TILTING DEVIATIONS IN MAGNETIC DECLINATIONS

Extracts from an article by William J. PETERS

published in *Terrestrial Magnetism and Atmospheric Electricity,* Washington, June 1929.

Experiments were made by swinging compasses in a wooden swing for the purpose of investigating deviations caused by the ship's rolling motion. Built of wood, fastened with copper and brass, the apparatus having one platform which remains continuously level during oscillations of the swing (parallel swing) and another (tilting swing) which, being rigidly attached to one of the uprights, will tilt at an angle always equal to that of the swing from its position of rest, the apparatus is suspended from the beams of the ceiling. The platform rests on brass, and intermediate bearings permit of shortening the radius of swing.

Peep-sights on the horizontal tie-pieces are used to set the swing accurately into the required azimuth by sighting on marks drawn on the walls of the building, after which the upper structure is securely blocked by wedges and clamped.

The oscillations are usually started and maintained by pulling on a cord leading from eyes in the swing to small fairleads or pulleys screwed into the wall. The amplitudes of the oscillations can be read on a graduated arc divided into single degrees cut in a wooden board resting on edge and movable on the floor.

The lubber line reading of a compass mounted on the tilting platform was usually made by the aid of a telescope attached close to one of the upper axles, a collimating lens, and a mirror mounted close to the centre of the glass cover of the compass. His head being then near the centre of motion, the observer could see the field of view continuously throughout an oscillation with very little moving of his head. A compass on the horizontal platform, or parallel swing, was read through a large reading glass which enabled the observer, reclining in the plane of the swing's motion, to see the graduations continuously by moving his head up and down through a small vertical range.

The top surface of the platform in parallel swing is 2.78 metres below the center of motion when the swing is in its position of rest or equilibrium. The tilting platform is 2.64 metres below the centre of motion.

The oscillations of the card of a compass which is constrained to regular oscillatory motion about a fixed axis are explained by three conditions: (*A*) the position of the centre of mass of the card and magnets not coinciding with centre of suspension; (*B*) a centrifugal couple arising from differences in radii of each elementary mass of the card about the axis of rotation; (*C*) changes in the magnetic couples arising from the tilting of the card. Deviations occur when the amplitudes of these oscillations are greater or tend to be greater on one side of the position of normal equilibrium than on the opposite.

The following facts are observed :—

(*a*) When the vertical plane of the swing's motion is N-S, that is, if the axle of the swing is E-W, the oscillations will be small if indeed there be any, and the mean reading of the lubber-line will not differ materially from the mean reading when at rest.

(*b*) When the axle is lying N-S, oscillations are usually seen, sometimes quite large, but the mean reading again is nearly the same as at rest.

(*c*) When the axle is lying in any other direction, and notably in an intercardinal direction, the mean reading of the lubber-line when the swing is in motion will usually differ from the readings taken when the swing is at rest, and hence give rise to deviations which seem to be fairly permanent so long as the amplitude of the motion of the swing remains constant.

(*d*) The deviations for axle NE-SW will have an opposite sign to the deviation for axle SE-NW.

(*e*) The sign of the deviation and its magnitude are peculiar to each compass.

(*f*) The magnitude of the deviation and the amplitude of the card oscillations increase with the amplitude of the swing and the radius.

Deviations in the same direction, that is, of the same sign, are observed when the compass is swung below the axle of the swing, or above the axle.

Deviations produced are given in tabular form for several compasses viz :— RITCHIE Compass, THOMSON Compass, WILCOX-CRITTENDEN Boat-Compass *D*, and DURKEE Boat-Compass *S*.

(A) *DYNAMIC DEVIATIONS.*

Under the name of *dynamic deviations* BIDLINGMAIER investigated the errors of magnetic instruments that might be persistently produced by the motion of a ship at sea, under the assumption that the ship rolls, pitches or rises and falls with a simple harmonic motion, and that the centre of gravity of the magnetic needle or system of magnetic needles does not coincide with the point of suspension. He also assumes during the course of this investigation that the plane of free motion of the magnet remains fixed in direction, that is, always horizontal in the case of a compass, always vertical in the case of a dip circle, and also that the motion is not damped.

He deduces a general expression for the deviation, δ, in the form of five factors

$$\delta = N \times S \times I \times P \times L$$

which he designates as the numerical, the ship, the instrument, the period and the position factor (*See*: F. BIDLINGMAIER — *Erdmagnetische See-Beobachtungen, I Teil, Die Grundlagen* (297-298), Berlin, 1909).

For the ordinary compass $S = (Ae/P)^2$, $I = (Ml/mH)^2 = (mZ/gmH)^2 = (\tan I/g)^2$, $P = 1/(P^2 - p^2)$, $L = \sin 2\zeta$ and δ is expressed in degrees. A = roll of ship; e = distance between compass and axis of roll; P = twice the ship's period; I = magnetic inclination or dip; g = acceleration of gravity; l = distance between centre of gravity of compass-card and point of suspension; m = magnetic moment of the compass-card; M = mass of the compass-card; H = horizontal component of the Earth's magnetic field; Z = vertical component of the Earth's magnetic field; p = time of a double oscillation of the compass-card; ζ = the magnetic course or heading.

The periods P and p are the times elapsed between two successive transits in the same direction through the position of equilibrium. The deviation becomes zero when A, e, I, or $\sin 2\zeta$ is equal to zero.

For RITCHIE Compass 39670 in the experimental swing just described, the magnitude of the deviation observed is 70 times greater than that computed.

The discrepancies between the deviations observed in the swing and the dynamic deviations computed for the swing are probably explained by the ignoration of conditions (*B*) and (*C*).

(B) *CENTRIFUGAL ACTION.*

If two aluminium rods of equal mass and length be assembled as a straight line on the pivot of a THOMSON dry compass mounted in the wooden swing and be allowed to come to rest, then when the swing motion is started this non-magnetic needle will orient itself at right-angle to the axis of swing. If two more rods of equal mass and length are added at right-angles to the assembly so as to form a cross, no change in orientation takes place even after prolonged swinging. This experiment seems to indicate that the existence of axes of maximum and minimum inertia plays a rôle, though other conditions such as the position of the centre of mass above or below the point of suspension and friction at point of suspension may also enter. The moments of ordinary navigational compasses may be considered for practical purposes as equal about any horizontal axis, so far as regards the graduated card, the buoyant chamber and other parts having their horizontal sections circular, but this equality of moments is frequently destroyed by the distribution of the magnets. The horizontal axis of least moment of inertia of the magnet or assembly of magnets generally coincides in direction with the direction of the magnetic axis. The excess of maximum moment over the minimum moment in the assembly of magnets is very different in various types of compasses, although the difference might not be very conspicuous in a casual inspection.

If the horizontal axis of harmonic motion of the ship or swing is in the same vertical plane as the magnetic axis and the principal axis of least moment of inertia, and if that principal axis be inclined to the horizontal axis of harmonic motion of the ship or swing, then there is evidently a centrifugal couple acting to increase the inclination brought about by longer radii to one half of the principal axis than to the other half. This couple may be resolved into components and one being taken in the plane in which the card is free to move would induce oscillations of the card.

(C) *KINETIC EQUILIBRIUM ERROR.*

Oscillations of the card caused by the tilting of the plane of the card were investigated by Sir William THOMSON, who called them the kinetic-equilibrium error. He defines the position of kinetic equilibrium of the compass at any instant as the position in which it would rest under the magnetic forces and a force of *apparent gravity* whose acceleration is equal to the resultant of gravity acceleration and the accelerations taken in opposite sense of the cardanic suspension due to the rolling of the ship. STARLING has shown that the compass in an aeroplane has deviations when the plane is banking. These errors or deviations arise from the same cause, a component of the Earth's magnetic field perpendicular to the plane of the magnetic meridian lying in the plane of free motion which is tilted from the horizontal by the accelerations of the rolling ship or changes in the speed or direction of the aeroplane.

There is, however, an important difference between the deviations of a compass tilted in an aeroplane and that of a compass on a rolling ship. In the aeroplane it is produced by a gradual tilting of the plane of apparent level as the aeroplane turns or changes speed. On a ship it is produced by oscillatory tilting as the ship rolls from side to side, and if the deviations were numerically equal, but of opposite sign for equal but opposite angles of tilt, they would disappear in the mean of observations extending over many compass-oscillations or they would be damped out in an instrument of a very long period as compared with the period of tilting. But they are not numerically equal except when the axis of tilting is in the plane of the magnetic meridian, a fact that Sir Willam THOMSON does not take into account. When the axis of tilting is perpendicular to the plane of the magnetic meridian, there is no component of the Earth's field in the tilted plane of free motion perpendicular to the plane of the magnetic meridian.

The study of these tilting errors is the principal subject of the article by Mr. PETERS.

Since it is not convenient to measure the angle of tilting of a compass-bowl subject to the rolling motion of a ship it is calculated from the angle of roll of the ship, and from the direction and magnitude of apparent gravity of a point in a ship rolling in non-resisting medium and having no vertical motion.

Equations are given for computing the direction and relative strength of the apparent gravitational field as affected by the acceleration of the rolling motions. These are used to determine the maximum angle of tilt produced by the maximum angle of roll. The kinetic equilibrium error for an angle of tilt in one direction is shown to be different for an equal angle of tilt in the opposite direction for certain elements in certain directions of the axis of tilting and hence gives rise to deviations.

The computed deviation in declination that results in the case of a magnet having a large moment of inertia, constrained to move about an axle parallel to the radius of swing and having considerable damping, has been found to be much smaller than would be indicated by the results of the experiments for the same conditions. It is concluded that this theory of tilting deviations does not account for the whole deviation observed and must be regarded as only contributing a part of the effect, as does also the theory of dynamic deviations.

The deviations in horizontal intensity and magnetic inclination will be the subject of a future paper.