into the calculation, in the process of friction, the frictional resistance, additional resistance, vertical and longitudinal wind water power is shown in the following table (unit: kN):

For this ship, the required traction power of the device should be at least 875kN.

According to the formula (13) the ship outfitting number can be calculated as 438.5, to the table 2, the cable allows force of the ship fasten berth is 2100kN, and the vertical and horizontal forces required are 1819kN and 1050kN.

So, for this ship, adsorption capacity of the devices needed to be provided shall be at least 1050kN.

In order to put the device into use in different width of the lock, the data for different types of vessels were calculated. The relation between the required traction force and adsorption capacity of the device, as shown in the Fig. 7 and 8:

Table 4 The magnitude of the resistance force

Towing resistance			Wind and water resistance	
Basic resistance R_0	frictional resistance R_f	33.7	Vertical water resistance F_{xc}	671.6
	residual resistance R_b	129.5		
Additional resistance R		27.8	Longitudinal wind force F_{xw}	12.4

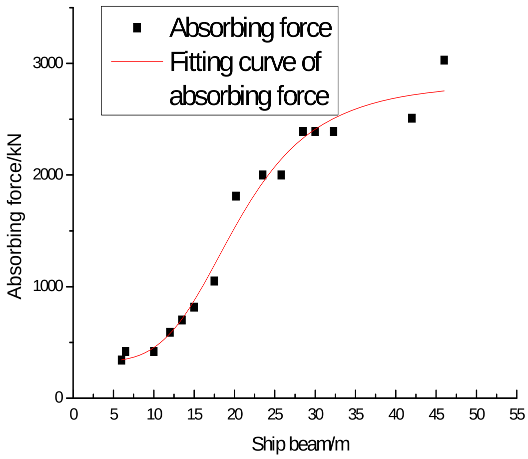


Fig. 7:The relationship between the beam and the adsorption capacit

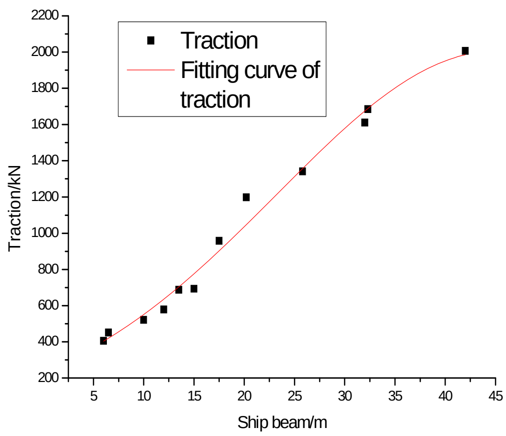


Fig. 8:The relationship between the beam and the traction force

According to the results in Fig.7 and 8, the functional relationship between breadth and function traction and adsorption capacity the device required is as formula (15), (16):

$$W = 2840.6 + \frac{2512.74}{1 + (\frac{B}{20.5})^{4.12}} \quad (15)$$

$$P = e^{(5.47 + 0.09B + 1.67B^2)} \quad (16)$$

The above two formula is analyzed in condition that different type ship in full load, based on the “ship construction rules”. Compared with the above example 3000 tons container ship, the results contrast is basically agreed, so the formula has universality and applicability. According to the formula, we can draw the power of different sizes required in the ship lock. They provides a powerful reference for the future construction of the lock and the best configuration power motor required for the lock.

6. Conclusion

By introduction of automatic ship lockage device and calculations of power which the device need we can use real ship examples and Origin software to verify the feasibility and practicability of this device, which provides strong support for the realization of the future theory of ship automatic lock:

The design of the device can meet the request for ship through lock, and make the vessel through the lock more efficient and safe, according to the functional relationship between different breadth and power given in the treatise the necessary configuration motor size can be conveniently obtained[13-14]. Compared with the traditional lock and berthing mode, the device has the following advantages:

The device has a simple structure, high reliability and convenient operation, it provides a good reference for the construction and improvement of modern ship lock.

The suction device can greatly buffer structure impact when berthing ships to dock, which reduces the collision accidents.

The device provides traction through the motor, not only reduces the dependence on the ship berthing tug, but also improves the efficiency of berthing and through lockage.

The research has solved the problems of automatic ship lockage based the magnetic force on device design theoretically. nevertheless, because of the limitation of team level and time, some improvements and enhancements in the aspects of further study should be done. For example, the applicability of the device for different types of vessels, the influence of magnetic force for correlated navigational equipment and so on. these problems of this device will need to be further studied.

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