

JOURNAL  
OF  
THE FRANKLIN INSTITUTE  
*DEVOTED TO SCIENCE AND THE MECHANIC ARTS*

---

VOL. CLXXV

MAY, 1913

No. 5

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ENGINEERING APPLICATIONS OF THE GYROSCOPE.<sup>1</sup>

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THE general phenomenon of a freely suspended rotating body, or gyroscope, has been very much obscured by its mathematical friends. Volume after volume of mathematical deductions have been compiled in an attempt to investigate and analyze the numerous gyroscopic reactions and their various ramifications. This interminable labyrinth of formulæ has given the world the impression that the phenomenon of freely suspended rotating bodies is so intertwined with theory as to be of little practical value. I am sure you will agree with me that this is very far from the truth when I have explained to what excellent uses it is possible to put these reactions.

The French scientist Foucault was the first to deduce any practical laws covering the reactions of the gyroscope. This he did in the year 1851, when he astonished the scientific world by demonstrating that the inertia of a rapidly rotating wheel was relative to space, and that the rotation of the earth could consequently be shown by this means.

Lieutenant-Commander Obry, an Austrian naval officer,

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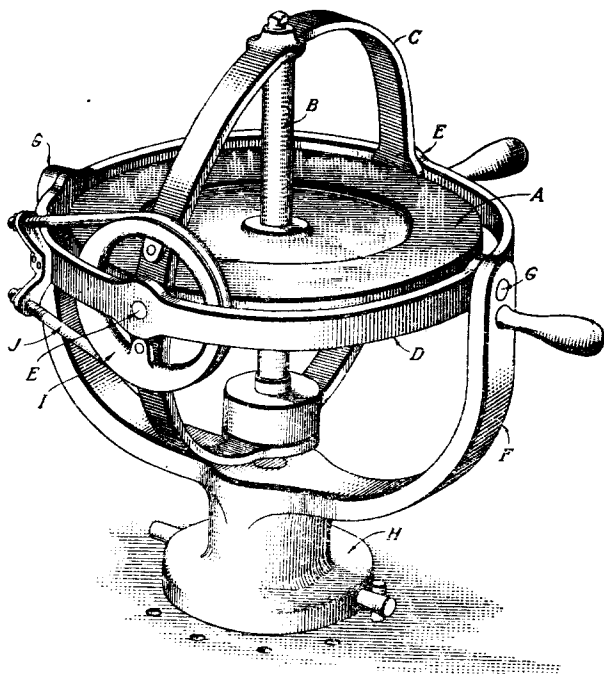
<sup>1</sup> Presented at the stated meeting of the Institute, held Wednesday, January 15, 1913.

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made the first practical application of the gyro by using it as a means for steering a torpedo. Before that time the torpedo was little more than a possibility in warfare, but since that time the gyro gear has been very highly developed and has been the most potent factor in making the torpedo an efficient instrument of war.

FIG. 1.



A simple gyroscope.

Although the many mathematicians who worked over the phenomena became involved in endless abstraction, the phenomenon is, nevertheless, very simple, and the engineering calculations necessary to its practical application are perfectly concrete and easily followed. The phenomenon can be clearly understood by referring to Fig. 1, which is a gyroscope suspended with three degrees of freedom; *i.e.*, freedom about its axis of rotation; *B*, freedom about the axis *G—G* and freedom about the axis *E—E*.

If the band *J* be securely clamped about the ring *I*, attached to the ring *C*, freedom about the axis *EE* would be suppressed

and the gyro would then be said to have a suspension with "two degrees of freedom."

Suppose the clamp *J* in Fig. 1 is released and the wheel *A* is rotating rapidly, with the side nearest the observer moving from right to left. If a force be impressed on the near side of ring *D*, tending to push that side downward about the axis *GG*, this force will be resisted and movement of the gyro will take place about the axis *EE*, the top of ring *C* and axle *B* moving toward the left. Movement of the gyro is thus seen to take place at right angles to the impressed force. This movement normal to the impressed force is called "precession."

Throughout the study of any gyroscopic apparatus it must be remembered that movement of the gyroscope does not take place in the direction of the impressed force, but that this tendency to move is transferred 90 degrees in the direction of rotation before it is manifested as motion.

Nothing but force caused by angular motion is resisted or causes precession; this angular motion may be about an axis within the gyro or remote from it, but must be angular motion. If linear motion be impressed, no gyroscopic reaction will result, even though the force so impressed be of large magnitude. As angular motion approaches linear motion,—i.e., as its radius of action is increased,—the less will be its gyroscopic effect.

If the precessional ring *C*, Fig. 1, be clamped to the ring *D* so that precession is not allowed, then forces impressed on the ring *D* will not be resisted, even though they be due to angular motion, thus showing that precession must be allowed or the gyroscope will not have the property of resisting forces impressed upon it. It is for this reason that fly-wheels and turbine wheels have no real gyroscopic effect, precession being suppressed by the bearings in which the shaft is held.

All these reactions are due to manifestations of the laws of inertia. The relations between them are expressed by the following equation:

$$M = \frac{WK^2N\omega}{307}$$

*M* = The gyroscopic moment in pound feet.

*W* = Weight of the spinning mass.

*K*<sup>2</sup> = Radius of gyration.

*N* = Speed of the spinning mass in revolutions per minute.

*ω* = Velocity of precession, or angular velocity of tilt of the mass about any axis normal to the spinning axis in units of angular velocity or radians per second.

The relation of the various elements of the phenomenon,—namely, (1) direction of spin of rotating the body, (2) the direction of the impressed force, and (3) the direction of the resulting precession,—may be best remembered by comparing with some known and easily recognizable phenomenon. In all probability the child's hoop gives the best clue to these relations. When as youngsters we rolled the hoop we supposed that we were steering it when we beat the hoop at its top upon one side or the other; the facts are we were not steering the hoop at all, but we were impressing a stress upon the hoop, about a horizontal axis, and true gyroscopic action turned the hoop about the vertical axis and changed its direction, thus doing the steering, although we were entirely ignorant of this fact. But it is through this fact that the toy gives us the clue we seek, inasmuch as it involves no feat of memory to correlate the three elements: first, the direction of its rotation cannot be questioned when we are following the hoop; second, there can be no question as to which side of the hoop at the top we beat with the stick which we hold in our hand as we run along back of the hoop or beside it; and, third, there is no question which way the hoop turns when it is so struck. When we beat the top over to the right, precession turns the front of the hoop to the right, and when we beat the top to the left, precession turns the forward point of the hoop to the left. And so here we have a very simple method of remembering this phenomenon, involving all its three elements in their true correlation. The force we impressed about the horizontal axis of the hoop was transferred 90 degrees in the direction of rotation and there manifested as the motion which turned the hoop about its vertical axis.

Among the first attempts at engineering applications of the gyroscope, we find many efforts which have as their object the stabilizing of unstable bodies. The most important of these efforts have been directed toward stabilizing ships at sea. A ship is in effect a pendulum, and is for that reason subject to oscillation when acted upon by the force of waves, which cause it to roll and pitch in the manner with which we are all familiar.

German naval architects have damped the oscillations of this ship-pendulum by interposing on it a second pendulum in the form of so-called anti-rolling tanks. Many of us remember, from our experiences in the physical laboratory, that if we interpose a small pendulum on the arm of a large pendulum, the

small pendulum will act in such manner as to damp the oscillations of the large pendulum, but only when acting in exact resonance with it and lagging 90 degrees in phase. This is exactly the principle of the anti-rolling tanks. The water in these tanks acts as a secondary pendulum which is calculated to oscillate in resonance with the ship but opposed to it in phase. From experiments in the physical laboratory, however, we know that considerable movement of the large pendulum must be set up before the small pendulum begins its oscillations or has any effect, and that if the period of the large pendulum be changed, or if the impulses which cause it to oscillate be changed, the small pendulum must stop and start over again. Briefly, this has been the trouble with the anti-rolling tanks. They have been at best a means for fractional damping of the roll only, and even this damping has been greatly handicapped by the fact that the impulses given the ship by the sea are totally irregular.

The most prominent workers in the field have been Sir Phillip Watt, Professor Biles, and the elder Freud in England, and, in Germany, Herr Frahm. The prominent scientist, Dr. Schlick, made several attempts to use part of the phenomenon of the gyroscope for stabilizing ships. A pendulous gyro was suspended in a ship with freedom of movement about its axis of rotation, which was vertical, and about its axis of precession, which was athwartship. This is called the "passive" type of gyro, and its application is beset with the same difficulties as the anti-rolling tanks; that is, a considerable movement of the ship must set in before the gyro has any effect.

Most of the advantages which would come to the maritime world by using a device for stabilizing ships are quite obvious. Briefly, they may be summarized as follows:

#### ADVANTAGES COMMON TO ALL SEAGOING SHIPS.

(A) Saving in power and consequent saving in fuel owing to the ability to maintain the shortest course between two points in bad weather, inasmuch as the ship will be in no danger from excessive rolling even when steaming in the trough of the sea.

(B) Saving in power and consequent saving in fuel owing to the fact that the wetted surface is not increased by wallowing, inasmuch as the vessel is always held on an even keel.

(C) Saving in power and consequent saving in fuel by elimination of rolling against the relatively stiff water when under

way. This increase in the power required to drive a vessel which is rolling is due to what is known as the keel or form line impingement. It is illustrated by the far shorter extinction curve of the roll of the vessel when steaming than when not under way.

(D) Saving in power and consequent saving in fuel by reducing the yawing and tendency to follow a sinuous course.

(E) Saving in fuel and weight by the elimination of bilge keels.

(F) Making small ships as comfortable for passengers as large ships, while at the same time being able to prevent the largest from rolling.

(G) Eliminating stresses in the structure of the ship and the stresses in the accessories and auxiliaries contained within the ship, which are caused by excessive rolling.

(H) Preventing deterioration in cargo caused by excessive rolling. This would particularly apply to ships carrying live stock as cargo.

(I) Ability to roll the ship artificially for the purpose of freeing from or rolling off sand or mud banks by opening the contacting crevices and gradually liquefying the encumbent mass.

(J) Making a ship more seaworthy by preventing the shipping of seas due to rolling.

(K) Vastly increasing the efficiency, certainty, and range of usefulness of ice-breakers,—in fact, opening up a whole new field of operations for this important class of ship.

#### ADVANTAGES APPLYING ESPECIALLY TO MEN-OF-WAR.

(A) Decreasing the amount of underwater armor, which it is necessary to place on men-of-war at present in order to protect that portion of the hull which might be exposed to the enemy by rolling.

(B) Steady gun platform.

(C) Ability to go into action in any state of sea or upon any course in rough weather.

(D) Improving the condition of men and officers by eliminating the fatiguing and other effects of incessant and constant rolling.

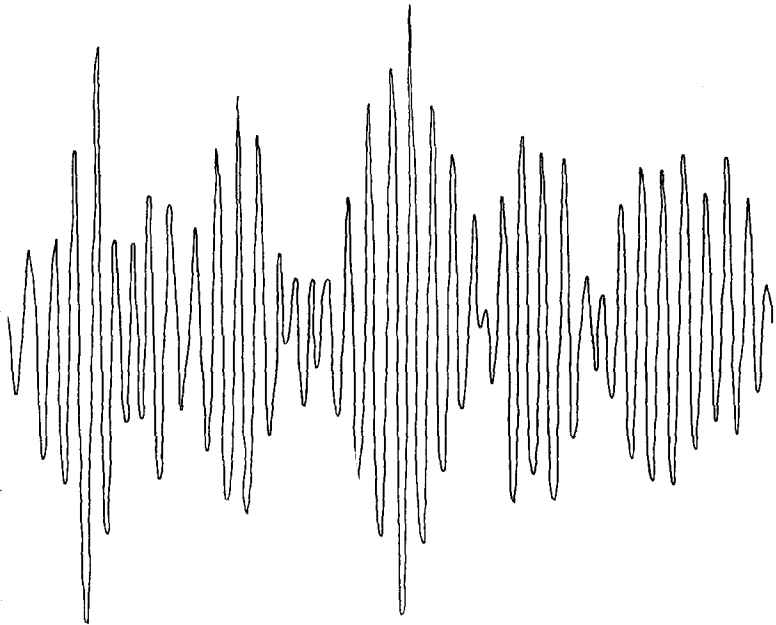
(E) Ability to roll the ship artificially to standard angles as desired, in competitive target practice.

Very early in the work of stabilizing ships Sir John I. Thornycroft gave it as his opinion that ships could never be

stabilized by means of the so-called "secondary resonance" phenomenon of the anti-rolling tanks, inasmuch as any device for efficiently quenching roll must deal with each impulse from the sea as it arises. To accomplish this he designed an anti-rolling pendulum hydraulically controlled to shift the centre of gravity of the ship so as to counteract each tendency to roll as it occurred. This device worked perfectly up to the breaking-down point of the couple so established.

A characteristic roll curve such as that shown in Fig. 2 will

FIG. 2.



Characteristic roll curve.

show that the roll is due to an accession of small impulses from the sea, and, if the ship is to be effectually stabilized, each of these small impulses must be counteracted as they occur.

This is the principle on which the active type of gyro operates. In the application made on the U. S. S. *Worden* the gyros are mounted with their axes horizontal and normally athwartship and with their precession rings pivoted about the vertical axis. Movements about the vertical axis are controlled by an engine called the precession engine (see Fig. 9); this engine is in turn controlled in any one of several ways, for instance, by a

small gyroscopic pendulum which maintains a fixed base line. A tendency to roll, of even so small an amount as 1/10 of a degree, is immediately felt by gyro pendulum, which accordingly controls the precession engine and causes it to move the gyros in such a manner as to deliver an impulse to the ship about its longitudinal axis which will exactly counteract the tendency to roll. This efficiently prevents any motion, and, as the ship is kept on an even keel, very little power is required to accomplish this. It efficiently performs the requirements set down by Sir John I. Thornycroft when he says that "the perfect stabilizer must act against the forces which are acting on the ship in such a way as to always resist the effect of the sea in producing motion."

Fig. 7 is a photograph of one of the *Worden* gyros, showing the wheel casing, the induction motor (lower left) which spins the wheel through a friction drive, the vertical precession ring, and the self-oiling bearings.

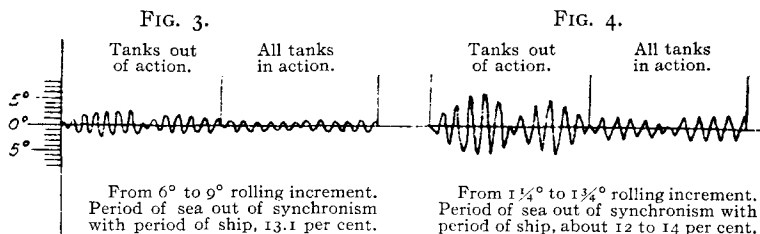
COMPARISON—DAMPING TANKS AND EQUIVALENT GYRO STABILIZING PLANT, S. S. ASHTABULA.

TANKS.								
Period of roll	Notes	Weights in metric tons			Percentage of displacement	Space required		Capacity for rolling ships
		Water	Tanks	Total				
6 Sec.....	Two tanks 60 feet and 40 feet long	784	95	897	19.8	<i>Cu.mtrs.</i> 960	<i>Cu. ft.</i> 33,180	None
6.6 Sec.....	Two tanks 40 feet and 30 feet long	490	65	555	12.4	626	21,600	None
COMPLETE GYRO EQUIPMENT.								
Any period..	One plant.....	0	0	51	1.1	64	2,200	Through an arc of 8° to 10°

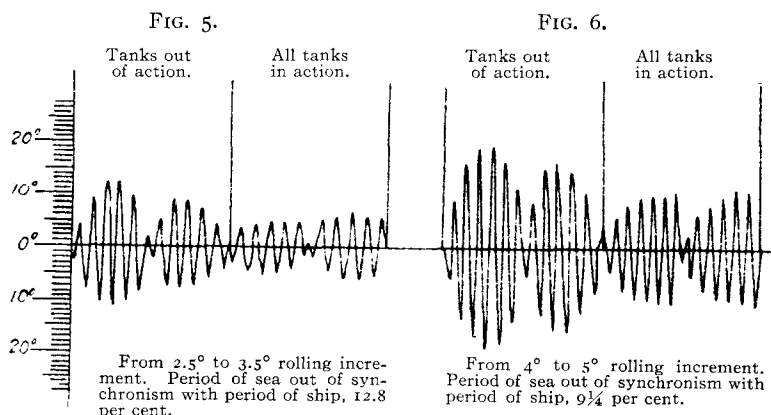
The gyro constitutes an ideal apparatus for this work, inasmuch as it is perfectly safe. It is unnecessary to run the wheel at any but comparatively low stresses. In fact, the stresses present can be brought below those used in hull practice. The comparatively slow motion of the wheel is very inexpensive to develop and maintain, representing only a small fraction of the power required to propel bilge keels; and this power, small as it is, is only required when the necessity for stabilizing arises.



and then only in proportion to the seas running at the time; whereas the power required to drive the bilge keels is a constant drag in all weathers. The power for controlling precession is trifling,—only sufficient to absolutely control and limit the precession movements at all times. This arises from the fact that in stabilizing the constant tendency of the ship is to do precession-wise work upon the gyro. This is fully borne out in prac-



tice, as it is found that the power required for the precession engine is almost *nil*, it being sufficient to control the implacement of the positive and negative energizations delivered to the ship. The gyroscope is ideal in another sense, for with it we have the weight of Thornycroft greatly augmented as to mass



moment by the simple fact that it is in rotation which constitutes a multiplier of tremendous magnitude, even though the actual rotative speed is comparatively low.

That Thornycroft was correct in his line of attack on this problem has now received emphatic confirmation. The effectiveness and mass moment of his weight have been mightily aug-

mented on one hand, while on the other its gravity load upon the ship has been decreased and at the same time the position of its centre of gravity is never shifted. If all these things had originally been in the hands of our distinguished contemporary it is impossible to predict the very great advance that the art of stabilizing ships would by this time have achieved, as only last year he stated: "I came to the conclusion twenty years ago that it was possible to make ships perfectly steady."

In connection with dealing with each individual increment, let us for a moment again refer to Fig. 2. As we trace the envelope of these curves in their rise and fall we note near the centre line where the phase is usually shifted there is always the first impulse of a new cycle, the one which starts the cycle. Now if no cycle of rolling ensued we would have simply a succession of these beginnings, which would naturally be of various signs and magnitudes. These are more numerous in a vigorous, choppy sea, where, as stated, the cycles themselves are shorter and the individuals which shift the periods appear oftener. Now if each of these beginnings could be efficiently suppressed neither the cycles nor the individual rolling constituting these cycles would ever come into evidence, and it is just this suppression that we are enabled to effect by the active type of gyro.

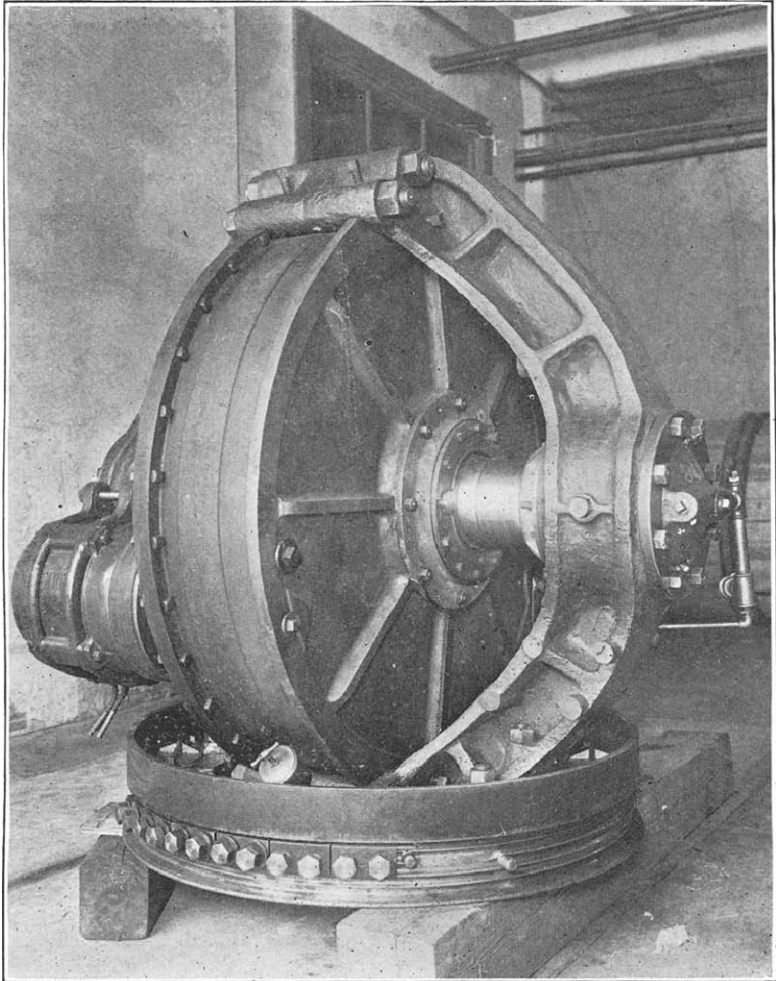
Calculations dealing with known tank equipment well illustrate the powers of the active gyro stabilizer. Let us take the case of Figs. 3 to 6, where only a comparatively small fraction of the roll was dampened, owing to the sea being out of synchronism even by but a slight percentage. The active equipment, as we have seen, is different. It most promptly deals with each momentary energization and "has no memory"; it cares not when nor from what direction the previous stress attack the ship.

The surprisingly small magnitude of the whole gyro equipment is due largely to its unique method of operation; that is, it makes up in activity and promptness what it may seem to lack in size and weight.

This small space is practically independent of location. It need not occupy the most valuable amidships space nor extend entirely across the ship at a point of greatest beam. It may even be divided up in two smaller spaces and be stowed away at any point selected by the designer. In this way the small space required may be that which is least valuable in the whole ship.

Again, the gyroscopic plant is entirely independent of the height component of location, as it is found to operate equally well in the lowest part of the ship and is entirely independent of sym-

FIG. 7.

One of the active gyros of the *Worden*.

metry as to disposition in relation to the ship's centre of oscillation. The gyro precessions being under individual control, each is rendered effective with full force. This persistent and incessant action always in the right direction, not waiting for the

period, but working more rapidly than the period, constitutes another explanation of the smallness of the necessary plant. In modern ships of low metacentric height it is found that the active gyro equipment will represent only a fraction of one per cent. of the displacement.

Another great advantage of the active type of stabilizing gyro, and the advantage that led to the design of this gyro for the *Ashtabula*, arises from the fact that it can be used to produce roll and so cause a ship to break through the ice or enable it to roll off a sand or mud bank.

The gyro employed only requires to be run at one-third or one-half speed for the production of all the rolling that could ever be required by the *Ashtabula* in breaking through the heaviest ice. This is owing to its incessant action developing its full force in proper direction and with the proper emplacement upon each half period. Very heavy rolling can easily be produced and maintained. The action under these conditions is far simpler than in preventing roll, inasmuch as the reaction of the ship, after rolling, is found to react back to the gyro sufficiently to automatically control its precessional movements.

The discussion of stabilized ships reminds me of an amusing incident which occurred at the navy yard in Washington during experiments preliminary to installing a plant on the U. S. S. *Worden*. These experiments were being made with models to simulate a ship, and it had been shown that the principle of the active type of gyro would enable us to do exactly what we had claimed we could do. After the experiments were over an old bluejacket who had been helping us asked me what it was all about, and I told him that the experiments just completed proved that we could prevent ships from rolling. He turned to me and in a very disgusted manner told me that if I had ever been to sea I would know that it was foolish to try to do anything of the sort. "Why," he said, "when you get out there in the middle of the ocean what have you got to hang on to to hold her?" He was right. You do have to have something to "hang on to." And that something must be very powerful. In the case of the stabilizing gyros it is the tremendously augmented inertia of the rotating mass.

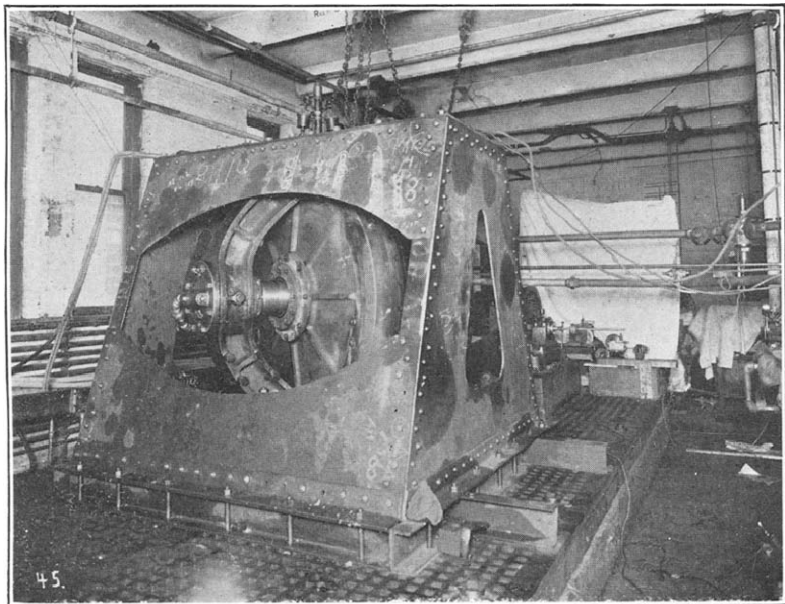
I recently had the honor of presenting a paper before the Society of Naval Architects and Marine Engineers, and after

this paper had been read I was told by the well-known engineer, Mr. W. L. R. Emmet, that the performance of the active gyros in preventing roll of ships described in my paper reminded him of those lines of Kipling:

I'm the prophet of the utterly absurd,  
Of the patently impossible and vain;  
And when the thing that couldn't has occurred,  
Give me time to change my leg and go again.

So far from being "patently impossible and vain," the results thus far actually achieved have been obtained by machinery

FIG. 8.



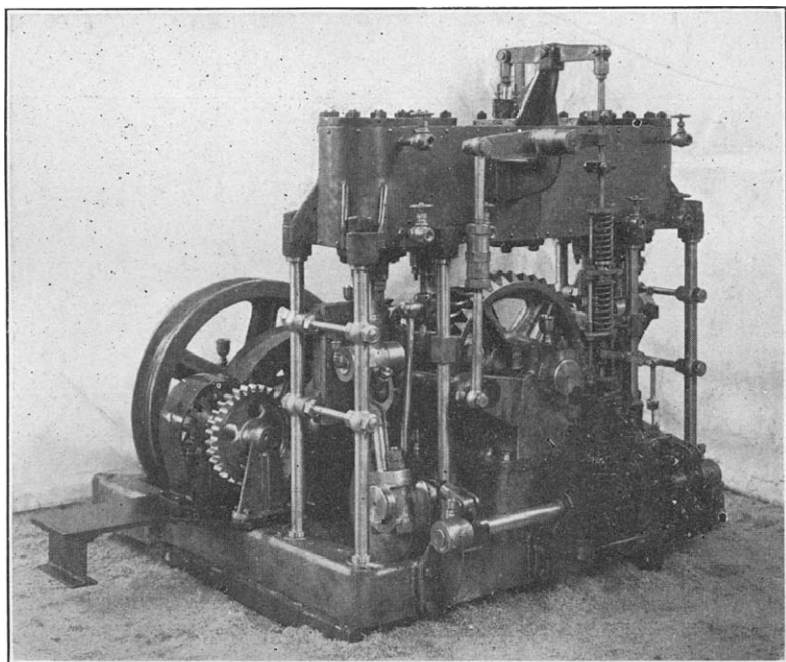
One of the active gyros in the tower during shore trials.

which though unusual is in fact of the simplest character. The installation was found to perform its function so naturally and with such apparent ease as to leave little to be desired as to method. This I believe to be parallel with what has often occurred in the past, that the problem that seems the most insurmountable, like Achilles, has a vulnerable point, and in fact the "thing that couldn't" has been found very simple of solution after it has been fully analyzed and when attacked from the proper angle.

Fig. 8 shows one of the active type of gyros preliminary to its installation on the ship. It was tested in the position shown in the Electrical Laboratory at the Navy Yard in New York. During this test it was found that the precession of the gyro would easily lift the heavy plate on which it was bolted. The weight of this plate and load was approximately 67,000 pounds.

Fig. 9 shows the precession engine.

FIG 9.



The precession engine.

Fig. 10 shows a rough stabilizing curve, the ends showing the sea running at the time.

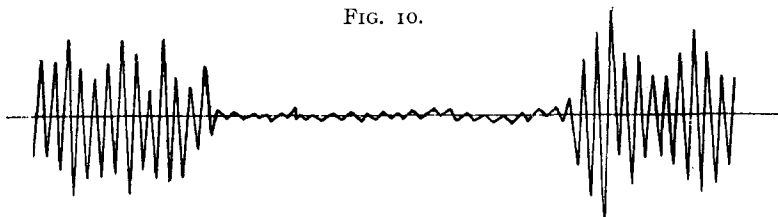
Fig. 11 is a view of the middle portion of the *Worden* from the starboard side, and shows what a comparatively small amount of space is occupied by the stabilizing apparatus.

Fig. 12 shows periodic motion of a ship and the dying-down curve in still water.

Fig. 13, taken from one to two minutes later, shows the dying-down curve when steaming at 15 knots. Both of these

curves were taken in smooth water. Great interest centres in the striking difference between these two curves. This comes from the fact that here, for the first time in the history of navigation,

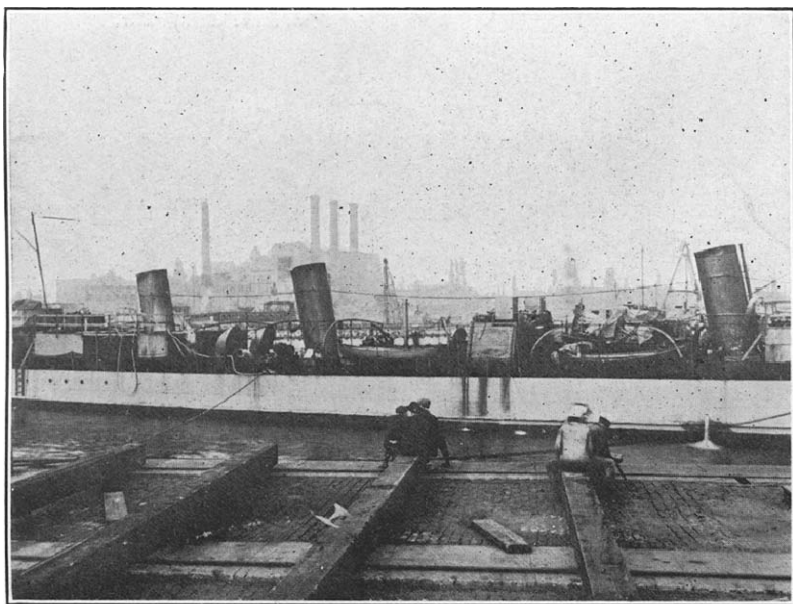
FIG. 10.



A rough stabilizing curve, the ends showing the sea running at the time.

and by the use of the active type of gyroscope, opportunity has been afforded for rolling a ship at will under practically all possible conditions of sea and headway; and here is presented a

FIG. 11.

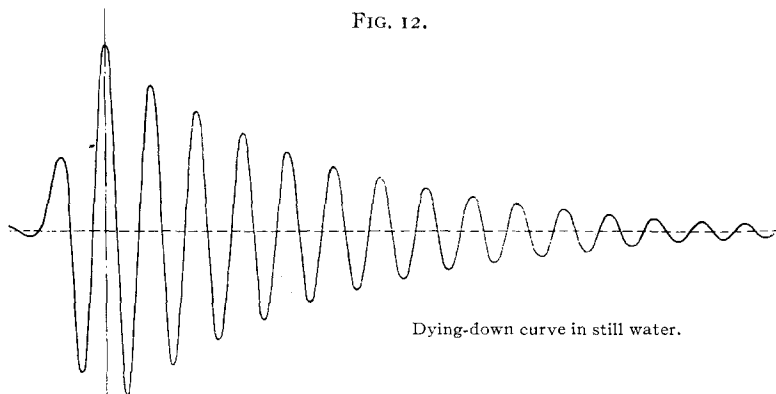


U. S. S. *Worden*, starboard side, middle section of ship only, showing gyro installation.

striking instance of the unexpectedly great effect upon the form-line resistance of the ship due to the relatively stiffer water which is present when steaming as compared with that when

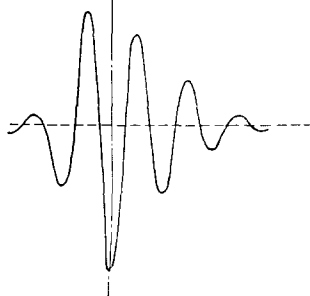
lying to, other conditions remaining the same. The interpretation of these results shows the relatively large amount of power expended due to form-line impingement resistance when steaming. Thus, from these curves may be calculated the exact amount of retardation or slowing-down effect which would be encountered by the ship when rolling as compared with the same ship when not rolling, while steaming at practically any rate.

FIG. 12.



Dying-down curve in still water.

FIG. 13.



Dying-down curve when steaming at 15 knots.

The results of these investigations indicate that quite a large amount of power is expended in driving a vessel at a given speed that rolls over and above one that does not roll.

Through the important work to which only brief reference has here been possible knowledge of the performance of the stabilizing gyro under service conditions has been accumulated.



This is now such as to enable us to calculate with all necessary accuracy the weight and space occupied in connection with practically any plant either for stabilizing or breaking ice; also to predict with certainty what the result will be, the amount of power required, and also to prescribe with fair degree of accuracy about what will be the stabilizing or rolling factor upon any given ship with the new active gyros fitted.

So far as appearance and construction are concerned, it is a far cry from the gyro stabilizer to the gyro compass, although both are founded on the same fundamental phenomenon,—that is, rotation, inertia, and precession.

As necessity is the mother of invention, so the reverse would also seem true, each development in science and engineering necessitating the development of some device or devices to increase the efficiency of the prime development. The magnetic compass served its purpose when ships were made of wood, and the compass could be depended upon to indicate the position of the North approximately. The development of the steel ship, especially the steel man-of-war, has made necessary some compass free from magnetic influences, and the gyro-compass is the result of this necessity.

The use of the magnetic compass involves the application of two classes of errors: variation, or errors arising from forces extraneous to the ship; and deviation, or errors arising from forces within the ship. Both of these classes of errors constantly vary in a manner not capable of prediction.

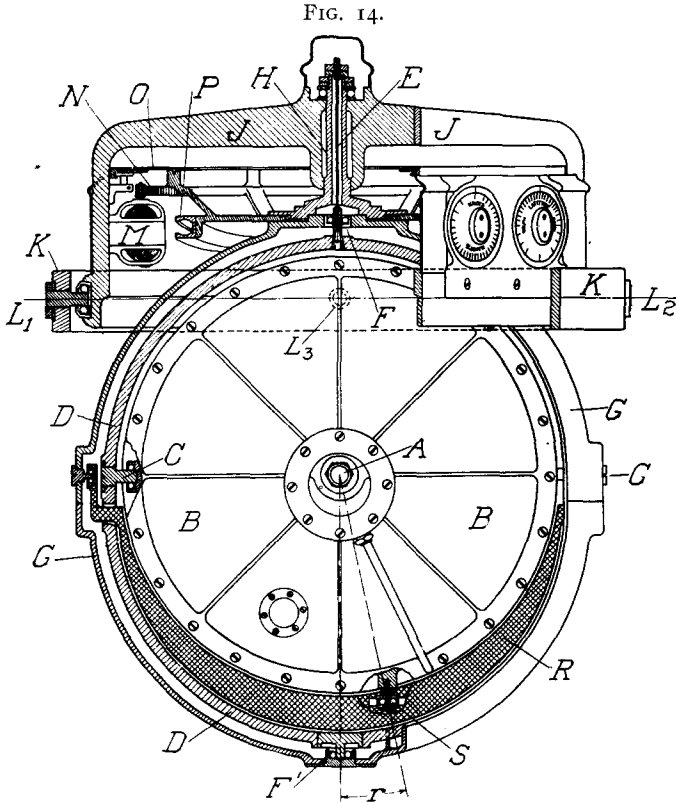
As the directive force of the magnetic needle is very weak, the compass tends to follow the ship's head instead of holding the meridian; the result is inaccuracy in steaming and observation of bearing.

All instruments used for men-of-war must be designed to contribute their part to the efficiency of the ship in battle. The compass in that case must be used behind armor, in which position the magnetic compass is of little or no value. In manœuvring in fleet and in navigating near the coast the use of the magnetic compass in getting bearings of the flagship or objects on shore makes it very inconvenient, as it involves the constant application of errors and transference of compass heading to pelorus, or dumb compass, from which observations are taken.

In the present day of the steel ship and submarine the use of

the magnetic compass, dependent as it is on a weak and variable force, is almost as much of an approximation as the means used hundreds of years ago in directing ships by observations of the sun, moon, and stars.

The gyro-compass indicates the direction of true or geographical North by reason of a force which is absolutely change-



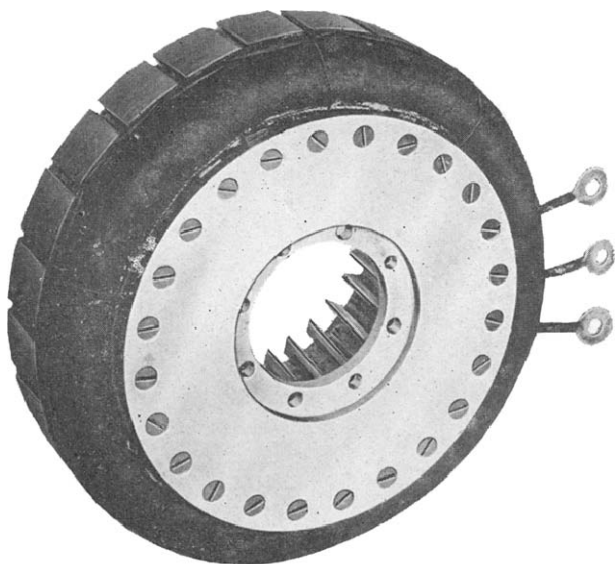
Cross-section of master compass.

less and undeviating,—that is, the force of the earth's rotation. An understanding of its operation will be facilitated by referring to Fig. 14, which is an elementary cross-section through the East-West plane of the master compass. The wheel rotates on an axis *A* within the casing *B*. This casing *B* is in turn pivoted upon a horizontal axis *C—C*, these pivots being fixed in the vertical ring *D*. Ball bearings are used both at *A* and *C*, and

the wheel runs in a vacuum which is maintained in the casing *B*. The vertical ring *D* is suspended by a stranded wire *E*, and is guided about the vertical axis by the bearings *F—F*.

The gyro, its casing, and the vertical ring constitute what is known as the sensitive element. Surrounding this sensitive element is the ring *G*, to which are secured the compass card and the stem *H*, and these parts are made to follow all movements of the sensitive element about the vertical axis. This is accomplished by the means of an electric follow-up system actuating a

FIG. 15.



Stator.

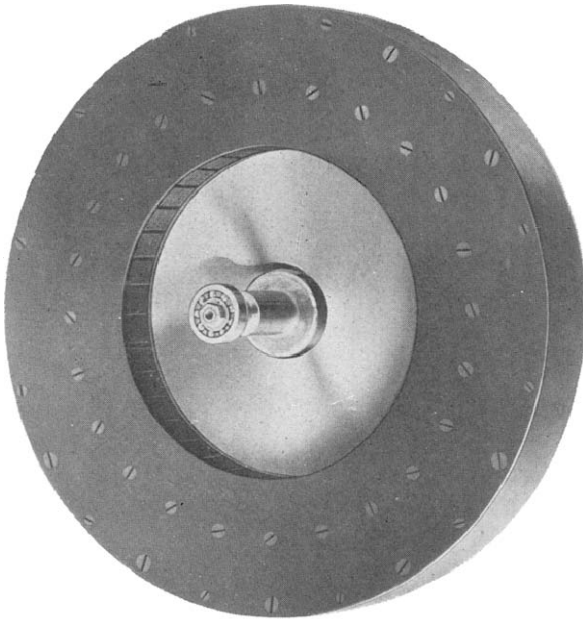
small motor *M*. The gyro, or sensitive element, serves only as the directive part of the instrument, and forms no part in actually driving the compass card or attachments thereof; the actual driving force being provided by the small motor *M*.

It will be clear that the outer ring *G* is at all times rigidly held in position with reference to the supporting frame *J*, although it is at the same time free to move around the vertical axis, and stands in practically constant relation to the gyro wheel or sensitive element. This ring, therefore, serves as a base to which the restraining element, or pendulum *R*, is attached by

means of the pivots shown. This restraining element is attached to the gyro casing at the point *S*.

A rapidly rotating wheel tends to maintain its plane of rotation relative to space, and if the axis of this wheel is not on the North-South meridian the earth in turning on its axis tends to "rotate from under" the gyro wheel and the axis of this wheel inclines with relation to the horizontal. This inclination takes place against the weight of the restraining pendulum *R*, which impresses a force about both the horizontal and vertical axes.

FIG. 16



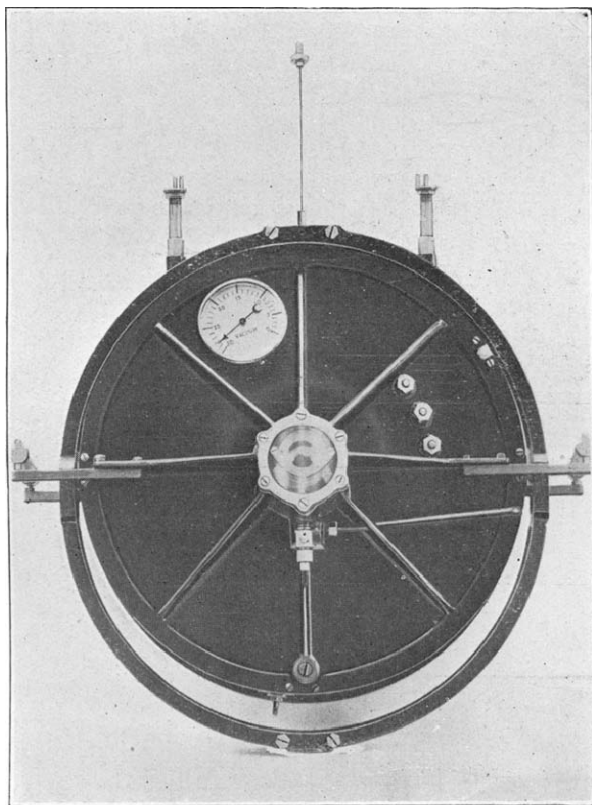
Rotor.

The force about the horizontal axis institutes a precession toward the meridian, while the force about the vertical axis damps this precession to bring the axis of the gyro to rest in a horizontal position when on the meridian, in which case the plane of rotation of the wheel is coincident with that of the earth, and the earth, therefore, no longer tends to rotate out from under the gyro wheel.

The directive force, while very large compared to that of the

magnetic needle, is, nevertheless, small, and the gyro-compass must be made with perfect freedom about the vertical axis. Since the top of the suspension wire is constantly moving to follow the bottom, the gyro is suspended from what is in effect a torsionless wire and perfect freedom is obtained about the vertical axis. This method of suspension has made possible an

FIG. 17.



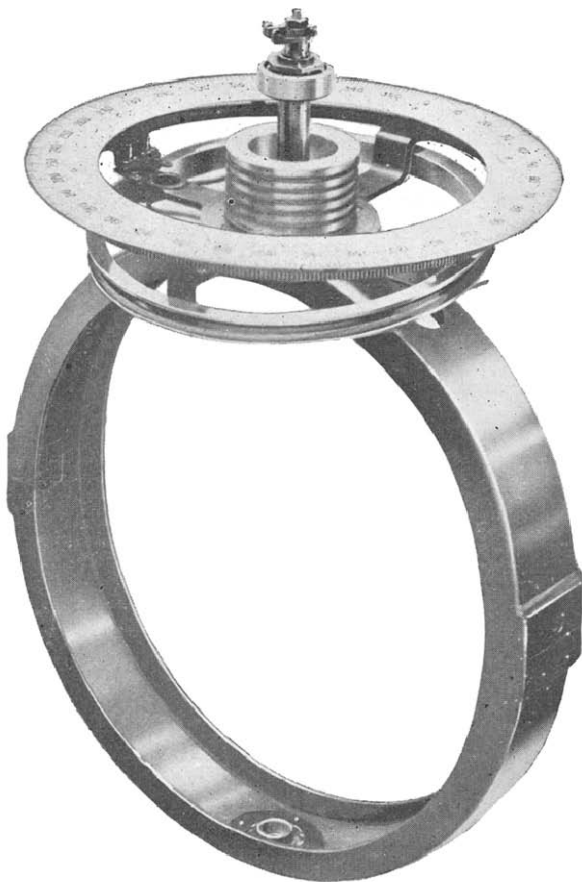
Wheel casing and vertical supporting ring.

extremely accurate instrument which is at the same time very durable and substantial.

To be rigidly exact, I must confess that the gyro does not take up its position exactly in the North and South meridian, but deviates from it by a known amount, the magnitude of which depends upon three variable factors,—namely, the latitude, speed,

and course of the ship on which it is mounted. The northerly and southerly components of speed act to change the apparent direction of the earth's rotation, and the effect of this speed varies with the latitude, inasmuch as the linear speed of any

FIG. 18.



Phantom card, azimuth gear, and cam for automatic correction mechanism.

point on the earth's surface varies with the latitude. Another latitude correction is introduced by the fact that the compass lags behind the meridian by an amount varying with the latitude; this lag being due to the fact that a certain amount of force is impressed about the vertical axis by the restraining pendulum for

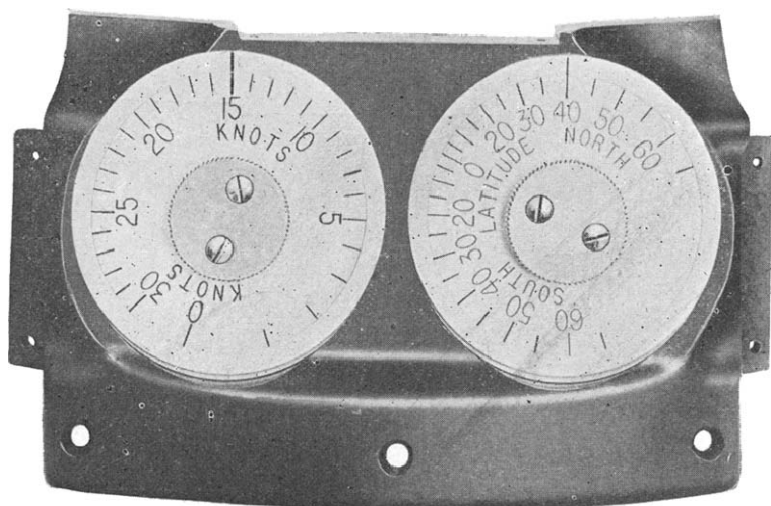
preventing oscillations. The total correction is expressed by the equation :

$$D = (H \cos K \div \cos L) \pm \tan L. \quad \text{Where } H = \text{speed};$$

$$K = \text{course, and } L = \text{latitude.}$$

An automatic correction device is attached to the compass card which, when set for approximate speed and latitude, applies all of these corrections. This device consists of a number of cams so laid out that when the dials are set for ships' approxi-

FIG. 19.



Automatic correction dials, setting 15 knots, 40° North latitude.

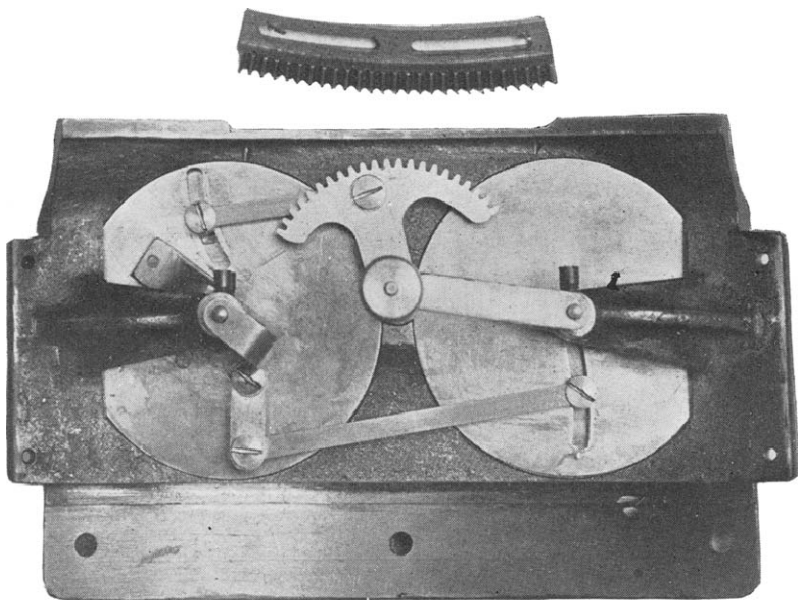
mate speed and latitude the various factors are combined and the correction is automatically applied.

The gyro-compass can, of course, be placed well below the water line and behind the heaviest armor of the ship. Its indications are repeated to any desired station on the ship by means of an auxiliary system operating the cards of so-called "repeater compasses." This system consists of a transmitter on the master compass which controls the poles of a small motor in the repeater compass in such manner that the armature of this motor is turned by steps to follow the moving dial of the master compass. The armature of this small motor is geared to the repeater dial so that one revolution produces a 2 degree movement of the

dial. The motor has six poles controlled in pairs, so that the armature stands between one pair, then half-way between that pair and the next, then between the next pair, and so on, having twelve resting positions in each revolution. The repeater dial, therefore, moves  $\frac{1}{6}$  degree for every  $\frac{1}{6}$  degree movement of the master compass dial, yielding a maximum error of  $\frac{1}{12}$  degree.

The results accomplished by the gyro-compass in service have been of the greatest interest in bringing out many unex-

FIG. 20.



Back of correction device.

pected advantages. It provides an accurate means of navigating, and a means which is perfectly free from lag. This results in considerable saving in coal by increasing the accuracy with which the courses are run from point to point and by decreasing the amount of helm used, inasmuch as the helmsman has a compass without a lag and can keep the ship on the course by using a small amount of helm. Many of the navigators who have used the compass estimate that the saving in coal accomplished amounts to eight or ten thousand dollars during a year of ordinary service. Applied to battleships, the results accomplished



are of the greatest importance. The ship may be steered as well from an armored station as from an unarmored station. With the gyro-compass the helmsman can, therefore, be stationed in the steering engine-room, where he is well protected and where there is little chance for failure of connecting him with the steering engine mechanism. The commanding officer can then manoeuvre the ship from the conning tower or other armored station

FIG. 21.

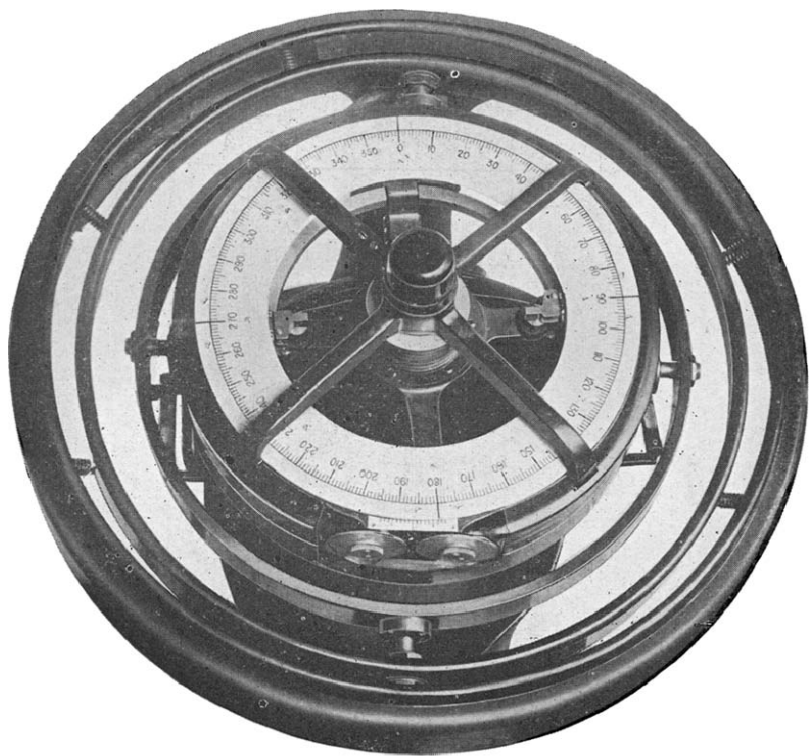


Master compass binnacle, lower part down.

by maintaining communication with the helmsman over the voice-tube or telephone. In formation in column, it is found that the position of ships can be maintained with far greater accuracy, as the small use of helm is conducive to the maintenance of constant speed of all ships. With the use of the magnetic compass the varying amounts of lag result in varying the amounts of helm used and in consequent variations of speed. This variation in speed makes it difficult to maintain the distance

between ships. In formation on line, or line of bearing, no possibilities exist for errors due to misapplication of the compass deviation or correction in closing or opening intervals by changing course toward or away from the flagship. The necessity for continuously applying deviation and setting the pelorus, or dumb compass, is avoided. A special type of bridge or conning tower

FIG. 22.



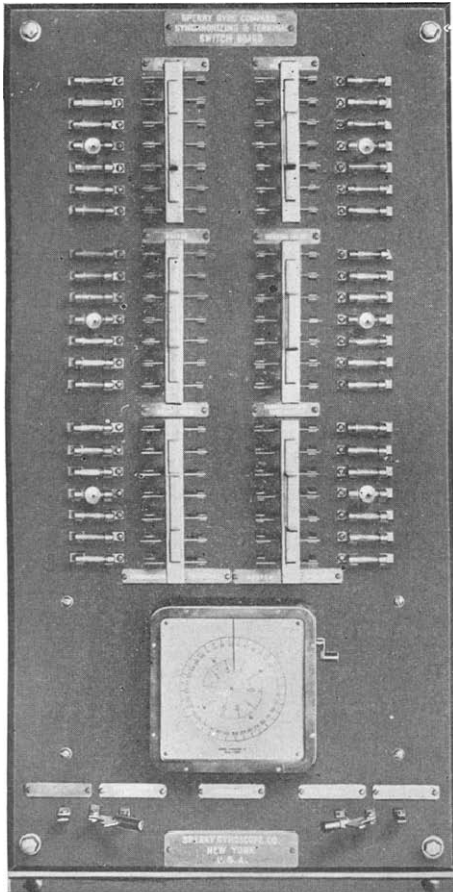
Master compass card from helmsman's position.

repeater, designed to replace the old pelorus or dumb compass, makes it possible to get the true bearing of the flagship directly. This is of great advantage, also, in navigating near the coast, as true bearings of objects on shore may be obtained with great accuracy. The use of the gyro-compass on submarines is estimated to have increased their efficiency fully 50 per cent. by providing a means for steering an accurate course when submerged.

Fig. 15 is a photograph of the stator of the induction motor driving the gyro wheel. This stator is mounted on the inner side of the gyro casing shown in Fig. 14.

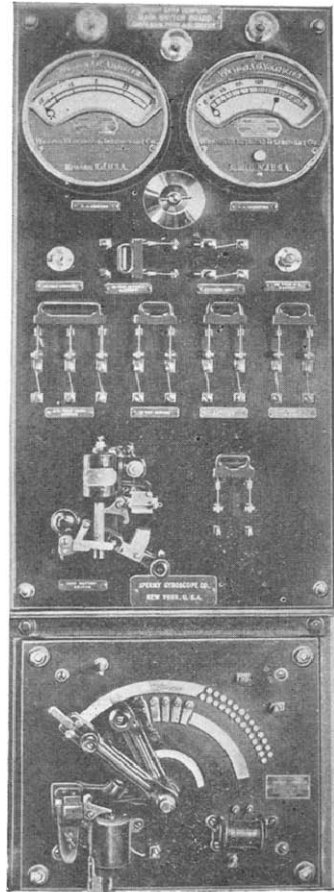
Fig. 16 is a photograph of the rotor, having inlaid on its inner periphery the short-circuited bars of the induction motor.

FIG. 23.



Synchronizing panel.

FIG. 24.



Main switchboard.

Fig. 17 is a photograph of the gyro mounted in the vertical cardan ring.

Fig. 18 is a photograph of the "phantom" ring which surrounds the sensitive element and is driven to follow it.

Fig. 19 is a photograph of the front view of the correction device.

Fig. 20 is a back view of the correction device.

Fig. 21 is a view of the assembled gyro-compass.

Fig. 22 is a top view of the compass.

Figs. 23 and 24 are views of the switchboards.

FIG. 25.



Repeating compass, binnacle type.

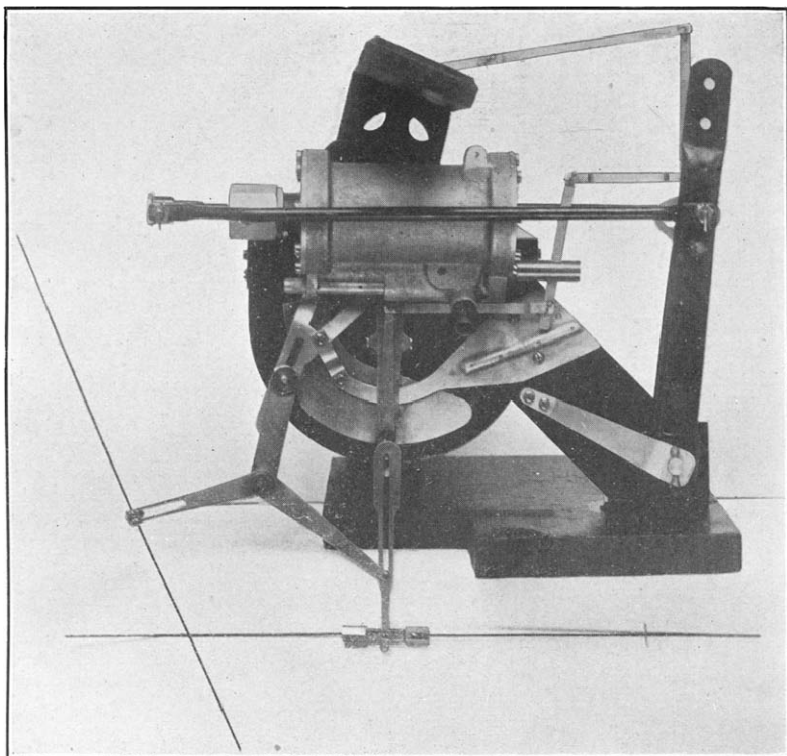
Fig. 25 is a view of the repeater, or auxiliary compass.

Perhaps the most interesting of all the apparatus which we have developed is the *aëroplane* stabilizer. Air is a very unstable medium, and the development of the heavier-than-air machine has shown us that the atmosphere is in a constant state of turmoil, rendering its navigation perilous. The aviator must

work constantly to maintain the stability of the machine about all three axes. With the present machines very long flights are nearly beyond the endurance of the aviator, and even short flights are difficult when the weather is at all bad.

Each aëroplane stabilizing equipment comprises a combination of devices for maintaining longitudinal stability and a com-

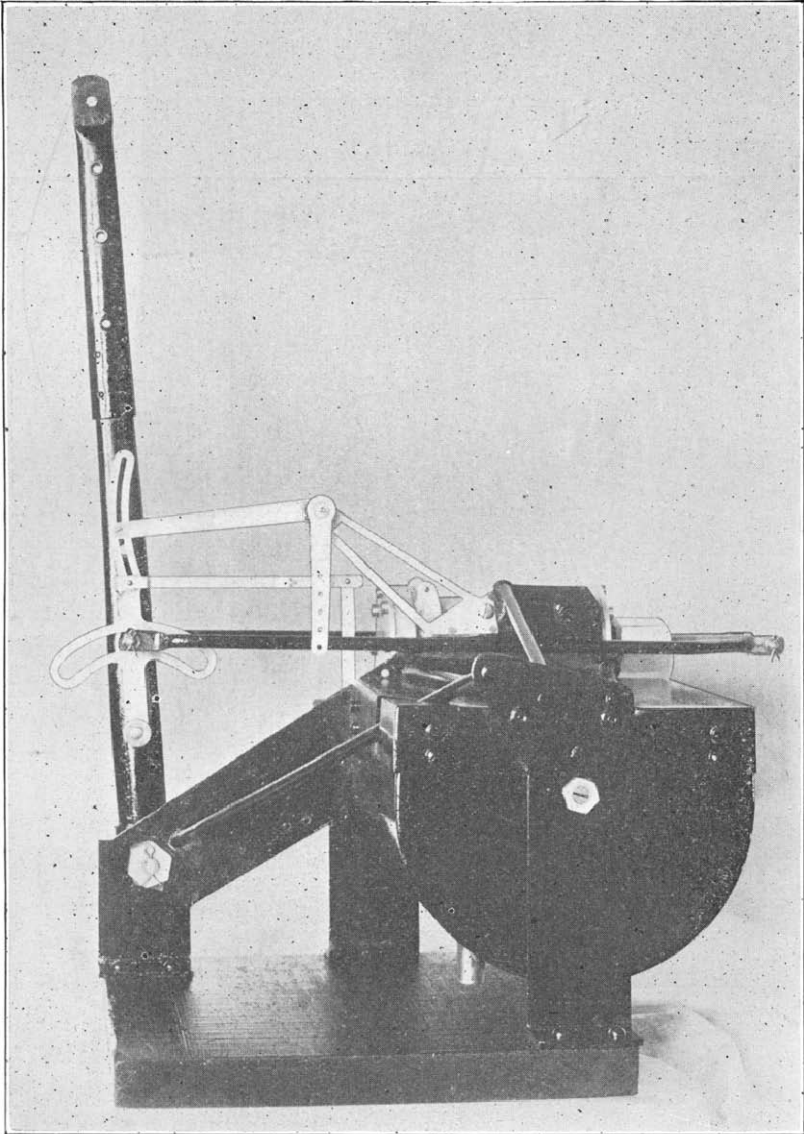
FIG. 26.



The lateral stabilizer.

bination for maintaining lateral stability. The longitudinal stabilizer uses three directive factors for controlling the movements of a pilot valve, which in turn controls a compressed-air cylinder operating a piston attached to the horizontal rudders. The controlling factors are: first, the gyro which through the pilot valve operates the horizontal rudders against tendency to tip about the horizontal axis; second, an air platen which operates

FIG. 27.



The longitudinal stabilizer.

the pilot valve to volplane the machine in case the speed drops below the critical speed necessary for sustaining the plane; third, a hand-setting device which permits the aviator to set the stabilizer for any inclination of climb or descent. The air platen further acts to adjust the throw of the levers so that when running at slow speeds a small tipping is counteracted by a suitable throw of the rudders. This is made necessary by the fact that the plane is, of course, more sensitive to inclinations of the rudders when running at high speed.

The lateral stabilizer serves as a directive factor, acting on the pilot valve to control the movements of the ailerons so that they operate to counteract against tipping laterally. When turning, the lateral stabilizer operates the control mechanism to bank the machine to an angle sufficient to prevent skidding.

The gyros of the *aéroplane* stabilizer are continuously spun by three-phase alternating current derived from a small generator driven from the shaft of the engine. This generator is designed to develop alternating current for driving the gyros, low-voltage direct current for exciting its own fields, and single-phase alternating current for use in connection with the radio set. The low-voltage direct current may also be used for ignition service of the engine.

It is an interesting fact that the gyros connected to the generator circuit act as boosters to restore part of the energy given to them when a circuit to the wireless is closed; thus momentarily the wireless equipment is supplied not only by the generator but also the gyros acting as induction generators.

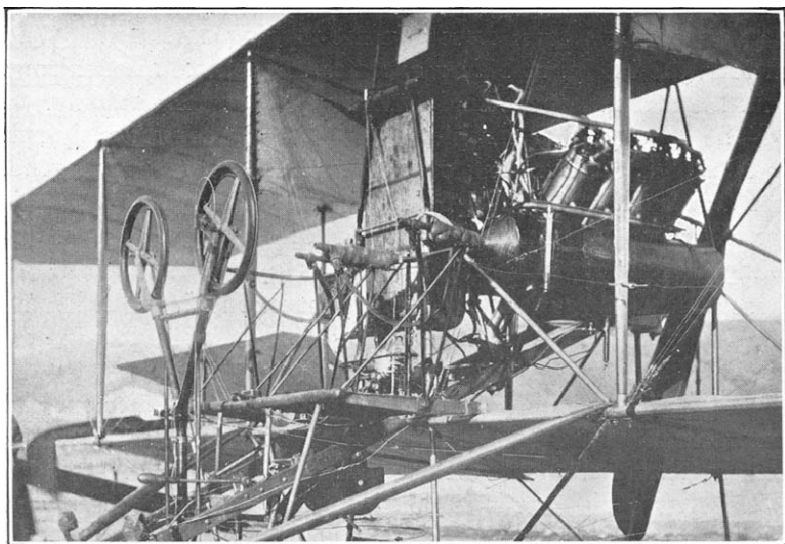
A valve connected to the compression space of one of the engine cylinders automatically stores compressed gas in a small accumulator tank, from which it is used to operate the pistons controlling the ailerons and rudders.

The same type of stabilizer may be used on any type of *aéroplane*, as the installation simply involves supporting it firmly on the machine and attaching the arm operated by the compressed-air piston to the wires or levers of the existing hand control. Both ends of the compressed-air pistons are provided with valves, all of which may be opened by releasing a thumb button attached to the steering wheel of the *aéroplane*. When these valves are opened the stabilizer continues to function, so far as the relation of all of its parts is concerned, but has no effect on

the ailerons or rudders, as the piston is prevented from doing any work. This makes it possible for the aviator to instantly shift from hand control to automatic control.

The weights and dimensions of the various parts of the stabilizer are surprisingly small. The weight of the generator is about 25 pounds and it occupies a space of about six by six by ten inches. The lateral stabilizer weighs about 18 pounds and is small enough to be conveniently disposed at the back of the

FIG. 28.



Aéroplane showing both stabilizers installed.

aviator's seat. The longitudinal stabilizer weighs about 17 pounds and is placed below the aviator's seat in such a position that he can see its operation at all times.

The automatic control of stability of the heavier-than-air machines will do much to decrease the growing list of fatalities, as it provides a means for acting simultaneously with the disturbing air currents, whereas the aviator must always wait until the effect has manifested itself before he applies the remedy, and then he very often misjudges the amount by which he should move his controls.



The automatic control of stability will be especially valuable to the military use of the aëroplane, as it will make it possible to fly in almost any condition of weather and will make long flights possible. In reconnaissance service only one man will be necessary, as the machine may be controlled automatically while the aviator makes sketches, records information obtained, or operates the radio set to communicate with his base.

Fig. 26 is a view of the lateral stabilizer.

Fig. 27 is a view of the longitudinal stabilizer.

FIG. 29.



Illustrating thumb button for cutting out automatic control.

Fig. 28 shows both stabilizers installed on the Curtiss hydro-aëroplane.

Fig. 29 shows the thumb button by means of which the stabilizers may be cut in or out.

In conjunction with the U. S. S. *Worden* trials were used interesting apparatus for recording the roll and pitch of the ship. Pendulous gyros were used to maintain the athwartship and fore and aft axes, and these gyros operated pencil arms resting on a paper tape moved by clockwork. It was found that this mechanism was so sensitive to changes in the angle of roll and pitch

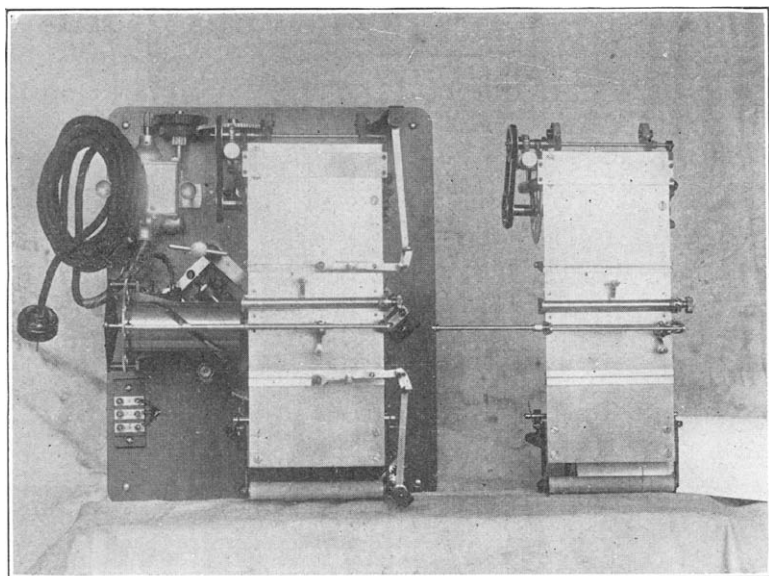
of the vessel that it would indicate the roll caused by two men moving from one side of the ship to the other.

Fig. 30 is a top view of the roll and pitch recorder.

Fig. 31 is a side view of this instrument.

The artificial horizon is the most recent application of the gyroscope. Although the problem at first appeared somewhat complicated, later developments showed that a 12-inch circular mirror could be maintained in a horizontal position with perfect accuracy and by the use of a very simple combination of gyros.

FIG. 30.

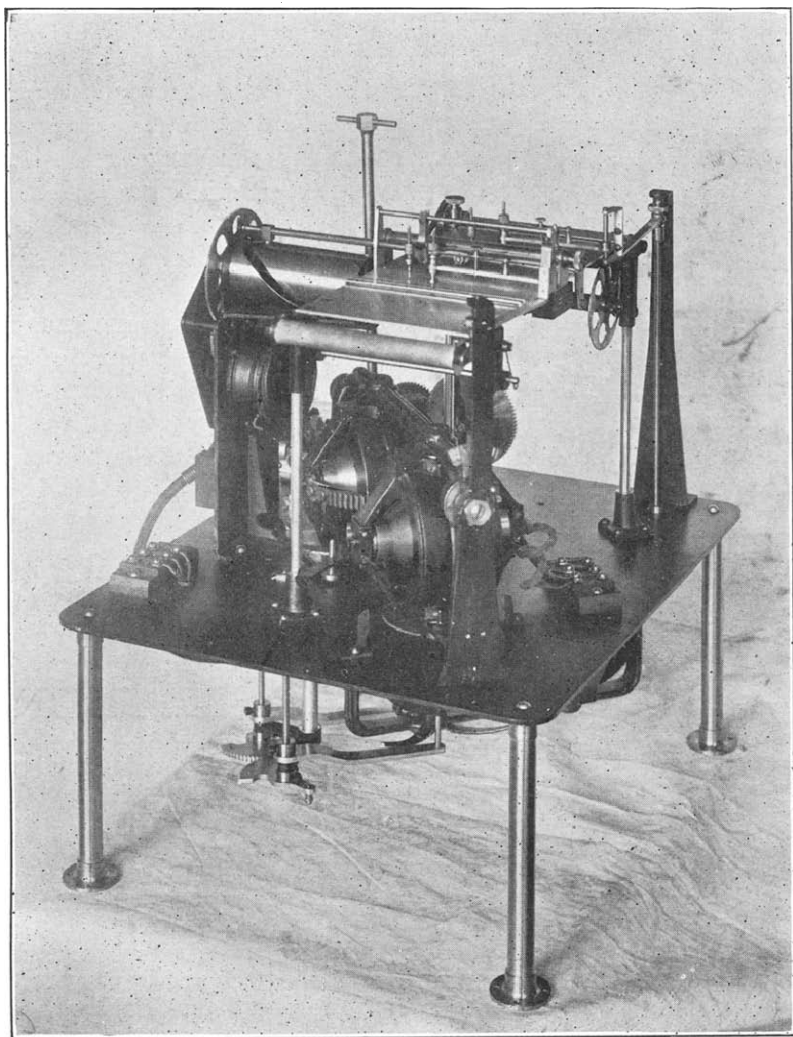


Top view of roll and pitch recorder and duplicate platten.

The artificial horizon as now constructed is portable and entirely self-contained. The mirror is levelled by hand. The double altitude of the sun or heavenly body is observed by measuring the angle between the body and its reflection; the mirror is then readjusted and the observation is repeated. If any error was introduced in the first observation by inclination of the mirror, this error will be equal and opposite in the second observation, and an average of the two observations, divided by 4, gives the exact altitude of the body. Errors are frequently introduced in navigation when measuring the altitude of a heavenly body

above a false horizon, caused by mist or by the mirage effect of the heat of the air on tropical seas. Very frequently observa-

FIG. 31.



Side view of roll and pitch recorder.

tions of the sun or heavenly bodies could be taken were it not that the horizon is obscured by low-lying banks of fog or darkness. The artificial horizon provides a means for eliminating

these errors in observations of altitude, and makes it possible to accurately measure the altitude of any heavenly body that can be seen, whether or not the horizon is obscured. The first artificial horizon has just been completed and is now undergoing a test under the supervision of the authorities of the United States Naval Observatory.

Though they differ widely in the details of their construction and in the results to be accomplished, all applications of the gyroscope are founded on the phenomenon of inertia relative to space. This broadly useful principle gives us the means for maintaining a base line or fixed axis from which we operate to quench roll in the case of the stabilizing gyros; to hold the North and South meridian, as in the case of the gyro-compass; to control the ailerons and rudders of the aëroplanes; to record the movements of vessels in rolling and pitching, and to hold the mirror of the artificial horizon horizontal.

The knowledge obtained in the engineering applications of the gyroscope has opened a wonderful vista of possibilities for accomplishing results of the greatest usefulness to mankind.

**Magnesite Deposits in Mexico.** (*Board of Trade J.*, Jan. 9, 1913.)—The Consul at La Paz, Mexico, states that large deposits of high-grade magnesite, containing 92 per cent. of magnesium carbonate, are found near Magdalena. The largest bed is about 30 acres in area, and is situated on the Margarita Islands; deposits have also been found on Cedros Island. The mineral is so hard as to require blasting for removal. A company has been formed to develop these deposits. One calcining plant will be installed on Cedros Island and another on Margarita Island, each with a capacity of 200 tons per day.

**New Leadless Storage Battery.** ANON. (*Sci. Amer.*, cvii, 25, 527.)—A Swedish inventor has put on the market a new type of alkaline storage cell. The plates consist of inactive retainers which are loaded with active material, nickel oxyhydrate mixed with graphite in the positives, and a finely-divided alloy of iron and cadmium and certain other substances in the negatives. This new cell resembles the Edison cell, not only in the electro-chemical reaction, but also in the fact that extreme ingenuity is shown in the mechanical construction to obtain high efficiency in space and weight and durability.