AN EXPERIMENTAL COUNTERROTATING MARKER BEACON

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Technical Development Report No 160

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT AND
EVALUATION CENTER
INDIANAPOLIS, INDIANA

February 1952

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Manuscript received August 1951

AN EXPERIMENTAL COUNTERROTATING MARKER BEACON

SUMMARY

This report describes the development of a counterrotating marker beacon for use as a visual aid to airplane pilots in circling approaches. This beacon uses two projectors rotating in opposite directions to provide a pilot with an indication of his position with reference to the desired approach course

After construction and test of several models, a beacon which gives good directional indication on a circling approach was developed

INTRODUCTION

In the discussions of the problems of approach lighting in the Airport Lighting Evaluation Panel of the Air Force-Navy-Civil Subcommittee for Visual Aids, stress has been laid on the need of the pilots for better guidance for circling approaches. This need was emphasized in the following paragraphs from Appendix A to the "Operational Requirements for Approach Light Systems," issued by this Panel on November 14, 1947

> Page 2, under "Findings"
> "3. That there is an immediate need for an approach light system which may be used as guidance for circling approaches in restricted visibility conditions down to three-fourths of a mile, in which case the approach may not necessarily be made with electronic aids or high intensity runway lights "
>
> Page 4, under "Discussion"
> "Until all runways are served by electronic aids and all approaches are made by the use of such aids, approaches will continue to be made by contact after a circling procedure Such an approach requires more adequate lighting outside the region of guidance than those provided by the approach light systems tested thus far, in order to facilitate circling and approaches to non-instrument runways "

These needs were stressed by the representatives of the Air Line Pilots Association and were recognized by all of the Panel membership

The needs were discussed in detail, and can be summarized as follows

1. The runway lights and approach lights should provide adequate visibility during the downwind leg of the approach
2. When circling into his final approach, the pilot should be given a positive means of aligning his aircraft with the runway axis.

A separate study is being made of the requirements for Item 1. This report is concerned with the development of a solution for Item 2.

An analysis of the problem indicates that the lighting aid must perform two functions To serve as a marker, it must be made conspicuous To assist the pilot in lining up with the runway after a circling approach, it must provide positive means of marking or identifying the extended axis of the runway.

A number of ideas proposed by various illuminating engineers were considered A counterrotating beacon seemed most promising to fulfill the dual function of landmark and course indicator This report describes an experimental beacon of this type.

BASIS OF GUIDANCE

The principle of the counterrotating beacon involves the use of a pair of identical projectors located on a line perpendicular to the axis of a runway approach One projector is mounted on each side of the axis, both are equidistant from it and are sufficiently separated to appear to the pilot as separate sources See Fig 1 The projectors are synchronized to rotate at the same speed, in opposite directions, and are so timed that both beams are in the same direction parallel to the axis at the same time To the pilot on approach the right-hand projector is rotating clockwise and the left, counterclockwise

Any aircraft pilot to whom the two projectors are visible can determine his position with reference to the runway axis by the relative timing of the flashes Two flashes in quick succession, followed by a short interval, indicate that he is near the axis The appearance is that of a single flash moving toward the axis, and the pilot simply follows this indication When he reaches the axis, the two flashes will appear simultaneously As he moves away from the axis to the right, he will see the right flash before the left flash If he moves away

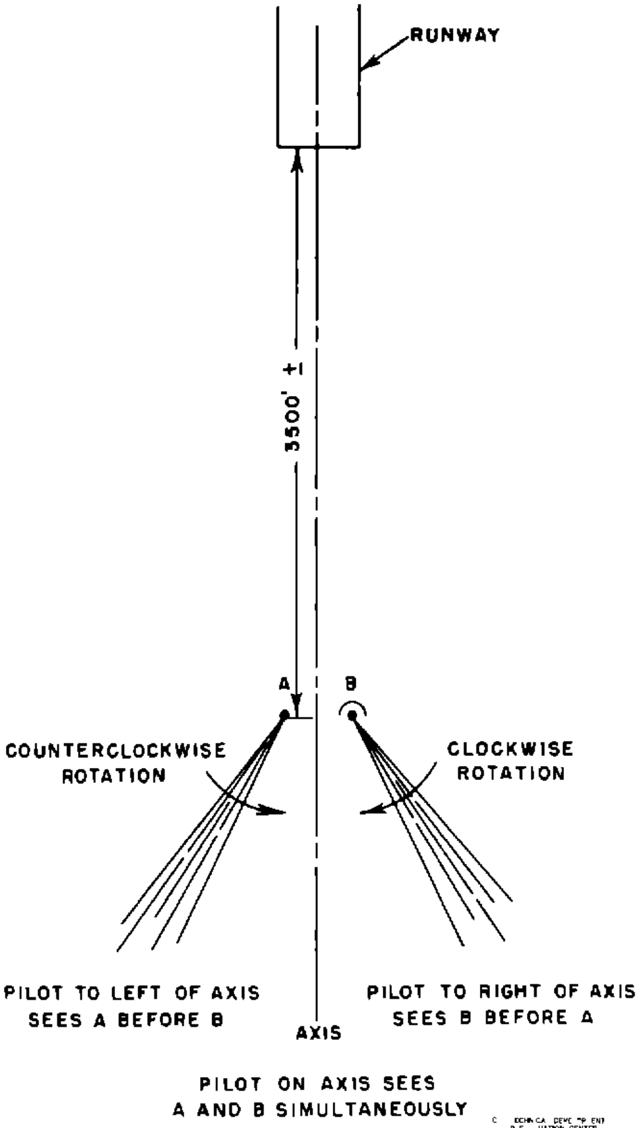

Fig 1 Diagram Illustrating Principle of Counterrotating Beacon Guidance

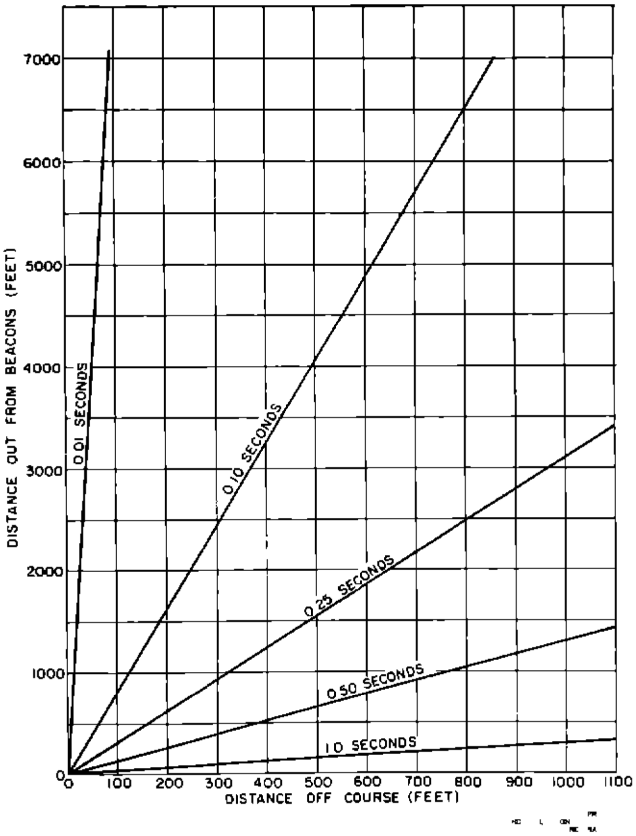

Fig 2 Time Interval Curves Showing Relation Between Distance Out From Beacons and Distance Off Course

from the axis to the left, he will see the left flash first.

One projector is screened so that the beam is concealed on the back course This is done because the back course, if both beams are visible, produces a directional indication which is reversed from that produced by the front course This could cause confusion to the pilot to whom it is visible and make it more difficult for him to interpret the front course.

The projector which is visible throughout 360° can serve as a landmark or target to a pilot on his downwind leg or in passing over the field It can be distinguished from the airport beacon by the relative rapidity of its flashes, 24 per minute against 6 or 12 for the airport beacon The curves in Fig. 2 show how the time interval between flashes varies with different positions of the airplane

INTENSITY REQUIREMENTS

Under existing Civil Air Regulations, circling approaches are generally permitted only in visibilities from 1 0 to 1 5 miles or more, depending upon the type of operation and type of aircraft Table I shows the atmospheric values, or transmissivities, that correspond to various visibility conditions, including the 0 75-mile visibility referred to by the Airport Lighting Evaluation Panel

The daytime values are calculated from the relationship

$$T^D = 0.02 \quad (1)$$

where

T = Transmissivity of the atmosphere per unit of distance

D = Distance between object and observer

The nighttime values are calculated from the general relationship

$$I = E_o D^2 / T^D \quad (2)$$

where

I = Candlepower of the light source

E_o = Threshold brightness value

D = Distance

T = Transmissivity per unit of distance

By assuming I = 25 cp (which is a recognized basis for observing night visibility), letting E_o = 0 2 kilometer-candle, and measuring D in hectometers, the values of T per hectometer can be calculated.

It would appear logical that a signal for circling approaches should be visible from at least the distance of the turning radius This radius is determined by the air speed and the angle of bank Curves have been developed to show this relationship[1] From these it can be assumed that the normal maximum turning radius would be approximately 1 5 miles, because this represents a bank of 15° at 175 mph, 10° at 145 mph, and only 7° at 120 mph

From Equation (2) and using values of T given in Table I, the required candlepowers have been calculated and are shown in Table II These calculations are based on a night threshold value of 0.2 kilometer-candle and a day value of 200 kilometer-candles to compensate for the lighted background

As the rotating beacons have the visual effect of a flashing light, it is necessary also to consider the effect of duration of flash on visibility This can be done by employing the relationship developed by Blondel and Rey,[2] as follows

$$E/E_o = (t + a)/t = I/I_o \quad (3)$$

where

E_o = Equivalent threshold eye illumination for a steady light

E_o = Approximately the threshold eye illumination for a steady light

I = Intensity required to produce E.

I_o = Intensity required to produce E_o

t = Duration of the flash in seconds

a = Empirical constant, approximately 0 21

The data given in Table II is based on a light with a horizontal beam spread of 11° and rotating at 24 rpm.

then

$$t = 11/360 \times 60/24 = 0\ 0764$$

and

$$I = \frac{0\ 0764 + 0\ 21}{0\ 0764} = 3\ 75\ I_o$$

TABLE I

Visibility Distances and Corresponding Transmissivity Values

Observed Visibility*	Transmissivity (Per Hundred Meters)	
Distance	Day	Night (25 cp)
0 75 mile	0.722	0.690
1 00 mile	0 780	0 785
1 50 miles	0 845	0.881

*Based on observation of solid object in daytime and 25-cp light at night.

[1] Pearson, H J. Cory, "The Slope Line Approach Light System," CAA Technical Development Report No. 104, March 1950, p 3

[2] Stiles, W. S , M. G Bennett, H. N Green, "Visibility of Light Signals With Special Reference to Aviation Lights," British Air Ministry Aeronautical Research Committee Technical Report, Reports and Memoranda No 1793, London, 1937, p 32

TABLE II

Required Candlepower for a Signal Light to Be Visible at Various Distances

Visibility Condition	Required for 1.5-Mile Range		Required for 2.0-Mile Range	
	Steady Burning (I_o)	Flashing (I)	Steady Burning (I_o)	Flashing (I)
Day				
0.75 mile	8,500,000	31,900,000	45,000,000	168,800,000
1.00 mile	580,000	2,175,000	3,000,000	11,250,000
1.50 miles	93,000	349,000	372,000	1,395,000
Night				
0.75 mile	1,030	3,870	300,000	1,125,000
1.00 mile	400	1,500	2,400	9,000
1.50 miles	25	94	100	375

Lamps are readily available which can produce beams of the dimensions and characteristics required, with values up to the order of magnitude of 500,000 candlepower. Thus it would appear feasible to produce a signal to meet most of the night visibility conditions outlined above, and also the 1.5-mile daylight range under visibility conditions of 1.5 miles. A lamp producing a beam of 60,000 candlepower would be adequate to produce an effective signal for 2.0 miles by night with the visibility down to 1.0 mile and for 1.5 miles with the visibility down to 0.75 mile.

EQUIPMENT DESIGN AND TESTS

For the first model of the counterrotating beacon, two commercial beacons designed for small airport use were coupled together mechanically. Tests showed that these beacons were not satisfactory as projectors for this application, because there was entirely too much spilled light and reflected light from the glass domes housing the lamps. The rate of rotation, 6 rpm, was also too slow.

Consequently, the domes and light sources were removed and metal housings were installed on the same bases. A sealed-beam lamp with narrow-beam spread was mounted in each housing, new gears were installed, and the rate of rotation was increased to 24 rpm. A number of flight tests showed that this beacon provided excellent identification without excessive spill and was satisfactory, provided the pilot was not flying above or below the main beam of light.

The next step was to replace the narrow-beam lamps with a pair of recently developed special sealed-beam PAR-56 airport approach lamps, installed in the holders in such a manner that the greatest spread was in the vertical plane. This change resulted in good vertical coverage without excessive lateral dispersal, so that two sharp, distinct beams were visible to the pilot through a wide range of altitude.

The 400-watt, 115-volt, PAR-56 standard approach lamps used in the beacon give peak candlepower values in the order of magnitude of 70,000 at rated voltage, with a spread of approximately 38° by 11°. If operated at 83 per cent voltage they will produce values nearer to 35,000 candlepower, will consume approximately 300 watts, and will have approximately nine times the rated life of 100 hours. This might be desirable where remote control cannot be provided and lights must be turned on and off by means of a time switch.

The counterrotating beacon must be located on the axis of an approach. Some experimenting was done at different distances from the threshold. The beacon was first installed for service tests at the middle marker on the southwest approach at Indianapolis Municipal Airport. This marker is 4,700 feet from the threshold. After the beacon was rebuilt, it was installed for use at the northwest end of the northwest-southeast runway. It was located 800 feet northwest of the threshold.

Flight tests proved that the beacon was usable at both sites, but when it was at the closer location the control tower received a number of complaints to the effect that the flashes were too bright when the pilot reached the immediate vicinity of the beacon. It appears, therefore, that the beacon should be somewhat farther out from the threshold than

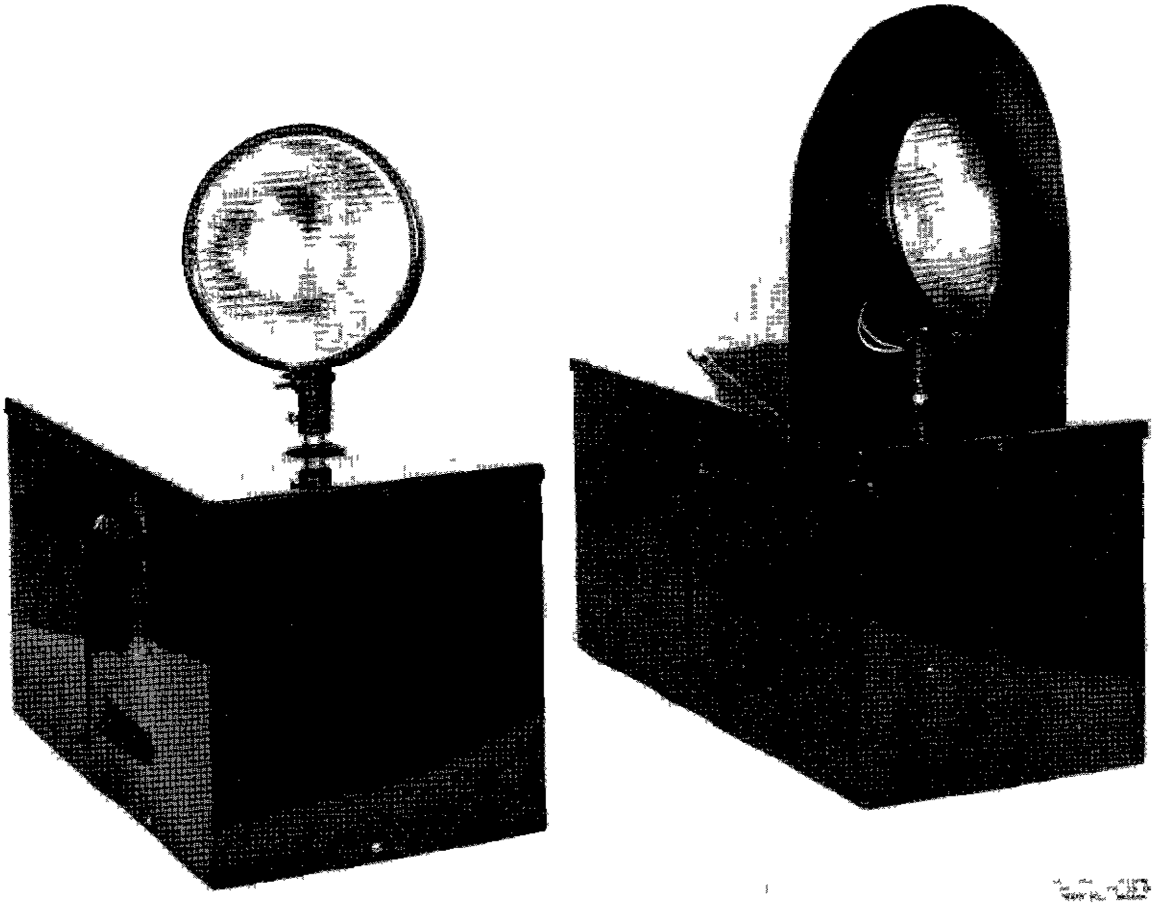

Fig 3 Counterrotating Beacon Assembly

800 feet While the exact distance is not important, from the standpoint of the accuracy of guidance, it is suggested, on the basis of flight observations, that the beacon be installed at a standard distance of 3,500 feet where feasible.

The separation of the two projectors must be sufficient to allow the pilot to identify the flashes as coming from different sources In the first model, the units were mounted 12 feet apart and were coupled with a mechanical shaft This spacing proved inadequate, and as it was impractical to provide adequate spacing with mechanical coupling, it was decided to apply a pair of Selsyn motors to synchronize the rotation electrically. Each of a pair of such motors was geared to one of the lamp holders and the motors connected electrically A small drive motor was geared to the shaft of the transmitting Selsyn motor With this arrangement it was a simple matter to vary the spacing between projectors It was found that a separation of about 30 to 100 feet was satisfactory

In order to determine the angular sensitivity of the indication, the projectors with 30-foot separation were operated at a location where it was possible to measure the minimum horizontal angle between positive on-course and off-course indications This angle was slightly less than 2 0°

The measured torque of the repeater Selsyn motor used in the model was one inch-pound Although sufficient for experimental operations under most weather conditions and for testing and demonstrating the principles of the beacon, this torque was not high enough for operation under ice or snow conditions Consequently, another model was built to use standard split-phase 1/4-horsepower induction motors which, when geared down to the proper speed, produce a torque approximating 100 inch-pounds This model, using the 400-watt lamps at full voltage, will operate at approximately 1,250 watts with a power factor of 83 per cent See Figs 3 and 4

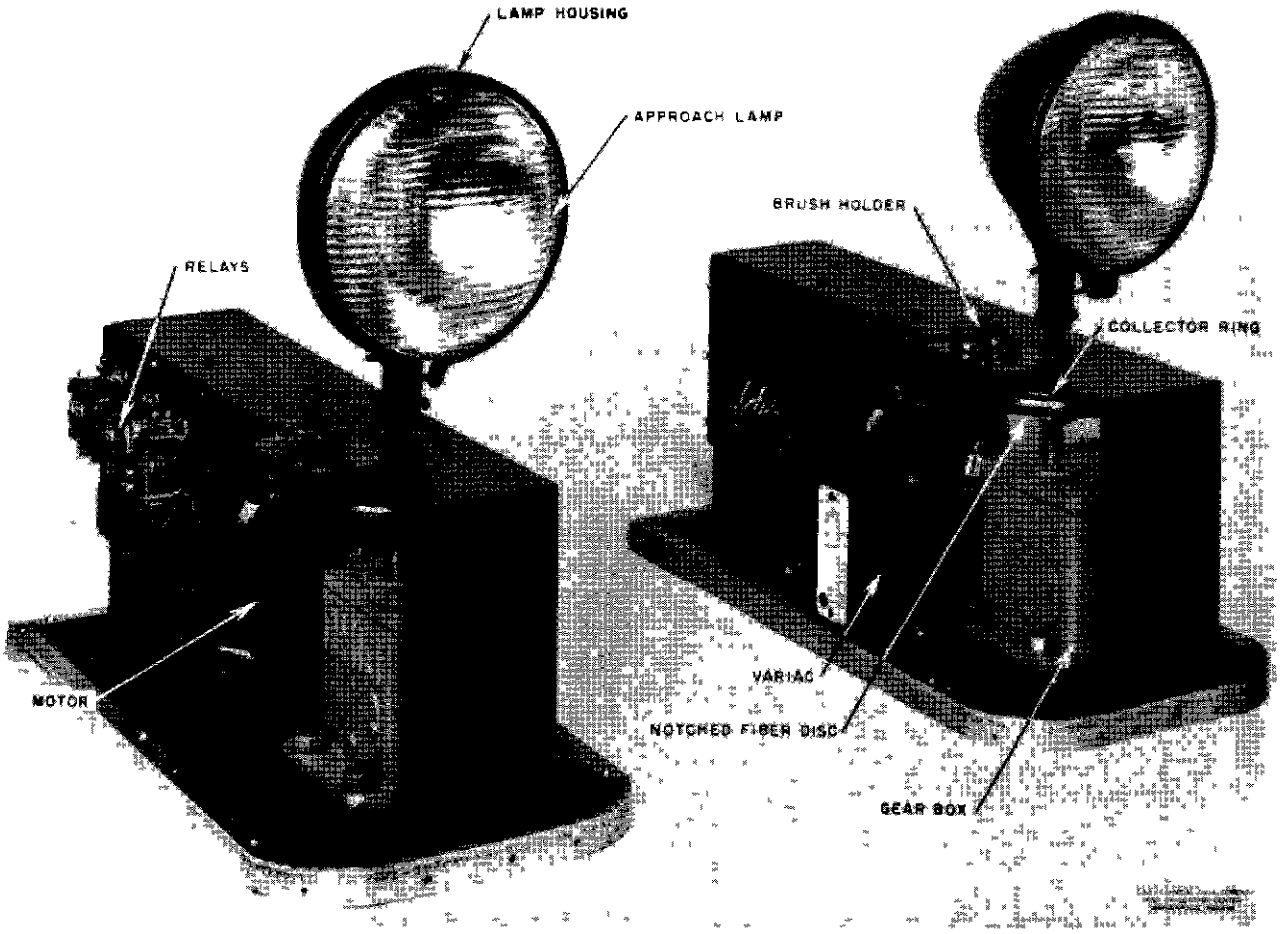

Fig. 4 Counterrotating Beacon, Cover Removed to Show Control Equipment

When the projectors get out of step an arrangement of relays and switches operates to stop one motor and thus permit the other motor to catch up See wiring diagram, Fig 5 In order to simplify this operation, one motor is kept rotating at a slightly slower speed than the other by reducing its line voltage to 105 volts A Variac was used for this purpose It is then necessary to design the control for the faster motor only The slight difference in motor speeds proved to be imperceptible

With this arrangement the projectors normally can be synchronized effectively in less than two revolutions of the projectors Tests run on this model, with a recording ammeter in the circuit to record the number of stops, indicate that there will be no difficulty in maintaining the desired operation The only time the lights are likely to be materially out of step is immediately after being started, and then they usually will synchronize within four or five revolutions, or within ten seconds

Production models can be simplified by using a vertical gear motor to eliminate the separate gear train and to reduce the size. The Variac used in the experimental model can be replaced by a small resistance.

CONCLUSIONS

1 Tests of this beacon, including observations from the ground and in the air, show that it gives positive on-course indication within an error of approximately 2 0° which is adequate for the operation outlined

2 The unshielded projector, with its short flash cycle, provides a target or landmark distinguishable from the airport beacon

3 The beacon will facilitate circling approaches and landings by furnishing accurate on-course indication

4 The beacon is applicable for installation on approaches to all runways and can be operated selectively to indicate the active

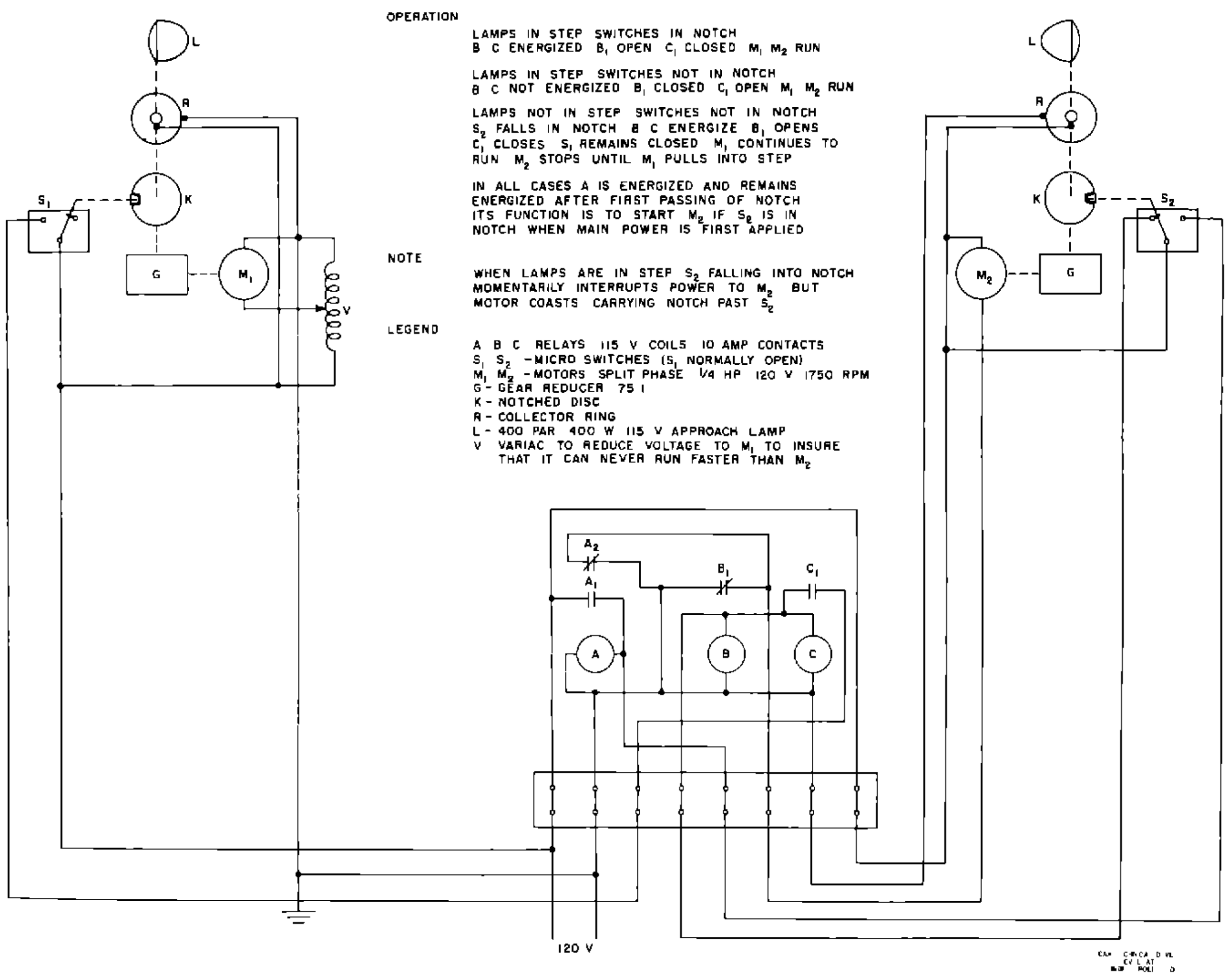

Fig 5 Counterrotating Beacon Wiring Diagram

runway

5 The optimum location appears to be about 3,500 feet from the runway threshold This can be varied widely, however, to meet local conditions

6 The equipment is simple and requires no expensive special parts

7 The beacon now in use at Indianapolis is applicable as a circling-approach aid under existing weather minimums It can be adapted to more severe weather conditions by selecting a light source capable of producing the beam intensity required for the specific visual conditions, as indicated in Table II. Likewise, remote intensity control can be provided

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