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## PRIZE ESSAY.

*(Competition for Associates, 1914.)*

# The Governing of Marine Engines and High Speed Auxiliaries.

BY REGULATOR (MR. R. J. WALKER, Associate).

OVER fifty years have passed since this important subject seriously engaged the attention of the marine engineer.

The necessity for some automatic means of adapting the power developed by the engine to any variation in its load has long been recognised in the case of land engines and is even more patent in marine practice, where the sudden and abnormal changes in load, due to the varying resistance offered to the propeller at different depths of immersion, demand speedy and effective alteration in the power developed if excessive racing is not to take place.

The racing of the engines, which follows the emergence of the propeller from the water, throws very severe racking stresses on the machinery, and the ruinous results on bearings, pump valves, etc., does not constitute by any means the only evil effect. The sudden increase of speed as the propeller leaves the water and the heavy blow with which the blades strike the surface on reimmersion are undoubtedly responsible for many of the shaft troubles so prevalent in spite of the ever increasing diameter demanded by the classification societies.

The two latter stresses affect the tail shaft in particular. If there is a long length of tunnel shafting, the engines take only a small proportion of the shock action. The tail shaft also, considered as a cantilever, is further subject to a considerable bending stress when the propeller is out of the water. The latter stress, of course, cannot be dealt with by any system of speed regulation, but good and efficient governing may do a great deal to minimise the evils attendant on the others, which, even if the workmanship and material of the engines and shafting are unexceptionable, may result in serious damage.

It is practically impossible by hand regulation to effectively control the engine speed in a light ship in heavy weather, even if linking-up is resorted to, and, as a result of the great development in power which marine engines have undergone during the last decade, some means of doing this automatically must be loked for.

Parallels are often drawn between the governing of stationary engines and that of marine engines. "Why," ask some engineers, "if it is possible to secure practically perfect speed regulation in the very largest types of land engine, cannot a governor be designed sensitive enough for marine requirements?"

A little consideration shows that this treatment of the matter is by no means justified, and, in fact, is manifestly unfair to the manufacturer of the marine governor, who has to make the best of conditions which no designer in land practice is ever called upon to meet.

The secret of the excellent governing which obtains in the stationary engine lies, not in any special arrangement of the governor, but in its massive fly-wheel, which stores energy when too much power is being developed and gives it out again when the load increases and the speed tends to fall. Under these conditions it is obvious that the governor is never called upon to face any sudden changes in the loading; the stored energy of the fly-wheel deals with these while the governor is coming into action, and the working of the latter can be easy and gradual.

No stationary engine is ever set to work without a fly-wheel. Apart from the fact that the sudden changes in speed required in manœuvring the ship preclude its use, it is not practicable to fit a marine engine with one massive enough to be of any service in dealing with the enormous alterations in loading to which any marine engine is subject. Such sudden and abnormal changes are unknown in land practice, and herein lies the essential difference between the two cases.

We may accept as an axiom the impossibility of ever obtaining in marine work the fineness in governing, common on land.

The lapse of time has been fruitful in suggestions for the improvement of speed regulation, and the performance of the best governors now on the market constitutes, in flexibility, efficiency and reliability, a notable advance on the results given by the pioneer forms. There is, however, still room for improvement. Most modern governors are open to the objection that they only come into action after racing has started, although, in some governors of this type hereafter described, the amount of racing which can take place has been cut down almost to the point of elimination. Another undesirable feature is that the action of most governing arrangements is not sufficiently flexible: they recognise practically no mean between racing and a dead stoppage.

The shock action to which the long suffering engines are thus subject, due to the sudden destruction of the momentum of moving masses of metal of considerable weight, is sufficiently objectionable in the ordinary slow running marine engine; in high speed machinery it is a feature which calls for serious consideration.

The ideal governor would be one which would anticipate the subsidence of the water from the ship's stern and cut off the steam or alter the cut-off of the valves before any racing could take place, and also work with enough flexibility to ensure that the amount of steam cut off would be in exact proportion to the decrease of load on the propeller, thus keeping the engine speed constant.

It is to be feared that an arrangement so sensitive is not likely to be evolved, and, indeed, a governor so finely balanced would probably give constant trouble through the hunting action to which it would be liable at sudden changes of load.

A certain amount of the friction and inertia inseparable from any mechanical device is by no means a bad thing, as it damps out the vibration which sets up the pendulum action known as "hunting," and a dashpot is often fitted to existing forms in cases where the weight of the rods and friction of the joints and bearings is not considered to be sufficiently great to neutralise troublesome oscillations, or where the amount of inertia is required to be adjustable. When these considerations are taken into account it will be seen that a very close approximation is made to the ideal by more than one type of governor now fitted.

Governors may be broadly divided, as regards their application to the engine, into two classes: (1) Those which act on a variable expansion gear and vary the speed of the engines by altering the cut-off of the valves; (2) Those which throttle the steam at the point of admission to the H.P. valve casing, thus directly varying the amount of steam which actually enters the engine.

Where it is possible to fit it, type (1) is beyond doubt the better of the two, the only steam over which it has no control being that actually in each separate cylinder when the governor comes into action, in addition to which, since it causes the point of cut-off in each cylinder to occur earlier in the stroke when the engine speed increases, the back pressure on the I.P. and H.P. cylinders is, for the moment, raised considerably, and the increased compression has a very appreciable effect in pulling up the engines.

In the second type all the steam which is beyond the main stop-valve when the throttling action commences, a very considerable volume in triple or quadruple expansion engines of any size, is quite out with the control of the governor and must do its work in the cylinders before the effect of the throttling can be entirely exercised, so that some speed increase is bound to take place in this case.

The first type, however, is nowadays only fitted to land engines, where it has given excellent results and has been proved to be considerably more economical than the throttling governor. The objection to it for marine work, apart from the complication of valves, etc., is the fact that it cannot be efficiently applied where piston valves are fitted (owing to the difficulty of keeping the latter steam-tight), and, as quadruple expansion engines, in which only the H.P. cylinder is fitted with a flat slide-valve are not now uncommon, the throttling governor in various forms is the type invariably fitted and the improvements which have been made in quickness of action and its simplicity in working have amply justified its adoption.

The forces which bring the governor into play may be derived (1) from the motion of the ship; (2) from the inertia of some rotating or reciprocating part of the engine or of some mechanical arrangement connected thereto.

(1) has been favoured by several inventors, and some governors based upon it which have, at one time or another, had a commercial existence, gave good results. Apart from other objections, it is open to the very serious one that a governor designed on this principle cannot, in the nature of things, take any notice of such an occurrence as a propeller dropping off or a shaft breaking.

Nevertheless, more than one modern governor is of this type, and a short resumé of the various forms which this method of governing has taken may be of interest.

The first one brought out was Taylor's, which appeared in the "fifties." The motive power was supplied by a float inside a cylinder fitted near the propeller, the bottom of this cylinder having a connection to the sea. A chain connected the float to the throttle valve and the whole arrangement was balanced by means of weights, the idea being that, as long as the propeller was immersed and, consequently, the cylinders full of water, the float would remain at the top and the throttle valve remain open, while, with the subsidence of the water from the stern, the float would fall and shut the throttle. This governor, however, was not a success.

Another governor brought out about this time was brought into action by the motion of the ship also, but in this case a pendulum was used to act on the throttle. This was Pinkney's. It does not seem to have had any success commercially.

Some fifteen years afterwards, in 1871, a great advance was made with this type with the introduction of the Dunlop governor. This met with considerable success, and is still to be found afloat.

Its details are as follows:—An air-vessel was fitted in the after-end of the ship, near the stern-tube or in the run and connected by a cock to the sea. The opening of this cock and the admission of the sea-water naturally resulted in the compression of the air in the vessel to a pressure equal to that of the head of water outside. A connection was taken from the air space to the underside of an air-tight elastic diaphragm, similar to that of a reducing valve, in the engine room. The diaphragm was connected to the valve rod of a small steam cylinder, the valve of which was so designed that the movement of the piston in the cylinder corresponded exactly with the movement of the diaphragm. This piston was connected through levers to and controlled the movement of the throttle valve of the engine to be governed. The upward distortion of the diaphragm, due to the air pressure below it, was resisted by a spring fitted on the top of it, the compression of this spring being adjusted so that a practically perfect balance was obtained, the slightest increase or decrease of air pressure, due to the changes in head of water at different depths of immersion of the sea-cock on the air-vessel, producing a corresponding movement of diaphragm and piston and consequent opening or shutting of the main throttle valve.

The Coutts and Adamson governor is of somewhat later date, but is similar to Dunlop's as far as the air-vessel and diaphragm are concerned, the only essential difference lying in the method of moving the piston in the governing cylinder. The steam valve is so constructed that the steam is only used to move the piston one way, *i.e.*, to close the throttle, and the other end of the cylinder is provided with a connection to the condenser which is uncovered by the slide-valve (which previously cuts the steam off) as the movement of the latter responds to the decrease of pressure below the diaphragm. Springs are fitted to assist the atmospheric pressure in returning the piston to the bottom of the cylinder.

The Thunderbolt governor can be brought into action either by the ship's motion (acting on a pendulum) or by the acceleration of the engines beyond a pre-determined speed. When it is used as a "uniform speed" governor, the pendulum attachment, which makes it an "anticipating" one, must be thrown out of action.

The governor consists, primarily, of a set of duplex double acting air compressors, driven by a belt from the main engines, which force air into a system of pipes and valves communicating with the bottom of a cylinder containing a spring loaded piston. The air pressure used is from 10 to 15 pounds per sq. inch, and the air, when admitted to the working cylinder, forces the piston up against the spring, and, the motion being transmitted through rods and levers, closes the throttle.

When the governor is not acting, the air delivered by the compressors blows off through a regulating port, which is opened or closed by the action of a pendulum. When the ship pitches, the pendulum remains vertical, and this causes the regulating valve to close the regulating port. This produces a sudden increase of air pressure which forces open a carefully-balanced, spring loaded valve and allows the air to enter the working cylinder, thus closing the throttle. When the ship regains its normal position the regulating valve opens, the pressure decreases, and the piston in the throttling cylinder is returned to the bottom end by the spring on top of it. This is what happens when the governor is used as an anticipatory one.

When the engines are required to run at uniform speed the pendulum is disconnected and the blow-off port closed until the necessary pressure for actuating the working piston is attained. Any increase in the speed of the main engines then produces an increase in the speed of the compressors, and, hence, a larger volume of air delivered than usual. As the area of the blow-off port is fixed, this produces a rise in pressure and consequent movement of the working piston and of the main throttle-valve.

The air-vessel and diaphragm still find a place in governing arrangements, and some time ago the writer came across one in which the motion of the diaphragm was utilized to move the throttle by means of an electro-magnet.

Turning to the inertia governor, the first of which there is any record, outside the ordinary centrifugal ball governor, is Silver's, invented in 1857. Its arrangement is shown in Fig. 1. (1) is a heavy fly-wheel which is free to revolve on the shaft (5), the wheel being provided with the vanes shown in order to absorb energy and increase the inertia at any increase in the speed of revolution. The quadrants (2) are free to turn on the pins shown on the boss of the fly-wheel and gear with the bevel wheel (3), which is keyed to the shaft, the latter being driven from the main engines through the pulley (4).

When the speed of the engine increases, the fly-wheel, owing to its inertia and to the resistance offered to the vanes, does not immediately respond, and the addition of the extra force required to overcome the inertia causes the quadrants to revolve on their pins, thus compressing the spring (6) and acting on the throttle valve through the lever (7) The provision of a fly-wheel large enough to give the necessary inertia made this governor too unwieldly and it had no great practical success.

The Churchill governor, brought out in 1879, met with considerable success. The pulley was dispensed with and the necessary inertia was provided by the rotation of a fan within a closed cylinder filled with water, the lagging of the fan shaft, owing to the absorption or diffusion of energy as the main engine speed changed, acting on the throttle valve through a system of double cams. An improvement afterwards fitted to this governor consisted of an intermediate valve on a pipe connected to stop valves at top and bottom of the L.P. cylinder. The governor acted on this intermediate valve as well as on the

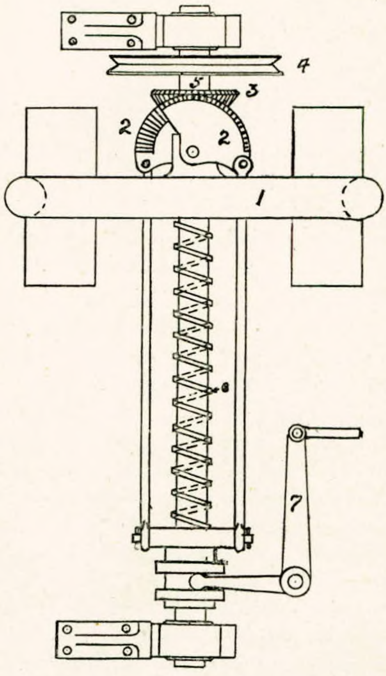


Fig. 1.

The Silver Governor.

throttle valve and, as soon as the throttling commenced, the intermediate valve was opened and steam admitted to both ends of the L.P. cylinder, thus throwing the piston into equilibrium.

The latest type of inertia governor is the Aspinall, which is shown in Fig. 2. This is by far the most efficient and popular of all governing arrangements, and its many advantages have amply justified its wide adoption. The governor is very simple and compact, as will be seen from the sketch, and can be bolted either to the pump lever or to a special lever fitted for the purpose. It consists of the hinged weight (1), the movement of which operates the two pawls (2). When the engine speed increases by about 5 per cent. above normal the inertia of the weight causes it to be left behind, reversing the position of the pawls and causing the bottom one to catch and carry upwards the engaging lever 4, thus closing the throttle valve. On the down stroke of the lever the small detent (5) is caught by the engaging lever and, if the engine speed is once more normal, the

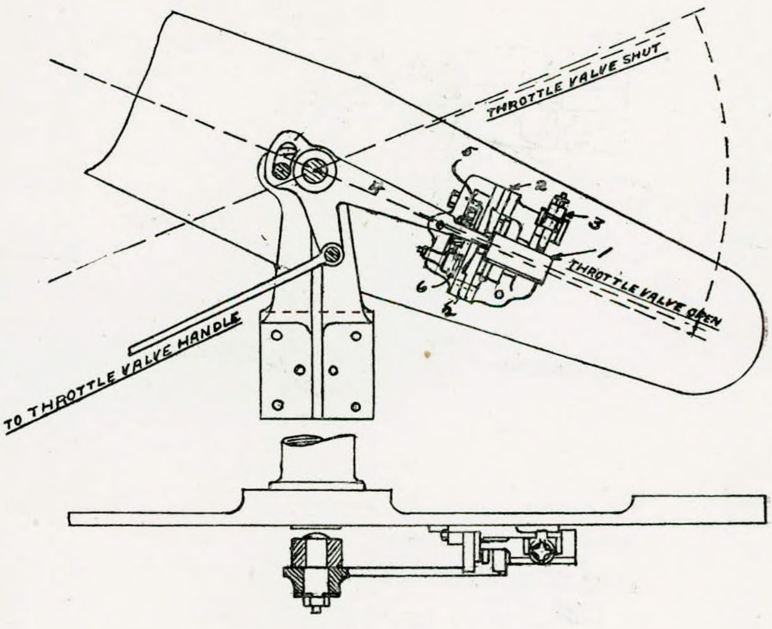


Fig. 2.

The Aspinall Marine Governor. Fitted to Air Pump Lever.

weight (1) returns to its original position, and the position of the pawls is again reversed, the top pawl now engaging with the lever and carrying it downwards, thus opening the throttle. The inertia force of the weight (1) is balanced by means of a spring (3), the compression of which is adjustable so that the governor can be set to act at any predetermined increase in the engine speed. The advantages offered by this governor are many. It is simple in construction and efficient in action, has no parts subject to wear and absorbs energy only when in action, and can be speedily and easily fitted by any ordinary mechanic. It is capable of application not only to reciprocating engines but also to turbines, in this case being fixed in a special lever driven by suitable gearing from the forward end of the turbine shaft. The governor, as fitted to steam turbines,

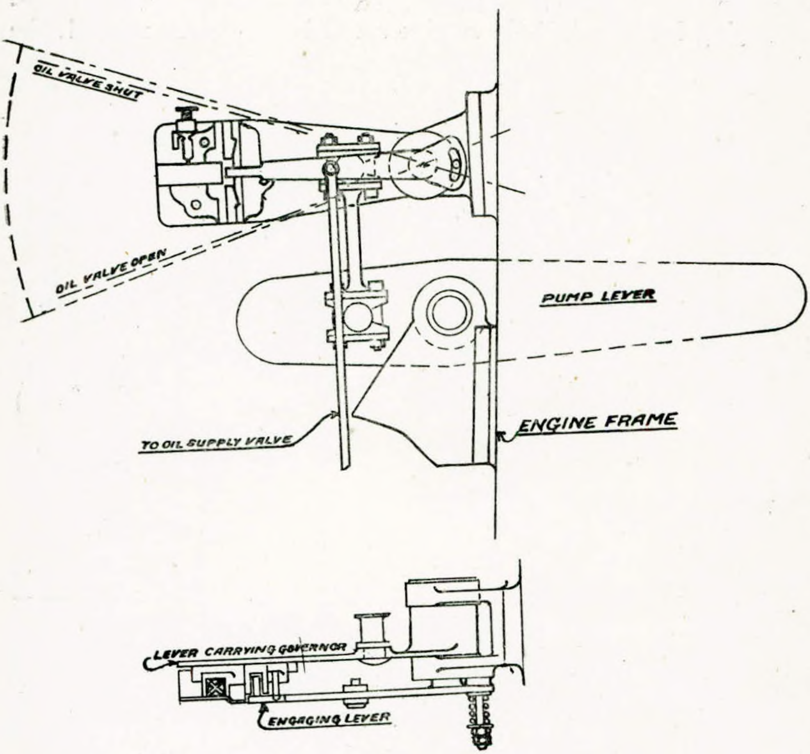


Fig. 3.

Arrangement of Aspinall Governor for Diesel Engines.

has usually only one pawl, the steam being cut off as before at a predetermined increase in the number of revolutions and the re-opening of the throttle valve being done by hand.

A very important feature of the Aspinall governor is the emergency gear. This comes into play in the event of a very excessive race taking place, *e.g.*, when a propeller drops off or a shaft breaks. The small weight (6) is then left behind, and this locks the weight (1) in the "shut-off" position, thus preventing the re-opening of the throttle valve.

The governor may be used to act on an ordinary butterfly throttle valve, but nowadays it is usually fitted, where reciprocating engines are concerned, in conjunction with a patent balanced stop valve. This valve is fitted with a piston slightly larger in area than the valve itself, and the difference of pressure keeps the valve open. The action of the governor opens

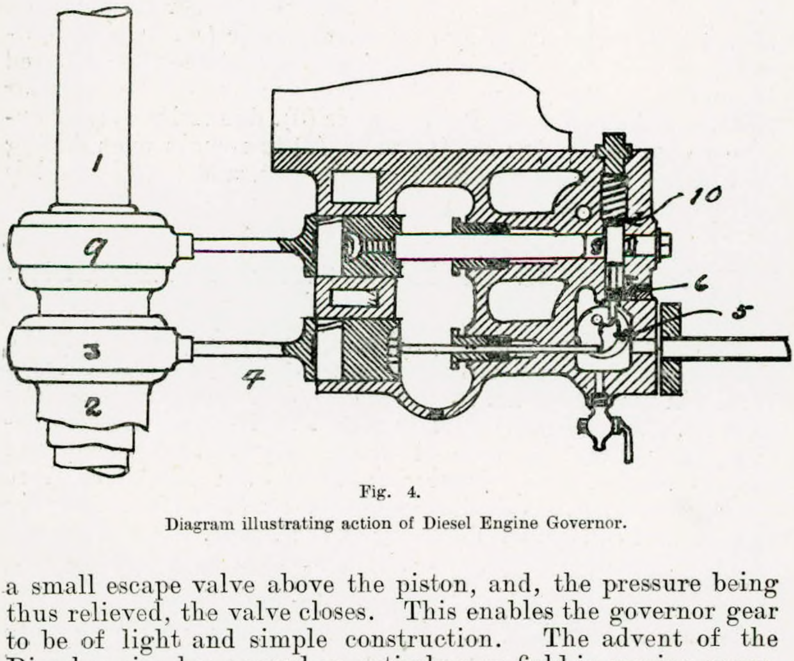


Fig. 4.

Diagram illustrating action of Diesel Engine Governor.

a small escape valve above the piston, and, the pressure being thus relieved, the valve closes. This enables the governor gear to be of light and simple construction. The advent of the Diesel engine has opened an entirely new field in marine governor design, as this engine lends itself to efficient governing to a much greater extent than does the steam engine. The Aspinall governor has been fitted with good results in two notable cases, to the engines of the *Selandia* and *Jutlandia*, a typical arrangement being shown in Fig. 3. The methods of cutting off the oil supply by means of the governor are varied; in some cases by a bye-pass valve fitted to the supply pipe, or by a cock fitted to the supply pipe, which diverts the oil through a relief valve back to the tank. Many engineers consider, however, that the working of the Aspinall governor is not sufficiently flexible for the requirements of oil engines and prefer governing arrangements of the type shown in (4). The governor shaft (1) is driven by suitable gearing from the crank shaft. The governor (not shown) consists of a sleeve carrying weights, whose outward or inward motion, due to increase or decrease of the engine speed, gives an angular motion, relative to the shaft, to the sleeve (2) which carries the eccentric (3). This eccentric, through the rod (4) and the small lever (5), operates the suction valve (6), the lifting of which admits the oil from the supply pipe (7) into the plunger cylinder (8), the plunger being driven from the governor shaft by another eccentric (9). On the outward stroke of the plunger the oil is forced past the spring loaded valve (10) to the engine fuel valves. Any relative angular motion of the sleeve (2) and eccentric (3), due to increase of engine speed, causes the suction valve (6) to remain open during part of the outward stroke of the plunger, and thus less oil is delivered to the engine.

## THE GOVERNING OF HIGH SPEED AUXILIARIES.

This is nowadays a subject of considerable importance to the marine engineer; inefficient governing of high speed machinery is certain to cause much inconvenience and may lead to serious damage. To take a typical instance, that of the dynamo engine, any large increase of speed may cause heating and damage to the dynamo insulation, while even a small decrease in the number of revolutions produces an appreciable drop in voltage and consequent dimming of the lamps.

A typical governor fitted to small high speed engines is shown in Fig. 5. It consists primarily of a drum fixed to the end of the engine shaft and carrying two weights (2), which are free to move outwards or inwards, the centrifugal forces being balanced by means of the adjustable spring (5). When the speed increases the weights (2) move outwards, and this motion is transmitted through the levers shown to the sleeve (3), which is free to move axially on the shaft. The motion of the bell-crank lever (4), which is actuated by the sleeve, forces up the rod (6) against the spring (5), thus closing the stop valve. This type of governor takes various forms, but the principle is the same in all cases and excellent results are obtained in practice.

In conclusion, while it must be admitted that modern design has produced governors of high efficiency, yet it cannot be held that the last word has been said on the matter. There is still

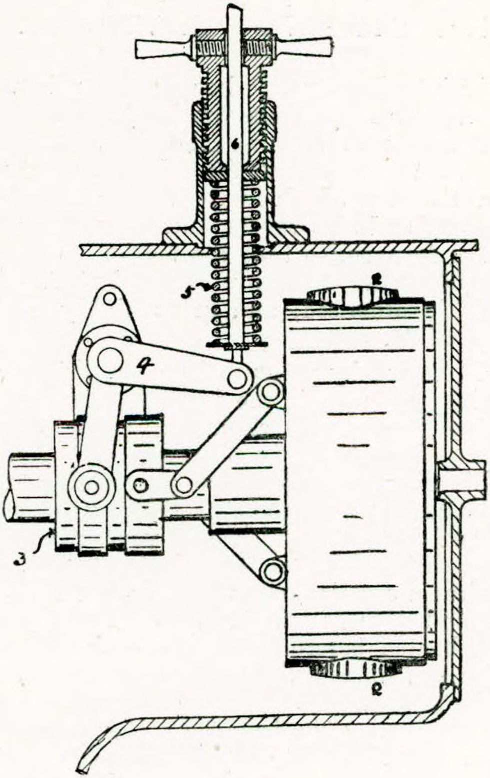


Fig. 5.

Governor fitted by Brush Co.

room for improvement and the subject, interesting in itself and offering as it does ample reward for successful research, is worthy of the attention of every engineer.

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PRIZE ESSAY.

*(Competition for Graduates).*

# Oil Fuel as Applied to Marine Boilers.

By DOMINION (Mr A. J. Walker).

Ever since the introduction of oil as a steam raising agent, experiments have been made from time to time to determine the most efficient means of burning the oil, and as the various theories have been propounded, there have been corresponding differences in the plant, both in regard to the construction of the burner itself, and also the manner in which the oil is introduced to the furnace, so that the matter naturally resolves itself into one of having the oil, immediately before ignition, in an as thoroughly atomised, and in as highly combustible, a condition as possible.

When oil is driven by pressure from an injector of proper construction it spreads out in the form of an inverted cone, and if well atomised, burns with an intensely hot flame. The oil is nearly always heated before reaching the injector in order to facilitate its flow and subsequent pulverising and burning, but this heating must be kept below the point at which the oil vapourises, as otherwise the presence of vapour in the oil column might extinguish the flame at the injector nozzle. The oil in burning requires a certain amount of air to assist and support combustion, and this is admitted from the furnace front, usually being heated before being utilised, as this materially assists ignition and burning. When the fuel has been ignited, the flame is brought into contact with a layer of fuel or brickwork in the furnace. The brickwork then fulfils several requirements as, being heated to a very high temperature, it helps to ignite the oil vapour, and if it is so built that the oil jet impinges on it, the impact serves to pulverise the oil still more, also it helps to prevent the flame being driven too rapidly through the furnace and saves the plates from the direct action of the flame.

In burning oil there is always a risk that there may be present, water and small particles of solid matter, which would choke the passages in the injector, the former being present in crude oil, and also when the oil has been stored in the double bottom and tanks of the vessel. It has been found that the presence of drops of water in the oil will extinguish the flame at the burner, and if a fine spray of oil mixed with air enters the furnace in any large quantity, an explosive mixture is formed. In order to get rid of the solid particles and water, the oil is pumped into settling tanks, which, as will be seen in Fig. 1, are fitted with a steam coil, the reason for this being due to the fact that the specific gravity of the oil generally used as fuel, is only a little below that of water, and the separation, therefore, would be very slow, but when warmed the oil expands at a much greater rate than the water, and the separation takes place with greater rapidity.

The oil is sprayed into the furnace in three ways, namely, by compressed air, by direct pressure, by steam injection. The first method, although, perhaps, the most efficient, has made comparatively little headway in marine practice owing to the amount of auxiliary machinery required, although it is claimed that when a turbo-air compressor is used for supplying the pulverising air to the burner, it absorbs less than 2 per cent. of the total steam raised, and as the steam jet system uses about 4 per cent. of the steam, it would appear there is a saving, but the capital cost of this system would be much greater and would entail more work for the engine-room staff. The direct pressure system is the one in most frequent use at the present day and may be exemplified by any of these types, the Wallsend-Howden, the Kermode, or the White. Figs. 1 and 2 show an installation on the Wallsend system. The oil is pumped from the main bunkers to the settling tanks and is drawn from there by pumps through a strainer of wide mesh, it is delivered through steam heaters to a discharge strainer and thence to the boilers. The average working pressure of the oil is about 170-200lbs. per sq. in. for ordinary steaming, but this must be regulated according to the amount of steam required. The temperature of the oil is regulated by the amount of steam admitted to the heater and depends on the viscosity of the oil, it generally ranges from 150-300°F, but the most suitable temperature is determined by experience with the different classes of oil used, Californian, Mexican, and other heavy oils having an asphalte base require to be burned at an increased temperature.

The operation of lighting up is comparatively simple. The hand pump shown, discharges through the strainer to the donkey boiler, in this case a Cochrane vertical boiler, the oil is raised to the required temperature by means of a small heating coil inserted in the furnace front, and when the inner sliding

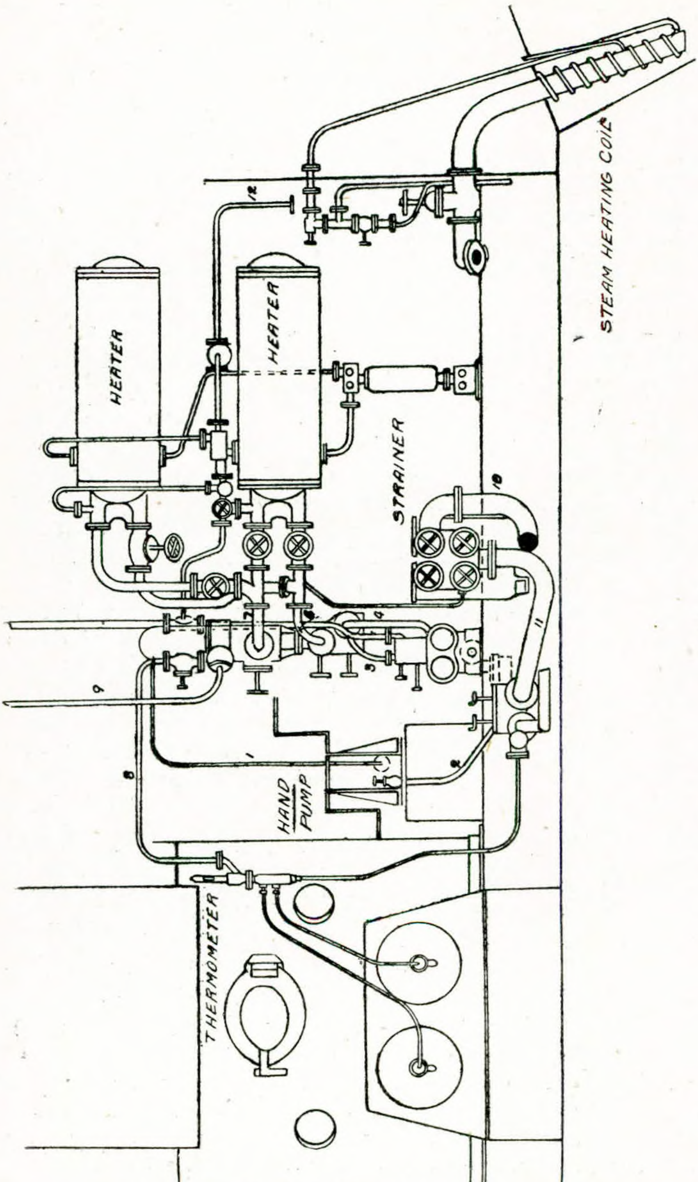

HEATER
HEATER
STRAINER
HAND PUMP
THERMOMETER
STEAM HEATING COIL

Fig. 1.

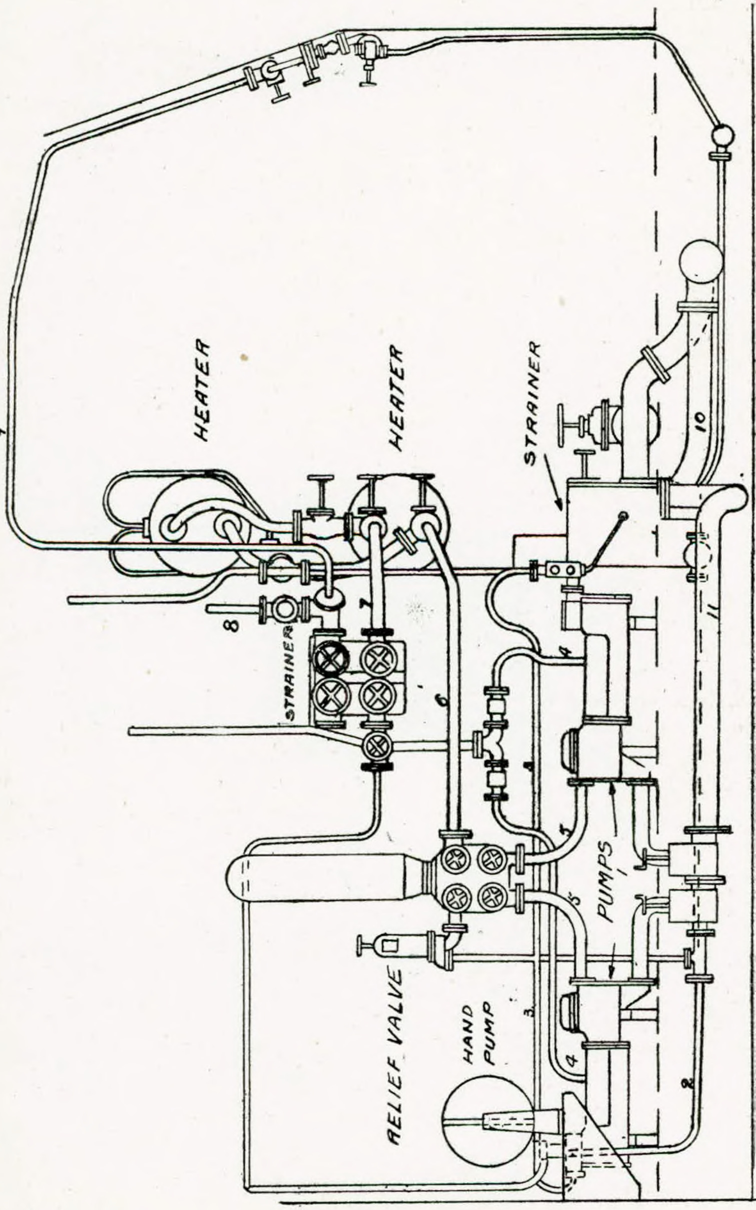

HEATER
HEATER
STRAINER
STRAINER
PUMPS
RELIEF VALVE
HAND PUMP

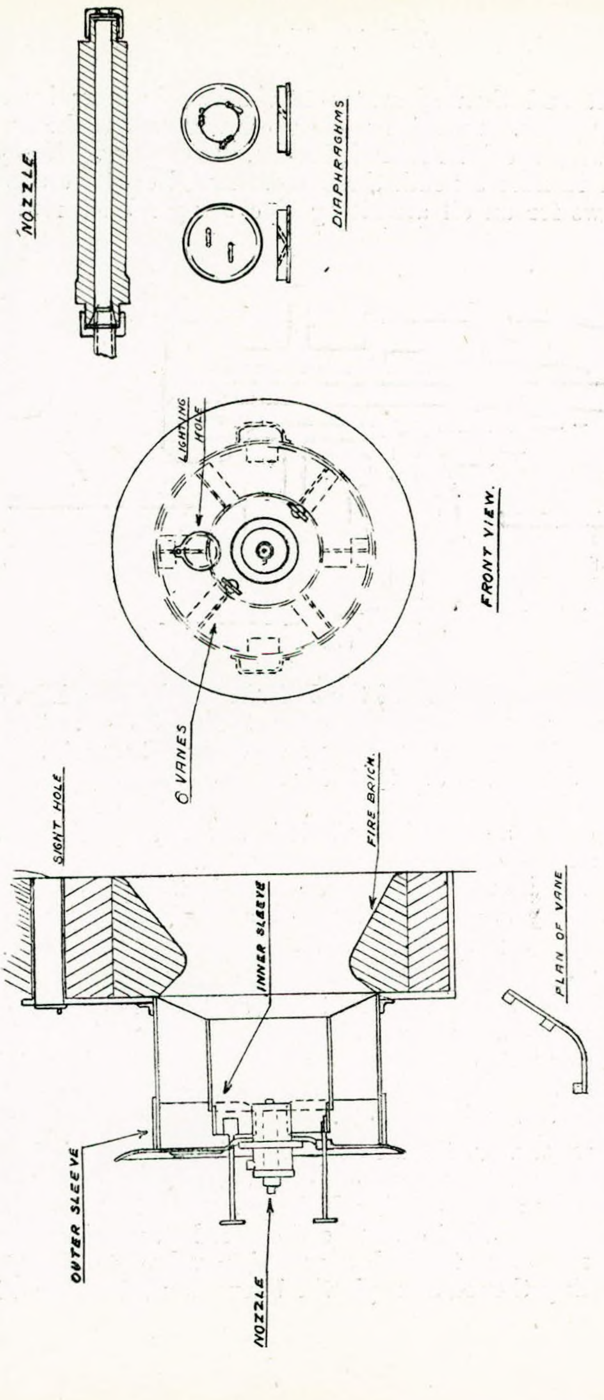
Fig 2.

sleeve on the air distributor shown in Fig. 3 is closed, and the outer sleeve fully open, admitting air freely, a piece of oily waste is inserted through the lighting up hole, shown in Fig. 3, and placed below the burner nozzle. When the oil in the pipe has been raised to the required pressure, about 100lbs. per sq. in., the waste is ignited by means of a torch and the valve controlling the oil supply opened, allowing the oil to be blown into the furnace in a fine spray. A special burner is provided for starting up, and when sufficient steam has been generated to work the pumps and get the installation under way on the main boilers, the burner is withdrawn and an ordinary burner substituted. Before lighting up it is advisable to allow air to blow freely through the furnace in order to get rid of any inert gases which may remain from the previous firing.

The introduction of air to the furnace is a matter which calls for serious consideration, as upon this is dependent the length of the flame, because if the flame is allowed to pass right through the furnace, heat is lost up the funnel and clouds of smoke are formed. Experience shows that if, instead of allowing the oil and air to flow forward as more or less independent streams, they are forced to mix by imparting a swirling motion to both, the direction of rotation of the oil being opposite to that of the air, the travel of the flame is reduced and smoke prevented. Therefore, as is shown on Fig. 3, the air is drawn through slides, and as it passes into the furnace it comes in contact with a series of vanes, which are so arranged that a swirling motion is given to the air before it meets the atomised fuel issuing from the burner.

The burner itself, Fig. 3, consists of a steel nozzle encased in a cast-iron body. At the inner end of the nozzle is fixed a perforated plate or diaphragm, which is secured in position by a cap. These diaphragm plates are made with holes of various sizes and number, so that the quantity of oil burned can be regulated by the size of diaphragm, the bore of the nozzle, and the pressure under which the oil is sprayed into the furnace.

The foregoing description holds good for most pressure installations, although there are many points of difference in detail, notably in regard to the burner. In the Kermode pressure burner, Fig. 4, the swirling motion given to the oil is attained by causing the liquid to escape under pressure through small channels cut in the face of the jet or tube, so that a cone of swirling oil particles is formed which unites freely with the air. Oil is allowed to flow from an overhead tank to the fur-




WALLSEND-HOWDEN PRESSURE SYSTEM.

Fig. 3.

nace front and then separates to the two burners by equal branching pipes. In this system the lower part of the furnace is filled with special firebrick blocks, through which the air enters the furnace beneath the flame. An alternative arrangement allows for an oil atomising pipe being carried round the furnace.

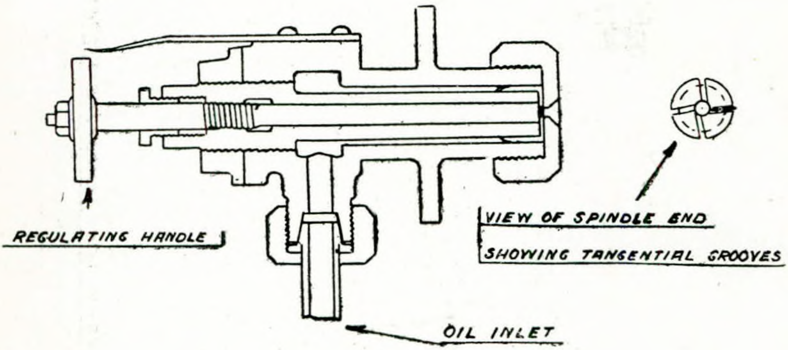



Fig. 4.

The distinctive feature of the J. S. White burner, Fig. 5, is, that in starting up it is not necessary to heat the oil. The cold oil is forced through the narrow orifice against a metal disc on the end of the spindle, so that it is sprayed at a wide angle and in a finely atomised condition. For hot spraying the spindle is drawn inwards, and the heated oil is forced through the same orifice in a more concentrated condition, a swirling motion being given to it by the spiral passages cut in the face of the cone. The oil supply is adjusted by means of the spiral passages, which can be regulated in area and number by means of the hand wheel.

These three systems may be taken as typical of the pressure system, as space will not permit of a more elaborate description, but it will be noticed that the tendency is to simplify the construction of the working parts, thereby minimising the risk of delay owing to breakdown, etc.

Dealing now with the steam pulverising system, it is found that the pumps of the pressure system are superseded by a steam jet, preferably superheated, which acts much in the same way as an injector on a boiler. The steam is led, usually from the auxiliary range, or through a reducing valve, to the furnace front, passing thence through the burner and drawing with it

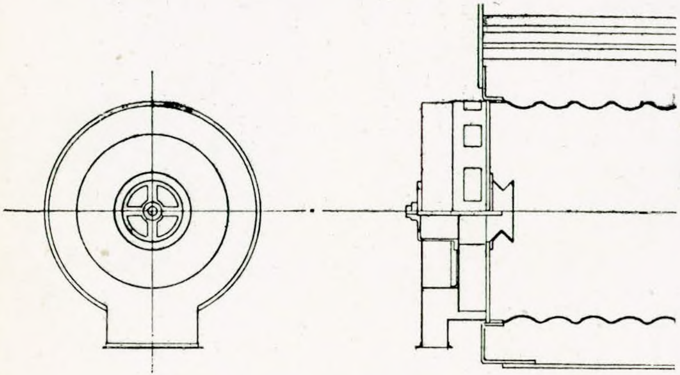


Fig. 5. White's Mechanical Oil Fuel System (Positive Draught).

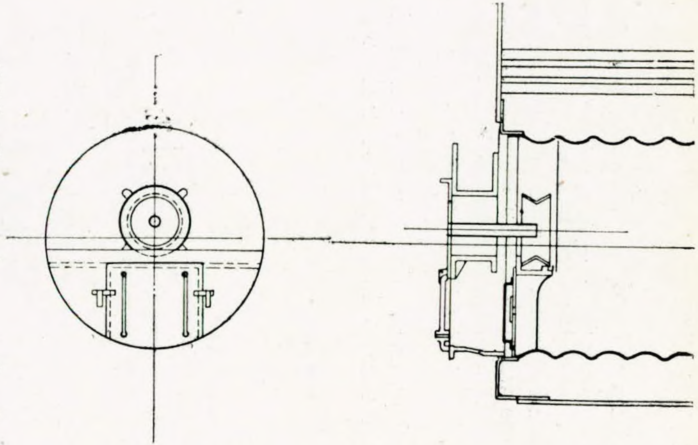


Fig. 5a. White's Mechanical Oil Fuel System (Forced Draught).

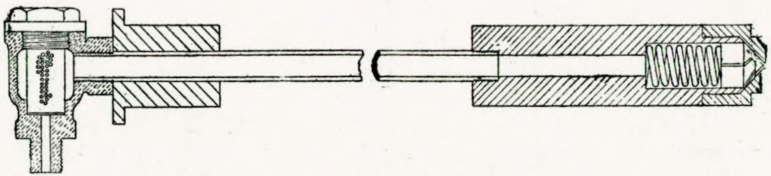


Fig. 5b. White Mechanical System Oil Fuel Burner.
Showing method of attaching Filter, Spring and Nipple.

the oil and air necessary for combustion. The design of the burner usually allows for the steam jacketing of the oil passage, so that the temperature of the oil is raised before it enters the furnace. This last point is a distinctive feature of the Rusden-Eeles burner, Fig. 6, a type which has been successfully employed on several ships. Steam escapes down the middle passage, round the spindle manipulated by hand wheel, the oil flows to the recess at the nozzle and, uniting there with the steam jet, is atomised, and owing to the construction of the spindle end is blown into the furnace in a balloon-like flame.

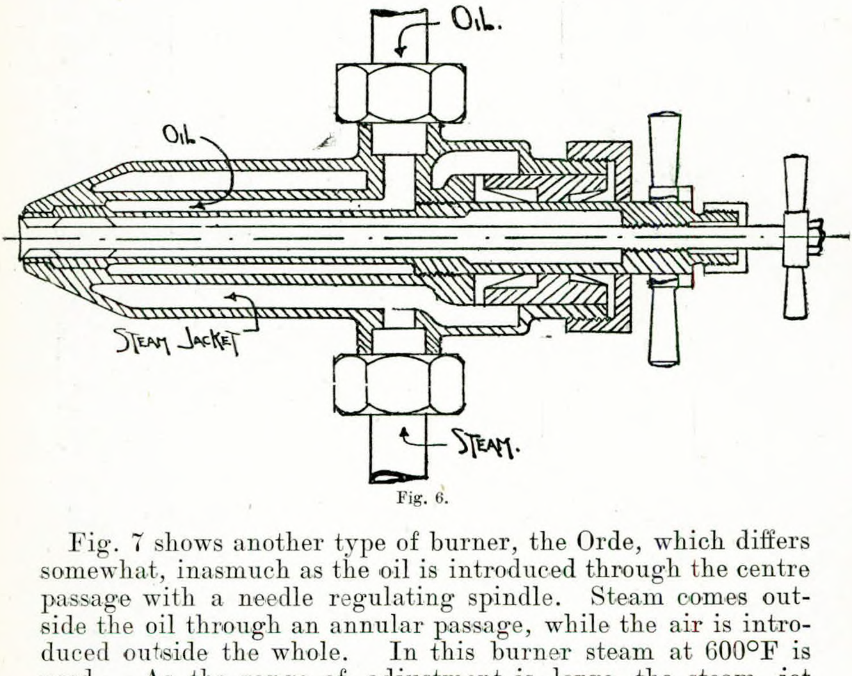



Fig. 6.

Fig. 7 shows another type of burner, the Orde, which differs somewhat, inasmuch as the oil is introduced through the centre passage with a needle regulating spindle. Steam comes outside the oil through an annular passage, while the air is introduced outside the whole. In this burner steam at 600°F is used. As the range of adjustment is large, the steam jet burner may be used for different powers within wide limits, while the amount of air supplied is determined by the character of the flame, which should be almost transparent, and of an intense white colour, or approaching pink when light oils are used. Steam injection facilitates the burning of the oil, as the minute particles, reaching a high temperature when they come in contact with the steam, are easily consumed and burn with less smoke than either of the other processes, but it has been found that the furnace space, especially in the Navy, is inadequate to allow of the perfect combustion of the large quantities of oil needed to develop the requisite power, when steam is employed, and also the extra steam needed necessitates auxiliary boilers. The amount of steam actually consumed in the pressure system is negligible, and undoubtedly this is the

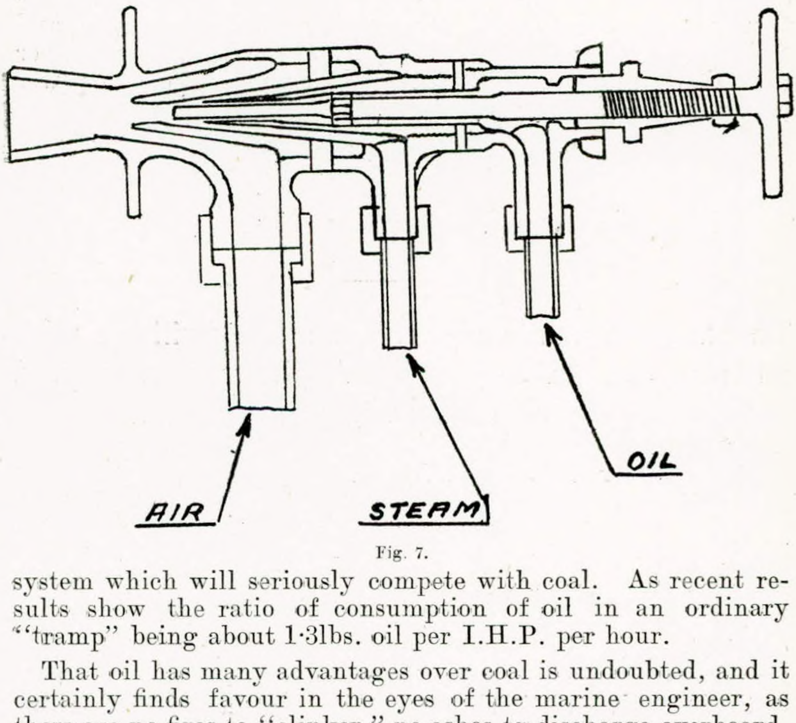



Fig. 7.

system which will seriously compete with coal. As recent results show the ratio of consumption of oil in an ordinary "tramp" being about 1·3lbs. oil per I.H.P. per hour.

That oil has many advantages over coal is undoubted, and it certainly finds favour in the eyes of the marine engineer, as there are no fires to "clinker," no ashes to discharge overboard, and the firing of the boilers becomes simply a matter of manipulating the valve controlling the oil supply. There are other advantages, however; the placing of the bunkers is altered, the facility with which the oil can be shipped and stowed in the double bottom and in bunkers, which, under ordinary conditions, would be inaccessible. In the Navy, the fuel can be pumped from lighters and oil-tankers in any but very rough weather, thus obviating that most disagreeable job, "coaling ship." The heat value in the furnace, besides being greater, is kept practically constant owing to there being no necessity to open the doors, and this, coupled to the fact that $1\frac{1}{2}$ tons of oil have the same stowage capacity as 1 ton of coal, thus giving the oil-fed ship almost 50 per cent. increase in steaming power, is a powerful argument in favour of oil burning. In the mercantile marine, it is the reduction in stokehold hands and the uniformity of speed that can be obtained, which, next to the extra cargo space given by the use of oil, constitutes the attraction of liquid fuel, and if, by a cheapening of processes and freights, or by an increase in output, oil can be had at cheaper rates than at present, coal would take second place as a power producer at sea.

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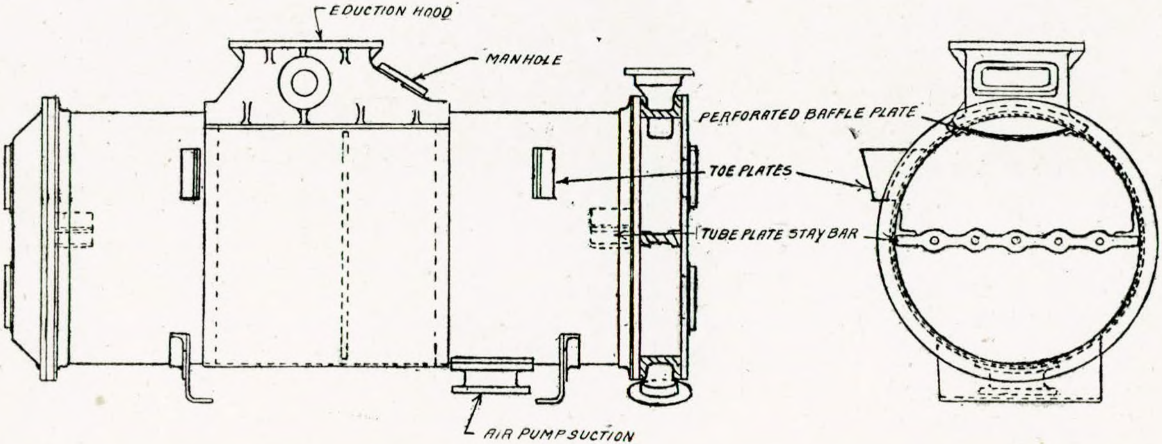
## OPEN COMPETITION.

# The Modern Condenser, Main and Auxiliary, with all necessary Pumps and Appliances connected therewith.

By Mr. JOHN S. McPHERSON
(Nom-de-plume Finnieston).

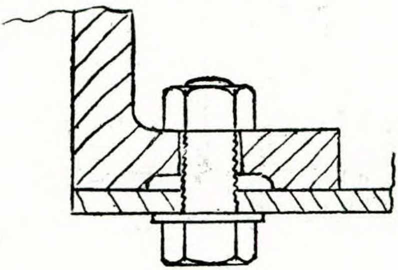
The surface condenser is an essential factor in modern marine propelling machinery, and plays an important part in the economy of the steamship. It is a large, heavy and expensive article, but these disadvantages are considerably outweighed by the following advantages over the old "jet" type:—Water in the hot-well is distilled and warmer; no continuous blowing-down of boilers; less deposit of scale, etc.; longer life for boilers and higher boiler pressure can be carried with safety.

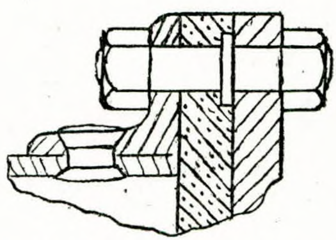
The favourite type of main condenser for modern reciprocating work seems to be that of cylindrical shape, constructed of steel plates $\frac{1}{2}$in. thick. It has the following advantages:—The shell is self-staying; patterns for water-ends, etc., are easily made and are easily machined; it is the cheapest for several reasons; and it is the lightest, being circular in shape, giving the least perimeter for a given area and therefore the minimum plating in shell. Various other shapes are in use, but space does not permit of their being described.



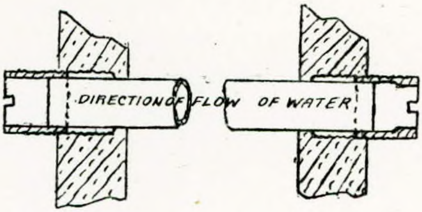

Main Condenser.

The condenser may be supported by strong brackets, built up of angle iron and plates or by cast-iron brackets of H section, chocked up from, and held down to, the tank top and also bolted to engine soleplate, tie-brackets being fitted between condenser top and engine columns. Another method of support is by girders stretching between engine back columns and bunker or ship's side, the girders being supported at each end by suitable cast-iron brackets. This arrangement allows of the condenser being kept apart from engine columns and facilitates search for, and caulking of, leaky parts of shell.

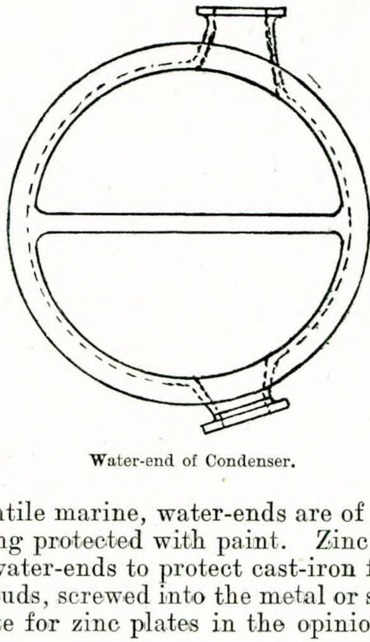




Tube plates are of rolled brass or Muntz metal, and of thickness, to allow of sufficient packing space for tubes, usually about $1\frac{1}{8}$in. These plates are bolted to angle or square section rings riveted to shell. As the bolts for the tube plates serve also for jointing the water-ends, they are made with a collar on them to ensure that the tube plate joint with condenser is not broken if water-end is taken off. The joint between condenser shell and tube plate is usually made with red lead putty and lead wire, or with calico or canvas soaked in red lead jointing paint. Tube plates are stayed by through stays of steel, the studs and nuts at end of these stays being of Muntz metal, as they come in contact with sea-water. Across the diameter, and inside of the condenser shell, is fixed at each end a strong cast-iron bar, supported by angle irons riveted to shell. This bar is secured to tube plate by Muntz metal studs and nuts or cheese-headed pins, grummets being used to ensure water-tightness.




Condenser tubes are usually of solid drawn brass, $\frac{3}{4}$in. or $\frac{5}{8}$in. outside diameter, and, when the condenser shell is of cast-iron, they are generally tinned all over. Their thickness varies from 19 to 16 W.G. Tube support plates of cast-iron or brass are fitted for every six feet of tube length in order to prevent tubes sagging in the centre. On entering the condenser, the exhaust steam is distributed over the length of cooling surface by a perforated baffle plate which is fixed under the steam entrance, thus also preventing steam impinging directly on the top row of tubes. This plate is usually galvanised. A number of V-shaped depressions should be left clear of the tubes on top rows to facilitate the passage of steam into the centre of the nest of tubes. The method of packing tubes is shown in the attached sketch, the full open ferrules being used where the circulating water enters, those with reduced inside diameter are used at the other end to prevent the tubes coming out by the pressure of water. Cotton cord or patent fibre grummets serve for the packing material used for tubes. At one end of condenser a clear space should be left in the engine room to allow of tubes being withdrawn, and if this is not possible, a part of the bulkhead at after-end of condenser should be removable. In modern practice the sea-water circulates through the tubes and not outside them for the following reasons:—(i) A larger cooling surface is exposed to the steam; (ii) the grease carried over from the engine by exhaust and deposited on tubes may be easily removed by using the boiling-out connection with water and a solution of caustic soda, and even without any cleaning the deposit is not of a nature to prevent withdrawing the tubes, as the deposit from sea-water would be; (iii) the circulating water deposit being of a hard nature requires to be removed by mechanical means (there are several patent condenser-tube scrapers on the market for this purpose); (iv) tubes offer more resistance to an internal than an external pressure; (v) when the packing requires to be examined or a perforated tube plugged, the joint broken for access to plug the tube is a water, not a steam joint.



Water-end of Condenser.

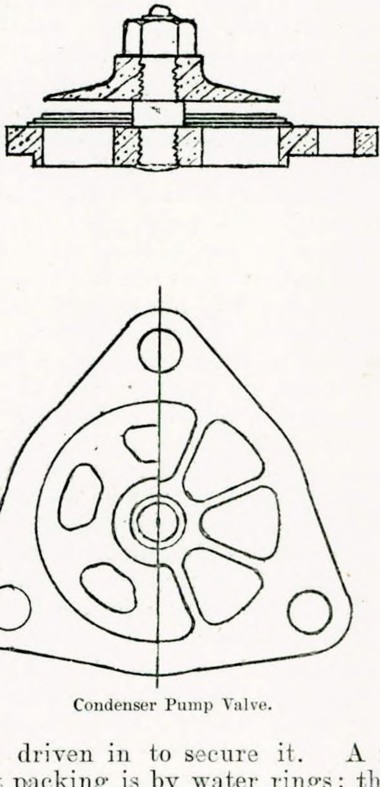
In the mercantile marine, water-ends are of mostly cast-iron, the interior being protected with paint. Zinc plates are sometimes fitted in water-ends to protect cast-iron from pitting. A few mild steel studs, screwed into the metal or steel plates, form a good substitute for zinc plates in the opinion of many engineers.

The water-end doors are of cast-iron, and have sight holes cored in them at suitable places to allow of packing, etc., being examined without the necessity of removing the large doors. Joints between the door and water-end are usually either lampwick soaked in boiled oil, or rubber insertion. The doors are stayed by studs screwed into the tube plate, the end passing through the door being of reduced diameter and secured on outside by nuts. Lifting brackets should be provided for hanging tackle to facilitate removal of doors for overhauling purposes.

A man-hole door is usually fitted on top of condenser or on eduction pipe, to allow access to interior of shell, and cleaning holes should be placed on bottom or any other place where mud may accumulate.

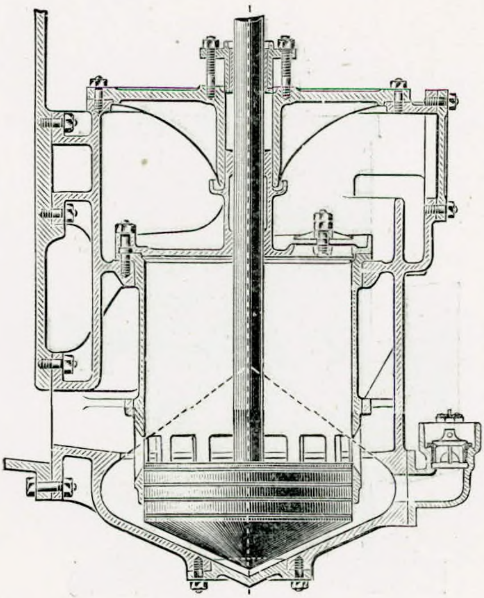
The main engine exhaust is led to the condenser by a cast-iron pipe, which is jointed to a hood fitted on top of condenser shell secured by screw pins or bolts and nuts; jointing material is usually canvas soaked in red lead paint. The air pump connection to shell is of cast-iron and is fixed in same manner as eduction hood. Another type of air pump connection is by a steel pad riveted to the shell. The air pump suction pipe is usually of cast-iron. Circulating pump inlet and discharge pipes are of copper or partly of cast-iron with one or more lengths of copper to ensure elasticity. These pipes should be well supported by strong clips or brackets. A steam connection is fitted on the condenser for boiling-out purposes previously referred to. A cock should be fitted on any part of the water-ends where air is likely to become trapped, thus preventing or hindering circulation in some of the tubes. On the level of top row of tubes a cock is fitted on the shell for connection to a vacuum gauge, the gauge itself being placed in view of the main starting platform; it is usually of the Bourdon type, graduated in inches of mercury. Sometimes a gauge of the barometer type is fitted, but seldom. Auxiliary exhaust connections to the main condenser (usually fan, dynamo, turning and reversing engines and all engine-room pumps) are led to a distribution box or boxes, through which the exhaust may be directed either to main or auxiliary condensers or to the atmosphere. In some cases, where no auxiliary condenser is fitted, the winch exhaust can be passed in to the main condenser, in which case a shut-off valve should be fitted on main eduction pipe to prevent exhaust going back to L.P. casing, which may be opened up at the time. Evaporator vapour entrance to the condenser is by means of a spring-loaded valve. Thermometer sockets are fitted at circulating inlet and outlet of main condenser to test the temperature.

In marine work several types of air pumps are fitted, both reciprocating and rotary, but in the space allowed the writer can only attempt to describe the two types mostly fitted, *i e.*, the foot valve type and the Edward's or solid bucket type. The first-named style consists of a brass bucket, with one or more valves, which works in a brass barrel, at the bottom of which is placed one or more valves, opening inwards, and at the top a corresponding number of valves opening outwards. On to the bottom of the barrel of the pump a cast-iron vessel of cylindrical shape is bolted, this being in connection with the interior of condenser. Condensed steam gravitates into this vessel, the air pump being placed as low as possible in relation to the condenser, and on the upstroke of the pump bucket the water flows through foot valves, which close on the downstroke, the water then passing in top of the bucket, which discharges it through the head valve on upstroke. The bucket of this pump is sometimes packed with rope-yarn, which is wound round a recess in the bucket cut for the purpose, each end of the rope being secured by inserting it into a hole bored for the purpose, a wooden



Condenser Pump Valve.

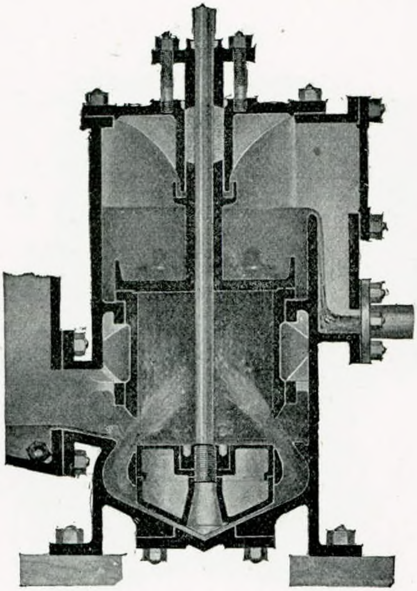
plug being then driven in to secure it. A more common method of bucket packing is by water rings; three or four recesses 1-16th. deep by ½in. broad are machined on the circumference of the bucket, thus effecting a water-seal. The pump rod is generally of forged bronze or Muntz metal. The bucket is fixed on a reduced end and secured by a Muntz metal nut, which is locked when in place. The foot, bucket and head valves are usually of the disc type, lift allowed being about ¼in. The pump rod passes through a packed gland over the head valve, and is secured to a cross-head, which receives its motion from the pump lever. An access door is fitted on the pump barrel to give access to foot and bucket valves without removing head-valve, and as part of the working face is removable with this door, care should be taken that the door can only go on one way, say by varying pitch of studs. as accidents have occurred by replacing in a wrong position this part of the working face.



Edward's Air Pump.

The Edward's air pump consists of a valveless bucket of conical shape, working in a brass barrel, the bottom part of which is inserted into a cast-iron vessel, having a conical bottom corresponding to the bucket. Part of the barrel which protrudes into this vessel has ports formed in it. Water gravitates into the bottom of the pump, and on downstroke of bucket, it is dashed through ports in the barrel to the top of bucket, which carries it through the head-valve. One advantage of this pump is the small clearances which can be used, *e.g.*, top, 5-16ths.; bottom, $\frac{3}{4}$in., being common clearances for a large pump. A valve is fitted to bottom of this pump to relieve any pressure above the atmosphere in condenser, this not being necessary in the other type of air pump described (although it is often fitted) as the pressure would relieve itself by lifting the foot, bucket or head-valves.

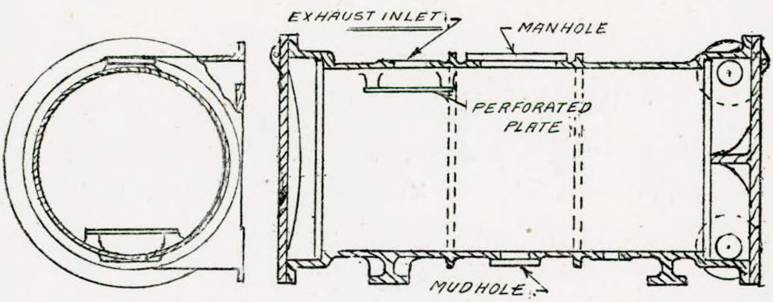
If the circulating pump is worked off the main engine it is usually of the reciprocating, double acting type. The main casting, bolted to engine columns, is of cast-iron, with a brass barrel driven into it and secured with steady pins. Water rings are used for bucket packing. Disc plates or rubber valves



Edward's Air Pump.

are used for suction and delivery valves. Access doors are fitted for examination of these valves. Air vessels are fitted on discharge side of pump to reduce shock, etc.

When the main condenser circulation is independent of main engines, it is invariably produced by a centrifugal pump worked by a steam engine. The pump shaft, coupled direct to the engine, is generally of forged bronze, keyed to impeller by brass key. The bearings supporting the shaft are lined with lignum vitæ, and are lubricated with water from interior of the pump. Impeller casting is of brass, and consists of a wheel having thin vanes as arms, these vanes being enclosed by and attached to two discs, thus giving strength to the vanes. Cast-iron or brass casing surrounds the impeller, it being made in halves, to allow of impeller, etc., being inserted, and is held together by fitted bolts. The jointing material is usually canvas or calico dipped in red lead jointing paint. Branches on casing, for inlet and discharge, should be on bottom half so as to allow of top being lifted for examination without breaking pipe joints. An air cock is fitted as near the top of casing as practicable, also an eyebolt for lifting purposes. To allow of circulating water for the condenser by ballast or general donkeys when required, a branch is sometimes fitted on circulating pump discharge to condenser. On twinscrew jobs it is usual to make cross connections between the circulating pumps, so that either pump can circulate either or both condensers.




Auxiliary Condenser.

Circulating inlets on ship's side are placed as low as possible. A cast-iron stool is held to ship's side by Muntz metal screw pins and nuts. Across sea entrance of this stool is fitted a brass grating to prevent entrance to circulating system of any solid substance. The area through holes in grating should be, at least, one and a half times the area of inlet pipe. Jointed to this stool is the inlet valve, the stool bringing it high enough to be accessible from the engine room floor. The casting for this valve has a connection on it (above the valve) for the bilge injection valve and sometimes also one for the connection from reserve inlet. This inlet (similar in construction to main inlet) is placed some distance up ship's side, and is so placed for use in muddy or sandy waters or when main inlet is choked. A steam connection is sometimes fitted on main inlet (below valve) to clear grating of dirt or ice.

The sketch shown, gives a common type of auxiliary condenser. The main casting is of cast-iron, and is similar in construction to main condenser. It is usually supported by brackets from ship's side or after bulkhead. For circulation it often has to depend on ballast or general donkey, but some pump makers construct very neat sets for auxiliary condenser duty alone such as:—A steam cylinder lying horizontally with piston passing through both ends of cylinder, one driving air and the other end driving circulating pump; a steam engine driving a centrifugal pump direct, while engine crosshead drives a pump lever which gives motion to an Edward's air pump; a De Laval steam turbine, the shaft being extended at each end, driving a centrifugal circulating pump at one end, while the other drives a rotary air pump.

In writing above notes, writer regrets that he had to cut some of them rather short owing to limit on length of essay.

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## * Failures of Heavy Boiler Shell Plates.

Summary of a Paper read by Mr. Sidney A. Houghton (Board of Trade Surveyor, Glasgow), before the Members of the Iron and Steel Institute, on May 8th, 1914.

In this paper some twenty-one cases of failure of large steel boiler shell plates are cited. These cases have all come under the author's notice during the last fifteen years, and an effort is made to tabulate the essential features of each case and to suggest as far as possible the causes of the failure and the probable means of prevention.

Although very careful methods of manufacture are generally adopted, instances of failures continue to be reported. Some of these are capable of reasonable explanation, but others occur mysteriously from causes that have neither been foreseen nor satisfactorily explained. All the plates dealt with were produced by the open hearth process. The usual mechanical—*i.e.*, tensile and bend—tests had given satisfactory results, and in each instance the plate had been bent cold in the rolls and all rivet holes drilled in place.

The cases considered are divided into three classes: A—plates in which cracks occurred, showing only on one side of the plate;

* cf. Paper No. CXCIX., Vol. XXV.

B—plates which cracked right across while they were being worked in the boiler shop; C—plates which failed under the hydraulic test.

Of thirteen examples in class A, eleven had been hammer-dressed, some very severely, to conceal surface defects. In a number of cases these defects appear to have been due to the surface of the slabs being overheated and so burned or decarbonised in the soaking pit, or to the plate being rolled and finished at too high a temperature. Some of the failures are attributed to the practice of piling (*i.e.*, stacking in piles) of hot plates immediately after rolling. Plates that are piled may be subject to great local differences of temperature, as their protruding ends and edges cool much more rapidly than their central parts. Check tensile and bend tests taken from the defective plates generally give good results except in the actual locality of the cracks, where failure of bends and low percentage of extension indicated the brittleness of the material. Some cracks appear to have developed during the bending process, and it is interesting to note the author's opinion that bending may produce what he terms "bubble" cracks, or cracks extending into the plate in the form of a section taken lengthways through an ordinary spirit level bubble. In two of the four cases in class B, the steel was found to have a comparatively high percentage of phosphorus, and this in conjunction with high carbon content or too much arsenic is stated to be sufficient to account for the cracking of the plates. One plate in addition to having been insufficiently rolled, had been finished at an excessively high temperature, and the fracture was more like that of a coarse casting than of a high-class boiler plate. In the fourth case the very fatal mistake had been made of not entirely machining away the raw sheared edge. The author quotes an authority as stating that the effect of shearing extends inward from the sheared edge for a distance about equal to half the thickness of the plate, and consequently this amount of the plate edge should be machined away to ensure the entire removal of the shearing effect.

The four cases in Class C must be regarded as the most serious of all. In each of these cases the actual factor of safety of the finished shell proved to be less than 2, seeing that a finished boiler is required to stand a hydraulic pressure equal to twice the working steam pressure. Two plates in this class cracked from the manhole to the edge of the plate, one cracked across the plate through some of the rivet holes of the manhole compensating ring but without actually touching the manhole. The fourth plate cracked across the solid plate from side to side.

In the first three cases the analyses show that the steel was not perfect, and contained certain local segregated impurities. But the author is of opinion that these defects alone would probably not have caused failure had not additional stresses been produced in the material through careless riveting of the manhole compensating rings. It is suggested that the safest method is to close up first the rivets at each end of the minor axis of the manhole, then work round gradually on each side to the ends of the major axis rimering out each hole in succession to take up any creeping of the ring. The possibility of fractures such as these would be avoided if manholes were cut in the end plates instead of in the shell.

The fourth plate in class C is thought to have been subjected to some abnormal heat treatment in the rolling mill. It is also reasonably certain that the ingot from which the plate was rolled had not had sufficient material cut away from its top end, and that a certain amount of the upper segregated impurities had been retained in the finished plate.

Discussing the practice of dressing plate surfaces with an emery wheel, the author points out that, although for purely surface defects this process may safely be adopted, he considers that plates which have been "buffed" to any considerable extent should be annealed before bending, as this will show whether the defect has been entirely removed.

Summing up, the following requirements should be complied with:—1. Ingots should be large enough to allow of all impurities being cut from the ends. The finished plate should not exceed in weight 45 per cent. of that of the ingot. 2. Annealing should be scientifically carried out. 3. The phosphorus content should not exceed 0·05 per cent., or when arsenic is present the sum of arsenic and phosphorus should not exceed 0·06 per cent. 4. Parts requiring to be dressed should undergo careful independent inspection before and after dressing. 5. Transverse tests should be taken occasionally from sides or ends of plates at points corresponding to the longitudinal axis of the ingot.

In the course of the discussion on the paper, mention was made of an interesting series of experiments made by Professor Arnold, of Sheffield, on a piece of boiler plate of undoubtedly good quality. Sample pieces of this plate were subjected to very drastic heat treatments, and yet gave good bend, tensile and fatigue test results. The Professor had, therefore, been forced to the conclusion that, provided the material was good to start with, any subsequent heat treatment could scarcely render it bad.

In opposition to this view it was contended by Dr. Rosenhain, of the National Physical Laboratory, that, provided suitable modern tests were applied, it could be readily shown that even initially good plates could be rendered bad by wrongful heat treatment alone.

A well-known steelmaker stated that steelmakers generally knew from experience how to avoid failures, but as this knowledge had only been gained by long and costly experience the individual steelmakers could scarcely be expected to publish their specialised knowledge broadcast. The responsibility of buying reliable material therefore lies with the steel user. Another steelmaker spoke in agreement with these opinions.

Dr. Stead, the distinguished metallurgist, pointed out that the two last-mentioned speakers had left the impression that they knew how to produce reliable boiler plates. Life depended on that knowledge. If steelmakers really did know, it would be but generous for them to explain how it was done. This, at least, was the humanitarian view, although from the commercial standpoint, it was somewhat impracticable. In any case a steelmaker who claims to possess the knowledge in question, must, of necessity, accept entire responsibility in the event of a defective plate being delivered by his works.

Almost all of Mr. Houghton's conclusions were severely criticised. Even his very definite remarks on the evil of hammer-dressing were challenged by a gentleman who stated that he had made a series of bend tests on hammered and unhammered specimens, and these tests went to show that hammer-dressing of itself does not tend to produce bad effects. Thus it appears that there is nothing approaching complete agreement as to the causes of many very mysterious failures, and although no very definite solutions of the deeper mysteries are given, yet there is a good deal of interesting matter in the paper and the subsequent discussion, and marine engineers would do well to consult a copy of the Journal of the Iron and Steel Institute (volume lxxxix.) and read the original paper and discussion in full. Appended to the paper are a number of interesting microphotographs and a tabulated statement giving details of each individual case of failure. A.L.

# ELECTION OF MEMBERS.

The following were elected at a meeting of Council of the Institute held on Wednesday, October 7th, 1914 :—

*As Members.*

Arthur S. Allen, 42, Clavering Road, South Wanstead, N.E.

Digby L. H. Collinson, The Elms, Sparrowsherne, Bushey, Herts.

Alexr. Finlayson, 18b, Golders Way, Golders Green, N.W.

Wm. Gordon, 90, Clapham Road, Lowestoft.

Sidney De Ritter, 1, Agnes Street, Burdett Road, E.

George F. Silley, 2, Hare Street, Calcutta, India.

John W. Watson, 107, Courtland Avenue, Ilford, E.

Shinkichi Yamada, Messrs. The Yokohama Dock Co., Ltd., Yokohama, Japan.

*As Graduate.*

D. Laugharne-Thornton, 18, Commercial Street, Shipley, Yorks.

# Notes.

Since the war commenced Mr. J. Rumsey, son of the resident officer-in-charge of the Institute premises, has been occupied as a scout at St. Albans, attached to the Y.M.C.A., and doing good patriotic work. He has now returned to assist in the Institute work.

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Mr. Norman Stewart, Assistant Secretary, was impelled by his convictions of what is right in the circumstances brought about by the war of devastation, to offer himself for the army, and has been drilling with the view of enrolling in the Seaforth Highlanders. It was deemed to be a commendable and patriotic act on the part of Mr. Stewart, and it was resolved to grant leave of absence to him for six months, with due sympathy towards Mrs. Stewart and their child in his honourable response to the call of the country. His Company is A, and his number is 5828.

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Another of our Graduates, Mr. Nicholas Rutherford, who wrote an essay for the competition, has enlisted for the war, in the "King's Royal Rifle Corps," 60th Foot (Celer et Audax).

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An expression of thankfulness that most of the engineers were saved, and of sympathy towards the relatives of the 3rd engineer (Mr. J. Brown), and of the electrician (Mr. Perrin), who were lost, was passed by the Council and conveyed to Mr. M. Turnbull, chief engineer of the hospital ship *Rohilla*, wrecked off Whitby on October 30th. The survivors suffered greatly on account of exposure to the severe weather. It is gratifying to know that they are recovering. Mr. J. H. Thomson, second engineer, in also a member of the Institute.

J.A.

from thence to one of three phases used for the gyro motors. Mounted concentrically with K, insulated from it, and also from the frame J, is the tube L, which also carries current to an annular mercury cup in the float F, and so supplies the second of the three phases. Connection for the third phase is made through the mercury between the metal of the bowl G and the float F, the third phase of the gyro motors being connected to the float.

The float F carries a conical steel tube O, upon the top of which is secured a triangular-shaped casting P of a strong aluminium alloy. This casting carries three sets of ball bearings, Q, R. and S, see Fig. 8, and these ball bearings carry vertical stems forming parts of the three gyro casings A,

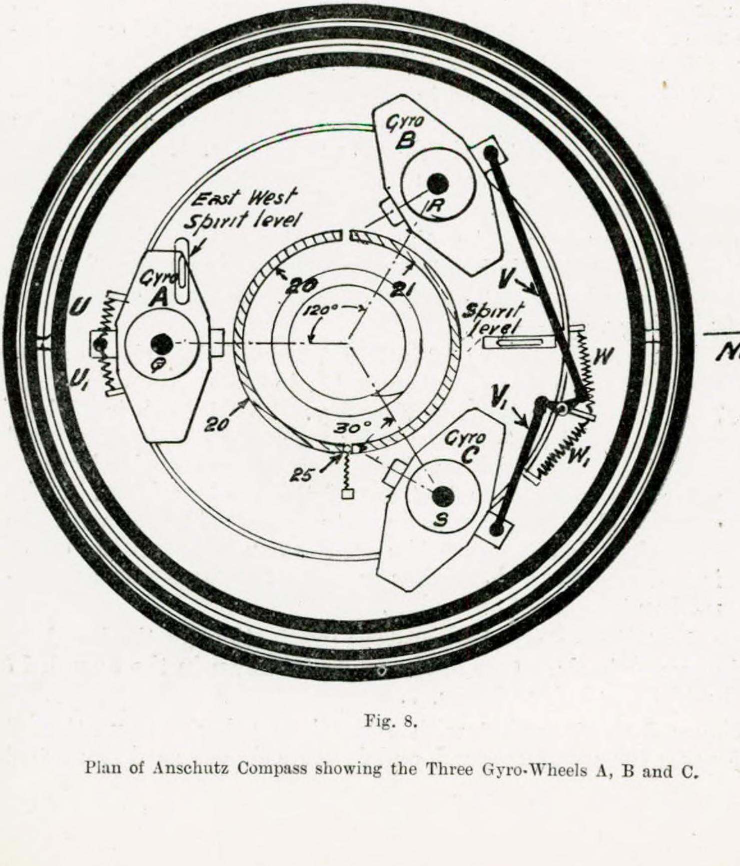



Fig. 8.

Plan of Anschutz Compass showing the Three Gyro-Wheels A, B and C.

B, and C. The centres of the ball bearings are set equidistantly from the centre of the frame casting and 120 degrees apart.

The gyro A in its casing is so mounted that its rotation axis is on a diameter of the whole floating system F and P, and coincides with the north and south line on the compass card T, which is rigidly attached to the casing P.

Referring to Fig. 8, the position of the casing A is maintained by the resultant tension of the two springs U and $U_1$. Gyros B and C are connected together mechanically by the connecting rods and links V. $V_1$. The rotation axes of gyros B and C are kept at an angle of 30° on either side of the N. and S. line on the compass card by the resultant tension of the two springs W and $W_1$.

Each gyro-wheel has its own 3-phase motor identical in size and connected in parallel, and it takes 1·1 amperes at 120 volts. The speed of rotation is 20,000 revs. per min., and the periodicity of the alternating current is 333 per second.

The three gyros arranged in this manner result in a combination which has the same directive force which was available in the earlier form with the single gyro as in Fig. 4. This directive force is due to the action of the gyro A and the resultant effect of gyros B and C.

Oilflow Damper.—As the three gyro-wheels rotate in different planes the air blast reaction damper mentioned above cannot be employed. Therefore, the damping is effected in the following way:—

> A casing marked 16 in Fig. 7 fitted below the compass card T has an annular trough 17, in which there is about 7ozs. of oil of a definite viscosity. The trough is divided up into small compartments by means of diaphragms, and these latter have orifices through which the oil slowly flows when the trough is tilted out of the level position. The speed of flow is adjusted so as to be out of phase with the normal period at which the trough can tilt, and the effect is to damp down the tilting in much the same way as anti-rolling tanks, act on a ship.

Incidentally the oil also serves as lubrication for the bearings of the gyro-wheels. One of the wicks is shown in the trough 17 on the left-hand side of Fig. 7.

The makers state that with this oil flow device any attempt to depress the north or south end of the compass card causes all three gyro-wheels to precess, and the moving system regains its horizontality after one or two swings, each having a period of about 90 minutes.

On the other hand, if the east-west end of the card is pressed down the gyro-wheel A, Figs. 7 and 8, swings in its plane of rotation and does not precess whilst gyro-wheels B and C precess equally in opposite directions, thus causing a disturbance of the equilibrium of the springs W $W_1$ shown in Fig. 8. This equal and opposite precession of B and C has no effect as regards the position of the compass card relative to the meridian. The springs reassert themselves when the pressure is removed, and the compass card regains its horizontal position about the E.W. line after a few swings, the period of which is about 1 minute instead of $1\frac{1}{2}$ seconds, as in the case of the earlier single gyro-wheel air-damped compass.

The movements of inertia of the whole moving system about the N.S. and E.W. axes being nearer one another in value there is an improvement in the performance of the instrument under rolling and vibration conditions.

Electric Motors.—Referring again to Figs. 7 and 8 it will be seen that the steel body of the mercury bowl G. carries two semi-circular contact rings 20 and 21. These are insulated from each other and from the bowl, and the gaps between their ends are only about ·07 inch wide, as shown in Fig. 8.

These semi-circular rings are connected to the slip rings 22 and 23, see Fig. 7, whilst the slip ring 24 connects the earthed phase to the mercury bowl G.

At the east point of the compass card T, there is a contact 25, see Fig. 8, in the form of a platinum ball slightly smaller in diameter than the opening or slot between the semi-circular rings 20 and 21. When the compass has settled down and the ball is midway between 20 and 21 no current flows through it, but as soon as the ship alters course the binnacle carries round the frame J and the bowl G, so causing 20 or 21 to touch the ball 25.

The object of this is to change the direction of the current in one of the phases, and thus change the rotation of a three-phase reversible motor, which is mounted independently of the compass, and therefore not shown in Figs. 7 and 8. This motor receives its supply via brushes which rest on the slip rings 22, 23 and 24.

The reversible motor drives a special commutator consisting of one longitudinal strip carried on an insulating cylinder, and furnished with a ring at one end on which there are carbon brushes. This gives undirectional current at 20 volts, which is supplied to the motor marked 26 at the bottom of Fig. 7.

This motor 26, is of the direct current, 4-pole type, similar to those employed in fire control instruments. The gearing is such that it takes 1,800 revolutions of the motor armature to cause one revolution of the large gear-wheel marked 27, which is keyed to the vertical axle H.

The direction of rotation is so chosen that as soon as semi-circular ring 20 touches the ball 25 the motor 26 turns the gear-wheel 27, and consequently with it the bowl G and the rings 20 and 21, so that 20 moves away from ball 25, so breaking the circuit.

It should be noted that as the bowl and the mercury in it is revolved the friction between the float F and the mercury in which it is floating is reduced.

The commutator above-mentioned has other brushes on it, set at 120 degrees apart, which serve to transmit step by step currents to the various repeater compasses placed in other parts of the ship. The cards of these repeater compasses are thus made to synchronise exactly with the compass card of the master compass.

## THE SPERRY COMPASS.

This compass, due to E. A. Sperry, of the United States, is suspended by means of a wire as in the original Foucault instrument, but with the difference that an automatic follow-up device is provided to take the twist out of the suspension wire directly the gyro-wheel moves. This relieves the gyro-wheel from the task of overcoming friction round the vertical axis.

Fig. 9 is a general view with the bowl lowered so as to show the gyro-wheel, etc., and its position relative to the horizontal gymbal ring. The two dials immediately over the gymbal ring are to give mechanical corrections to allow for varying speeds and latitudes. The outer ring surrounding the gyro-wheel casing is called by the makers a phantom ring, and it will be noticed that the gyro-wheel casing and the outer ring are not quite concentric. The crescent-shaped space between them contains a pendulum. On the right it will be noticed that there is a spirit level supported by brackets from the gyro-wheel casing.

Fig. 10 is a view looking at the north-end of the gyro-wheel casing. The wheel is carried in ball bearings in casing B, and this casing is in turn carried on the horizontal axis C and a ring, which is called the cardan ring. The cardan ring D is suspended by a stranded wire E, which passes through two steadying bearings FF. The top of the wire is held in a frame which can be rotated, and attached to this frame and moving with it is the ring G, which the makers call a phantom ring because it follows the cardan ring about the vertical axis. The upper frame which surrounds the above-described sensitive element is suspended in gymbal ring K by bearings $L_1$ and $L_2$ in the manner usual with all compasses.

Fig. 11 is a diagrammatic view taken from Fig. 10, the various parts being analysed out and named. The pendular nature of the construction is thus clearly seen.

Follow-up System.—Fig 12 shows the gyro-wheel casing tilted over so as to show more clearly the cardan ring and the attachments. The pillars at the top are for making connections to the follow-up motor, and when the compass is completely assembled, these pillars carry small gold-covered wheels

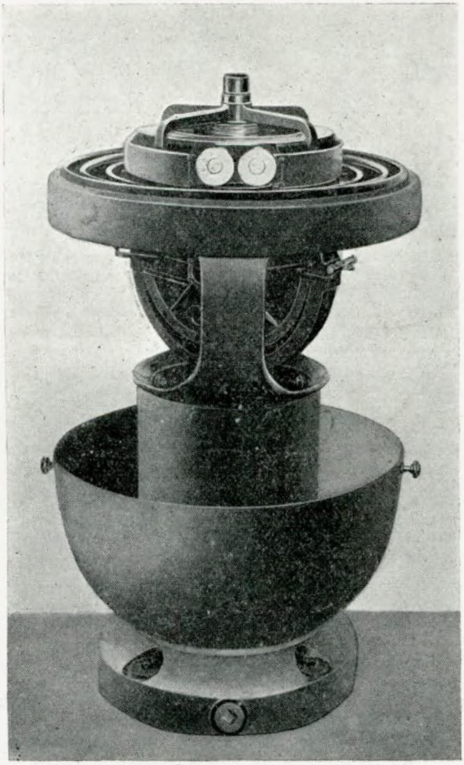


Fig. 9.

Sperry Gyro-Compass.

Bowl lowered to show Gyro-Wheel casing, Phantom ring, Spirit level, etc.

which rest against two flat commutators carried in the movable frame of the compass, of which the phantom ring and suspension head are integral parts.

Each commutator has two gold-covered segments, see *bb* of Fig. 13, which are insulated from each other by a narrow piece of mica. When the frame and sensitive element are both at

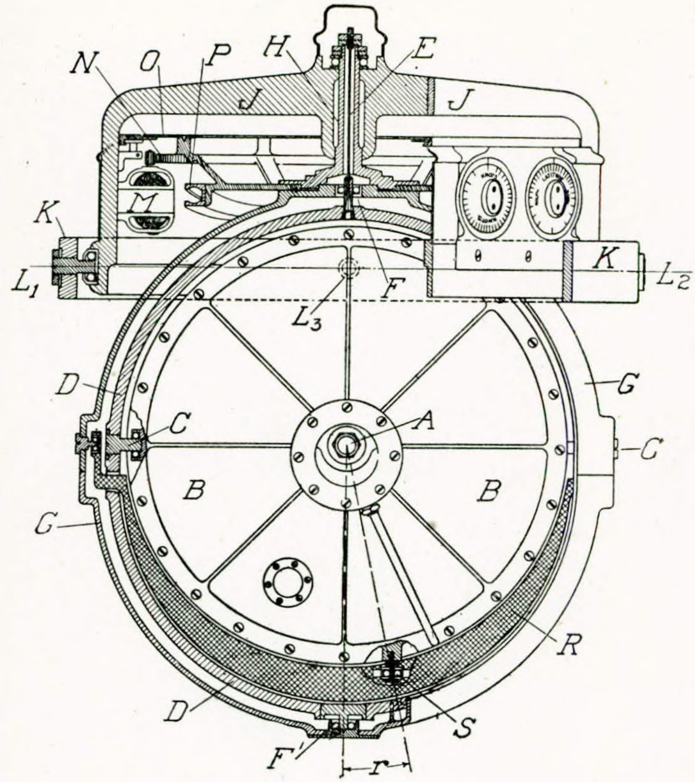


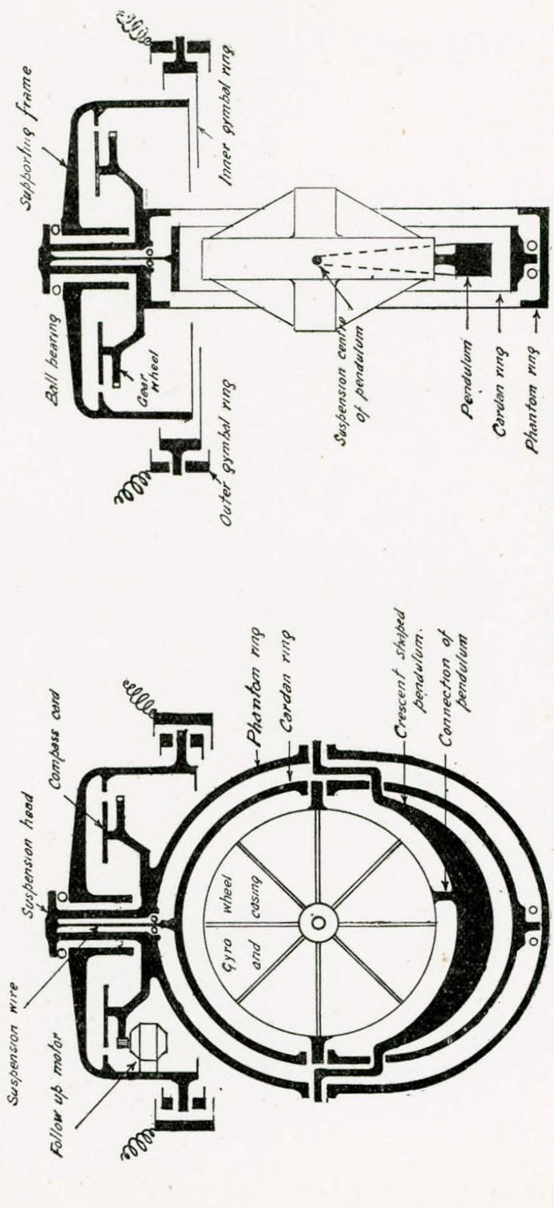

Fig. 10.

SPERRY GYRO-COMPASS

Diagrammatic Section and Partial Elevation looking at North End

References.

A Axis or spindle gyro-wheel.
B Gyro-wheel casing.
C Horizontal axis.
D Vertical cardan ring.
E Stranded supporting wire
F Top steadying bearing.
$F_1$ Bottom steadying bearing.
G Outer or phantom ring.
H Hollow stem supporting ring G.
J Main frame.
K Gymbal ring.
$L_1$ $L_2$ $L_3$ and $L_4$ Gymbal bearings.
M Azimuth or follow-up motor.
N Gear wheel driven by motor M.
O Compass card.
P Cam forming part of correcting device.
R Crescent-shaped pendulum.
r Angle of eccentric attachment
S Attachment of R to gyro casing.




Diagramatic sketch of Sperry Compass.

Fig. 11.

rest, the trolley wheel *a* of Fig. 13 (which is carried by the post on the vertical cardan ring) rests against both segments, thus energizing both field coils controlling the movements of the follow-up motor M. This follow-up motor is shown to the left of Fig. 10, and it drives the wheel attached to the compass card and suspension head.

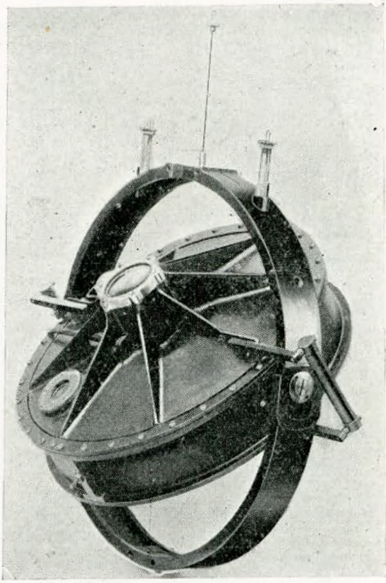


Fig. 12.
SPERRY GYRO-COMPASS.
Gyro-Wheel Casing, Cardan Ring and Suspension Wire, etc.

Directly the gyro-wheel moves about the vertical axis each trolley wheel moves on to one or the other of the segments, thus rotating the motor M and causing the frame, phantom ring, compass card and repeater transmitter to follow the gyro-wheel. The *top* of the suspension wire is thus always following the *bottom* of the wire and the wire is nearly torsionless so that the suspension has very little friction about the vertical axis.

From the electrical connections shown in Fig. 13 it will be seen that the motor M is fitted with duplicate and oppositively wound field coils *ff* and $f^1f^1$. When the trolley wheel is on contact $b_1$, the field coils *f* and *f* are excited and the motor-runs in one direction, and when the trolley wheel is on contact $b$ the fields $f^1 f^1$ are excited and the motor runs in the opposite direction.

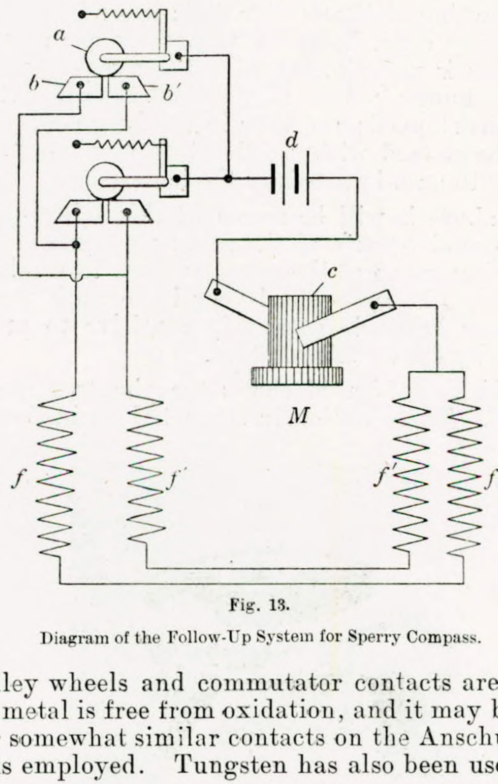



Fig. 13.

Diagram of the Follow-Up System for Sperry Compass.

The trolley wheels and commutator contacts are of gold because that metal is free from oxidation, and it may be here mentioned, for somewhat similar contacts on the Anschutz compass, platinum is employed. Tungsten has also been used.

In order to prevent or reduce sparking between the trolley wheel $a$ and the contacts $bb$, a small condenser is connected across, and this acts as a sort of cushion for absorbing the energy that would otherwise dissipate at the contacts.

Hunting of Compass Cards.—By means of a mechanical device on the motor, the trolley wheels are kept moving from one contact to the other so as to keep the parts in a constant state of vibration and reduce static friction. This is also an advantage because the compass card and the cards of the repeater compasses are also always hunting for about one-fourth of a degree. This term "hunting" refers to a rapid oscillation in the horizontal plane about the axis of the repeater card. It is an excellent thing for three reasons; 1st: so long as the repeater card is hunting at its usual speed and amount, the officer-of-the-deck can be reasonably certain that the master gyro-compass is running satisfactorily; 2nd: if the helmsman, using the non-hunting card, keeps on the course for any length of time—and this is not difficult with the gyro-compass—it is a peculiarity of human nature that he will turn the wheel to see if the gyro has stopped; and thus in the long run, a straighter course can be steered with the hunting card; 3rd: it avoids any tendency to auto-hypnosis of the helmsman.

From the above it will be seen that this follow-up motor is the most essential feature of the Sperry compass. The motor does the driving round of the compass card, transmitting gear, etc., and leaves the gyro-wheel very little work to do. The latter can thus be made extremely sensitive to precessional action set up by the earth's rotation.

Phantom Ring.—Fig. 14 shows the phantom ring and the compass card. Three of the six contact rings in the centre are

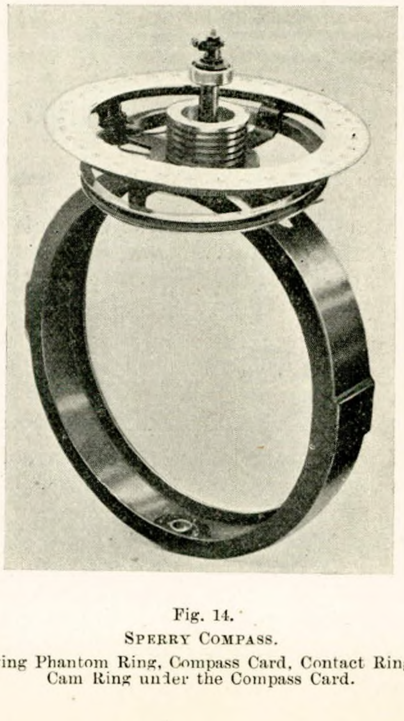


Fig. 14.

Sperry Compass.

Showing Phantom Ring, Compass Card, Contact Rings, and Cam Ring under the Compass Card.

for the purpose of passing 3-phase current to the gyro-wheel motor, two are to pass direct current to the follow-up motor, whilst the remaining one is for an alarm circuit. In case any electrical connection is broken or anything abnormal occurs, a bell on the control switchboard is caused to ring.

It will be noted that part of the large-toothed driving wheel shows below the edge of the compass card and below this again there is a grooved ring. This is a cam, and it is connected to the above-mentioned mechanical correction dials (see Figs. 9 and 10), the effect of these mechanical correctors being to alter the lubber line of the compass.

Crescent-shaped Pendulum.—One of the most essential parts of the compass is the crescent-shaped pendulum marked R in Fig. 10. This pendulum swings on trunnions in the phantom ring, and it should be specially noted that it is connected to the bottom of the gyro-wheel casing at the point S, which point is thus offset to the vertical centre line and to the horizontal centre line. The function of the crescent-shaped pendulum is to provide a *yielding* connection between the gyro casing and the phantom ring, and provide a means of suppressing freedom about the horizontal axis. When the compass is off the meridian and the rotation of the earth has thus caused the axis to incline out of the horizontal, gravity acts to bring it back.

When under the effect of the earth's rotation, the horizon, upon whose centre the gyroscope is situated, gets inclined with reference to the position it previously occupied, the axis of the wheel remains parallel to its former position, and it thus becomes inclined towards the earth's surface, that is to say, towards the *new position* of the horizon. Being subject to gravity the crescent-shaped pendulum tends to keep the gyro-wheel always in the same position with respect to the earth, and it thereby causes it to swing into the meridian. It does not swing the whole suspension frame into the meridian, but only begins to do so, for as before explained, the actual work is done by the follow-up motor.

The following description is due to Mr. R. E. Gilmor of the Sperry Gyroscope Co.:—

The pendulum being attached eccentrically to the vertical axis serves to partly suppress freedom about that axis, thus damping the oscillations of the gyro to bring it to the meridian by the shortest path. Further, since the phantom ring *G* stands in constant relation to the casing *B*, but is none the less independent from it, this ring forms the base from which movements may be made to produce a positive orientation of the wheel. At any position on the earth's surface except at the equator, the earth's rotation has a vertical component, its action being such as to tend to leave the north end of the axis of the gyro on the east side of the meridian. When the axis is left behind the meridian a portion of the tangential component of the earth's rotation causes a tilt which introduces the gravity couple of the pendulum about the horizontal axis. Simultaneously with this the couple about the vertical axis is also introduced, tending to destroy the couple about the horizontal axis. For every latitude there is some position of lag behind the meridian at which the couple about the vertical axis just maintains the axis of rotation at a tilt such that the couple about the horizontal axis can cause the necessary precession to follow the vertical component of the earth's rotation. A northerly or southerly component of the ship's speed acts to change the apparent direction of the earth's rotation, so that the resting position of the axis of the gyro varies with change in speed and course of the ship on which it is mounted. The variation of lag behind the meridian for variation of latitude and variation in course and speed of the vessel make it necessary to correct the axis of the gyro in accordance with the equation—

$$D = \frac{a\ K \cos H}{\cos L} - b \tan L,$$

in which $a$ and $b$ are constants, $K$ is the speed, $H$ the course, and $L$ the latitude. This correction is automatically solved and applied to the compass by means of a mechanical correction, shown in Fig. 10, which, when set for approximate speed and latitude, constantly corrects the lubber's point of the compass card, and the repeaters in such manner that the headings shown are always referred to the true geographical north.

## ELECTRICAL DRIVE.

Some references to the 3-phase electrical drives of the above-mentioned compasses will be of interest as much ingenuity has been given to perfecting this most essential feature*. The gyro-wheels of both the Anschutz and the Sperry compasses are similar in so far as the web is at one side of the rim and the rotor conductors are carried in slots in the inner periphery. The Anschutz wheel is only 6ins. diameter and 1in. wide and it is solid, whereas the Sperry wheel is 12ins. diameter and 2ins. wide and it has charcoal iron laminations on the inner periphery. These laminations are held in by the junk ring shown in Fig. 15 which is secured by the inner row of screws. The outer row of screws which is duplicated on the opposite side of the rim is for the purpose of accurately balancing the wheel. These screws are short and are merely filed down until exact dynamic balance is attained. As the spindle cannot deflect to allow the wheel to find its own balance, as in the case of the de Laval type of spindle used with the Anschutz gyro-wheel, it is the more important to secure exact balance.

* At one time the writer thought that it might be possible to drive a gyro-wheel as a homopolar motor. The solid construction of the rim and the very high peripheral speed are favourable factors, but the principal difficulty lies in the rubbing contacts for current collection. A description is given in British Patent No. 21671—1910.

The spindle is separate from the wheel, and is tapered where it passes through the boss. This enables the steel of the wheel to be of different quality, and in this case it is vanadium steel.

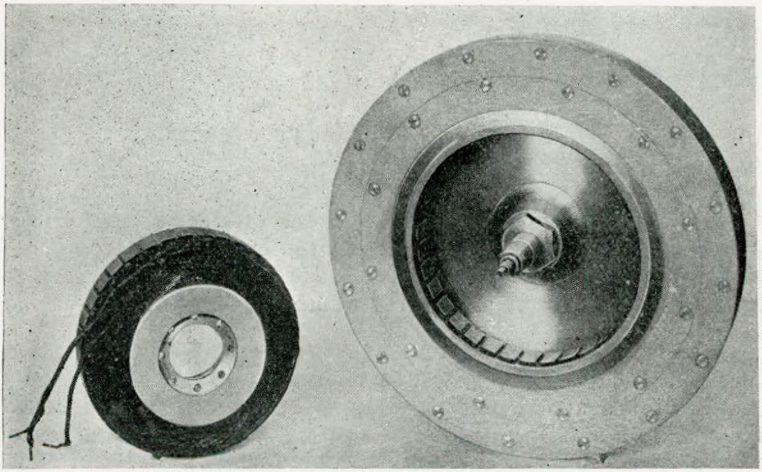


Fig. 15.

Stator and Gyro-Wheel with Rotor for the Sperry Compass.

The wheel and spindle weigh about 43lbs., whereas the wheel of the Anschutz compass only weigh 6lbs. In the latter case the spindle and the wheel are in one piece. The casing is of an aluminium alloy, and it is fitted with vacuum valve and gauge, for in order to keep down the current and, therefore, the heating, so it is necessary to run the wheel in vacuo. A window is also fitted in the casing and a scroll is painted on the side of the wheel, which can be observed through the window. It is looked at through a special instrument having a revolving slit, and when the speed at which the slit revolves synchronises with the speed of the wheel, then the scroll appears to be standing still. In this way the speed of the gyro-wheel can be read off at any time.

Periodicity.—The Anschutz gyro-wheel runs at about 20,000 revs. per minute and the Sperry wheel at about 8,600 revs., and in order to get these speeds it is necessary to generate 3-phase current at much higher periodicities than those commonly used for lighting and power circuits.

The motors of the gyro-wheels have two poles, and consequently the periodicities are for the Anschutz:—

$$\frac{20,000 \times 2}{60 \times 2} = 333 \text{ periods per second.}$$

and for the Sperry compass:—

$$\frac{8,600 \times 2}{60 \times 2} = 145 \text{ periods per second.}$$

Motor Generator.—The motor generator is quite small and usually consists of a direct current motor coupled to a small alternator of special construction. Its construction is very robust as it has to run for months without stopping.

Owing to the quick speed of the gyro-wheel and the importance of not passing too much current through the stator it usually takes about half-an-hour to run it up to full speed. To actuate a starting resistance step by step during this period would be tedious, and therefore the alternator of the motor generator is specially designed with a large voltage drop so as not to pass more than a given amount of current. This is a condition given by an alternator of the inductor type. To start up the gyro-wheel it is only necessary to switch current on to the motor generator and to connect the high periodicity alternator to the gyro-wheel motor. The latter then gradually runs up to full speed without attention. Should the direct current supply fail and so allow the no-volt release to act, the gyro-wheel motor can still remain connected up, whilst the starting switch is used to run the motor generator to speed again, without any attempt at synchronising.

## ERRORS.

It will be readily seen that the conditions to be met on board a ship, especially in rough weather, are very different to those on a stable base on land. Not only are there difficulties due to rolling and pitching and vibration, but the course the ship is sailing, the varying speeds at which it travels, the latitude it happens to be in, all affect the gyroscope compass to a more or less degree. The errors set up in the above-mentioned compasses by these various conditions may be enumerated as follows:—

1st. Error due to latitude.
2nd. Error due to change of latitude at constant speed.
3rd. Error due to change of speed.
4th. Error due to rolling and pitching.
5th. Error due to slowness of gyroscope.
6th. Error produced by steering.

Now it happens that most of these errors can be traced to one feature which both the Anschutz and the Sperry have in common, namely, that they are pendular, that is to say, they depend upon the force of gravity to be effective. They may be represented in diagrammatic form by Fig. 16, and Fig. 17 explains the principle of working.

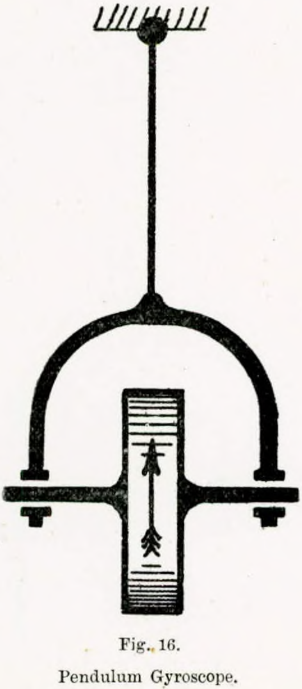


Fig. 16.

Pendulum Gyroscope.

Assume the compass is on the equator at A, Fig. 17, then, after some hours it will have rotated with the earth to position B. Now, as the gyro-wheel tends to remain parallel to itself, it will try to be in the position shown by the dotted lines at B,

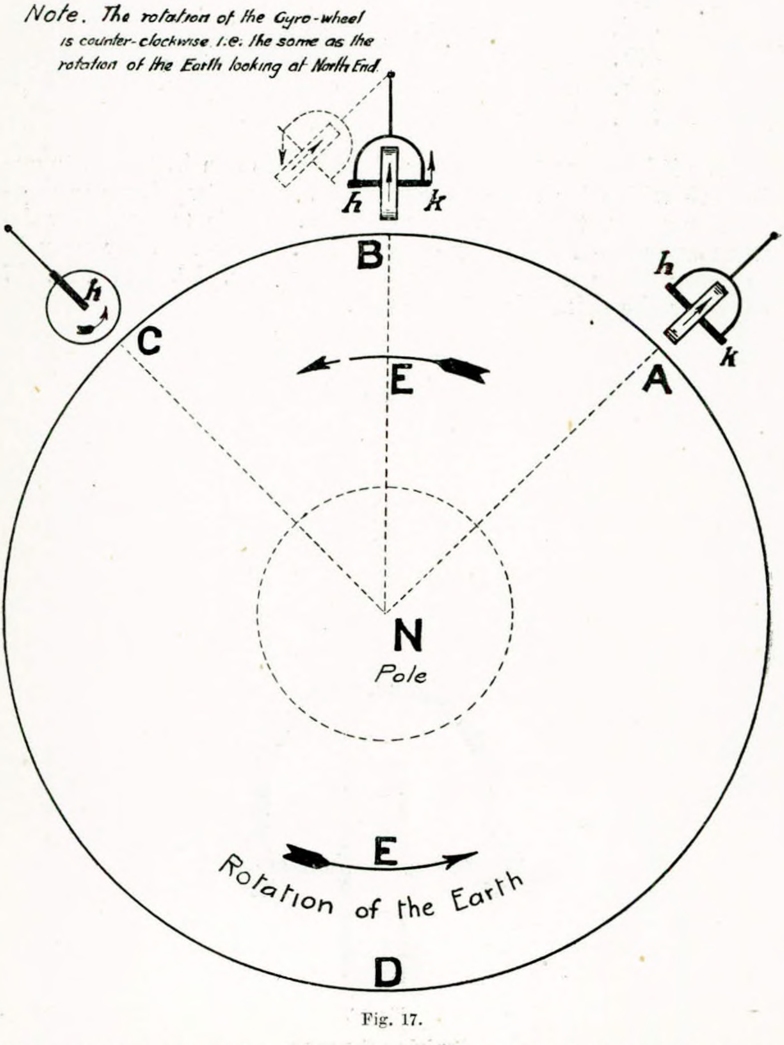



Fig. 17.

Diagram to illustrate the Effect of Earth's Rotation on a Pendularly Suspended Gyroscope.

but being pendular the force of gravity will dispose it as shown by the full lines at B. In doing so the end of the axle of the wheel marked *h* will be depressed whilst the other marked *k* will be raised. The effect is the same as if pressure were exerted on the ends of the axle as shown by the small arrows, and the result is a precession of the end *h* towards the pole N, and this precession stops when the axle end *h* points north as shown at position C. If the axle overshoots, it will come again under the influence of the earth's rotation and gravity, and precess back until it points towards N, where it will remain. No further effect then takes place, because it continues to move round with the earth, parallel to itself.

1st. Error due to Latitude.—When on any other latitude than on the equator, a pendular gyro-compass is subject to an error whether it be on board ship or on a stable base on land. The error corresponds to the declination of a magnetic compass, with this difference, that while the magnetic declination varies yearly and irregularly all over the earth's surface, gyroscope declinations are regular and constant for a given latitude.

If we assume in Fig. 18 that the gyro-compass at F points north, then after say 12 hours it will be at G and under the effect of gravity it will be suspended vertically, *i.e.*, disposed towards the earth's centre. In coming into this new position, the axle end *k* has dipped and the axle end *h* has been raised as represented by the arrows at the dotted position G. The dotted lines are parallel to the position that the gyroscope occupied at F Fig. 18. Now, as the axle end *k* dips under the influence of gravity, this produces a precession of the axle end *h* (in position G) backwards or into the paper. In other words, the gyro-compass tends to point more towards the east of the meridian. A little consideration will show that this couple depends on the angle ($2\gamma$) at P, or in other words it depends on the latitude, for the angle at $\gamma$ increases with the latitude, being maximum at the poles and zero at the equator.

So soon, however, as the axis of the gyro-wheel leaves the meridian, it becomes subject to the vertical movement of the horizon round the earth's axis, that is to say, it gets tilted out of vertical. Being still under the effect of gravity, it tends to come vertical again and so bring the axis of the gyro-wheel back into the horizontal plane, hence another precession back into the meridian.

For every latitude there is an inclination of the pendular system out of vertical, at which the righting couple produced by gravity, which is the one bringing the gyro-compass back *into* the meridian, is just equal to the perturbing couple producing the original deviation *out of* the meridian.

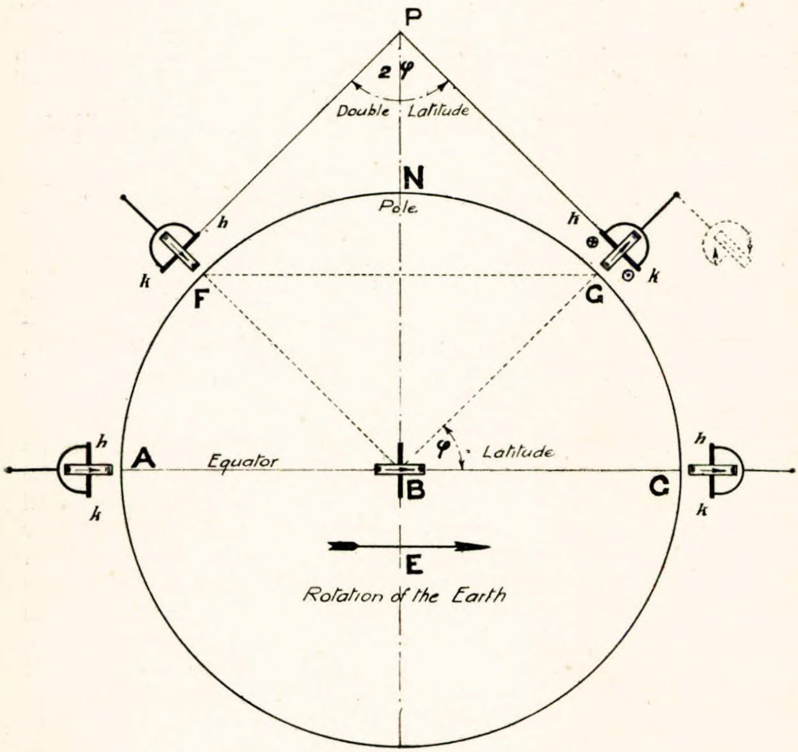



Fig. 18.

Diagram to illustrate Error due to Latitude.

The Anschutz compass is adjusted for this by means of the small weight *t* shown in Fig. 5 for 50°N. For every other latitude a correction has to be applied to the readings as shown by the curve in Fig. 19, which is plotted from correction tables supplied with the compass.

For the Sperry compass there are no such tables, but the corrections for this latitude error are added to or subtracted from the reading of the card by means of the mechanical corrector shown in Figs. 9 and 10. This is set by hand, and adjustments can be made for every 5° of latitude. The right-hand dial gives the mechanical correction for latitude.

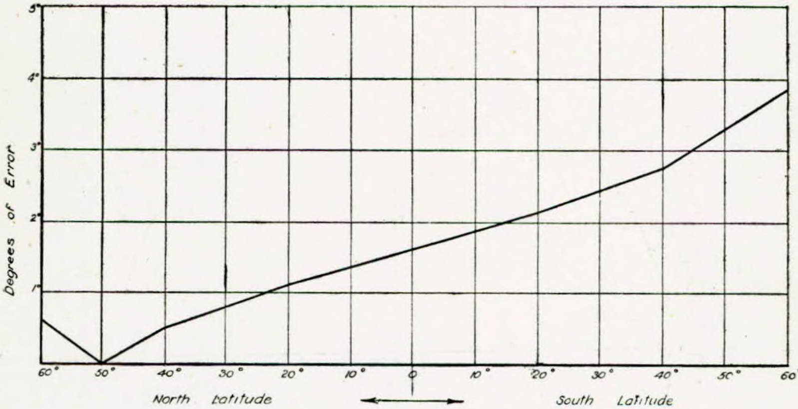



Fig. 19.

Curve shewing amount of Error at different latitudes with the Anschutz Compass adjusted for 50° N.

2ND. ERROR DUE TO CHANGE OF LATITUDE AT CONSTANT SPEED.—Since every ship's movement along the earth's surface is a movement of the gyro-compass in space, it follows that the motion of the ship on her course must influence the indications of the compass.

Referring to Fig. 20, if a ship sails along the equator from A to C, no error will be produced, because the gyro-wheel axis moves parallel to itself. If, however, it sails towards the poles, as for instance from A to F or from C to G, the gyroscope becomes inclined, dipping its axle end $h$ and raising the other $k$, and thus producing a westerly deviation. For example, at position F the axle end $h$ will go into the paper, whilst at the position G the end $h$ will come out of the paper, and this is, of course, for constant ship's speed towards the poles.

If the ship sails from B to F or B to G, then her speed will be represented by dotted lines BF and BG respectively, while her northern progress will be AF or CG. Only the northern progress affects the indication of the compass, and as it is proportional to the ship's course, speed and latitude, this error is proportional to all these three factors.

In the Anschutz compass this error is corrected by adding a value to the compass card readings, and the makers provide calculated figures for this purpose for various speeds. Figs. 21A and 21B are plotted from these readings, for 20 and 30 knots and show how the error increases with speed.

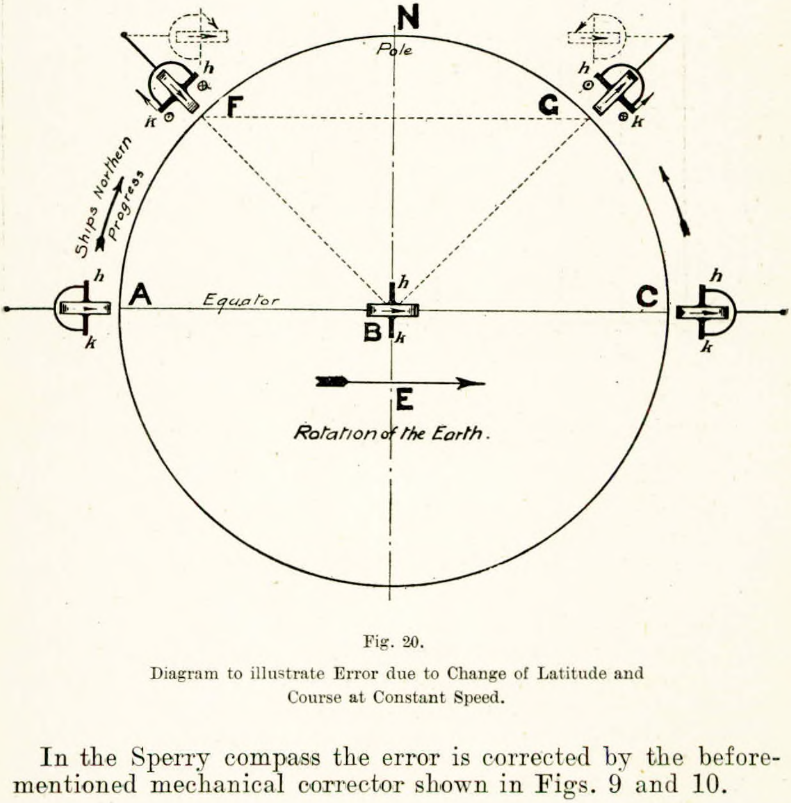



Fig. 20.

Diagram to illustrate Error due to Change of Latitude and Course at Constant Speed.

In the Sperry compass the error is corrected by the before-mentioned mechanical corrector shown in Figs. 9 and 10.

3RD. ERROR DUE TO CHANGE OF SPEED.—When the ship is accelerated on her course, another error takes place owing to the gyro swinging out on account of its inertia and because it is suspended, pendulum-like. If the acceleration or retardation of the ship's speed takes place in a course due east or west there is no error because the axle of the gyro-wheel then swings parallel to itself, but in any other direction than due east or west there is an error.

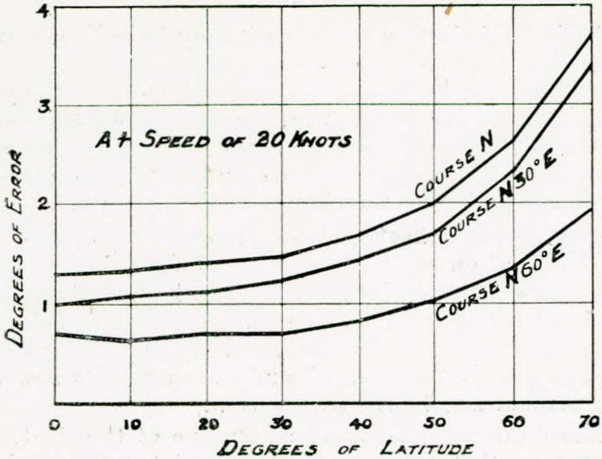



Fig. 21A.

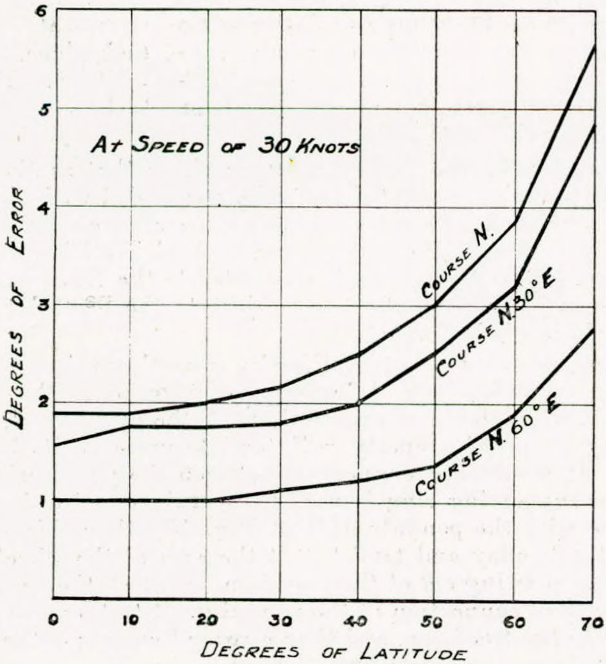



Fig. 21B.

Curves showing increase of Error due to Change of Course and Latitude at Constant Speed.
(From Tabular Figures supplied with the Anschutz Gyro-Compass.)

This ballistic deflection error, as it may be called, can be regarded also as the over-running of the compass when altering its resting position for the ship's original speed to the position corresponding to the ship's new speed. The ballistic error therefore lies always in the same direction as the change of the error produced by change of course and of latitude at constant speeds, before and after the change of ship's speed.

As the ballistic deflection is dependent on the time of one complete oscillation of the gyro-compass, it is evident that if the period of oscillation is of appropriate length, the gyro-compass will not over-run its new resting position. Therefore, by allowing sufficient time for the oscillation damping device to act, the compass is "dead beat" and comes into its new resting position without any ballistic deflection.

The Anschutz compass takes advantage of this fact, and is constructed so that for some particular latitude, the ballistic deflection amounts exactly to the above-mentioned difference of error produced by change of latitude and course at constant speed before and after the change of speed took place. There is, therefore, no deflection at that particular latitude. For any other latitude there is an error which has to be corrected by means of a calculated table.

The makers of the Sperry compass claim that as the gyro-wheel of their instrument is centrally suspended with three degrees of freedom, the compass cannot be affected by ballistic deflection. It is true that the gyro-wheel itself is suspended centrally, but as the casing is connected to the framework and not free in its movements it is subject to the pendular movements of the whole frame.

If we consider a ship travelling on a north-south course and altering its speed, then the gyroscope, together with the support, will swing out of the vertical, while the gyro-wheel, owing to its gyroscopical property will tend to preserve its horizontality. If a yielding connection between the gyro casing and the gyro supporting ring is used to restrain one freedom as is the case with the pendulum R of Fig. 10, then this will be brought into play and tend to tilt the axis of the wheel, thus producing a swing *out* of the meridian. But at the same time the point S of connection of the pendulum R to the gyro casing is offset to *two* freedoms, and thus a second component is introduced, helping the gyro-wheel to keep in the meridian.

This effect is opposite in direction to the first-mentioned dip of the gyro-wheel axis. Consequently, if the excentricity of the point of connection of the casing to the pendulum or freedom restraining device is properly chosen, the two precessions counteract each other, and the gyro-wheel axle will remain horizontal.

Evidently, not only must the position of attachment of the yielding connection to the gyro-casing be properly chosen to eliminate ballistic error, but the strength of the yielding connection must also be suitable, and even when both these conditions are fulfilled the correcting effect is only for a certain latitude. In respect of this error there is no difference between the Anschutz and Sperry compasses.

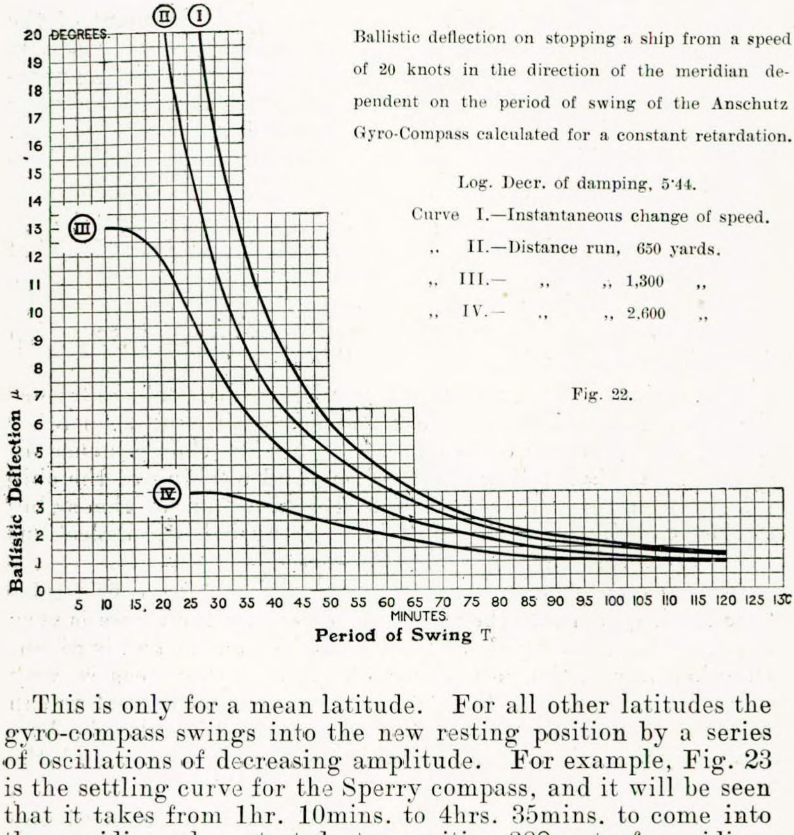
The yielding connection of the Sperry compass must be adjusted to give no ballistic deflection at a mean latitude, that chosen being 50°N. In all other latitudes, just as in the case of Anschutz, the overswing of the gyroscope over its resting position for the new speed varies with small oscillations which decrease in size but last a considerable time.

4TH. ERROR DUE TO ROLLING AND PITCHING.—The nature of the two compasses necessitate very free suspension, or in other words, they are quite free to swing under the influence of gravity. It thus follows that rolling and pitching of the ship introduces sudden acceleration and retardation of the swing of the pendulum, which result in so many ballistic deflections out of the meridan.

As these oscillations around the meridian take considerable time to disappear and the ship's movement on the waves is very unharmonic, no warning of their comencement or end is given. In other words, the perturbing effects of stormy seas is very irregular and no correction tables or mechanical correctors can allow for them. To attempt to cope with this difficulty the Anschutz compass is now fitted with three gyro-wheels and the Sperry compass with two gyro-wheels.

5TH. ERROR DUE TO SLOWNESS OF GYROSCOPE.—After being displaced out of the meridian, both the Anschutz and Sperry gyro-compasses take considerable time to return into it again, and this causes an error in steering. For different courses, speeds, and latitudes, the compass has a different resting position for each set of conditions, and when any of them are changed it is slow to settle in the new resting position. The time taken may be an hour or more. Fig. 22, for example, shows the time taken by an Anschutz compass to alter its resting position for change of speed only in course N. and when dead beat. Taking the best of the curves, namely, number

IV., it will be seen that starting at 30 minutes the compass does not settle down in the new position before 90 minutes, in fact, it does not definitely settle until after about $1\frac{1}{2}$ hours.




Ballistic deflection on stopping a ship from a speed of 20 knots in the direction of the meridian dependent on the period of swing of the Anschutz Gyro-Compass calculated for a constant retardation.

Log. Decr. of damping, 5·44.

Curve I.—Instantaneous change of speed.
,, II.—Distance run, 650 yards.
,, III.— ,, ,, 1,300 ,,
,, IV.— ,, ,, 2,600 ,,

Fig. 22.

This is only for a mean latitude. For all other latitudes the gyro-compass swings into the new resting position by a series of oscillations of decreasing amplitude. For example, Fig. 23 is the settling curve for the Sperry compass, and it will be seen that it takes from 1hr. 10mins. to 4hrs. 35mins. to come into the meridian when started at a position 38° out of meridian. Also, for an amplitude of 2°, it takes from 2hrs. 45mins. to about 4hrs. 30mins. to come into the meridian.

As the speed course and latitude must of necessity change constantly it follows that there is always more or less steering error and the error is, of course, greatest when the change in course is considerable.

6TH. ERROR PRODUCED BY STEERING.—The steering error is due to the wandering of the gyro-compass during turning and the consequent drag. Its maximum value in the Anschutz compass is about $1\frac{1}{2}$ degrees, while in the Sperry it is guaranteed not to exceed one third of a degree.

SUMMARY OF ERRORS.—The 1st, due to latitude, and the 2nd, due to change of latitude at constant speed, are caused by the gyro-compass not having sufficient righting momentum.

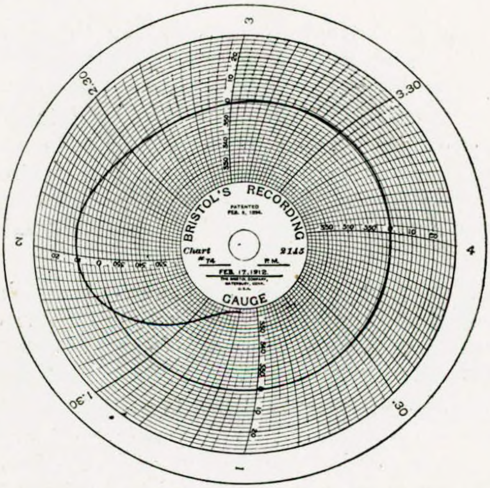



Fig. 23.
Settling Curve by Automatic Recording Instrument, Showing Damping Coefficient (Sperry Compass) taken at the U.S.A. Navy Yard, New York, February 17th, 1912.

The 3rd, due to change of speed, and the 4th, due to rolling and pitching, are caused by the ballistic nature of the suspension.

The 5th error, due to slowness of the gyroscope, may be said to be due to inertia.

The 6th, produced by steering, is due to friction and inertia.

The first three errors are approximately allowed for in the Anschutz compass by the use of calculated tables, and in the Sperry compass by means of hand-operated mechanical correctors.

The last three errors cannot be eliminated, but the most serious one, namely, the 4th, has been minimised by the addition of extra gyro-wheels.

It will be noted that one group of errors is caused by insufficient righting moment as introduced by gravity, and the other group is caused by the ballistic properties.

Clearly, the ideal gyro-compass should be one that will automatically adjust itself for all conditions as they arise so that correction tables and mechanical corrections are unnecessary.

## THE SEA STAR GYRO-COMPASS.

Sea Star is the distinctive name given to a gyro-compass designed by Capt. V. H. Rozic and E. Kilburn Scott. It is an attempt to make the righting momentum not depend on gravity for its magnitude, but to be always determined by the amount of deflecting momentum that has to be counteracted, the means to this end being forcible and automatic. Another feature is that the gyro-wheel is so mounted that it is non-pendular about its horizontal axis, and therefor not subject to ballistic effects.

One object in view has been to dispense with correction tables and mechanical correctors. Another to devise an instrument that could be made small and cheaply so as to be of use on merchant vessels, aeroplanes, etc.

Fig. 24 is a sketch of a small table model, one form of the compass showing how the various parts go together. The gyro-wheel is suspended centrally within three ring-like frames which can move relatively, and three freedoms are provided with all the axes at right angles to each other as is common to all gyroscopes.

FRAMES.—The *main frame* suspended from two gymbal rings and usual shock absorbing springs carries the whole instrument. At the bottom there are gear-wheels driven by an electric motor, to which the name meridian motor has been given, to indicate its purpose. It may, however, be called a "push" motor in contradistinction to the "follow-up" motor of the Sperry compass.

The *inner or second frame* is suspended from the main frame by pivots at top and bottom, and the top pivot extends through the main frame and has a compass card attached to it. The bottom pivot is also extended, and has keyed to it a large gear-wheel, through which the inner frame can be slewed round the vertical axis in either direction, by the meridian motor.

The *third or central frame* is pivoted horizontally in the inner frame so that the gyro-wheel axle can tilt in a vertical plane,

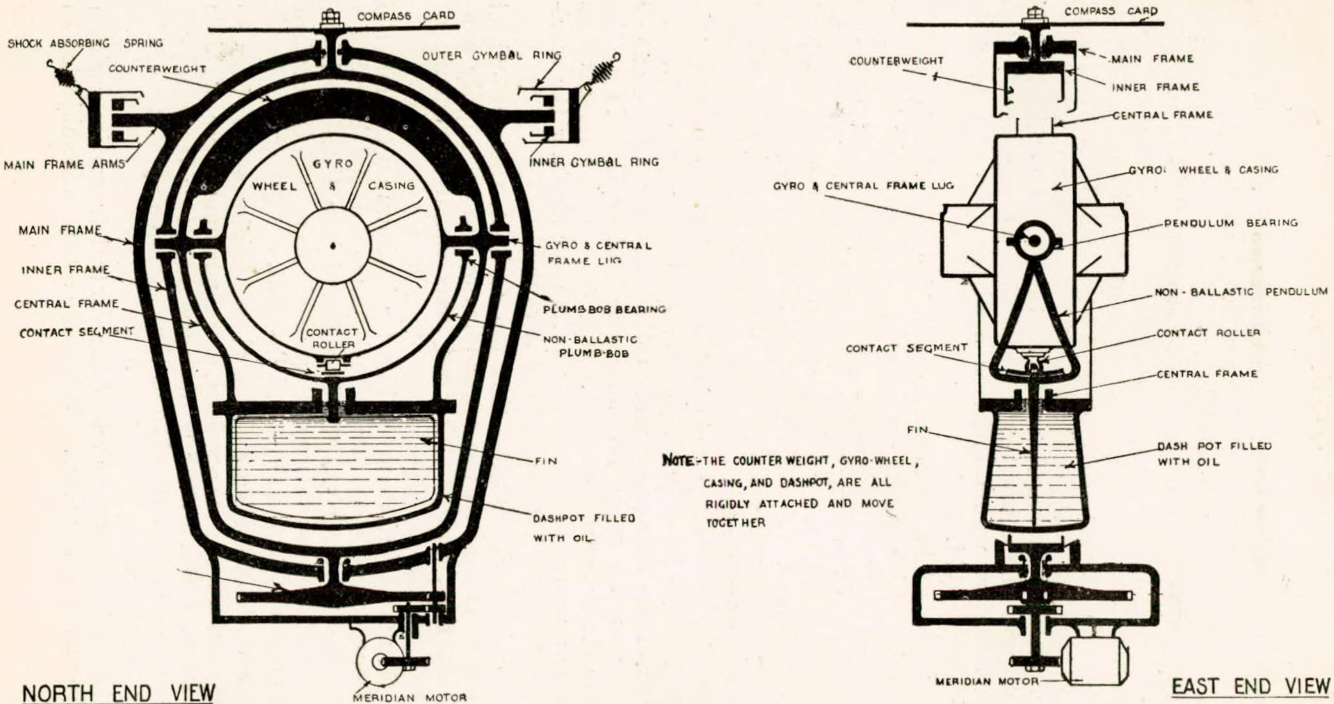



Fig. 24.

SEA STAR GYRO-COMPASS.

Diagrammatic Sketch showing the Three Frames, Contacts, Plumb-bob and Damping Device.

the gyro-wheel casing being fixed rigidly to the central frame. In this particular model a dashpot is attached to the central frame, and it is counterpoised by a weight at the top so that the centre of gravity of the whole coincides with that of the gyro-wheel.

Attached to the underside of the gyro-wheel casing there is a small contact roller which rests on a commutator consisting of two insulated metal segments on each side of a narrow non-conductor, which may conveniently be called the gap. Electric wires connect the contact roller and the two segments to the meridian motor, which latter is a direct current type with double wound field.

PLUMB-BOB.—The segments are on a Y shaped plumb-bob, the two arms of which are hung from the horizontal pivots or lugs of the central frame. Under the influence of gravity this plumb-bob tends to hang vertically, and it is the only part of the instrument that gravity does act upon because the gyro-wheel is non-pendulous. It will be remembered that in the Anschutz and Sperry compasses gravity acts directly on the gyro-wheel and its pendular attachments.

When the gyro-wheel axle is horizontal the contact roller rests on the gap between the segments, therefore for all other positions of the axle the contact roller can only rest on one or the other of the segments, and immediately that is so the meridian motor begins to rotate. The roller and segments thus constitute an automatic two-way switch for starting the meridian motor to slew the central frame round.

It should be remembered that the dashpot, the gyro-wheel and casing, as well as the central frame are all rigidly connected together, and so follow all precessional movements of the gyro-wheel.

Fig. 25 will help to convey this for it shows on the left the normal conditions with gyro-wheel horizontal and plumb-bob vertical, and on the right the gyro-wheel in a tilted position, whilst the plumb-bob being still vertical has caused the contact roller to come on to the left-hand segment.

To prevent a disturbance of the plumb-bob by jerks as in very bad weather, when guns are fired, or at sudden changes of ship's speed, its movement must be damped, and this is done by a damping fin which is attached to the plumb-bob just under the contact segments.

As the dashpot forms part of the central frame its position depends on the gyro-wheel. When the compass is subjected to

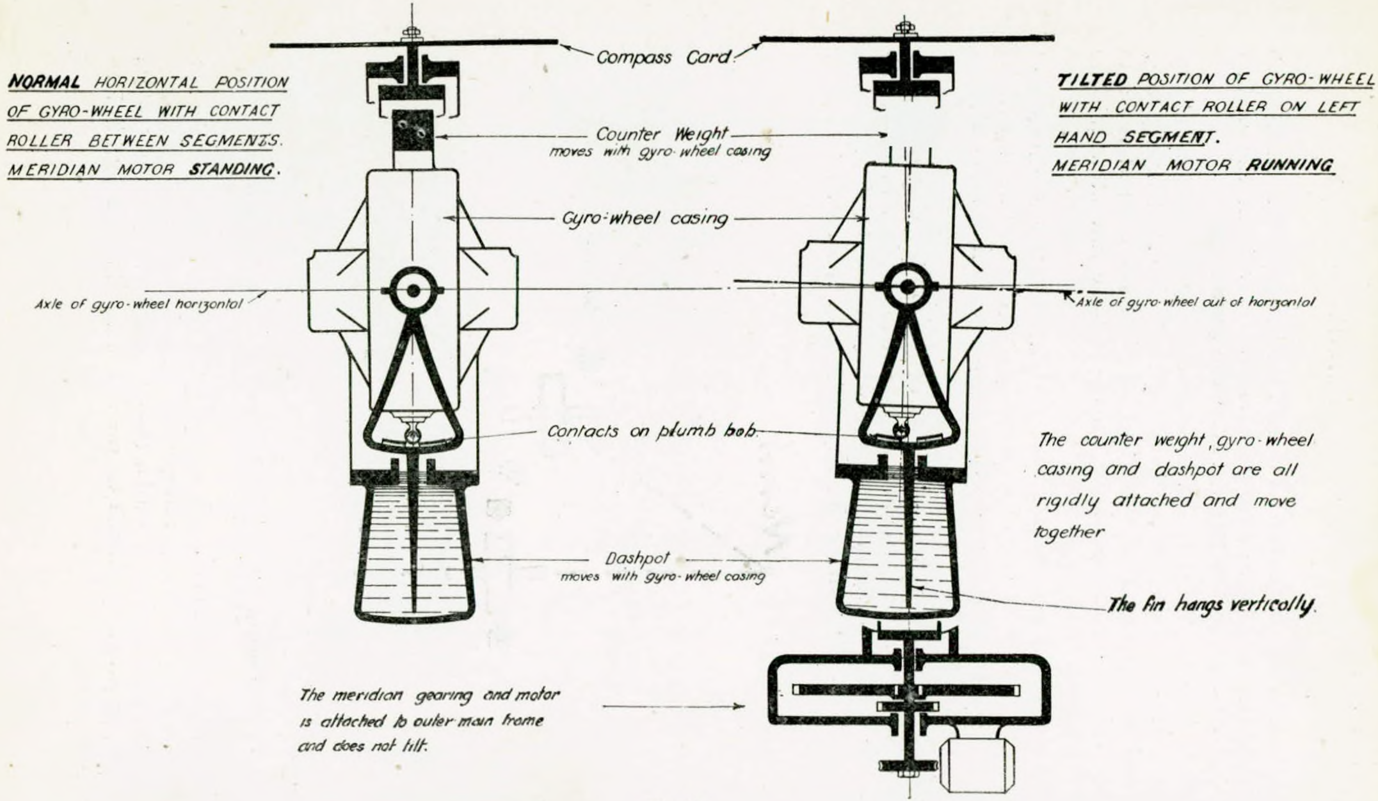



Fig. 25.

Sea Star Gyro-Compass.

Indicating the positions of Gyro-Wheel and Plumb-bob.

a jerk the viscosity of the oil causes the plumb-bob to swing with the trough, and there being no relative movement the contact roller remains on the gap between the segments.

It is necessary that the damping of the plumb-bob should be considerable, subject to the limiting condition that if displaced it shall not return to the vertical more slowly than at the rate of 15 degrees of arc per hour, this being the rate at which the earth rotates.

The above described plumb-bob, with electric contacts and damping device serves to explain the working, but it will be readily seen that there are other ways of carrying this out, and one is referred to below.

METHOD OF WORKING.—In order to explain the working of the Sea Star compass we will first assume it to be placed on a stable base on land, and to have its gyro-wheel axle set exactly in the meridian as at position X, Fig. 26. As the earth rotates it

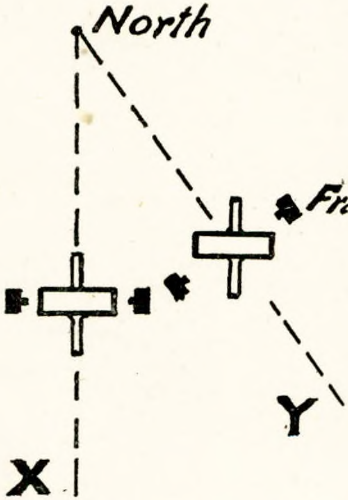



Fig. 26.

NOTE.—The direction of rotation of Gyro-wheel is clockwise, i.e., opposite to the rotation of the Earth looking at North End.

carries the compass through space, and after a time it arrives at position Y. The supporting frame tends to remain perpendicular to the meridian, whilst the gyro-wheel, on account of its gyroscopic property, tends to remain with its axis parallel to itself.

This is indicated diagrammatically at Y, but, of course, it is impossible to be so because the supporting frame holds the gyro-wheel and will not allow it to remain parallel to itself.

Clearly, therefore, a couple is set up, and as the gyro-wheel cannot go one way it goes another, that is to say the axle tilts in a vertical plane. In thus tilting, it brings the contact roller on to one of the segments, and the meridian motor is set in motion to relieve the couple; the gyro-wheel axle then comes back horizontal again.

Expressed in another and more scientific terms: Under the combined movements of the ship and the earth the gyro-wheel precesses by tilting, and in doing so completes a circuit through the meridian motor by means of the contact roller and segment. The motor then slews the central frame (and therefore also the inner frame and the gyro-wheel) round the vertical axis in a contrary direction to that which has occasioned the said precession. This slewing motion is a restoring motion, and as soon as the spin axis of the gyro-wheel is again horizontal the contact roller comes on to the gap between the segments and the motor stops.

The action therefore is simply that the movements of the gyro-wheel about a vertical axis are constrained ones, primarily due to the moving of the gyroscope in space and secondarily due to the restoring movement produced by the motor. Under the primary effect there is a tilting precession in one direction and under the secondary effect the reverse tilting precession. It follows that if these two movements are exactly equal the amount of rotation about a vertical axis under the restoring movement produced by the motor is equal to the primary movement, and the result is that the gyro-wheel automatically sets itself in the meridian and stays there so long as it is kept spinning.

Diagram.—A diagram on the lines given above for the pendular compasses will help to make the comparison clearer, but as the Sea Star compass is non-pendular it must be indicated diagrammatically in a different way, as shown in Fig. 27.

Assume the gyro-wheel to be started spinning at position A then after some time the earth's rotation, which is from west to east, that is counter-clockwise, looking upon the North Pole, (see arrow E) will have brought the compass to position B. The gyro-wheel tends to preserve its axle parallel in space, and thus in relation to the earth's surface, that is to the horizontal plane; the western end of the gyro-wheel axle marked $h$ will *appar-*

*ently* dip, and the end $k$ will rise. This brings the contact roller on to a segment, and as represented at B, it is the left-hand one. The meridian motor which controls the freedom round the vertical axis then commences to slew the inner frame.

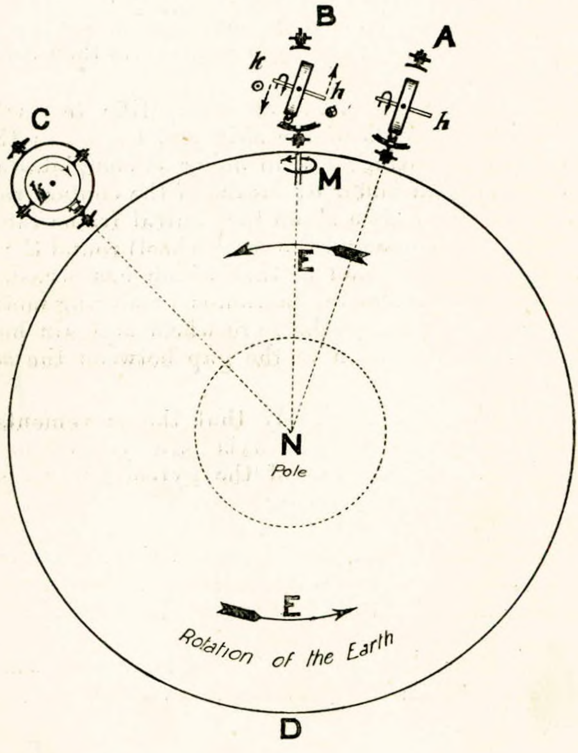



Fig. 27.

Diagram to illustrate the effect of the Earth's rotation on the Sea Star Compass.

The question is, in which direction must the meridian motor rotate the inner frame in order to bring the gyro-wheel axle horizontal.

As represented at B the left end, that is the eastern end of gyro-wheel axle $k$ rotates clockwise, and it is elevated above the horizontal. Now, as long as it has such an elevation the meridian motor will keep on rotating. To stop it we must bring the roller back to the gap or in other words cause the gyro-wheel to precess in the direction of the dotted arrows shown at the ends *k* and *h*.

Now look upon the instrument from the top, namely, from B towards M, and assume for a moment that the rotation is clockwise, then the gyro-wheel will tend to so dispose its rim that it also rotates clockwise. The clockwise end, being end *k*, it is evident that the tilt of the gyro-wheel axle would thus be still further increased, and that we do not want.

On the other hand, if the meridian motor rotates the instrument counter-clockwise as shown by the curved arrow M, then the end *k* will dip and the motor will come to a stop. This action of the motor thus brings the end *k* out of the paper, and as the earth's rotation continues to have effect on the gyro-wheel axle, so long as it is out of the meridian the motor will continue to slew the inner frame round until the end *k* of the gyro-wheel points due north as shown at position C.

Direction of Rotation.—The Sea Star differs from the Anschutz and the Sperry compasses in that the direction of rotation of the gyro-wheel is clockwise when looking at the north pointing end of the gyro-wheel spindle (see Fig. 27). The other two run counter-clockwise, as shown in Figs. 18 and 20. They must do so because it is only when running that way that the gyro-wheel will precess to point north.

Owing to the direction of rotation of the gyro-wheel of the Sea Star compass being opposite to the rotation of the earth (see Fig. 27) the gyro-wheel is in a state of permanent unstable equilibrum, and therefore as soon as it has been deflected in the slightest degree there is a strong tendency to increase, and the motor is immediately started to correct the deviation. There is thus a very great sensitiveness when in the meridian, which is clearly a desirable feature for any instrument depending for its effectiveness on the delicate action of the earth's rotation. This sensitive characteristic of the Sea Star should allow it to be built in small sizes, for the kinetic energy of the wheel is of lesser importance than with other compasses.

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Mr. J. W. Gordon: I have been extremely interested in Mr. Kilburn Scott's paper, and I should like to offer my congratulations to him on the very clear statements he has made concerning the principle of these gyroscopic compasses. It is an extremely difficult subject to explain, and his paper makes the matter clearer, in a small space, than ever I have seen it made before. With regard to the compass in which he himself is interested, that is an extremely interesting matter, because, of course, there is no question that the gyroscopic compass, as at present put upon the market, is much too expensive and much too cumbersome an instrument, and it is very important to get an instrument either of less weight or running at slower speeds than the compasses now in use. There are two points in the description of his own compass, however, that are not quite clear to me. In the first place he attaches great importance to the reverse spin, that is to say, to the fact that the disc, when the compass is pointing due N. and S., is spinning in the direction opposite to that of the earth, and he says that the unstable equilibrium so set up tends to make the compass more rapid in its action. In fact he attaches principal importance to that circumstance, because in that way he considers that he gets the increased sensitiveness that enables him to use a less weight than in those other compasses. That I do not follow at all. When the compass is pointing due north or south, the effect of the earth's "field"—I speak of the rotation of the earth as operating upon the compass—is zero. The great difficulty with this type of compass is that its movements are asymptotic. Supposing this edge to represent the north and south line and the pointer which I am holding to represent the compass; then, when the compass is pointing at a wide angle to the north and south as I am pointing now, then you have a very powerful interaction between the rotating earth and the compass. The force of the reaction varies as the sine of the angle between the meridian and the compass, and consequently when that angle gets very small the sine is very small, and when the compass is pointing true the action of the earth upon it is nothing. That is the whole trouble; there being no reaction in that point the velocity of approach carries it on and it over-runs the meridian. When it has over-run by a certain angle, the earth's force is effective to bring it back, and so an oscillation is set up, but the period of oscillation is very slow, and if there were no damping device it would go on indefinitely.

That problem is dealt with in Anschutz and the Sperry compasses by this contrivance. The compass is so swung that it tends to point a little aside from and ahead of the meridian, so that the inherent tendency to oscillate, of which I have just spoken, is overcome by this tendency to move ahead of the earth's North Pole. Then, to correct this error—the crescent-shaped pendulum of Fig. 10—which pulls the compass back, so to speak, and gives to it a retrograde precessional motion corresponding to the retrograde motion in the heavens of the earth's North Pole. In other words, you may say that these compasses work like clocks. You have a weight which operates like the weight of a clock to keep time with the earth's rotation, and if that is properly adjusted as the earth carries the compass round with it this weight causes the compass to work in towards the meridian at the proper speed. Mr. Scott, if I understand him aright, proposes to get rid of that weight altogether and to rely upon the tendency of the compass to settle in the meridian under the influence of the earth's rotation; but inasmuch as when it gets into the meridian there will be no force acting upon it, it will, I should have thought, give very uncertain readings—there will be a swaying angle in which there will not be sufficient force to bring it home, and therefore a compass constructed upon that principle would be so uncertain in its readings that it would fail of utility. But I am only theorising, and this is a matter of experiment. No doubt if this matter has gone so far as I understand it has, the utility of the new compass has been experimentally proved and Mr. Scott has an answer to my difficulty, I should be glad to hear what the answer is.

There is just one point in the paper in reference to which a word might make clear a statement which is made. In speaking of Foucault's gyro-wheel disc, the author says: "If, however, one freedom is controlled or partly suppressed, then, by reason of the earth's rotation the gyro-wheel axle will so move or precess that it tends to set itself with its axis of rotation parallel to the axis of the earth itself, in other words the gyro-wheel axle will point towards the pole." I think that is a little misleading. It points towards the celestial pole and not the pole of the earth, which is what we want a ship's compass to point to. Therefore, Foucault's gyroscope would be useless for navigation because, except on the equator, it would point to the celestial pole instead of the terrestial, and on latitude 50 deg. it would point a long way to the east at one time of the day and to the west at another time of day.

A hearty vote of thanks was accorded to Mr. Kilburn Scott, on the proposal of the Chairman, seconded by Mr. Gordon.

It was agreed to adjourn the discussion till Monday, October 12th.

## DISCUSSION.

*Monday, October* 12, 1914.

CHAIRMAN:—MR. JAS. ADAMSON (Hon. Secretary).

CHAIRMAN: We are met to-night to discuss the paper which was read here last week by Mr. Kilburn Scott. Several remarks were made at that meeting, and those by Mr. J. W. Gordon it is thought desirable to have brought before the meeting to-night again, together with other communications which have been received, after which Mr. Scott will explain any points which require to be elucidated and reply to any criticisms that have been made.

The Sperry Gyroscope Company write as follows:—

"We take pleasure in acknowledging your kind letter of the 9th October enclosing proofs of Mr. Kilburn Scott's paper. We have read this paper with great interest, and congratulate its author on the thoroughness and care with which it has been prepared. The phenomena of the gyro-compass are exceedingly complex, not only in theory, but in the mechanical detail necessary to put theory into useful practice. In consequence of this it would be difficult to submit a complete discussion of Mr. Scott's paper, much as we would like to do so. We are greatly obliged to you for your invitation, however, and beg to take advantage of it to the extent of some few remarks regarding Mr. Scott's discussion of the errors to which gyro-compasses are subject.

In the Sperry Gyro-Compass we have succeeded in eliminating these errors, but in doing so we have had to resort to some complication. This complication is to the best of our knowledge and belief, the minimum possible in any gyro-compass, and is of such a nature as to permit us to make the machine thoroughly strong and reliable. Although in results obtained, the compass must be, and is, an instrument of precision, it is, in construction, a machine of hardy design.

All the sources of error which Mr. Scott speaks of, are due either directly or indirectly to the fact that the force of gravity is utilized to make the instrument seek the north.

A non-pendulic and non-ballistic gyroscope such as that used in the torpedo, cannot be used as a gyro-compass because the compass must hold its plane with reference to the meridan for days instead of for minutes. To do this it must be equipped to oppose the ever present disturbing influence of friction. For this reason it must be made a direction-seeking instrument, *i.e.*, it must constantly seek its true position in the meridian, so that the friction which may tend to disturb it, is opposed by its directive force. To give the compass this direction-seeking quality it is necessary to:—(1) Use a gyro-wheel which will try to maintain its plane in space; (2) Utilize the force of gravity for suppressing the freedom of the gyro-wheel; and (3) So arrange the suppression of freedom by gravity that the rotation of the earth will cause the force of gravity to act on the gyroscope in such a manner as to cause it to seek and maintain the north and south meridian.

So far, our experience of many years, coupled with constant experimental and research work, has enabled us to accomplish the above only by the use of:—(a) a heavy wheel; and (b) pendulic suppression of freedom.

We have had sufficient experience as pioneers in our branch of engineering to know that nothing is perfect—that everything can be improved, but we believe that in this case the fundamental principles prevent any great departure from the present form of gyro-compass. We are sending by the bearer one of our repeater compasses, which we hope will be of interest. It is the only piece of apparatus which we have available at present, as everything else is in process of test or installation for H.M. ships and submarines."

Mr. Kilburn Scott, explaining the repeater compass on the table, said that a complete equipment for a warship consisted of a master compass, which is placed with its motor generator and switchboard in a safe place in the interior of the ship; also six repeater compasses, which are placed on the bridge and various places where most convenient for navigation purposes. It is the repeaters that are therefore used for the working of the ship. Current is conveyed to them from the master compass equipment by means of seven-strand cables, and the small motor inside each repeater moves its compass card in exact synchronism with the compass card of the master compass. They are, in fact, like synchronous clocks, and of course repeaters can be used with any type of gyro-compass. On account of the flexibility of the cable, if a certain standing position happens to be inconvenient, the repeater can be quickly moved to another standing position. As to the other points in Mr. Gilmor's letter from the Sperry Company, no one is more ready than myself to appreciate the beautiful ingenuity of the Sperry instrument, and the immense amount of research and skill which has been required to evolve it. Each worker in this field, as in fact in any other, is indebted to those who have gone before. We are all, for instance, exceedingly indebted to the wonderful researches of Leon Foucault, as he himself was the disciple of Sang. No doubt Mr. Sperry learnt many points from Dr. Anschutz, and I am quite certain, judging from my own knowledge of scientific and engineering developments, that neither of these gentlemen evolved the compasses bearing their names off their own bat as it were. The brain energies of a large number of assistants and others are embodied in the perfected instruments, and, further, the negative or eliminating work has been quite as valuable as the positive or successful results.

One astonishing thing in connection with gyroscopes is the number of ways in which various people think of them and their action; also, if I may say so without offence, the dogmatic way with which many think their own interpretation the only correct one. They appear to find it difficult to get out of the rut of their own line of thought. There is a feeling abroad, sometimes very plainly stated, that with the Sperry and Anschutz compasses the millennium, as it were, has been reached. It is excusable, perhaps, when expressed by those who have sunk tens of thousands of pounds in development work.

My paper is an attempt to trace the lines on which development has hitherto gone, to explain as minutely as clear diagrams can show them, the essential parts of the instruments, and especially to show plainly and without mathematics the various errors to which present gyro-compasses are subject. Finally, it is an endeavour to point out that perhaps after all the finality of gyro-compass design has not been reached in those at present in use. That it may be possible to take advantage of the action of gravity by letting it act upon a light plumb-bob contacting device instead of a heavy pendular gyro-wheel and casing. That it may be possible to make a gyro-compass with an auxiliary motor to "push" instead of to "follow up."

We may be wrong, for, of course, everyone is liable to error, especially in such an involved problem as the gyro-compass presents. Mr. Elphinstone, the managing director of Elliot

Bros., said to me the other day that the Anschutz compass was the most tricky and difficult apparatus his firm had ever undertaken, and everybody knows what exceptionally fine and accurate work his firm is famous for.

The fact that in order to meet the requirements of the rolling and pitching test of the British Admiralty as carried out by Prof. Henderson at Greenwich, the Anschutz compass has had to have two additional gyro-wheels added and the Sperry an extra gyro-wheel, shows that there are possibilities open for improvement. Even Prof. Henderson himself has taken out patents recently.

Capt. E. W. Owens (Examination Department, Board of Trade) writes as follows:—"I am sorry I could not have more time to give to Mr. Scott's interesting and illuminating paper; but if I may presume upon such a subject, submit the following few remarks with much diffidence.

I do not think the author is on the right track in comparing the ordinary magnetic compass with the gyro-compass—it is hardly fair to one or the other. Each has its excellencies. The Kelvin compass works with fair satisfaction in all manner of vessels in all parts of the world and would do better still if more study were given to the cognate subjects relating to magnetism than is generally given by navigating officers in the merchant service.

In naval vessels there is rich ground for the gyro-compass for, as stated in the paper, the closeness of electrical machinery of many descriptions plays strange freaks with a magnetic compass, especially in submarine craft. But in the magnetic compass a natural force is always present to direct it, either in the ocean liner or in the smallest boat that leaves her side. Nothing can happen, except the destruction of the compass itself, to destroy the sense of direction. Against this, the navigator is offered in the gyro-compass an instrument unaffected in any degree by either construction of hull, cargo, or the geographical position of the ship, etc. There is no need for any correction for magnetic variation and deviation, the wrong application of which has taken many vessels to destruction. Anything that tends towards simplicity tends towards correctness.

It was somewhat of a diappointment to navigators, when investigating the Anschutz and Sperry gyro-compasses, to find that there are several corrections to be applied before the proper course can be steered. The great cost of these compasses is also prohibitive on all vessels except war vessels, where a saving equal to the cost of the compass can be made by the use of magnetic metals, instead of the more expensive non-magnetic metals. Instead of a natural force, an artificial force has to be used to drive the gyro-wheel, etc., and this, of course, necessitates electrical plant. If a gyro can be constructed free from ballistic errors, if it can be constructed cheaper than those at present on the market, and if it can be driven by other than electric current, say by compressed air, it should have an excellent future and would be welcomed by navigators most heartily. It seems to me that the Sea Star Gyro-Compass offers desirable features because:—(1) the gyro-wheel is so mounted that it is non-pendular and so it is rid of ballistic errors; (2) the direction of rotation being clockwise gives to the gyro-wheel permanent unstable equilibrium and, therefore, great sensitiveness.

I shall look forward with deep interest to a trial of the Sea Star compass, trusting that it will do what its inventors have promised for it. It appears to be founded upon sound mathematical principles and should be cheap to construct. The meridian motor controlling the freedom round the vertical axis by means of electric contacts brought into action by the tilting of the gyro-wheel, is most ingenious, as it really acts like the brain of the instrument."

Capt. V. H. Rozic, who, unfortunately, was unable to attend, had had sent to him a copy of Mr. Gordon's remarks at the last meeting, and answered the points as follows:—"Mr. Gordon falls into the usual error of thinking of the Sea Star compass as if it worked in exactly the same way as the Anschutz and the Sperry. As a matter of fact the description in paper and the diagrams make it clear that, while the Anschutz and the Sperry *precess* into the meridian, the Sea Star is *pushed* into the meridian. It is inherent in the Anschutz and Sperry compasses that the gyro-wheels rotate *counter-clockwise* (as shown in Fig. 17), whilst it is just as inherent in the Sea Star that the wheel rotates *clockwise* (as shown in Fig. 27).

The difference between the instruments can be seen by referring to Figs. 1 and 2. In the Anschutz and Sperry compasses the force F is produced by reason of the earth's rotation and their pendular nature, and by reason of it the wheel must precess to bring its counter-clockwise rotating end to point north. On the other hand in the Sea Star compass the meridian motor is made to turn the gyro-wheel motor about the vertical axis as indicated by the small circles at A and B in Fig. 1.

The Anschutz and Sperry compasses are asymptotic in movement, and therefore a damping device is necessary to prevent them swinging across the meridian, the maximum force tending to bring them into the meridian being when the gyro-wheel axle is at 90 deg. from the meridian. The Sea Star compass is not asymptotic. It is true that the effect of the earth's rotation is proportional to the sine of the angle that the gyro-wheel axle makes with the meridian, but that has nothing to do with the speed with which the gyro wheel is pushed into the meridian.

As soon as the gyro-wheel starts running the earth's rotation tilts the gyro-wheel axle, and that immediately starts the meridian motor in such a direction as to take out the tilt. There is a certain amount of play, but the tilt of the gyro-wheel cannot be larger than half the gap between the contact segments, and that is made very small. When the meridian motor is moving the gyro-wheel moves at a uniform rate of speed into the meridian, and when in it there is no tendency to swing beyond because the meridian motor then stops. The gyro-wheel cannot tilt any more, because the sine of the angle its axle makes with the meridian is zero, and the earth's rotation can have no effect upon it. The meridian motor cannot run without the contact being made, and the contact cannot be made without there being a tilt on the gyro-wheel axle, consequently, the compass is dead when in the meridian.

Mr. Gordon makes a remark about the celestial and terrestrial poles. As a matter of fact they both lie in the meridian plane, and for practical gyroscopic compasses the terrestrial is the only one we are concerned with.

Mr. R. L. Logan: I gather from Mr. Gordon's remarks with regard to the Sperry compass, that it was all right while the vessel was going on a steady course, but it was sluggish in indicating a change of direction, and by means of the crescent-shaped weight shown on Fig. 11, the motor was set at work to correct this. The dashpot on the Sea Star compass would, I think, be a source of trouble.

Mr. E. Kilburn Scott: I am not sure that I understand Mr. Logan's query aright, but I may say that all gyro-compasses must have something for gravity to act upon, so as to set up precession to bring the gyro-wheel into the meridian. In the case of the Anschutz and the Sperry compasses the heavy gyro-wheel and casing, etc., are made pendular, whereas, in the case of the Sea Star, it is the small and light electric contacting device that we make pendular. In their letter quoted above, the Sperry Co. admit that all the errors of their compass are due either directly or indirectly to the fact that the force of gravity acts on the pendulic gyro-wheel and casing.

As the Anschutz and Sperry gyro-wheels and their attachments are of considerable weight they are very heavy pendulums. For example, the wheel alone of the Sperry compass weighs 43lbs., so that with all its attachments the whole pendular system weighs considerably over $\frac{1}{2}$-cwt. It is thus a very heavy pendulum to have on such a very unstable platform as that of a ship. Again, as regards damping. All gyro-compasses must have a damping device of some kind because of the instability of the platform and the varying speeds and directions in which a ship travels. In the case of the Anschutz and the Sperry compasses the damping device acts directly on the gyro-wheel, and it is necessarily heavy and cumbersome.

Mr. E. W. Ross: I was much interested in the paper we heard last Monday evening and was in hopes that more visitors would attend to-night who actually knew about the working of these delicate instruments. We engineers, are, of course, accustomed to bigger and more massive apparatus. What is the necessity for putting a gyro-compass on board the ordinary steamer? As Mr. Scott has pointed out, up to the present such are only fitted in warships and similar vessels. If that is so it shows there has been a necessity for such an instrument, and I should be pleased to know what and why that necessity is. We are told that there are synchronous compasses placed in various parts of the ship, and that there is a master compass placed in the depths of the ship out of the way. Recent events have shown that such a position is not a safe place, and if this master compass is put out of action what are we to rely upon for our seamanship? Is this supposed to be the only compass on board ship or are we to depend on the mariner's compass as we know it? What has been found wrong with the old mariner's compass to necessitate this new invention? We know that on the mariner's compass there is a strong force leading the needle to the north—I take it the true north. Is there in the gyroscopic compass any means for allowing for deviation, as we know that the North Pole is not exactly the magnetic pole? What arrangements are made to make up for the error between the true and the magnetic poles? As for this damping device, on the mariner's compass the slightest movement of the ship draws the compass away to the North Pole and the course is still shown on the compass card. If this gyro-compass is used, with the damping arrangement as described, when the ship swings round very rapidly, would the compass follow with sufficient speed to show the direction, or would it take some time before it came to the proper direction? It is a very interesting, but a very delicate arrangement to have on board ship.

Mr. Kilburn Scott: In reply to Mr. Ross, any gyro-compass is delicate as compared with, say, the marine engine of a tramp steamer, but much of the mechanism on a battleship and submarine in connection with gun sighting and speed governing is quite as delicate as a gyro-compass.

As a matter of fact, gyro-compasses are always constructed to keep on running from one end of a voyage to the other. That must be so; although, of course, if current is cut off on purpose or by accident, there is sufficient stored energy in the gyro-wheels to keep them running for some hours, and they maintain direction and are servicable for navigation for certainly half-an-hour. The time that a gyro-wheel will continue to run depends on the vacuum. The large wheels of the Brennan mono-rail car, $3\frac{1}{2}$ft. diameter and 3,000 revolutions, used sometimes to keep spinning for four hours after the car was brought into the garage.

Of course, warships fitted with gyro-compasses carry magnetic compasses as well, just as the gas lamp standards were kept up in the City long after the change to electric light had been made. Large German liners, as, for example, the Vaterland, are navigated by gyro-compasses, and the time will surely come when the gyro-compass will be much simplified and cheapened and they will be used in the merchant service. It will be part of the engineer's job to look after this mechanism just as any other, and for this and other reasons I foresee that in the future he will have to be an electrical expert, and his theoretical attainments be much higher.

When changing course rapidly there is a drag on the compass card just as with a magnetic compass, but it is less. It is within the power of man to make the north-keeping property of a gyro-compass what he likes, for it depends primarily on the power of an electric motor and weight and speed of the wheel. With a magnetic compass one has to reckon with the natural magnetism of the earth, which is beyond man's power to alter, and the magnetism which he can impress on a few small pieces of magnet steel, the saturation point of which is strictly limited.

Mr. W. Longland, B.Sc. (Eng.): I should like to criticise one thing mentioned in this discussion, namely, that the Sea Star compass always points dead north. My idea is that, although it points northward, it has a slight to and fro movement all the time. To make this clear I will explain the behaviour of the compass when it is stationary relative to the earth, say, when it is placed on a table. In the first place, however, I wish to remind you of the behaviour of an ordinary gyroscope. The latter consists of a wheel so mounted that it can rotate about three axes mutually perpendicular to one another. If, while the wheel is rotating about the axis passing along its axle, a force acts in such a way as to tend to rotate the wheel about the other horizontal axis, then the wheel, instead of rotating about this axis, rotates about the vertical one. But if the force acts so as to tend to rotate the wheel about the vertical axis, the wheel rotates about the horizontal axis which does not pass along the axle of the wheel. Such is the behaviour of an ordinary gyroscope.

The Sea Star compass is something similar, inasmuch as it can rotate about three axes mutually perpendicular to one another. But it differs from an ordinary gyroscope in that the rotation about the vertical axis is controlled; the control being of such a nature that the axle of the wheel always sets in a northward-southward direction. But that the axle does not remain stationary in the meridian, even when the compass is stationary with respect to the earth, will now be demonstrated. Imagine the compass, having its wheel rotating, to be set with its axle in the meridian, as at A in Fig. 2; in which the black rectangle represents the wheel, the dots represent the frame that carries the wheel and which can rotate about the vertical axis. The plane of the frame is perpendicular to the meridian.

After a certain time the rotation of the earth will carry the compass into a position such as at B. The frame should still remain perpendicular to the meridian, and the wheel should remain with its axle in the meridian. But the wheel, by reason of its rotation about its axle, tends to remain parallel to its position at A (this is shown by the rectangular outline at B). As mentioned above, the action of the frame is to tend to keep the axle of the wheel in the meridian. The result is that a torque acts on the wheel tending to rotate it about its vertical axis, and this, as explained in the case of an ordinary gyroscope, causes the wheel to start to rotate about the horizontal axis,

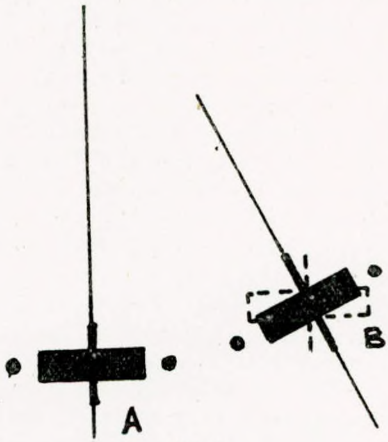


Fig. L.

perpendicular to its axle. The tilt thus given to the wheel brings the contact roller into touch with one of the contact-segments on the pendulum (see Fig. 24 of the paper). The motor is set going and the frame is started rotating about the vertical axis. The action of this rotation on the wheel is to swing it so that the roller ceases to be in contact with the segment, and the motor is stopped. The frame, therefore, ceases to rotate. But the inertia of the wheel carries the roller over until it comes in contact with the other contact-segment. The motor, and with it the frame, are immediately started rotating in the opposite direction to that in which they were previously rotating. The result is that the wheel swings the roller free from this strip and into contact with the first-mentioned strip, and the whole process is repeated. Hence, the axle of the wheel is continuously oscillating about both a horizontal and a vertical axis, and, therefore, does not point due north and south. If this is true, then there should not be any backlash in the gear wheels between the motor and the vertical axle, for, if there were, the motor would not respond quickly when called upon to rotate the frame about the vertical axle, which means that the oscillations would be greater than are necessary.

The small oscillations, which of necessity occur, are not objectionable, inasmuch as they show that the compass is working properly.

The distinctive feature of this compass is that it does not depend upon the action of gravity to work it, but only to operate the switch for the electric motor, and the latter immediately twists the frame and wheel in the required direction. The compass is, as a consequence, without errors, excluding those due to friction, such as affect other gyro-compasses. As for the errors due to friction the one which might be important is that caused by the friction at the bearings of the pendulum, but these, I am given to understand, are to be ball bearings, so that even this error will not be a large one. Any other frictional resistance to motion, the motor will readily overcome it.

The representative of the Sperry Company, in the communication which he has sent, says, to put the matter shortly, that the compass will not work. I cannot agree with him. The compass will work; but the principle upon which it works is different from that for the Sperry compass, and in not grasping the possibility of this he falls into an error.

Mr. J. Cruickshank: What precaution is taken to keep the compass in the fore and aft line of the ship when it is being shifted about? Unless proper standing places were provided it would be difficult to prevent errors creeping in owing to the lubber line of the compass bowl not being in the true fore and aft line of the ship. I understand that the gyro-compass points to the true north. The mariner's compass is corrected for the deviation because it points to the magnetic north.

Mr. Kilburn Scott: All gyro-compasses point to the true north and not to the magnetic north, and thus they do not have the deviation errors of the magnetic compass. But the Anschutz and Sperry compasses are subject to other errors which I have explained very fully in the paper, and these are due, principally, to those compasses being pendular or ballistic. If the gyro-compass or its repeater is moved it must, of course, be plaçed in a correct standing position.

Mr. E. W. Ross: How would you support the idea of "unstable equilibrium" in regard to direction of rotation of the gyro-wheels?

Mr. Kilburn Scott: I would do it by analogy. The difference between a gyro-wheel running counter-clockwise (that is, in same direction as the earth when looking at the North Pole), as in Anschutz and Sperry compasses, and of a gyro-wheel running clockwise, as in the case of the Sea Star, may be indicated by the following analogy:—A gyro-wheel running counter-clockwise may be considered as analogous to a pendulum hung from the top as in the case of the pendulum of a clock, and it may be said to be in a stable condition. On the other hand a gyro-wheel running clockwise may be considered as analogous to a pendulum suspended from the bottom, as, for example, the pendulum of a metronome, and that may be considered as an unstable condition. Analogies have their uses, but, of course, they must never be pressed too far. We maintain, however, that by having the gyro-wheel of the Sea Star compass running clockwise (that is opposite to the rotation of the earth), it is in a state of permanent unstable equilibrium, and therefore in an extremely sensitive condition. The slightest tendency of the gyro-wheel to tilt and it at once does so, because of this sensitiveness, and immediately gives current to the meridian motor to correct the tilt by precessing the gyro-wheel into the meridian. In other words, the least movement of the earth's rotation is at once "sensed" or felt by the Sea Star compass. By this acting so very promptly, it is claimed for it that it can be made smaller and cheaper than others. That is the nearest analogy I can give to the wheel being in an unstable condition. You will remember that Mr. Gordon admitted that a clockwise direction of rotation would be unstable, and therefore very sensitive.

Capt. Parry: Coming to the practical working of this compass, if the ship is rolling very heavily would the compass card give an apparent oscillation, and, if so, would the oscillation be greater than that in the mariner's compass?

Mr. Kilburn Scott: In respect to oscillation in very rough seas, I think there is little to choose between the two compasses—the Anschutz and the Sperry compasses and the best magnetic compasses. It is in the fact that a gyro-compass is non-magnetic that it scores. Take a submarine for example. If a magnetic compass is used it has to be fitted outside the skin of the vessel, and the compass card is read by means of mirrors. It cannot be placed inside the submarine, because it would be affected by the electric machinery, etc. Absolutely correct direction is everything in submarine navigation, and therefore they must have gyro-compasses. I believe I am right in stating that not only every warship, but also every submarine in the German Navy has a gyro-compass. The first successful gyro-compass made for ship use was developed by a German, and his compasses have been used in the German Navy for a good many years. The Sperry compass has been used in the American Navy for several years, and the Sperry Company are now working night and day making them for our Navy.

Mr. CRUICKSHANK: Is the Sea Star type on the market, and have you had one at sea?

Mr. KILBURN SCOTT: No; it is quite new and it has never been described or shown publicly before. Invitations have been sent by your Secretary to all those interested, so as to ensure that everybody has an opportunity to criticise. If there are any errors in the Sea Star instrument, we say in so many words, come and show us what they are. I take it, that is one reason why such institutions as this exist.

Mr. CRUICKSHANK: What would your instrument cost?

Mr. KILBURN SCOTT: One feels somewhat diffident in dealing with questions of cost at an Institute's meeting, but as I have been asked I will say something. As a matter of fact it is a vital question, because the compasses at present made are very costly. For example, a complete equipment of master compass, six repeaters, motor generator, switchboard and cabling fitted complete on a warship may be anything from £1,250 to close on £2,000. On the other hand £100 is a good price to give for a magnetic compass. You see, therefore, that the question of cost is vital and simply cannot be ignored. Anyone who simplifies and cheapens the gyro-compass is doing a service to the community, but it is a most difficult proposition to work upon. After one has thought out what looks like an important improvement or even has made a lecture table model, the next difficulty is to get a practical working instrument built, for there are few firms who can do the precision work, whilst the expense is very great. I should say that, from first to last, the expense of developing the Anschutz and Sperry compasses to a practical stage must have been over £50,000. Of course, those who follow on are saved a good deal of the pioneering negative work, but, nevertheless, it is an expensive business trying to bring an instrument of this kind to a commercial success.

It is the fashion at this moment to decry the German Governmental system, but this I will say, that if the German Government had not deliberately gone out of its way to assist Dr. Anschutz, there would not have been a practical gyro-compass to-day. The American Government also helped Mr. E. A. Sperry very materially. A battleship is really the only place where a gyro-compass can be properly tested. The Sperry Company has a most ingenious rolling platform, but it cannot entirely reproduce all the complicated motions that a ship goes through in very rough weather. The actual tests must be made on board ship, and requires months of patient observation.

So far as the actual material is concerned, there is not a great deal of metal in a gyro-compass, but it is of an expensive kind. The gyro-wheel, for example, must be of a special alloy —steel—to withstand the tremendous stresses due to running at high speeds. The casings and other parts must be aluminium alloy to reduce weight, and, of course, all the bearings must have ball races.

It is in workmanship and testing that the great expense lies, and a principal difficulty is to get the three axes exactly at right angles and crossing each other at one point. Now, clearly, the more gyro-wheels there are to a complete compass, the more expensive must it be. The Anschutz has three such wheels, and therefore nine axes to adjust correctly; the Sperry compass has two gyro-wheels, and therefore six axes.

Mr. F. M. Timpson: Is it a fact that the magnetic compasses on aircraft do not give true indications?

Mr. Kilburn Scott: There is a great deal of electrification in the clouds, and it has been suggested that it might affect the compass, so I wrote to Mr. Mervyn O. Gorman, of the Royal Aircraft Factory, *re* this. His reply is as follows:—

> "It is quite untrue that the electrification of the upper air affects compasses. Certainly, nothing definite has yet been proved, and I do not think it likely. I think the weight of a gyroscopic compass will be a grave difficulty in its use on aeroplanes."

A hearty vote of thanks was accorded to Mr. Kilburn Scott, on the motion of Mr. Timpson, seconded by Mr. Ross.

The meeting concluded with a vote of thanks to the Chairman.

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Mr. J. W. Gordon wrote on November 10th:—"I have now been very carefully into the details of the Sea Star compass and perceive that I had not hitherto appreciated the essential character of its design, which is, that the gyroscope is employed simply to supply steadying power, and not for the purpose of developing the Foucault reaction at all. It is, therefore, quite immaterial whether the gyroscope is spun in the same direction as the earth, or in the reverse direction. In fact, it appears to me that it would be equally immaterial if the axis of the gyroscope were spun at any other angle to the earth's axis. It may, I think, be worth your while to consider whether it would not materially simplify the construction if the spinning axis were placed in the vertical line. The great advantage of placing the gyroscope in that position would be that its oscillations would not be communicated to the compass card, and, indeed, the driving of the compass card would not in that case give rise to any precessional movement of the gyroscope.

The meridian, in the case of your mechanism, is found, not by the gyroscope, but by the plumb-bob. When the axis about which the plumb-bob swings is due east and west and the rotation of the earth does not tend to cause the plumb-bob to swing either in the north or south direction and consequently it hangs free of both the north and south contacts. But if the axis about which the plumb-bob swings is turned so as to point, say, a little north-west and south-east, then the rotation of the earth causes the plumb-bob to swing north and make contact with the northern contact point. If, on the other hand, the axis of swing is inclined to the south-west and north-east, then the rotation of the earth causes the plumb-bob to make contact with the southern contact point. The actuating motor is caused to drive in one direction or the other according to the contact made, and hence the mechanism will always tend to settle down in such a position that the contact points are due north and south of one another. This is how, in your case, the meridian is found, and the Foucault effect of the earth's rotation upon the orientation of the gyroscope has nothing whatever to do with it.

In theory this appears to be both a highly ingenious and perfectly feasible system, and the only doubt which I entertain as to its practicability is a doubt as to whether satisfactory contact can be made with so small a power as is available for making contact in this case. I am, of course, aware that Captain Rozic says that it is just as easy to secure good contact with this mechanism as with the Sperry mechanism. But about that I can form no independent opinion. In the first place, I am not sufficiently familiar with the Sperry mechanism to judge whether it or similar mechanism can be applied to your compass. In the second place, I do not understand that you have yourselves definitely settled on the details of your contact mechanism. The difficulty to my mind is this. Suppose that the contact line were placed east and west instead of being north and south. Then the pressure available for producing contact would be proportional to

$$\text{Sin}\left(\frac{t''\pi}{43200}\right)\text{LW}$$

where $t''$ is the time in seconds which has elapsed since the beginning of contact between the plumb-bob and the contact point. L is the radius of gyration of the plumb-bob, and W its weight. Now this is a very small quantity within any reasonable limits of value for the constant $t''$, but it is considerably in excess of the force which you have available for making contact.

If we write

$$\text{C}=\text{Sin}\left(\frac{t''\pi}{43200}\right)\text{LW}$$

then the force actually available in your case for making contact will be

$$\text{Sin}\,\Delta\,\text{C}$$

$\Delta$ being the small angle which the line of contacts make with the meridian.

I find it very difficult to suppose that this almost infinitesimally minute force can provide effective control for your contact mechanism when the line of contacts is in reasonably close approximation to the meridian line.

In the case of the actual mechanism which you describe, there is the further difficulty that the free precession of the gyroscope would tend to counteract the righting movement of the compass card and thus actually to make the compass sluggish. My feeling is that it would, for this reason, compare badly with either the Anschutz or the Sperry mechanisms. But as I have said above, I think that this difficulty could easily be got rid of* by altering the position of the spinning axis so that the movement of the compass card should not produce any precessional reaction in the gyroscope itself.

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* In a subsequent letter Mr. Gordon adds that having further considered this suggestion he sees it to be impracticable because the compass card itself would become unsteady.

# ELECTION OF MEMBERS.

Members elected at Council Meeting held on Wednesday, November 18th, 1914.

*As Members.*

Henry Chas. Blane, 256, Hornby Road, Blackpool.
Thos. John Hegg, 85, Woodford Road, Forest Gate, E.
John Hanick, Dalhousie Jute Mill, Baidyabete P.O., Bengal.
Owen Thos. Jones, Altus, Holyhead.
John McLeod Mitchell, Eastern and Australian SS. Co., Sydney, Australia.
Frederick Peel, 128, Laygate, South Shields.
Jas. Ritchie, "Glenbrae," Hakin, Milford Haven.

*As Associate.*

John Edgar Nickson, 132, Worsley Road, Winton, Patricroft, near Manchester.

*As Graduate.*

Thos. Shacklock Wilson, 7, Ash Grove, Wallsend-on-Tyne.

TRANSFERS—

*From Associate Member to Member.*

A. J. Lebeda, Rosslyn Cottage, Ellens Road, Leeds.

*From Associate to Member.*

S. Hutton, c/o. Messrs. Mackinnon Mackenzie, B.I.S.N. Co.'s Agents, Calcutta.

*From Graduate to Associate.*

S. W. Brown, 22, Cann Hall Road, Leytonstone, N.E.
Jas. Marsden, Inglewood, Hawkwood Road, Boscombe, Hants.