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FILM TAKE-UP SERVO AND CONTROL

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Abstract

An improved film reel take-up unit is designed for Spiral Readers. The requirements were a maximum film speed of 35 ft/sec at an acceleration of 5g. Low cost was also of primary interest.

Design

The general design of a reel unit consists of: A motor to drive the film spool; an error-sensing element to detect whether the unit should take in or let out film; an amplifier to drive the motor in response to the error signal.

The amplifier is generally the most costly element, because of the dc power supplies and transistors with high current capabilities. Use of a triac with ac line phase control was conceived as the most efficient solution to these problems. Such a Triac drive circuit is shown in Fig. 1.

The circuit consisting of $R_1$, $R_2$, $R_3$, $R_4$, $C_1$, $D_1$, and $D_2$ forms a square wave at 60 Hz of about 60 volts peak to peak (p-p). The slider of $R_4$ determines the dc reference level of the square wave. Thus, with the slider in different positions, the wave forms at the slider are as shown
on Fig. 2. $R_5$ and $C_2$, then, provide a charging curve that exceeds the
diac threshold (28 to 35 V) only if the slider is off center. Positive
half-waves fire the Diac and Triac if the slider is in one direction, and
negative half-waves if the slider is in the other. The result is a simple
bidirectional motor drive with a high current gain. The gain with respect
to the arm position $\frac{dv}{d\theta}$ is controlled by the setting of $R_4$ and $R_5$.

By connecting the slider of $R_4$ to a "flailing arm" ("dancing arm")
an error signal may be converted to a motor-drive signal.

RE-2 picks up slowly, preventing sudden current surges when the
system is turned on. RE-1 disconnects the error signal when reels are
being changed.

$R_7$, $R_8$, and $C_4$ are a frequency-compensation network, in which
values were determined in the following manner. A reel system may be
roughly thought of as a position-feedback servo. Thus, the error signal
(from $R_4$) goes down at -20 db/decade and is 90 deg lagging in phase.
An additional "roll-off" is introduced due to the motor and load response
curve. It is difficult to measure the open-loop frequency response due
the 60 Hz everywhere in the circuit. But the approximate position of
the second roll-off corner frequency may be obtained from closing the
loop without frequency compensation and observing the frequency at which
the system oscillates.

The phase shift at this oscillating frequency is -180 deg. A
phase-lead network may then be placed in series with the open loop to
reduce the phase shift (see Fig. 3). To insure stability the -20 db/decade
compensation was set to start at a frequency of 1/2 the oscillation frequency.
A restriction on \( C_4 \) is that it must introduce little distortion of the 60-Hz square wave from the slider of \( R_4 \). A 3-\( \mu \)F capacitor at 60 Hz has an impedance of 1 k\( \Omega \), making it sufficiently small to transmit the square wave unaffected. \( R_7 \) and \( C_4 \) provide a 1.5-Hz roll-off network. \( R_8 \) helps maintain a more constant dc resistance to the \( R_7 \) \( C_4 \) circuit.

**Performance on Spiral Reader I**

Two prototype reel units were installed on Spiral Reader I (see Figs. 4 and 5). The present capstan drive was operated at its maximum speed and acceleration, but was unable to match the capabilities of the reel units. (This simplified the computer control software operations by eliminating a previously required capstan-velocity ramp subroutine). The final version of the control unit is compact—only 4 by 4 by 8 in. (see Fig. 6).

**Performance**

<table>
<thead>
<tr>
<th></th>
<th>Reel unit</th>
<th>Spiral reader capstan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum speed (ft/sec)</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Maximum acceleration (g)</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

**Motor specification limits**

Maximum motor current surge: 80 A (motor rated at 100 A surge)

Average current: 8A (motor rated at 8.6 A average)

**Cost of electronic parts**

1. Motor (U-16, printed circuit motors) $165
2. Control parts 

Total $215
LEGENDS

Fig. 1. Film take-up servo control.

Fig. 2. Wave forms corresponding to different positions of slider.

Fig. 3. A Bode plot, showing method of frequency compensation.

Fig. 4. Prototype control installed on Spiral Reader.

Fig. 5. The film take-up control (prototype) and reel.

Fig. 6. Final version of the control.
Fig. 1

- All diodes: LED21282
- All wiring #22 except heavy lines;
- heavy lines #12
Fig. 2

Slider to one side
Slider centered
Slider to other side
Open loop: no compensation

Frequency at which motor and load start roll-off (approx. oscillation frequency)

-20 db/decade

-40 db/decade

Compensated response

Phase-lead compensation

Fig. 3
Fig. 5
Fig. 6
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