A current-regulated magnet power supply for magnetic resonance and susceptibility studies

J Sithansapat, A K Ghoshal, D K Dey, A K Pati and S N Battacharyya
† Department of Magnetism and † Department of Physical Chemistry, Indian Association for the Cultivation of Science, Jadavpur, Calcutta-700032, India

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Abstract This note describes a highly stabilized magnet power supply system for magnetic resonance/susceptibility instrumentation, which is capable of providing a current of 0–5 A into a 40 Ω magnet coil together with linear current sweep facilities. This system can easily be adopted for magnets of any resistance. The dc drift is about 1 part in 10^4 per hour and low-frequency peak-to-peak noise is less than 1 part in 10^6. Long-term (1 h) nonlinearity in sweep is less than 1%.

1. Introduction
The present current regulator circuit is similar in principle to most of the current regulators available in the literature (Garwin et al 1959, Brog and Milford 1960, Cole and Vaughan 1963, Cook et al 1964). Considerable simplification in design and saving in cost have been obtained by the use of presently available inexpensive integrated circuit operational amplifiers. Moreover, to make it suitable for recording magnetic resonance spectra, a linear current sweep facility over a wide range at a number of sweep rates has also been provided. Magnet current can also be set at any desired value by manual operation.

2. Circuit description
The basic current regulator circuit is shown in figure 1.
Power is derived from 220 V ac mains and then stabilized by an ac voltage stabilizer T1, which also acts as an isolation transformer. The output of T1 is then converted to dc using a bridge rectifier D1–D4 followed by a choke-capacitor smoothing filter circuit.
The principle of operation of the current stabilizer is as follows. The magnet coil, the series element consisting of 20 power transistors having $P_{CEO}$ of 250 V and a 0.2 Ω standard resistance $R_s$, which are in series, are connected across the 220 V ac source. The temperature of $R_s$ is kept at 35°C within a thermostatic chamber whose temperature is regulated to within ±0.05°C. The current passing through the magnet coil...
and series element also passes through $R_s$ and as a result a voltage $V_s$ develops across it. This voltage is compared with a very stable reference voltage $V_r$, derived from a standard cell $E_1$ buffered by a unity-gain amplifier $A_2$. The difference in voltage between $V_s$ and $V_r$ is amplified by a high-gain (≈ 70 dB) amplifier $A_3$. For $A_2$ a low-cost operational amplifier μA741 of moderate slewing rate is used because, for an inductive load like the magnet coil, an expensive, fast-response operational amplifier is not necessary. A 100 pF capacitor is inserted in the feedback path of the amplifier to prevent any oscillation. The output of $A_3$ is fed to the base of transistor $Q_3$ through an emitter follower. Transistors $Q_3$ and $Q_4$ provide the required current gain to transistors $Q_3$-$Q_4$ connected in parallel. Any drift in magnet current will alter $V_s$ in the same direction and cause the output voltage of $A_3$ to effect the required current stabilization. The current through the magnet coil can be varied by changing $V_s$ between 0 and 1 V by means of a ten-turn Helipot VR1 which causes a change of current from 0 to 5 A through a 40 Ω magnet coil.

3 Sweep unit
A simple electronic current sweep circuit has been described by VanderVen (1968). However, to obtain long-term integration, which is essential for faithful recording of magnetic resonance spectra, this circuit needs an expensive operational amplifier having very low input bias current as well as very low input offset voltage.

For economic reasons, a mechanical sweep circuit has been incorporated. For current sweep provision, the voltage reference circuit is slightly altered as shown in figure 2. The voltage derived from a standard cell $E_1$ is buffered by an operational amplifier $A_3$ and fed to two ten-turn Helipots, VR1 and VR2, which provide two voltages $V_m$ and $V_s$ respectively. An operational amplifier, type MC1456, having low input bias current and low average temperature coefficient of input offset voltage is used as a summing amplifier, the output $V_s$ which is the difference between the input voltages $V_m$ and $V_s$. Therefore, any variation in $V_m$ or $V_s$ will change $V_s$ which, in turn, will alter the magnet current, and thus linear sweep is derived by driving the potentiometer VR2 with the half-synchronous clock motor through a variable gear train. Speed of sweep can be adjusted by changing the gear ratio before, the potentiometer VR1 is used for manual sweep.

4 Performance
NMR has been used to measure the stability of the magnetic field of a Newport 4 in electromagnet (resistance of the coils is 40 Ω) powered by the present stabilizer. The stability is about 1 part in $10^6$ per hour which in terms of field is less than ±2 x $10^{-4}$ T. Low-frequency peak-to-peak noise is less than 1 part in $10^4$. The linearity of the current sweep has been measured by a digital multimeter of 0.1% accuracy. The short-term (15 min) and long-term (1 h) nonlinearities in this stability are less than 0.4% and 1.5% respectively. Current sweeps can be made from 0 to 5 A in the present circuit arrangement at a time taken for the total sweep can be varied from 1 min. by changing the gear ratio of the synchronous motor.

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