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DESIGN AND CONSTRUCTION OF A SIMPLE MÖSSBAUER SPECTROMETER

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Summary

A Mössbauer spectrometer built to study the internal (hyperfine) fields in magnetic compounds is described. The design of the electromechanical transducer and the circuits for the reference signal generator and feedback network are given.

Basic Principles

The Mössbauer effect[1] is the nuclear resonant absorption by the daughter nuclei (e.g. Fe^{57}) of the gamma rays (14.4 Kev) emitted by the parent nuclei (Co^{57}). Many factors can, however, cause the energy of the γ-rays to be different from the energy difference between the nuclear energy levels of the daughter nuclei. By moving either the absorber or omitter so as to cause a Doppler shift of the γ-ray frequency, the γ-ray energy can be made to be equal to the resonant absorption energy. The difference between the non-Doppler shifted γ-ray energy and the resonant energy can be determined from the Doppler shift velocity needed to bring the two energies into coincidence.

The basic operation principle of any Mössbauer spectometer is that each channel in a multichannel analyzer (MCA) stores the γ-ray intensities passing through the absorber for a given velocity of the moving component. There are two ways in which this can be accomplished and are called the constant velocity mode and the constant acceleration mode. In the former mode, the source or absorber is moved back and forth at a constant speed. The counts of the γ-rays passing through the absorber are then stored in a single channel. The speed of the moving component is changed step by step, with the counts stored in a different channel each time. In this way, an entire count-vs-velocity spectrum is obtained.

In the constant acceleration mode, the moving component is moved in such a way that the whole velocity range from $v_{max} \rightarrow 0 \rightarrow -v_{max}$ is continuously and periodically swept through (usually with a frequency between 1 and 100 Hz). A MCA is used to sort and store the data by having different channels open only when the velocity of the moving component is in given range. To synchronize the opening and closing of the different channels as the velocity range is swept through, two methods are used, the pulse height method and the multiscaler (or time mode) method.

In the pulse height method, a voltage proportional to the instantaneous velocity is used to modulate the detector coming from a single channel analyzer in such a way that the pulse height is proportional to the velocity. These pulses are then analyzed and stored into different channels according to their heights. In the multiscaler method, the gating voltage that sequentially opens and closes the various channels in a repititious cycle also triggers the emission of a square wave which is the input velocity sweep signal used to drive the electromechanical transducer. To prevent any possible drifting of the mechanical velocity from the input signal, a feedback system is usually incorporated into the Mössbauer spectrometer.

Present Mössbauer Spectrometer

The spectrometer used in the present study belongs to the constant acceleration mode type with an electromechanical transducer (double loudspeaker type). It is coupled to a ND-2400 MCA[2] operating in the time mode. This spectrometer is based on the spectrometers described by Kankeleit[3]. A block diagram of the spectrometer is shown in Fig. 1.

The reference generator creates a triangular wave from a square wave taken from the last bit of the binary address scaler in the MCA. The triangular wave is used as the reference velocity sweep wavefrom for the transducer which converts the electrical signal into mechanical motion. A pick-up coil, which is mechanically connected to the drive coil, measures the instantaneous velocity of motion and then produces a signal proportional to the velocity. The reference signal is substracted from the pick-up signal at the error amplifier. The error signal is passed through the RC circuitry and enters into the power amplifier which is driving the transducer. In this way, the velocity sweep of the moving component follows exactly the reference signal. Feedback is obtained through an aluminium rod connecting the two coils rigidly to each other. This set up has produced a parabolic motion which is in good synchronization with the channel numbers of the MCA. The cathode ray tube (CRT) of the analyzer displays the true velocity spectrum without any need of corrections or normalization.

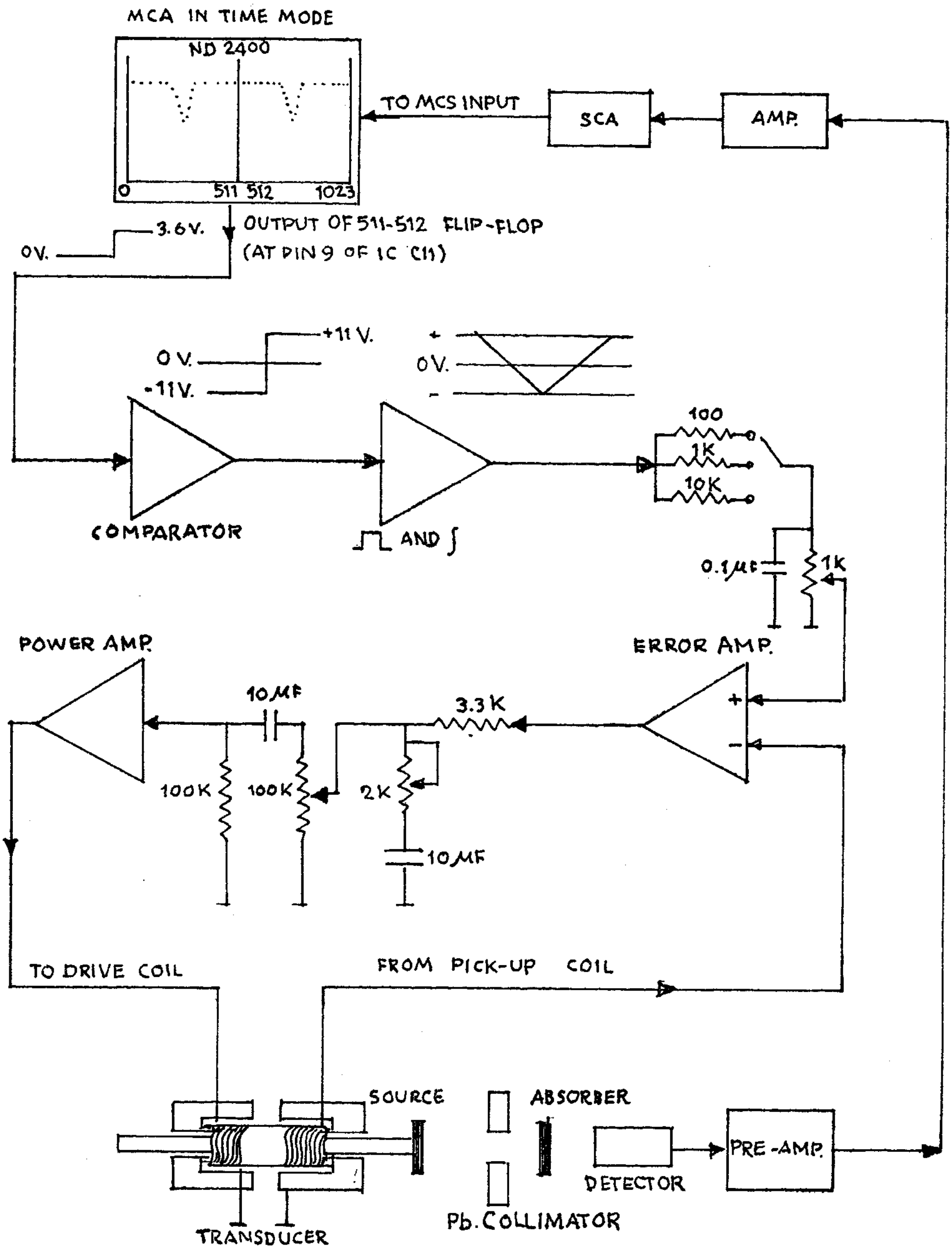


Fig. 1. Block diagram of the velocity spectrometer. (All resistance in ohm.)

Electromechanical Transducer

Fig. 2 shows the design of the electromechanical transducer. It consists of two loudspeaker-type systems rigidly connected front to front with brass bolts. Its moving parts include a drive and a pick-up coil both mounted on an aluminium rod connected to the frames of the loudspeakers by two linen-bakelite springs (1/32" thick). The shape of the springs is chosen so that unwanted lateral and angular motion is reduced to a minimum.

The drive and the pick-up coils are wound separately on cylindrical paper at the ends of the connecting rods. These coils are then painted with epoxy glue to make them rigid. The rigidity is important for controlling the transducer motion of the feedback system[4]. The coils have a length of 0.25 in. The pick-up coil consists of 200 turns in four layers of 0.0036 in. wire. The drive coil consists of 50 turns in two layers of 0.0068 in. wire in a bifilla arrangement. The coils are free to move in the magnet gaps. The permanent magnets (10 W "Bell") produce a magnetic field of about 12 KG in the radial air gap. The system has a basic resonance frequency near 33 Hz for sinusoidal drive motion. The impedances of the drive coil and pick-up coil are 8.5 Ω and 512.5 Ω, respectively, at the resonance frequency.

The pick-up coil provides an output signal of approximatedly 150 mV for a velocity of 10 mm/s. A voltage range of ± 150 mV for the triangular velocity reference waveform is required of the velocity setting potentiometer to cover the range of ± 10 mm/s. For a motional amplitude of 0.1 mm (10 mm/s. at 25 Hz.), the pick-up linearity was better than 0.15%

Reference Generator

The electronic circuits of the comparator and the reference generator are shown in Fig. 3. A square wave is taken from the last bit of the binary address scaler (at pin 9 of IC-C_{11} in the ND-2400 MCA) which defined the first and the second half of the MCA memory. This d.c. square wave signal is about 3.6 volts and has a period which depends on the number of channels to be used and the dwell time per channel selected. By using 1024 channels and a 40 μs dwell time, a period of about 24.4 Hz was obtained. This square wave was modified by comparing it to a reference voltage at pin 4 (1.8 V) of IC_1, the comparator, to produce a square wave a.c. signal of the same frequency as the input d.c. signal. The a.c. signal is then passed through a squaring circuit, which is a Zener diode clipping amplifier using a IC-operational-amplifier-type 741. The resulting square wave was then integrated by an integrating circuit similar to that of Kalvius *et al.*,[5] except that the μA 727 op. amp. was replaced by two μA 741 op. amp. and the d.c. offset was different. The integrating circuit is presently designed for a frequency of 25 Hz. and a d.c. gain of about one. If another drive frequency is desired, the integrating capacitor (1 μF) should be changed. Since good amplitude stability is required of any waveforms to be produced, it is necessary to use a voltage follower as a buffer to eliminate any loading effects.

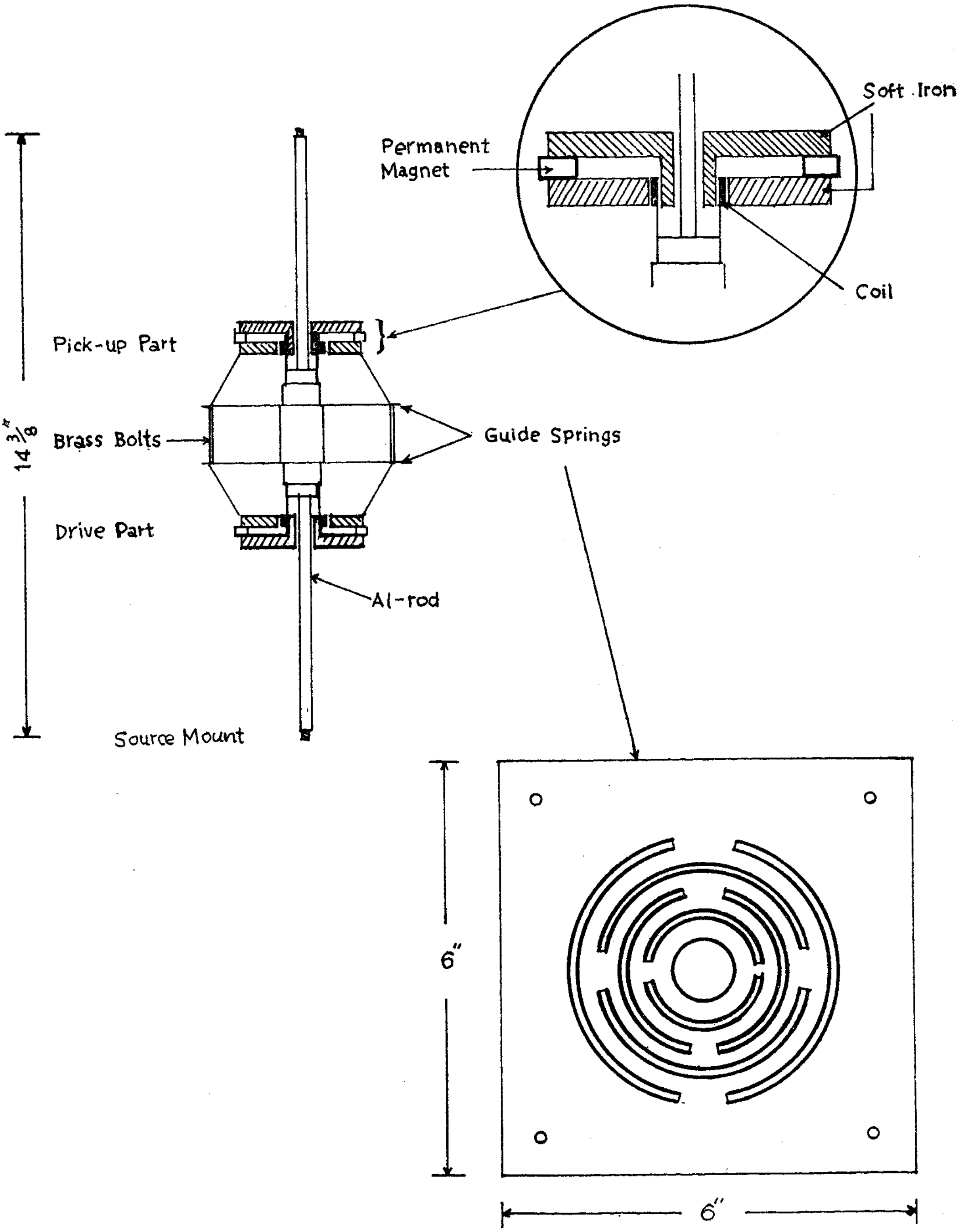


Fig. 2. Electromechanical transducer and the design of the guide spring.

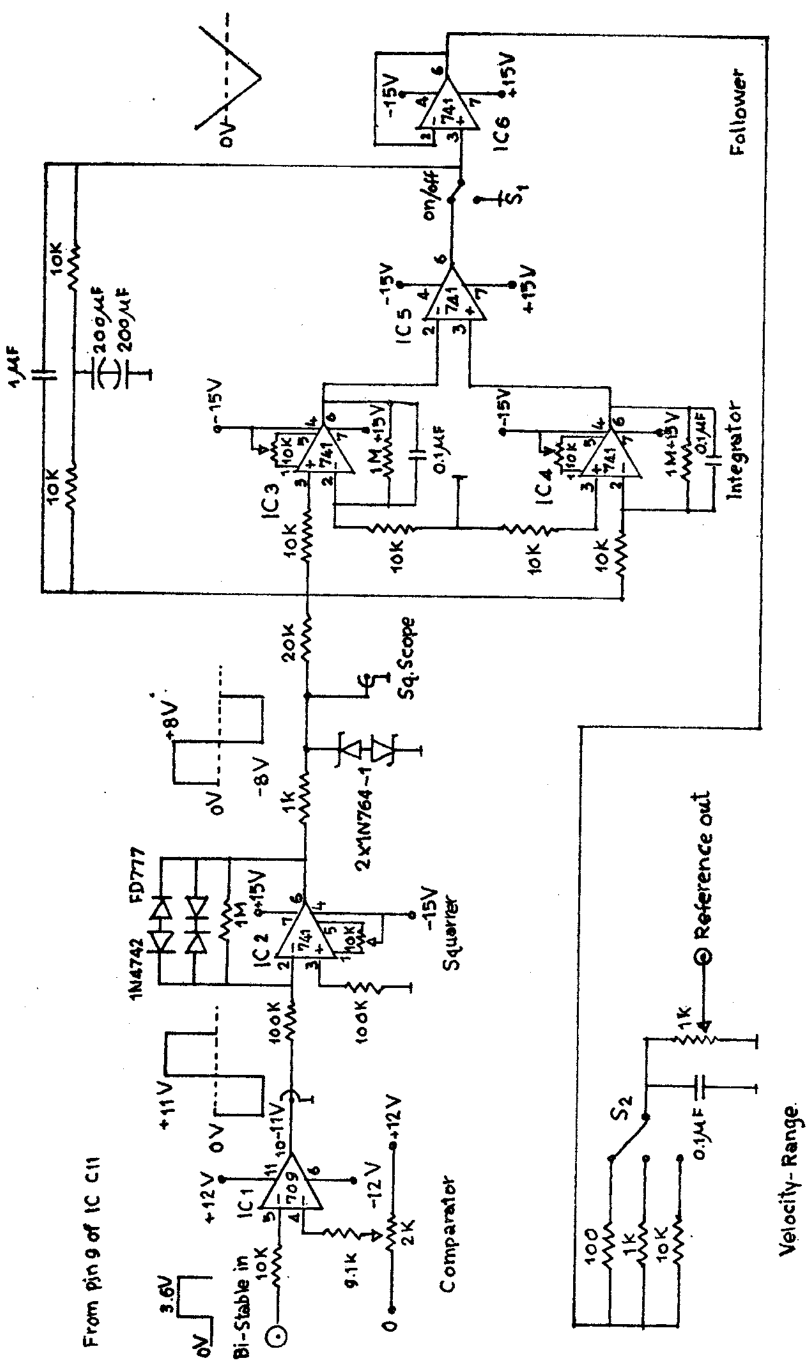


Fig. 3. The triangular wave reference generator and the comparator circuit. (All resistance in ohm).

Feedback System

The feedback circuit consists basically of an error amplifier (differential amplifier), a filter network, and a power amplifier. Without this network, the system will fall into a self-sustained oscillations at a low overall feedback gain. Fig. 4 shows the circuit of the feedback system using IC-op. amp. By connecting the pick-up coil and the reference output of the circuit of Fig. 3 at pin 4 and 5 via the 10 KΩ resistors of IC_7, respectively, the error signal is generated. IC_7 is an amplifier constructed around a μA 709 op. amp. (this being a differential amplifier having a gain of about 10). The error signal is then fed through a variable low-pass filter. The filter network consists of F_1, R_2 and C_2, R_3 controls the gain of the feedback loop and R_4 and C_4 constitutes the filter for removing the d.c. component of the error signal before it can enter into the power amplifier.

The power amplifier was designed to satisfy the following requirements: reliable response to very low input frequencies, wide band, high voltage gains and sufficient output current to drive the transducer. The first stage of the amplifier is a μA 709 op. amp. which provides the voltage gain. The final stage is a complementary Darlington connection of the single-ended push-pull amplifier. A 5KΩ potentiometer at the DC adjust position is used to balance the circuit. The op. amp. 1, 2, 3 and 4 are used as buffers to eliminated loading effects. If long connecting cables (> 10 m) are used, a voltage follower should be connected directly after the pick-up coil to reduce the loading effects. This additional voltage follower in the circuit is indicated by the broken lines in Fig. 4.

Spectrometer Performance

With the present spectrometer, velocities in the range from 1 to 100 mm/s can be controlled. The lower limit is determined by the amplifier input noise and the upper limit by the elastic limitations of the springs and the need for an uniform magnetic field in a space between the magnets equal to the amplitude of oscillation. In the medium velocity range (± 10 mm/s) the linearity of the velocity can be within 5%. The triangular reference signal, the velocity pick-up signal, and the error signal, used during an experimental run, are shown in Fig. 5. The error signal voltage was about 0.15% of the reference signal voltage (both measured peak-to-peak). The gamma radiation is detected by a thin beryllium window (0.005") NaI (Tl) scintillation detector coupled to the ND-2400 MCA in the conventional way.

Fig. 6 shows the resonant absorption of the 14.4 KeV ray emitted from a CO^{57}-Pd source by a natural iron absorber (0.025 mm. thick) during a 24 hour experimetal run. The dips in the Mössbauer spectrum are due to the Zeeman splitting of the Fe^{57} nuclear levels by the hyperfine fields inside iron absorber. The spectrum in the second half is a mirror image of the spectrum in the first half. The baseline curvature of the spectrum is due to the geometrical effect caused by the fact that each velocity is coupled to a certain source position during the time intervals that each channel is opened. Therefore a variation in the count rates with the velocity will exist even in the absence of an resonant absorption. To eliminate this effect,

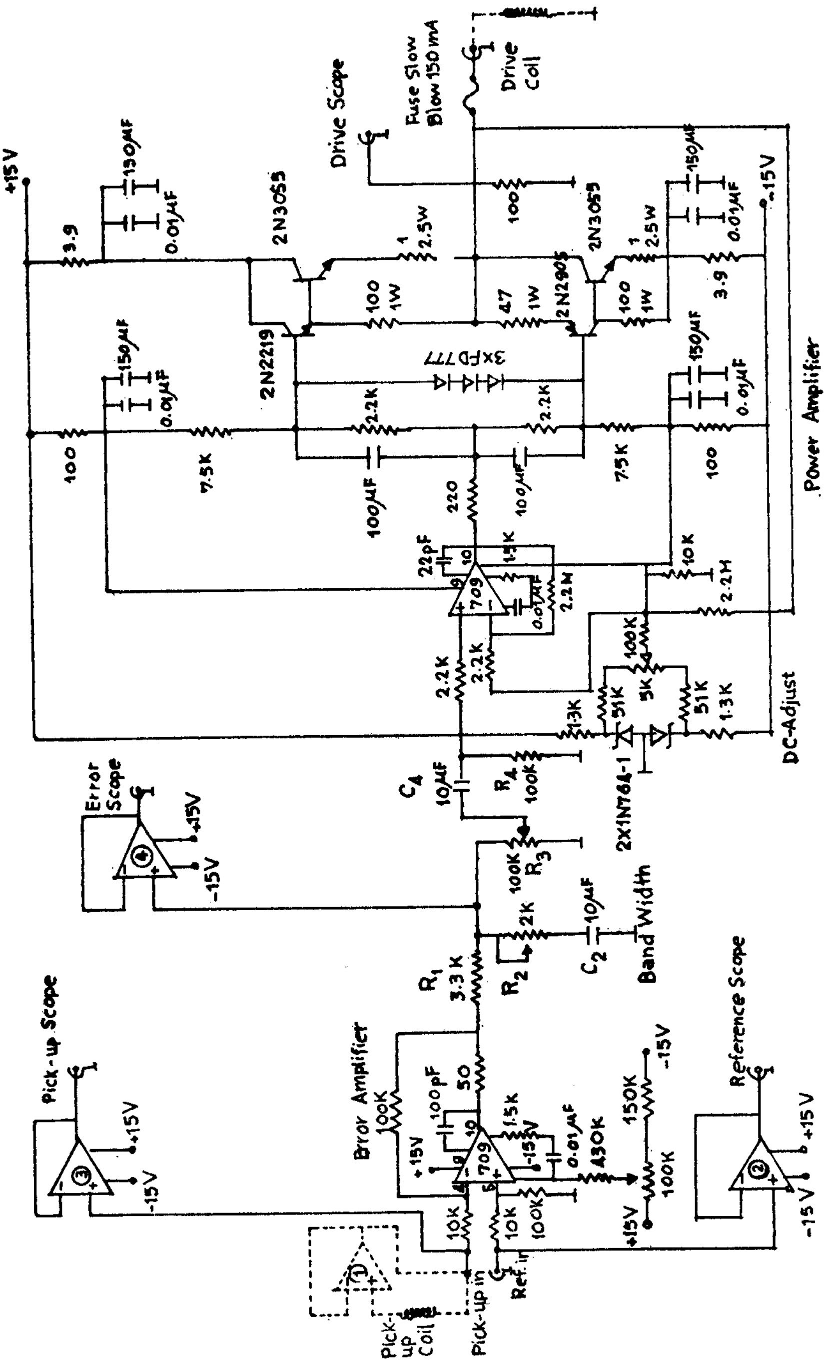
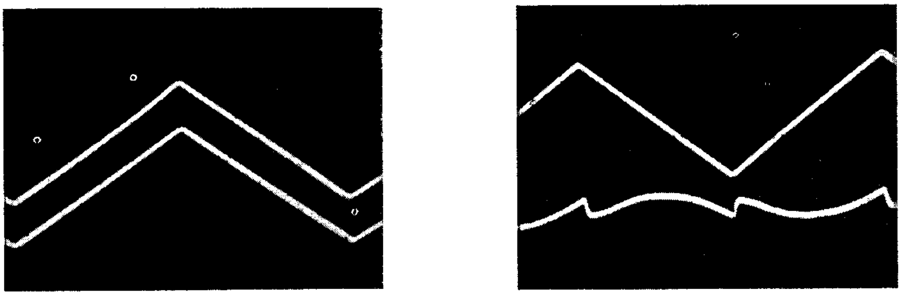


Fig. 4. Circuit diagram of the feedback system. (All resistance in ohm).



(a) (b)

Fig. 5. (a) Oscilloscope display of the triangular reference signal, 300 $mV_{p\text{-}p}$, 24.4 Hz (upper portion) and the velocity pick-up signal (lower portion).

(b) Oscilloscope display of the reference |signal and the error signal (4.5 $mV_{p\text{-}p}$).

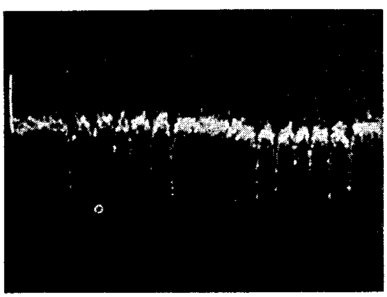


Fig. 6. Mössbauer spectrum of a natural iron absorber (0.025 mm thick), the second half of the spectrum being the mirror of the first half.

the counts in the first half of the spectrum is added (folded) to the mirror counts in the second half. Misalignment of the source, absorber and detector will also result in a asymmetric geometry effect which can not be eliminanted by the folding procedure.

The present Mössbauer was built to study the interaction between the Fe^{57} nucleus and the internal fields inside magnetic materials such as the spinel ferrites and the Heulser alloys. Some studies on the internal fields inside $CoFe_2O_4$ have been started. To facilitate these studies, we will be modifying the spectrometer so that the folding procedure can be done during the course of the experimental run by having the MCA address scaler operate in the forward and backward. We will also be building a Dewar system for carrying out Mössbauer studies at temperatures down to liquid nitrogen temperatures.

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บทคัดย่อ

ได้ออกแบบและสร้าง เครื่องแปลงกำลัง วงจรของสัญญาณอ้างอิง และสัญญาณป้อนกลับ เพื่อประกอบเป็นสเปคโตรมิเตอร์ชนิดมอสบาวเออร์ สำหรับใช้ในการศึกษาสนามแม่เหล็กภายในของสารประกอบแม่เหล็ก