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An electromechanical feedback system for the measurement of Mössbauer effect spectra in multiscaler mode of operation of a pulse-height analyzer is described. The equations of motion of the system have been examined analytically (through use of an IBM 7094 and Cal Comp plotter). The velocity drive has been linearized by introduction of a correction term in the Fourier expansion of acceleration.

MÖSSBAUER EFFECT VELOCITY DRIVE LINEARIZED BY SHAPE CORRECTION

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In Mössbauer effect experiments the substance under study is used as the absorber in an arrangement whereby radiation emitted by a source penetrates the absorber and is detected with a scintillation, semiconductor, or proportional counter. The energy of the γ rays is modulated by use of the Doppler effect,

$$\partial E = Ev/c,$$

where v is the relative velocity between the source and the absorber, c is the velocity of light, and E is the energy of the photon. The hyperfine nuclear structure of the absorber is obtained by measuring the counting rate as a function of the energy of the γ rays penetrating the absorber.

Four major pieces of equipment are used in measuring the Mössbauer absorption spectra. A counter is used to detect the full spectrum of γ rays passing through the absorber. A linear amplifier containing a single-channel analyzer amplifies the pulses produced by the γ rays and selects the appropriate energy level on the basis of pulse height. A pulse-height analyzer is used in pulse-height-analysis mode to adjust the single-channel analyzer to select the proper γ ray. The pulse-height analyzer is used in multiscaler mode to accumulate the Mössbauer effect spectrum (see Fig. 1). The multiscaler mode Mössbauer effect system controls the address-advance clock pulse and start-pulse inputs to the pulse-height analyzer in such a manner as to synchronize the pulse-height analyzer with the absorber velocity.

The system uses a tuning fork oscillator as a primary frequency standard to control the timing of the clock pulses, the start pulses, and the velocity wave. The frequency stability of the tuning fork oscillator is ± 0.02% over a temperature range of 35 °C. The frequency of the tuning fork oscillator is 20 kc/sec. A two-bit scaler is used to divide the 20-kc primary frequency by two or four to produce a clock-pulse frequency of either 10 kc or 5 kc. The clock frequency is further divided by the number of channels in the pulse-height analyzer (400) to produce a start-pulse frequency of either 25 cps or 12.5 cps. A square wave out of the scaler is integrated to produce a triangle wave at the frequency of the start pulse. The triangle wave is used to control the closed-loop velocity drive, thus producing a linear relationship between channel number and velocity.

The electromechanical drive capsule (Fig. 2) consists of a drive coil resembling a loudspeaker driver and a Sanborn 6LV1 velocity transducer coupled to a suitable absorber holder. The drive coil provides an accelerating force proportional to the current passing through it. The velocity transducer provides an output voltage proportional to the instantaneous velocity. In principle, such a system could be accelerated with a square wave of current to produce a triangular velocity waveform and a parabolic displacement

$$\frac{\partial^2 x}{\partial t^2} = AI \sum_{n=1}^{\infty} B^{-1} \sin(Bt), \qquad (1)$$

where A is a proportionality constant, $B = (2n-1)\omega$, and I is the absolute value of the current amplitude. (See Fig. 3.) The velocity would be simply the integral of acceleration,

$$\frac{\partial x}{\partial t} = -AI \sum_{n=1}^{\infty} B^{-2} \cos(Bt), \qquad (2)$$

and the integral of the triangular velocity waveform would be a parabolic displacement,

$$x = -AI \sum_{n=1}^{\infty} B^{-3} \sin (Bt). \tag{3}$$

When the velocity control feedback loop was originally closed it was observed that the drive waveform resembled a square wave with a sinusoid of inverse phase superimposed on it. It was not possible to linearize the velocity wave even by increasing the loop gain to the critical damping limit (see Figs. 4 and 5). The nonlinear characteristic of the drive results from the fact that the moving parts of the mechanism are suspended by elastic "spiders." The spring constant of the spiders coupled to the mass of the moving system constitutes a simple harmonic oscillator with resonant frequency, ω_0. The response of such a system to a square-wave accelerating force is

$$\frac{\partial x}{\partial t} = -AI \left\{ \sum_{n=1}^{\infty} B^{-2} \cos (Bt) - K\omega_0^{-1} e^{-(\omega-\omega_0)^2} \sin \omega_0 t \right\}, \tag{4}$$

where K is the "Q" of the simple harmonic oscillator, ω_0 is its resonant frequency, and ω describes the frequency of the driving waveform ($\omega = 2\pi f$). In order to obtain a triangular velocity wave the drive waveform needs to contain a square-wave component and a sinusoidal component capable of canceling the $\sin \omega_0 t$ term contributed by the simple harmonic oscillator.

If the system were operated at the resonant frequency of the electromechanical drive, the drive waveform necessary to produce a triangular velocity wave would be

$$\frac{\partial^2 x}{\partial t^2} = AI \left\{ \sum_{n=1}^{\infty} B^{-1} \sin Bt - K \sin \omega_0 t \right\}. \tag{5}$$

The first term of the preceding equation is the square acceleration wave which produces the triangular velocity component, and the second term cancels the simple harmonic oscillation component of the motion. In practice it was found unnecessary to produce a true sinusoid as a correction term. Instead, it was found that integration of the reference triangle wave produced a parabolic term which sufficed for a first-order correction and was readily available and inherently synchronous with the triangle wave (see Figs. 4 and 6). The acceleration term thus is

$$\frac{\partial^2 x}{\partial t^2} = AI \left\{ \sum_{n=1}^{\infty} B^{-1} \sin Bt - K' \sum_{n=1}^{\infty} B^{-3} \sin Bt \right\}. \qquad (6)$$

The correction term is introduced at the error-summing network.

The approximation of a linear velocity wave achieved by this method of compensation is quite good, as may be noted in Fig. 6. Small nonlinearities may still be seen at the vertices of the triangular velocity wave, but these are due to the bandwidth of the feedback loop rather than to the built-in simple harmonic oscillator. It is possible that this compensation technique might find application in other types of feedback-controlled mechanisms.

FIGURE CAPTIONS

Fig. 1. Multiscaler mode ^{57}Fe spectrum.

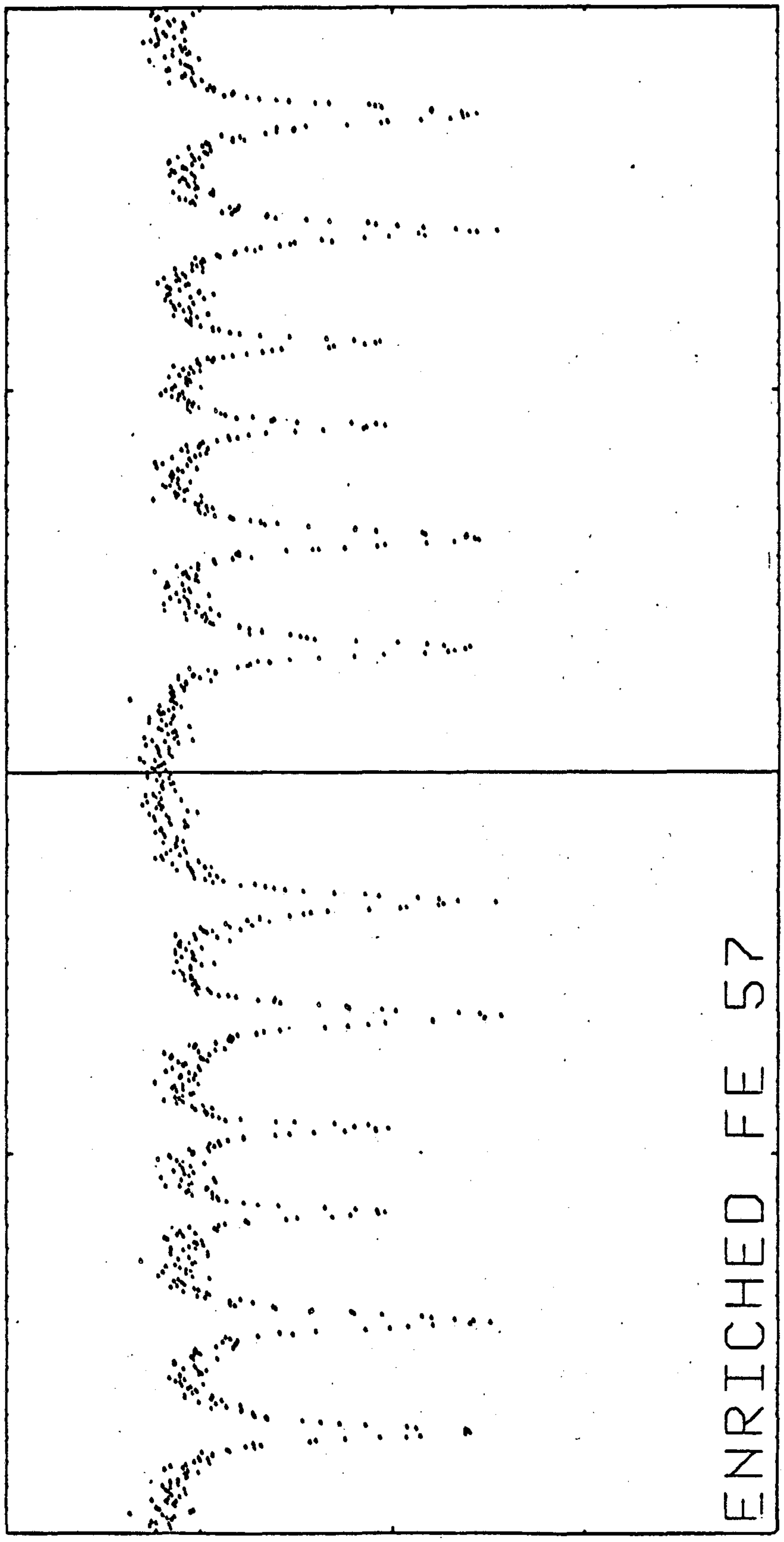
Fig. 2. Electromechanical drive.

Fig. 3. Cal-Comp plots of Eqs. (1) through (6), summed over the first 100 terms.

Fig. 4. Block diagram of multiscaler mode Mössbauer effect system.

Fig. 5. Waveforms (individually explained).

Fig. 6. Waveforms (individually explained).



MUB-8059

Fig. 1.

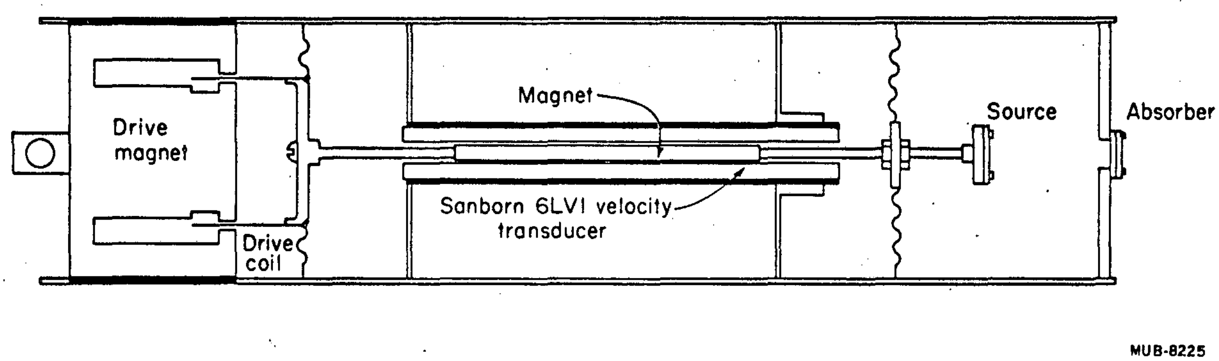

Magnet
Drive
magnet
Source
Absorber
Sanborn 6LV1 velocity
transducer
Drive
coil
MUB-8225

Fig. 2.

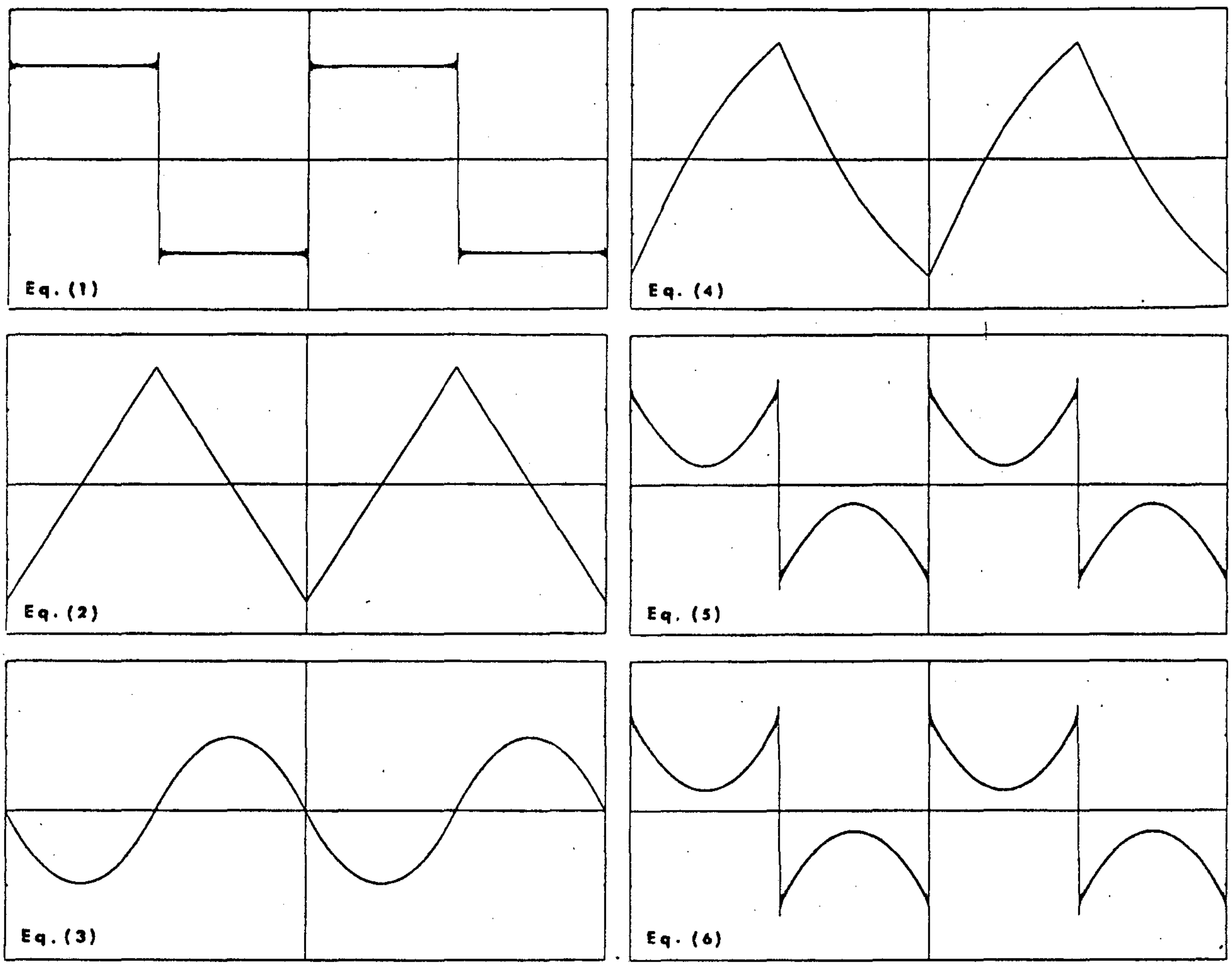


Fig. 3.

MUB-8286

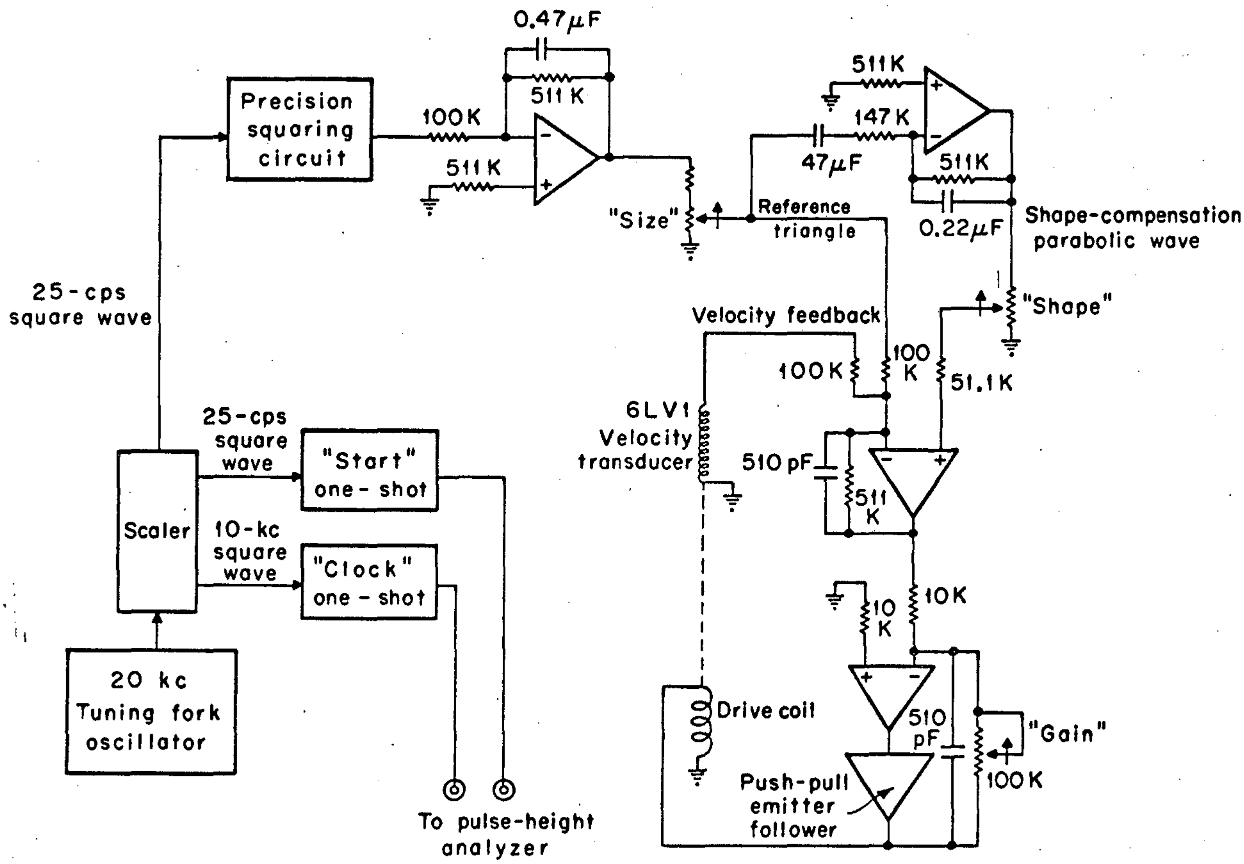
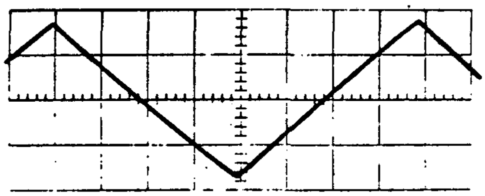
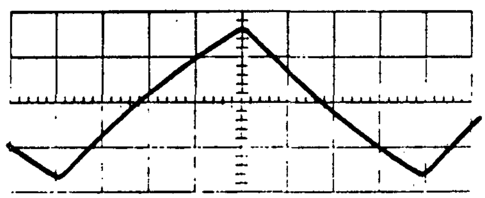

0.47μF
511 K
100K
511 K
Precision squaring circuit
"Size"
Reference triangle
511K
147 K
47μF
511K
0.22μF
Shape-compensation parabolic wave
"Shape"
25-cps square wave
Velocity feedback
100 K
100 K
51.1K
6LV1 Velocity transducer
510 pF
511 K
25-cps square wave
"Start" one-shot
Scaler
10-kc square wave
"Clock" one-shot
10 K
10K
20 kc Tuning fork oscillator
Drive coil
510 pF
"Gain"
100K
Push-pull emitter follower
To pulse-height analyzer
MUB-8026

Fig. 4.

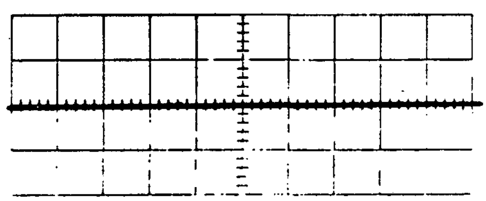


Reference triangle wave
vertical, 100 mV/div
horizontal, 5 msec/div



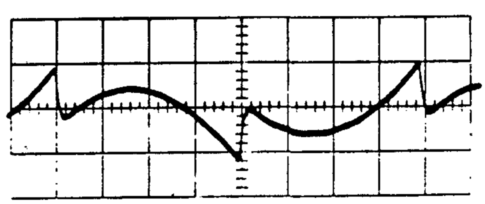
Velocity feedback
vertical, 100 mV/div
horizontal, 5 msec/div

Notice that there is a definite curvature in the velocity wave.



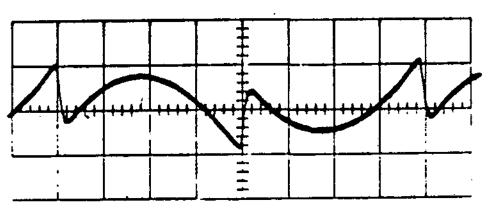
Compensation input
vertical, 20 mV/div
horizontal, 5 msec/div

During this test the compensation input is connected to ground.



(Ref. triangle + Vel. feedback) ÷ 3
vertical 5 mV/div
horizontal, 5 msec/div

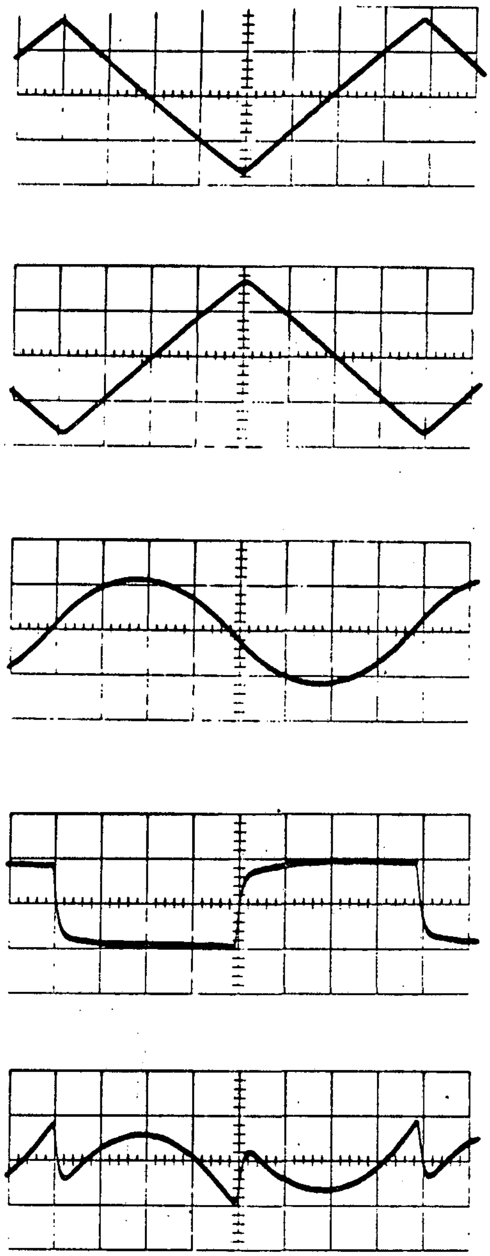
The factor of three is introduced as the summing network scale factor.



Drive output
vertical, 500 mV/div
horizontal, 5 msec/ div
Load ≈ 3 ohm.

MUB-8430

Fig. 5.



Reference triangle wave

vertical, 100 mV/div
horizontal, 5 msec/div

Velocity feedback

vertical, 100 mV/div
horizontal, 5 msec/div

The nonlinearity observed in Fig. 2 has been overcome by the parabolic compensation.

Compensation input

vertical, 20 mV/div
horizontal, 5 msec/div

This term is:

$$-K' \sum_{n=1}^{\infty} (2n-1)^{-2} \omega_0^{-2} \sin[(2n-1)\omega_0 t].$$

(Ref. triangle + Vel. feedback) ÷ 3

vertical, 5 mV/div
horizontal, 5 msec/div

The factor of three is introduced as the summing network scale factor.

Drive output

vertical, 500 mV/div
horizontal, 5 msec/div

Load ≈ 3 ohm.

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Fig. 6.