A Constant Speed Drive for Mossbauer Experiments

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In recent years, there has been much interest in recoilless emission and absorption of low-energy gamma rays. When a free nucleus of mass m emits a gamma of energy W_g, the nucleus recoils with an energy W_r which is approximately equal to

$$W_r = \frac{1}{2m} \left(\frac{W_g}{c} \right)^2 \qquad (1)$$

where c is the speed of light. For the 14.4 kev gamma from Fe^{57} shown in Fig. 1, this energy is about 0.002 ev corresponding to a speed of 82 meters/sec.

It might seem that the recoil energy and speed are insignificant until it is realized that the "natural" or Heisenberg line width is only about

$$\Gamma = \frac{h/2\pi}{\Delta t} = (6.60)10^{-16}\ (10^7/1.4) = (4.7)10^{-9}\ \text{ev} \qquad (2)$$

There will, thus, be no absorption if this same gamma falls upon another identical, but unexcited nucleus because the energy of the gamma ray is shifted off the absorption resonance curve.

The Mossbauer Effect

In 1958 Rudolph L. Mossbauer demonstrated that it is possible to bind a radiating nucleus to a solid so firmly that the recoil momentum is shared by the entire lattice rather than being concentrated in one atom. When this happens, the corresponding recoil energy of Fe^{57} is of the order of 10^{-19} ev, a shift so insignificant in comparison with the width of the nuclear energy level that now resonant absorption can take place.

Atoms bound in solids can absorb energy only in units of the phonon vibration energy. If the calculated recoil energy is less than the phonon energy, the radiated quantum carries away the full energy in many emissions and there is no recoil.

Constant Speed Drive

In order to sweep out a resonance curve and to perform other interesting Mossbauer experiments in nuclear and solid state physics, a very constant speed drive is needed. Some experimenters employ a lathe. We have chosen to follow the basic design of A. J. Bearden, who rotates a stainless steel foil at such an angle to the gamma ray path that there is a longtitudinal component for Doppler shifting the resonance curve. Both the angle and the speed of rotation are adjustable in our modification shown schematically in Fig. 2.

A sheet of 1-mil stainless steel absorber is sandwiched between two plastic disks mounted on a freely rotating shaft. The source material Co_{57} and phototube are mounted on a bar. The velocity component of the absorber, relative to the source, can be adjusted by pivoting the bar. The velocity component can also be changed by varying the speed of the wheel.

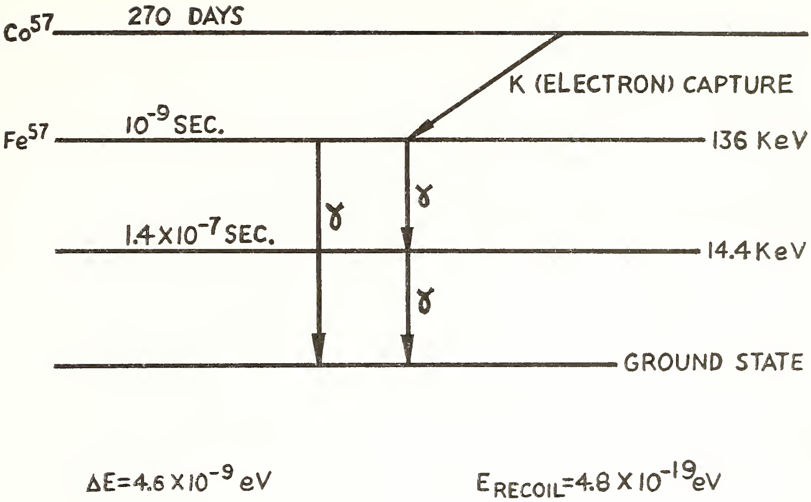

Figure 1. Decay of Co^{57}.

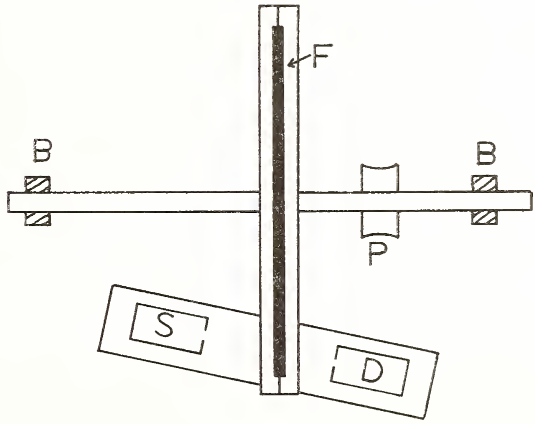

Figure 2. Top schematic of wheel, showing the shaft held in bearings B, sources and photomultiplier detector D on pivoted bar, stainless steel foil F held between two plastic discs, and o-ring drive pulley P.

The wheel is driven by a Servo-Tek dc motor using an o-ring and pulley. This motor, geared down to 18 rev/min maximum output speed, operates with 100 volts on the field winding and a maximum of 2.0 amperes through the armature. The armature requires 55 volts at full speed. Coupled directly to the motor is a generator tachometer whose voltage is directly proportional to the motor speed. This speed is linear with armature current in the range 1.3 to 2.0 amperes. In order to control the motor speed, thus, one must control the armature current.

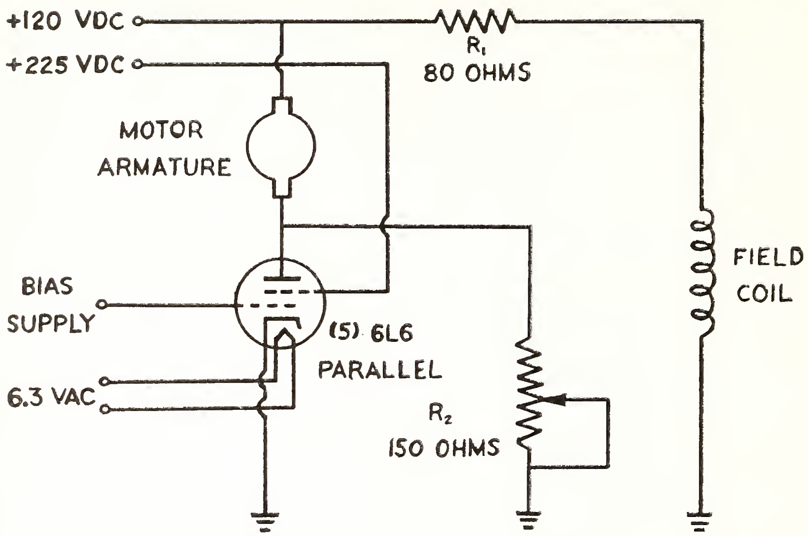

Figure 3. Connections to motor.

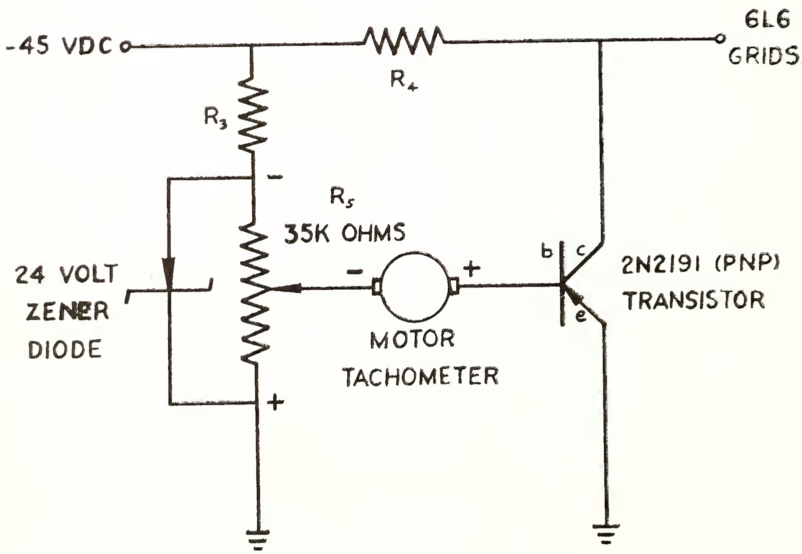

Figure 4. Transistor amplifier and feedback.

Motor Control Circuit

The total voltage across the armature and tubes in Fig. 3 is 120 while across the field winding is 100 volts. The current through the armature divides; 1.3 amperes is carried by a large rheostat R_2 and the remainder of the current is carried by the five 6L6's in parallel. By controlling the grid bias of the 6L6's the current through the tubes, and therefore the motor speed can be controlled.

The motor tachometer generates 1.3 volts per rev/min of the output shaft. This tachometer voltage is compared to a stable reference voltage supplied by a 24-volt zener diode in parallel with a 35 k-ohm potentiometer, as shown in Fig. 4. Their difference is fed to a PNP transistor. After amplification the difference voltage is coupled to the grids of the 6L6's.

In operation, an increase in speed of the motor increases the tachometer voltage. This provides a less negative voltage of the transistor base relative to the emitter, which in turn causes more current to flow through the transistor. Thus, the control grids of the 6L6's are driven more negative, which reduces the current through the tubes and decreases the motor speed.

Operation of the Circuit

To start the motor, the reference voltage is set to zero so that 6L6's are operating at maximum bias. This limits the current in the tubes to a safe value. The large rheostat R_2 coarse speed control is then set to a value such that the motor just begins to run—about 1.3 amperes through it. Next, the potentiometer across the zener diode is set so that the 6L6 grid bias is minus 15 volts. This adjustment is the fine speed control.

Because of the feed-back system being used, the fine speed control must be adjusted several times, until the grid bias remains constant at about minus 15 volts. Once this operating condition is reached the motor will run at a constant speed, compensating for circuit element heating or line voltage variations.

One of the tests performed on the motor control was as follows: a resistor and switch were placed in the 120 volt input to the armature. While operating the motor, the resistor was switched into the circuit. This dropped the input voltage by 12% but the motor speed decreased by only 3% and very quickly returned to its original value.