Magnetic Suspension Densimeter

J. W. Beams

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line, usually a 50 Ω coaxial cable, which is charged through a leakage resistor by a dc voltage supply. A magnetic reed Hg switch is used to hold off the high dc voltage (as high as 10 kV). When the relay closes the Hg switch, the transmission line discharges into a matching load resistor, and half of the applied voltage is delivered to the load with a risetime and a falltime of the order of 1 nsec. (A 100 nsec pulse of 5 kV can be obtained with a 50 Ω pulser at a repetition rate of 4.5 Hz.) The pulse width, which is determined by the length of cable used, is of the order of 10 nsec/m.

The pulse generator described in this note is shown in Fig. 1. It consists of a Times Wire and Cable TR504 double-coaxial-shielded 50 Ω cable, a Clare Hg-wetted relay switch A135893 Hg 2c encased in a General Radio insertion unit No. 874X, surrounded by Dow Corning silicone grease. Three of the four Hg-switch pins have been *carefully* filed off.

By using the two shields of TR504 cable as the high and low ends, where the i.d. of the outer shield is 6.48 mm and the o.d. of the inner shield is 5.59 mm and $\sqrt{\epsilon}\approx 1.5$, the standard expression for a coaxial line gives an approximate impedance of 6 Ω. The breakdown voltage of the dielectric between the shields is 6 kV. With TR506 cable an impedance of 2 Ω can be obtained.

The Clare Hg-wetted relays are designed to match a 50 Ω coaxial line. The principal effect of the impedance mismatch at the switch is to produce ringing at the start of the pulse and to increase its falltime.

Figure 2 shows a typical voltage pulse, ~2 kV, across a 6 Ω carbon resistor. The slashes are caused by the response of the sampling oscilloscope to the low repetition rate of 4.5 Hz.

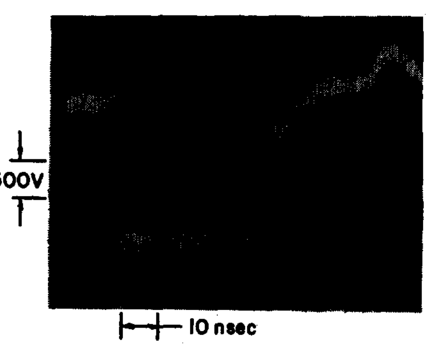

FIG. 2. Typical voltage waveform across 6 Ω carbon resistor.

This low-impedance pulser has been used to pulse low-resistivity bulk n-GaAs devices through the Ohmic, past the Gunn, and into the avalanche regime.

Magnetic Suspension Densimeter*

J. W. BEAMS

Department of Physics, University of Virginia, Charlottesville, Virginia 22903

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ESSENTIALLY the magnetic densimeter determinations consist in freely suspending magnetically a small ferromagnetic body (or buoy) inside of a small transparent container which is filled with a solution whose density ρ and partial specific volume $\bar{v}$ is to be determined. When the buoy B is freely suspended at rest at a constant vertical position inside of the solution, the upward force F exerted by the axial magnetic field H of the air core support solenoid is given by the relation $F=M(dH/dz)$, where M is the magnetic moment of the suspended body and z is the distance along the vertical. In the original design[1–4] both M and dH/dz are varied simultaneously and the assumption is made that $M\cong K'H$, where K' is a constant. This gives the relation $K'H(dH/dz)=(\rho-\rho_B)Vg=K_1K_2I^2$, where ρ_B is the density of the suspended buoy, V is the volume of the buoy, g the acceleration of gravity, and I the current in the solenoid. For an air core solenoid, $H=If_1(z)$ and $dH/dz=\mathrm{I}f_2(z)$ so that at a constant vertical position $H=K_1I$ and $dH/dz=K_2I$, where K_1 and K_2 are constants which may be determined by calculation, but which usually are determined by calibration with solutions of known density. In practice K' is not strictly constant but varies slowly with H even when the supported buoy contains magnetically soft material. Consequently in order to obtain the desired precision it is necessary to calibrate with a number of solutions of known density over the working range of the densimeter. Furthermore the sensitivity is inversely proportional to $(\rho-\rho_B)$ so that it is necessary to construct and calibrate several buoys with different ρ_B, S. With the arrangement described in this paper most of the above time-consuming procedures are not required and the ultimate reliability of the method is improved. This is accomplished by maintaining H constant at a given vertical position of the buoy and varying dH/dz alone. Figure 1 shows a schematic diagram of the apparatus. The buoy B, usually made by enclosing a ferromagnetic body in glass, is freely suspended by the air core solenoids S_1, S_2, and S_3 inside the solution contained in C. It is convenient, though not necessary, if S_2 and S_3 have the same number of turns and are as nearly identical as possible. All three coils have a common vertical axis. When S_2 and S_3 are identical they are usually, although not necessarily, spaced at a vertical distance equal to their radius in a manner similar to Helmholtz coils. The buoy B is on the common axis of S_1, S_2, and S_3 and an equal distance from S_2 and S_3. Its vertical position is checked by the microscope M. In supporting B a constant current I_1 is passed through S_1 which is not quite sufficient to support B at the desired position, as determined by the 30× nonferromagnetic microscope M focused on a fine scratch on B. Next a current I_2 is passed through S_2 and S_3 which are connected in series in such a way that at the desired position of B their magnetic fields cancel and their magnetic field gradients add. Consequently, as the current I_2 in S_2 and S_3 is increased the resultant magnetic field H at the buoy B produced by the currents in S_1, S_2, and S_3 remains constant if I_1 in S is constant. On the other hand if I_2 is in the proper direction, dH/dz increases and the upward force on B increases. If now the current I_2 through S_2 and S_3 is regulated by the sensing coil P and control circuit, the buoy B is held at the desired height.

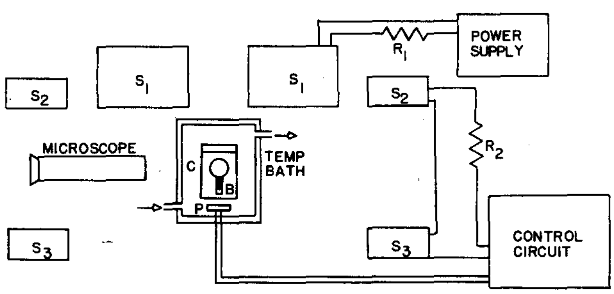

FIG. 1. Schematic diagram of the magnetic suspension densimeter.

I_2 is linearly proportional to $(\rho-\rho_B)\ Vg$ or to ρ since ρ_B, V, and g are constant, $dH/dz=K_4I_2$, where K_4 is a constant and the magnetic moment M of B remains practically unchanged. The current I_1 in S_1 can be held constant to one part in 10^6 by commercial constant current power supplies and determined with the same precision by measuring the potential drop across a standard resistor R_1 with a potentiometer or differential voltmeter with digital read out. The current I_2 is also determined with the same precision by measuring the potential drop across a second standard resistor R_2 in the same way. It is necessary to calibrate the buoy B, preferably with two solutions of known density. On the other hand, unlike in the original design the same buoy can be used over a wide range of concentrations without appreciable change in precision. As long as it is not necessary to change I_1 appreciably to obtain support which is usually the case in practice, the buoy need not be recalibrated.

The densimeter will operate equally well when the current I_2 is reversed but in this case I_1 must be increased so that the buoy is first supported by S_1 when I_2 is zero. Furthermore, in many cases it is more convenient to place the constant temperature bath, the cell C and buoy B above S_1 and construct B so that it floats in the solution with no current in the solenoids. The currents I_1 and I_2 are in such a direction that the force on B is down instead of up during a measurement. Comparable precision is found with B above or below S_1. Recently in some experiments the solenoid S_1 in Fig. 1 has been satisfactorily replaced by two identical cylindrical barium ferrite magnets each magnetized along its length. They are mounted with their axes coincident with the axis of S_2 and S_3 with like poles pointing up. The vertical positions of the upper and lower magnets are such that the magnetic field produced at the upper magnet by S_2 is equal and opposite to that in the lower magnet produced by S_3. As a result the magnetic field at the buoy remains approximately constant as I_2 is varied. Also it has been found that small magnetically hard ceramic cylindrical magnets which have comparatively large permanent magnetic moments could be substituted for the magnetically soft material in the buoy. A necessary condition in all of the above experiments is that B remain on the axis. The condition for this lateral stability is that $(dH/dz)^2-2H(d^2H/dz^2)$ be negative.[5] Any of the support solenoids that have been described in the past are satisfactory for S_1 and reference should be made to this work. S_2 and S_3 in most cases have a larger i.d. than the o.d. of S_1 and the maximum ampere turns in each solenoid now in use is about 5000. The control circuits and the buoy B are essentially the same as previously described.[1–4] Optical sensors may be used instead of the pick up coil P except for turbid solutions. For turbid solutions the microscope can be replaced by a second sensing coil placed above B. At present the precision of the density measurements is set by the variations in the temperature of the material in C and is the order of one part in 10^6. The accuracy of the partial specific volume determinations is limited by the accuracy with which the solutions can be prepared and is one part in 10^3.

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