Precision Speed Control of a High-Speed Camera

PAPER **M—2**

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An efficient method for regulating the speed of a high-speed motion-picture camera is described. A reluctance pickup is placed near the sprocket teeth of the drive spindle on a Fastax camera. Each time that a sprocket tooth passes the pickup, a voltage pulse is generated. The amount of time between pulses is measured and compared with the desired amount of time. An error signal is derived that controls the conduction angle for a pair of thyratrons. The thyratrons control the power into the camera motors and hence the camera speed.

This sampled data feedback loop allows one to control the picture rate of the camera with a high degree of precision. When power is applied, the camera accelerates rapidly to the preselected speed and maintains this speed until power is removed. This method is not only useful at high picture-taking rates but is also effective at speeds much lower than are normally possible with a high-speed camera. This activity has support from the U.S. Army, Navy and Air Force.

In many applications where a high-speed motion-picture camera is used, it is desirable to control the picture-taking rate accurately. The method of control described below incorporates a reluctance pickup, which is used to generate an electrical signal when a tooth on the film-drive sprocket of the camera passes near it. The placement of this pickup in a Fastax camera is shown in Fig. 1. The clearance between the pickup and a sprocket tooth is 0.005 in. By timing the interval between the pulses from this pickup, the speed of the camera between the two preceding frames is determined. This speed is electrically compared with the desired camera speed, and the voltage applied to the motors of the camera is adjusted correspondingly. This method, although seemingly complicated, is actually quite simple and extremely versatile. It permits a high-speed camera to be operated at speeds much slower than has previously been possible, the speed of the camera may be changed by simply turning a switch on the speed control unit, acceleration times are cut by as much as an order of magnitude, and the speed of the camera remains remarkably constant during a run.

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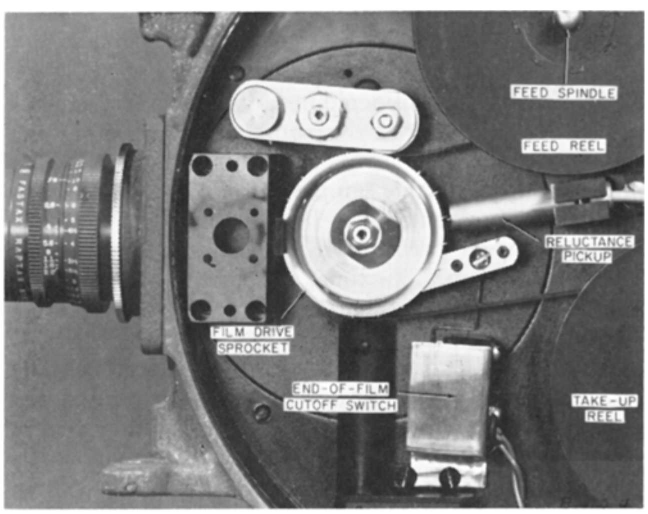


Fig. 1. Detail of Fastax camera showing the reluctance pickup.

Although this control can be used equally well with a camera that has a rotating prism, it is being used with a Fastax camera from which the prism has been removed. The Fastax therefore operates as a streak camera, in conjunction with a strobe light source that is flashed once per frame. The exact synchronization of the strobe is very important, since a small error in the time of triggering the strobe will cause objectionable jitter in the motion picture; the synchronizing signal is derived from the signal from the reluctance pickup.

Method of Speed Control

At the instant that the electrical signal from the reluctance pickup passes through zero going positive, a tooth on the film-drive sprocket is in line with the pickup and the picture is properly framed. The signal from the pickup is amplified by a difference amplifier and directly coupled into a Schmitt level-detecting trigger circuit. The level adjustment on the difference amplifier is set so that the output of the Schmitt trigger jumps at the instant that the input signal passes through zero going positive. The signals from the reluctance pickup and the Schmitt trigger are shown in Fig. 2. This type of triggering circuit is used because it provides ease of adjusting the precise level of triggering, relative freedom from drift of the triggering level with time and freedom from the bias of triggering level that an a-c device might develop when overloading occurs.

The output of the Schmitt circuit is used to trigger the strobe and drive a blocking oscillator. These interconnections are shown in the block diagram, Fig. 3. Since the film moves at a continuous rate through the camera, the strobe is used to frame the picture. Accuracy of framing is dependent on the reliability of the Schmitt trigger circuit. If the triggering level should vary by even a small amount, the motion picture would have an objectionable jitter.

The blocking oscillator serves two purposes. It drives a sample-and-hold circuit and resets the sawtooth generator timing circuit. The sample-and-hold circuit is used to sample the output voltage of the saw-tooth generator during the time that the blocking oscillator is conducting. This conduction takes place at the time of the positive-going zero crossing of the signal from the reluctance pickup, and the conduction interval is short

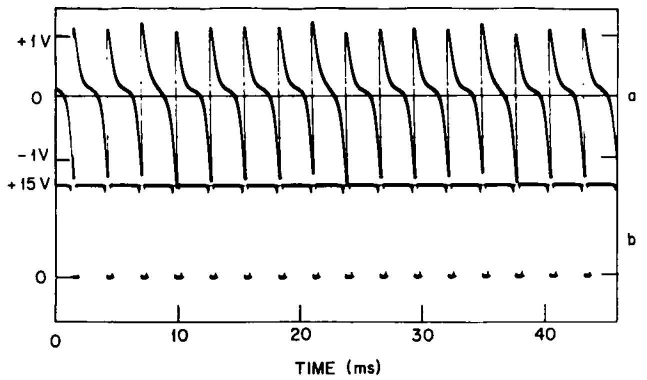


Fig. 2. (a) Electrical signal from reluctance pickup. (b) Output of Schmitt trigger circuit. Camera speed, 384 pictures/sec.

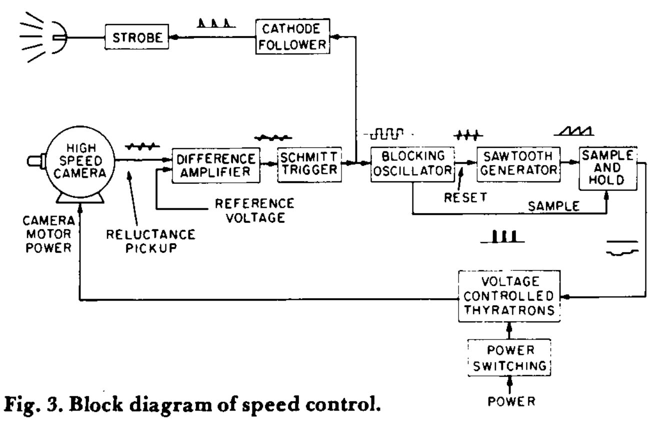


Fig. 3. Block diagram of speed control.

Fig. 4. Precision speed control for Fastax.

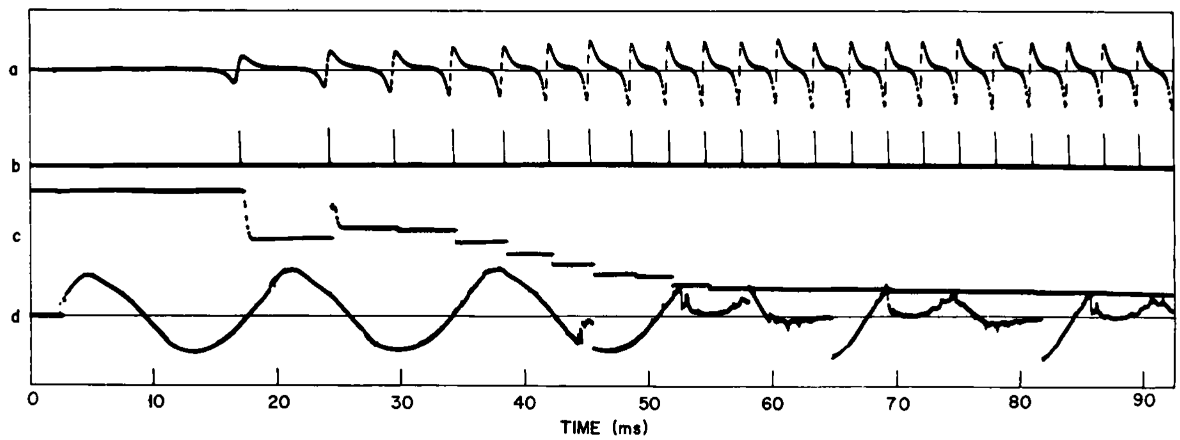


Fig. 5. Electrical signals during acceleration to 384 pictures/sec: (a) reluctance pickup; (b) signal to strobe; (c) output of sample-and-hold circuit; and (d) camera motor voltage.

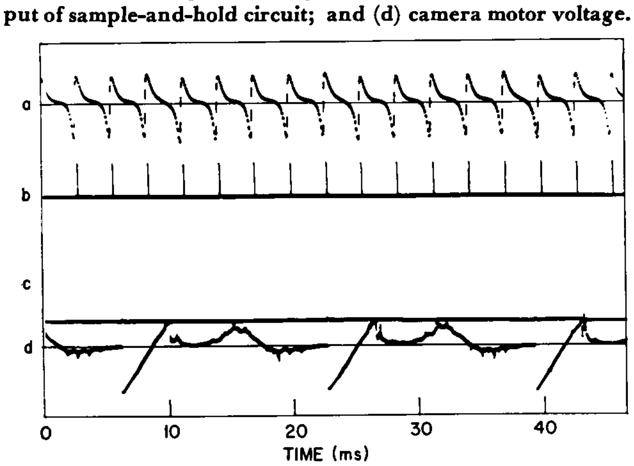
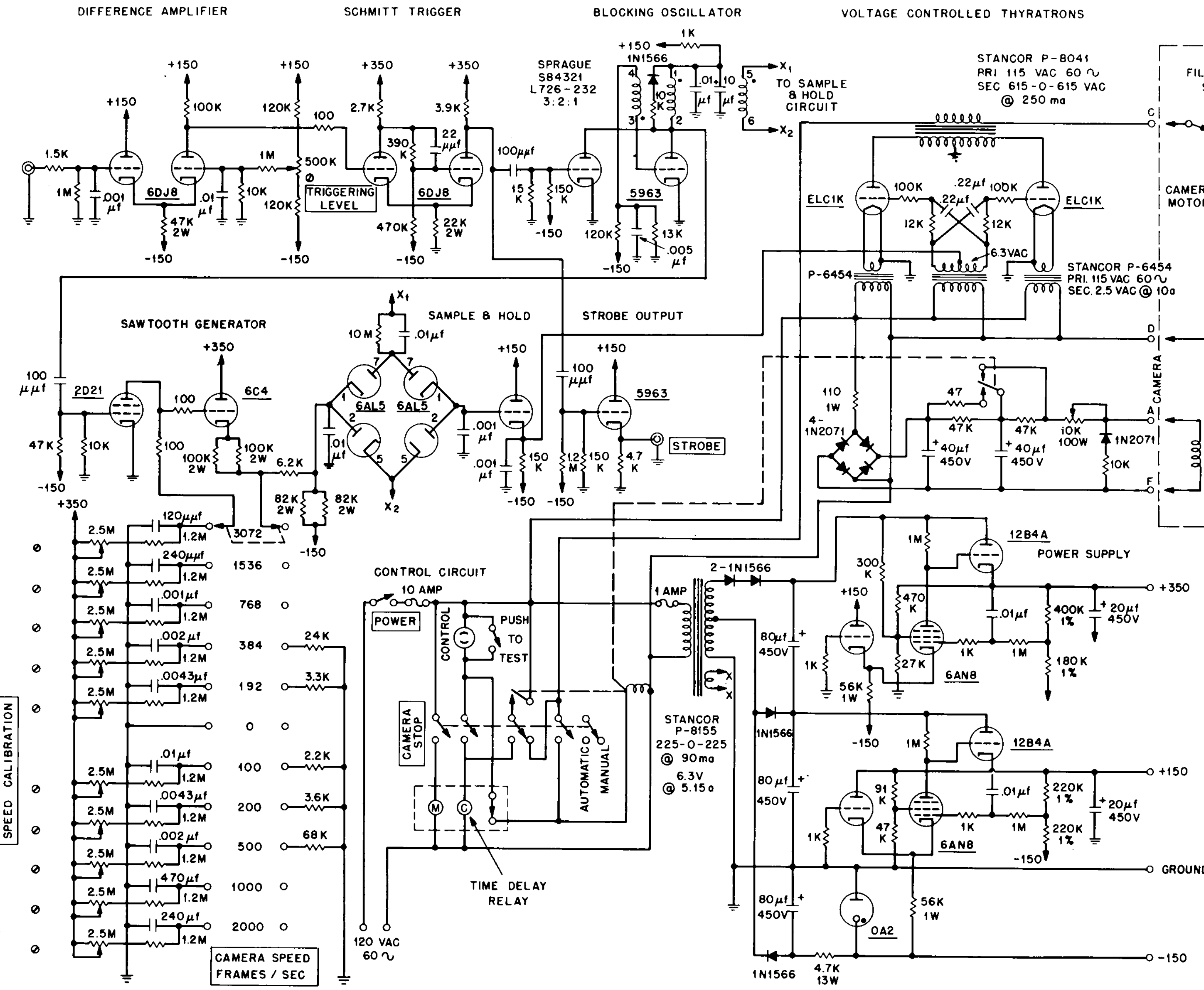


Fig. 6. Electrical signals during steady-state run at 384 pictures/-sec: (a) reluctance pickup; (b) signal to strobe; (c) output of sample-and-hold circuit; and (d) camera motor voltage.

enough for it to be considered instantaneous. The sample-and-hold circuit retains this sampled voltage from the sawtooth generator during the quiescent period. The output voltage of the sample-and-hold circuit is approximately proportional to the time between the passing of the two preceding sprocket teeth across the reluctance pickup. This time, and therefore the output voltage, is inversely proportional to the velocity of the film running through the camera gate.

As the blocking oscillator goes into its quiescent state, a signal is sent to the sawtooth generator. This signal resets the sawtooth generator (in effect resetting to zero the clock of the speed control). The output voltage of the sawtooth generator is approximately proportional to the time since it was last reset. This output is connected to the input of the sample-and-hold circuit.


DIFFERENCE AMPLIFIER
SCHMITT TRIGGER
BLOCKING OSCILLATOR
VOLTAGE CONTROLLED THYRATRONS
SPRAGUE S84321 L726-232 3:2:1
TO SAMPLE & HOLD CIRCUIT
STANCOR P-8041 PRI 115 VAC 60 ∿ SEC 615-0-615 VAC @ 250 ma
TRIGGERING LEVEL
6DJ8
5963
ELC1K
6.3VAC
P-6454
STANCOR P-6454 PRI. 115 VAC 60 ∿ SEC. 2.5 VAC @ 10a
SAWTOOTH GENERATOR
SAMPLE & HOLD
STROBE OUTPUT
2D21
6C4
6AL5
STROBE
CAMERA
4-1N2071
1N2071
SPEED CALIBRATION
CONTROL CIRCUIT
10 AMP
POWER
CONTROL
PUSH TO TEST
CAMERA STOP
AUTOMATIC
MANUAL
TIME DELAY RELAY
120 VAC 60 ∿
1 AMP
2-1N1566
STANCOR P-8155 225-0-225 @ 90ma 6.3V @ 5.15a
12B4A
POWER SUPPLY
6AN8
OA2
1N1566
+350
+150
GROUND
-150
CAMERA SPEED FRAMES / SEC
3072
1536
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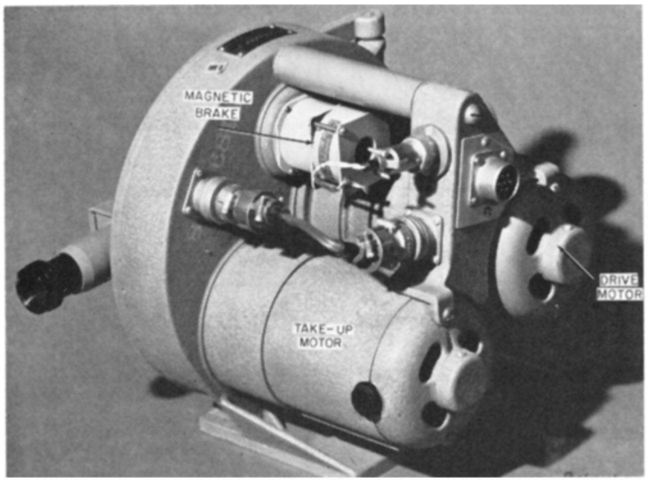

Fig. 8. Detail of Fastax camera showing the magnetic brake.

The signal from the sample-and-hold circuit is fed into a voltage-controlled thyratron circuit. This circuit consists of a pair of thyratrons operating as voltage-controlled switches, in push-pull. They control the amount of 60-cycle 120-v power that is applied to the camera motors. The higher the control voltage that is applied to the thyratron circuit input, the greater the percentage of time that the thyratrons are conducting.

One might note that the sweep rate of the sawtooth generator uniquely controls the camera speed. This sweep rate, and consequently the camera speed, may be changed quite easily by switching a capacitor or changing a resistor in the generator. In practice, the camera

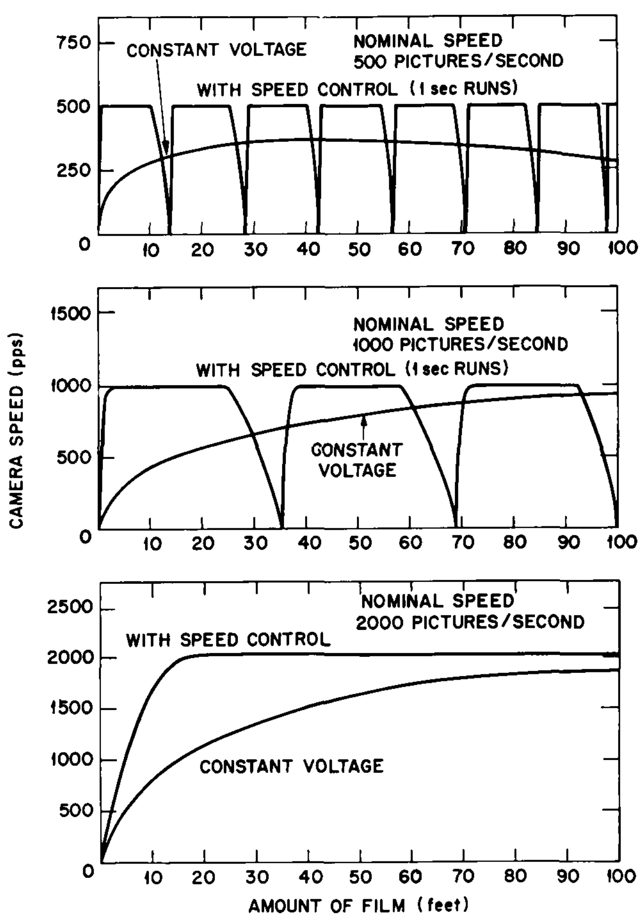

Fig. 9. Speed characteristics of a Fastax camera with and without speed control and magnetic braking.

speed is adjusted by a single multiposition switch on the control unit, as is shown in Fig. 4.

Operation

Since control information is received only at discrete intervals, and the nature of the thyratron restricts us to camera-voltage control at discrete intervals, the stability and response of the entire system must be investigated carefully.

When the camera is first turned on, the film is not moving and no signal has been generated by the reluctance pickup. The sawtooth generator has not been reset, so its output is at maximum. The input to the voltage-controlled thyratron circuit is large enough for conduction to occur during nearly all the cycle, providing maximum power to accelerate the film. When the camera has reached a speed, less than the desired speed, such that another half-cycle of full voltage will increase the speed of the camera above the desired speed, the potential applied to the thyratron circuit is changed so that the camera will receive just enough power to bring it to the desired speed during the next half-cycle. At each control period after that, an error signal is applied to the thyratron circuit so that the right amount of power is supplied to the camera to maintain the desired speed. In other words, when the film is running at the desired speed, the voltage on the sawtooth generator builds up to such a point that the thyratron circuit is supplying just the right amount of power to keep the film running at this speed. If the film slows down or speeds up by even a small amount, the power to the camera motor increases or decreases, respectively, by relatively large amounts. This feature keeps the camera speed remarkably constant. The signals from the reluctance pickup, the strobe output, the sample-and-hold circuit, and the thyratron circuit are shown during the acceleration of the camera in Fig. 5 and during steady-state operation in Fig. 6.

An attempt has been made to adjust the overall "gain" of the speed control in such a way that, during each and every control period, the camera speed is corrected by the full amount of the error in speed at the beginning of the control period. The gain of the control circuit is defined as the ratio of the voltage output of the sample-and-hold circuit to the time between pulses from the reluctance pickup. The entire "loop gain" is the ratio of the power on the camera motors (which directly affects the camera speed) to the time between pulses from the reluctance pickup. If the loop gain is too great, there will be an overshoot in speed; that is, if the speed is too low in period 1, it will be too high in period 2. If the loop gain is too low, there will be overdamping; that is, if the speed is too low in period 1, it will also be too low in period 2.

The gain for the speed control is adjusted for each camera speed setting with fixed resistors that are switched in and out of the cathode circuit of the sawtooth generator. This is shown in the schematic diagram, Fig. 7. While it is desirable to set the loop gain exactly, the setting is not very critical, and it can be misadjusted a great deal before the overdamping or the overshooting becomes undesirably great.

Stopping the Camera

With the Fastax High Speed Camera, there is no satisfactory provision for stopping the camera in the middle of a roll of film. With the addition of a magnetically operated brake connected to the feed spindle of the camera — a relatively simple modification — the film can be quickly stopped at any time during a run. The position of this brake is shown in Fig. 8. This feature not only conserves film but obviously saves a considerable amount of time that would normally be spent reloading film into the camera.

Conclusion

The type of speed control described here greatly increases the versatility of a high-speed camera. The camera can now accelerate to its operating speed in a split second, making it possible to shoot pictures of events that cannot be anticipated far in advance. The constant-speed feature makes it feasible to put an ultrasonic soundtrack on high-speed motion pictures.

Acceleration curves for the camera with the speed control are compared in Fig. 9 to the performance of the camera when operated from the constant voltage output of a Variac.

To obtain sound motion pictures with the high-speed camera, the camera is operated at a power-of-two (2^n) times the normal sound motion-picture speed of 24 frames/sec. A magnetic tape recorder is operated simultaneously at this same multiple (2^n) times its normal playback speed. (2^n has been chosen because commercial tape recorders normally operate at powers-of-two times $1\frac{7}{8}$ in./sec., i.e., $1\frac{7}{8}$, $3\frac{3}{4}$, $7\frac{1}{2}$, 15, 30, 60 and 120 in./sec.) Picture and sound records can then be played back at normal playback speed, synchronized with one another to give the slowed-down sound motion picture. The frequencies of the recorded sounds are reduced by the same factor that the pictures are slowed; the procedure is well suited to the study of phenomena whose sounds lie — wholly or in part — above the audible range.

This camera and speed-control combination is extremely useful for studying the relations between an acoustic disturbance and a rapid event. One such event that has been studied very successfully with this equipment is the echo-location and catching of thrown targets by bats in flight. The ultrasonic echo-location pulses of the bat are rendered audible by the reduction of playback speed. The event is slowed down to a speed at which accurate visual observations can be made.

Magnetic braking of the film conserves time and film when it is not desirable to use a full 100 ft of film during one run.