The Gyrostatic Compass.

By S. G. BROWN, F.R.S.¹

I HAVE directed attention to several faults that have to be rectified if the compass is to be of use on a ship, and I shall now discuss the last, but by no means the least, of the errors that may arise if the instrument is not properly designed. This error was not known when the gyro-compass was first brought out, and it proved a most difficult fault to correct, while its elimination has had more to do with the design of the later forms of gyro-compass than any other factor.

If a gyro-wheel is precessed towards, and kept pointing to, the north by an ordinary pendulum weight, it will work well on board ship provided that the ship is steaming on a fairly smooth sea; but if the direction of the ship points anywhere in the quadrants—that is, north-west or north-east, south-west or south-east—and the ship rolls, the wheel will try to set itself so as to bring the rim of the spinning wheel in line with the roll; and in a long-continued and heavy roll the compass may show an error of 20° or more—a most serious fault, and one that would render the instrument quite useless in a heavy sea. This error is called the “quadrantal error.” The extent of the error depends upon the violence of the ship’s rolling and the direction of the axis of the wheel. If the ship points direct north, south, east, or west, the error is nothing, but it would be a maximum in any of the directions before mentioned.

I think Anschütz was the first to point out the error and suggest a cure. This I gather from one of his publications in the year 1911, in which, speaking of the tendency of the compass to wander when on board ship, he says:—“Theoretically, the influence of rhythmic turning movements on a gyroscopic apparatus must disappear completely if not only the real, but also the apparent, movements of inertia of the movable system become equal for each plane.”

If we go back again and study our simple gyro-compass, we see that the movable system is not symmetrical. In the direction of the axis of the wheel the effect of tilting movement is more or less resisted by the spinning wheel—this may be termed the stabilised direction; while at right angles to this—that is, in the direction of the rim of the wheel—there is no resistance to tilting encountered, and this direction we term the direction of free swing. A simple form of gyro-compass pointing, therefore, in a direction, say, north-west on board a rolling ship has a force applied to it tending to turn it so as to bring its direction of free swing into line with the roll.

Anschütz gets rid of the error by multiplying the number of his gyro-wheels and by making the instrument as symmetrical as possible. In England the quadrantal error was first discovered and studied, I believe, by the Admiralty Compass Department. In the year 1914 the Sperry Co. claimed to have effected a cure for the error by attaching the pendulous weight, not directly to the gyro casing, but through a pin arranged to move in a slot in the casing. In order that the axis of suspension of the pendulum may remain vertical when the compass oscillates with the rolling of the ship, a small auxiliary gyro was employed to stabilise the pin connection between the pendulum and the gyro casing.

We therefore see in these applications of Anschütz and Sperry two general ideas. In the first case the idea is to make everything symmetrical, like a ball, so that there is no stabilised or free swing direction

to the wheel, and, therefore, no tendency to turn; while in the second a method is provided to prevent the point of application of the pendulum weight from moving and acting as a crank, and, by keeping the pendulum weight always vertical in the north-west direction, to destroy its power of turning the compass. In the Brown compass the quadrantal error is eliminated by making the weight operate completely out of phase with the roll—that is, at 90° displacement.

If a gyro-compass is worked by a weight which tends to precess the wheel in phase with the roll, then there must be a quadrantal error, but there will be no error if it is forced to operate completely out of phase with it. It is also essential, as Anschütz has remarked, that the real moments of inertia shall be the same in all directions of the movable system of the compass; that is to say, the moving system should be in dynamic balance, as it is termed.

If a child’s hoop is suspended by a string and is swinging in one direction, the hoop tends to set itself lengthwise to the direction of the swing. On the other hand, if an exactly similar hoop be placed over, but at right angles to, the first, and suspended as before, then on swinging the hoops there will be no tendency for them to turn, as they are now in dynamic balance. It is for this reason that the mass distribution of the moving system of the gyro-compass should be in dynamic balance, and to carry this out adjustable weights are fitted, usually in the direction of the spindle of the wheel, to counteract the weight of the supporting ring of the gyro casing, and thus there is no tendency for the compass to turn, due to this cause, when under the action of rolling.

The Brown gyro-compass is shown diagrammatically in Fig. 4. A is the gyro-wheel in its casing B. This case is carried on knife-edges M in the vertical ring F, and is thus free to tilt under the action of the rotation of the earth. The vertical ring turns in azimuth on a frictionless mounting, consisting of an oil-pump at the bottom and a ball-bearing, *m*, at the top. XY is the three-phase motor that drives the oil-pump.

The gyro-wheel is the rotor of a three-phase motor, and current is led into the moving system through the three sets of iron contact rings R and S. These rings do not touch, but the outer set are hollow, and mercury fills the space between them, so that there is little friction. The vertical ring is dynamically balanced by two projecting weights D. O is the pendulous mounting, supported by gymbal rings and by the outer row of springs to take up shock.

The gyro-wheel runs at 15,000 revolutions per minute, and thus acts as a powerful blower, giving an air-pressure equal to some 3 in. of water. Fixed to the vertical ring, but connected through the hollow bearing M to the inside of the case, is the air-jet L. This jet blows into the two halves of the air-box K, and thence through the pipes J; the air-pressure is thus transmitted to the oil in the two sets of bottles C and D. H is another air-jet similarly mounted, and employed to act upon a pair of contact-making vanes I.

The contacts I, through the agency of the controller, which is fixed on the switchboard, are to work the repeaters and the step-by-step motor V; this motor forces round the follow-up ring N to keep the contact-making vanes I always opposite the air-jet, and in doing this all the repeaters on the ship follow suit. U is the compass card fixed to the upper por-

¹ Discourse delivered at the Royal Institution on Friday, January 30. Continued from p. 48.

tion of the vertical ring, and O the lubber-line support.

By removing the four screws marked *n* the gyro-compass can be completely removed from the gymbal rings. The instrument thus removed is shown in Fig. 5.

To explain the action of the oil bottles I have introduced Figs. 6 and 7.

Fig. 2 illustrates the simplest form of compass, in which the wheel and case B are controlled by the pendulous weight W. When the case tilts, as shown, W is moved to one side of the vertical support, and the weight tries to bring the case again to the horizontal.

Suppose the wheel revolves in the direction of the arrow *a*, the righting torque is in the direction of the arrow *b*; then the wheel and case will turn in azimuth in the direction of the arrow *c*. Such a compass would

other. At the middle of swing of the pendulum the air-jet is at the middle of the air-box, and there is no difference of air-pressure, and, therefore, no movement of the oil; and when the swing is at the end of its path, and not moving, the air-jet is at one side of the air-box and producing the maximum movement in the oil; it will therefore be seen that the movement of the pendulum and that of the oil are out of phase with each other. It is for this reason, given good dynamic balance, that there is no quadrantal error whatsoever with this method of control.

Fig. 7 illustrates the method of damping the compass. Fixed to the same air-box K are the two damping bottles C, C, smaller than E, E, but the air here acts in the opposite direction to that in Fig. 6.

In one of these damping bottles is the adjustable needle-valve, and this valve has a constricted passage,

FIG. 4.

have a quadrantal error, because the weight W would produce stresses in phase with the roll.

Fig. 6 illustrates the method of control of the Brown compass. When the case B is horizontal the bottles E, E are half-full of oil, and the air-jet L is blowing equally into the two halves of the air-box K; but when the case tilts, as shown, then the air-pressure blows into one side of the box more than into the other, and in such a direction as to force the oil from the lower bottle into the one raised. There is, therefore, a considerable righting torque indicated by the weight of the oil W trying to restore the case back again to the horizontal.

When the pendulum swings under the action of the rolls of the ship, the air-jet L moves from one side to the other of the air-box in tune with the roll, blowing the oil periodically from one bottle to the

and thus the flow of oil from one bottle to the other is suitably retarded.

As regards the accuracy of the compass, I may mention that one on board a flagship in the North Sea during the war was observed with particular care, especially during very heavy weather, and it was reported that it was never more than $1\frac{1}{2}^\circ$ from the true north position during the whole of the tests.

Trials on a commercial ship have demonstrated the fact that the employment of a gyro-compass resulted in the ship steaming every day more than 3 per cent. greater mileage; in other words, one day's steaming in thirty would be saved, resulting in a proportionate saving in coal and all other expenses.

I come now to a most important application of the gyro-compass, namely, its employment as a gun director.

The use of the gyrostad in the Whitehead torpedo has revolutionised naval strategy, and I believe the use of the same instrument in the form of a gyro-compass gun director may possibly produce profound changes in gunnery practice in the future.

Modern naval warfare is entirely different from that of the past in the fact that the rival fleets come into action when separated by many miles; the guns have, therefore, to be worked and fired while the distant targets are invisible to the gunners.

The guns have to be directed by observers in an elevated position, these observers communicating the distance of the target and its direction in space.

The direction in space must be supplied by a gyro-compass on board the ship, and it is essential that the compass for this purpose should be of extreme accuracy.

Once the guns are properly trained, they may be joined up and controlled by the gyro-compass, and for this purpose the turrets would be designed to act as huge repeaters, keeping the guns pointing on the target, changing only on receiving new directions from the observer.

The compass would hold the guns pointing on the distant target quite independently of the movements of the ship, which may at the time be steaming at full speed and manœuvring. Such movements are

It has been suggested that the day of the big battleship is over, but I am doubtful of this, as I

FIG. 5.

FIG. 6.

FIG. 7.

a great protection to ships against submarine and aerial attack.

understand that ships can be made proof against ordinary submarine attack by means of blisters filled

with oil, as in our Navy, or by coal-dust, as used by the Germans.

Working the guns with the ships at full speed, as I have just stated, will be an additional protection, while submarine craft will be more dangerous operating against fixed objects, such as harbour defences, etc., in which case they could be detected from the shore by submarine listening devices, such as my liquid microphone.

In closing this discourse, I should like to say that a good deal of credit is due to Anschütz for the courage he displayed in being the first to attempt a gyro-compass, knowing as he did the extremely feeble force that is likely to result from the earth's rotation, and in the fact that the instrument must be carried on a rolling pitching, plunging vessel. With us who follow it is a question over again of Columbus and the egg. For myself, if I had known at the commencement of my acquaintance with the gyro-compass—some five years ago—all the difficulties that had to be encountered, I think I should have abandoned the pursuit.

Notes.

At the meeting of the Royal Society on June 3 the Bakerian lecture will be delivered by Sir Ernest Rutherford on "The Nuclear Constitution of the Atom."

SIR JAMES DEWAR has been elected a corresponding member of the French Academy of Sciences in the section of general physics in succession to the late Prof. P. Blaserna.

THE Institute of Research in Animal Nutrition at Aberdeen has received a gift of 10,000*l.* from Mr. J. Q. Rowett. The amount required from public sources for the establishment of the institution is 25,000*l.*

MR. A. A. CAMPBELL SWINTON, during his presidential address to the Wireless Society of London on February 28, reviewed, with the aid of experiments, advances in wireless telegraphy since 1914, and received, in full view of the audience, messages from Gen. Ferrié in Paris and from the Slough station of the Radio Communication Co. These messages were received, not on the usual external aerial, but on a simple loop of wire standing on the lecture-table.

In the course of a speech at a Conference of Provincial and Suburban Wireless Societies, held on February 27 under the presidency of Sir Charles Bright, Capt. F. C. Loring announced that the Post Office is in favour of granting wireless licences of about 10 watts where an amateur can prove that he thoroughly understands the apparatus and is a proficient operator, and that his transmitting station is to be used for genuine experimental work and not merely for communication between other stations in a general way.

WE are officially informed that Dr. Carlos Ameghino has been appointed director of the National Museum of Natural History, Buenos Aires, in succession to Dr. Angel Gallardo, who retired in 1916 to become Minister of Education. The new director is the younger brother of the late Dr. Florentino Ameghino,

the distinguished palæontologist, who held the same office from 1902 until his death in 1911. During the earlier part of his career Dr. Carlos Ameghino explored many parts of Patagonia and made the great collections of fossil vertebrate remains which were studied and described by his brother. During recent years he has been interested in the evidence for the association of man with extinct mammals in Argentina.

THE council of the Linnean Society has issued to the fellows a statement of the present financial position and outlook of the society, recommending them to increase the annual contribution from 3*l.* to 4*l.* The cost of publication is now so high that the Transactions have already been suspended, and the Journal is so much reduced that the issue of many valuable papers has to be postponed for an indefinite time. The due maintenance of the library and the preparation of an up-to-date catalogue are impossible in existing circumstances, and all establishment charges still tend to rise. If the difficulties appeared to be temporary some of the small invested funds of the society might be used, but as there is no prospect of a return to former conditions an increased income is absolutely essential. Nearly all the learned societies are at present faced with similar problems, and the time seems to have arrived when there should be some action in common to consider the possibility of help from public funds.

THE following are among the lecture arrangements at the Royal Institution after Easter:—Major G. W. C. Kaye, two lectures on recent advances in X-ray work; Prof. Arthur Keith, four lectures on British ethnology: *The Invaders of England*; Major C. E. Inglis, two lectures on the evolution of large bridge construction; Mr. Sidney Skinner, two lectures on (1) *Ebullition and Evaporation*, (2) *The Tensile Strength of Liquids*; Mr. R. Campbell Thompson, two lectures on (1) *The Origins of the Dwellers in Mesopotamia*, and (2) *The Legends of the Babylonians*; Mr. A. P. Graves, two lectures on *Welsh and Irish folk-song* (with musical illustrations); Prof. W. H. Eccles, two lectures on the thermionic vacuum tube as detector, amplifier, and generator of electrical oscillations; Prof. Frederic Harrison, two lectures on (1) *A Philosophical Synthesis as Proposed by Auguste Comte*, and (2) *The Reaction and the Critics of the Positivist School of Thought*; and Prof. J. H. Jeans, two lectures on recent revolutions in physical science, (1) *The Theory of Relativity*, and (2) *The Theory of Quanta* (the Tyndall lectures). The Friday evening meetings will be resumed on April 16, when Prof. J. A. McClelland will deliver a discourse on ions and nuclei. Succeeding discourses will probably be given by Prof. H. Maxwell Lefroy, Prof. F. O. Bower, the Right Hon. Lord Rayleigh, Prof. Karl Pearson, Prof. J. A. Fleming, Prof. W. L. Bragg, and other gentlemen.

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