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AN AUTOMATIC MEASURING ENGINE USED FOR THE 35-MM FILM FROM THE DECLINATION CIRCLE OF THE OTTAWA MIRROR TRANSIT TELESCOPE

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AN AUTOMATIC MEASURING ENGINE USED FOR THE 35-MM FILM FROM THE DECLINATION CIRCLE OF THE OTTAWA MIRROR TRANSIT TELESCOPE

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ABSTRACT: An automatic measuring engine has been developed which is capable of measuring the 35-mm film from the declination circle of the Ottawa Mirror Transit Telescope. The accuracy of measurement is within 0.6 micron, which represents 0.1 second of arc on the declination circle. The rate of film measures is approximately four frames per minutes.

RÉSUMÉ: L'auteur décrit la conception et la construction d'un appareil automatique de mesure du film de 35 mm. qui sert à photographier le cercle de déclinaison du Cercle Méridien à réflexion d'Ottawa. La précision des mesures atteint 0.6 de micron près, ce qui représente 0.1 de seconde d'arc sur le cercle gradué. La vitesse de mesure du film est d'environ quatre photos à la minute.

Introduction

The declination circles of meridian instruments have usually been read with microscopes by an observer (McClenahan, *et al.*, 1951). Personal error, tedious observations, and the effects of the observer's body heat near the instrument necessitated the development of a photographic system which is remotely controlled. The concept of the Ottawa Mirror Transit Telescope has, from its inception, included a photographic system for the declination readout. It was decided, therefore, to develop a device which would measure the graduation lines on the film to the required accuracy. Other observatories (Watts, 1950; Naur, 1958) were engaged in similar activities at this time and it was decided to use their type of mechanical design from the outset.

A high measurement precision of the graduation lines necessitates a high contrast and sharpness of definition on the film. These factors can be realized only if the graduation lines on the circle have been engraved with utmost care and illuminated in the right direction with parallel light. There have been difficulties in obtaining a graduated circle with the qualities necessary for a photographic system.

There are several problems in measuring the distance between a graduation line inscribed on metal and a reference line. The first is the definition of the position of a graduation line. A line has two edges which are non-uniformly rough. If the roughness of the line can be resolved, the bisection of the area describes one definition of the centre of the line as a whole. For each section of a line a central line can be defined in the same way. The line of centroids along the length of the graduation defines a centre which is not necessarily straight. In this case, the definition must include another parameter: the distance from one end of the graduation. The inscribed graduations not only have rough edges but also have rough 'valleys'. The light which is reflected from the edges and from the inner parts of the graduation marks is therefore scattered in various and preferred directions. The position of the line is thus partly determined by the illumination.

A measurement of any graduation includes a reference or fiducial line which cannot be made arbitrarily sharp. In the case of the transit circle, the fiducial must remain in a fixed position relative to the moving graduation. In large instruments which are susceptible to temperature changes, expansions and contractions occur in the metals and the position of the fiducial is subject to error. There are several methods of construction and various selections of metals which can decrease these effects.

The distance between graduation and fiducial lines can be measured with greater precision by magnifying the images of both. The defects of the inscribed lines become larger upon magnification and there is thus a limit to the precision attainable. Ultimately the limit of precision depends on the sharpness of both graduation and fiducial lines.

— The measuring engine which would provide a readout of the distance measures should be easy to operate and, in the philosophy of the Ottawa design, should deliver its information to a tape punch for computer reduction and to an electric typewriter for editing purposes. The film should be easy to insert so that the same portion of the film strip is used each time. Control of the illumination intensity should produce consistent results from film to film. Since the contrast on different films will be non-uniform, the measuring engine should accept a wide range of contrasts. Because of the volume of star observations, the engine should provide the output in a short time. These considerations have led to an almost completely automatic measuring engine.

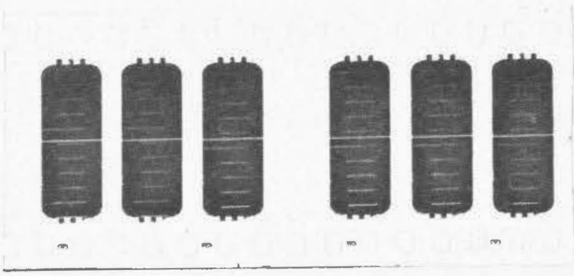

Figure 1. A typical section of 35-mm declination film (represents a 6X magnification of the 30-inch declination circle). The bright middle line on each frame is the fiducial mark. The small markings on the side of each frame designate the camera number. The film must be constrained in the film carriage so that identical sections of the graduation lines are measured on each frame.

Design Philosophy

The automatic measuring engine has been designed to measure the 35-mm film from the declination circle of the Ottawa Mirror Transit Telescope. Figure 1 illustrates a typical section of the film. The fiducial line, which is a fine wire fixed to a camera, is shown in the figure. The measuring engine is designed to provide a position readout of the fiducial line and of the adjacent graduation line on one side. When this has been completed the film is automatically advanced and the same measures are performed on the next frame. This procedure is carried out until there are no more frames left and all action ceases. Additional graduation lines can be measured in a semiautomatic fashion so that the scale of the film can be determined.

The engine operates on a phase-sensitive servomechanism principle and the output is available in both tape punch and typewriter form. The film is illuminated by an incandescent lamp which is perpendicular to the film surface (Figure 2). An image of the film is transferred by means of optics to a viewing screen and to an adjustable slit which is set wider than the image of the lines. At the slit, the light is divided and separated by a system of three prisms. The prisms are adjusted so that two beams are equally intense when the line is centred in the slit. The two beams then pass through a chopping wheel which cuts the light at a frequency of 60 Hz. The two beams of light then fall on a photocell which produces a signal of 120 Hz. This signal is preamplified and fed to a power amplifier which energizes the servomotor. The film carriage which supports the film and the film counter is coupled to the servomotor through a system of gear reductions. A complete servoloop is thus described. If the line which is being measured is not in the centre of the slit the resulting signal from the photocell will not be 120 Hz but will develop into 60 Hz. It is clear then that the line, as it is shifted about the centre of the slit position, will produce 60 Hz signals which differ in phase by 180 degrees. If the reference phase of the servomotor is set correctly it will stabilize at the middle of the line. Alternatively, the phase of the chopping wheel may be set to coincide with that of the motor.

A Coleman digitizer which reads the servomotor shaft position to one tenth of a revolution is attached to the servodrive. The number of counts between two graduation lines is

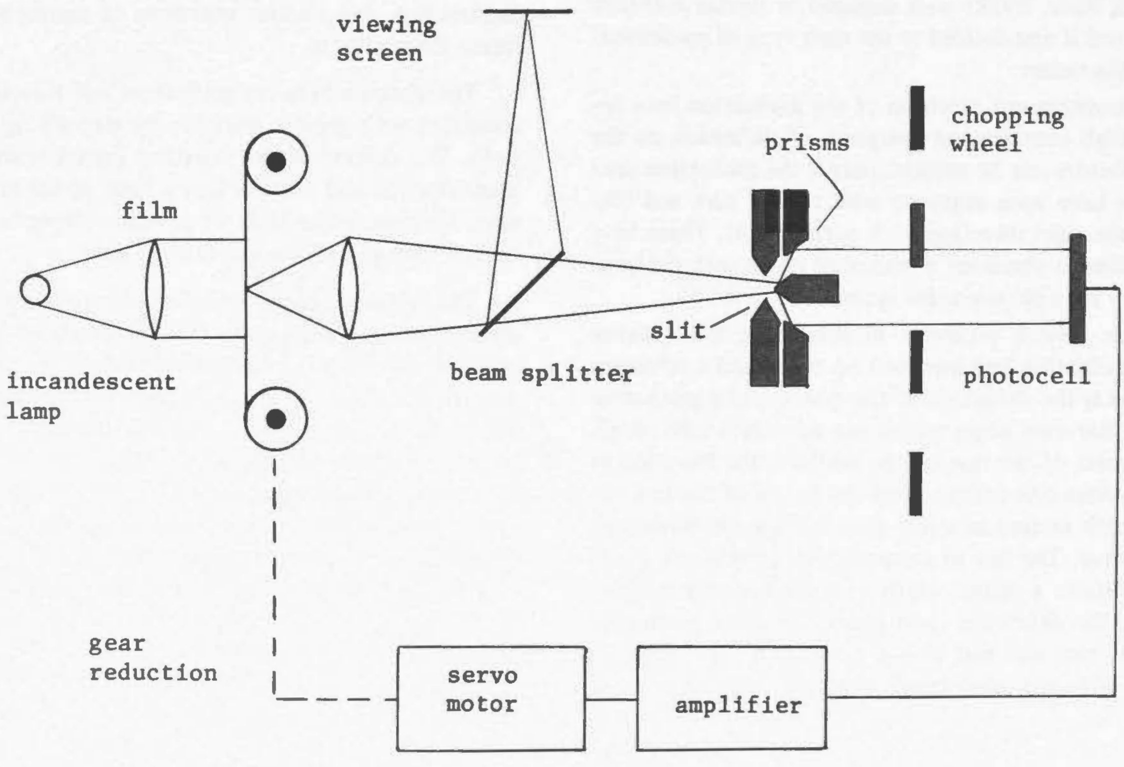

Figure 2. Block diagram showing the design philosophy used for the automatic measuring engine.

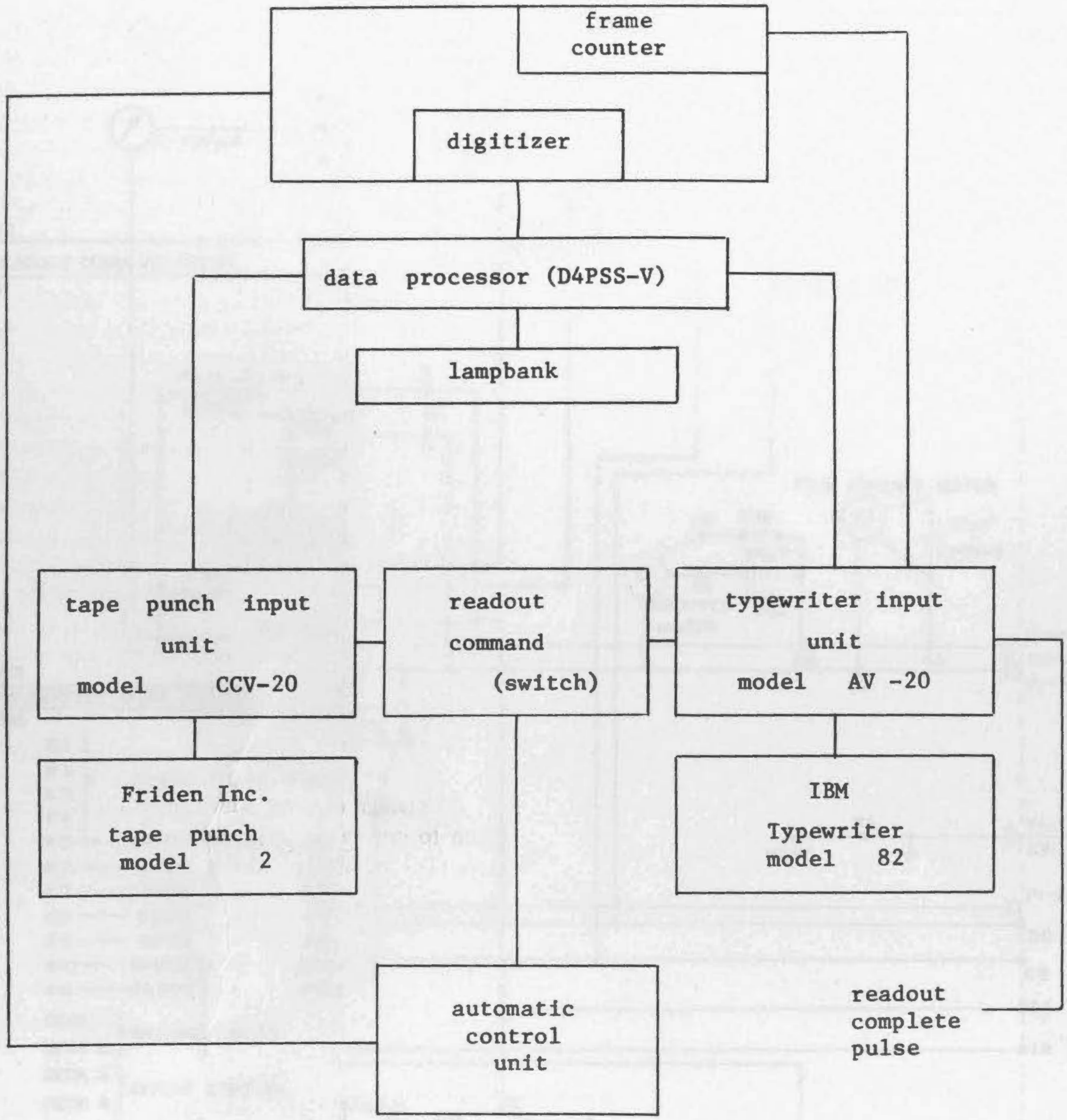

Figure 3. Block diagram showing the complete readout system.

approximately 5,800. The information of the shaft position is held in the memory of the data processor (Figure 3) until it is scanned by the typewriter and tape punch inputs. After completion of the readout the measuring engine advances to the next line and the servosystem settles on it and again readout ensues. The film advance motor is actuated and the next frame is in position to be measured.

The mechanical components of the engine are mounted on a rigid cast-iron surface. Most of the relays and associated electronics are located in a separate control chassis. D.C. power is supplied by a precision power source (HP/6265A) and the A.C. power is derived from a stable supply (HP/3907-15A). The film carriage can hold the film from one of the six declination circle cameras at a time.

Electrical Description

A description of the automatic operation of one cycle of measurement is as follows (Figure 4). There are four stages of operation: (1) return to zero, (2) delay and hunt at zero, (3) advance to line, and (4) delay and hunt at line. The sequence of measuring is started with the film carriage screw between the graduation line and the fiducial line. Relay K1 is closed after the manual mode is actuated and then the automatic mode is initiated. When relay K1 is closed a direct current goes via the normally open (n.o.) contact of relay K1-6 and the normally closed (n.c.) contact of relay K9 to the clutch, hence advancing the film. Direct current also goes to the delay circuit module. When the 100 μfd. capacitator in the film advance module has been charged sufficiently, the

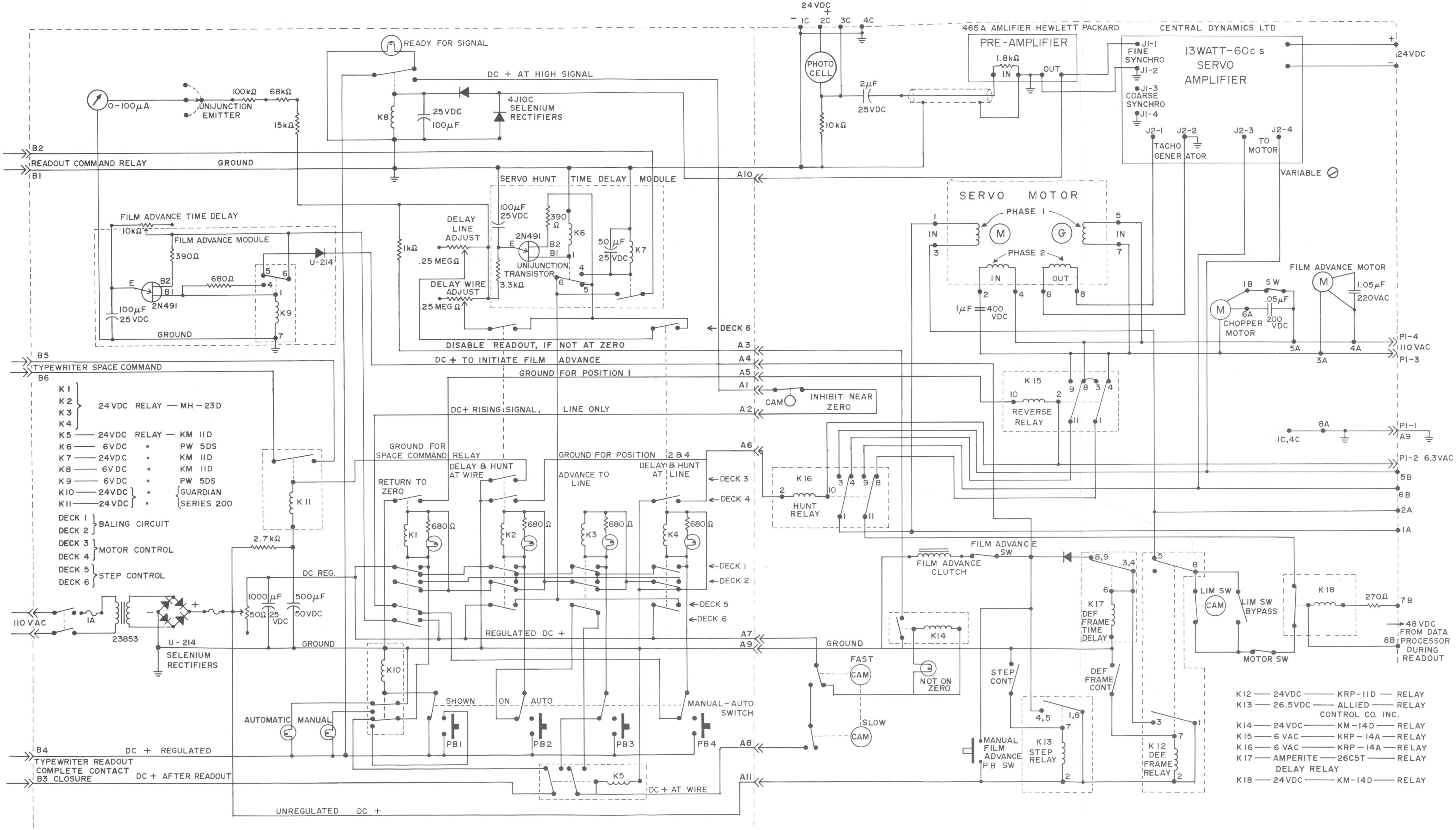

Figure 4. Automatic measuring engine control circuit.

unijunction transistor (2N491) fires and breaks the circuit. By this time the film step contact has been actuated and the clutch remains in operation until one frame has advanced and the step contact has been broken and hence relay K13. Relay K9 is latched by a 680-ohm resistor until stage one is finished. As the fiducial line is approached, relay K8 closes from the rising signal at the fiducial line but the 'inhibit near zero' cam-operated contact prevents passage of the direct current signal. When the fiducial line is reached, relay K5 is closed and direct current passes the n.o. contact of relay K5-1 via the n.c. contact of relay K3-5 to the trigger point of relay K2. Relay K2 is then latched and relay K1 is released. As relay K2 closes, the charge in capacitor C11 escapes into relay K11 closing relay K11 momentarily. The contact on relay K11 provides a circuit to actuate a 'space command' to the typewriter. The servosystem hunts for a balance position while direct current goes via relay K2-5 to relay K6; then to the n.c. contact of relay K6, and through relay K2-6 to charge the unijunction transistor capacitor through the 0.25 Meghom variable resistor. When the unijunction fires, relay K6 closes, sending direct current to the n.o. contact of relay K6 for a few milliseconds. This latches relay K7 which stays closed for about 100 milliseconds because of the storage capacitor. Deck one of relay K7 sends the readout command to the Coleman digitizer. The numerical position of the servosystem and the frame number is then read out to the typewriter while the tape punch receives only the servosystem position.

The voltage at the emitter of the unijunction transistor increases since the direct current through relays K5-1 and K3-5 restores relay K2; but before the unijunction can refire, the 'readout complete pulse' passes through the n.o. contact of relay K5-2 to the trigger point of relay K3, latching K3 hence breaking the relay K3-5 path to the trigger point of relay K2.

The servosystem runs to the graduation line, ignoring the rising signal as it leaves the fiducial line, but accepting the signal near the graduation line (through the n.c. contact of relay K1-5) which fires stage four. The servosystem hunts for a balance position while direct current goes via deck 5 of relay K4 to the unijunction time delay module as before. This time the delay is set by the 0.25 Megohm variable resistor in deck 6 of relay K4. Again the unijunction fires and readout follows. The readout complete pulse relatches relay K1 through the n.c. contact thus completing the cycle. As the servo leaves the graduation line, direct current from the rising signal is blocked by the n.o. contact of relay K1-5.

When a readout command is given, the information found by the digitizer is stored by the data processor and then the typewriter and tape punch inputs scan this information and feed it out to the typewriter and tape punch. The frame number information is derived from a frame counter and is scanned only by the typewriter input (Coleman digitizer handbook).

Precision of Measurement

There are several factors which directly influence the precision attainable with the measuring engine. The signal at the photocell and the resulting signal to the servomotor determine the torque which keeps the motor in a balanced position when the system is centred on a line. The relative phase of the reference frequency of the servomotor and that of the chopping wheel can be set so that the measuring engine settles on the centre of a line. An error in this adjustment results in different measures for the same two lines at different intensities of film illumination. Scratches near the graduation lines on the declination circle may alter the balance position of the servosystem if the resulting marks on the film lie within the slit width. If the film is not held securely in place (Figure 1) large random errors will occur. If the film does not have sufficient contrast, the servosystem cannot distinguish a line distinctly from the background and poor precision results. A nonstable source of A.C. effects a jittery balance position and the readout is therefore not stable. It is most important that the supply voltage for the photocell be extremely stable because any irregularities are amplified and fed directly to the servomotor.

The automatic measuring engine was set up to measure one frame repeatedly. Over 33 measurements the standard deviation was two units on the measuring engine which is equivalent to 0.6 micron on the declination film. The scale of the measuring engine unit is 3/58 micron and using this factor the uncertainty is 0.1 micron on the declination circle. Because the diameter of the declination circle is 30 inches, the equivalent angular standard deviation is 0.1 second of arc.

Listed below are some typical results as delivered by the electric typewriter. The same five frames were measured four times.

8701 01	8712 01	8700 01	8697 01
1679 01	1686 01	1676 01	1672 01
8697 02	8704 02	8691 02	8690 02
1683 02	1692 02	1674 02	1673 02
8669 03	8675 03	8659 03	8661 03
1758 03	1760 03	1745 03	1749 03
8730 04	8714 04	8713 04	8704 04
1808 04	1795 04	1792 04	1786 04
8791 05	8769 05	8758 05	8758 05
1906 05	1877 05	1882 05	1876 05

The accuracy of the measuring engine is not the final positional accuracy of a star in declination. Since the light from a star is reflected in the transit telescope mirror, the reading errors are doubled. Effects of eccentricity, the nonperpendicularity of the circle to the axis of rotation, and first terms of the circle's bending are averaged out in the three pairs of microscope readings. A complete analysis of the declination errors also utilizes information from the collimator measurements.

The rate of film measurement with the automatic measuring engine is approximately four or five frames per minute.

Discussion

The present photographic system is working reasonably well and a significant improvement has been achieved over the manual method; however, there is still a rather long delay before results can be tabulated. An improved system would observe the declination circle directly and the raw data would be available immediately. Photoelectric methods are being used at several observatories (Efimov and Otryashenkov, 1960; Lausten, 1967). A direct electrical system known as the "Inductosyn" (Farrand Controls Inc.) is presently undergoing experimental study at Washington (Klock, 1967). It is evident that the photographic system will have to be superseded by another method if any additional significant improvements are to be made. Any new system will have to be operated remotely and should not interfere with the declination circle in any way.

Acknowledgments

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