Chapter 1 : A Treatise on Electromagnetic Phenomena and on the Compass and Its Deviations Aboard Sh

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But these geometric constructions can conveniently generate and then calculate the magnetic deviation of a ship compass at a location. With our electronic calculators and computers, we take for granted the effortless arithmetic and trigonometric calculations that so vexed our ancestors. Pre-calculated tables for roots and circular functions, generated through hard work, were often used to create tables of magnetic deviations for specific ships and locations. To reduce the chance of misreading these tables, a few types of graphical diagrams, not just dygograms, were invented to provide fast and accurate readings of magnetic deviation. These graphical calculators are the focus of this part of the essay. Computing the Magnetic Deviation There were a few graphical methods of looking up the magnetic deviation on a ship at sea. A common type of chart, or deviation card, is shown in the figure on the right. Here the sailor would follow his compass heading on the inner circle and arrive at a course on the outer circle that is corrected for the magnetic deviation of the ship at the location for which the card was constructed. The simple nature of this chart belies its advantages in obtaining a fast and reliable correction. The semicircular and quadrantal components are also individually plotted as dashed curves in the ones I have seen. To read the correction, you would find the compass heading on the scale, proceed up the dotted line to the solid curve, then back to the scale along the solid line or parallel to them for intermediate scale values. Simple in design, robustly effective in use! It can be seen here that the solid curve is the sum of the plotted semicircular curve, the quadrantal curve, and the constant deviation A when significant. Only the semicircular deviation and the new total need to be re-plotted for other locations. As ship design evolved from simple iron plating to iron hulls with larger engines, the inaccuracy of the inexact coefficients A, B, C, D and E became noticeable. On the other hand, the equation expressing the magnetic deviation in terms of the exact coefficients A, B, C, D and E was difficult to compute, despite a set of mathematical tables and rules specifically prepared for this purpose by Smith. In an attempt to deal with this, Smith invented the geometric constructions he called dygograms to provide a graphical calculation of the magnetic deviation for any compass course using the exact rather than inexact coefficients. We will briefly investigate each of these. To create a dygogram for a given ship, it is assumed that the exact coefficients A, B, C, D and E are known. However, Smith does derive inverse series for extracting these exact coefficients from the inexact coefficients A, B, C, D and E that can be obtained by harmonic analysis from measurements taken as the ship is swung. So as the ship swings completely around, the semicircular contribution make one revolution while the quadrantal contribution makes two revolutions. For the Dygogram I type, Smith modeled the net deviation as one point revolving on a circle at a certain angular speed, with a second point revolving on an outer circle centered on the first point but at half that speed. With correct scaling, the inner circle represents the contribution of the quandrantal terms while the outer circle represents the contribution of the semicircular components. This is an epicyclic motion similar to the Ptolemaic epicycles that modeled positions of the outer planets, except that Ptolomy had the outer circles rotating faster than the inner ones. This can also be modeled as a point on a circle as the circle rolls around the circumference of another circle, where here the effective radius of the inner circle is increased by the radius of the outer circle. This is akin to a penny rolling around another penny, in which Abraham Lincoln rotates twice for every revolution of the outer coin. Smith originally assigned the faster quadrantal rotation to the outer circle, and to me this is the instinctive way to do it, but by the 3rd edition of the Admiralty Manual he reversed these to take advantage of simplifications in construction proposed by Lieut. Colongue of the Russian Imperial Navy. It was named from the Latin limax for snail by Gilles-Personne Roberval in in his use of it to draw tangents as a means of differentiation. We will be using miniature versions of it as we go. Referring to the dygogram components in red in the figure to the right, we place a point O at the bottom of the page and at a convenient distance above it we place a point P.

Then using this as a unit length we move right a distance A to plot the point A, right again a distance E to plot the point E, up a distance D to plot the point D, up again a distance B to plot the point B, and right a distance C to plot the point C. So we extend the math term is produce ND a distance equal to ND in an opposite direction from point D and we get the appropriate point S SOUTH on the curve that will provide at O the magnetic deviation for a magnetic course of due south, that is, the angle between the vertical line OX and the line OS. The distance A simply produces a constant offset angle. We mark a point Q where the north-south line NS intersects the inner circle. You can see on the figure that east-northeast is marked at a position At each location we mark points on the paper corresponding to N and S on the straightedge and we connect them to construct the curve. Then with a protractor centered at Q we mark various cardinal and intercardinal points of the compass on the outer curve and the dygogram is complete. The outer curve can indeed loop within the inner circle in some cases, as seen in the dygogram at the top of this essay which is also reproduced on the right. In practice most of the construction lines are removed in the final dygogram. From this graphical calculator we can now easily find the magnetic deviation for any magnetic course of the ship. Smith also provides a couple of constructions to approximate the magnetic course for a desired compass course. But the best construction he describes is again due to Lieut. Then with dividers we draw the arc of a circle that passes through three points: O, Q and this intersection point. The magnetic course for this intercardinal point is So these two examples demonstrate that we can find the deviation for any compass course on the dygogram with a few extra steps. Once the dygogram is constructed for one location, Smith provides simple procedures for plotting the dygogram at any other location from as few as two measurements of deviation vs. In the process the values of the location-specific coefficients B and C are also found. It is a clever transformation. Smith relates that it occurred to him to turn the paper with the same velocity that the ship turns, i. Here we see, from an Earth-centered point of view, the Sun revolving in a circular orbit around the Earth and Mars circling in what appears to be a perfect dygogram! And it very nearly isâ€"it certainly is an epicycloid. If Mars were to have an orbital period of 2 Earth-years instead of 1. Now as we know, Copernicus demonstrated that by changing the reference frame to a Sun-centered system by fixing the paper on the Sun as the orbits trace we find that the orbits of Earth and Mars end up as simple nested circles. We have an analogous situation here. To construct this type of dygogram, a circle of radius 1 of some unit of length is drawn with a center O. Then using this unit length we move up from O a distance B and right a distance C and mark this point o. Then we move up a distance D and right a distance E. We draw a circle with its center at o that passes through this last point. This small circle is marked n, e, s and w and degrees are marked on it in a clockwise direction. Degrees are marked on it counterclockwise from north. Again Smith provides methods of plotting such a dygogram for different locations from a few observations. The finished dygogram appears as in the example below on the right. Once the dygogram is created, Smith provides the following succinct procedure for reading the magnetic deviation for a given magnetic course: If the large circle is graduated we may measure the angle ORr by producing RO, Rr, to intersect the circle in J and j. The arc Jj will then be twice the required angle. Then we move it parallel to itself there are linkages for parallel rulers until it intersects the two circles at the same marked angle. Again we see the power of a graphical calculator to naturally close in on a solution that would otherwise be a tedious trial-and-error arithmetic calculation. Smith describes drawing a large set of lines between points on the two circles that have corresponding marked angles to provide a convenient, overall visual layout. Also, if the large circle is considered to be an upside down compass card, we can glue the upside-down small circle onto the compass card itself. In those days the needle was attached to the compass card, so the card turns with the needle and the compass course is the reading of the card in the forward direction the ship is facing. When the ship is at sea, we can find which drawn line between the two circles is fore-and-aft which will be parallel to the compass course shown on the fore edge of the rotated card , and this will cut the two circles in points corresponding to the magnetic course. Or better yet, we can steer a magnetic course by turning the ship until the line connecting the desired magnetic course values on the two circles is fore-and-aft. Smith termed this a steering dygogram. It seems absolutely brilliant to me, but the lack of ready literature on it suggests it was never really taken up. But a ship at sea would have to carry a set of charts like these for various locales, one more variable that could lead to disastrous errors. However, in a French engineer named Charles Lallemand created a uniquely designed and somewhat famous graphic, a hexagonal chart of his own invention, to calculate the magnetic deviation of the ship Le Triomphe no matter where it was located. Greenhill used a dygogram to model the reaction force on the axle of a pendulum. And just now as I write the final paragraphs of this essay, I look at the steering dygogram and it reminds me of sun compasses used as very early navigational aids. And that reminds me of portable sundials, which sparked my interest in nomography and graphical calculators in the first place. And that reminds me that the Equation of Time correction the difference between the mean clock time and the actual solar time that must be accounted for in any good sundial is composed of a sinusoidal term with a period of a year and a sinusoidal term with half that period! The other component is the angle between the equator and the plane of the orbit or the ecliptic tilt. Whitman provides a relatively simple but accurate formula for the EOT for a given day: The perihelion date varies with the year depending mostly on leap year differences, and it ranges from Jan. The EOT is typically averaged over the four-year leap day cycle anyway. So a dygogram can model the EOT if the Now in an equatorial sundial the hour lines are also equally spaced around the circumference of a circle. So it might be possible to adapt the steering dygogram to provide the EOT correction right on the sundial. I will have to think about that. An Exquisite Endeavor The centuries it took to untangle the mysteries of magnetic deviation represent an enormous, sustained effort by scientists, mathematicians, ship captains and crews. Many people provided the mathematical and scientific tools and data needed to analyze the problem, and in fact this essay has focused only on contributors in the West. From my point of view, the heroic efforts made by these men to overcome the deadly consequences of magnetic deviation comprise a very heartening thread of history and an inspiring illustration of the role of the mathematical sciences in advancing our civilization. If you find you are unable to read particular pages that you are interested in, please contact me and I will try to provide an excerpt for personal research under Fair Use provisions. A collection of papers on the subject of magnetic deviation, measurement and corrections. W, and Arrott, A. A refreshingly short and highly readable history of magnetic deviation. United States Naval Institute pp. A mathematically detailed article on the Type I dygogram, including a unique analysis of its validity by treating each magnetic component in isolation.

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