THE CURRENT BALANCE

OBJECT

To measure the mutual force between two parallel electric currents with the current balance.

APPARATUS

Current balance telescope and scale, Variac and transformer, precision ac ammeter (0-10, 0-20 amps), set of milligram analytical weights (0-350 mg in 50 mg steps), spirit level, 2-meter stick equipped with caliper jaws, micrometer caliper, cross section paper. (The manufacturer's "instructions" for operating the current balance are required for reference.)

THEORY

The ampere, MKS system, is defined as "that unvarying current which, if present in each of two parallel conductors of infinite length and one meter apart in empty space, causes each conductor to experience a force of exactly 2 x 10-7 newton per meter of length". In the experiment, Fig. 1, an alternating current (r.m.s. value is equivalent to an "unvarying current") in two conducting rods A, B each of length L connected in series electrically produces mutual repulsive forces of equal magnitude F on the rods. The upward force F on rod A is balanced by a weight placed upon the small pan W. Balance of the upward electromagnetic force by the downward weight is observed with a telescope and scale.

$$\text{F} = 2 \text{ x } 10\text{-}7 \frac{L}{d} \text{I}^2 \text{ newtons} = \frac{\mu_0}{2\pi}\left(\frac{LI_{rms}^2}{d}\right), \qquad (1)$$

where d is distance between the axes of rods A and B when the balance is in the zero-current equilibrium position. $d=do+2r$, do = distance between wires , r = radius of each wire measured with micrometer.

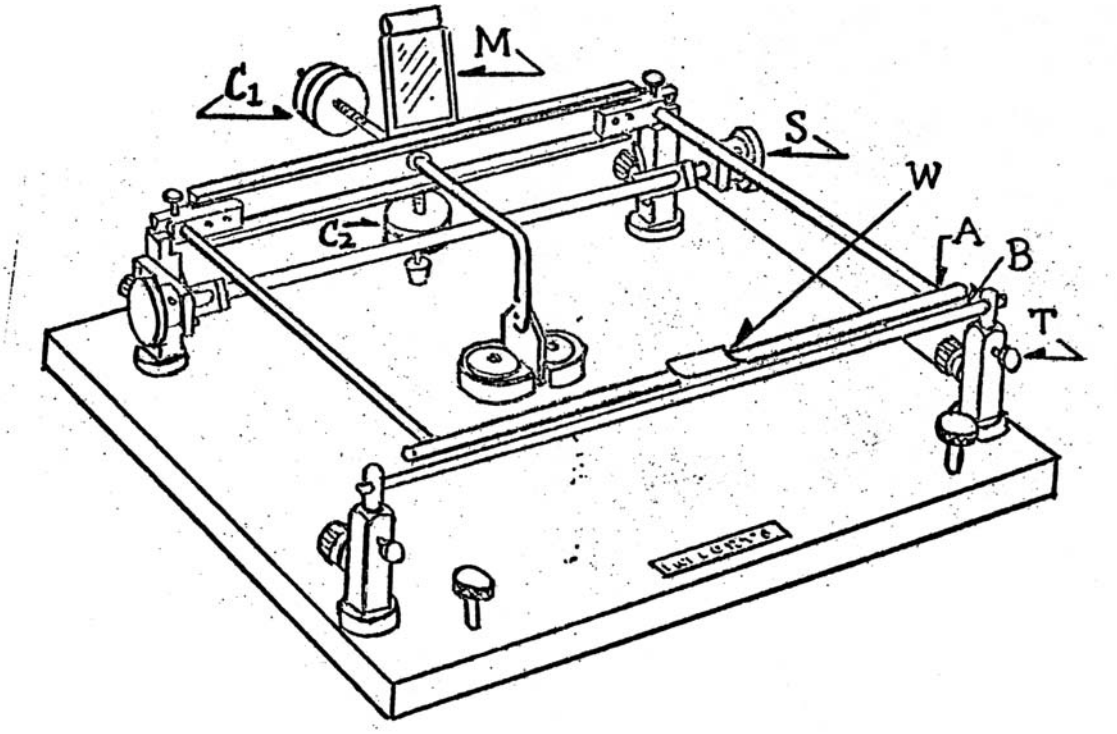

FIG. 1

PROCEDURE:

1. With Variac switch "off" and the Variac plug disconnected from the ac outlet receptacle, plug the transformer into the Variac. Using wires, connect the transformer output to the current balance rods A, B and the AC ammeter in series. The ac ammeter uses the lower range. The hookup wires connected to the posts of the current balance apparatus should be brought out perpendicular to the moving frame of the apparatus to minimize interaction between hookup wires and the frame.

2. Make sure that the two parallel rods A, B (Fig. 1), the balance knife-edges and bearings are clean so as to avoid sticky operation. Inform the instructor if cleaning is necessary.

3. Use the spirit level and the leveling screws on the base of the current balance to adjust the current balance base firmly in a horizontal plane. Adjust the counterpoise C_1 (Fig. 1) so that the frame (with balance beam released using thumbscrew S) oscillates freely and comes to rest with the front horizontal bar A a few mm above the stationary bar B. Adjust the counterpoise C_2 (Fig. 1) until the period of oscillation of the released frame is 1-2 secs; the frame should come to rest in 10-15 secs when the poles of the damping magnets are about 2mm apart.

4. The alignment and straightness of the rods A, B (Fig. 1) must be checked. To do this place a small coin on the scale pan W to bring the rod A in light contact with rod B (after releasing the current balance beam.) Use thumb screws T on the front posts and similar screws on the back posts (not shown by Fig. 1) to adjust the alignment of rods A, B by sighting from front and above. A sheet of white paper behind the rods will aid in the adjustments when sighting from the front. If the rods appear to require straightening, inform the instructor. CAUTION: the apparatus is sensitive and delicate, handle gently and with care.

5. Set up the telescope and scale with the scale of the telescope 1-2 meters from the mirror M (Fig. 1) of the current balance. Sight and adjust the optical lever arrangement, first removing the coin from the pan W. Record the zero-current equilibrium position of the current balance frame ad indicated by the telescope crosshair reading upon the telescope scale. Note that an adjustment of the telescope crosshair reading upon the scale for convenience and accuracy. Repeat the zero-current equilibrium position reading a number of times, record and calculate the mean reading.

6. Measure with the 2-meter stick equipped with caliper jaws the distance from current balance mirror M to telescope scale to 0.1 cm. Make several readings being careful not to disturb the position of the current balance and the telescope and scale. Record all readings, the mean is b of Eq. (3) below. Likewise, measure the distance L, length of rod A from center to center of the side-arm rod supports. Also measure a of Eq. (3); this is the distance from a current balance knife edge to the center of rod A – measure this distance along each side-arm rod, record all readings and use the mean as a. Finally, measure with the micrometer the mean diameter 2 of rods A, B.

7. The separation d, Eqs. (1) and (2), or rods A, B when the balance is in the zero-current equilibrium, position is calculated by

$$d = d_o + 2r, \qquad (2)$$

where d_o, the separation between rods A and B when the balance is in the zero-current equilibrium position, is calculated from the geometry of the optical lever arrangement (see Fig. 2):

$$d_o = \frac{Da}{2b}; \qquad (3)$$

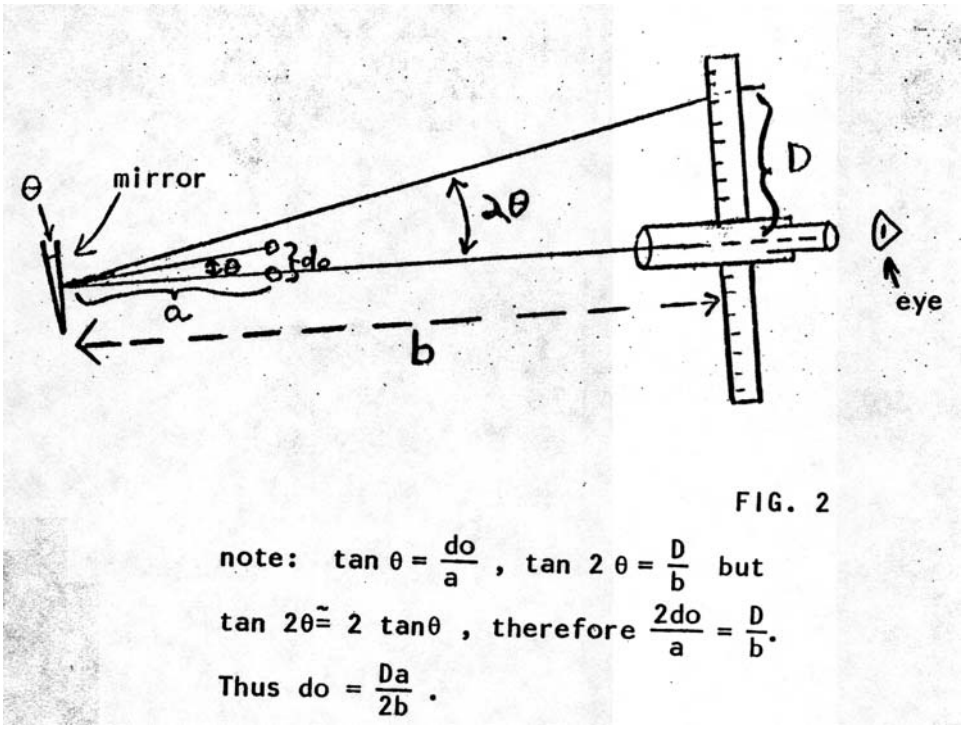

FIG. 2

note: $\tan\theta = \frac{do}{a}$, $\tan 2\theta = \frac{D}{b}$ but

$\tan 2\theta \tilde{=} 2\tan\theta$, therefore $\frac{2do}{a} = \frac{D}{b}$.

Thus $do = \frac{Da}{2b}$.

where D is difference in readings of the telescope scale when rods A, B are in contact (small coin on pan W) and when the balance is in the zero-current equilibrium position (small coin removed from pan W).

8. Now make a series of measurements to determine the forces F exerted by currents I, Eq. (1) in the rods A, B. With the current balance beam lifted off the knife edges, using thumb-screws S, place gently with the forceps a 50 mg weight upon the pan W. Release the current balance beam. Plug the Variac into the wall and adjust the Variac dial for electric current in rods A and B. Adjust the electric current so that the telescope scale reading is again the same as for the zero-current equilibrium position (Procedure 5) which setting requires the upward electromagnetic force F between rods A, B to be balanced by the downward force due to the 50 mg mass on pan W. Record as precisely as possible, the r.m.s. ac current I as indicated by the ammeter. Repeat the Procedure a number of times for a mean value of I.

9. Continue adding fractional weights 50 mg at a time, recording a series of readings and the mean r.m.s. current I each time, until a current 15-20 amperes is attained. The zero-current equilibrium position setting of the telescope crosshairs on the scale

is to be established for each weight-electric current combination. After each current adjustment turn "off" the Variac and lift carefully the current balance beam off the knife edges before changing the weight on the pan W. Turn "on" the Variac and release carefully the current balance beam before each electric current adjustment by the Variac.

10. Plot the force F in newtons vs I^2 on cross-section paper, using all values of F and I. Draw a best-fit straight line through the points.

11. Calculate the force F in newtons for each observed current I by Eq. (1). Plot these values of F also on the cross-section paper used for Procedure 10, using a different symbol for plotting of these calculated F values than for the observed F values of Procedure 10.

12. Calculate the percent difference for each pair of F values, Procedures 10-11, and the mean percent difference.

PROBLEMS: (to be completed during the Laboratory Period and recorded on the DATA SHEET).

1. Assuming that the calculated values of F, Procedure 11, are correct calculate the percent errors of the various F values of Procedure 10. Now assuming that these errors in the measured values of F (Procedure 10) are due to ammeter inaccuracy, calculate the percent error of each I. (see INTRODUCTION, Propagation of Errors).

2. Prepare a neat and orderly tabulation of all results and errors.

3. Complete the F vs I^2 plots on cross-section paper in pencil. These are to be initialed by the instructor before leaving the laboratory and then inked for the LABORATORY REPORT.

4. Determine the error introduced in two or three of the measurements of Procedure 9 by arranging the connecting hookup wires (see Procedure 1) approximately parallel, instead of perpendicular, to the side-arm rods of the current balance beam. Make measurements of the balancing current I for the two positions parallel and perpendicular of the connecting hookup wires in each case examined. Record all readings and calculate the percent error due to incorrect positioning of the connecting hookup wires.