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Radio Telemetering from Magnetically Suspended Rotors*

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A method of radio telemetering temperature with miniature circuits from magnetically supported spinning rotors is described. The circuits are stable and give rotor temperatures with precision of 0.01°C. They are especially useful in the magnetically supported equilibrium ultracentrifuge but are applicable to all types of high speed rotors.

IN many experiments with magnetically suspended rotors, it is important to know the temperature of the floating rotor.[1] This is especially true in the case of magnetically supported equilibrium ultracentrifuge rotors.[2] Since no direct electrical or mechanical connection to such spinning rotors is practicable, in the past, the temperature has been measured by standard infrared radiation techniques. Unfortunately, these techniques are not precise enough for most purposes (order of 1°C). Consequently, accurate determinations of the temperature can be made only after the rotor has been spinning long enough for it to reach thermal equilibrium with its surroundings. This requires considerable time. In this paper, a method of telemetering or radio broadcasting the value of the temperature of the rotor is described. Miniature telemetering circuits mounted in or on the rotor near the axis of rotation have been used to telemeter the temperature measured by a small thermistor which may be mounted anywhere on the rotor. Telemetering circuits small enough to be swallowed by humans have been used by a number of workers[3–6] to transmit temperature, pressure, etc. from within the human body. In the ultracentrifuge rotor, in addition to meeting the small space requirement, the circuit must not be critically affected by centrifugal fields and must be as accurate and reliable as possible.

Figure 1 shows a diagram of a circuit which has been used for measuring the temperature of the equilibrium ultracentrifuge rotor[2] to less than 0.01°C. The circuit was found not to be affected by rotor speeds at least to 300 rps, which is the maximum speed usually required with standard size rotors (weight about 30 lb) used in equilibrium ultracentrifuge experiments. The unit has three subsystems consisting of a temperature sensor, a switch, and a carrier frequency generator. The temperature sensing and encoding is performed by a blocking oscillator, whose pulse repetition rate is determined essentially by C_4 and the combination of a 20-kΩ thermistor and R_4. In order to eliminate errors resulting from power supply variations or from changes in component values because of age, deformation by centrifugal fields, etc., two repetition rates are measured. The first, N_0, is determined by C_4 and R_4 alone and the second, N, by C_4 and the parallel combination of R_4 and the thermistor Th. Ideally, the ratio of these two repetition rates is a function solely of the resistance of the thermistor, and thus of the temperature. Switching between these modes is accomplished by means of a transistor switch V_3, which is actuated through an inverter V_4 by a collector-coupled transistor multivibrator circuit containing V_5 and V_6. The resistance of the transistor switch is sufficiently large in the "off" state to eliminate any effect of the thermistor on the reference repetition rate N_0. In the "on" state the switching transistor contributes a small resistance in series with the thermistor. This resistance may be a slowly varying function of the temperature. Consequently, it is advisable to calibrate by measuring the ratio N/N_0 with the unit held at various constant known temperatures. The carrier signal (~5.5 Mc) is generated by a tunnel diode oscillator whose power output is approximately 0.04 mW. The transmitter is coupled to the blocking oscillator by R_2 and C_3, which permit the pulses produced by the blocking oscillator to increase the bias of the tunnel diode V_1 sufficiently to drive it out of its negative resistance region and shut off the carrier frequency for the duration of each pulse. The transmitting antenna is wrapped around the base of the rotor while the receiving antenna is formed of several turns mounted concentric with the base of the rotor. Power is supplied by four type 625 mercury cells, which operate the unit continuously for more than 200 h. The total power consumption is roughly

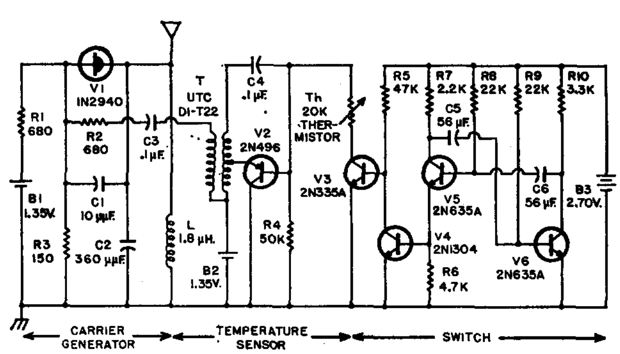

FIG. 1. Circuit diagram.

* Supported by Navy Bureau of Weapons and ARO (Durham).
[1] J. W. Beams, Phys. Today 12, 20 (1959).
[2] J. W. Beams, R. D. Boyle, and P. E. Hexner, Rev. Sci. Instr. 32, 645 (1961).
[3] J. T. Farrar, V. K. Zworykin, and J. Baum, Science 126, 975 (1957).
[4] R. S. Mackay and B. Jachobson, Nature 179, 1239 (1957).
[5] J. T. Farrar, C. Berkley, and V. K. Zworykin, Science 131, 1814 (1960).
[6] R. S. Mackay, Science 134, 1196 (1961).

6 mW. With the exception of the batteries, which are removable, the entire circuit is mounted in epoxy resin and supported by the rotor. The batteries are insulated electrically from the rotor by plastic. In its present form the circuit occupies a volume of slightly less than 2 in.[3] and is mounted on the axis near the base of the rotor.

At room temperature, $N_0 = 175$ and $N = 540$ and a change of 1°C produces a change in N of over 10 cps. This makes it possible to determine the temperature of the rotor to less than 0.01°C. It should be noted that the circuit is not observably affected by a 500-G magnetic field and that it is shielded by the rotor.

It is clear that, in addition to temperature, quantities such as pH, pressure, small potential differences, etc. can be radio telemetered from magnetically suspended rotors. Because of well-known commutation difficulties with high speed rotors, radio telemetering should become useful for shaft-mounted rotors as well as those that are magnetically suspended. In many applications, especially with very high speed rotors, the active transmitter circuit described above is too large and consumes too much power. In such cases, passive transmitters should be used. These transmitters carry no power source but only a resonant circuit whose frequency is sensed from outside. This characteristic frequency is altered by some circuit element which changes in response to changes in the quantities which are to be measured. These passive circuits are to be preferred in the highest centrifugal fields and where the observations are to be carried out on small rotors over extended periods of time. Such circuits designed for ratio telemetering from within the body have been discussed in detail by Mackay[6] and others.

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Quest: An On-Line Event-Processing Routine*

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An on-line computing system called QUEST can be used by a physicist to analyze unusual bubble-chamber events. The production version of a program called PACKAGE has been modified so that the physicist can control the progress of a specific event through the subroutines of PACKAGE. Feedback from the computer to the operator permits him to decide what hypothesis he should try next, depending upon the results already obtained. Because the physicist requires time to think what to do next, the QUEST system has been designed so that it can interrupt and then restore other programs.

At the Lawrence Radiation Laboratory a data-processing system is used in which the tracks of nuclear particle events occurring in a bubble chamber are photographed and analyzed. First the pictures are scanned; then if an interesting event is found the film is placed on a measuring projector (MP) and coordinate points along each charged track on three stereo views are measured. These measurements are converted to magnetic tape and, after some reorganization in a program called PANAL,[1] are processed by a program called PACKAGE. This program, written for the IBM 709 or 7090, is a combination of two programs already described: PANG[2] and KICK.[3]

PACKAGE consists of many very complicated subroutines which are the same for all types of events. The progress of each event is controlled by an event-type subroutine which calls the various subroutines in the main program. In general an event-type subroutine has to be coded for each topological event type in an experiment. The PACKAGE program is currently about 27 000 words long without the experiment-dependent event-type coding, which usually contains about 2000 words.

The PANG part of the program reconstructs the tracks in space from the coordinate measurements on the two best stereo views, and calculates the momentum at the center of the track and the azimuth and dip angle at each end of the track. Also it inserts and reconstructs the neutral tracks from vertex-point measurements. These calculations consist of two parts:

* Work done under the auspices of the U. S. Atomic Energy Commission.

[1] M. H. Alston, J. P. Berge, J. E. Braley, G. H. Campbell, R. J. Harvey, M. Hutchinson, and T. C. Schneider, "IBM Program PANAL," Lawrence Radiation Laboratory, Alvarez Group Memo 358, November 1961 (unpublished).

[2] W. E. Humphrey, "Description of the PANG Program, and Supplement No. 1," Alvarez Group Memos 111, September 1959, and 115, October 1959 (unpublished).

[3] "Reference Manual for KICK IBM Program," edited by A. H. Rosenfeld, Lawrence Radiation Laboratory Report UCRL-9099, May 1961 (unpublished); J. P. Berge, F. T. Solmitz, and H. Taft, Rev. Sci. Instr. **32**, 538 (1961).