RP77

A COURSE-SHIFT INDICATOR FOR THE DOUBLE-MODULATION TYPE RADIOBEACON

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ABSTRACT

To further increase the reliability of the visual directive radiobeacon system developed by the Bureau of Standards, a course-shift indicating instrument primarily for station use has been developed which serves a twofold purpose—(1) to indicate to a station operator whether a given course as laid out in space remains unvarying during a given time of operation, and (2) to greatly facilitate a check of the beacon calibration.

The circuit arrangement used in applying this instrument at the beacon station comprises a rotatable pick-up coil inductively coupled to the two loop antennas of the beacon, a detector-amplifier unit, a suitable filter unit, and a differential ratio instrument. The ratio instrument consists of two fixed field coils and an armature or rotor coil. A pointer attached to the rotor coil moves over a suitable scale. The force actions of the two field coils upon the rotor coil are in opposition so that with equal currents in the field coils the pointer assumes a mid-scale position. The filter unit is so designed that with equal 65 and 85 cycle voltages impressed upon the instrument equal currents flow through the field coils. If the 65-cycle voltage becomes greater than the 85-cycle voltage, one field coil carries a greater current than the other and the net force action upon the rotor coil becomes greater than zero, the pointer attached to the rotor coil moving to the left of its mid-scale position. The reverse is true if the 85-cycle voltage becomes greater than the 65-cycle. The differential action of the two field coils upon the rotor coil, therefore, serves directly as a means for comparing the relative amount of 65 and 85 cycle modulation in the radio-frequency voltages induced in the pick-up coil coupled to the two-loop antennas.

Corresponding to each setting of the beacon course, there is a definite ratio of 65 to 85 cycle modulation in the two loop antennas of the beacon. For each course setting, then, there is a definite position of the rotatable pick-up coil at which the amounts of 65 and 85 cycle modulation in the voltage induced in the coil are equal, the instrument pointer being then at its mid-scale position.

The course-shift indicator has a twofold application at the beacon station.

1. For a given course setting the coupling coil is rotated so that the instrument pointer is at center scale or zero. A station attendant is then certain that the course marked out in space remains unvarying so long as the instrument pointer remains at zero. A change in course of 0.1° is readily detected. Easy adjustment is provided on the beacon transmitting set whereby a shift in the course once detected may be corrected.

2. If, during the original calibration of the beacon, the settings of the scale attached to the pick-up coil, when ratio instrument reads zero, corresponding to the various beacon course settings are recorded, the beacon is calibrated once and for all. A recalibration of the beacon may then be effected very rapidly and within the beacon station.

The instrument herein described may also be used as a visual course indicator on large aircraft. Its advantages and disadvantages as compared with the vibrating-reed course indicator are discussed.

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I. INTRODUCTION

To further increase the reliability of the visual directive radiobeacon system developed by the Bureau of Standards, an indicating instrument primarily for station use has been developed which serves a twofold purpose—(1) to indicate to a station operator whether a given course as laid out in space remains unvarying during a given time of operation, and (2) to serve as a check on the beacon calibration.

A brief description [1] of the directive radiobeacon is essential to a clear understanding of the operation of the course-shift indicator. The directive radiobeacon consists essentially of a master oscillator supplying power at 290 kc to two power amplifiers which, in turn, feed two loop antennas crossed at an angle of 90° with each other. Each power amplifier is modulated to a selected low-frequency note, the two modulating frequencies chosen being 65 and 85 cycles per second. One loop antenna, therefore, radiates a 290 kc wave modulated to 65 cycles while the other emits a 290 kc wave modulated to 85 cycles. Due to the directive properties of the loop antennas, these waves are a maximum in the directions of the planes of the antennas transmitting them and of zero value in the directions perpendicular to these planes. An airplane flying along a line bisecting the angle between the two antennas will, therefore, receive the two waves with equal intensity. If the airplane deviates in either direction from this line, the signal from one antenna becomes stronger and the other weaker. Equality of received signals thus indicates a fixed line or "course" in space and provides a means for guiding aircraft along that "course." For the purpose of orienting the course in any given direction a 4-coil goniometer, consisting of two stator coils crossed at an angle of 90° with each other and two rotor coils also crossed at 90°, is employed. The stator coils are connected to the plates of the power amplifiers while the rotor coils are connected each in series with one loop antenna.

The currents in these antennas, due to the driving voltage of one stator goniometer coil, create a resultant field corresponding to that

[1] A more detailed description may be found in a paper on Radio Aids to Air Navigation, by J. H. Dellinger and H. Pratt, Proc. I. R. E., **16**, pp. 890–920; July, 1928.

Other papers dealing with the details of the beacon system are: Receiving Sets for Aircraft Beacon and Telephony, by H. Pratt and H. Diamond, B. S. Jour. Research (RP19), October, 1928; and Design of Tuned-Reed Course Indicators for Aircraft Radiobeacon, by F. W. Dunmore, B. S. Jour. Research (RP28), November, 1928.

which would be produced by an imaginary or phantom loop rotating with the goniometer rotor and carrying only one modulation frequency. Since there are two primary or stator coils, two such phantom loops, one for each modulation frequency, rotating as the two movable goniometer coils rotate together, allow the equisignal zone or "course" in space to be oriented in any direction. For any given course setting, then, each loop antenna carries radio-frequency current modulated at both 65 and 85 cycles per second, the ratio of 65 to 85 cycle modulated radio-frequency power in each loop depending upon the position of the goniometer. A change in the proportion of 65 to 85 cycle modulation constitutes a change in course.

The course-shift indicator is a direct-reading switchboard type instrument designed to indicate a change in the relative amounts of 65 and 85 cycle modulation in the two antennas and, in consequence, a shifting of the course.

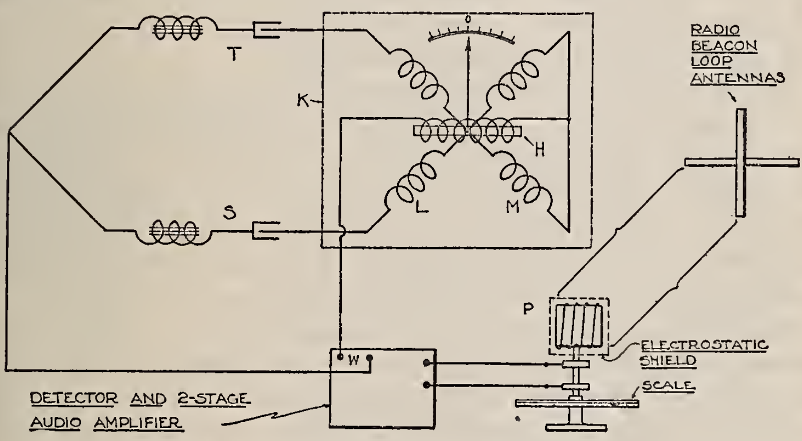

FIGURE 1.—*Circuit used with course-shift indicator*

II. DESCRIPTION OF COURSE-SHIFT INDICATOR

The circuit arrangement used in applying the course-shift indicating instrument at the beacon station is shown in Figure 1. A rotating inductance coil *P* is coupled magnetically to both loop antennas, electrostatic coupling being prevented by means of the electrostatic shield shown. Exact equality of magnetic coupling to the two antennas is not essential. The terminals of coil *P* are connected to the input terminals of a detector-amplifier unit consisting of a grid bias detector and two stages of amplification, the final stage comprising two 5-watt tubes in push pull in order to provide ample power output to the course-shift instrument.

The course-shift indicating instrument is a modification of a commercial horizontal-edge switchboard type of frequency meter having an external reactor box. The meter consists of two field coils, L and M, and an armature or rotor coil, H. A pointer attached to the rotor coil moves over a suitable scale. The force actions of the two field coils upon the rotor coil are in opposition, so that with equal currents in the two field coils the pointer assumes a mid-scale position. The reactor box contains two filters, S and T, having constants such that with equal 65 and 85 cycle voltages impressed upon the instrument equal currents flow through the field coils L and M. If the 65-cycle voltage becomes greater than the 85-cycle voltage, the field coil L carries a greater current than M, while if the 65-cycle voltage is smaller, the reverse is true. The differential force action of the fields L and M upon the armature H, therefore, serves directly as a means for comparing the relative amount of 65 and 85 cycle modulation in the radio-frequency voltage induced in the coupling coil P. The resonance curves of the tuned circuits employed are given in Figure 2. The three curves shown are to be associated with the respective circuits given in the figure. The theory of operation of the instrument may now be given in somewhat greater detail.

With a voltage of 65 cycles frequency impressed upon the instrument terminals, the circuit SLHW, which is tuned to 68 cycles, carries a 65-cycle current whose value may be designated as $\overline{AC}$, while the circuit TMHW, tuned to 95 cycles, carries a 65-cycle current of value $\overline{BC}$. Similarly, with an equal voltage of 85 cycles frequency impressed, the circuit SLHW carries an 85-cycle current of value $\overline{DF}$ while the circuit TMHW carries an 85-cycle current of value $\overline{EF}$.

With both signals impressed simultaneously, field coil L carries currents $\overline{AC}$ and $\overline{DF}$, while field coil M carries currents $\overline{BC}$ and $\overline{EF}$. The rotor coil H is the return path for all these circuits. The components of the force action of the field coil L upon the rotor coil H are then proportional to

$$\overline{AC}\times\overline{AC}+\overline{AC}\times\overline{BC}+\overline{DF}\times\overline{DF}+\overline{DF}\times\overline{EF} \qquad (1)$$

while the components of the force action of the field coil M upon the rotor coil H are proportional to

$$\overline{BC}\times\overline{AC}+\overline{BC}\times\overline{BC}+\overline{EF}\times\overline{DF}+\overline{EF}\times\overline{EF} \qquad (2)$$

The net force action is then proportional to the difference between (1) and (2), or to

$$(\overline{AC}\times\overline{AC}+\overline{DF}\times\overline{DF})-(\overline{BC}\times\overline{BC}+\overline{EF}\times\overline{EF}) \qquad (3)$$

Obviously, the first half of (3) should be made equal to the second half if the pointer is to be at mid scale when equal 65 and 85 cycle voltages are impressed.

Assume now that the 65-cycle voltage increases while the 85 cycle decreases. The currents $\overline{AC}$ and $\overline{BC}$ are proportionately increased

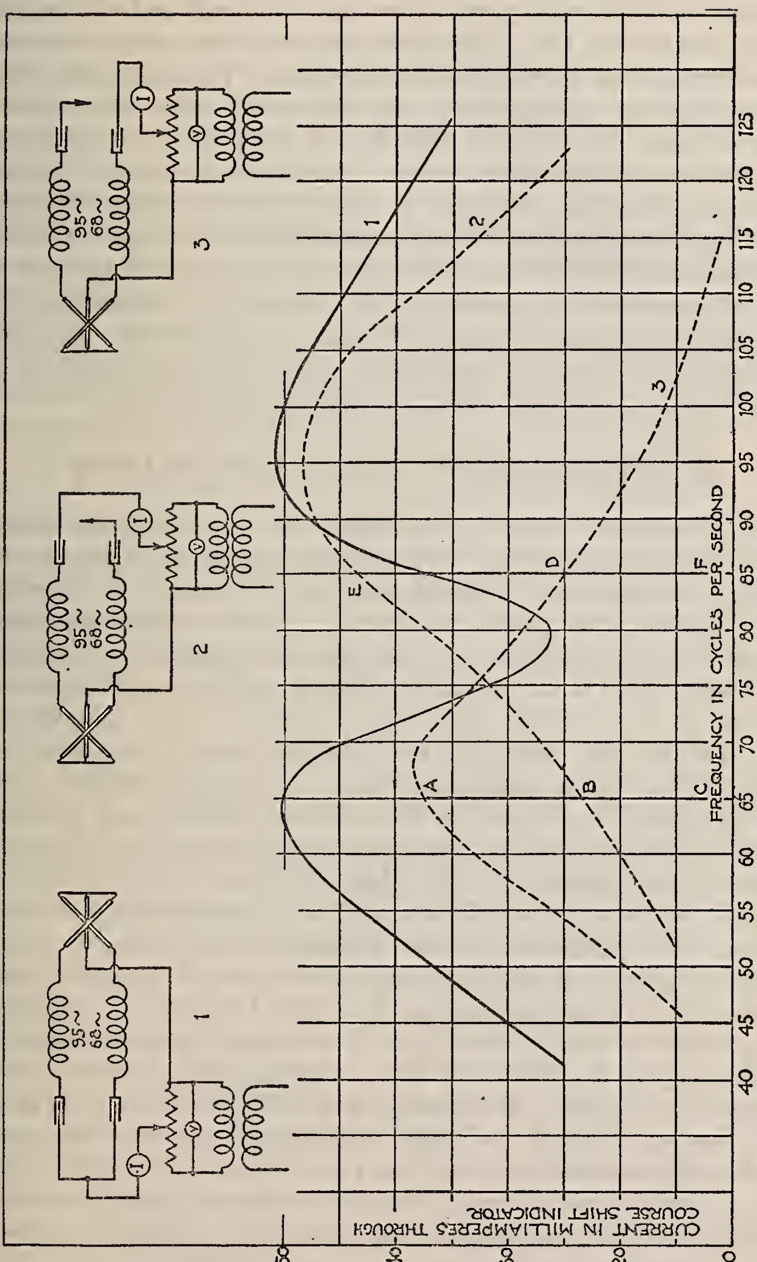

FIGURE 2.—*Resonance curves of course-shift indicator circuits*

and the currents $\overline{DF}$ and $\overline{EF}$ are reduced. The first half of (3) thus becomes greater than the second half and the net force action upon the rotor coil becomes greater than zero, the coil and the pointer moving toward the left. The reverse is true if the 85-cycle voltage increases while the 65-cycle voltage decreases. The sensitivity of the course-indicating instrument may be considerably increased if sharper tuning of the circuits SLHW and TMHW can be obtained. The greater selective effects on the modulation frequencies thereby secured amplifies the difference in currents in the stator fields and accordingly the difference in force exerted by these fields on the rotor. For example, in the first case considered (the 65-cycle voltage increasing and the 85 cycle decreasing), the current $\overline{DF}$ decreases as $\overline{AC}$ increases, while the current $\overline{BC}$ increases and $\overline{EF}$ decreases. Obviously, the difference between the first and second halves of (3) would be greater if $\overline{BC}$ and $\overline{DF}$ were of smaller magnitudes.

III. APPLICATION AT THE BEACON STATION

The application of the course-shift instrument at the beacon station may now be shown. With the goniometer on a given course setting, radio-frequency voltages modulated to 65 and 85 cycles per second are induced in the coil *P* (fig. 1), the relative amplitudes induced being dependent upon the relative proportion of 65 to 85 cycles modulation in the two loop antennas and also upon the relative coupling of the coil, *P*, with these antennas. It is simpler and equivalent to deal with the two phantom loops crossed at 90° set up by the beacon as described above, one phantom loop carrying only current modulated to 65 cycles per second and the other phantom loop only current modulated to 85 cycles per second, the position of the phantom loops being a function of the goniometer setting. By rotating the coupling coil, *P*, a position is found where the magnetic coupling to the two phantom loops is equal. At this setting the pointer of the course-shift indicator will be at mid scale, or zero. If the phantom loops are now shifted in position, either by a change of the goniometer setting or by a change in the percentages of 65 and 85 cycle modulation in the two physical loops due to circuit changes in the beacon, the equality of coupling of the coil, *P*, to the two phantom loops is no longer maintained and the instrument pointer deflects either to the left or right of zero. A 1° shift of the phantom loops, corresponding to a 1° change in the goniometer setting, results in a deflection of the instrument pointer of approximately 1 cm.

The twofold application of the course-shift indicator at the beacon station is now evident. Suppose that the goniometer is set on a given beacon course and the coupling coil rotated to adjust the course-shift indicator pointer to zero. A station attendant is then certain that the course marked out in space remains unvarying so long as the instrument pointer remains at zero. As noted above, a 1° shift in the course will result in a 1 cm deflection of the instrument pointer, so that a change in the course of 0.1° may easily be detected. Easy adjustments of the radio-frequency voltage supply to the two amplifier trains of the beacon transmitting set are provided whereby a shift in the course once detected may be corrected.

To check the variations in the course during the operation of the beacon, a series of tests was made, each lasting from two to six hours. At no time was a deflection greater than 0.5 cm observed, the maximum deflections usually occurring during the warming up of the beacon transmitting set. Moreover, the shifts were as much on one side of zero as on the other. It is conceivable, however, that over a long period of operation difference in tube aging, etc., may introduce a permanent shift in the course.

The second application of the instrument described lies in the ability to recalibrate the beacon in very simple fashion with its aid, once the beacon has been properly calibrated. The usual procedure in calibrating the beacon consists of orienting the course on a given point and checking the course at a distance to insure that it has been properly oriented. This is repeated for a number of points of diverse geographical location. The calibration obviously involves a considerable amount of time and effort and should be repeated at definite intervals.

If, during the original calibration of the beacon, the settings of the scale attached to coupling coil P (at which the course-shift indicator reads zero), corresponding to the various goniometer settings are recorded, the beacon is calibrated once for all. A curve showing the calibration of the course-shift indicator-coil position in terms of the goniometer-rotor angles is given in Figure 3. So long as this calibration remains true, the beacon calibration is also correct. The points of the entire curve of Figure 3 may be checked in a very short time.

The peculiar shape of this curve is due to the unsymmetrical location of the coil P with respect to the two loop antennas. With a perfectly symmetrical arrangement, a straight line would be obtained. The figures on the curve indicate the degrees of rotation of the goniometer necessary to throw the course-shift indicator needle off scale either to the right or left and thus serve as a measure of the sharpness of indication of this instrument at each point. Since the instrument scale measures approximately 13 cm over all, the sensitivity of the instrument is seen to range from 0.7 to 1 cm per degree shift of the course, depending upon the setting of the coupling coil P.

Figure 4 shows the apparatus constituting the course-shift indicator installed at the Bureau of Standards beacon station at College Park, Md. The detector amplifier unit does not appear in the photograph.

IV. USE AS A VISUAL INDICATOR FOR THE DOUBLE-MODULATION TYPE OF RADIOBEACON

From the description of operation of the course-shift indicator it is evident that it may also be used as a course indicator on shipboard or on aircraft. To accomplish this it is only necessary to receive the double-modulation radio beacon signals with amplitude sufficient to properly operate the instrument. The operating voltage necessary

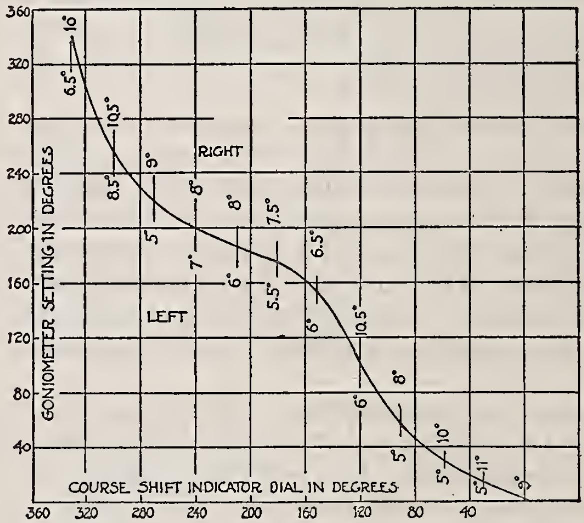

Figure 3.—*Calibration curve for course-shift indicator*

is of the order of magnitude which may be obtained from the output of a well-designed receiving set.

In order to prove the usefulness of this instrument as a visual course indicator, tests were made with it at a distance of 12 miles from the radiobeacon. The results obtained are given in the curve of Figure 5, which plots the deflections of the instrument pointer in centimeters to the right or left of zero, as the beacon course was oriented through 360°. The effect is identical with that obtained if an airplane carrying the instrument circled around the beacon maintaining a constant distance of 12 miles. The curve indicates that there are four courses, *A*, *B*, *C*, and *D*, which may be used, two of which, *A* and *C*, are sharper than the other two, *B* and *D*, as evidenced by the slope of the curve at these points. This is in accordance with

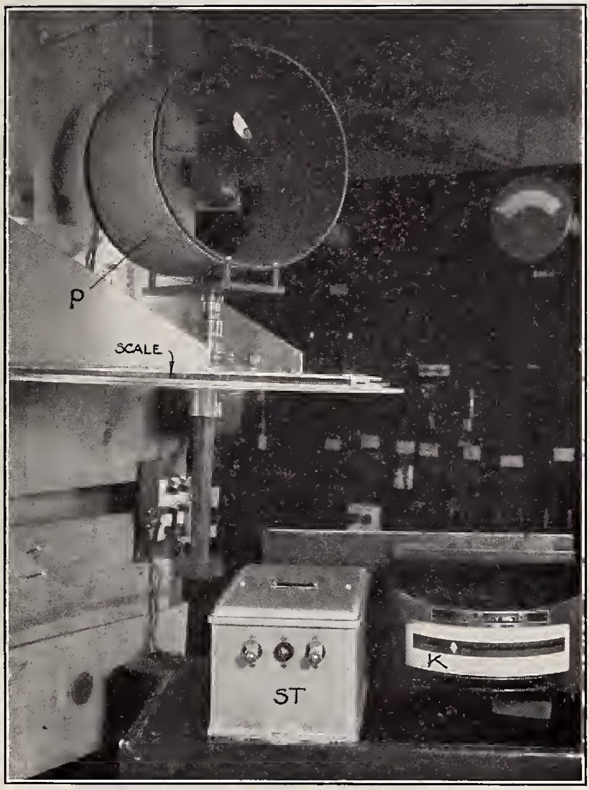

FIGURE 4.—*Course-shift indicator apparatus installed at College Park (Md.) double modulation beacon station*

results obtained with the vibrating-reed course indicator.[2] A course may here be defined as the locus of the positions in space at which the instrument receives equal signals from the phantom loops set up by

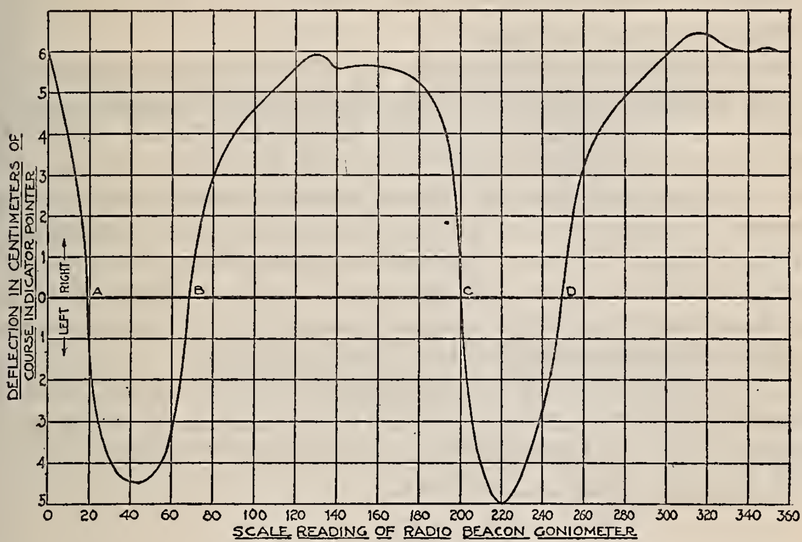

FIGURE 5.—*Scale reading of course-shift indicator installed on airplane as airplane circles 360° around the beacon*

the beacon, the instrument pointer being then at mid-scale or zero setting.

Figure 6 was prepared from the data of Figure 5, course *A*, and shows the instrument scale calibrated in degrees deviation from the

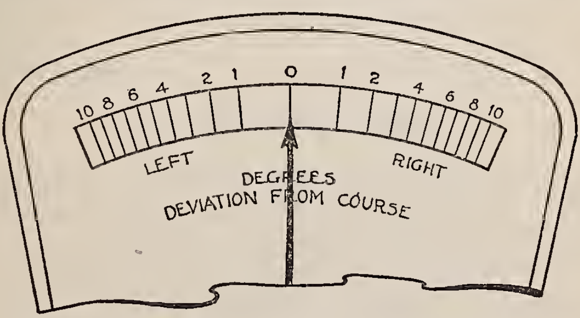

FIGURE 6.—*Scale of course-shift indicator calibrated in degrees deviation from course*

Calibration made 12 miles from beacon.

course. A deviation of 0.1° from the course may easily be detected. For the instrument used this calibration would not be practicable unless precautions were taken to keep the instrument operating

[2] See reference to third paper in footnote 1, p 3.

voltage of constant magnitude, since the type of coil spring used introduced a voltage error in the instrument, the degree of sharpness of indication being in part dependent upon the strength of signal impressed. This voltage error can, however, be eliminated by using a different coil-spring design.

It is interesting to compare the use of this instrument as a visual course indicator with the vibrating-reed type of indicator now employed. Its chief advantage over the reed indicator lies in the extremely sharp indication of course made possible by its use. The disadvantages are those of greater weight, greater signal strength required for operation, and greater chance of injury to moving parts. From the point of view of freedom from atmospheric disturbances or other interferences the reeds are, under constant condition of use, much preferable, since much sharper tuning may be obtained mechanically at the low modulating frequencies employed.

The authors express their appreciation to B. W. St. Claire, of the General Electric Co., for his valuable cooperation in the design of the final model of the indicating instrument herein described.

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