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MEASURING ROTARY TABLE ANGLE ERROR

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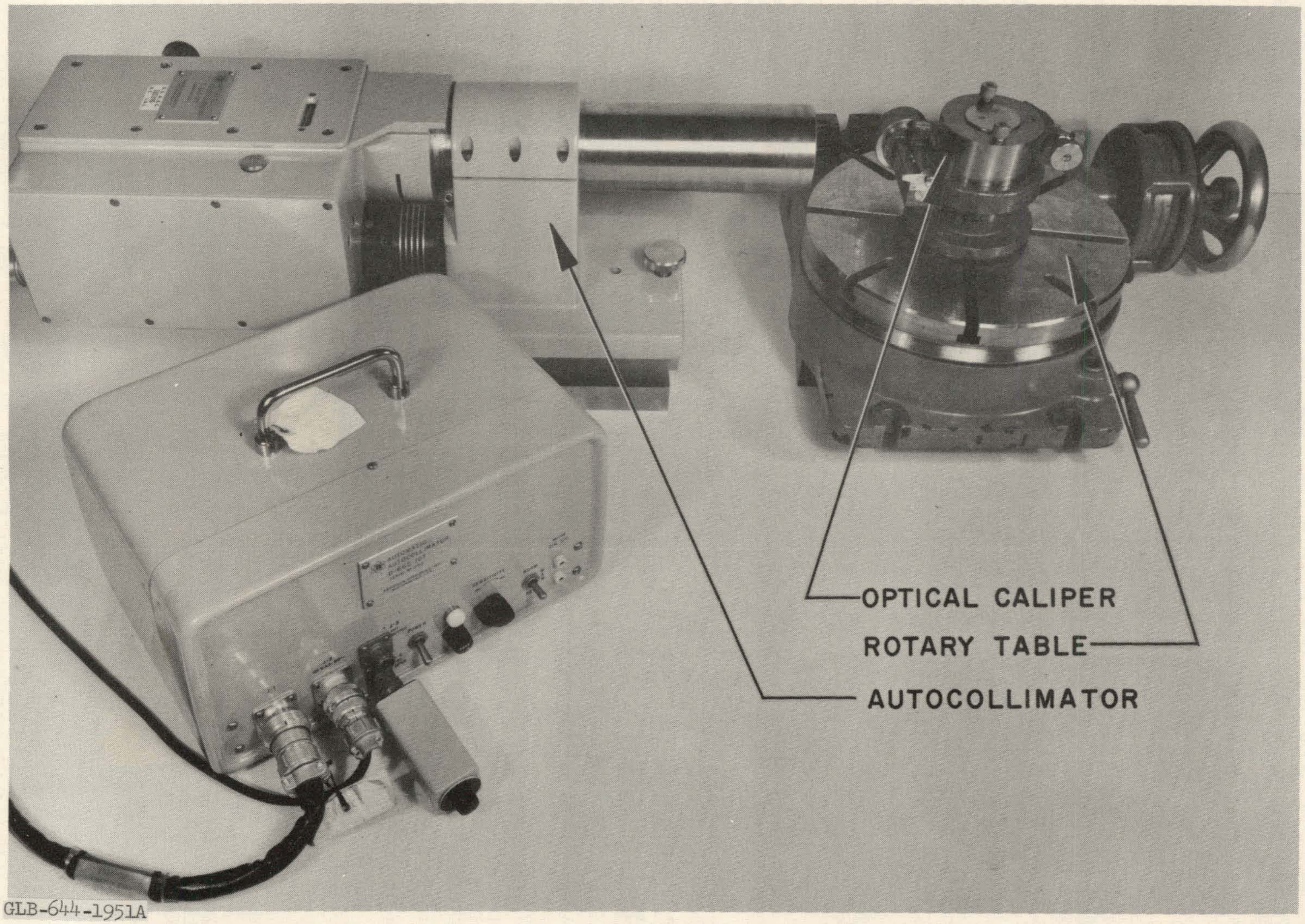
April 27, 1964



Experimental set-up for measuring rotary table angle error.

MEASURING ROTARY TABLE ANGLE ERROR

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ABSTRACT

The angle errors of a rotary table can be accurately measured by stepping off the angles with an optical caliper and computing table error from (1) the error readings at each angle measured and (2) the cumulative caliper error that will be evident when the circle is closed at 360°, eliminating the necessity of adjusting the caliper to the exact setting.

I. PROBLEM

The problem is to measure the error, relative to zero, of the angle marks around a rotary table.

II. THEORY OF MEASURING TECHNIQUE

An optical caliper is used to measure equal angles that sum to 360°. If the caliper is set at the exact angle to be measured, table error can be determined by reading the error between caliper position and table step. Commonly, however, the caliper will not be at the exact angle being measured so that the error reading is a combination of the caliper error and the table error. This makes it necessary to subtract caliper error from the results to get table error. Because equal angles of a closed circle are being measured, it is known that:

1. Table errors are random but, for a full circle, will sum to zero because an error of one angle setting must be exactly compensated by an opposite error at one or more other angle settings.
2. The caliper error is the same at each step and can be obtained by summing the combined table and caliper step errors and dividing by the number of steps measured.

Figure 1 shows how the error of slightly undersize calipers set to measure 60° will, when summed, result in an error of six times the caliper error. Figure 2 shows how the random table errors (no caliper error shown) will sum to zero at closure. If random table errors sum to zero at closure, then summing the table step and caliper step differences will leave the cumulative caliper error. Figure 3 shows how the caliper step and table step differences will sum to leave the cumulative caliper error. Dividing this sum by the number of equal angles measured will give the caliper error, which can then be subtracted from the caliper step and table step differences at each angle to give the table error.

An optical caliper and a collimator are used to measure the angles. The accuracy obtained depends on such factors as the sensitivity of the collimator, rigidity of the set-up, and care in setting of caliper. The use of this equipment is explained in Section IV.

Figure 4 shows a typical data sheet for measurements of table error at 60° angles around the table. It is important in recording data to get the signs right. If the table step being measured is greater than the caliper step (as it is in our example) the difference (Column IV) is recorded as plus. If the table step is less than the caliper step, the difference is recorded as minus.

The columns of Fig. 4 are defined as follows:

Column I - Identifies the angle at which the data on that line were obtained.

Column II - Gives the collimator reading on the upper optical caliper mirror at each angle.

Column III - Gives the collimator reading on the lower optical caliper mirror after moving table through angle to be measured.

Column IV - Gives the difference between optical caliper step and the table step measured from each previous table step. It is plus if the table step being measured is greater than the caliper step and minus if the table step is less.

Column V - Gives the caliper error for each angle measured to closure. It is obtained by dividing the sum of Column IV by the number of steps measured to closure.

Column VI - Gives the table error at each angle measured. It is obtained by subtracting Column V from Column IV at each line.

Column VII - Gives the cumulative table error relative to zero. It is obtained by cumulatively summing Column VI.

III. THE SPECIAL CASE – CLOSURE AT LESS THAN 360°

If the table error of an angle is known, closure for small angles may be made at the angle of the known error by subtracting its known error from the error readings to that point and proceeding as before to obtain table error. This is possible because the table angle errors to closure will sum to the known error at closure. In practice, this is often done to reduce cumulative operator error that might result from taking the many readings needed to close at 360°. Figure 5 shows how the caliper and table errors combine for measurements of table error at 15° intervals with closure at 60° where the known table error is -5 secs. Figure 6 shows a data sheet for these measurements.

IV. MEASUREMENT PROCEDURE

The following is the step-by-step procedure for measuring the angle errors of a rotary table.

1. Select a surface plate or any other table that is rigid and large enough to hold both rotary table and autocollimator. Mount rotary table on plate and secure.
2. Place optical caliper on center of rotary table and secure. Make sure that hold-down clamps clear lower rotation of optical caliper.
3. Mount collimator on same table as close to optical caliper as possible.
4. One axis of the autocollimator must be sensitive to the direction of rotation; the other axis of the autocollimator must be completely insensitive to tilting of the rotational components. This can best be accomplished with the autocollimator constrained to the direction of rotation.
5. Adjust autocollimator on lower mirror with rotary table set at the starting position and record reading.
6. Index rotary table forward to desired setting and swing upper mirror into field of view of the autocollimator and clamp. By using the fine adjustment on the upper mirror, adjust mirror to same reading on autocollimator that was noted with lower mirror setting and tighten lock screws.
7. Return to starting position and repeat Steps 5 and 6. It is difficult to set the optical caliper exactly to the angle to be measured. Though the

agreement between the rotary table and the optical caliper should be close, Section II explains why it is not important to set the optical caliper exactly to the angle.

8. You should now be ready to start readings. Return to starting position of rotary table and lower mirror of optical caliper, and record autocollimator reading in column as indicated in Fig. 4.

9. Advance rotary table to the next setting and again record autocollimator reading in column as indicated in Fig. 4.

10. By using worm gear release as illustrated in Fig. 7, return optical caliper so lower mirror is again in the field of view of the autocollimator. By means of the fine adjustment on the optical caliper, any autocollimator reading can be obtained without too much trouble. Record reading.

NOTE: It is not necessary to retain previous reading on autocollimator.

11. Advance rotary table to next setting and record reading of upper mirror.

12. Repeat Steps 8 through 11 until a complete closure has been achieved. Then prepare the data table as shown in Fig. 4. Be careful to indicate plus or minus signs as explained in Section II. The accuracy that can be obtained depends entirely on the operator and equipment. Here are some useful suggestions.

a) Use no more than three or four readings to complete a closure. Small errors can be additive; by reducing the number of stations, the cumulative errors are reduced.

b) Check the system for repeatability. Readings should never be recorded if they do not repeat.

c) Autocollimator set-up as is explained in Step 4 is critical. Great care must be taken in the set-up of the instrument.

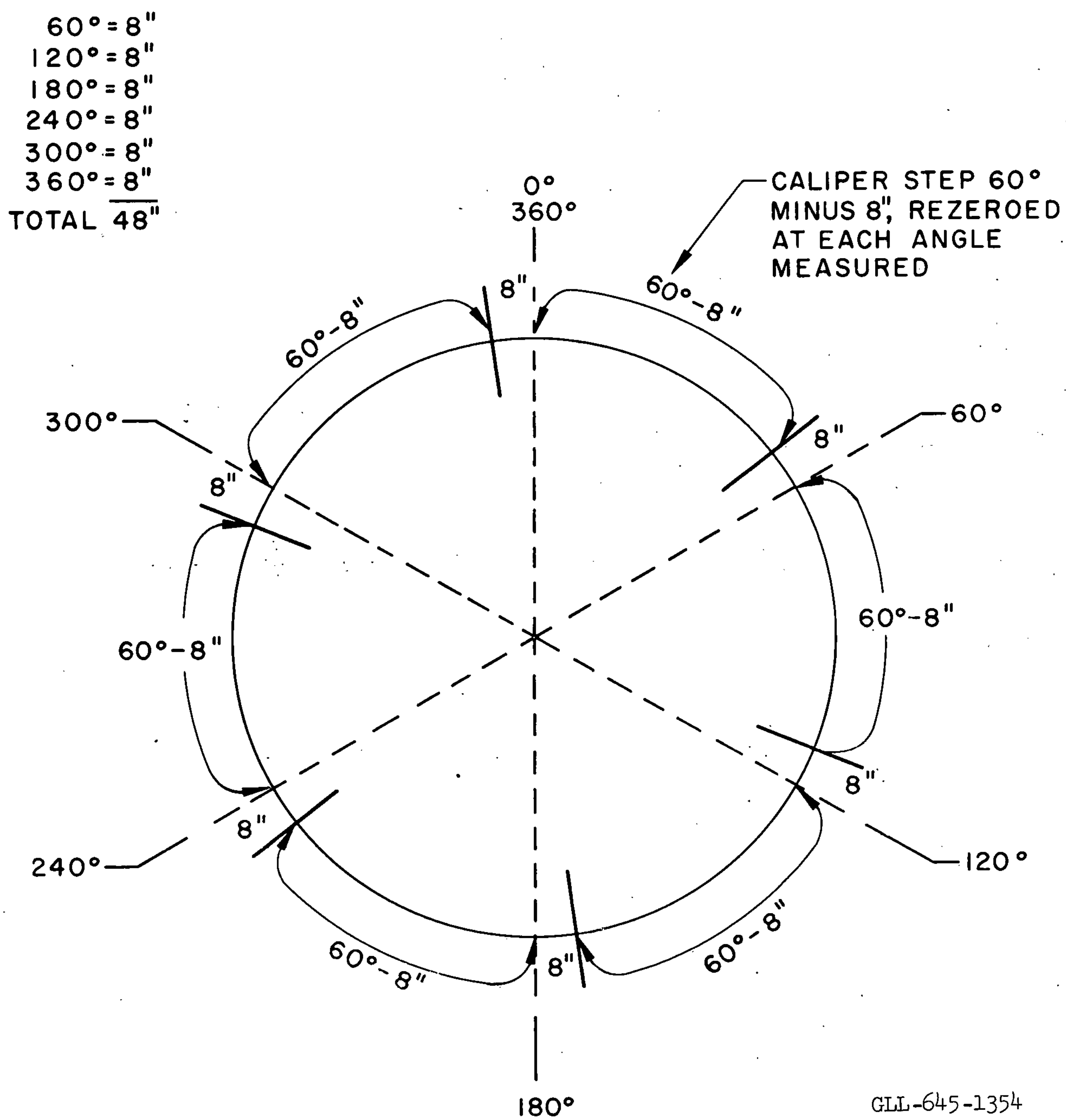

Fig. 1. Caliper error only. The caliper error is equal to the sum of the error at each step, divided by the number of steps measured.

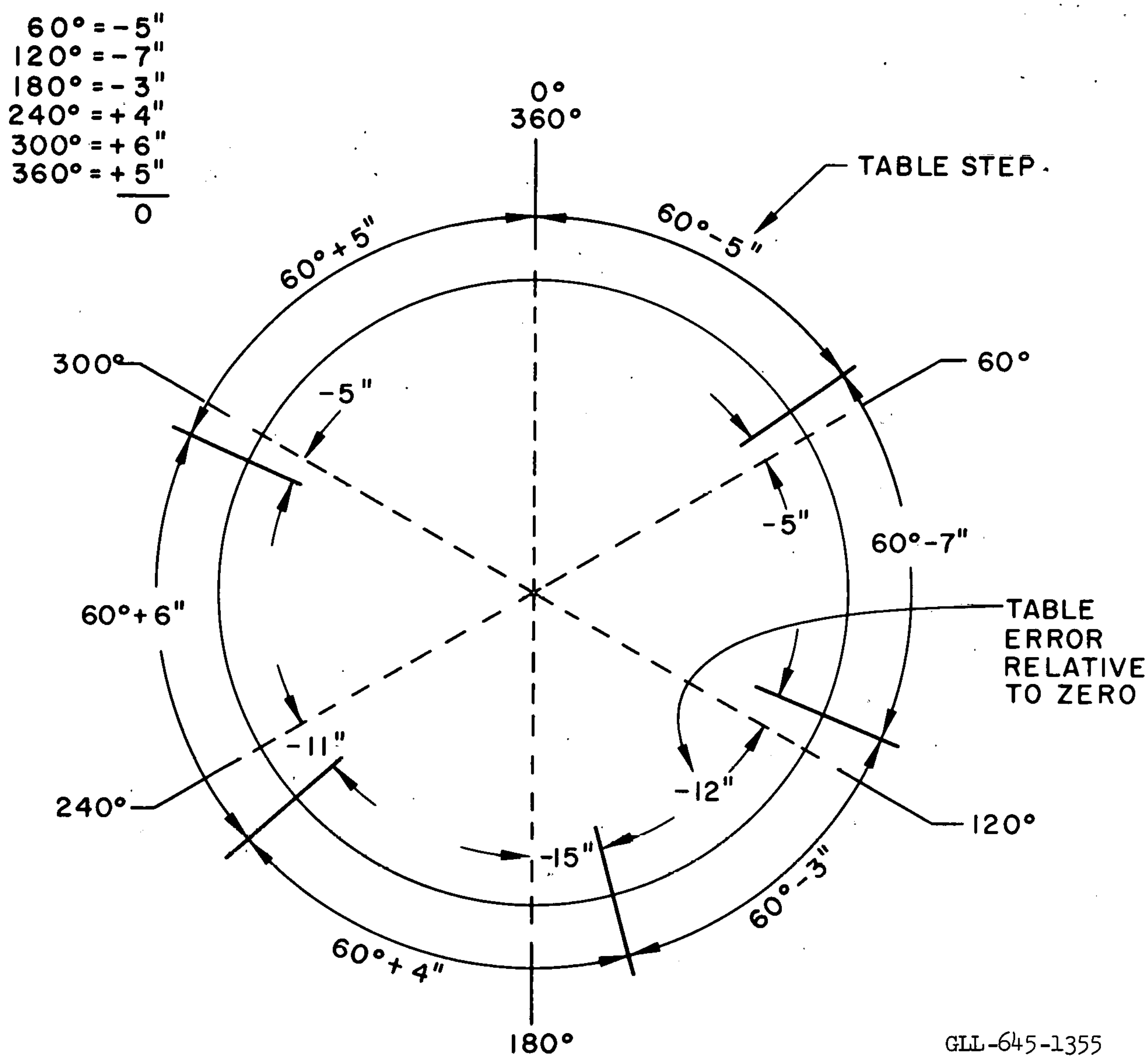

Fig. 2. Table error only. The sum of the x table step errors must equal zero.

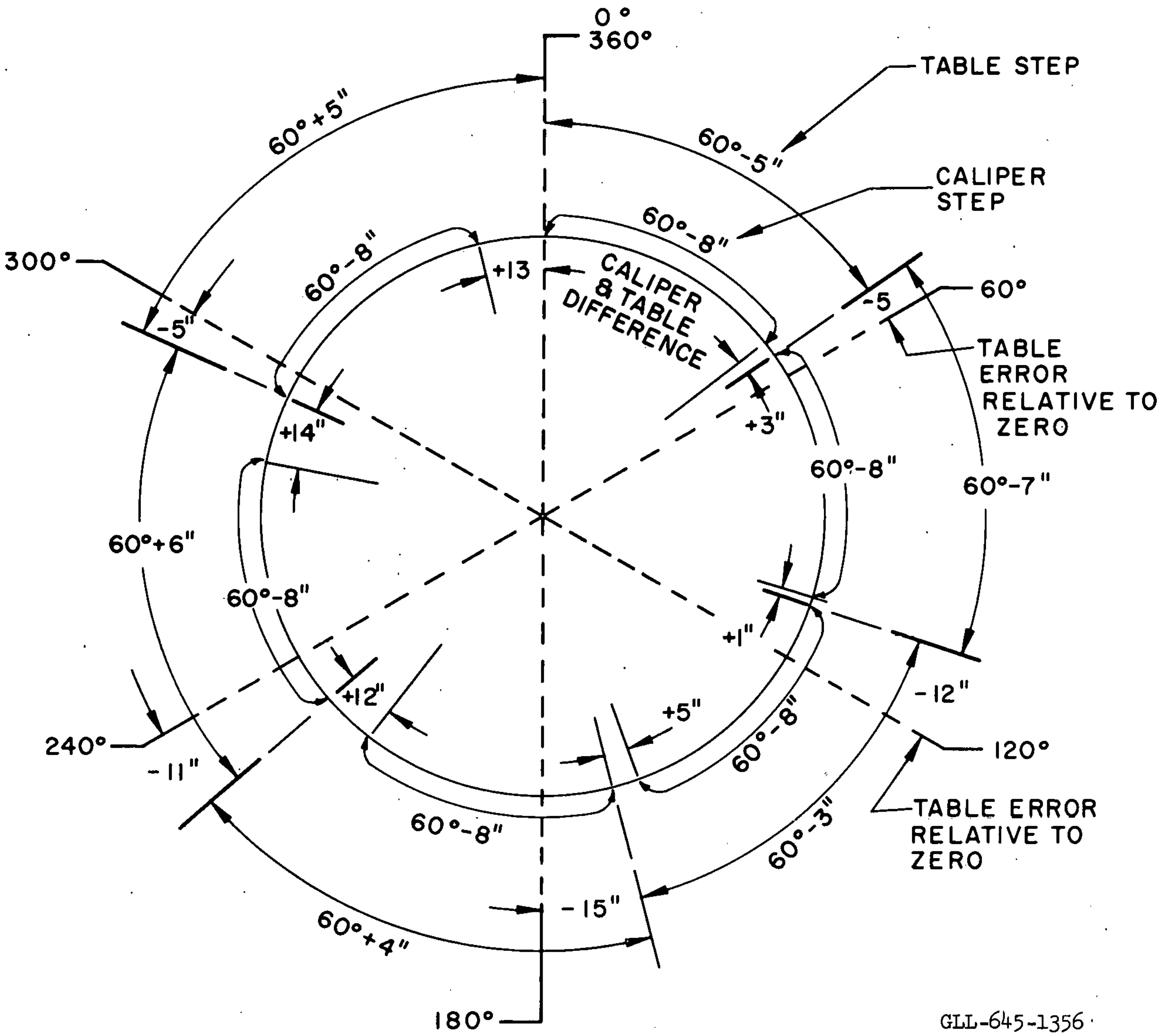

Fig. 3. Caliper and table step error.

I TABLE ANGLE	II AUTO-COLLIMATOR READING (lower mirror)	III AUTO-COLLIMATOR READING (upper mirror)	IV CALIPER STEP AND TABLE STEP DIF-FERENCE	V CALIPER STEP ERROR	VI TABLE STEP ERROR (COLUMN IV - COLUMN V)	VII TABLE ERROR RELATIVE TO ZERO (cumulative sum of COLUMN VI)	
60°	45	48	+3	+8	-5	-5	
120°	48	49	+1	+8	-7	-12	
180°	34	39	+5	+8	-3	-15	
240°	26	38	+12	+8	+4	-11	
300°	22	36	+14	+8	+6	-5	
360°	34	37	+13	+8	+5	0	

Column IV summed =	+48	
Subtract known error at closure =	0	
Sum of Column IV (less closure error) divided by number of angles measured	+48 ÷ 6 =	+8

Column IV is plus if the step being measured is greater than the caliper setting and minus if the step is less.

Fig. 4. Closure at 360 degrees.

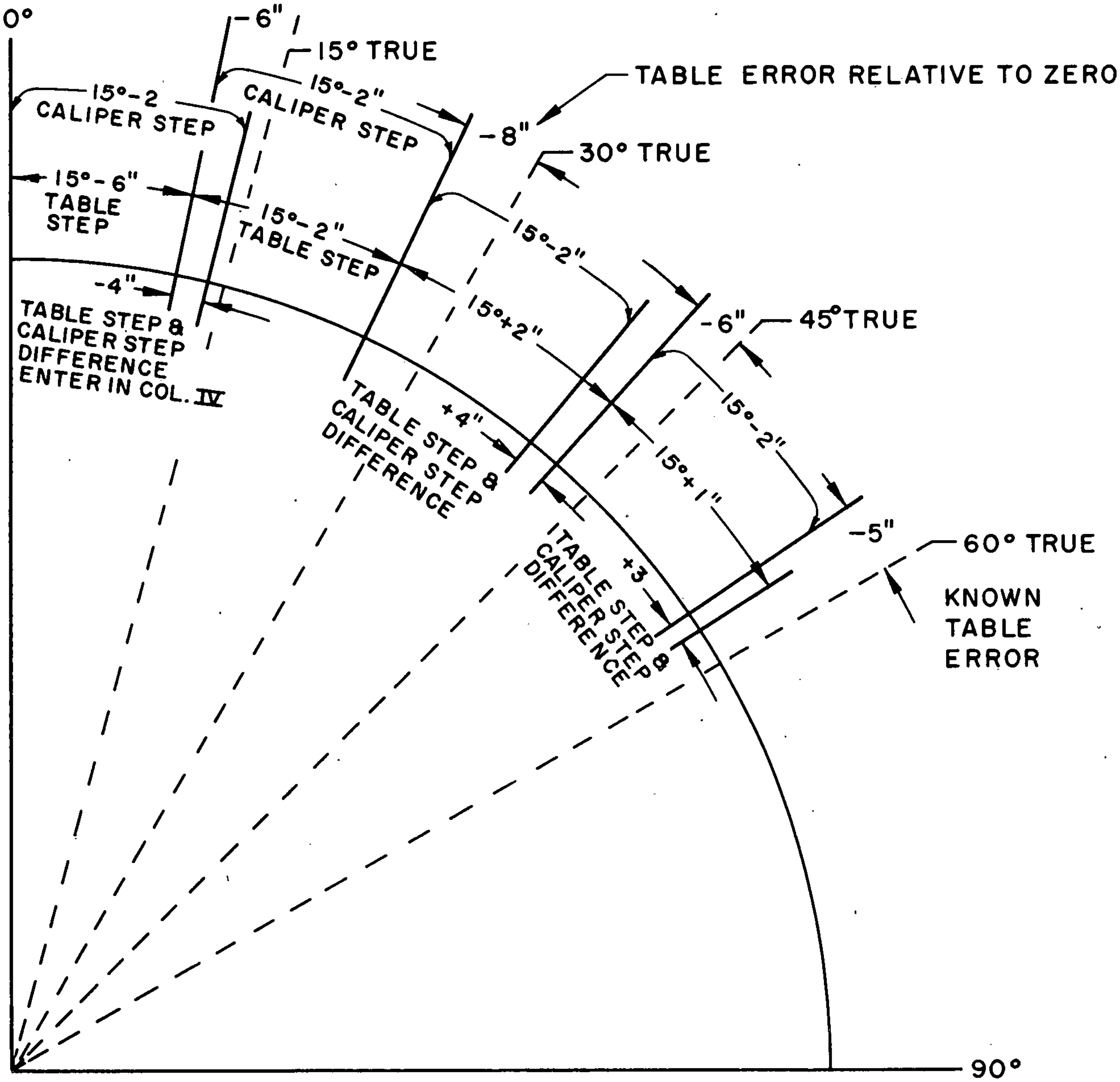

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Fig. 5. Closure at less than 360 degrees.

I	II	III	IV	V	VI	VII	
TABLE ANGLE	AUTO-COLLIMATOR READING (lower mirror)	AUTO-COLLIMATOR READING (upper mirror)	CALIPER STEP AND TABLE STEP DIF-FERENCE	CALIPER STEP ERROR	TABLE STEP ERROR (COLUMN IV - COLUMN V)	TABLE ERROR RELATIVE TO ZERO (cumulative sum of COLUMN VI)	
15°	55	51	-4	+2	-6	-6	
30°	60	60	0	+2	-2	-8	
45°	35	39	+4	+2	+2	-6	
60°	36	39	+3	+2	+1	-5 = Known Error at 60°	

Column IV summed =	+3
Subtract known error at closure (60°) =	-5
Sum of Column IV (less closure error) +8 ÷ 4 divided by number of angles measured =	+2

Column IV is plus if the step being measured is greater than the caliper setting and minus if the step is less.

Fig. 6. Data sheet for closure at less than 360 degrees.

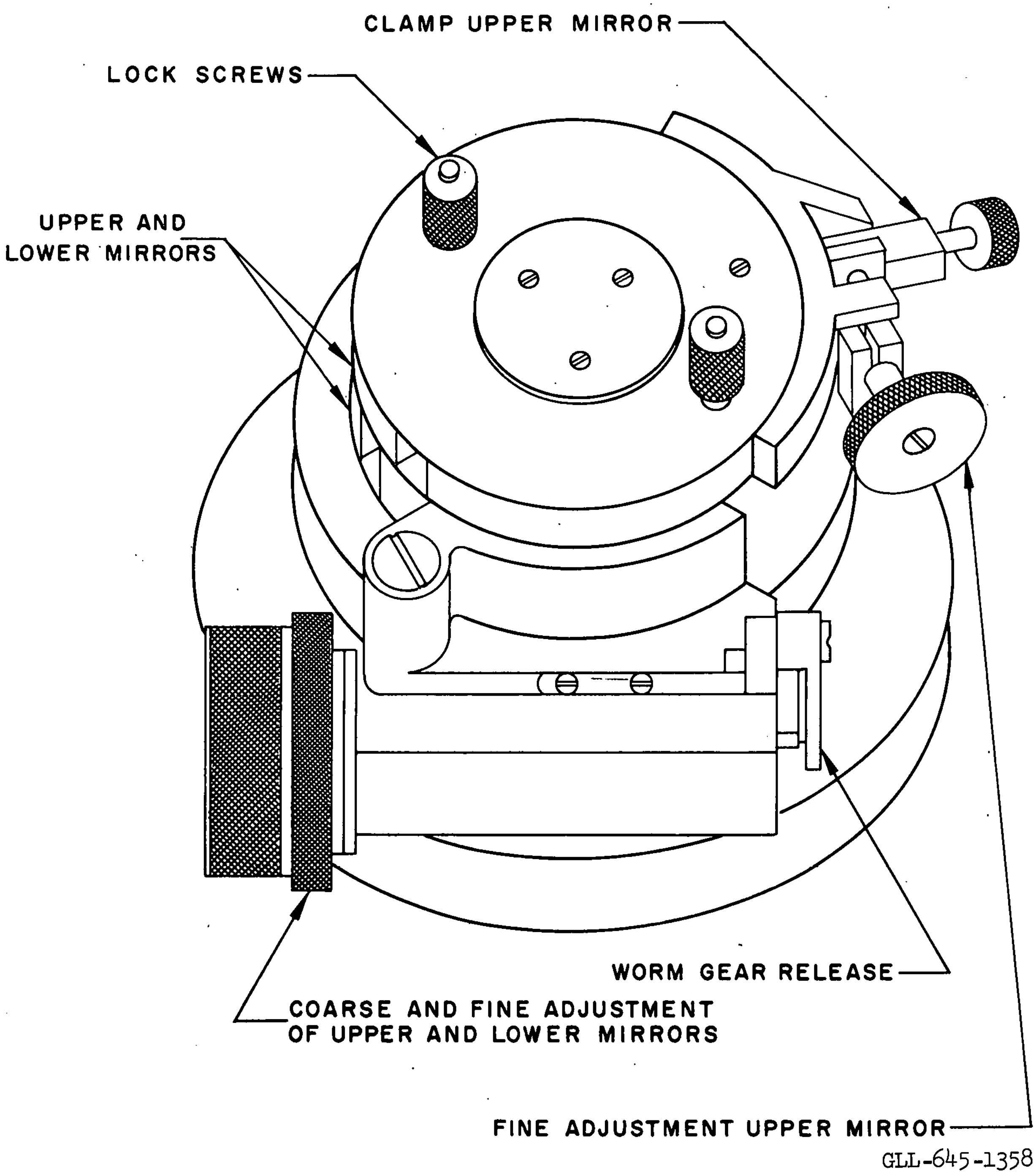

Fig. 7. Optical caliper.