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ZOOM LENS CONTROL

INTRODUCTION

THE ZOOM LENSES of the 1950s, because of their limited range, were complementary to fixed focal length lenses rather than replacements for them. Users of these early zoom lenses still needed fixed focal length lenses and turrets on their cameras. By contrast, a modern Varotal* can now perform more functions than a full turret of fixed focus lenses with great gain in convenience and closely comparable picture quality. This naturally leads to the replacement of turret cameras by the "zoom only" Marconi Mark V.

Zoom lenses have sometimes been criticized for the unnatural effect of jerky zooming which can occur with elementary controls. High-performance servo systems have now been developed, which give smooth and accurate control with minimum effort, to exploit the full potentialities of the new Varotal lenses.

A special system has been developed for the Marconi Mark V camera incorporating in one unit a Varotal V lens and its associated servos for zoom, focus and iris, including all the necessary silicon solid-state electronics. It has provision for a wide variety of modes of control, each of which can be introduced by connecting the appropriate demand unit (Fig. 1).

THE DEMAND SYSTEMS

The cameraman has only two hands with which to control pan, tilt, focus and zoom, and he may also have to "dolly" the pedestal. Smooth zooming with a conventional mechanical control occupies the right hand completely, and quite a lot of the brain, requiring considerable concentration. The left hand is fully occupied aiming the camera and neither hand is free for focusing. This led to a combined zoom and focus control which enabled both to be controlled by the right hand; but focusing involved rotation of the wrist, and only a very limited range could be covered without a change of grip, which interrupted zooming. A focus twist-grip is now more popular, enabling the left hand to focus and aim the camera simultaneously, but changing grip is still necessary, which interferes with aiming. The difficulty can be eased by passing the pan bar under the left arm, but this restricts tilt movement.

Zoom Rate Thumb Control

The direct control of zoom position with adequate resolution involves a long travel of the operator's hand. The rotation of a typical positional control of $1\frac{3}{4}$ turns demands a motion of the hand through a curved path of 4 ft. This movement can be replaced by one of less than an inch by controlling zoom *rate* rather than zoom *position*. With rate control, fast zooming takes less effort and slow zooming requires less concentration. A rate-control lever, spring loaded to the zero position, can easily be operated by the left thumb without loss of grip of the hand for pan and tilt. The focus function then has the undivided attention of the right hand.

The zoom rate demand unit can be mounted on the pan bar in a variety of positions. It incorporates a handle for aiming the camera. As the camera is tilted, this handle rises or falls relative to the cameraman and it can rotate in its housing, so that no change of grip is necessary and the thumb rests naturally in the position of zero demand in all attitudes (Fig. 2). With this

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Fig. 1. Zoom package on camera.

arrangement there is no tendency to operate zoom accidentally due to aiming and so the spring pressure can be made light enough to avoid fatigue.

Preset Zooming

Camera operation can be improved even further by the use of the Sental* zoom pre-set unit (Fig. 3). Any one of eleven speeds may be pre-selected on a rotary switch. A zoom at this speed is started by touching the appropriate button. The "wide" and "narrow" buttons start a zoom which continues at the chosen speed until the "stop" button is pressed (unless the end of the range is reached first), which returns the control to the thumb for instant choice of zoom rate.

In addition to the "wide" and "narrow" buttons there are five buttons which can be pre-set by the cameraman to any zoom positions. Touching any one of these seven buttons starts a zoom to the corresponding position at the selected speed. The chosen button lights up.

During a slow pre-set zoom, the cameraman's attention can be devoted entirely to aiming and focusing. Pre-set zooms can be timed on rehearsal and repeated accurately. On top speed the pre-set unit gives the effect of a quick-change turret with seven lenses and without loss of focus.

The buttons operate electrically interlocked self-hold relays which avoid the difficulty of silencing and weatherproofing mechanically interlocked self-holding buttons. A zoom indicator is provided on the pre-set unit.

Focus Control

The standard focus demand unit with a three-spoked capstan is normally mounted on a short right-hand pan-bar (Fig. 4). Sufficient friction has been incorporated to prevent accidental movement of the capstan and the feel has a slightly viscous component to enable fine adjustment to be made.

Provision is made for a variety of alternative focus control systems by appropriate connection to the focus demand socket.

Remote Control

The demand unit cables may be extended to several thousand feet without special precautions. Provision is made for a wide variety of panel mounted demand systems including pre-set zoom, focus and iris. Remote indication can be provided even with local control.

THE ZOOM SERVO

The Zoom Servo is required to give continuously variable control of zoom rate in both directions and pre-set zoom positional control is required.

Smoothness of Motion

The limit of zoom perceptibility is taken as being set by a movement at the edge of the picture of $1/1{,}600 \times$ picture width. This represents a magnification change of 1 in 800. A 10 to 1 zoom could be made up of 1,850 such changes ($800 \log_e 10$).

This limit is used as a guide to the smoothness required in zoom motion. It does not represent the resolution requirement for pre-set positional control.

Speed Range

A Varotal lens has a linear relation between servo movement and the logarithm of focal length, so that a particular servo movement from any position always changes the magnification by the same ratio. A constant servo speed therefore gives an exponential zoom whose time constant is inversely proportional to servo speed (Fig. 5).

For programme production it is sometimes required to carry out a zoom change so slowly that the picture motion is barely noticeable. It is found that this is achieved by covering the above limit of perceptibility

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approximately ten times per second, giving a time constant of 800/10 = 80 seconds. The zoom servo should be capable of motion at the speed corresponding to this time constant, without jerks or short-term fluctuations exceeding the limit of zoom perceptibility specified above. Such a speed would cover the 10 to 1 range of the Varotal V lens in 185 seconds ($80 \log_e 10$).

At the other extreme, to perform the function of a turret, any focal length should be available on demand within 1 second. This gives a speed range requirement corresponding to end-to-end times from 1 second to 185 seconds. The Sental* zoom servo for the Marconi Mark V camera will in fact cover the zoom range continuously in any time from 0·75 second to 5 minutes (300 seconds). This speed range of 400 to 1 is achieved in any tilt attitude.

Fig. 3. The Zoom pre-set unit.

DESIGN OF ZOOM SERVO

Type of System

After considering a number of possibilities, it was decided to develop an electrical closed-loop servo system consisting of a motor controlled by amplified signals from a tachogenerator and potentiometers. For rate control, a demand voltage is compared with the tachogenerator signal. The difference, representing velocity error, is amplified and fed to the motor (Fig. 6).

For pre-set positional control a positional demand voltage is compared with the voltage from a potentiometer geared to the servo. The difference, representing position error, is used to control the velocity of the servo. If the position error signal were fed to the amplifier alone, the servo would overshoot or even oscillate unless a very low gain were used. To prevent overshoot and permit a high enough gain, the position feedback signal is combined with a velocity feedback signal from the tachogenerator (Fig. 7).

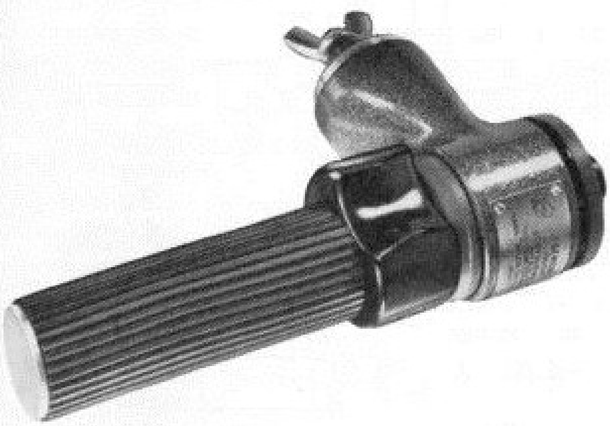

Fig. 2. Zoom demand unit.

Choice of Motor—A.C or D.C

For a full zoom of Varotal V in 0·75 second pointing vertically, with adequate safety margins, a motor output of about 5 W is required. The choice between a.c and d.c servo motors is determined by five considerations:

(a) *Efficiency*

Small d.c servo motors have efficiencies of about 50% compared with 15% for a.c induction servo motors of the same size. A suitable d.c motor would therefore require a maximum input of about 10 W

Fig. 4. Focus demand unit.

and an a.c motor about 30 W of which 15 W would come from the amplifier.

(b) *Temperature Rise*

A.c servo motors usually have two windings, each consuming half the input power at full load. One winding is controlled and the other is fed continuously. A suitable a.c motor controlled in this way would dissipate about 15 W continuously, leading to a considerable temperature rise. The d.c motor would dissipate power only when moving, and even then only 1 or 2 W under normal conditions. The 10-W requirement would only be approached with a combination of several unfavourable circumstances.

(c) *Weight*

A suitable d.c motor weighs 230 g. whereas an a.c servo motor of the same power output for 50 c/s weighs 730 g.

(d) *Response Time*

The servo stability and performance requirements dictate a useful torque response up to about 500 c/s. This cannot be achieved by a 50 c/s a.c induction motor.

(e) *Life*

The minimum specified life of the d.c servo motors actually used corresponds to $7{\cdot}5 \times 10^6$ zooms end to end. This would permit two full zooms per minute for 5 hours per day for 34 years, before changing the brushes. The life of the equipment is therefore not affected by the motor.

Choice of Tachogenerator—A.C or D.C

Having decided to use a d.c motor, the tachogenerator could still be an a.c or a d.c type.

(a) *Drift*

The use of an a.c tacho would avoid the difficulty of designing a low-drift d.c amplifier. This advantage would be more than offset by the null signal of the a.c. tacho itself which varies with time, temperature and rotor position.

(b) *Response Time*

The servo performance requirements demand a useful tachogenerator response up to about 500 c/s and this cannot be achieved with a 50 c/s carrier.

Feedback Loop Design and Stabilization

The velocity feedback characteristics to give the required speed range and smoothness of motion on rate

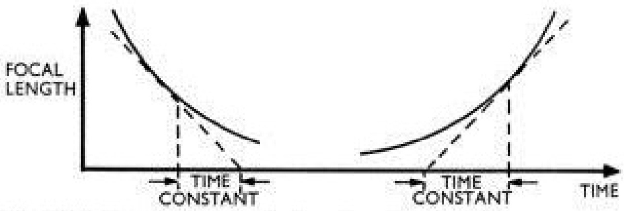

Fig. 5. Diagram showing rates between focal length and time.

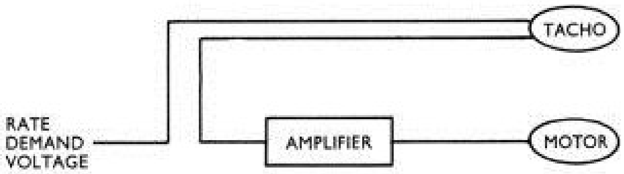

Fig. 6. Diagram showing the electrical closed loop servo system.

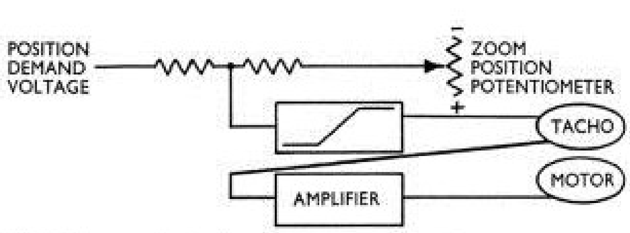

Fig. 7. Diagram showing how the position feedback is combined with a velocity feed-band from the tachogenerator.

control are more than adequate to prevent overshoot when the positional loop is closed. The feedback loop design requirement is thus reduced to that of a high-performance velocity control system with a speed range of 400 to 1. The loop gain requirements necessary to make zooming at any speed in the range sufficiently uniform will now be considered.

Motion of the servo is disturbed by variable friction in the lens which could occur at any frequency within a wide range. At any particular frequency the resulting perturbation to the motion of the zoom mechanism must meet either one or other of the following conditions:

Either (*a*) The velocity variation must be less than 10% of the demanded velocity.

or (*b*) The peak-to-peak amplitude must correspond to less than the limit of zoom perceptibility.

The velocity limit (*a*) applies at zero and low frequencies and the amplitude limit (*b*) at higher frequencies (Fig. 8). The cross-over frequency at which these two conditions are equivalent is 0·2 c/s for the lowest specified speed corresponding to a 5-minute 10 to 1 zoom.

These conditions set a lower limit to the loop gain as a function of frequency (Fig. 9).

Above 0·2 c/s the loop gain falls with increasing frequency until the inevitable mechanical resonances are reached. Nyquist's stability criterion demands that the open loop response locus passes the 0 dB–180° phase point correctly. To achieve this, with satisfactory margins and tolerances, the first mechanical resonance, due to compliance in the coupling between the tachogenerator and motor, was increased to over 1,500 c/s. This involved careful design of the self-aligning coupling which allows for 5 degrees of freedom between the motor and tachogenerator. The notch of a parallel T filter spans the tolerance band of this resonance to prevent the 0 dB–180° point being encircled on the second time round. This filter inevitably introduces phase lag at lower frequencies. This lag, and that due to motor inductance, are partially compensated by phase advance in the 200 c/s region from a filter network in one of the inner feedback loops, which also increases the very low frequency gain where motor back e.m.f is significant.

The filter networks (Fig. 10) have been designed to shape the response locus to ensure adequate stability margins. The Nichols chart (Fig. 11) shows a closed loop response peak of less than 1·5 dB, even when the gain is reduced for high speeds. This ensures a docile servo free from ringing and buzzing.

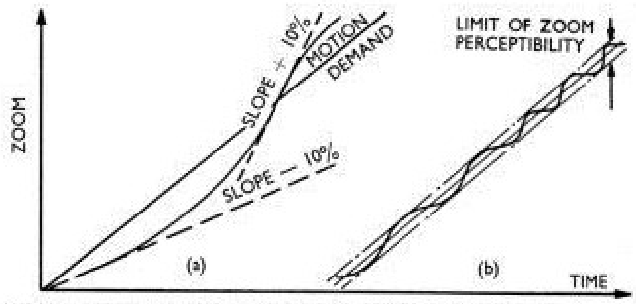

Fig. 8. Graph showing the velocity limit and the amplitude limit.

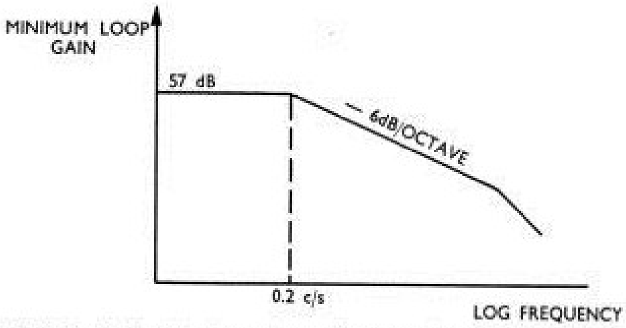

Fig. 9. Graph showing loop gain as a function of frequency.

180° phase lag occurs at 550 c/s and 0 dB gain at 200 c/s giving closed loop linear response time of the order of 1 millisecond.

It is interesting to note that a requirement for steady slow zooms of 300 seconds leads to a 1 millisecond response and the need for mechanical resonance to be above 1,500 c/s.

THE FOCUS SERVO

The main requirements of the focus servo are high resolution, the ability to change focus quickly, rapid acceleration and versatility.

Resolution

With Varotal V at maximum focal length, at an aperture of *f*/4, the depth of focus, based on a circle of confusion 0·002 in. diameter, is given by a movement of the focusing element of 0·0034 in. A servo resolution one-eighth of this is considered acceptable. This is 0·0004 in. or 1/2,000 of the total travel of 0·75 in. The Sental focus servo moves the focusing element with a resolution of 0·0002 in. corresponding to one-sixteenth of the depth of focus.

Speed

A rapid change of focus is required when changing subject and it has been found that an adequate maximum speed is one which covers the range in 0·5 second.

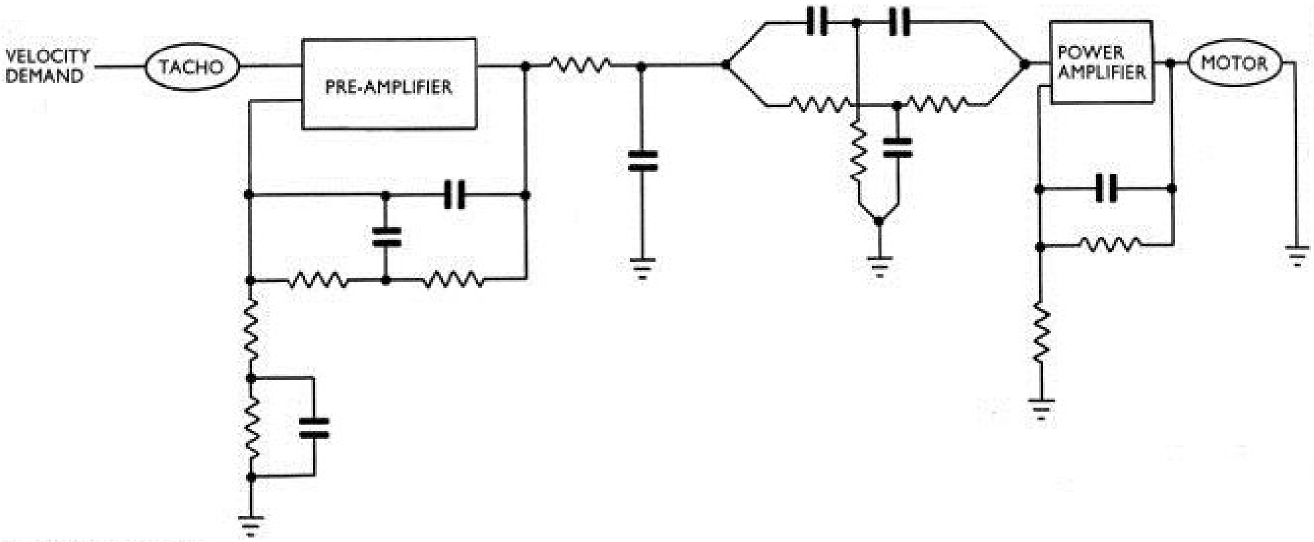

Fig. 10. Filter networks.

Acceleration
The accuracy with which a cameraman can hold focus on a moving target depends on his reaction time combined with that of the servo. The Sental focus servo will stop dead from full speed in less than 30 milliseconds, and in its linear range has a response time of about 1 millisecond.

Versatility
Provision is made for the possible use of pre-set control.

FOCUS SERVO DESIGN

The energy required to drive Varotal V focusing mechanism through its range is slightly less than the energy required by the zoom motion. However, it is desirable to traverse the movement in rather less than the 0·75 second taken by the zoom servo. Thus the power required from the focus servo is sufficiently similar to the zoom requirement to permit the use of the same type of motor and power amplifier, controlled by a suitable error signal and pre-amplifier. The focus motor, of course, makes fewer revolutions than does the zoom motor.

The Error Detection Problem
Positional rather than rate control is customary for focus, but the re-set device for a positional servo presents problems. Ideally the servo resolution should be better than 1 part in 2,000. For a potentiometer system both wirewound and carbon types were investigated.

Wirewound potentiometers can just meet the resolution requirement in one direction, but can have backlash greater than their resolution.

Carbon film potentiometers having adequate life and resolution for servo use are still expensive and mostly too bulky.

Moulded carbon low-price potentiometers are frequently used in some servo applications, but do not easily yield the resolution required. High-price moulded carbon potentiometers have disadvantages similar to those of the carbon film type—too much space, too much money.

Synchros and digital encoders were each considered but they are rather bulky and expensive, particularly for multiple pre-set control which would involve one synchro or encoder for each pre-set position.

Thus there are several positional systems which could be made to work, but none is ideal.

The Pseudo-positional (Rate-rate) Servo
It is customary for the displacement of the focusing glasses to correspond to the displacement of the focus capstan. This condition can be satisfied if the velocity of the focusing glasses corresponds to the velocity of the focus capstan. This, in turn, suggests an unorthodox system which will be seen to have several advantages. A velocity error signal is derived by comparing signals from two tachogenerators, one driven by the focus motor and one by the capstan. This velocity error signal is amplified, shaped and applied to the focus servo motor.

Thus the demand and re-set devices are tachogenerators which have virtually unlimited resolution.

Their cost is reasonable, especially if we consider that a focus servo with potentiometer reset would require, in any case, a tachogenerator as well for stabilization:

The rate-rate system offers several advantages:

(a) It has very high resolution as described above.

(b) It does not require end-stops in the demand unit which would have to be precisely matched to those of the lens or drive unit. A non-critical stop system is incorporated which reduces the speed as the lens stops are approached.

(c) Its sensitivity can be changed at will without disturbing focus.

(d) Multi-point control is possible without the necessity for override switching.

(e) If the demand to a normal positional servo is moved very quickly and then stopped, the servo will continue to move until it catches up with the demand, giving the impression of an overshoot. Such a control would be difficult to use for focus. When the demand to a rate-rate system is stopped, the servo tends to stop immediately.

Provision is also made for positional control using a wirewound reset potentiometer. This permits the use of control panels with any number of pre-set focus positions.

Feedback Loop Design

The minimum speed required from the focus servo was assumed to be that necessary to make a small improvement in focus of the order of 1/2,000 of the total range (one-eighth of the depth of focus) in a time of 0·1 second.

By comparison, at the maximum speed, the servo covers $\frac{1}{5}$ of the total range in 0·1 second. Thus the required speed range is of the order of $\frac{1}{5}$ to 1/2,000 or 400 to 1 (similar to the zoom).

The focus resolution requirement of 1 in 2,000 is slightly more severe than the requirement set by the zoom limit of perceptibility, but is in fact met by the same servo loop. This permits the use, for focus, of printed circuit boards and many other sub-assemblies identical to those used for zoom.

THE IRIS SERVO

The Iris Sental servo provides calibrated positional control and is self-aligning. To give solid feel, the servo must be able to keep pace with the demand, and to meet this requirement it is capable of driving at seven stops per second. The resolution and hysteresis of the control system are each 1% of the travel, giving an overall repeatability of setting of 2% which is one-seventh of a stop.

Design of the Iris Servo

The requirements of aperture control are less severe than those of Zoom and Focus and can be satisfied completely by a simple remote-position control system, using potentiometers for demand and reset.

Potentiometers

A low-price type of moulded carbon potentiometer track, with the wiper mounted on a pre-loaded ball-bearing spindle is perfectly adequate for Iris.

Velocity Feedback

Velocity feedback is used to stabilize the positional servo loop. This feedback is also used to limit the speed in response to a step change in demand position, which occurs with a pre-set or preselector demand.

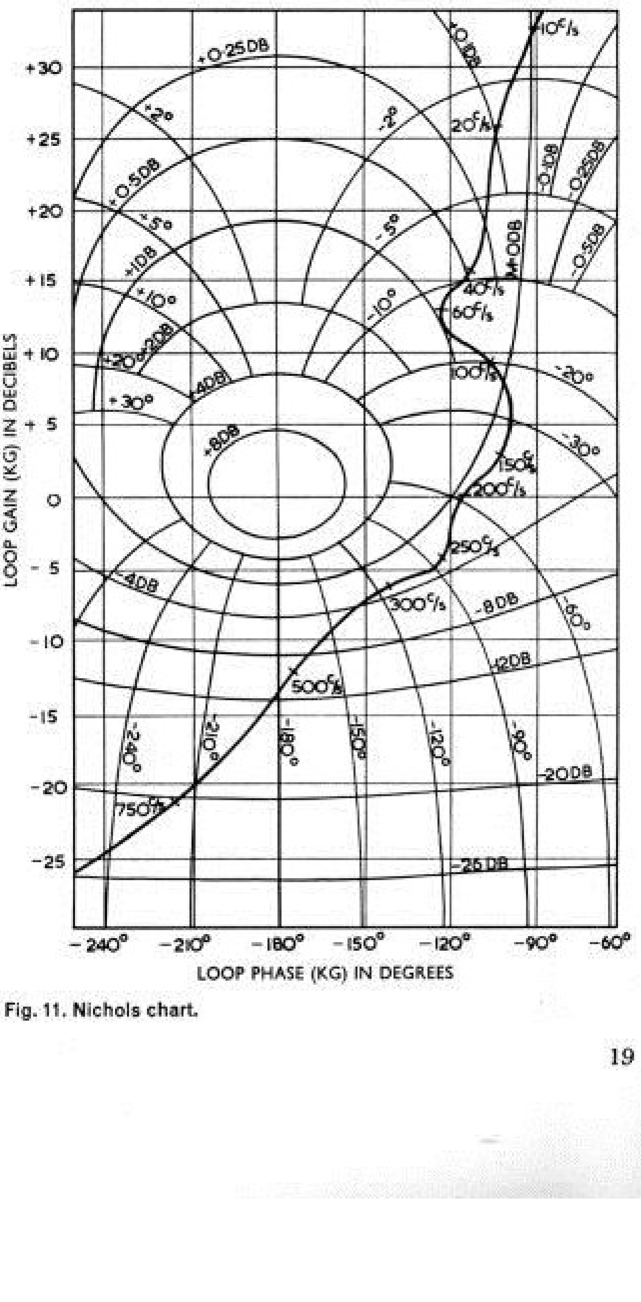

Fig. 11. Nichols chart.

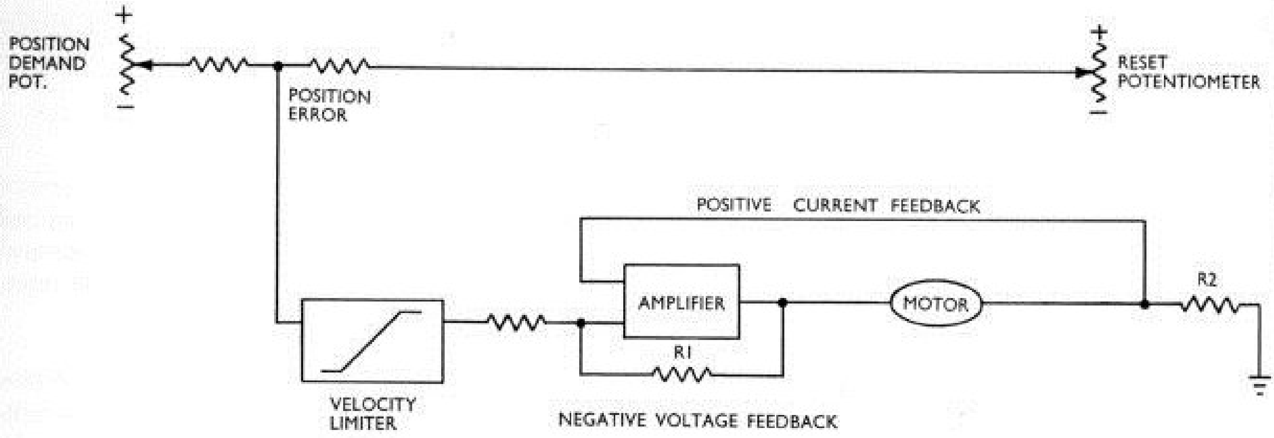

Fig. 12. Diagram showing velocity feedback.

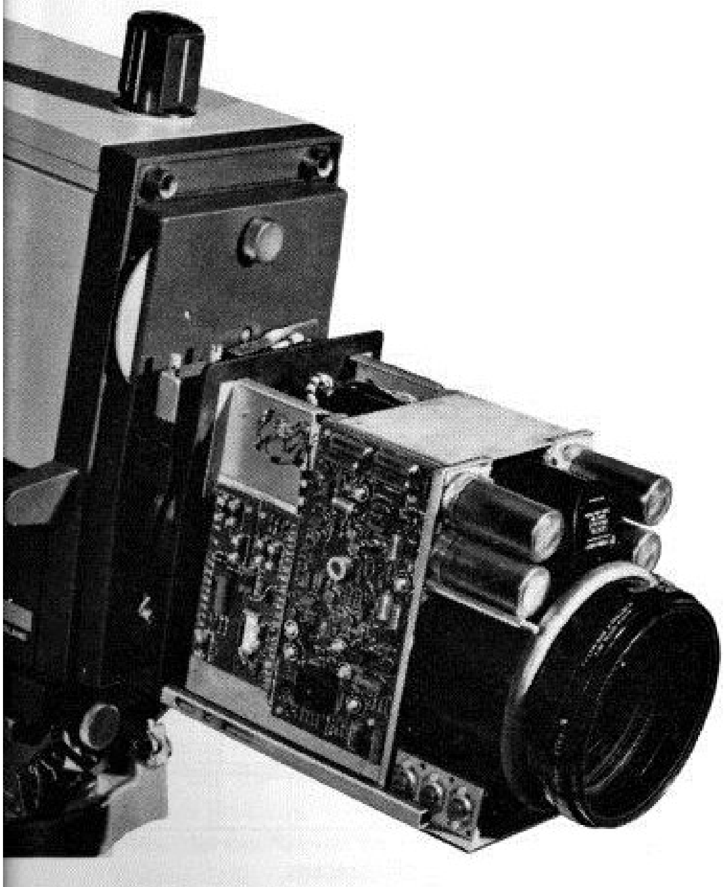

Fig. 13. Zoom package.

As the requirements of Iris are less stringent than those of Zoom and Focus, an unusual method of obtaining the velocity signal can be used.

The drive motor generates a back e.m.f proportional to speed. By using this back e.m.f the cost of a separate tachogenerator is saved (Fig. 12).

The negative feedback path via R1 provides the necessary velocity feedback but contains an unwanted component due to the current flowing through the resistance of the motor. This is neutralized by positive feedback of a voltage proportional to the motor current only, developed across the small resistor R2.

THE RESULT

The systems outlined above are the basis of the versatile and growing Sental range of control equipment specially designed for television. Married to the Marconi Mark V camera, the latest addition to the range, is the Varotal V SP incorporating Sental servos for controlling zoom, focus and iris. It is mounted on the camera by a new standard quick-latch mechanism developed jointly by Marconi and R.T.H. It weighs approximately 33 lb (15 kg) and consumes about 30 W.

Varotal V SP is equally suitable for studio and outside broadcasting and will operate continuously in ambient temperatures from −20°C to +55°C.

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REFERENCES

P. A. Merigold: *Sound and Vision broadcasting*, Vol. 5, No. 1, Spring 1964.
BBC Spec. TV140.
James Nichols and Phillips: Theory of Servo-mechanisms; McGraw-Hill Inc.