THE REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 22, NUMBER 9 SEPTEMBER, 1951

Laboratory and Shop Notes

A Device for Determining the Direction of Flux Lines in the Time Varying Magnetic Field of a Particle Accelerator

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(Received December 8, 1949)

THE stable particles in the beam of an accelerator such as the synchrotron oscillate about a surface which is near the median plane of the magnet gap.[1] The position of this surface can be determined if the direction of the magnetic flux lines near the median plane of the gap is known and if the variation of the magnetic field with radius in the median plane is known. The flux lines are vertical near the median plane of the gap in a magnet with the usual horizontal gap—these lines are vertical at the median plane in the ideal case. This paper describes a device for determining in a time varying magnetic field the position where the magnetic flux lines are vertical.

The method is a null method. A coil is suspended vertically in the magnet gap with the axis of the coil horizontal and perpendicular to the beam path. The magnet is pulsed with the coil at various vertical positions in the gap. The voltage induced in the coil, which is proportional to the rate of change of net horizontal flux through the coil, is viewed on a cathode ray oscilloscope. When the center of the coil is at a point where the flux lines are vertical, there is no net horizontal flux linking it, and the induced voltage is zero. If the coil is above this point there will be a voltage induced, and if the coil is below the point a voltage of opposite polarity will be observed.

This method has been used on a pulsed electromagnet which has a time rate of change of magnetic field of approximately 5000 gauss per second and in which the radius of curvature of the flux lines is approximately 19 feet. The coil for this test was wound with approximately 3000 turns of No. 38 Formvar covered copper wire on a 1.6-inch square core of linen-base Bakelite. The axial thickness of the winding was 1/4 inch, and its width was approximately 1/2 inch. To the top of the coil were attached knife-edges by which it hung from its supporting frame (see Fig. 1). The knife-edges were formed from Lavite "A," which was baked after forming to give it hardness. They were ground to their final sharpness after baking. The knife-edges rested upon Lavite blocks that were mounted in the supporting frame. The supporting frame pivoted on a pin about a vertical axis through the center of the coil. A Lucite balancing weight was threaded on a screw protruding from the side of the coil. This was used to adjust the balance of the coil until its axis was horizontal. A tightly and uniformly twisted pair of No. 38 wires which was left very slack in order that it would exert no torque upon the coil was used to take the signal from the coil. The bottom edge of the coil carried two vanes which moved in oil baths for the purpose of damping out mechanical oscillations. A Lucite box around the coil assembly protected it from air currents. The box was painted with a colloidal silver preparation to provide a thin film of silver which was grounded and served as an electrostatic shield. Lines were scribed in the silver film to minimize eddy current disturbances. The signal was taken to the oscilloscope through a shielded two-conductor microphone cable. A one megohm series resistor was included in the circuit in order that the induced current in the measuring circuit would not be great enough to produce a perceptible torque on the coil.

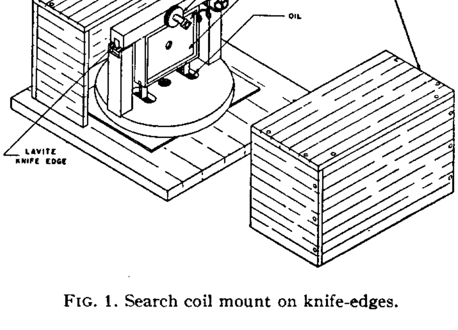

FIG. 1. Search coil mount on knife-edges.

The coil can be balanced in the field that is being tested. When the coil is properly balanced, it can be rotated through 180° about a vertical axis and the polarity of the signal will reverse, but its magnitude will not change. The balancing weight is moved on its supporting screw until this condition is obtained. Since the only forces acting upon the coil are those of gravity and the reaction of the support, the coil will now be properly aligned whatever its location.

To make the measurements the coil is moved to various positions in the field until a zero signal is obtained when the magnet is pulsed. A zero signal indicates that the flux lines are vertical at the center of the coil.

The measurements were made with a Tektronix Type 512 oscilloscope using 0.3 sec per centimeter triggered sweep and a vertical sensitivity of 0.05 volts/cm.

With continuously variable vertical positioning for the coil it was possible to determine the positions where the magnetic flux lines were vertical to within a sixteenth of an inch. This means that this equipment can detect a 0.0006 radian change in the direction of the flux lines. Only a small reduction in signal is introduced if the axis of the coil is not exactly perpendicular to the beam path, for the voltage induced is proportional to the cosine of the angle between the axis of the coil and the perpendicular line. It was found that this alignment could be made accurately by eye.

The work described in this paper was performed under the auspices of the Atomic Energy Commission.

[1] M. E. Rose, Phys. Rev. 53, 392 (1938); Robert R. Wilson, Phys. Rev. 53, 408 (1938).

A Cathode-Type Arc-Ion Source

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(Received April 2, 1951)

IN the usual design of an arc-ion source a tungsten filament serves as the cathode, and in operation a plasma is formed between this element and the anode. One of the peculiar features of all arcs is the constriction of the plasma, which produces a large current density over a small area of the tungsten wire. This results in a higher local temperature, or "hot spot," because of positive ion bombardment, and causes the material to erode or boil away more rapidly in this region. The original location of such a spot depends upon the geometry and upon any minute imperfections, such as die marks on the filament material. For obvious reasons, once such a "hot spot" has been formed, the arc invariably will restrike to the same area. Thus, it is a common experience to remove a filament after a few hours of operation to find that it is in excellent condition except where the erosion occurred.

The foregoing facts suggest the use of an indirectly heated cathode, with the filament or heater isolated from the arc circuit. The advantage of such a design is the greatly increased life since the filament is no longer subjected to ion bombardment and erosion, and the cathode remains effective until the entire cathode material boils away.

A cross-sectional view of a design that was successfully tested in the laboratory is shown in Fig. 1. The principal parts are as follows: The heater element, H; the axial cathode rod, C; the anode, A; the shield, D; and the conical housing, B. Compared to the standard heater type cathodes used in electron tubes, this design appears to be "inside out"; that is, the heater surrounds the cathode rod. The advantage of this arrangement is that the emitting surface of the cathode is small and can more easily be heated, particularly since a considerable fraction of the energy is supplied by ion bombardment. The particular geometry of the anode and housing shown in the figure was designed for use in the University of Michigan 42-in. cyclotron and is not essential for the satisfactory operation of the arc itself. For other applications an entirely different geometry may be required. When in operation, the magnetic field of the cyclotron, which is parallel to the axis of the cathode rod and the anode cap, confines the discharge to a small cylinder directed toward the anode cap or the bottom of the housing. The shield, a thin (0.005 in.) tungsten sheet, which is maintained at the same potential as the cathode, prevents the arc striking to the bottom of the housing. The sizes of the cathode rod and the heater are determined by a compromise between the available power, the magnitude of the arc current, and the desired life of the cathode. A cathode of 0.050-in. diameter tungsten wire and a heater of 0.100-in. diameter appear to represent a good compromise for our use. The filament is heated by direct current, although in the past it has been customary to heat with rf because of the relatively large forces on the filament structure due to the interaction of the current and the magnetic field. Since the shear strength of the wire is proportional to its cross-sectional area, or proportional to the square of the radius, while the current required is proportional to the three-halves power of the radius, relative mechanical strength is gained with increase of the wire diameter. We have found the life of a 0.050-in. filament to be independent of the type of heating current.

A schematic diagram of the arc circuit is shown in Fig. 2. The operation may be described as follows: The heater is brought up to emission temperature by means of generator 1. The anode voltage, supplied by generator 2, is adjusted to approximately 250 volts. On closing switch 1 an arc is formed between the heater and anode, the current of which may be regulated by resistor R_1. On closing switch 2 the cathode, immersed in the plasma, will attract ions provided the cathode potential, supplied by generator 3, is negative with respect to the filament. This ion bombardment, together with the heat supplied by the heater, raises the cathode to emission temperature. At this point, switch 1 may be opened, causing the arc to shift entirely to the cathode rod. The heater being isolated and drawing none of the arc current is no longer subjected to ion bombardment and the formation of "hot spots." After the transfer of the arc, the heater temperature may be reduced considerably without the cathode emission being impaired.

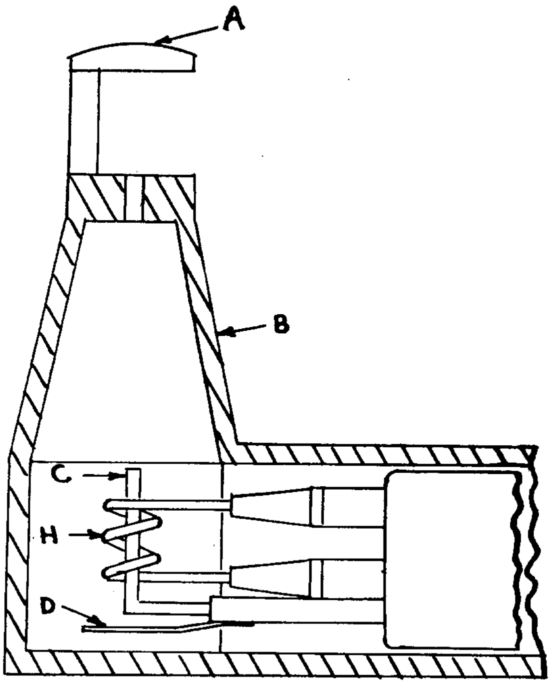

FIG. 1. Cross-sectional view of cathode-type arc-ion source. A = anode cap, B = housing, C = cathode rod, D = shield, H = heater.

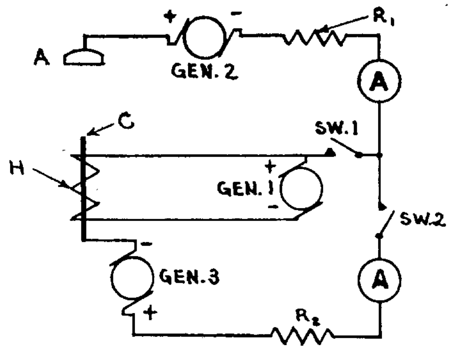

FIG. 2. Schematic diagram of the arc circuit.

The stability of the arc is determined by the external circuit as well as the geometry and material of the electrodes. Figure 3 shows a typical characteristic curve for an arc discharge. If a

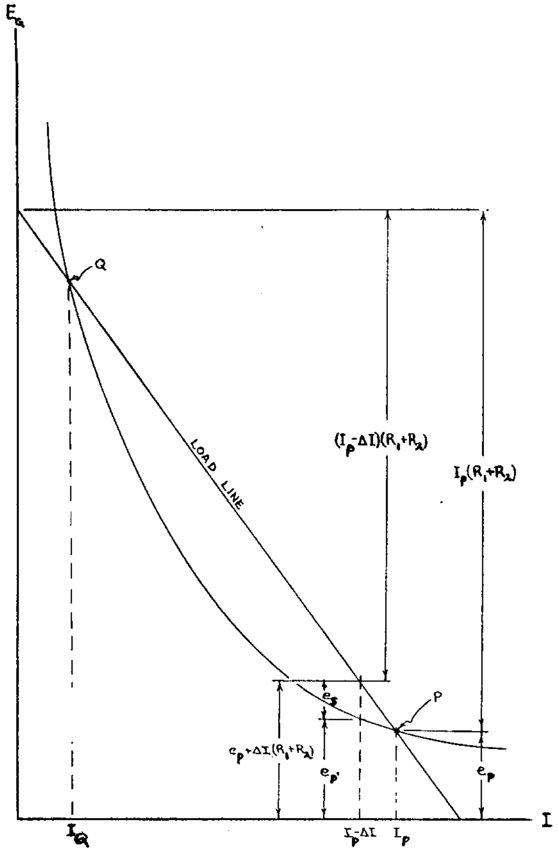

FIG. 3. Current voltage relations for formation of a stable arc.

stable arc is to be formed, the external resistance (R_1+R_2) must be so adjusted that the load line cuts the E_G-I curve. Point "P" is a stable operating point for the load line drawn. This may be seen in the following way. If the current should decrease by the amount ΔI below I_p, then the voltage across the resistors (R_1+R_2) is decreased by $(R_1+R_2)\Delta I$ and the voltage across the arc is increased by the same amount; but to maintain this new current, a voltage of only $e_{p'}$ is required; hence, a surplus voltage $e_s=e_p+\Delta I(R_1+R_2)-e_{p'}$ exists which causes the arc to draw more current and to return to its stable point. The same reasoning applies if I_p increases by ΔI. Point "Q," on the other hand, is an unstable point. If I_Q increases by ΔI, the current will run away until point "P" is reached. If I_Q decreases by ΔI, the arc will go out.

A working model having all the features shown in Fig. 1 has been constructed and tested. The results indicate that it is possible to transfer the arc from the heater to the cathode, and that a stable arc can be maintained. However, it is not yet possible to give any quantitative data on the increased life of cathodes with this new design compared with the standard filament type of ion source.

Decreasing Relay Differential Electrically*

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(Received March 5, 1951)

THE magnetic relay, so often used in commercial equipment, has been in disfavor lately in the field of measurement. Even in those applications where its speed of operations is quite sufficient to make it a useful device, its somewhat large differential and, hence, inherent inaccuracy has limited its use. All too often this inaccuracy has led to the adoption of the far less reliable and less sturdy vacuum tube or thyratron as the control switching method. In general, the per unit differential of an electromagnetic relay is given as

$$D=(E_{PI}-E_{DO})/E_{PI},$$

where E_{PI} is the voltage at which the relay pulls in, and E_{DO} is the voltage at which the relay drops out.

Thus, for example, a relay which "makes" at 6 volts and "breaks" at 5.4 volts is a relay with a 10 percent differential. It is, of course, fallacious to speak of "make" and "break" in this connection since the nature of the contact mechanism has nothing to do with the definition of pull in and drop out.

There are many ways of changing the differential of a relay, but, first, let us consider the reason why this differential exists. Consider an open, simple relay. The magnetic circuit has a certain reluctance, and the spring exerts a force on the relay armature. As the voltage applied to the relay coil is increased from zero, the magnetic attraction force exerted on the armature also increases. At some value of applied voltage (and, hence, current) the magnetic force on the armature just equals the spring force. If we neglect the question of friction at the armature bearings, the armature is now in unstable equilibrium. The force holding it open exactly equals the force tending to close it. If the voltage on the armature is increased slightly, the relay snaps shut. The cause of this snap, or toggle, action also produces the differential. Consider what happens when the voltage is increased above the equilibrium point. The magnetic force on the armature then exceeds the spring force, so that the armature starts to close. As the armature closes, however, the spring force on it increases approximately linearly with the armature motion. The magnetic force, however, increases much more rapidly. As the armature moves, the reluctance decreases, the gap flux density increases, and the magnetic force increases as some higher power of the armature motion. The result is a regenerative action, and the gap closes with a snap.

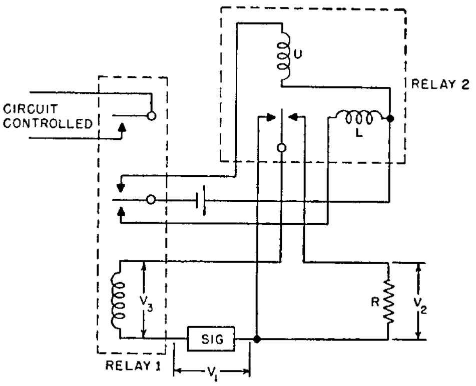

FIG. 1. Low-differential relay circuit.

Once it is closed, however, a different set of circumstances prevails. Now, with the voltage still at its pull-in value, the magnetic force on the armature is greater than the spring force. In order to open the armature, the voltage must be decreased until the forces again balance. Any further incremental decrease causes the armature to snap open as it snapped shut before. The result is a hysteretic action, or a differential.

From the foregoing information, it becomes apparent that the quantity in the numerator of D, the difference between the pull-in and drop-out voltages, is a characteristic of the relay construction. Since it is this difference, rather than the actual differential with which we are concerned (because of our ability to bias to change differential), we shall consider means for changing this difference.

Obviously, it should be possible to change the mechanical construction of a relay in such a way that the differential is reduced. If, for example, a spring of a fairly high stiffness factor is used, and is set so that there is virtually no spring force when the spring is open, a low difference relay can be obtained. Such a procedure, however, results in a very slow acting relay unless the armature mass is reduced considerably. If, on the other hand, it is desirable to use a commercially available relay as a low difference relay, there are some electrical systems that can be used to reduce the difference. Consider the action of the two relays in the circuit of Fig. 1. Relay 1 is the control relay, and is furnished with an extra set of SPDT contacts. Relay 2 is a mechanical locking relay whose sole function is the reductional differential of relay 1. When the L coil of relay 2 is energized, the relay armature moves to the right and remains there until the V coil is energized. Consider that both relays are "out." The control circuit for relay 1 thus consists only of the signal source S and the coil; hence, $V_3=V_1$. If V_1 is now increased until it reaches the pull-in point, relay 1 closes, which locks relay 2. With relay 2 locked, however, the control circuit now consists of S, and the coil, in series with the external resistor R. The voltage V_3 is now less than the signal voltage V_1 by the amount V_2, determined by R. If this new voltage V_3 is just slightly greater than drop-out, a very small reduction in V_1 from the pull-in value will cause the relay to drop out. When this happens, the U coil is energized, the resistor is replaced by a short circuit, and any small increase in V_1 will again cause relay 1 to pull in. It is evident that the difference between pull-in and drop-out has been reduced by V_2 volts. It has been found experimentally that a relay which is normally a 10 percent differential relay can quite easily be made to operate with a differential of less than 1/2 percent by the foregoing method. The circuit, does, of course, have the drawback that an additional source of power and an additional relay are required. The time required between successive pull-ins of relay 1 is now increased by an amount equal to the cycling time of the locking relay. In general, this will represent an increase in time of only a factor of 2 and can often be neglected. While this circuit works quite satisfactorily whether relay 1 is an ac or dc relay, a considerable saving can be obtained when relay 1 is a dc relay. The function