VOLUME I - FINAL REPORT

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FINAL REPORT

February 9, 1968

Progress Report for Period

23 November 1967 to February 9, 1968

STAT

File No. 11037

This document is presented as the Final Report under Contract to the U.S. Government, [redacted] STAT

In addition, the report represented herein covers the period 23 November 1967 to February 9, 1968.

[redacted] STAT

[redacted] STAT

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COMPUTER PROGRAM - SPECIFICATIONS AND INSTRUCTIONS

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ROUTING AND RECORD SHEET

SUBJECT: (Optional)

FROM:	EXTENSION	NO.
C/PP&BS/NPIC		DATE 7 March 1968

TO: (Officer designation, room number, and building)	DATE RECEIVED	DATE FORWARDED	OFFICER'S INITIALS
1. DDI Planning Officer 2E-45, Headquarters	8 Mar	8 Mar	JE
[redacted]	8 Mar	18 Mar	BE
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			

COMMENTS (Number each comment to show from whom to whom. Draw a line across column after each comment.)

Jay:

STAT

Per your telephone request of 6 March, attached is a set of the 3-volume final report covering Phase I of the High Precision Stereo Comparator Program. The Statement of Work for Phase II is contained in Part IV of Volume I.

It is my understanding that, prior to your call, [redacted] called STAT TS&SG directly. A copy of the attached was sent to [redacted] STAT by TS&SG on the afternoon of 6 March.

According to [redacted] STAT [redacted] was particularly STAT interested in the computer aspects of the comparator. Volume III deals with computer program specifications and instructions.

TS&SG would appreciate the return of the three volumes when you have completed your review.

ESC

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PART I

PART I

DESCRIPTION AND OPERATION OF THE STEREOCOMPARATOR

INTRODUCTION

The [redacted] Ultra High Precision Stereocomparator is a highly sophisticated tool for use in stereo analysis of aerial photographs. The machine combines in one instrument facilities for overall viewing, variable magnification, binocular viewing, and stereo presentation, together with capability for measurement with submicron accuracy. In addition, the machine aids the operator's measuring task by automating the job of stereo tracking. Every consideration has been given to operator comfort, convenience, and speed; the resulting machine represents the optimization of human-engineering in combination with state-of-the-art accuracy. STAT

The major functions of the Stereocomparator include:

1. Measuring and detecting image position to submicron accuracy.

2. Simplified (and in some cases semiautomatic) accessing of corresponding regions of the film to produce stereo pairs.

3. Providing ability to see detail on the film compatible with measurement precision.

4. Seeing the converted equivalent regions in variable magnification for best interpretability.

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5. Converting these regions optically into stereo views.

6. Superimposing equivalent points on the photographs.

7. Providing data output for external processing into actual ground measurements and dimensions.

SYSTEM CONFIGURATION

The photograph included as the Frontispiece to this report shows an overall view of the machine. The major assembly of the machine is the unit containing the measuring engines, optics and lighting systems, and operator console. In addition to the main assembly, the system contains three double-bay Electronic Equipment Cabinets, a double-bay Utilities Control Cabinet, and an auxiliary Machinery Room in which are located the various compressors, vacuum pumps, cooling equipment and other support functions for the machine. In order to aid discussion of the system, each of these major assemblies will be discussed separately.

A. Main Assembly

The main assembly is comprised of the following elements:

1. Measuring Engines: The measuring engines are constructed of granite blocks for thermal stability. The base of each engine is a monolithic block which has the top surface lapped flat to within .000050 inch. A hole in the middle of the block allows light from the illumination system to pass up to the film plane, and various inserts are placed in the block to mount the engine drives, etc. A granite tee is used as an intermediate stage and is driven along one axis relative to the base. The top stage is guided by the tee and is driven relative to it in a direction orthogonal to the driven axis of the tee. In this manner a complete X-Y Cartesian system of motion is obtained. All movable granite pieces float on extremely stiff air bearings for high

accuracy and low friction. The stages are driven by a special Threadless Leadscrew (TLS) arrangement. The TLS offers excellent control and negligible backlash. Non-cogging printed-circuit DC motors furnish drive power to allow a 16,000:1 range of engine speeds.

Attached to the measuring stages are the film drive units. These drives are used to transport the film to the desired frame or to rewind the film. The drive accommodates up to 500-foot reels of film of any width from 70mm to 9.5 inches. Constant tension is maintained on the film under all operating conditions, and a transport speed range of from zero to 250 feet per minute is provided.

The film platen is a special glass optical flat for low distortion and uniform focus. Attached to the platen is a specially made vacuum-clamping system which achieves extremely rapid pulldown and release. Control over the clamping system is synchronized with film transport action to provide safe, convenient handling of the film under all circumstances.

In order to provide overall viewing facilities, built in light tables are included on the measuring engines. By merely pushing a button, the operator can cause the measuring engines to travel to their inboard forward limits, thereby placing the films adjacent to the operator's chair. Console controls allow adjustment of the cold-cathode tubes to secure a range of lighting levels.

The submicron measuring capabilities of the measuring engines are made possible through the use of advanced laser-interferometer systems. A pair of servo-stabilized CW Neon-Helium lasers supply the reference wavelength, and interferometers count interference fringe pattern movements derived from a comparison of stage position with a fixed reference mirror. Extreme precision, reliability, and simplicity of adjustment make this linear measuring system most effective. The least count of the interferometer system itself is 0.16μ , but by using proprietary [redacted] count conversion equipment, a display and output STAT least count of 0.1μ is obtained.

2. Optical Bridge: The optical bridge contains the various lenses and drive assemblies which provide the controlled distortions necessary to rectify the photograph geometry for stereo. Additional equipment is included to allow injection of a floating reticle spot for measuring purposes. Since the reticle is injected into the optical path as close as possible to the film plane (for utmost measuring accuracy), it is necessary to predistort the reticle image in a manner complementary to the distortion introduced by the main viewing optics in order to maintain a uniform reticle shape and size at the eyepieces. This is accomplished by means of servo-controlled follow-up systems in the reticle projector area in the optical bridge. Additional equipment in the optical bridge includes the image dissector scanning assemblies used for image analysis and correlation, and various photomultiplier tubes and shutters which control the light levels in the system.

The optical bridge itself is fabricated of heavy Meehanite castings to provide an extremely rigid structure which is relatively stable with time and temperature. The cross-sectional areas of the members are sufficiently large to keep deflections within extremely small limits.

The optical elements are fabricated into smaller subassemblies which can be tested as integral units. These subassemblies are doweled and bolted into place to assure precise alignment of the optical axes.

The main viewing elements situated in the optics bridge are:

a) the viewing zoom, which has a 10:1 range

b) the objective changeover system, which has 1X and 2X lenses (to give the machine a total range of 10X to 200X) and also contains the focusing mechanism

c) the anamorphic elements which can be varied from 1:1 to 2:1 and stretch axis aligned over a continuous range

d) the image rotator system, which is also continuous.

The reticle projectors housed in the optics bridge complement the main viewing optics to obtain round reticle floating spots. A 75 watt arc lamp is housed in the optics bridge for the reticle illumination source.

The binocular eyepiece assembly mounts onto the optics bridge also. This assembly contains the various prismatic elements used to accomplish reversal of views (left to right eye, etc.) and to provide binocular viewing when desired. Also incorporated in the assembly are the variable-density filters used to adjust the eyepiece brightness level and the high-speed safety shutters for eye protection. Micro-switches activated by the prism changeover mechanism alter the computer program and operator controls to take into account the various optical presentations at the eyepieces.

3. Operator Control and Display Console: This assembly contains all of the normally-used operator controls. The upper portion of the console is a display panel which contains the readout Nixie tubes showing the X and Y coordinates of the two measuring engines (in .1μ units) and meters which show the settings of elements in the optical trains. In addition, four sets of thumbwheel switches are incorporated to allow presetting of the stage Nixie readouts to any desired numbers.

Pushbuttons are provided to allow the stage position displays to be reset to zero, preset to the thumbwheel number, and to have the count direction (sense of the axis) reversed.

Potentiometers are positioned on the display panel to allow the Image Analysis System to be zeroed to reference points.

The lower portion of the Operator Display and Control Console contains the pushbuttons and control devices used to operate the machine. A 180-button keyboard is centrally located to control the operation of the computer, data output, and miscellaneous functions.

Stage motion is controlled by a dual-range joystick which is switchable to either or both stages and by a pair of trackballs which are used for fine positioning. The optical elements can be manually positioned by using dual-speed bi-directional velocity control knobs placed conveniently around the trackball areas. Logic in the machine switches the controls so that the operator is not confused during reverse stereo operation. The computer performs rotations on the track-ball and joystick signals, so that in all cases the images appear to move in the direction in which the operator moves the control element.

The platen illumination power and intensity controls are also located on the operator console. A pair of joysticks used to control film transport motion are located on the front surface of the console for convenience.

4. Main Frame: The main frame is constructed of extremely heavy box sections for utmost rigidity. The granite measuring engine bases and optical bridge are mounted directly to this frame. Under and within the frame are servo-controlled pneumatic shock mounts. The entire weight of the main assembly rests upon these mounts, so that the whole machine is isolated from floor vibration. The Operator Control and Display Console is not supported on the mounts, and is in fact isolated structurally from the main assembly. Since the operator's headrest at the eyepieces is mounted to the Operator Console, it follows that the main assembly is entirely isolated from disturbances caused by the operator's manipulation of the controls.

The high-intensity 450 watt arc lamps supplying the main illumination and the dual-range variable condenser systems are mounted to the frame under the measuring engines also. This optical arrangement allows illumination of only the area covered by the viewing system for maximum efficiency and constant illumination level. Control of this equipment is fully automatic.

B. Electronic Equipment Cabinets

There are three such cabinets in the system. Electronics Cabinet Number One contains the servo and test equipment used for the measuring engine drives and film drives. Electronics Cabinet Number Two contains the servo equipment used in the optics drive systems and illumination control systems. Electronic Cabinet Number Three contains the internal computer, all digital logic, punch control, output data link, counters, Image Analysis Equipment, laser power supplies, and interferometer controls. All of the electronics equipment is designed for maximum reliability and serviceability.

C. Utilities Control Cabinet

This is a double-bay cabinet similar in appearance to the Electronic Cabinets. In it are contained the pneumatic controls for the stage air bearings, various air filters and regulators, pressure switches, and solenoids. Electrical controls and equipment contained in the Utilities control Cabinet include the circuit breaker panels for the machine, tally lights to indicate equipment status, arc lamp power supplies, and various alarm and malfunction circuitry and interlocks.

D. Machine Room

This room contains various air compressors, vacuum pumps, cooling systems, and support equipment for the machine.

STAGE CONTROL

Position (motion) of the two measuring engines may be directed by means of a joystick and two trackballs. Four pushbuttons marked - JOYSTICK LEFT, JOYSTICK RIGHT, JS./TB. BOTH, and TRACKBALLS INDEPENDENT - allow selection of which stage(s) is controlled by which control(s). The JS./TB. BOTH may be selected by itself or in conjunction with any one of the other three pushbuttons. In addition, the TRACKBALLS INDEPENDENT may be selected in conjunction with either JOYSTICK LEFT or JOYSTICK RIGHT, in which case the JS./TB. BOTH pushbutton is reset (not selected). In either the MANUAL mode or the ENTER mode, direction of stage control by these buttons is straightforward. With JOYSTICK LEFT (or JOYSTICK RIGHT) the left (right) stage only moves in response to deflection of the joystick. With JS./TB. BOTH selected, and neither JOYSTICK LEFT nor JOYSTICK RIGHT selected, the two stages move in unison as directed by the joystick. With the TRACKBALLS INDEPENDENT pushbutton selected, the left stage is controlled by the left trackball, and the right stage is controlled by the right trackball. With JS./TB. BOTH selected and TRACKBALLS INDEPENDENT not selected, both stages move in unison in response to rotation of either trackball. In MANUAL mode or ENTER mode, direction and velocity of the selected stage(s) are proportional to deflection of the selected control(s). Thus in these two modes neither eyepiece viewing mode or settings of the optical elements causes any modification of stage control.

In AUTOMATIC mode and in AUTOMATIC WITHOUT ELECTRONIC CORRELATION mode, direction and velocity of the selected stage(s) in

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response to deflection of a stage control is modified in accordance with settings of the optical elements in such a way that the image viewed in the appropriate eyepiece appears to move as directed by the control. Actual stage motion in this case may be quite different than deflection of the control would otherwise indicate. In these two modes, also, the eyepiece viewing mode affects the way in which the four pushbuttons referred to above direct stage control.

In the two automatic modes, stage control direction is as follows:

1. JOYSTICK LEFT selected - Left stage only is controlled by the joystick in all cases except that REVERSED STEREO selected results in the right stage only being controlled by the joystick.

2. JOYSTICK RIGHT selected - Right stage only is controlled by the joystick in all cases except that REVERSED STEREO selected results in the left stage only being controlled by the joystick.

3. TRACKBALLS INDEPENDENT selected - Left stage is controlled by the left trackball and right stage is controlled by the right trackball in all cases except that REVERSED STEREO selected results in the left stage being controlled by the right trackball and the right stage being controlled by the left trackball.

4. In cases where both stages are being simultaneously controlled by the joystick or by either trackball the eyepiece viewing modes have no effect on stage control. Thus, in either of the binocular viewing modes, the stage which is not being viewed moves along with the one which is, just as though the two were being viewed

in stereo. Stage tracking is exactly the same for REVERSED STEREO as it is for NORMAL STEREO.

5. When both stages move simultaneously under direction of one control, the modification of direction and velocity by settings of the optical elements (once the latter have been adjusted so as to establish a stereo model) is such that approximate stereo tracking of the two stages will occur, at least over a short distance. If stage tracking errors creep in, then the latter may be manually corrected by using one of the individual stage control options. Thus a convenient mode of operating would be as follows: With the JS./TB. BOTH push-button and the TRACKBALLS INDEPENDENT pushbutton both selected, common stage tracking may be directed by the joystick and stage tracking errors may be corrected with the trackballs. An alternate mode would be with the JS./TB. BOTH pushbutton and the JOYSTICK LEFT (or JOYSTICK RIGHT) pushbutton both selected. In this case, either trackball would control common stage tracking and the joystick would permit correction of tracking errors.

6. In the AUTOMATIC WITHOUT ELECTRONIC CORRELATOR mode, the computer repeatedly computes a stage to stage transformation whereby it attempts to correct (prevent) tracking errors. This transformation type of stage control produces the effect of motion in a stereo model of a geometric plane surface which represents the local region of the ground surface. So long as the operator directs the stages by either of the both-stages by-one control modes he may direct the floating dot to any point in this plane surface. To move the floating

dot out of this plane surface, the operator may either use the trackballs in the TRACKBALL INDEPENDENT mode or he may use the joystick in the JOYSTICK LEFT or JOYSTICK RIGHT mode. Using the stage controls in any of these independent stage control modes signals the computer to discontinue tracking in the plane surface and allows the operator to direct the floating dot to any point in the stereo model. The operator may then, if he so wishes, direct resumption of tracking in the previously established plane surface, simply by using the joystick or either trackball in the mode which calls for the selected control to drive both stages together. Note that switching in and out of the tracking mode is controlled directly by the joystick and trackballs without requiring that any of the mode selecting pushbuttons be changed.

While in the AUTOMATIC WITHOUT ELECTRONIC CORRELATOR mode, the operator may initially establish a tracking plane surface, or later establish a new (different) plane for tracking as follows:

a. Using the joystick or trackballs in the respective mode for independent stage control successively move to each of three points through which it is desired to have the tracking plane pass.

b. While located at each of these three points operate the pushbutton marked REORIENT to notify the computer that the floating dot is at a point in the desired tracking surface. After three such points have thus been established, the operator may direct tracking in a plane through these three points by operating a stage control in its respective common stage drive mode.

After a tracking plane has been established, the operator may also produce the effect of shifting the tracking plane without changing its slope. This is done by operating either the trackballs or the joystick in an independent stage mode to locate on one desired point outside the tracking plane. While on this point, the operator depresses the pushbutton marked REORIENT. The operator now uses the joystick or a trackball in a common stage control mode and the computer produces tracking in the plane through the selected point, but parallel to the previous tracking plane.

It should be noted that computer control by means of the transformation described above is possible only in cases in which complete information is available regarding the position, orientation, velocity, etc., of both camera stations.

7. In the AUTOMATIC (with electronic correlator) mode operation appears much as was described under 6, but tracking errors are avoided by an electronic correlator (Image Analysis System) instead of by a computed transformation. In this case, however, the operator is not able to directly select the particular tracking surface which is followed. The tracking surface is determined by the correlator based on images formed on its two Image Dissector tubes. The operator can sometimes exert an indirect influence on the tracking surface followed by adjusting the scale factor control, thus limiting the images being correlated to certain features within a restricted field of view. Otherwise the operator may direct motion out of the correlation surface by operating the trackballs or joystick in an

independent stage control mode. Similarly, the operator may direct tracking in the correlation surface by operating the joystick or one of the trackballs in a common stage control mode.

OPTICS CONTROL

The Stereocomparator has two optical trains, each of which may modify the image of its respective photograph in the following four respects: magnification, rotation, anamorphic expansion, and direction of anamorphic expansion. Eight five position switches on the control console allow the operator to adjust the extent of each of these optical transformations to any value in the available range. Each switch operates as a velocity control of one particular element (zoom lens, image rotator, etc.). The five positions are for no change (neutral) and for high or low speed adjustment in either direction, with spring return to the neutral position (center). Besides these major controls, there are also a number of incidental controls (brightness, focus, size of reticle, etc.). The latter will not be discussed here, however.

If either the MANUAL mode or the ENTER mode has been selected, then all eight of these controls are operable at any time the operator wishes to modify the setting of any optical element.

In either of the AUTOMATIC modes, however, all of the above switches except the two controlling magnification are normally inoperative. This is because the computer (with or without help from the correlator) is controlling the optics so as to maintain a stereo model automatically. Nevertheless the operator may modify the scale factor of the stereo model with either magnification control (i.e., either control causes both zoom lens to increase or decrease at the proper relative rate so the stereo model is not destroyed).

In the AUTOMATIC modes, the operator may temporarily take manual control of the optics elements by selecting the OPTICS INDEPENDENT pushbutton. Whenever this button is selected, the computer exerts no control of the optical elements and the eight switches mentioned above operate just as they do in the MANUAL and ENTER modes. If, however, the operator remains in the AUTOMATIC mode, and simply resets the OPTICS INDEPENDENT button, then the computer resumes automatic control of the optics from the settings which existed at the time this button was selected (i.e., the computer cancels out the manual adjustments which were made in the interim).

In the AUTOMATIC modes, the computer (with or without help from the correlator) is directing the various optical elements by incremental drive commands. Hence, the actual settings of the various elements are effectively the integrals of the past incremental commands. The operator can at any time establish new additive constants for these integrals. This is done by using the OPTICS INDEPENDENT button to take manual control as was described in the preceding paragraph. Having set the optics as he desires, the operator does not now reset the OPTICS INDEPENDENT button. Instead, he selects the REORIENT button. The computer then reads the settings of all the optics elements and resumes incremental control. The incremental control this time, however, proceeds from the new settings. The computer itself resets both the REORIENT and the OPTICS INDEPENDENT button in this case.

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Thus there is provision for the operator to control the optics manually whenever he desires, and provision for the computer to take control when directed to do so by the operator. The computer may be directed either to resume control from an earlier group of settings which it has remembered, or to resume control from the new settings which the operator has established.

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AUTOMATIC STAGE TRACKING

It is convenient to refer to one measuring stage as the "master" stage and the other as the "slave" stage. In stereo tracking the master stage is controlled so as to follow the operator's control commands in a relatively direct fashion. The slave stage is controlled so as to take positions corresponding to the master stage as required to produce the stereo model. For each position of the master stage, the proper corresponding position of the slave stage is determined by the computer assisted by the Image Analysis System (electronic scanning and correlation system).

At any instant the computer has values in some of its registers for positions for both stages. For the master stage these values result from integrating all past image motion commands from the operator (via the joystick and/or trackballs), after first transforming these in accordance with the settings of the master optics. For the slave stage these values result from integrating the master stage motion commands transformed as required to maintain stereo. The method of computing these values is discussed in Part III under Task 43.

Periodically the computer compares its computed values for intended stage positions with the actual stage positions (as read from the stage position registers). The differences in these values are output to the stage position servo systems which run so as to reduce the amounts of these differences toward zero. Because the stage speeds and accelerations cannot be infinite the actual stage positions generally follow the computed positions with some time lag. At this point it is well to examine the nature of this time lag for each stage.

For simplicity each stage will be treated like a one axis servo system. Both stages actually have two similar axes with inter-related position commands. Nevertheless, one axis approximations will give sufficient insight into the nature of the time lags.

Let Δw represent the image position increment read from the joystick or one of the trackballs in some particular sampling period. Let $\Delta x_1 = \Delta w/M_1$ and $\Delta x_2 = \Delta w/M_2$ represent the corresponding position increments for the master and slave stages, where M_1 and M_2 are the magnifications of the master and slave optical trains. Since the computer integrates these position increments we may represent the Laplace transforms by

$$sX_1 = sW/M_1$$

and

$$sX_2 = sW/M_2.$$

Figure I shows a simplified block diagram of the two servo systems, the electronic correlator and the computer. This diagram is drawn according to the usual conventions for representing the Laplace transforms of a set of differential equations. From Figure I it is evident that

$$Y_1 = \frac{A_1 s_1}{s^2 + s_1 s + A_1 s_1} \frac{W}{M_1}$$

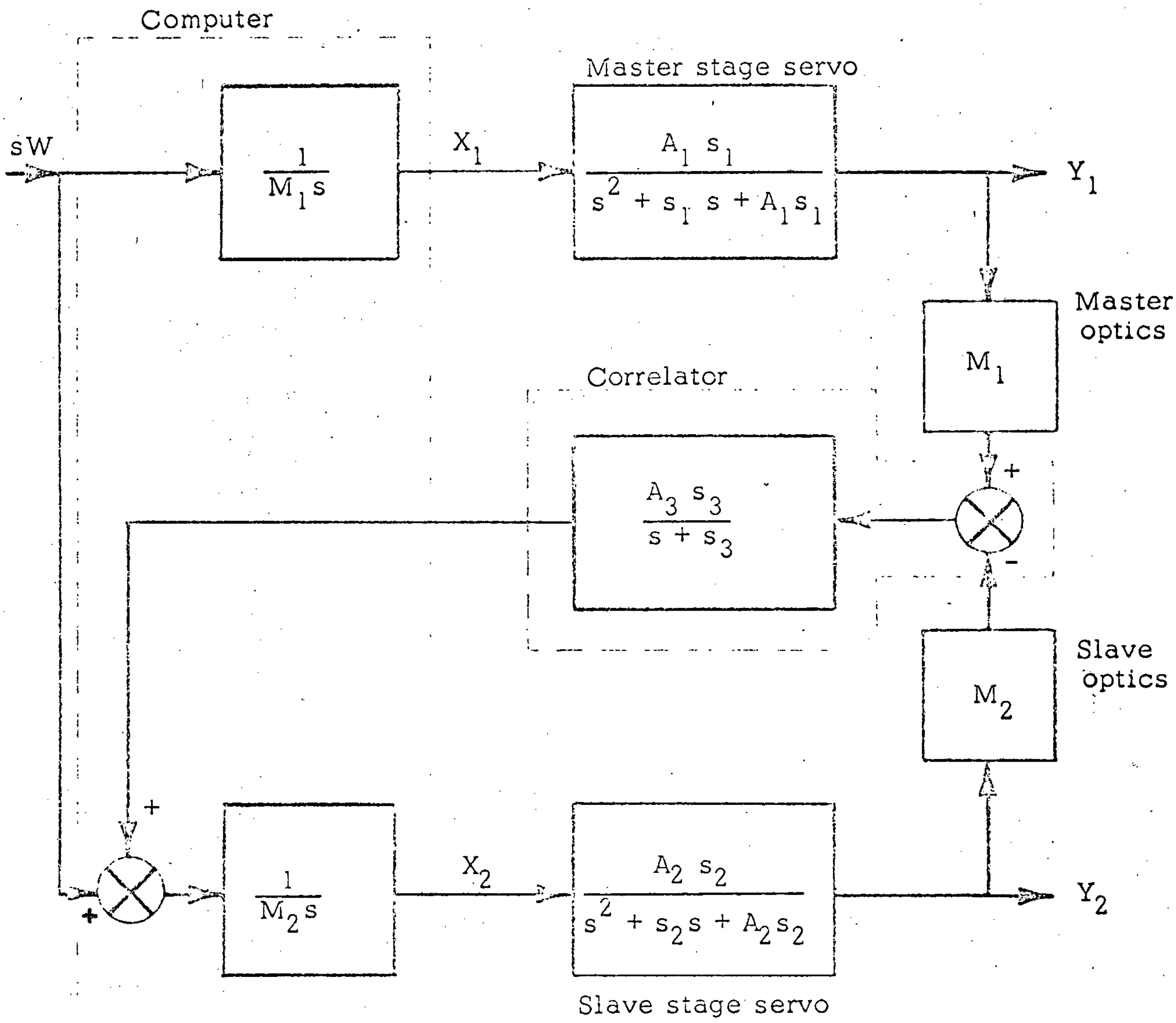

Figure I. Block diagram of the stage tracking system.

sW is the incremental input from the joystick or a trackball. Y_1 and Y_2 are the positions (one axis only considered) for the master and slave stages. A_1, A_2, A_3, s_1, s_2, and s_3 are real constants, and s is a complex number corresponding to frequency.

and $$Y_2 = \frac{A_2 s_2}{s^2 + s_2 s + A_2 s_2} \left[\frac{W}{M_2} + \frac{A_3 s_3}{M_2 s (s + s_3)} (M_1 Y_1 - M_2 Y_2)\right]$$

$$= \frac{A_2 s_2 \left[s (s + s_3) \frac{W}{M_2} + A_3 s_3 \frac{M_1}{M_2} Y_1\right]}{s (s + s_3)(s^2 + s_2 s + A_2 s_2) + A_2 s_2 A_3 s_3}$$

The expressions

$$\frac{A_1 s_1}{s^2 + s_1 s + A_1 s_1}$$

and $$\frac{A_2 s_2}{s^2 + s_2 s + A_2 s_2}$$

for the two servo systems would be identical if the two systems were perfectly matched. They are shown different for generality but numerical differences between the two are, in fact, quite small. From tests on the stage mockup it has been found that reasonable numbers are as follows:

$$s_1 \cong s_2 \cong 100$$

$$A_1 \cong A_2 \cong 50$$

corresponding to an 8 hertz bandwidth. The expression

$$\frac{A_3 s_3}{s + s_3}$$

for the correlator includes an undetermined constant A_3 and the angular frequency response which is given in the Itek report* as about 1 over 50 milliseconds - i.e., 20 radians per second. Thus the denominator

* XI [redacted] Final Report page 20 STAT

$$s\,(s + s_3)\,(s^2 + s_2 s + A_2\, s_2) + A_2\, A_3\, s_2\, s_3$$

is $$s\,(s + 20)\,(s^2 + 100\,s + 5000) + A_2\, A_3\, s_2\, s_3.$$

Study of this shows that it is reasonable to make the constant $A_2\, A_3\, s_2\, s_3$ about 300 000 in which case the roots are -4.09, -14.5, and -50.7 ± i 49.8. The root -4.09 is close to zero, indicating slow response. By making $A_2\, A_3\, s_2\, s_3$ larger than 300 000, the corresponding root is caused to move away from zero, i.e., in the direction of faster response. In the latter case the root corresponding to -14.5 moves toward zero and there is a limiting case with the two real roots coinciding. If the constant $A_2\, A_3\, s_2\, s_3$ is made still larger then the two roots corresponding to -4.09 and -14.5 become complex and the response is unstable for practical purposes. Thus the constant $A_2\, A_3\, s_2\, s_3$ should be as large as practical without having these two roots become complex. Because the theory is only an approximate representation of the actual physical situation it is desirable to allow a substantial margin of safety. Practically speaking, 300 000 is probably about as large as it's wise to go.

The foregoing discussion shows that the slave stage transfer function (including the effect of the correlator) has, in addition to a pair of complex poles close to those which apply for the master stage transfer function, two real poles which are approximately

$$-4.09 \text{ and } -14.5.$$

It will now be shown that the latter two poles essentially apply only to the portion of Y, which is not given by the expression for the master stage. Thus, let:

$$Y_1 = \frac{A_1 s_1}{s^2 + s_1 s + A_1 s_1} \frac{W}{M_1} + Y_0$$

where Y_0 corresponds to a difference (x-parallax) in the pictures on the two stages. This difference must be adjusted primarily by the correlator since the computer cannot predict such a difference. When this value of Y_1 is substituted in the expression for the slave stage, the result becomes:

$$Y_2 = \frac{A_2 s_2}{s^2 + s_1 s + A_1 s_1} \frac{s(s + s_3)(s^2 + s_1 s + A_1 s_1) + A_1 A_3 s_1 s_3}{s(s+s_3)(s^2 + s_2 s + A_2 s_2) + A_2 A_3 s_2 s_3} \frac{W}{M_2}$$

$$+ \frac{A_2 A_3 s_2 s_3}{s(s + s_3)(s^2 + s_2 s + A_2 s_2) + A_2 A_3 s_2 s_3} \frac{M_1}{M_2} Y_0$$

Since $A_1 \cong A_2$ and $s_1 \cong s_2$ this is approximately

$$Y_2 = \frac{A_1 s_1}{s^2 + s_1 s + A_1 s_1} \frac{W}{M_2} + \frac{A_2 A_3 s_2 s_3}{s(s + s_3)(s^2 + s_2 s + A_2 s_2) + A_2 A_3 s_2 s_3} \frac{M_1}{M_2} Y_0$$

The first term on the right side of this expression is identical with the expression for the master stage and represents the slave stage response to operator commands. The second term shows the response to differences in the two pictures as detected by the correlator. As stated above, the second part contains time lags which are in addition to those contained in the first part.

The foregoing analysis did not allow for possible time lags directly in the optical systems. Figure II shows a generalized equivalent of Figure I which provides for such possible time lags (insofar as they can

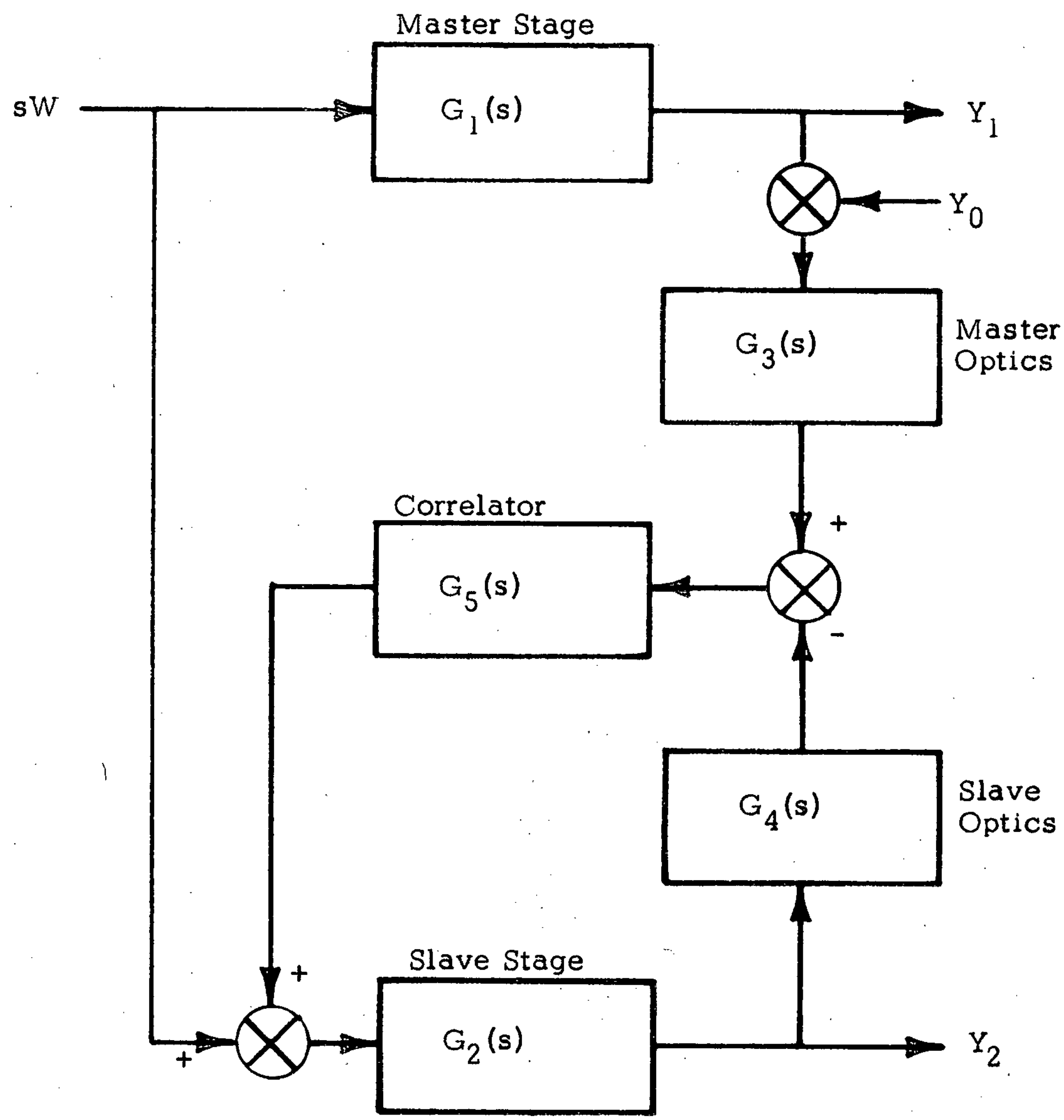

Figure II. Generalized block diagram corresponding to Figure I.

be treated by linear theory). G_1 (s) and G_2 (s) are the transfer functions for the master and slave computer-stage servos. G_3 (s) and G_4 (s) are hypothetical transfer functions for the master and slave computer-optical systems. G_5 (s) is the transfer function for the correlator. The functions G_3 (s) and G_4 (s) are not the basic transfer functions of the optics servos per se but are functions which allow for the fact that stage motion may generate signals which call for readjustment of the optical system settings. Such readjustment may produce an indirect effect on the stage position depending on the particular pictures which are on the stages. Thus there may be additional time lags due to the readjustment of the optical system settings but the effect on the stage servo response should be small.

From Figure II we write the following relations:

$$Y_1 = G_1 (s) sW$$

and $$Y_2 = G_2 (s) [sW + G_5 (s) (G_3 (s) Y_1 + G_3 (s) Y_0 - G_4 (s) Y_2)]$$

These may be written in the form

$$Y_1 = G_1 sW$$

$$Y_2 = \frac{G_2 [sW + G_3 G_5 (Y_1 + Y_0)]}{1 + G_2 G_4 G_5}$$

Substituting the first in the second gives

$$Y_2 = \frac{G_2 [sW + G_3 G_5 (G_1 sW + Y_0)]}{1 + G_2 G_4 G_5}$$

$$= G_2 \frac{1 + G_1 G_3 G_5}{1 + G_2 G_4 G_5} sW + \frac{G_2 G_3 G_5}{1 + G_2 G_4 G_5} Y_0$$

Thus, if $G_1 (s) \cong G_2 (s)$ and $G_3 (s) \cong G_4 (s)$, the response of the slave stage to operator commands (sW) is substantially the same as the response of the master stage. On the other hand, the response of the slave stage to differences in the two pictures (Y_0) has additional time lags which are now seen to result from the optical systems as well as from the correlator. As stated before, however, the additional effect of the optics systems on these time lags is not very great.

Some of the foregoing statements were made rather loosely and were given without proof. This was for the sake of readers who might not care to go into all the details. The following treatment covers the same ground but with more detail.

On page 20 the following expression was given for the master stage response

$$Y_1 = \frac{A_1 s_1}{s^2 + s_1 s + A_1 s_1} \frac{W}{M_1},$$

shown with the general operator command function (W(s). A particular command function of considerable interest is that for a suddenly applied constant velocity. In this case $W(s) = v/s^2$, where v is the value of suddenly applied velocity. Our primary interest is in the response for values of time greater than some very small value. Consequently we will approximate the expression given, by its form for small values of s (the latter correspond to large values of time, t). Then

$$Y_1 \cong \frac{A_1}{s + A_1} \frac{v}{M_1 s^2}.$$

The inverse Laplace transform of this is

$$y_1 = \frac{v}{M_1} \left(t - \frac{1}{A_1} + \frac{1}{A_1} e^{-A_1 t}\right)$$

Experiments with the test stage have given a value of A_1 about 50. Let us, however, take the very conservative value of 30. v/M_1 has a maximum rated value, for stereo tracking, of 100mm/sec. divided by the overall magnification. Thus in what may be taken as the worst possible case

$$y_1 = \frac{100}{M} (t - 0.0333 + 0.0333e^{-30t})$$

This indicates a steady state velocity lag of (100/M) x 0.0333mm. The field of view is greater than 150mm divided by the magnification, hence the velocity lag as a proportion of the field of view is

$$3.33/150 = 0.0222.$$

The expression also shows that at t = 0, $y_1 = 0$ and the velocity lag is initially zero. Furthermore the velocity lag builds to 90% of its final value in

$$t = \frac{2.3}{30} = 0.077 \text{ sec.}$$

$$(\text{ since } e^{-2.3} = 0.1).$$

The corresponding computation for the slave stage is as follows:

$$Y_2 = \frac{A_2 s_2}{s^2 + s_1 s + A_1 s_1} \; \frac{s(s+s_3)(s^2 + s_1 s + A_1 s_1) + A_1 A_3 s_1 s_3}{s(s+s_3)(s^2 + s_2 s + A_2 s_2) + A_2 A_3 s_2 s_3} \; \frac{v}{M_2 s^2}$$

For small s this is approximately

$$Y_2 = \frac{A_2 \quad [s(s+s_3) + A_1 A_3 s_3 (s + A_1)^{-1}]}{(s + A_2)[s(s+s_3) + A_2 A_3 s_3 (s + A_2)^{-1}]} \; \frac{v}{M_2 s^2}$$

$$= \frac{A_2 \quad [s^2 + (s_3 - \frac{A_3 s_3}{A_1}) s + A_3 s_3]}{(s + A_2)[s^2 + (s_3 - \frac{A_3 s_3}{A_2}) s + A_3 s_3]} \; \frac{v}{M_2 s^2}$$

In evaluating this expression it will be assumed that the slave stage has a bandwidth which is 30% greater than that of the master stage. The design of the stage servos is such that it should be easy to balance the two more closely than this. Thus again the calculations are being kept on the conservative side. The various values being assumed are

$$s_1 = 60 \qquad s_2 = 78$$

$$A_1 = 30 \qquad A_2 = 39$$

$$A_1 s_1 = 1800 \qquad A_2 s_2 = 3042$$

$$s_3 = 20 \qquad A_3 s_3 = 60$$

Then

$$Y_2 = \frac{39\,[s^2 + 18.00s + 60]}{(s + 39)\,[s^2 + 18.46s + 60]}\;\frac{v}{M_2 s^2}$$

$$= \frac{39\,(s + 4.417)\,(s + 13.58)}{(s + 39)\,(s + 4.210)\,(s + 14.25)}\;\frac{v}{M_2 s^2}$$

The inverse Laplace transform of this is

$$y_2 = \frac{v}{m_2}\,[t - 0.0333 + 0.01224e^{-4.210t} - 0.005082e^{-14.25t} + 0.02618e^{-39t}]$$

From the above we see that the steady state velocity lag for the slave stage is precisely the same as that for the master stage - even without assuming matched bandwidth. The time to reach 90% of the final value of lag is longer, however, (0.31 sec.) for the slave stage. Thus the two stages start together, move apart very slightly, and come back into precise correspondence after a short period of time. The fast transients will pretty much disappear in about the first 0.1 seconds. Hence, for times greater than this, the transient displacement between the two is approximately

$$y_2 - y_1 = \frac{v}{M} \, (0.01224e^{-4.21t})$$

At maximum rated tracking speed, as a proportion of the field of view, this is

$$.0082e^{-4.21t}$$

which decays to .005 in 0.14 seconds and to .001 in 0.21 seconds. It appears doubtful that an operator can see such a small, brief displacement between the two stages at maximum tracking speed.

Now consider the slave stage response to a difference between the two pictures as detected by the correlator. For this purpose, the artificial assumption is made that, at some time, the two stages are displaced apart by some definite amount and that the correlator suddenly commences to command correction of any existing displacement. The response to this suddenly applied correction of a definite displacement is calculated. The appropriate formula for this calculation was given on page 24 as

$$Y_2 = \frac{A_2 A_3 s_2 s_3}{s\,(s + s_3)\,(s^2 + s_2 s + A_2 s_2) + A_2 A_3 s_2 s_3} \; \frac{M_1}{M_2} \, Y_0$$

For the particular case described above

$$\frac{M_1}{M_2} \, Y_0 = \frac{d}{s}$$

where d is the amount of initial displacement (scaled for the 2 magnifications). For small values of s the formula is approximately

$$Y_2 = \frac{A_2 A_3 s_3 d}{s\ (s + A_2)\ [s\ (s + s_3) + A_2 A_3 s_3\ (s + A_2)^{-1}]}$$

$$= \frac{A_2 A_3 s_3 d}{s\ (s + A_2)\ [s^2 + (s_3 - \frac{A_3 s_3}{A_2})\ s + A_3 s_3]}$$

Putting in the values stated on page

$$Y_2 = \frac{(39)\ (60)\ d}{s\ (s + 39)\ [s^2 + 18.46s + 60]}$$

$$= \frac{(39)\ (60)\ d}{s\ (s + 4.210)\ (s + 14.25)\ (s + 39)}$$

The inverse Laplace transform of this is

$$y_2 = d\ (1 - 1.591e^{-4.210t} + 0.661e^{-14.25t} - 0.0697e^{-39t})$$

Thus the displacement is eventually corrected completely. Correction becomes 90% complete when each of the transient terms is less than 0.1. Only the most slowly decaying one need be considered since, by the time it's down to 0.1 the others will be negligibly small. Hence:

$$\frac{0.1}{1.591} = 0.0628$$

For $e^{-4.210t} = 0.0628$,

$$t = 2.77/4.210 = 0.66 \text{ seconds.}$$

Thus, as was stated earlier, the response of the slave stage to a suddenly applied correction of a correlator detected difference is appreciably slower than the response of both stages to an operator control command.

All of the preceding analysis assumed the correlator to be functioning. If the correlator is turned off then the two stages respond to operator control commands as interpreted by the digital computer. The computer commands one stage as a master stage and the other as a slave stage but there is negligible time difference in the computer commands to the two stages. If, however, the two stages are not exactly balanced in bandwidth then there will be a difference in the response of the two stages to their respective computer commands. Figure I shows that if the correlator circuit is opened then the slave stage has the same form of response function as the master stage.

The master stage response was calculated on page 28 assuming a bandwidth of $30/2\pi$ hertz. The result was given as

$$y_1 = \frac{v}{M_1} (t - 0.0333 + 0.0333e^{-30t})$$

The corresponding slave stage response, assuming that it has a 30% greater bandwidth is

$$y_2 = \frac{v}{M_2} (t - 0.02564 + 0.02564e^{-39t})$$

Thus the steady state velocity lag for the master stage is 30% greater than that for the slave stage. This produces a steady state displacement between the two stages at the maximum rated tracking speed* as a proportion of the field of view

$$= 0.769/150 = .00513,$$

i.e., slightly over 1/2%. Hence in order to meet the specified maximum value of 1/2% it is necessary either to make the bandwidth of the slower stage somewhat greater than $30/2\pi$ hertz or else to make the difference between the two bandwidths somewhat less than 30%. It can be calculated that if the slower stage has a bandwidth over an even 5 hertz and the other

*It also produces a proportionately smaller displacement at lower stage speeds.

stage exceeds this by up to 30% then the velocity lag displacement between the two at maximum rated tracking speed will be less than 1/2% of the field of view.

AUTOMATIC OPTICS TRACKING

Insofar as the optics can be separated into equivalent one-axis systems, the analysis given above for stage tracking also applies at least in principle to optics tracking. Thus Figure II applies to any single optical axis (master and slave) if $G_1(s)$ and $G_2(s)$ now represent the optics servos for that axis and $G_3(s)$ and $G_4(s)$ are included to allow for possible additional time lags in the optics response due to stage motion. In fact, $G_3(s)$ and $G_4(s)$ are probably simply unity gain (constant) transfer functions. Nevertheless the input Y_0 represents differences in the two pictures and the latter are functions of stage position (different functions for different pictures). Thus, as an approximate analytical device, the time delays in Y_0 may be absorbed into $G_3(s)$ and $G_4(s)$.

Thus the response time for the slave optical system, like that for the slave stage motion, must be considered in two parts. The response of the slave system to operator commands as interpreted by the computer (sW) is substantially the same as that of the master system. The response of the slave system in compensating for correlator detected differences in the two photographs (Y_0) contains additional time lags, however.

The servo system for any optical axis may be approximately represented, as having principal poles consisting of a single pair of complex poles. This is similar to the function used for the stage servos. The optics servos, however, have a narrower bandwidth (about 3 hertz) than the stage servos (about 8 hertz). Thus the principal poles for the optics servos are approximately $-20 \pm i20$. As a result the two real poles which for the stage servos were calculated as -4.09 and -14.5 are - for the optics servos - somewhat nearer to zero. The difference is not very great, however.

SUMMARY OF AUTOMATIC TRACKING

Although each stage has two axes and each optical train has four primary axes (magnification, rotation, anamorphic stretch ratio, rotation of anamorphic stretch direction) the design of the system is such as to practically isolate each axis so far as internally produced time lags are concerned. Hence, as a good approximation, each axis (of the stage or of the optics) may be analyzed separately. The various cross couplings which occur are treated as though confined to the inputs to the several axes. Hence, the time response of the complete system may be broken down to the time response of each axis to the inputs to that axis.

Analyzing each axis separately shows that two inputs need to be considered - one the operator's control signals, and the other differences in the two pictures which are not simply due to geometry but which arise primarily from the relief in the object photographed. It is found that the slave system response to the operator control commands is essentially identical to the master system response, and is quite fast. The slave system response to the photograph differences is, however, appreciably slower.

To see how this works, in practice, imagine that the stages and the optics are initially stationary with settings such that the operator, the computer, and the correlator are satisfied that proper stereo correspondence has been established. Now let the operator use the joystick or one of the trackballs in a tracking mode to command motion of the images in a certain direction and at a certain velocity.

The stages accelerate to 99% of their respective final velocities in about 0.1 seconds (assuming an 8 hertz bandwidth). As the stages move (assuming that the photographs change scale factor due to tilt distortion and due to geometry) the computer generates changing position commands to the optical systems.

Treating these changing motion commands as suddenly applied constant velocity inputs - the optics accelerate to 99% of the commanded velocities in about .2 seconds (assuming a 3 hertz bandwidth). Insofar as the photographs can be predicted by the computer and insofar as the various master and slave systems have matched bandwidths, the two systems stay in proper stereo correspondence while moving at the commanded velocities (providing these do not exceed the rated values for stereo tracking). If, however, some stereo non-correspondence begins to develop, the correlator detects it and begins commanding corrective action with a time lag not over .05 seconds. Actual correction of the non-correspondence is, however, somewhat slower.

The easiest way to state the time lag in correcting non-correspondence (detected by the correlator) is to imagine that some definite displacement has accumulated and that the correlator suddenly applies a command for its correction. This is more pessimistic than the actual situation wherein the correlator begins corrective action as soon as the displacement starts to develope, but it is easier to analyze. Such a non-correspondence displacement whose correction is suddenly commanded by the correlator will decrease to 10% of its initial value in about .66 seconds for the slave stage and about .8 seconds for the slave optics. Any displacement which is initially more than about 5%

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of the field of view is apt to be outside the pull-in range of the correlator. Hence these times are ordinarily sufficient to reduce the displacement to less than 1/2% of the field of view.

Maximum rated stage speeds which maintain correspondence on identical photographs are rated at 10mm/sec. at 10X magnification varying inversely with magnification to .5mm/sec. at 200X magnification. Maximum error in correspondence (on identical photographs) at these speeds is rated as less than 1/2% of the field of view at the selected magnification. These values are believed to be more than adequate for all practical applications. Since actual photographs are not identical, tracking errors can be expected to develop if these maximum tracking speeds are used. As seen above, there may be quite noticeable time lags in correcting such tracking errors if they are allowed to accumulate. It should be easy, however, to judge the maximum tracking speed for any particular photographs since the first manifestation that a tracking error is starting to develop will be departure of the floating dot from the surface of the model. A slight reduction in tracking speed will then allow the floating dot to settle back to the surface. Thus, it should be easy to track in stereo without having tracking errors accumulate to the point where they begin to produce eye strain and to do this at stage speeds which are very respectable indeed.

PART II

PART II

DESIGN SPECIFICATIONS

GENERAL SPECIFICATIONS*

1. The Stereocomparator has two optical trains. The following specifications apply separately for each optical train.

Magnification with anamorphic stretch ratio at 1/1: continuously variable from 10X to 100X, or from 20X to 200X; depending on selection from two different objective lenses.

Anamorphic stretch ratio: continuously variable from 1/1 to 2/1: direction of maximum stretch continuously variable without limit.

Image rotation: continuously variable without limit.

Brightness at each eyepiece: continuously adjustable from 0.06 to 1.2 stilbs (175 to 3500 foot lamberts). Set value is automatically maintained for average film density variations over range 0 to 3.0; high speed shutter provides protection against sudden increase in brightness.

Type of reticle: floating dot principle; bright round dot projected to center of each eyepiece.

Size of reticle: continuously adjustable from just over diffraction limited** to 4 times diffraction limited; size and shape maintained automatically for variations in magnification and anamorphic stretch ratio.

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* Tentative until revised after completion of the Optical Design

** Equivalent object, size of Ares disc of an apparent point source at the film plane.

Apparent position of reticle: superimposed on the film plane; position shift with respect to the point at which the main optical axis intersects the film plane is less than ± 1/4 micron for changes of setting in the zoom lens, anamorphic stretch ratio, image rotation, fine focus, size of reticle, and adjustment or switching of the eyepieces.

Range of coarse focusing control: 3 millimeters vertical movement of objective lens.

Range of fine focusing control: 0.7 millimeters vertical, movement of objective lens.

Low power objective lens: 80mm focal length, F/2.1, operates as a collimating lens.

High power objective lens: 40mm focal length, F/1.25, operates as a collimating lens.

Objective lens selection: via pushbuttons on control console; accidental alteration of selection during a measurement sequence produces automatic notification to the operator that measurements have been invalidated and automatic provision for starting the sequence over.

Diameter of field of view at the film plane: inversely proportional to overall magnification, greater than 15mm at 10X and greater than 0.75mm at 200X. Values are specified at 1/1 anamorphic ratio; at other stretch ratios the field of view at the film plane in the direction of maximum stretch is also inversely proportional to the stretch ratio.

Diameter of exit pupil: 1.2mm with low power objective and 1.0mm with high power objective.

Field of view at eyepiece: greater than 35° included angle.

Eye relief: 20mm $\pm$ 2 mm.

Interpupillary distance: continuously adjustable from 50 to 75mm.

Eyepiece line of sight: 15° below horizontal and 6° adjustable convergence, with 2° vertical adjustment of one eyepiece relative to the other.

Independent focusing of the two eyepieces.

Eyepiece modes: 4 selectable; normal stereo, reversed stereo, binocular viewing of left stage, and binocular viewing of right stage.

2. The Stereocomparator has two measuring stages. The following specifications apply separately for each measuring stage.

Construction: Base block, top stage, and intermediate guide stage are each a single piece of lapped granite. The top stage is supported by 4 air bearings and the intermediate stage is supported by 3 air bearings; both sets of support air bearings are with respect to the top plane surface of the base block. Guidance of the intermediate stage with respect to the base and of the top stage with respect to the intermediate stage are by means of compensated air bearings. Film is vacuum clamped to a glass platen mounted on the top stage. Film spools and drive system are also carried on the top stage. Film illumination occurs, from below, through appropriate openings in the base block and in each stage.

Measuring Range: 9-1/2" x 20" rectangle.

Size of film accommodated: any width from 70 mm to 9-1/2 inches, any length from a cut chip to 500 ft., any thickness from 2 to 7 mils.

Maximum speed of top stage: 3 inches per second in any (horizontal) direction.

Maximum acceleration of top stage: 10 inches per second squared in any (horizontal) direction.

Maximum angular deviation of top stage from true rectilinear translation: less than 1 arc second each in pitch, roll and yaw.

Maximum measurement error due to pitch, roll and yaw of top stage: too small to measure (see Appendix II-A).

Maximum vertical deviation of top of film platen: ± 10 microns.

Type of measuring system: Twyman-Green interferometers on each axis, powered by single mode gas laser light source.

Basic least count of measuring system: 1/4 wavelength of He-Ne laser light (approximately 0.1582 microns).

Converted least count of measurement read-out system: 0.1 microns.

Maximum counting rate of measurement system: over 1 megahertz.

Maximum time required for reversing counting direction: less than 2 micro-seconds.

Type of readout: BCD (1,2,4,8 code for each digit); sign - magnitude representation; provision for setting count origin to zero or to any preselected number.

Maximum deviation from straightness of interferometer travelling mirrors: ± 0.079 microns in any 2-inch length; ± 0.3 microns over total length.

Maximum non-perpendicularity of X and Y axis travelling mirrors for interferometers: 1 arc second.

Room air conditioning:

Temperature: $72^{\circ}F \pm 0.5^{\circ}F$

Humidity: 55% RH + 15% RH, -5% RH

Control digital computer: Honeywell DPD 516; 16-bit word length, 16384 words of storage; high speed arithmetic option; teletypewriter input - output; high speed parallel transfer to and from Stereocomparator interface electronics.

PERFORMANCE SPECIFICATIONS

Resolution: CONTRACTURAL

a. White light from a Xenon arc

	Linepairs/mm	
Objective focal length	40mm	80mm
10X Magnification		45
20X Magnification	80	
100X Magnification		400
200X Magnification	800	

b. Yellow-green filtered Xenon arc light

Objective focal length	40mm	80mm
10X Magnification		50
20X Magnification	100	
100X Magnification		500
200X Magnification	1000	

c. The resolution degradation between the center of the field of view and at one third of the distance toward the edge of the field of view is less than 10%.

Maximum RMS absolute error of coordinate measuring system: 0.4 microns plus 10 parts per million, each axis, provided the room environmental conditions are within specification (not including operator pointing errors or errors in the film itself).

Maximum speed of stages while tracking corresponding points in two identical pictures: 100mm/second divided by the selected overall magnification.

Maximum error in tracking corresponding points in two identical pictures at maximum rated tracking speed: 1/2% of the diameter of the field of view at the selected overall magnification. This specification applies both when the Image Analysis System is on and when it is off. If the Image Analysis System is operating, however, theory says there should be no steady state tracking error when tracking on two identical photographs.

At tracking speeds less than the rated maximum, the tracking error is proportionately smaller than 1/2% of the field of view.

Maximum time required for the stages to accelerate to 90% of the speed which is finally reached, after a command for constant velocity (not in excess of the maximum rated tracking speed) is suddenly applied through the control console: 0.1 second.

Maximum time required for the stages to accelerate to 99% of the speed which is finally reached, after a command for constant velocity (not in excess of the maximum rated tracking speed) is suddenly applied through the control console: 0.2 second.

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Maximum pull-in range of Image Analysis System (electronic scanners and correlator): at least ± 5% of the field of view at the selected magnification.

Maximum time required to reduce a suddenly released tracking error which is detected through the Image Analysis System to less than 1/2% of the field of view (provided the two pictures contain sufficient information for satisfactory correlation): 1.5 seconds if the error is initially 5% of the field of view, proportionately less if the error is initially less than 5% of the field of view.

PART III

TASK 1

STATEMENT OF WORK, SPECIFICATIONS, REPORT PREPARATIONS

I. Introduction

This report provides the technical summary of [redacted] design effort as performed during Phase I. Each task has been completed and the technical results summarized, except for those items directly concerned with, or interfaced with, the Optical Subsystem. We anticipate that the technical summary of those items, including the Optical Subsystem will be completed and submitted during early March, 1968. STAT

II. Summary

The report has been written in a manner which attempts to avoid repetition and duplication of discussion which may have appeared in previous monthly progress reports. Each task reported is augmented by a reference index which appears as the last page of the task. This reference index indicates the volume and page numbers of previous reports where further amplification of an item mentioned in the text can be found. Figure T1-1 provides a convenient cross-index of volume numbers and dates published. We feel that in this manner the reader can be spared repetition of information of which he might already be aware and knowledgeable.

The reader will also note that there are three additional sections in this report. We have included Part I - Description and Application; Part II - Performance Parameters and Specifications; and Part IV - Report on the Phase II Fabrication Effort. Part IV also includes the Statement of Work and General Description (Appendix IV-A) and Specifications (Appendix IV-B). This information is provided in accordance with Phase I contract requirements.

REFERENCE SHEET

Volume	Period Covered
I	January 9 through February 24, 1967
II	February 24 through March 31, 1967
III	April 1 through April 30, 1967
IV	May 1 through May 31, 1967
V	June 1 through June 30, 1967
VI	July 1 through July 28, 1967
VII	July 29 through August 25, 1967 - Appendices
VIII	August 26 through September 29, 1967
IX	August 26 through September 29, 1967 - Appendices
X	September 30 through October 27, 1967
XI	October 27 through November 24, 1967

Figure T1-1

TASK 2

SCHEDULING AND PLANNING

I. Introduction

The Scheduling and Planning effort for Phase I has been completed with the exception of the coordination of the Optics Subcontractor's effort with the [redacted] designed equipment. Pert/Flow diagrams (1) are still being utilized to assure management control of this portion of the program. STAT

II. Summary

The use of Pert in Phase I, and the attendant success of this system, has indicated to [redacted] that the same method of control should be employed during Phase II. Initial steps in this direction have already been taken during the pricing of Phase II, and plans are to utilize the Pert system throughout the fabrication, assembly and installation cycles. STAT

REFERENCES

Task 2 - Scheduling and Planning

(1) I, pages T2-1 and T2-2.

TASK 4

MANAGEMENT, ADMINISTRATION AND SUPERVISION

I. Introduction

Program Management is extremely pleased with the demonstrated success of Phase I. As indicated in this report, the design goals have been met and the program will be completed in accordance with the original program plan.(1)

II. Summary

At this writing, the status of the overall program is as follows:

90% of schedule completed.

93% of program actually completed.

89% of budget expended.

These percentage figures represent the delay in completion of Optics design and in turn, the [redacted] equipment which is dependent upon the Optics design for finalization. Individual task summaries in this report define those areas of Optical interface affected. STAT

III. Conclusion

The obvious success of the management control procedures used in Phase I indicate that these same procedures will be utilized during Phase II.(2) The fact that Phase II is hardware-oriented will dictate that control in greater depth be initiated. The system used, however, will be essentially the same.

REFERENCES

(1) Task 4 Management, Administration and Supervision I, pages T4-1 and T4-2.

(2) Task 1 Statement of Work, Specifications, Report Preparations I, Pages T1-1 and T1-2.

TASK 7

MAIN FRAME AND STRUCTURAL ELEMENTS

I. Introduction

The main frame is a two-piece structural member supported and isolated from ground by a vibration isolation system.(1)

II. Summary

The frame is fabricated from steel plate into a closed box section to provide maximum torsional rigidity, and is designed to support the machine load in case of failure of the vibration isolation system.(2)(3)

The main frame is designed to support and maintain, both vertically and horizontally, the positions of the base granite(2), and therefore the stage and optical bridge left and right(4), and to support the central optical bridge(4) and maintain its fixed position with respect to the optical bridges left and right.(3)

The main frame provides three-point support for each base granite. Each support is a leveling jack utilizing a wedge action to produce vertical adjusting motion.

III. Conclusion

The main frame has been designed and will interface the Stereo Comparator with the vibration isolation system.

REFERENCES

(1) Task 7 - Main Frame and Structural Elements
XI, page T7-1.
Task 35 - Vibration Absorption & Leveling - Final Report

(2) Task 7 - Main Frame and Structural Elements
I, pages T7-1 and T7-2

(3) Task 7 Main Frame and Structural Elements
II, page T7-1 and Appendix T21-C.

(4) Task 21 Optical Bridge and Supports - Final Report

TASK 8

SKIN

I. Introduction

The purpose of the skin is to enhance the appearance of the functional machine without deteriorating the machine functions or necessary required adjustments.

II. Summary

The skin will produce a cover over the optical bridge castings and at the same time will provide an enclosed area at the rear of the machine for all utilities and electronic interface panels. The skin enclosing the optics will be dust tight at all interfaces.

Included in the skin category will be a pod over the control console which, aside from its primary function, will provide an area of minimum outside light distraction for operator comfort.

The two side rails are completely functional in that they provide the operator with a means of chair movement, both into and out of the console area, and also provide a kickboard so that the chair and/or the operator will not be able to disturb the base granite proper in the event of excess side movements.

III. Conclusions

The skin has been designed both functionally as noted above, and in accordance with the industrial designer's recommendations.

TASK 9

GRANITE & WAYS ASSEMBLY FOR STAGES

I. Introduction

The granite and ways actually total 12 pieces of granite with varied purposes.[1]

II. Summary

The base granite provides a stable, flat to 50×10^{-6} inches, platform which the "T" section, or moveable ways, and the stage use as a reference through an air bearing interface to maintain a constant distance between the film plane and the objective lens regardless of stage position in the 10" x 20" viewing area.

The moveable ways provide "X" and "Y" axis reference for the stage through guide air bearings working on the flat to 50×10^{-6} inch ways, and provide a means of mounting the "Y" axis drive.

The stage provides the stable platform on which is mounted the film platen[2], the vacuum clamp film holddown system[2], the film drives[3], the moveable interferometer mirrors[4], and the articulated utilities arm on which all utilities and electronic cables as required enter the stage area.

The other pieces of granite are necessary to integrate and provide stable platforms for the interferometry system.[4] This includes the "X" and "Y" axis interferometer and the laser.

III. Conclusion

The granite and ways as designed have been proven in the breadboard testing and are acceptable.

REFERENCES

(1) Task 9 Granite and Ways Assembly for Stages I, page T9-1 and Figure 2.

(2) Task 13 Film Platen & Film Clamping - Final Report

(3) Task 12 Film Drive & Transport System - Final Report

(4) Task 22 Interferometer Assembly - Final Report

TASK 10

AIR BEARINGS

I. Introduction

The air bearings are the frictionless guide method[1] utilized to maintain the stage and therefore the moveable interferometer mirrors in a perpendicular relationship with respect to the laser beam reflected from the respective interferometers[2]. The air bearings also support the stage and maintain the film plane[3] as a horizontally moveable, vertically non-changing plane.

II. Summary

Maintaining the perpendicularity relationship of the moving interferometer mirrors is necessary to insure that no position counts are lost or gained while the stage is moving.

The film plane being maintained as a vertically, non-changing plane is necessary because of the extremely small depth of field of the optical system[4].

The air bearings support and guide the stage on a thin film of very dry and highly filtered air about 3 to 5 microns thick[5]. The design of the air bearing surface and the orifice size[6] produce an air bearing that is very stiff[1][4], (has a very high spring rate), and this is the force that maintains the stage with respect to the guide ways[6] and maintains a constant stage liftoff height.

III. Conclusion

The air bearing system has been manufactured and tested on the breadboard and found acceptable for use on the Stereo Comparator.

REFERENCES

(1) Task 10 Air Bearings
IV, page T10-1, Para. III.

(2) Task 22 Interferometer Assembly - Final Report

(3) Task 13 Film Platen & Film Clamping - Final Report

(4) Task 10 Air Bearings
IX, Appendix T10-B

(5) Task 10 Air Bearings
VIII, pages T10-1 to T10-3, Para. II.

(6) Task 10 Air Bearings
XI, pages T10-1 and T10-2, Para. II.

TASK 11

STAGE DRIVES

I. Introduction

The stage drives are friction type devices utilized to convert rotaty to linear motion and thereby position the stages, and therefore the film plane[1], on their "X" and "Y" axes to any point within the 10" x 20" limits under the objective lenses by either manual or automatic command.[2] In addition, the stage drives must also control the velocity of the measuring engines so that stereo fusion is maintained under conditions of motion of the photographs.

II. Summary

The mechanical portion of the stage drives consists of a friction type leadscrew called the threadless leadscrew[3][4], a printed circuit type drive motor and tachometer generator connected directly to the leadscrew[5], and an attachment of the leadscrew nut to the stage[6].

The threadless leadscrew has been extensively tested and proven satisfactory for this application[7].

The high degree of positioning accuracy and controllability required imposes extremely stringent requirements on the drive system used to power the engines. The electronic equipment which comprises the stage drive system includes the following assemblies:

a) High current power amplifiers which supply the driving voltage to the servo motor.

b) Printed circuit motors which are capable of operation over an extremely wide speed range with very little jitter or cogging.

c) DC Tachometer generators attached to the motor to provide velocity feedback signals which are utilized to stiffen and damp the overall system.

d) Specially-made 23-bit digital-to-analog converters which receive the digital command numbers from countdown registers in the electronic assembly and convert these digital numbers to analog voltages according to a prescribed pattern. These voltages are applied to the power amplifier to cause motion of the stages.

e) Ancillary equipment for performing various tests and adjustment functions on the measuring engines and various limit relays to prevent damage to the measuring engine whenever a limit of mechanical travel is reached.

III. Conclusion

The stage drive system as designed and tested by during STAT the past year provides excellent stability, accuracy and stiffness, and it is anticipated that this drive system will prove entirely satisfactory with respect to performing in such a way as to allow stereo tracking on the finished machine.

IV. Discussion

The printed circuit motor used to drive the measuring engines is quite unique in that it exhibits very low cogging, and has almost no inductance. This is primarily due to the construction of the motor in which a great number of poles are etched on a circuit board which acts as the armature. This armature has quite a low polar moment of inertia, but since it is only possible to print one layer of windings on each side of the armature discs, it can be seen that the motor consists essentially of a series of one-turn windings. The extremely low terminal impedance of the motor (0.530 ohm) causes the motor to require quite large currents in order to develop appreciable torque. In fact, the torque constant of the motor is only 7.5 ounce/inches per ampere of applied current. Due to the rather large mass of the stage and drive shaft which must be accelerated very rapidly, a great deal of torque is required and corresponding high current levels can be expected during normal operation of the machine.

The selection of a suitable amplifier to provide the current to drive the motor proved something of a problem, and after surveying the amplifier units available on the market, it was finally decided to design a servo driver especially for this type of motor.[8][9] This amplifier design proved extremely satisfactory in our experiments with the breadboard system, and since the same motor is used in the stage drives, the film reel tensioning drives and the illumination brightness control drives, it was decided to utilize this amplifier design in all of these areas in the machine so that the total requirement for the machine is 10 of these units.

In order to provide high positioning accuracy for the measuring engine, it is necessary to make the drive system relatively insensitive to the torque loading on the drive motors caused by friction. It is also necessary to simultaneously adjust the overall drive ratio from the motor to the stage such that a maximum slewing velocity of 3" per second can be obtained. The combined requirements of high speed and high accuracy are attained through the use of an extremely stiff velocity feedback loop so that the overall stiffness of the system is on the order of 12,750 ounce-inches per rad. The net result of the incorporation of this velocity feedback loop (velocity feedback signal being derived from a DC tachometer generator mounted on the motor shaft) makes the system capable of positioning the drive shaft to an accuracy of one count from the laser system (0.16 micron) in the presence of 10 ounce-inches of friction loading.

Since the mechanical drive provides little friction drag, then this one count accuracy is quite easily obtained by the system.(10) Our experiments with the breadboard system indicated that positioning at extremely low speeds (well below the .001 inch/second speed called for in the design goal) is possible while still maintaining the 3" per second maximum slew speeds.

As originally proposed, a servo bandwidth of approximately 12 cycles per second was anticipated, but due to mechanical resonances found present in the system, the overal bandwidth had to be restricted to 8 cycles. The bandwidth of a servo system is an indication of the speed with which the system can respond to sudden changes in the input commands. Our experiments have shown that the 8 cycle bandwidth is entirely adequate for the purposes of the machine.[11]

In order to allow computer control of the stages, it is necessary to incorporate into the stage drive servo system a digital-to-analog converter. This converter takes the digital numbers from the computer, or from various counter circuits, during manual mode of operation, and converts them into analog voltages according to prescribed formula for use in driving the servo amplifier.[12] In order to allow any position of the stage to be specified during the pre-positioning mode of operation, we found it necessary to incorporate 23-bit digital words in the system, although a range of 16 bits is all that is actually required to drive the stage at full speeds. Our experiments with this D/A converter indicated that the acceleration characteristics selected for the converter are satisfactory for both large and small error cases. The test facility built into the D/A converter also allows observation of the input to the stage drives for purposes of maintenance.

REFERENCES

Task 13 - Film Platen & Film Clamping

(1) Final Report

Task 11 - Stage Drives

(2) I, page T11-1, para. I.

(3) I, page T11-1 and T11-2, para. III, Appendix B

(4) II, page T11-2, para. III.

(5) II, page T11-1, para. II.

(6) X, page T11-1 and T11-2.

(7) X, page T11-1 and T11-2.

(8) IV, page T11-1.

(9) VI, page T11-1.

(10) IV, page T11-4.

(11) V, page T11-2.

(12) VII, page T11-1.

TASK 12

FILM DRIVE AND TRANSPORT SYSTEM

I. Introduction

The film to be analyzed on the Stereo Comparator will come in lengths of up to 500 feet. Except for very short chips, this film will be on rolls.

Film width can be anywhere from 70mm to 9-1/2", while film thickness can be from .002" - .007".

Even though most film will come in standard widths provision must be made to accommodate any intermediate format. Therefore, an adjustable, universal width film drive and transport system has to be designed in order to handle the film at speed ranges suitable for slow scanning and rapid slewing.

Film changes should be made possible within two minutes in order to limit down time.

The film drive should be joystick controlled for bi-directional film movement.

II. Summary

After the preliminary specifications for the film drive and transport system had been established, it was found necessary to modify the standard [redacted] design to allow for: STAT

a) Higher slewing speed.

b) Greater film acceleration.

c) Closer film tension limits to insure even winding tension on the film at all speeds and reel diameters.

The first design concept is described in the June 1967 report for this task[(1)].

The disadvantage of this early design concept is that in order to provide the required function, several rollers are required which would cause an elaborate design with an inherently high profile.

Hence, a subsequent design was developed where only two rollers were needed, and which would perform the various functions more efficiently than the previous package.

This new design is discussed in Reference (2). A mock-up was fabricated to develop an optimum configuration for ease of film handling, either with emulsion side up or down[(3)]. The design parameters and control system for this film drive and transport system are explained in Reference (4).

The film drive control system is comprised of three servomechanisms plus associated control circuitry. Two of the servomechanisms are high current systems (similar to those used in the stage drives) for driving the film reels. The high power requirement is dictated by the necessity for

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maintaining a proper tension in a full reel of 9-1/2" wide film.

The third servomechanism is a comparatively low-powered capstan drive system. In order to maintain constant tension in the film under all conditions -- variable quantity of film on the reel, variable width of film, and accelerations of the transport -- it was decided to use a configuration containing tension sensing dancer arms. The dancer arm system maintains complete control over all of the above parameters simultaneously, whereas the more conventional radius sensing arm does not allow control of film tension during acceleration of the transport.[5]

In addition to the three basic servo loops which provide the drive forces within the system, a control arrangement is required to allow tension being relaxed in the system during vacuum clamp-down, and to allow the film to be picked up and tension reinstated in the system when slewing is required. It is also necessary to provide controls which will allow the system to be placed in a condition suitable for loading and unloading the film. This is accomplished by means of two electronic assemblies per transport which contain various relay circuits and signal generators to provide the proper timing and control functions for the main servo loops.[6]

One of the unique features of this new type of film transport is the fact that it is not necessary for the film to be threaded so tightly that all the slack has been taken out of the system prior to energizing the servo systems. In previous designs, if any slack existed in the film pack, at the moment the transport was turned on, heavy correction current would be applied to the motors which would, at times, actually stretch or break

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the film. The new design incorporates special circuitry which senses whether or not slack is present, and if slack exists, the controllers will generate low velocity commands which will wind the slack out of the system at a safe rate.

III. Conclusion

Two identical film drive and transport systems for stereoscopic viewing have been designed.

The film transport system will be bi-directional, and continuously variable with a slew rate of 2.5 ft./min. to 250 ft./min. (i.e., .5 inch/sec. to 50 inches/sec.). The film will be capstan driven.

The system has been designed to insure that a workable film tension is maintained throughout the slew limits, and that protection from abrasion, scratches and tearing is assured.

The film transport system will handle film up to 500 feet in length on rolls, varying in width from 70mm to 9-1/2 inches, and in thicknesses from .002 to .007 inches. Changeover to a different film size can be accomplished within 2 minutes.

The system is capable of handling film either emulsion up or down, and winding film with emulsion either in or out.

The entire film transport system is supported on the main film stage, and it is controlled by a single axis joystick, mounted on the control console nearest to the film that it controls. The joystick is springloaded for automatic return to its center (neutral) position.

IV. Discussion

The capstan drive was used to give better film control over the variable slew rate. Simultaneously, a closer control over film tension can be maintained by this method of film drive.

An interface requirement is that, since the film is being slewed through the narrow gap between glass platen and objective lens, air cushions are provided to avoid contact with these components while the film is being moved.

REFERENCES

Task 12 - Film Drive and Transport System

(1) V, pages T12-2 to T12-3, Figure T12-1.
(2) VI, pages T12-1 to T12-2, Figure T12-1.
(3) VI, page T12-3, Figures T12-3 and T12-4.
(4) VI, pages T12-1 to T12-4, Figures T12-1 and T12-2.
(5) VII, Figure T12-1.
(6) IX, page T12-1.

TASK 13

FILM PLATEN AND FILM CLAMPING SYSTEM

I. Introduction

In order to view film and measure coordinates on this film by means of the X and Y movements of the measuring engines, it is necessary that the film is firmly held against the glass platen. Air pockets that could thwart accurate coordinate measurements must be non-existent, and no relative motion between film and platen is allowed.

Hence, not only is an accurately lapped, flat glass platen necessary, but also a suitable film clamping system is imperative.

II. Summary

A. Film Clamping System

Besides the [redacted] developed clamping arrangement, several STAT other film clamping methods were investigated, but none of them proved satisfactory(1). Hence, the [redacted] vacuum clamping system was used as a STAT basis for this design.

A breadboard was fabricated and tests were conducted to determine clamping time for various formats(2).

Subsequent data obtained from the optical survey indicate that the objective lens would cause interference with the clamps. The clamps had to be redesigned for a lower profile to avoid lens contact(3).

A new set of vacuum clamps was fabricated and tests were made. It was found that the reduced vacuum passage materially improved the clamping qualities [4].

B. Glass Platen

Since the depth of field at 200X magnification is only approximately 2 microns, it is imperative that the glass platen supporting the clamped film is extremely flat, lest the 9-1/2" x 20" film format will lose its focus during the automatic mode of the measuring engine.

To obtain an optimum size for the glass platen, calculations were made to compare weight, strength, and deflection [5].

c Due to late developments in the optical system, the glass platen has been enlarged to the present final size of 23.500" length, 15.000" width, and 1.250" thickness.

III. Conclusion

A film platen and film clamping system has been designed to accommodate film formats varying from 70mm x 20" to 9-1/2" x 20".

The system will accommodate either cut chip film or roll film while size adjustment for different formats will be accomplished within two minutes. The film holddown system will not degrade the view through the objective lens, except for .062" wide strips on the sides of the film necessary for clamp down seals.

When the film is clamped, it will remain flat over the entire format* with emulsion either up or down.

Clamp down of the film will be accomplished within 10 seconds except where wide, .002" thick, film is used, in which case it may take

* The fine focus control is designed to maintain required accuracy so this is not necessary.

20 seconds.

After the roll film is properly loaded in the film transport system, the clampin, unclamping, transporting and reclamping operations will be interlocked for automatic operation.

IV. Discussion

Clamp-down time of the film must be kept to a minimum to avoid delay of other stereo comparator functions when in a coordinate measuring mode. A clamp-down time of 3 - 20 seconds, depending on film format was found to be adequate for this purpose.

The vacuum clamping system is interfaced with the film transport system by means of an arrangement that prevents any film drive movement while the film is clamped, thus avoiding the possibility of film tearing.

The vacuum system will be alternated with a compressed air system which will keep the film off the platen when not clamped. This air will also serve as a form of platen cooling.

The glass platen itself was originally planned to be made from Pyrex, primarily for its machinability and its heat transfer capabilities. However, Pyrex is a poor grade of glass, full of striae, hence an alternate was sought.

The platen will now be made from a recently developed, low expansion type glass, E-6. This glass has the same good machining capabilities as Pyrex, and in addition, has good optical quality.

REFERENCES

Task 13 - Film Platen and Film Clamping System

(1) II, pages T13-3 to T13-4.

(2) IV, pages T13-1 to T13-3; Figure T13-1.

(3) V, pages T13-1 to T13-2.

(4) VIII, page T13-1.

(5) II, pages T13-1 to T13-2; Figure T13-1 and Appendix T13-B.

TASK 14

FILM COOLING

I. Introduction

The illumination optics system for the Stereocomparator will impart a certain amount of radiant energy to the film which in part will be transformed into heat. Some of this heat will be conducted away through the platen glass, and through the film itself.

However, heat will be generated at such a rate that the natural conduction will not be adequate to keep the film temperature at a safe level where distortion will not take place.

Hence, a forced air cooling system is contemplated to increase the rate of heat exchange with the ambient environment in order to maintain a permissible heat balance.

This report concerns itself with tests conducted at [redacted] to obtain STAT
the necessary parameters for efficient film cooling.

II. Summary

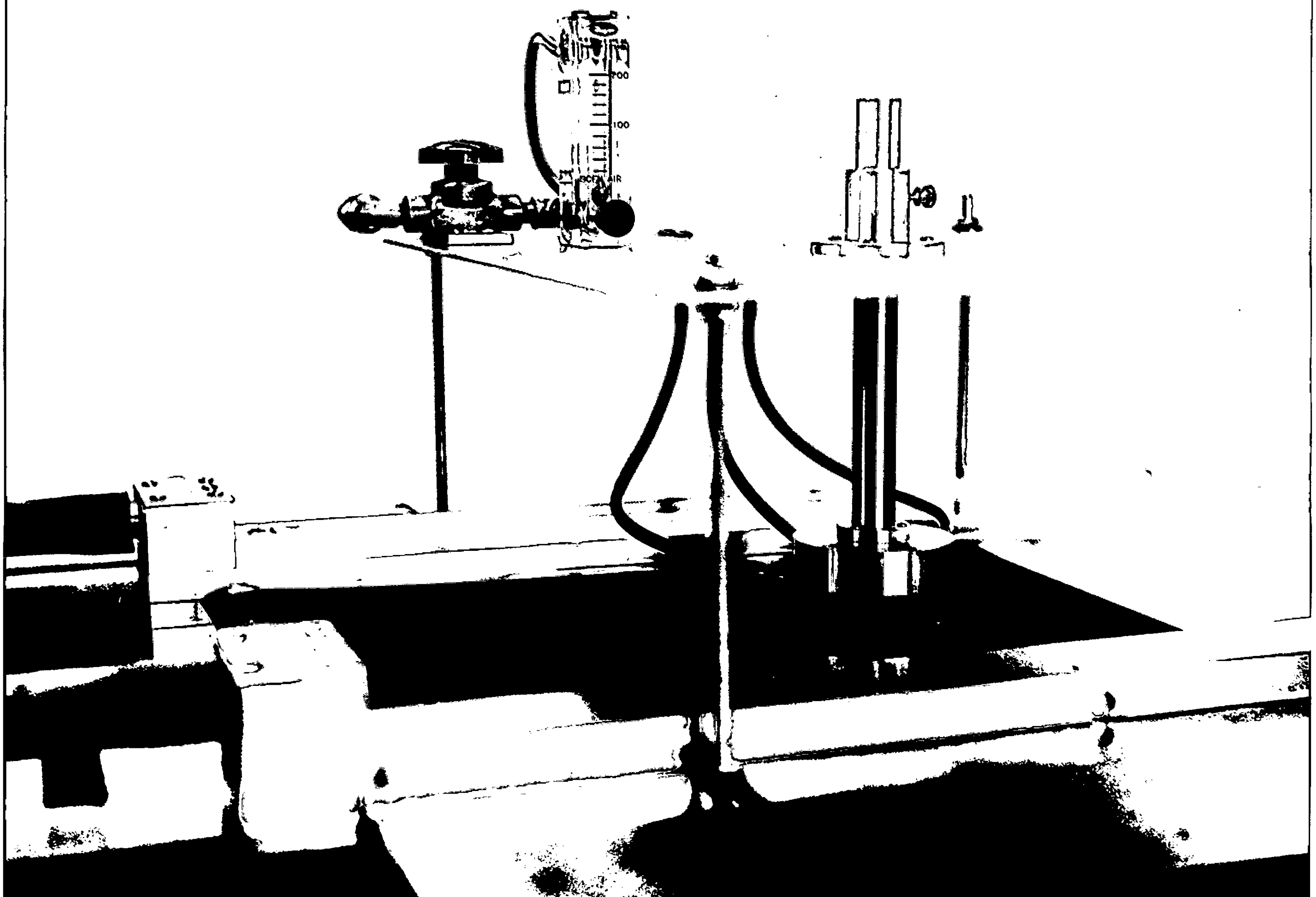
An electro-mechanical analog of the illumination optics system was developed which simulates the conditions under which heat is being applied to the film at various settings of magnification.

A group of air nozzles, surrounding a wooden model of the objective lens, supplies the cooling air.

The entire system is shown in Figure T14-1.

III. Conclusion

At this time a final design of the film cooling system cannot be


200
100
SCFH AIR

made since the optics design package for the Stereocomparator has not yet been completed.

The principles for film cooling have been laid down in this report, and the interfacing shall be done when the optics design package will become available.

IV. Discussion

The test set-up represents the area in the immediate vicinity of the objective lens. It is here that the forced air film cooling must take place.

To supply heat to the film, a set of spirally wound heating elements were made up from .032" diameter Ni-Chrome wire. The diameters of the heating elements selected are: .035" -- .100" -- .200" -- .300" -- .500" -- .700", where .035" represents the diameter of the light spot on the film at 200X magnification, while the .700" represents the diameter of the light spot on the film at 10X magnification.

The other sizes were chosen for convenience. The platen was counterbored, and partially packed with asbestos material to minimize heat being radiated and convected away from the film. The heating element was placed flush with the platen surface to insure contact with the film.

Power was supplied to the heating elements by means of a 32 VDC Source. The wiring diagram is shown in Figure T14-2. Multiplication of voltmeter and ammeter readings gives the watts supplied to the heating elements, neglecting any line losses.

Even though several aspects of film cooling are being investigated, two major criteria form the basis for the tests:

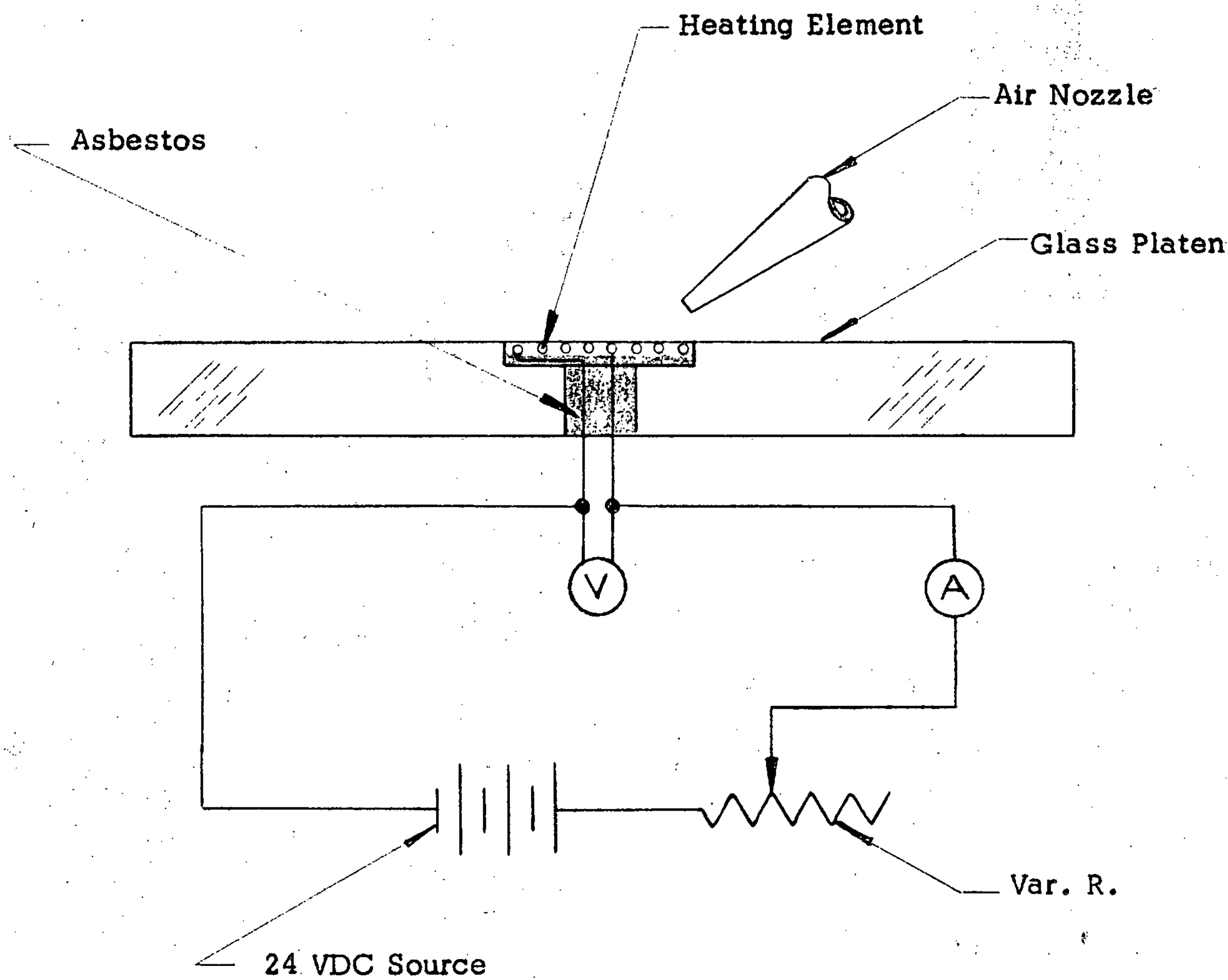

Heating Element
Air Nozzle
Asbestos
Glass Platen
V
A
Var. R.
24 VDC Source

Figure T14-2

a) The incidental sound of the cooling air coming from the nozzles must remain within noise levels acceptable to the operator.

b) The film is allowed to absorb only the amount of heat that will cause no detectible distortion of the film.

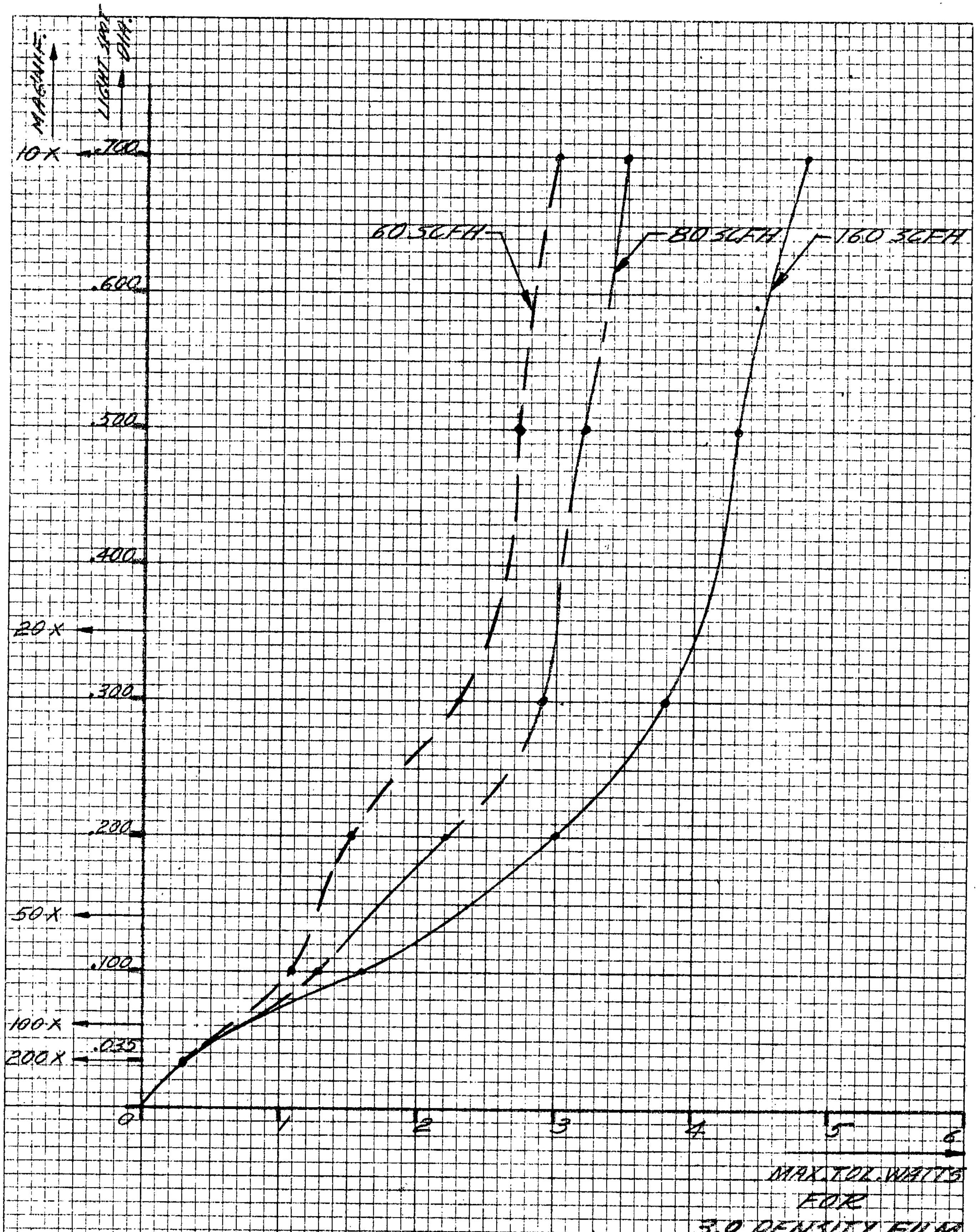
In keeping with criterion a) it was experimentally shown that air flows from a 125 psig source of 60, 80, and 160 standard cubic feet per hour (SCFH) would be acceptable.

As far as criterion b) is concerned, no instrumentation was used to measure film distortion. A permanent mark on the film, noticeable with the naked eye, was considered the condition where excessive heat had been applied. The next lower power setting was the one accepted as permissible.

All testing done, and described in this report, was performed with .005" thick film.

Table I represents results from tests with the heating coils to determine the tolerable heat on the film, while Figure T14-3 is a graph of this data.

Subsequent tables represent data from tests that were performed with a heater button purchased from: MINCO Products, Inc., Part No. H4A10W28. The heater button diameter of .70" represents the light spot diameter on the film at 10X magnification.



EXPERIMENTAL DATA CURVES
OF
HEAT VERSUS MAGNIFICATION

FIG. T 14-3

TABLE I

COIL DIA. (inch)	TOLERABLE WATTS @ Cooling Air		
	60 SCFH	80 SCFH	160 SCFH
.035	.3	.3	.3
.100	1.1	1.3	1.6
.200	1.5	2.2	3.0
.300	2.3	2.9	3.8
.500	2.7	3.2	4.3
.700	3.0	3.5	4.8

TABLE II

Cooling Air (SCFH)	Toler. Heat Button not Insul. (Watts)	Button Temp. With Film (° F)	Button Temp. Without Film (° F)
60	5.1	200	135
80	6.2	212	132
160	6.7	210	123

TABLE III

Cooling Air (SCFH)	Tolerable Heat Button Insulated (Watts)
60	3.2
80	4.6
160	5.8

TABLE IV

Cooling Air (SCFH)	Watts for a 9° F Temp. Rise from Ambient (71° F)	
	With Film	Without Film
60	.018	.14
80	.018	.20
160	.018	.28

TASK 15

OPTICAL SURVEY AND SPECIFICATIONS

This Task was completed June 25, 1967, and report sent to you at that time. See report entitled: Survey Report on Vendor Facilities and Design Capabilities for Proposed Optical System of the Ultra High Precision Stereo Comparator.

TASKS 16, 17 and 18

VIEWING OPTICS, VIEWING ILLUMINATION AND RETICLE PROJECTOR AND ILLUMINATION

I. Introduction

Completion of the Optical subsystem design effort is scheduled for March 15, 1968 in accordance with the information which was imparted to the customer during the November 14, 15, 1967 meetings.

II. Summary

Subsequent to the November 1967 progress meeting, the Optical subcontractor has submitted his progress reports numbered 4 (November) and 5 (December). These reports were submitted by [redacted] in lieu of the December progress report. All subsequent indications from the Optical subcontractor are that the March 15, 1968 date will be met. STAT

III. Conclusion

No further progress information has been received as of this date. **A trip report covering the last visit by [redacted] personnel to the subcontractor which was made the week of January 15, 1968 is attached as Appendix T16,17,18-A.** STAT

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TASK 20

PLATEN ILLUMINATION

I. Introduction

The Stereo Comparator is equipped with general platen illumination to allow for viewing the entire platen area. The platen is arranged for automatic moving to a viewing position adjacent to the operator.

II. Summary

The solution adopted has been to place the cold cathode tube into a shielded enclosure. This was accomplished by using a "SEE AND SHIELD/PANEL" EMC-GLASS manufactured by Technical Wire Products, Inc. - Technit.

III. Conclusion

An illumination system has been designed which is variable over the range of 650 to 2300 foot lamberts. This illuminator has been provided with an RFI attenuation system.

IV. Discussion

The EMC-GLASS is a specially treated non-polarized knitted wire mesh shielding material laminated in a plate glass (or plexiglass) to give optimum shielding effectiveness, yet permitting clear visibility with little distortion or obstruction.

The tube being completely enclosed, the two wires connecting the tube to the H.V. transformer go through a plug located at the bottom side of the enclosure. The cable itself, going to the H.V. transformer is shielded, and so is the transformer which will be located at the rear of the machine. Sketch T20-1 illustrates the final assembly.

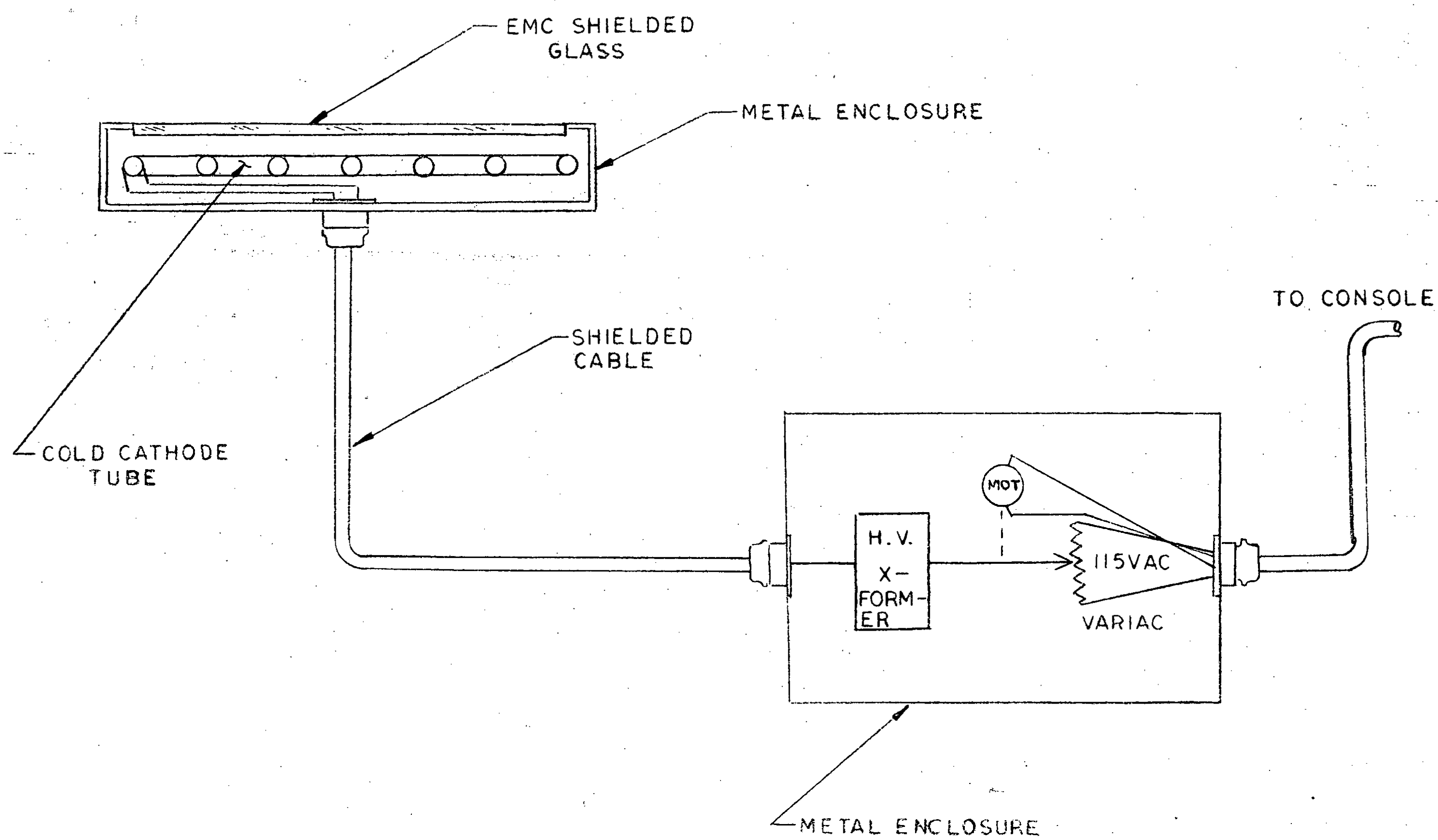

Figure T20-1

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TASK 21

OPTICAL BRIDGE AND SUPPORTS

I. Introduction

The optical bridge provides stable mounting surfaces for the viewing optical train including the reticle projector(1)(2).

II. Summary

The optical bridge is basically three separate structures(3), separated by regions of collimated light so that any shift of the system will be absorbed in this collimated region. The central optical bridge is supported on the vertical section of the main frame(4), and supports the eyepiece and switching assembly(5), the left and right relay system(5), the left and right anamorphic unit(5), and the left and right image dissector(6), and brightness control.

The two other optical bridge structures are the left and right optical bridges supported by the base granite. Each one houses the same equipment, one for left side and one for right side. The optical equipment supported by the left and right optical bridges is the 10 to 1 zoom system(6), the reticle projector including lamp and cooling(7), and the double objective system(6).

The optical bridge structures are fine grain cast iron stress relieved prior to rough machining and stress relieved again prior to final machining to minimize any structural shifting.

III. Conclusions

The optical bridge as designed registers and supports the optical train in a manner acceptable to the functional purpose of the Stereo Comparator.

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REFERENCES

(1)	Task 21	Optical Bridge and Supports II, page T21-1, para. I.
(2)	Task 21	Optical Bridge and Supports II, page T21-1, para. III.
(3)	Task 21	Optical Bridge and Supports II, page T21-1, para. II
(4)	Task 7	Main Frame and Structural Elements Final Report
(5)	Task 16	Viewing Optics Final Report
(6)	Tasks 24,25	Scanning Device, Correlation Logic Final Report
(7)	Task 18	Reticle Projector and Illumination

TASK 22

INTERFEROMETER ASSEMBLY

I. Introduction

The principle use of the interferometer system is to determine the "X" and "Y" coordinates of the measuring stages carrying the film platens.

II. Summary

The interferometer system is comprised of the following elements:

A. A laser source of spatially and temporally coherent monochromatic light.

B. A system of beam splitters and mirrors arranged to create interference bands or fringes.

C. Electronic circuitry for sensing the position of the fringes.

The basic standard of measurement used in the interferometer system is the wavelength of a single mode frequency-stabilized Helium-Neon laser. Under constant temperature and atmospheric pressure conditions, this wave length can be predicted to an extremely high degree of accuracy and thus forms a linear measurement device.

The interferometer assembly is arranged to produce counting signals for each quarter wavelength of movement of the stage (which equals 0.158 micron). The laser system selected for use in the Stereocomparator is the Model #5800 frequency-stabilized laser, manufactured by Perkin-Elmer Corporation(1). Our experience with this unit over the past several months indicates that the reliability and stability of the system are very good.

The servo lock feature of the laser provides excellent control over the output wave length and amplitude. It was found that the system would drift out of resonance due to temperature changes when the servo lock was turned off, thereby necessitating re-tuning of the laser cavity. With the servo lock switched into the system, however, it was found that the laser, when once adjusted to the proper null position, would maintain its adjustment indefinitely. For this reason, we are requiring that the servo lock feature be included in the equipment purchased for the machine.

The collimating telescope which is used to increase the laser beam size from the nominal 1mm diameter to the 6mm diameter required by our interferometer system is manufactured by Spectra Physics. It was found that this particular telescope provided excellent control of beam diameter and collimation. However, due to the extremely short focal length of the lenses used in the telescope, it was necessary to provide an adjustable adaptor ring to allow the telescope to have its optical center line aligned with the center line of the laser beam in order to ensure that the exit beam would lie parallel to the axis of the laser.

The beam splitter and mirror system for the measuring equipment is divided into three mechanical assemblies. A beam splitter assembly placed directly in front of the collimating telescope divides the laser beam into two orthogonal paths so that a single laser may be utilized as the light source for both the "X" and "Y" axes of a single measuring engine. Thus, total requirement for the machine is for two of the laser assemblies.

Mechanical adjustments on this beam splitter, combined with mechanical positioning arrangement for the laser itself, allow the exit beams to be placed parallel to the top surface of the granite and substantially at right angles to one another.

The second major element in the measuring system is the interferometer assembly itself. This consists of a beam splitter and a fixed mirror contained in a mechanical configuration which permits adjustment of each of these devices in all three axes of tilt. The beam splitter and mirror must both possess an extremely high degree of flatness in order to have the interference fringes be reasonably straight and uniform.

The third major element is a mirror mounted upon the stage which is placed in such a way as to reflect the beam from the interferometer back to the interferometer. This mirror must possess an extremely high degree of flatness because deviations from flatness on the part of the mirror may either cause phase shifts in the light beam which would confuse the counting circuitry or cause the axes of the measuring engine to be distorted. Examination of the principles of this system shows that the "X" and "Y" axes of the engine are precisely those of the reflecting surface of these mirrors mounted on the stage, and it is therefore imperative that the mirrors be flat.

The electronic circuitry in the interferometer consists of two photo-sensitive field-effect transistors which receive light from the fringes and develop corresponding electrical signals. In order to raise these signal outputs to a level which is high enough to avoid noise problems when transmitting the signals over the cables leading to the electronic racks, we have incorporated pre-amplifying circuitry. The drift of the electronic circuitry must be extremely low in order to prevent an accumulation of measuring errors over an extended period of time. Drift in solid state circuitry is caused primarily by temperature variations, and even though the environment of the circuitry will be highly controlled, it was deemed necessary to utilize fairly sophisticated techniques in order to arrive at circuitry which would be largely insensitive to temperature changes. It was found possible to design the preamplifier in such a way so as to provide a zero temperature coefficient over a rather large area of temperatures.[2]

III. Discussion

The success of the techniques used have been proven in the breadboard experiments on the measuring engine, and it can be said that temperature instability of the electronic circuitry contained in the interferometer pick up head is virtually non-existent. The other two considerations for the electronic circuitry in the interferometer are bandwidth and signal-to-noise ratio. For the circuit configuration used, it was found experimentally that the bandwidth of the counting electronic circuitry exceeds the requirements imposed on this machine by a factor of three, and signal-to-noise ratios on the order of 20 to 40 db are attained. These values are more than adequate for the digitizing circuitry which the interferometer drives[3].

Adjustment of the interferometer system to provide proper signals is a comparatively simple procedure, although certain important factors must be taken into account. The use of the Twyman-Green interferometer configuration normally causes the beam to return to the light source. This is not permissible with the use of a laser for two reasons. The first of these is that the energy coupled into the laser cavity from the return beam can upset the frequency stability of the laser due to thefact that the return beam contains interference fringe information which may reinforce or cancel the electro-magnetic oscillation occurring in the laser cavity. It was noticed during our experiments that if the return beam were accidentally allowed to enter the cavity, very erratic output fluctuations occurred in the laser. The second reason is that a photocell is mounted on the end of the laser cavity which is opposite to the exit beam end. This photocell is used to provide a feedback signal for the servo lock circuitry and it is found that if the interferometer return beams strike this photocell, the servo lock becomes extremely unstable and may, in some cases, extinguish the light output of the laser altogether. For the above reasons, it is necessary to distort the optical paths of the interferometer system so that the return beam does not enter the laser cavity. It was found that if the return beam is positioned just adjacent to the exit beam of the laser that the small geometrical distortion thereby introduced caused no significant problems or measuring errors.

The second consideration that must be taken into account in the adjustment system is proper collimation of the beam from the laser. It was found that if the beam becomes either convergent or divergent that due to the presence of single-ended input circuitry to the electronics (electronics are sensitive to the absolute value of the light level), as the stage was moved closer or farther away, the brightness level changed accordingly, and DC shifts are produced in the electronic circuitry which can, if severe enough, cause the system to move completely out of its operating range. Proper collimation eliminates this problem.

The third consideration is the mechanical alignment of the moveable mirror on the stage with respect to the interferometer pickup head. It was found that if the mirror is not positioned rather precisely perpendicular to the axes of the measuring beam, as the stage is moved, the return beam tends to shift its position in the interferometer. This effect, if severe enough, can cause the fringes to disappear altogether.

A relatively simple alignment procedure was adopted during our experiments which consisted of aligning the long axis mirror of the measuring engine **closely** perpendicular to the long axis interferometer by means of a Mahr gage (since the long axis has the longest path range and is therefore the most critical), and then using an auto-collimator to set the short axis mirror at **closely** right angles to the long axis mirror. This adjustment procedure was found to produce satisfactory alignment for both axes of the stage simultaneously over the entire operating range of the measuring engine.

IV. Conclusions

The interferometer measuring system as presently designed has shown itself to be a highly accurate and reliable means of linear movement. Generous safety margins with respect to counting speed, signal-to-noise ratio, and thermal stability have been incorporated in order to guarantee maximum counting accuracy and reliability. Our experiments have shown that under ideal environmental conditions the largest error present is below the required threshold for satisfactory Stereocomparator performance. We are thus satisfied that the present system design will be entirely satisfactory as a measuring arrangement for the Stereocomparator.

REFERENCES

Task 22 - Interferometer Assembly

(1) II, Appendix T22-D.

(2) II, page T22-5, paragraph B.

(3) II, page T22-7.

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TASK 23

OPTICS DRIVE SYSTEM

I. Introduction

The Stereo Comparator contains a great number of optical elements, all of which must be simultaneously adjusted to provide proper stereo fusion, to inject the floating reticle spots properly into the optical path, and to provide the correct illumination levels required by the image analysis system and the operator. The optics drive system consists of the various electrical and mechanical components required to adjust the optical elements to produce these desired functions.

II. Summary

In order to accomplish the above objectives, it is necessary to provide three distinct types of optical control system, and these are as follows:

A. Elements which are directly controllable by the computer from information derived from the non-real time program computations and from the correction factors supplied by the image analysis system, or from operator controls.

B. Those elements which are controlled by other optical elements in the system, such as the reticle projector system and components for main illumination source.

C. Elements which are subject to operator control, but are not dependent upon the operation of other elements in the system, such as the reticle size and brightness controls and the objective changeover systems.

In addition to the above components, it is necessary to include circuitry to generate signals which inform the computer of the status of certain of the optical elements in order to coordinate the motions of the optical elements in such a way that the computer does not try to fight operator adjustments or produce incorrect measurement readings due to objective lenses having been moved between measurements. A further function of the control system is the prevention of damage to the film due to excessively high light levels. It is necessary to compute correction signals based on the zoom settings and film density which will adjust the light level in the system to a safe value. These functions are all accomplished automatically in the Stereo Comparator so that the operator need not be concerned with these auxiliary functions.

Optical System Components

The drive components for most of the optical systems include the following items:

(1) Small (1" diameter) motors which contain as an integal part of the assembly DC tachometer generators and planetary gear reduction trains.

(2) High precision multiple-cup potentiometers for feedback, gain adjustment, and follow-up to maintain constant resolution and accuracy of the system.

(3) 35 watt, 12 volt amplifiers designed and packaged by STAT

specially for the purpose of driving these systems[1].

(4) Limit relay assemblies which provide overtravel protection on systems which have mechanical travel limits. A two-stop system is used. As one of the mechanisms approaches its limit of travel, the first limit switch contacting causes a STOP command to be issued to the servo amplifier, which causes the system to come to a stop with maximum deceleration. The circuitry is arranged so that the mechanism can be backed away from this stop, but further travel in the direction of the limit is not permitted. The second limit is used only in the event of component failure and it activates relay circuits which virtually disconnect the motor from the drive circuitry, and it is necessary therefore to manually back the mechanism away from this limit in the event the limit is ever reached. Under normal operating conditions, however, this will not occur.

(5) Analog control unit assemblies which perform various scaling and offset functions by means of operational amplifiers, and comprise the electronic circuitry which handles the inter-relationship of elements between the various optical systems. In addition, the relay control circuitry which accomplishes changeover of the operator controls for reverse stereo operation and the relay control circuitry which places the computer-controlled elements in either the manual or automatic modes of operation is located within this unit. The auxiliary control signals which are sent to the computer are generated within this assembly as well.

(6) A relay control unit which supplies power to the various motor systems that are not amplifier-driven and which contain the circuitry necessary to perform the lens changeover functions.

(7) A multiplexed A/D-D/A converter to provide interface with the computer.[2]

III. Conclusions

The use of both digital and analog position feedback loops for the optics servomechanisms provides rapid and accurate control of both the optical elements used to produce the stereo model and also the auxiliary control functions used to produce uniform reticle characteristics and lighting control. The basic assucracy of the system is:

(a) for angular servo elements, $\pm 1^{\circ}$

(b) for linear servo elements, $\pm 0.5\%$

Sufficient servo bandwidth is provided to produce stereo fusion under dynamic conditions as well. In addition, every consideration has been given to operator eye comfort and safety.

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IV. Discussion

Optical Systems which are Computer-Controlled

There are four optical assemblies in each optics train which can be directly controlled by the computer in order to produce stereo fusion. These are the viewing zoom system, the anamorph stretch ratio system, the anamorph axis rotator, and the image rotator. Construction of the elements in these four systems are all substantially the same, although certain differences are required to take into account the fact that the rotation elements have a continuous range, whereas the linear elements (zoom and anamorph stretch ratio) have limited ranges of operation. A typical system of this type consists of a rather high-stiffness rate loop contained within an analog position-feedback loop. Feedback for the position loop is derived from high-precision potentiometers located in the optical mechanical assembly. Rate feedback is derived from a tachometer mounted directly in the motor housing. This analog position loop lies in turn within a digital position loop which adds the effects of the computer tracking signals and image analysis correction signals. Interface to the digital equipment is provided by a multiplexed D/A - A/D converter which also contains sample-and-hold circuits to supply the error signal during the periods between successive computer output cycles. The computer scans the optical trains at a rate of 30 scans per second by successively addressing analog switching circuitry in the D/A - A/D converter. When the computer has addressed a given system, it proceeds to issue a command to the A/D converter which was connected to the analog feedback information at the time the particular system was addressed by the computer. Upon completion of the analog-to-digital conversion, the A/D converter signals the computer to indicate completion of this operation. The computer then reads the setting of the optical element in digital form and generates a command position based on the tracking information derived in the non-real time program and the correlator correction signal. The computed output position is routed to the D/A portion of the A/D - D/A converter and the computer simultaneously addressed the optical system for which the signal is intended. This addressing operation gates an analog switch which allows the analog voltage produced by the D/A converter to be gated into a sample-and-hold circuit connected to the input of the desired servo system. On succeeding scans, the computer does not sample the analog feedback circuitry, but merely computes a predicted position based on the tracking information derived from the non-real time program. The correlator error signal is also applied at every scan to provide a rather tight feedback loop around the entire optical train, and a mathematical analysis of the entire computing operation shows that theitracking parameters appear in the system only as inputs, whereas the correlator error signals appear as a digital integrated feedback signal. The consequences of this scheme on the operation of the system are that the tracking information is used during abrupt motions of the stage and optical elements, and the correlator feedback signals are used to drive the optical systems very accurately to null to reduce steady-state error of the system to acceptable limits.

Elements Controlled by Other Optical Elements in the System

The settings of some of the optical elements in the Stereocomparator are determined by the settings of other portions of the optical train. These include the reticle zoom system, the illumination system, the reticle anamorph ratio system, the reticle image rotator system and the illumination brightness control system.

In order for the floating reticle dot to appear round at the eye pieces after going through the main viewing optics, it is necessary to provide control over the reticle size and shape so that the image of the reticle dot is passed through optical elements whose transfer functions are complementary to the settings of the optical elements in the main viewing path. This is accomplished through the use of optical servo-mechanisms, containing elements very similar to those located in the main viewing path, controlled by the main viewing elements. The main viewing zoom system contains a potentiometer which provides a follow-up signal used to drive both the reticle and illumination zoom systems. Amplifiers fed by this follow-up pot adjust scale factors and offsets to provide signals to servo amplifiers; these amplifiers drive the reticle and illumination zooms so that the projected reticle size remains constant at the eyepiece, and the illuminated area on the film encompasses just the field of view of the main viewing optics. Similarly, a follow-up pot in the main viewing anamorph ratio system provides a signal which is proportioned by an amplifier to cause the reticle anamorph system to pass the reticle spot through an optical transfer function complementary to that of the main anamorph viewing element. The continuous-rotation capabilities of the main anamorph axis rotation system presents some problem in providing a follow-up function for the reticle image rotator system. In order to allow the reticle image rotator to continuously follow the anamorph rotator system (which has unlimited rotation capabilities) it is necessary to use a two-phase command system for the reticle image rotator. The analog position potentiometers located on the main anamorph rotator each have a "dead zone" and these two "dead zone" areas occur at angles displaced by 180°. It is therefore not possible to utilize only one follow-up potentiometer to drive the reticle image rotator, and both of the anamorph rotator pots are utilized. Two amplifiers process the potentiometer signals separately. The reticle image rotator system contains a four cup commutation and feedback potentiometer assembly which provides not only the position feedback signals for the reticle image rotator loop but also decides which of the two error signals the system will obey. The net result of this arrangement is that the reticle image rotator can continuously follow the angle of the anamorph rotator to adjust the complementary axis of the reticle system at the same angle as the stretch axis of the main viewing system. Thus a round reticle spot is always obtained at the eyepiece. It is not necessary to include a field rotator in the reticle system because of the circular shape of the reticle spot itself.

An automatic control system has been incorporated in the Stereocomparator which maintains the average illumination level to the eyepiece and to the image dissector tube of the image analysis system at a substantially constant level. This constant brightness level is required in order to assure uniform performance of the correlation circuitry regardless of film density, and to allow the operator to maintain the required light level necessary to distinguish small density differences even at high film densities. The illumination level applied to the film is controlled by means of variable-density filter wheels placed in front of the main illumination source, and control for the position of these variable elements is derived by means of a photomultiplier pickup assembly located in the optical bridge near the image dissector assembly. Since the optical image supplied to the photomultiplier tube has passed through the entire optical train it can be seen that the correction signal derived from the photomultiplier takes into account the settings of all of the main viewing optical elements. The system is adjusted so that the sum of the film density and filter wheel density remains constant and thereby produces a uniform illumination level for all conditions of film densities.

In order to maintain an acceptable light level at the eye pieces and image dissector tubes under all conditions of magnification for the optical train, it has been necessary to incorporate a variable illuminated area arrangement in the Stereo Comparator. As the magnification of the system is increased, the field of view decreases proportionately, and in order to maintain a reasonable constant light level at the eye piece, it is necessary to vary the illuminated area on the film in such a fashion as to just encompass the field of view covered by the main viewing system. As magnification of the viewing system increases (with corresponding decreases in field or view), it can be seen that the light from the main illumination source is concentrated on a smaller and smaller area. The heat absorbed by the film from

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the illumination source is a function of film density, and under the simultaneous conditions of high magnification and high film density, it is possible to have enough energy absorbed by the film in a small area to cause localized heating and even distruction of the film. In order to prevent this, additional control circuitry has been incorporated in the illumination brightness system which samples the zoom setting of the system and the position of the vairable density illumination element (thereby deriving an indication of the film density), and computes a non-linear function which is applied to the illumination brightness system. Thus if the operator adjusts the zoom, and the photo cell system attempts to adjust the brightness control to dangerous operating point, this computing circuitry produces an override signal which prevents the illumination level from rising to a point which would damage the film.

An additional condition can occur which might be uncomfortable or damaging to the operator's eyes. This condition occurs when scanning a film of high density which has much lower density areas adjacent to the high density areas. Such a film might be one in which a picture is taken of the ocean at night with a moonlit cloud cover appearing in areas of the picture. If the operator had the system adjusted for the very dark-appearing ocean and suddenly scanned into the cloud-covered area, he would experience an extremely large increase in brightness (monentarily) until the illumination brightness control system had a chance to reduce the light level applied to the film. In order to prevent possible eye damage or temporary blinding of the operator, we have incorporated a high speed shutter system which is controlled by the photomultiplier pickup head circuitry. If the light level increases suddenly by more than 50%, a signal is produced which activates a shutter within .001 second to block the light from the operator's eye until the servo has reduced the light level to a safe value.

Auxiliary Control Functions

Certain of the optical elements in this system are subject to arbitrary settings by the operator. These elements include the reticle size control, the reticle brightness control, objective lens focus controls, and objective changeover controls. These elements are not actually part of any servo loop in the system and are therefore driven by relatively simple two-speed bi-directional relay control circuits. A relay control unit has been incorporated into this system which allows the operator to arbitrarily adjust any of these mechanisms.

The objective changeover is an automatic device which causes the illumination system to change range simultaneously with the change of objective lens. Control of this function is supplied by lighted pushbutton switches located in the console keyboard assembly. In addition to performing the actual changeover operations, the circuitry in the changeover system supplies certain signals to other portions of the Stereocomparator system. An interlock signal is supplied to the computer which indicates that the objective has been changed, and the computer will require new orientation measurements due to the fact that changing the objectives shifts the optical exis of the system slightly, thereby possibly invalidating previous measurements.

The changeover circuitry also supplies range signals to the illumination brightness control system so that the operating point fo the film burn-prevention circuitry is adjusted to take into account the selection of the objective lenses. Additional circuitry causes the feedback signal from the photocell pick up heads to be disconnected from the illumination brightness control assemblies during the actual period of objective change-over. If this circuitry were not present, the fluctuation of light level during the actual changeover operation would cause the illumination brightness system to run to unpredictable light levels, and when the objective lens swung into the viewing path possibly dangerous light levels would be present. As the system is presently arranged, whenever the objective changeover system begins to move, the illumination system is commanded to run toward a minimum light level condition until the objective changeover operation is completed at which time the brightness control system comes back into operation in the normal manner.

REFERENCES

Task 23 - Optics Drive System

(1) VII, page T23-1.

(2) VII, page T23-4.

TASKS 24 and 25

SCANNING DEVICE and CORRELATION LOGIC

I. Introduction

The above two tasks were originally defined separately since it was thought that Task 24 would serve two functions (see below), only one of which was related to Task 25. It turned out, however, that the second function was not needed, and Tasks 24 and 25 were in fact two parts of the design of one system - The Image Analysis System. For this reason, the two tasks will here be described as one.

In the work statement prepared prior to the final contract negotiations Tasks 24 and 25 were described separately as follows:

Task 24 - Scanning Device - The requirements for scanning needs (video pickup devices) are two-fold. The primary requirement is as a source of video for the image analysis (correlation) systems. The secondary requirement is as an input to the closed circuit TV monitor system. The optical pickup point is just ahead of the eyepiece, hence the image scanned is essentially that seen by the operator.

The resolution should be as high as practical, consistent with the scanning rate used. Scanning rate should be at least 60 frames per second as a goal with consideration given to the practicality of 120 frames per second. The video bandwidth should match the space frequencies of the optical image (estimated at 100 to 40,000 elements in the field of view).

Based upon the above, the type of photo pickup device will be determined (i.e., vidicon or image dissector), and the design of the device (if image dissector) and/or specifications will be defined. Then camera design can proceed (two pickup tubes for each camera), based upon the factors described. The task shall include signal through video amplifier output, ready for correlation inputs. Note that one complete scanning device is required for each optical train.

Task 25 - Correlation Logic - Electronic correlation logic is to be developed which will, as a design goal, implement the concepts of an image analysis system. Video signals from the scanning system will be used as input. Output will be two analog signals which are approximately proportional to the X and Y axis linear displacements of one image with respect to the other. Bandwidth and signal to noise ratio should be adequate for image displacements ranging from 1/2% to 10% of the diameter of the scanned image.

II. Summary

During the final contract negotiations the work statement for Task 25 was, in effect, enlarged to include the possibility of a 6 signal Image Analysis System as an alternate to the 2 signal system described. It was agreed that the contract price was based on the design of a 2 analog output signal image analysis system. It was also agreed that [redacted] would explore the worth of a 6 output signal system and that, should such an enlarged system prove desirable, there would be grounds for an increase-of-scope negotiation. As will be described, the relative advantages of the 2 signal versus the 6 signal version were subsequently explored. The final outcome was the design (via a subcontract) of the 6 signal version, and it is this design which is being delivered at the conclusion of the contract. No negotiation for increase-of-scope has taken place, however.

A little before the time of the final contract negotiation, [redacted] STAT
received an unsolicited proposal from the [redacted] to undertake STAT
a subcontract for design of an "Image Registration System". The proposal included the servo systems for the stages and for the optics, as well as the scanner-correlator portions which later were called the "Image Analysis System". [redacted] analyzed this proposal and determined that it contained STAT
serious weaknesses in the methods used to obtain the servo signals. The latter involved what were effectively analog computer circuits which provided insufficient separation between the six different axes and which required an organization of correlation with poor signal-to-noise ratios.

[redacted] devised a means[1] for using a digital computer to replace STAT
the analog computing circuits in the [redacted] proposal. The greater computa- STAT
tional power of the digital computer meant much greater separation of the six axes, to the point that cross coupling is practically negligible. It also allowed a different scheme for organizing the various types of correlation which resulted in higher signal-to-noise ratio.

A specification[2] was written for an Image Analysis System. This specification clearly defined two alternates, a two-signal version and a six-signal version. It was written in such a way that quite probably [redacted] could design a system meeting all of STAT the requirements. It was also written in a way which it was hoped would encourage competitive bidding by other companies, at least the two-signal version if not the six-signal system. This specification was sent to thirty companies with an RFP based on an anticipated contract with four months duration.

Although a number of companies indicated a capability to design at least the two-signal system, only [redacted] STAT replied with a responsive proposal. The other companies all considered four months to be insufficient time in which to execute a design meeting the requirements of the specification. [redacted] STAT

[redacted] submitted a proposal offering to deliver a design for STAT the six-signal version within the four-month period but stating that a substantial part of this design would remain proprietary [redacted] STAT

[redacted] STAT

After clearing with the Government that [redacted] would STAT withhold rights to the alleged proprietary portions of their proposed design, [redacted] held a negotiation with the [redacted] and subsequently granted them a subcontract. STAT The subcontract called for delivery of a six-signal Image Analysis System designed according to a slightly revised(3) version of the specifications referred to above, and attempted to spell out which portions would remain proprietary [redacted] STAT

III. Conclusion

With [redacted] monitoring, Itek performed satisfactorily STAT
on the subcontract and delivered the completed design according to schedule. Items delivered included a Final Report(4)*, interface drawings, and manufacturing specification drawings. Because of the proprietary reservations, the drawings are not sufficient for manufacturing by anyone except [redacted] but this situation STAT
had been cleared in advance with appropriate representatives of the Government.

During the time span in which all of the above occurred, several decisions were made regarding alternative possibilities which had been stated in the work statement.

1. It was found that the closed circuit TV monitor would be useful for only one purpose - point finding in connection with the recall operation. [redacted] and Government technical monitors STAT
together worked out a different scheme for point finding and recall, thus entirely eliminating the need for a TV monitor. As a result, the dual camera units described for Task 24 could now be simplified to camera units satisfying only the requirements of the Image Analysis System.

2. Although Task 24 was written to allow the possibility that the camera tubes used might be vidicons, it was already felt that Image Dissector tubes would probably be required. Further analysis confirmed the requirement, and the specifications for the

*The following [redacted] reports are included as appendices to this STAT
report: "Operating Instructions for the Image Analysis System", Appendix T24-A, and "Breadboard Tests and Components of the Image Analysis System", Appendix T24-B.

Image Analysis System firmly called for Image Dissector Tubes. [redacted] STAT subsequent proposal stated that [redacted] had reached the same conclusion STAT as a result of their experiments.

3. As has been stated, the decision to use a six signal correlator was made partly by default, i.e., no one bid on designing a two signal correlator. It should be noted, however, that during the time span in which the I.A.S. specifications were prepared and bid obtained, a related, though separate, activity was also going on. This was analysis and testing of the computer program (Task 43). By the time bids were received for the I.A.S., it had been pretty well determined that the computer program was capable of making the extra computations required for a six signal correlator in the time available for such computation. Had this not been the case, then the original scheme with a two signal correlator would have been the only practical one.

REFERENCES

Tasks 24 and 25

(1) I, Task 25, pages T25-1 to T25-8.

(2) IV, Task 25, Appendix T25-C

(3) VI, Task 25, page T-25-1, Figure T25-1, Appendix T25-D

(4) XI, Task 24 and 25, pages T24-1 and T25-1, Figure T24,25-3

TASK 26

DIGITIZING LOGIC SUB ASSEMBLY

I. Introduction

The digitizing logic consists of analog amplifier circuitry and digital circuitry which transform the sinusoidal outputs of the interferometer preamplifier circuits into direction-sensitive pulses used to drive the various counting circuits in the Stereo Comparator.

II. Summary and Discussion

The analog circuitry consists of operational amplifiers which raise the level of the interferometer signals and allows adjustment of the DC level of these signals as well as frequency compensation.[1] These amplified analog outputs are then routed to the digitizing circuitry which makes the conversion into pulses.[2]

In order to facilitate adjustment of the interferometer assembly, additional circuitry has been included which will aid maintenance personnel in performing the required electromechanical adjustments. This circuitry includes a symmetry-indicating circuit which allows the DC level of the interferometer to be adjusted so as to provide symmetrical square wave outputs from the Schmitt triggers, and a digital phase meter which shows the phase relationship between the two interferometer channels.

These various test circuits are routed to a switchable galvanometer located on the digitizing logic chassis front panel, and in all cases, a center-scale reading indicates that proper operating conditions have been

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attained. The digitizing logic assembly also contains the power supplies which provide the operating voltages for the interferometers themselves. This power supply circuitry is highly filtered and shielded against RF interference in order to prevent the possibility of interference disturbances causing false counts in the system.(3)

III. Conclusion

Our breadboard testing of this equipment indicated that it provides a convenient means for adjustment of the various parameters within the interferometer counting system, and provides extremely reliable measurement of the positions of the measuring engine stages.

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REFERENCES

Task 26 - Digitizing Logic Sub Assembly

(1) II, page T22-8, paragraph 3.

(2) II, page T26-1.

(3) VII, page T26-1.

TASK 27

METRIC READOUT

I. Introduction

Mensuration techniques and programs are well developed, and are based upon the international "standard meter" as the common unit of length. All measurements are referred back to the "standard" which is a very well known and well defined quantity, accepted throughout the entire world. Historically, the meter was defined as one ten millionth (10^{-7}) of the distance from pole to the equator of the earth. Later it was redefined slightly as the distance between two lines scribed on a platinum bar.

Now we are measuring distances in terms of the wavelength of light -- specifically the red line at approximately 6328 Angstrons - the line for Helium Neon. The relationship to the standard meter is well known and defined, but very awkward to work with. A quarter wave-length is approximately 0.1582049575 microns in length. (A micron being one millionth of the meter.)

II. Summary

In order to circumvent the nuisance of odd numbers and to get everyone back in step with the metric system, [redacted] had proposed, STAT designed, built and tested a proprietary Metric Readout System. This system is essentially an electronic converter, taking quarter wave-length counts (0.158204 microns) from a specifically designed interferometer, and accumulating equivalent 0.1 micron counts.

III. Discussion

While it is true that the ratio between the quarter wave length of the laser light used, and 0.1 micron is not an integral number, it is a number with a ratio very close to 8 to 5. This fact is used to build a simple systematic converter. The trick is in correcting the accumulating metric number from time to time as outlined in the disclosure [redacted] STAT [redacted] (1) STAT

With corrections performed according to the disclosure, no metric number will ever be more than 0.25 microns from its real value, and will normally be less than 0.1 microns from its actual value.

The ratio of 8:5 results in a number between the integers 1 and 2. If one were to count quarter wave lengths, and assign the value of 1 or 2 to each quarter wave length increment in a given manner, a table could be constructed which would give a metric equivalent for each and every quarter wave length position. (2) Indeed, this is the way the Metric Readout works.

The scheme is physically implemented by means of two counters, one counting the quarter wave length increments in integral fashion. The second counter, the Metric Counter, accumulates counts at an input of 1 or 2 for each quarter wave onput of the other counter. The count of 1 or 2 is determined by the position (or count) in the quarter wave length counter. Both counters, of course, are reversible, and the operation is the same whether counting upwards or in the downward direction.

One important feature of the Metric Readout system is its settability. Any number can be preset into the counters at any time, or they can be reset to zero. Direction, being a vector quantity, has its associated sign. The counters will count up (plus) for a selected direction of stage motion, and down (minus) for the other direction. At zero, the counter will change sign and count upward (magnitude) with the opposite polarity. Thus plus and minus coordinates are readable directly from the Metric Readout. Because the count (into the Metric Counter) can be either 1 or 2, special circuitry must be employed to ensure that around zero, counts and direction are properly accounted for.

Several methods were employed to ensure that the metric readout was doing exactly what it was designed to do.

Comparison of quarter wave length counts with 0.1 counter indication was made.

Random counts were fed into the system, with an external counter accumulating these quarter wave length counts. The quarter wave length number was inserted into the methematical formula.[3] The numerical result was compared to the number in the metric readout counter, and in each case there was agreement.

Second method was to take the number of quarter wave length counts in the external accumulator and multiply by 0.1582049575. The product and the reading in the metric counter had to agree, which they did within one count.

IV. Conclusion

Tests were run on the breadboard stage. A Sheffield Air Gauge

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with least count divisions of 10 millionths of an inch (1/4 micron) was used as the stage reference position. A lapped piece of steel was attached to the stage as an anvil for the Sheffield gauge in order to ensure accuracy. A number was set into the metric counter, about 2-1/2 to 3 microns, so that zero crossings would not be confusing when trying to find a reference position.

The test consisted of putting a simulated preposition number into the count down register. The stage moved to the new position, then was brought back carefully to the original position as indicated on the metric readout. The position as indicated on the Air Gauge was generally within 1/8 micron, about the readable limit. Occasionally a bit of sticktion was noticed, but if the stage were moved a few microns and returned, the reading was right there where it had been at the start, within a small part of a quarter micron. It should be noted that vibrations of the room caused a varying reading of a quarter to half a micron on the metric readout, so average readings were taken. The second place (micron) digit was steady, unless of course the reading was near the zero tenth micron digit.

It should be further pointed out that the above tests were made with accelerations above those specified for the stage, giving a great degree of confidence in the overall system.

Cross reference is directed to Task 42 of this report.

REFERENCES

Task 27 - METRIC READOUT

(1) Report #1 (January 9 through February 24, 1967) Appendix C.

(2) See Appendix C. Report I, Tables I and II.

(3) Appendix C.

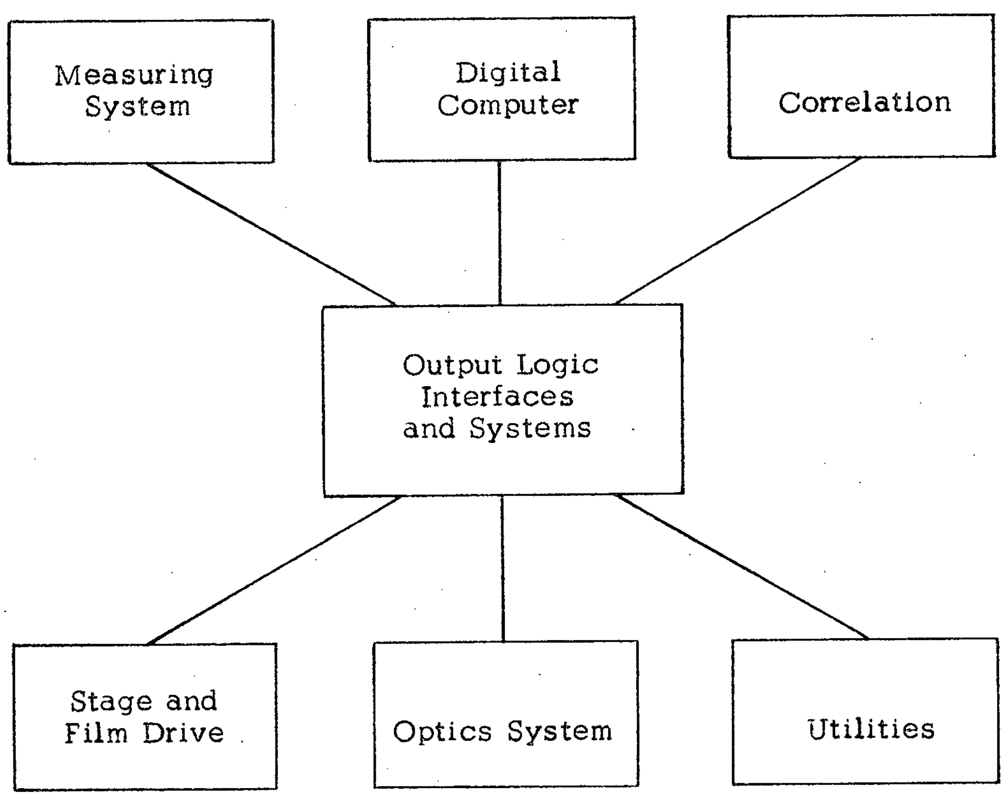
TASK 28

OUTPUT LOGIC, INTERFACES AND SYSTEMS

I. <u>Introduction</u>

The major components of the Stereo Comparator are:

1. Measuring System[1]
2. Digital Computer[2]
3. Correlation[3]
4. Stage and Film Drive[4]
5. Optics System[5]
6. Utilities[6]
7. Output Logic, Interfaces and Systems



1. The Measuring System contains the interferometer assembly, the digitizing logic and the metric readout. Measuring, displaying or storing the X and Y coordinates of the stages are performed by the Measuring System.

2. Digital Computer

Used in conjunction with the optical-electronic correlation circuitry, the computer controls the setting of the various optical elements and the position of the measuring stages so as to maintain an optical presentation of a stereo model for operator viewing. The computer, in effect, continuously extrapolates from regions of two photographs known to be in stereo correspondence in order to predict adjacent regions which are in near correspondence.

3. Correlation Image Analysis

The Correlation supplements the computer analysis by establishing error signals showing the extent of lack of correspondence (between two regions) and signalling the computer whenever exact correspondence exists.

4. The stages can be directly driven, when in Manual or Enter mode, by actuation of the joystick or trackball. In Auto mode, joystick and trackball signals are first fed into the computer which in turn provides the proper input to the stage drive. The stage position is known to the computer by sampling the stage position counters.

5. The optical systems such as

Illumination

Focus

Magnification

Anamorph

Reticle

Image Rotation

are manually activated from the console or computer controlled.

6. The Utilities controls and monitors air pressure, air cooling, air bearing flow, vacuum, etc., throughout the whole system.

7. The Output Logic Interfaces and Systems can generally be thought of as the Master link between all the 6 previous subsystems mentioned.

Following is the final report on the interface logic. The report has been subdivided into 10 different sections which are outlined in Drawing SK-396A, Figure T28-1, some of which have already been completely described in previous reports, in which case a reference is indicated.

II. Technical Discussion

1. Mode and Control Selection.

The logic described herein relates the MANUAL, ENTER, AUTO W/O ELEC. CORR., AUTO W/ELEC. CORR., JS-L, JS-R, JS/TB BOTH and TB INDEP. keys to the transfer of data from the trackball counters and the joystick digital outputs of the A/D-D/A Converter[7] to either the Internal Computer and the Electronic Correlator or to the stages. It also relates the OPTICS INDEP. and REORIENT keys to the Internal Computer. This logic is compatible with the flow chart shown under Task 43.

The four mode keys MANUAL, ENTER TYPE & RECORD, AUTO W/O ELEC. CORR. and AUTO W/ELEC. CORR. are mutually exclusive and set corresponding flip-flops. When the machine is first turned on none of them is active, leaving the stage and optics controls inactive. When either MANUAL or ENTER and JS/TB BOTH are active the Trackball Counter bits or Joystick digital outputs from the A/D-D/A are fed in parallel to the left-right gates feeding the Stage Drive Counters.

If either or both stage readout selections are made, either automatic mode may be selected by the appropriate key in which case a level (SKS 75 or 76) from the flip-flop activated by the chosen mode key will signal the computer to use the trackball or joystick data available on the INB of the computer in the appropriate program. If either stage interlock is made and that stage readout is selected or both stage interlocks are made, an "Interlock" level is sent to the computer (INA 21-13). If only a single stage has been selected and the corresponding interlock is lost, or if both stages have been selected, whether or not currently active, and either interlock is lost, the "Interlock" level to the computer is lost and the machine mode is reset to MANUAL unless it is in ENTER.

Activation of any of these four mode keys enables the optics controls. However, if an automatic mode has been selected, upon release of an optics control, the optics will return to their position determined by the computer model.

The JS-L, JS-R, JS/TB BOTH and TB INDEP. keys determine how the joystick and trackballs control the right and left stages when in MANUAL or ENTER TYPE & RECORD modes, or the right and left views when in the AUTOMATIC modes. Figure T28-4 in Report #8 shows the six control connections which may be made with the four keys. The JOYSTICK/TRACKBALL BOTH key resets the JOYSTICK LEFT or JOYSTICK RIGHT state and the TRACKBALL INDEPENDENT state. The JOYSTICK LEFT AND JOYSTICK RIGHT keys reset the opposite state. The JOYSTICK LEFT or JOYSTICK RIGHT state in conjunction with the TRACKBALL INDEPENDENT state resets the JOYSTICK/TRACKBALL BOTH state.

In either the MANUAL or ENTER mode, connection of the joystick and trackballs to the Stage Drive Counter left/right gates is as described in Section 3. The connection of the trackballs is controlled by two lines from the JS/TB BOTH flip-flop and the TB INDEP. flip-flop. Line A only (see SK-396A) is active whenever the TB INDEP. flip-flop is set, while both A and B are active when the JS/TB BOTH flip-flop is set and the TB INDEP. is not set. The connection of the joystick is controlled by two lines from the JS/TB BOTH, JS-R and JS-L flip-flops. Both lines C and D are active when JS/TB BOTH is set and neither JS-L nor JS-R is set, while C alone is active when JS-L is set and D alone is active when JS-R is set.

When in either of the automatic modes, if the TB INDEP. key is active, as soon as either trackball is moved, a flip-flop is set which provides a "0" level to the internal computer (INA 05-11). As soon as the computer tests this level, it goes out of the stereo tracking program into a program where the trackballs control the stages independently, but with proper optical correction. Which trackball controls which stage depends on whether the eyepiece is in the NORMAL STEREO (INA 05-10) or REVERSED STEREO (INA 05-7) position.

Either pressing the JS/TB BOTH key, and hence resetting the TB INDEP. key, or moving the joystick puts the computer back on the tracking program. If the latter action was taken, operation of the joystick moves the stages with stereo tracking, and subsequent use of the trackball moves the stages individually, since the TB INDEP. key is still active.

Likewise, in either automatic mode, if the JS RIGHT or JS LEFT key is depressed, as soon as the joystick is moved, a flip-flop sends a "0" level to the computer (INA 05-11) and only the designated stage moves with operation of the joystick. Then pressure of the JS/TB BOTH key or operation of either trackball takes the computer back into tracking. The latter action allows subsequent use of the joystick again in the designated independent type of operation, since the JS RIGHT or JS LEFT key is still active. The eyepiece modifies left and right stage control as with the trackball.

In the AUTO W/O CORR. mode both TB INDEP. and either JS RIGHT or JS LEFT may be depressed, in which case both the joystick and the trackballs will control the stages independently. Tracking may be regained by pushing JS/TB BOTH.

The optics-independent condition may be alternately activated and deactivated by pressure of the OPTICS INDEP. key. The associated flip-flop sends a level to the internal computer (INA 05-13) to allow independent manual readjustment of the two optics trains. That is, any manual control of an element on one side will not cause the corresponding opposite element to move.

If an automatic mode is selected and the computer has been taken out of stereo tracking, or the OPTICS INDEP. is active, the REORIENT key may be activated. This key sets a flip-flop which sends a level to the computer (INA 05-12) and also sets additional flip-flop (Optics Indep. reset). Operation of a MAG control also sets these flip-flops.

Upon receipt of this level, the computer stereo-tracking model is updated to be compatible with the present stage and optics settings. (See Task 43 of the September Report.) An OCP pulse (OCP 05) is emitted from the computer at the end of this updating which resets the REORIENT condition. If the REORIENT key has been used with the OPTICS INDEP., the OPTICS INDEP. will be reset as soon as the computer goes into tracking (INA 05-11). This facility is implemented with an additional flip-flop which gates the no-stage-control-independent line (INA 05-11) to the OPTICS INDEP. reset when set. This flip-flop is then reset when the OPTICS INDEP. flip-flop is reset and the computer is tracking.

The AUTO W/ELEC. CORR. flip-flop enables the electronic correlator. If this mode is selected and the electronic correlator is correlating a level is sent to the computer (INA 21-16). If not, or if the optics, joystick or trackball is in an independent condition, the ELEC. CORR. INOP. light will light.

2. Trackball Counters.

The trackball counter uses a forward-backward binary counter DTC #524 with a capacity of 4 bits per module. Nine bits plus a sign bit are required; therefore three cards are used. The total counter capacity is 1024 counts.

The trackball has a 25 pulse per turn encoder. With a gear ratio of 4.5, the number of pulses generated in one revolution of the trackball is 112 pulses.

Refer to Figure T28-2 for the following discussion.

The Phase 1 output pulse leading edge of the trackball pulse is applied to one shot #1; the trailing edge fires one shot #2. The Phase 2 output pulse is applied directly to a series of gates, and this pulse, combined and gated with the #1 and #2 one shot pulses determine the up and down direction as far as the trackball counter is concerned.

Flip-flop #1 is set by the leading edge down pulses and reset by the leading edge up pulses. The outputs of FF#1 are

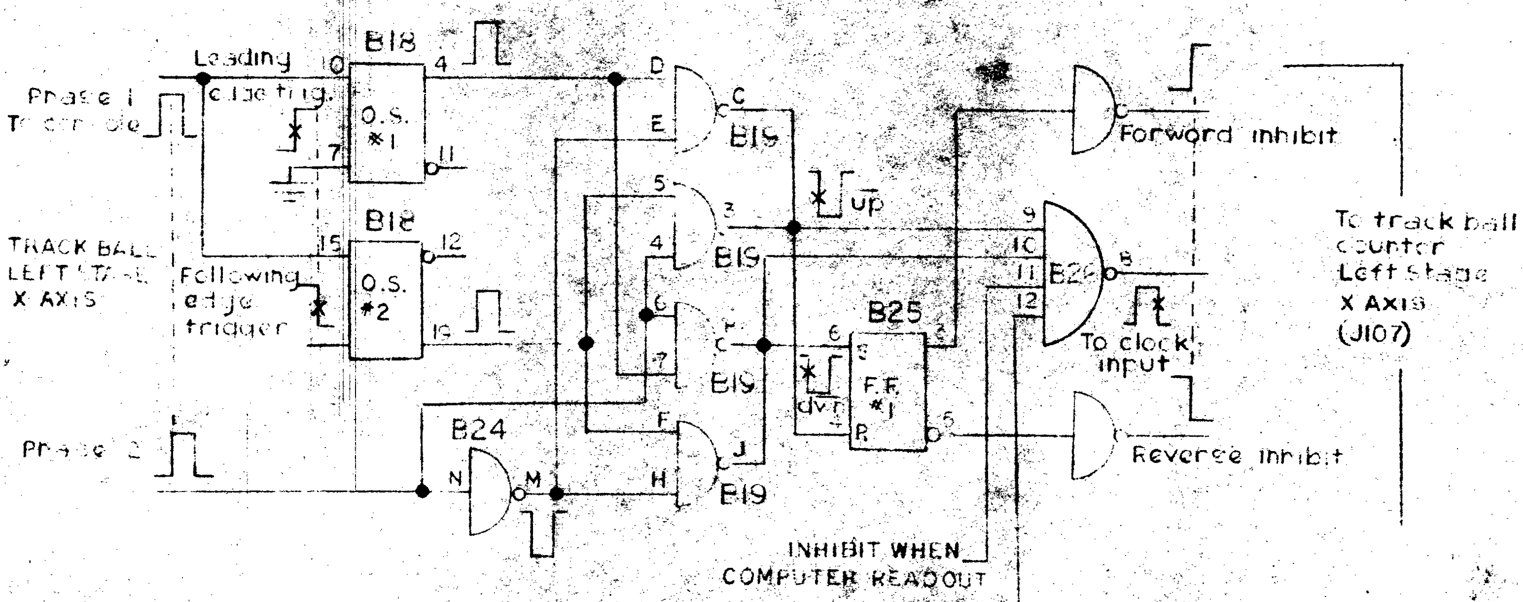


FIG. T 28-2

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respectively applied to the proper inhibit input of the trackball counter. When counting "up" FF#1 is reset by the up pulse, FF#1 pin 5 output is high and through an inverter applies a negative signal to the reverse inhibit.

Reversely FF#1 pin 3 output is low and through an inverter applies a positive signal to the forward inhibit which enables the counter to count forward.

Both up and down pulses are applied to the clock input of the counter through a four-input gate. The two other inputs to the gate are inhibit lines:

1. Inhibit trackball counter when computer readout of the counter takes place.
2. Inhibit trackball counter when readout in manual mode takes place.

In both cases, the inhibit is required to allow the counter to ripple through and settle down before readout. In AUTO W/CORR. or AUTO W/O CORR. the trackball counter outputs are fed into the internal computer.

An OCP instruction sets a flip-flop which:

1. Inhibits all 4 trackball counters
2. Sets the ready line DRLIN
3. Enables the INA address gate to the trackball counter outputs.

The OCP instruction is followed by 4 INA instructions to readout the 4 trackball counters (2 per stage) if the program calls for it. The last

INA is gated with RRLIN to provide a reset pulse to the ready flip-flop, and to re-enable the trackball counters. The 9 magnitude bits of the trackball counter are connected to the 9 lowest significant bits of the computer input bins as shown in Figure T28-3.

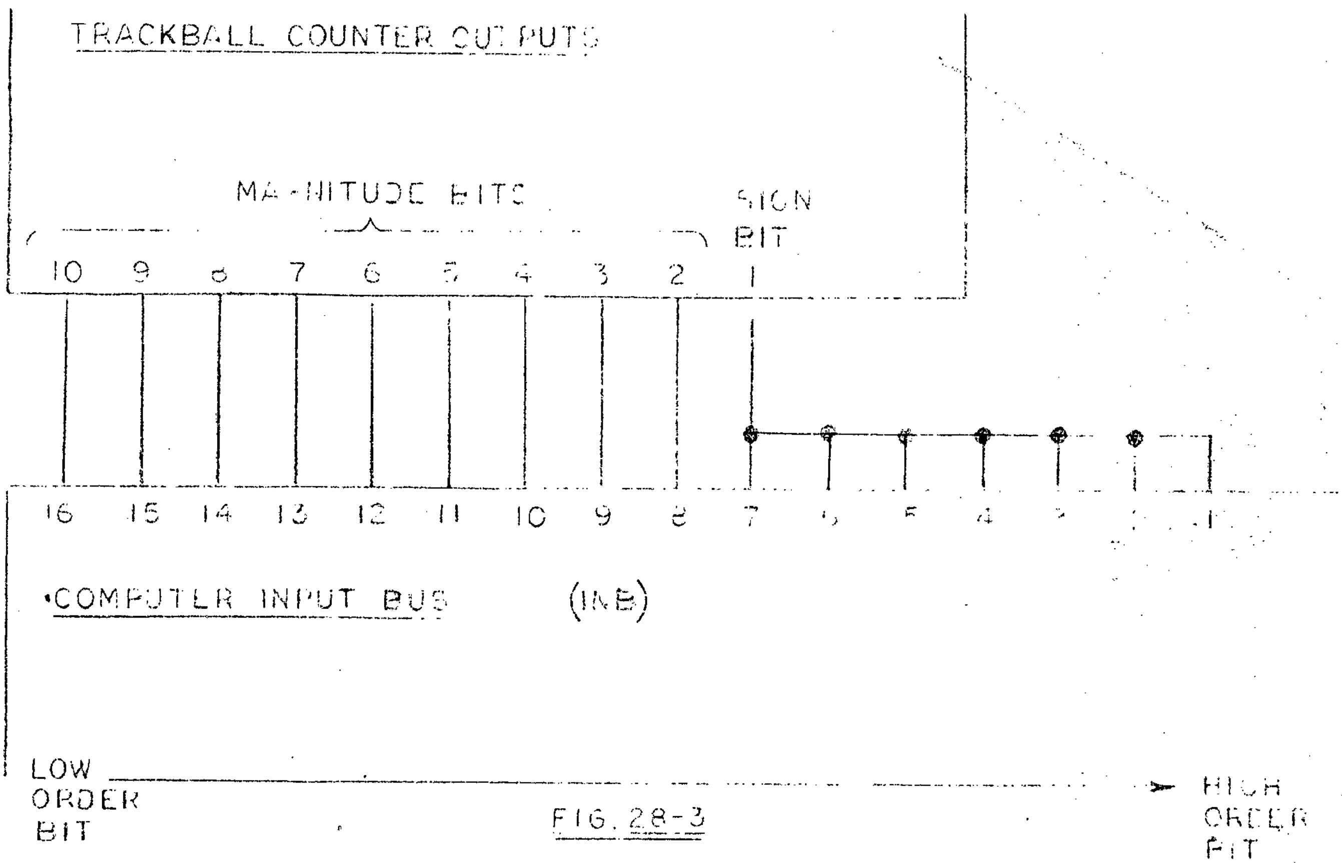

FIG. 28-3

3. Stage Drive, Fine/Coarse Selection. See Figure T28-4.

The stage drive or count down register has a 23-bit capacity. The outputs are gated and connected to a D/A converter which in turn drives the appropriate stage motor.

Joystick and trackballs command the stages to move at a slow or fast speed by use of two separate Fine/Coarse pushbuttons.

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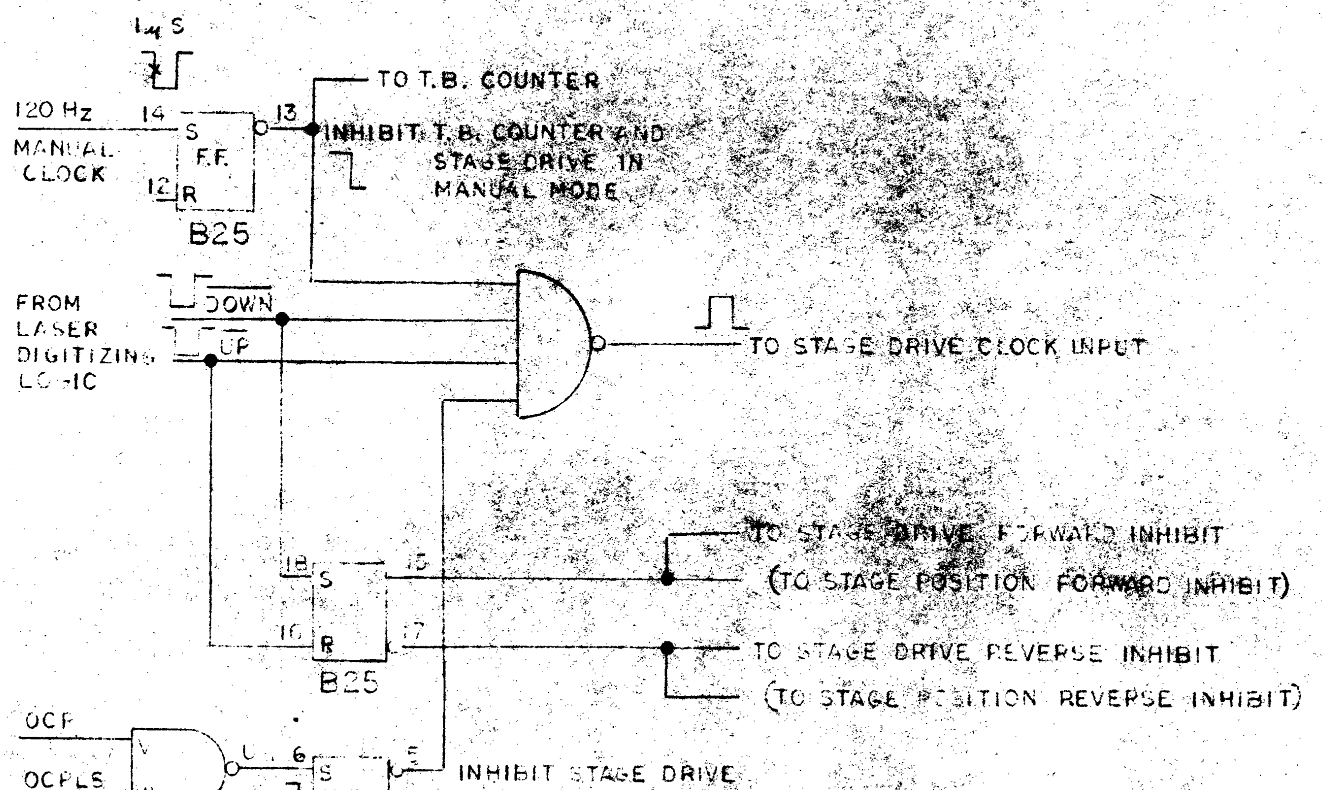
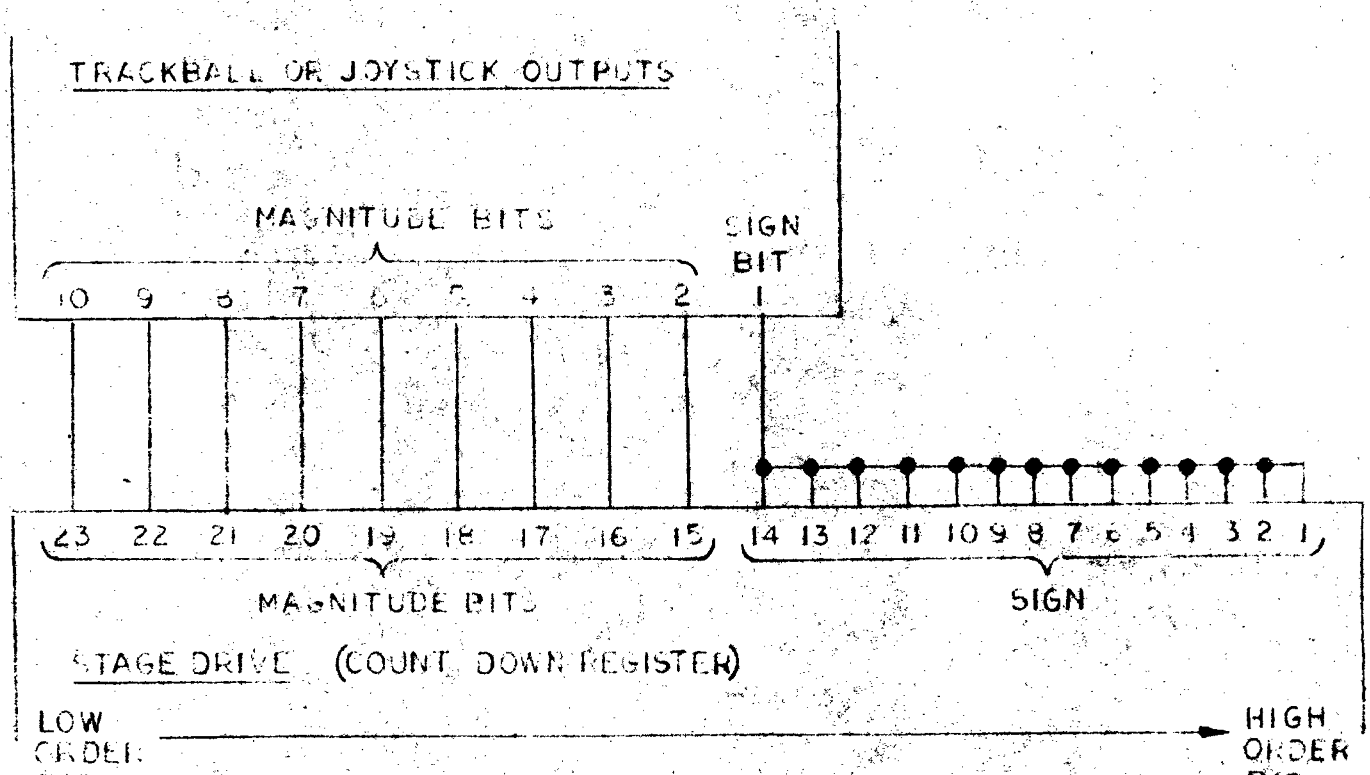


120 Hz
MANUAL CLOCK
S
F.F.
R
B25
TO T.B. COUNTER
INHIBIT T.B. COUNTER AND STAGE DRIVE IN MANUAL MODE
FROM LASER DIGITIZING LOGIC
DOWN
UP
TO STAGE DRIVE CLOCK INPUT
TO STAGE DRIVE FORWARD INHIBIT
(TO STAGE POSITION FORWARD INHIBIT)
TO STAGE DRIVE REVERSE INHIBIT
(TO STAGE POSITION REVERSE INHIBIT)
B25
OCF
OCPLS
B23
F.F.
B32
INHIBIT STAGE DRIVE WHEN IN AUTO W/CORR. OR AUTO W/O CORR.

FIG. T28-4

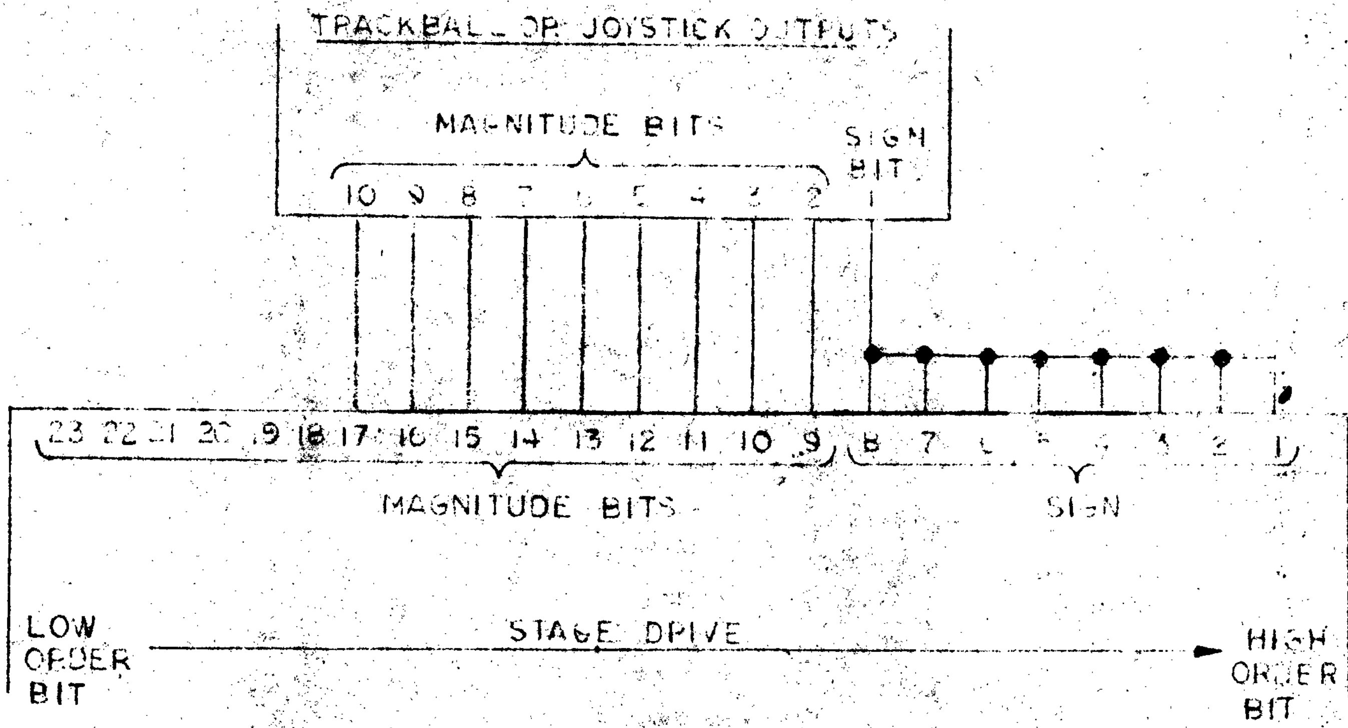
The first one used in conjunction with the joystick is directly located through the joystick shaft.

When the joystick is "off center" non-actuation of the Fine/Coarse pushbutton drives the stage in a slow motion, or fine. The FF connected to the switch is in the reset position. Gating between A/D, D/A and stage drive is such that the nine output bits are connected to the nine least significant bits of the stage drive. (See Figure T28-5.)



FINE STAGE TRAVEL
FIG. T28-5

Upon actuation of the switch, the stage goes into fast motion (or coarse). The FF is set and the gating is such that the nine output bits are shifted 6 bits up on the stage drive. (See Figure T28-6.)



COARSE STAGE TRAVEL

FIG. T28-6

This provides an input of 64 times greater magnitude to the D/A.

A second Fine/Coarse pushbutton is used in conjunction with the trackballs.

This Fine/Coarse flip-flop is set whenever the joystick is centered and the Fine/Coarse pushbutton is depressed.

The same gate switching takes place as explained above for the joystick. The 10 output bits (magnitude and sign) in this case come from the trackball counters.

The sign bit is connected to the eight highest order bits of the stage drive.

In AUTO W/CORR. or AUTO W/O CORR. the computer transfers data into the stage drive. An OCP instruction followed by an OTA is required. The OCP sets a flip-flop which

1. inhibits all 4 stage drives
2. sets the DRLIN line (ready line).

A double precision word is used to transfer data into the stage drive. The stage drive (countdown register) has a 23-bit capacity. The computer output bus OTB has only 16 lines. Two OTAs are therefore required to load the stage drive. (Total of eight OTAs for both stages.)

The first OTA addresses the 8 high order bits of the stage drive. In this case OTB 16 through 9 are connected respectively to bit 8 through 1.

The second OTA addresses the 15 low order bits of the stage drive. OTB 16 through 2 are connected respectively to bits 23 through 9. OTB 1 is a fixed "1" (see Figure T28-7).

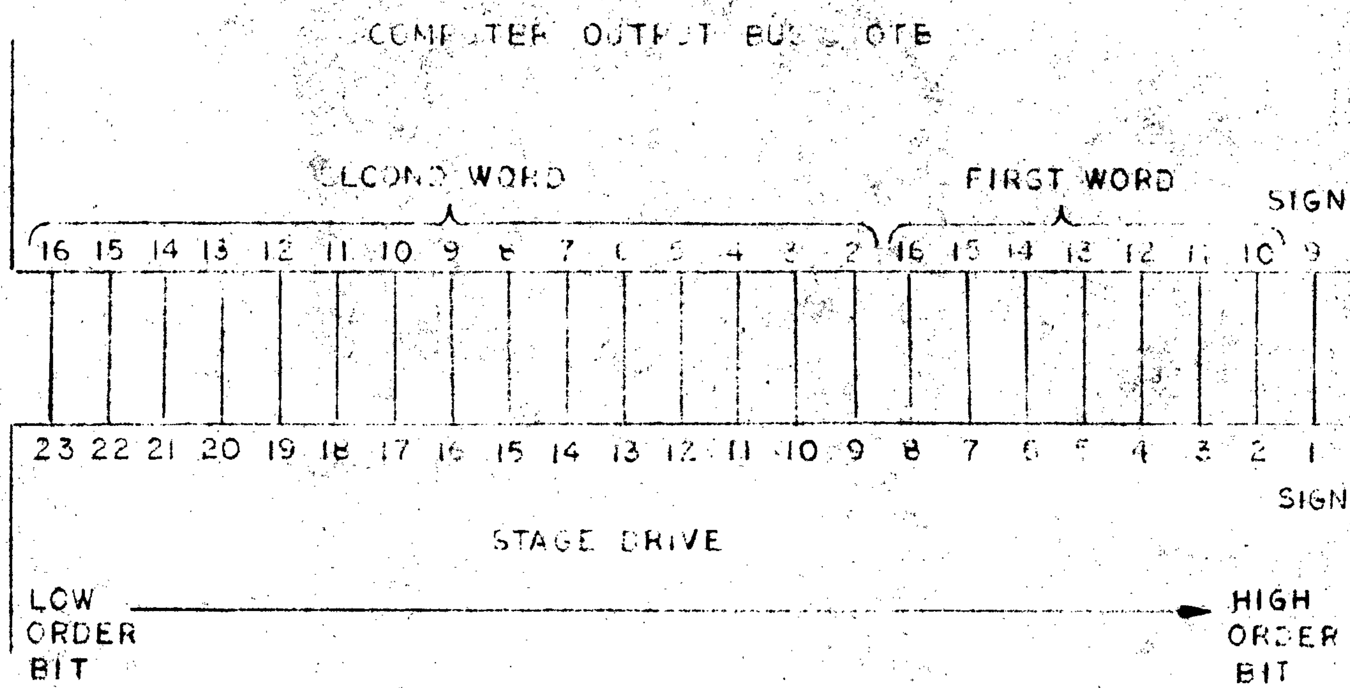


FIG. T28-7

4. Stage Position Counters and Buffers.

The Stage Position Counters register the fringe counts from the interferometers which measure each stage position - left X, left Y, right X, right Y. Each of these 23-bit data are transferred to a buffer register which is sampled by the internal computer.

Each counter is gated for either forward or backward counting flip-flops whose state is determined by the relative phasing of outputs. The flip-flops are the same ones which gate the stage drive counters. The same sets of interferometer outputs are OR'd, each driving a latch formed by two cross-connected NAND gates, one of which steps its counter. An OCP pulse (OCP 30) from the computer fires a 1.4 microsecond one shot, the trailing edge of which fires a 0.5 microsecond one shot. The OR'd result of these two periods inhibits, in each of the four cases, the counter input for 1.9 microsecond, during which any pulse input is stored in the latch. The 0.5 microsecond pulse gates the counter output into the buffer register after the 1.4 microsecond of counter inhibition allows the counter to settle. All four counters are inhibited and sampled simultaneously. After the counter inhibition is removed, any count stored in a latch is applied to the counter.

The four buffer registers are addressed sequentially and read into the computer input bus. The high order bits of each register are read in first, (e.g., INA 30) followed by the low order bits of the same register (e.g., INA 31).

5. Stage Selection and Recording.

The stage selection logic determines from which stage coordinates will be read out. The seven RECORD keys determine the significance of the reading and the PUNCH and EXT.COMPUTER keys allow readout to either or both of these devices.

Each individual stage may be selected for readout as soon as its corresponding interlock circuit is made (film clamped, vacuum proper, etc.). Both stages may be selected only by means of the BOTH STAGES key, after both interlocks are made. Selection of either stage individually resets the opposite stage selection. If the machine is in the ENTER mode when a BOTH STAGES selection is made, the machine is put into MANUAL mode.

As soon as both interlocks have been made, loss of either interlock will remove all stage selection, whether one or two stages are currently selected. If both stages are selected, pressure of the ENTER key will cancel all selection, after which RIGHT STAGE or LEFT STAGE may be selected.

Either right or left or both stages must be selected to enable the RECORD keys.

In addition, if the eyepiece is switched to LEFT BINOCULAR, only the LEFT STAGE key can be made to light and only left stage data will be read out. The corresponding is true for RIGHT BINOCULAR.

There are seven RECORD keys on the console: RECORD REFERENCE, RECORD FIDUCIAL, RECORD TIMETIC, RECORD INITIAL, RECORD INTERMEDIATE, RECORD TERMINAL, RECORD MULTIPLE. These are momentary. Pressure of any one, when enabled, sets its flip-flop which lights its lamp, sends a level on a particular line to the Output Interface, activates the Start Record line to the Output Interface, and in the case of the first three, sends a level on an individual line (INA 21-7, 8 or 9) to the internal computer and on an OR'd line to the Output Interface. Figure T28-8 shows the Record circuitry.

If two RECORD keys are pushed simultaneously, only the lower one will operate, and another will not operate until an acknowledge signal from either the internal computer, punch control or external computer re-enables the RECORD keys. If the PUNCH key is depressed to connect the punch control, the punch control acknowledge signal will reset the RECORD keys. If the EXT. COMPUTER key is depressed to connect the computer link and the PUNCH key is not depressed, the external computer acknowledge signal resets the RECORD keys. If neither the PUNCH nor EXT. COMPUTER key is depressed, the internal computer acknowledge pulse (OCP21) resets the RECORD keys.

Assuming the flip-flop Rec. Int. shown in Figure T28-8 has been reset and the "Enable Record" line active, depression of any RECORD key sets its flip-flop, activates the "Start Record" and sets, through OR logic with the other RECORD keys, the flip-flop Rec. Int. The set condition of the Rec. Int. flip-flop then inhibits further selection of RECORD keys until one of the aforementioned acknowledge pulses resets this flip-flop or it is reset by pressing the ALARM RESET key. The first three RECORD flip-flops are OR'd and, along with the four remaining, are fed to the Output Interface and Computer Link. If the RECORD key selected is one of the first three, as soon as it is depressed it may be sensed by the internal computer, since its address gate is enabled by a flip-flop set by a one shot triggered by the Start Record line. This flip-flop is reset by internal computer control (OCP 21). Logic is

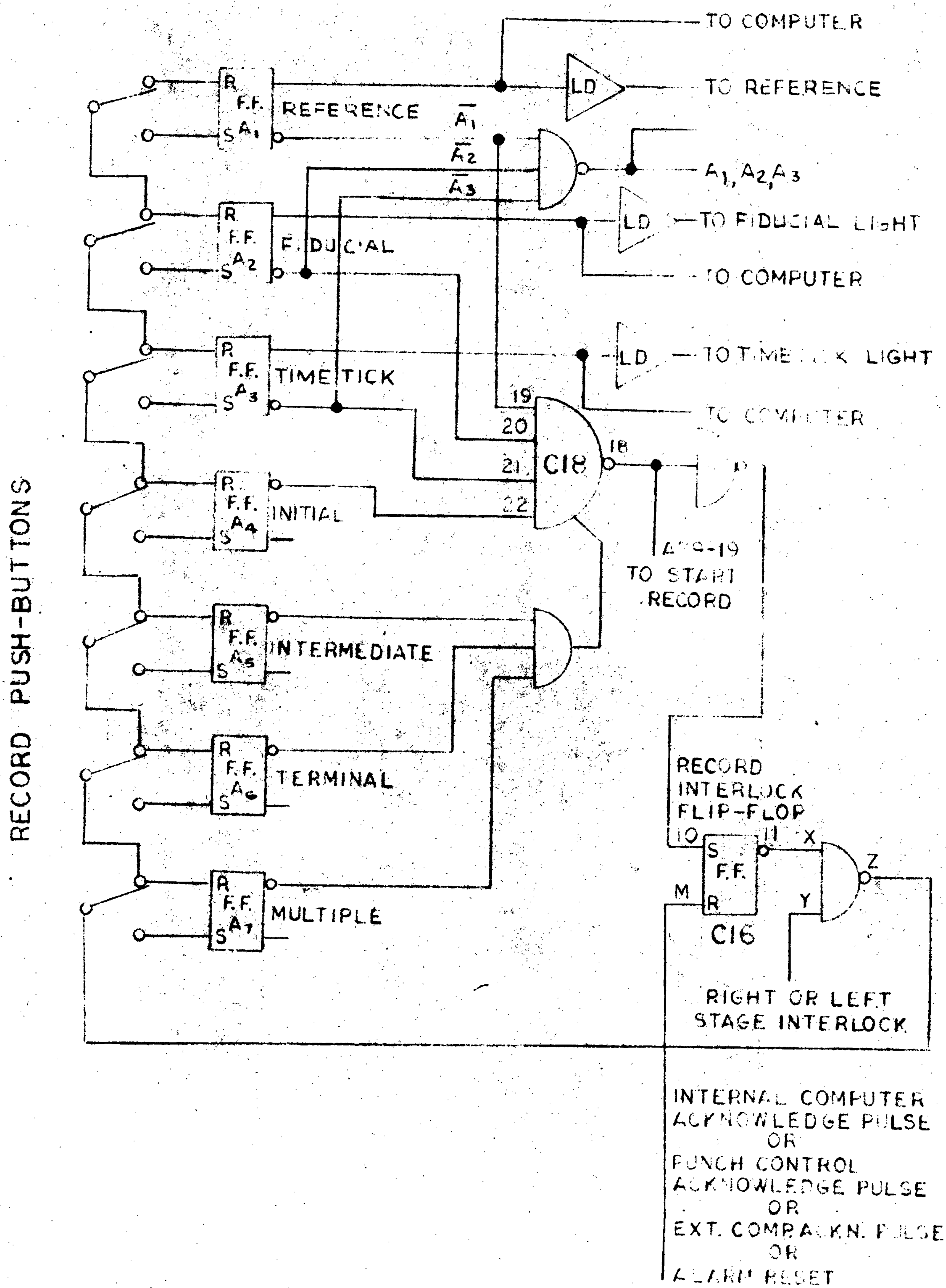

TO COMPUTER
LD
TO REFERENCE
REFERENCE
A1, A2, A3
TO FIDUCIAL LIGHT
TO COMPUTER
FIDUCIAL
TIME TICK
TO TIME TICK LIGHT
TO COMPUTER
19
20
21
22
C18
18
INITIAL
TO START RECORD
INTERMEDIATE
TERMINAL
MULTIPLE
RECORD PUSH-BUTTONS
RECORD INTERLOCK FLIP-FLOP
10
11
X
Y
Z
M
C16
RIGHT OR LEFT STAGE INTERLOCK
INTERNAL COMPUTER ACKNOWLEDGE PULSE
OR
PUNCH CONTROL ACKNOWLEDGE PULSE
OR
EXT. COMP. ACKN. PULSE
OR
ALARM RESET

FIG. T28-6

used such that, of the devices selected, the last to acknowledge is chosen to reset the Rec. Int. flip-flop. The time to acknowledge is least for the internal computer, intermediate for the external computer and greatest for the punch. If the PUNCH key or the EXT. COMPUTER key or both are active, as soon as a RECORD key is depressed coordinates of the stage or stages selected are recorded by the selected devices. Figure T28-9.

As soon as acknowledgement has been received, the Rec. Int. flip-flop resets the chosen selection and another selection may be made.

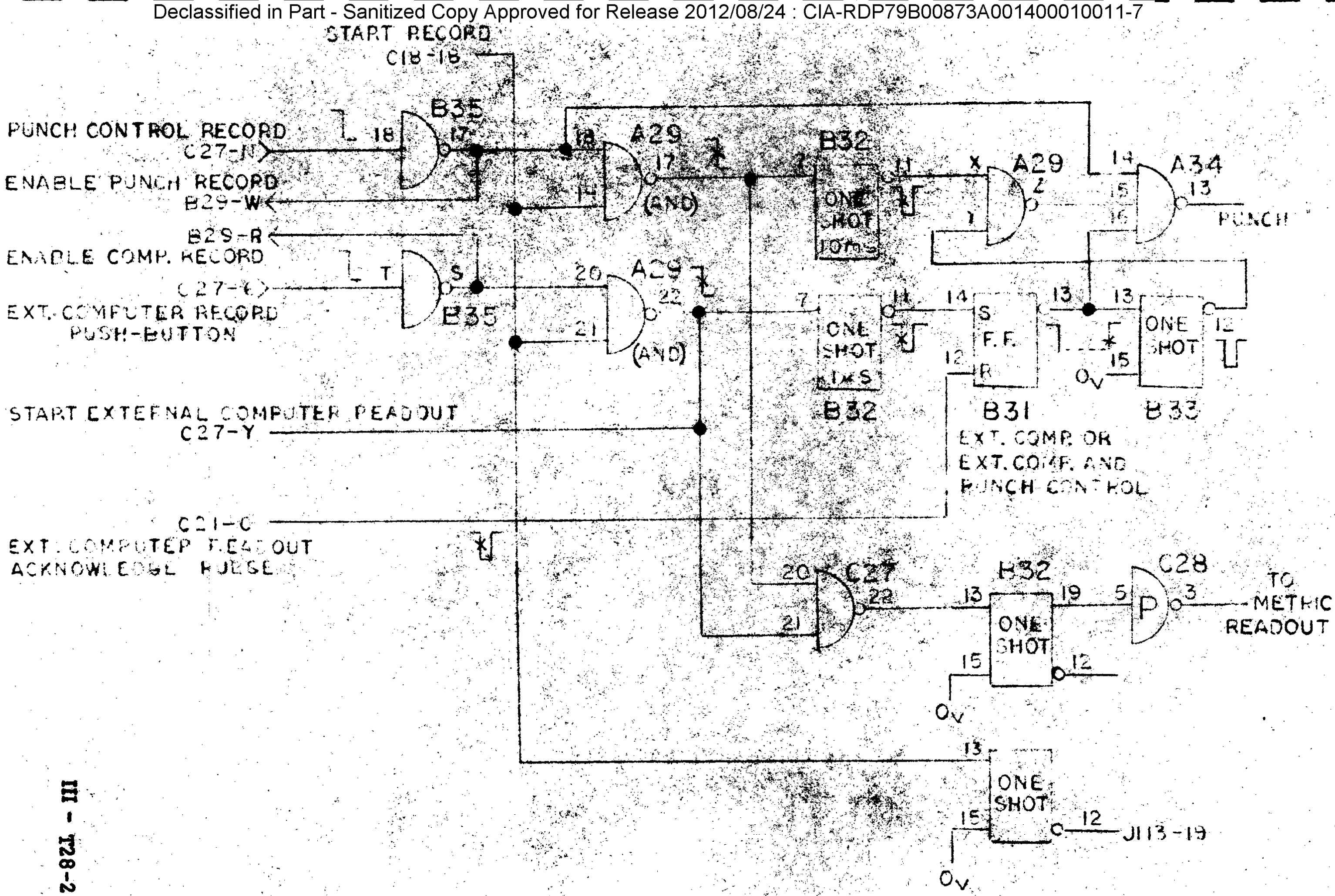

START RECORD
C18-18
PUNCH CONTROL RECORD
C27-N
ENABLE PUNCH RECORD
B29-W
B29-R
ENABLE COMP. RECORD
C27-X
EXT. COMPUTER RECORD
PUSH-BUTTON
B35
A29
(AND)
B32
ONE SHOT
10ms
A34
PUNCH
F.F.
B31
B33
START EXTERNAL COMPUTER READOUT
C27-Y
EXT. COMP. OR
EXT. COMP. AND
PUNCH CONTROL
C21-C
EXT. COMPUTER READOUT
ACKNOWLEDGE PULSE
C27
C28
TO
METRIC
READOUT
J113-19

FIG. T28-9

6. Recall[8]

7. Miscellaneous Keys.

The L. MAG. HI and L. MAG. LO keys respectively set and reset a flip-flop whose level is fed to the internal computer (INA 21-15) in order for the program to properly control the optics when the left optics train is set in the high magnification or low magnification positions respectively. The R. MAG. HI and R. MAG. LO keys control the program for the right magnification in similar manner (INA 21-14).

The REFERENCE lamp is controlled by a flip-flop which is set by an OCP pulse from the computer (OCP 70) and reset by another (OCP 71). The TYPEWRITE lamp is controlled likewise (OCP 00 and OCP 03, respectively).

8. Output Interface.

The output interface has been described in Task 28, Report VII (T28-1 through T28-15). The following covers only a description of the allowed communication interval circuit and the Alarm circuit (see Figure T28-10).

Upon setting of the transmission control flip-flop

1 - the Alarm flip-flop is reset

2 - AC1-1 allowed communication interval one shot is fired

3 - flip-flop #3 is reset

If Error Acknowledge signal is returned it

1 - sets flip-flop #3

2 - inhibits one shot AC1-1

Flip-flop #3 blocks gate 1 (60 ns delay). When AC1-1 one shot is reset, AC1-2 one shot fires. At that time gate 1 is already blocked and Alarm flip-flop will not be set.

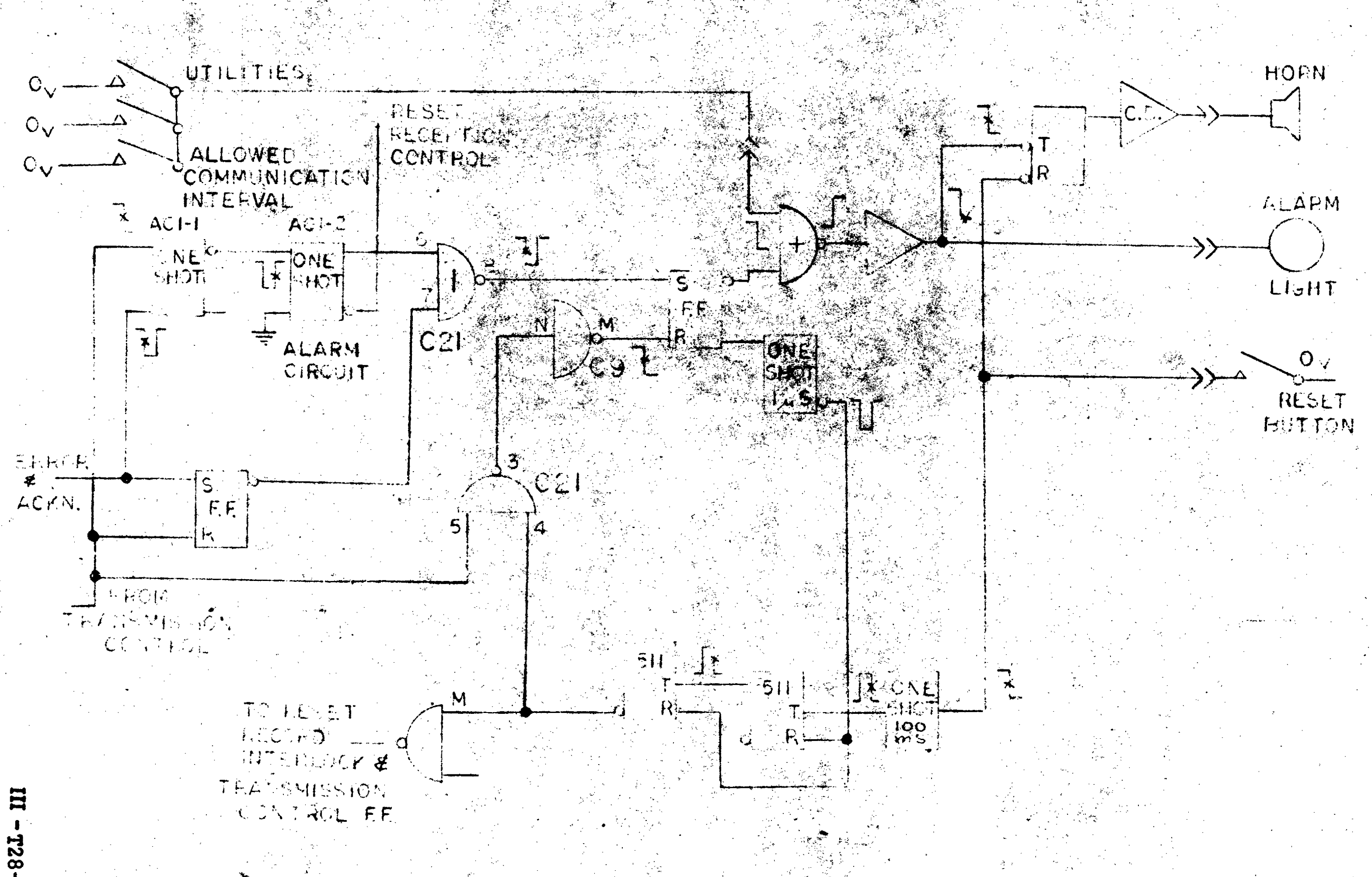

UTILITIES
ALLOWED COMMUNICATION INTERVAL
RESET RECEPTION CONTROL
ACI-1
ACI-2
ONE SHOT
ONE SHOT
ALARM CIRCUIT
C21
C9
S
F.F.
R
ONE SHOT
1 μS
HORN
C.F.
T
R
ALARM
LIGHT
RESET BUTTON
ERROR
≠
ACKN.
FROM TRANSMISSION CONTROL
C21
TO RESET RECORD INTERLOCK & TRANSMISSION CONTROL F.F.
511
T
R
ONE SHOT
100 mS

FIG. T28-10

If after Δt time (duration of AC1-1 one shot) no Error or Acknowledge signal is returned the trailing edge of Δt fires AC1-2.

Since flip-flop #3 has not been set, gate 1 is enables, the 1μs one shot of AC1-2 sets the Alarm flip-flop. Simultaneously an Audio Alarm signal is initiated by the setting of a flip-flop which in turn energizes the horn. By depressing the reset Alarm pushbutton the horn is turned off. By depressing a <u>second time</u> the reset Alarm pushbutton the Alarm flip-flop is reset and the Alarm light is turned off. Simultaneously the Record Interlock flip-flop is reset and a new record can be generated.

Any failure in the Utilities (vacuum, pressure, etc.) will automatically set the Alarm light and the Alarm horn. To turn off light and horn the same procedure explained above is required.

9. Punch Control.[9]

10. Address Decoder.

The Address Decoder receives seven addresses buses (ADB 10 through 16) from the internal computer and provides 80 mutually exclusive address lines to gate the various computer datum and command inputs and outputs (INB, DRLIN, OTB and OCPLS) in accordance with the program. Certain compound addresses are also made available for use by the A/D-D/A Converter.

ADB 13 through 16 are applied in both normal and complemented form to each of five binary-to-16-line decoding cards. Each card is enabled by a different function of ADB 10 through 12, decoded by standard gate cards. As a result, only one of the 80 outputs of the Address Decoder will be active for each 7-bit binary-coded parallel input.

In addition, a pair of lines is active for any of octally numbered lines 10 through 17, and another for lines 50 through 57, 60 through 67, 100 through 107, and 110 through 117. These lines are used by the A/D-D/A Converter discussed under Task 23.

11. Implementation.

All of the logic functions accomplished under Task 28 are implemented with standard logic modules manufactured by Data Technology Corporation. Each logic chassis drawer contains up to 108 modules. Multi-conductor Cannon connectors interconnect chassis. The drawers for Task 28 are Assembly Numbers 6120, 6144, 6125, 6110.

REFERENCES

(1)	Task 22	Interferometer Assembly I, II, XI	
	Task 26	Digitizing Logic II, VII	
	Task 27	Metric Readout I, II, V, VIII	
(2)	Task 43	Computer Programming I, II, IV, VII, VIII, X, XI	
(3)	Task 25	Correlation Logic I, II, IV, VI, X	
(4)	Task 11	Stage Drive I, II, III, IV, V, VI, VII, X, XI	
	Task 12	Film Drive and Transport System V, VI, VII, X, XI	
(5)	Optics System		
	Task 15	Optical Survey and Specifications I, III, IV, V	
	Task 16	Viewing Optics VI, VIII, X, XII	
	Task 17	Viewing Illumination VI, VIII, X, XI	
	Task 18	Reticle Projector X, XI	
(6)	Task 34	Utilities III, VI, XI	
(7)	Task 23	Optical Drive Assembly VII and Appendix T23-D	
(8)	Task 28	Recall VIII	
(9)	Task 28	Punch Control VIII	

TASK 29

CABLING

I. Introduction

It is necessary to make a great number of electrical interconnections between the various equipment cabinets and major assemblies in the Stereocomparator.

The work done on this task includes the layout and drawing of the electrical interconnection cables which are routed from equipment cabinet to equipment cabinet and from the equipment cabinets to the main assembly, as well as internal cabling to the various elements in the main console assembly.

II. Summary

Cables are routed into three major panel areas on the Stereocomparator. All three of these areas are accessible by opening the two doors on the back of the vertical column which lies between the two measuring engines. Wiring to the stage drives, film drives, illumination systems, lasers and interferometer assemblies terminates in a connector panel located just above the base of the main frame of the machine. Wiring to the control console and display panels terminates in a pair of connector panels located on each side of the main optical support frame approximately halfway up the support frame. Wiring for the optical servo systems, correlator image dissector tubes, and automatic brightness control photomultiplier heads is routed to a pair of panels located near the top portion of the optical bridge at the rear of the machine.

III. Conclusion

[redacted] past experience with the abovementioned types of connectors and cabling means indicates that the system will possess an extremely high degree of reliability and ease of maintenance and installation. STAT

IV. Discussion

The connectors selected for the interconnection of the various elements in the machine are for the most part Cannon series K round connectors. These units have a history of ruggedness and reliability, and in addition, they are easy to assemble and install. Drawings have been prepared of each cable, and assembly drawings of the various elements in the system show the placement of cables. Every cable has its own number so that no confusion will result when the machine is installed. In some cases it was necessary to depart from the use of Cannon K connectors in order to interface with equipment supplied by outside vendors. The principal examples of this are in the image analysis system and in the laser assembly. In certain instances, due to the great density of the wiring, it was necessary to go to a slightly different style of connector so that all interconnections could be made within the

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space available. In particular, it was necessary to use the smaller Cannon Military Standard (MS) style connectors for the connection of wires to the optical servo subassemblies.

It is possible to completely disconnect the machine from all electrical cabling, and when the doors of the rear of the machine are closed, all the wiring for the machine is hidden from view. The cables running to the various equipment cabinets from the machine are routed through the computer floor so as to be out of sight also.

TASK 30

CONTROL CONSOLE AND CHAIR

I. Introduction

The purpose of this task is to provide a complete operating area for the Stereocomparator and its auxiliary equipment.

The human engineering aspects of operator comfort, vision and control functions(1) were used in the design of the control console and chair(2).

II. Summary

The physical and psychological environmental design criteria was obtained through information from the customer's specifications, human factors consultants, meetings with the customer, texts on human engineering, and industrial design consultants. Various sketches and drawings of the control console and chair were developed and discussed before the final design was fixed.

The location and slope angle of the display panel were fixed by recommendations from the human factors consultants and human engineering texts. The arrangement of the components developed logically from their sizes and shapes as well as from the space available.

III. Conclusion

The console is located between the two measuring engines and below the optical bridge. Except for the loading operation, the console will offer complete control of all operating and most recording functions such as: optical adjustments, film drive, stage motion, computer format and record command.

The spatial arrangement of the console has been selected and the functions to be controlled by the operator have been fixed. The arrangement of the controls has been completed in accordance with function and need, simultaneously maintaining simplicity and operator ease as fundamental factors. The general design of the console has evolved from space allowance, the operator's reach from the operating position, and this logical division of control parameters.

After discussion with the customer, it was decided to install a computer floor[3] over the main floor at the customer's site. This will allow the operator's chair to be at normal height for easy accessibility.

All keys, switches, displays, meters, etc. on the console are identified as to function and use by appropriate descriptive nomenclature. All of the controls are arranged in the most feasible and logical manner. Certain operating and control keys as well as the indicator keys in the keyboard are colored red for the left stage and green for the right.

The control panel is at normal desk height from the computer floor and an adjustable headrest is provided for the eye piece assembly. The chair will have adjustments for seat height and tilt. A hood[4] over the control and display panels is provided which will eliminate stray light and shadows and other visual distractions from the console area as well as to enhance the appearance. This is described more fully in Task 8 - Skin.

The operating and controlling items on the control panel are readily visible in subdued light. The keyboard keys are lighted with two levels of light and are grouped and colored so as to be readily located as to function. Other lighted switches on the control console are colored. The colors were selected to match with related keys on the keyboard as well as with the four film loading switch panels on the outboard bridge supports. The colors selected for the lighted switches and keys were obtained through consultation with various manufacturers of these items and plastic materials vendors.

The components in the Control Console that may require adjustment or replacement are readily accessible for servicing.

The Control Console Assembly is mounted on casters and can be easily removed from its operating position between the measuring stages after removing the electrical and pneumatic connections from the cross connect panel directly behind the console. All of the components related to the display and control panels are mounted on their respective panels and these panels can be removed from the console assembly with standard tools. Each item on each panel is easily removed. Items on the display panel may be inspected and adjusted without removal from the console by removing the back cover of the console. An inspection plate is provided underneath the control panel which can be readily removed for inspection and adjustment of control panel components.

IV. Discussion

Following is a general description of each of the subassemblies related to the Control Console:

Chair - The operator's chair is to be the ultimate in design for physical comfort and use. The specifications for the functional design of the chair were obtained from human factors consultants. The appearance specifications were obtained from the industrial design consultants.

A computer floor is included in the system and a standard height of chair will be used, also the chair proper will be adjustable for seat height, tilt, etc.

Headrest - Part of this task is the design of an operator's headrest. This headrest is to support the operator's head while he looks through the microscope eyepieces of the Stereocomparator. The headrest is supported by the Control Console. Anthropological and human factors considerations have been incorporated into the headrest so that the operator's fatigue, from viewing for long periods of time, is minimized. The headrest will be made of a cushioned rubber material which will be contoured for good contact with the operator's head and will have fore and aft adjustment. The headrest is mechanically separated from the eyepieces and optical bridge so as to eliminate any vibration by the operator to the optics measuring system.

A means for sanitary protection of the operator's forehead will be provided. This will consist of a paper cover wrapped around the headrest in such a manner that the operator can replace a soiled sheet with a clean one.

Hand Rails

To insure against the operator having physical contact with the stages while in the operating area, a barricade is provided on each side of the operating area. These consist of decorative panels with moldings for hand rails. They are attached to the console and are mechanically separated from the measuring and optics assembly. This item is more completely described in Task 8 - Skin.

Keyboard Assembly

The keyboard assembly contains two matrices: an 8 x 10 control and conditioning keyboard and a 10 x 10 numerical entry keyboard. All keys are lighted with two levels of illumination.[5]

The 8 x 10 section contains keys to condition, control, indicate and initiate certain functions pertaining to the operation of the Stereocomparator and the auxiliary computing and recording equipment. Each key top contains appropriate nomenclature describing the function. The key tops are colored and grouped to provide visual separation according to function.

The numerical entry keyboard consists of 10 key sections with each key top lighted with two levels of illumination. Partial depression of any key will release any other key in the same vertical column. Full depression will increase the luminance of that key and latch that key in its value setting position. Each key in each vertical section is interlocked to prevent depression of more than one key in each column.

The keyboard assembly may be readily removed as a unit from the control panel assembly, and each vertical key section may be easily removed from the keyboard assembly for inspection and servicing.

Film Drive Joystick

Two film drive joystick assemblies are provided. They are located near the outer edges of the front face of the control cabinet and are used to wind and unwind the film on each stage. To move the film toward the rear of the stage, the joystick is raised and it is lowered to wind the film towards the front of the stage. The speed of winding is related to the angle of deflection of the joystick.

Each joystick may be latched in its full speed position for long runs of film or for rewinding.

Trackballs

The two trackball assemblies are located on the control panel at each side of the stage drive joystick and are used for fine positioning of the stages. The trackball to the left of the joystick controls the image viewed in the left eyepiece, and the other controls the image viewed in the right eyepieces.

The trackball assembly contains a ground and polished solid aluminum ball which rides on an air bearing. The ball is operated by the operator's fingers and under manual control the stage will move in the same direction that the ball is rotated. The stage will move at varying speeds depending on the speed of rotation of the ball.

Controls for two levels of stage speed are provided by the TRACKBALL COARSE and TRACKBALL FINE keys in the control section of the keyboard.

Stage Drive Joystick

The stage drive joystick assembly is located in the center of the control panel, directly behind the keyboard assembly, and is provided as one of the means for positioning the upper stages. Movement of the joystick handle in any direction from its centralized position will cause the stage or stages to move appropriately. The speed of movement of the stage can be controlled by the amount of deflection of the handle. The stage drive joystick can move the stages at either of two speeds by the operator selection of a button on the top of the joystick handle.

The stage drive joystick can drive one stage at a time, or both stages simultaneously. Keys are provided in the control section of the keyboard to select the desired mode.

Control Switches

Control switches are provided to modify the photo image by changing the parameters of the optical system and to control the level of light for the general platen illumination. Two sets of four double knob switches are provided for the photo image adjustment. These switches are located radially around each of the trackballs. Their functions are:

Anamorphic rotation and squeeze.

Zoom magnification and focus.

Image rotation and brightness.

Reticle size and brightness.

A fifth control on each side is provided for the general platen illumination. The lower knob controls the brightness of the platen illumination lamp. The upper knob controls off and on.

The function of each control switch is shown by engraved nomenclature on the control panel in front of each knob.

The function of the lower knob is indicated by a circle and the upper knob function is indicated by a smaller dot preceding the nomenclature. Each knob (upper and lower) operates two switches, one for each direction of rotation. The knobs will return to a centralized neutral position by built-in spring action.

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REFERENCES

(1) Task 41 - Stereocomparator Mockup
I, pages T41-1, 2

(2) Task 41 - Stereocomparator Mockup
V, page T41-1; Appendix T41-B
VI, page T41-1, Appendix T41-F and G

(3) Task 30 - Control Console
VII, page T30-1, 2

(4) Task 8 - Skin - Final Report

(5) Task 30 - Control Console
XI, pages T30-1, 2

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TASK 32

COMPUTER CONSOLE

I. Introduction

The computer and computer control console are used as an integral part of the logic Rack #3.

II. Technical Discussion

The control console is a single unit which contains the system operating controls and indicators. The console is connected to the system enclosure containing the processor's main frame logic, via three cables.

III. Summary and Conclusion

The use of the controls and indicators contained in the computer console is described in the Programmers Reference Manual.

TASK 33

ELECTRONIC RACKS AND CONTROL CABINETS

I. Introduction

In order to meet the requirements for heat loading on the room in which the electronic equipment cabinets are located, it was found necessary to specify specially-constructed rack assemblies which contain provisions for a closed-circuit cooling system. If the cooling air from the electronic cabinets were to be vented into the room in which the machine is located, a very severe heat load would be placed upon the air conditioning and temperature regulation equipment used to hold the room temperature within the degree of constancy required for accurate measurement.

II. Summary

Arrangements have been made with a cabinet manufacturer to include fittings on the floor of the cabinet and plenum chambers within the cabinet to allow routing of the cooling air both into and out of the racks through the floor. The cabinets themselves are more or less sealed, and connector feed-through plates are installed in the floors of the cabinets in order to allow the electrical connections to be made with equipment located within the cabinet. (Reference Appendix T33-A.) The work done under this task includes specification of the exact rack configuration as well as the cabling and power distribution equipment used within the racks. As stated under Task 29, Cannon series K connectors are used in most of the cabling, and the only exceptions are in certain areas where smaller connectors are required due to the great density of the wiring.

The cabinet itself is more or less a standard item with the exception noted above, and is fitted with specially-designed glass doors over the front of the electronics assembly. The purpose of the doors is two-fold: First, to prevent critical settings on various electronic chassis from being upset by accidental contact by personnel; secondly, in the event that additional RFI shielding is required above and beyond that provided by the front surfaces of the electronic chassis themselves, it will be possible to fabricate the door from leaded or gold-flashed glass to provide additional shielding.

III. Conclusion

The electronic cabinets specified for the Stereocomparator fulfill the requirements for system shielding and cooling. In addition, they furnish a handsome and extremely servicable means for containing the electronic hardware. The system of wiring adopted will insure neat, reliable interconnection of all equipment for maximum system dependability.

IV. Discussion

Layout drawings of the racks show the various mechanical

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assembly details and interconnection diagrams for the equipment cabinets, including the power distribution wiring which supplies the line voltage to the various assemblies. At the present time, it is expected that conduit will be used for running AC power lines in order to meet usual building code specification requirements, and fittings for conduit will be available on the floor of the cabinets. AC outlets are provided internally within the cabinet for powering the various assemblies, and additional pairs of AC outlets are provided on the front of the equipment cabinets near the floor for convenience when using electrical test equipment in adjusting the system. Concurrent with the design of the racks themselves is the requirement for use of a support frame underneath the equipment cabinets which will raise the cabinets to the level of the computer floor. This support frame will contain the ducting used to route the cooling air into the cabinets[1]. A customer-supplied cooling system will keep the temperature within the cabinets to within acceptable limits for measuring accuracy of the machine.

The cabinets are somewhat deeper than usual (30") in order to allow greater packaging density for the electronic components. By this means, it was possible to use fewer equipment cabinets so that the floor space requirements for the system are not excessive.

Slide out drawers for the digital equipment are provided to allow easy access for testing of the circuitry, and analog circuit components have all of the required test points and adjustment controls on the front panel (either directly on the panel or under removable cover plates) so that it is not necessary to remove the chassis from the equipment racks in order to perform adjustment of the equipment.

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REFERENCES

Task 33 Electronic Racks & Control Cabinets

(1) VII. page T33-1.

TASK 34

UTILITIES, VACUUM AND AIR SYSTEMS

I. Introduction

The utilities consist of the air and vacuum system sources and controls, the system power circuit breakers, and the arc lamp power supplies. The air and vacuum sources and associated equipment are in the Machinery Room, while the rest of the air system controls and the power distribution is in the Utilities Cabinet. The vacuum control valves, switches and reservoir are on the Utilities Panel on the back of the machine proper, or nearby.

II. Summary

The sequence of energizing the system from the Utilities Cabinet is covered, followed by a description of the interlocking of the utilities with the Film Control Stage Support, and other portions of the system. The utilities portion of the stereo comparator provides the electrical power distribution and control, the cooling air and failure interlocks, the air and vacuum control systems and failure interlocks, and the arc-lamp power supplies. All utilities are designed for fail-safe operations.

III. Conclusion

The pneumatic portion of the utilities now consists of four separate systems:

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1) A high pressure system of 150-175 psi that will supply properly conditioned, compressed air to the air bearings, vibration isolators, and air cylinders.

2) An intermediate pressure system of 60 psi that will supply properly conditioned, compressed air for film cooling, and film lift-off.

3) A low pressure, high volume air system to provide cooling for the optics illumination, optical bridge and platen.

4) A vacuum system for film clamping.

The Utilities Cabinet contains, as well as the air and vacuum systems described above, a main breaker panel, a control panel and two arc lamp power supplies. The former contains a 100A, 3-wire, 220V breaker, a 24V power supply for the utilities control, and a 100A, 2-wire, 220V contacter. All power for the utilities rack enters through the main breaker. The power for Cabinets 1, 2 and 3; the computer, the teletype, the card punch and the main and reticle illumination, and the 24V power supply passes through the individual breakers on the control panel. Lighted pushbuttons on the control panel activate the air and vacuum systems and the four arc lamps.

IV. Discussion

Based on a preliminary design survey of the Stereo Comparator a schematic concept of the utilities was developed. The requirements for this tentative system were discussed in a previous report.[1]

However, subsequent developments in the Stereo Comparator design eliminated the need for a water cooling system on the illumination lamphouses. Additionally, it was decided that an adjoining room would be used to install auxiliary equipment at the customer's facilities. Hence, a new utilities design was developed.[2] This is shown schematically in Drawing No. E-6296. This drawing is subdivided in such a manner that the location of the various components at the installation site is shown. The system is described in a previous report.[2]

Most of the utilities control units are housed in a standard size cabinet. All interconnecting hoses and pipes between the auxiliary machinery room, the utilities cabinet, and the Stereo Comparator are below the computer floor. In and outgoing connections on the utilities cabinet are made through the bottom of the cabinet. The internal piping arrangement in the utilities cabinet is shown in Drawing No. E-5808.

All control for the utilities is from the utilities cabinet. (See T34 Appendix C, Electrical Diagram of the Utilities Control, and T34 Appendix D, Control Panel Schematic.)

If the MAIN BREAKER on the Main Breaker Panel, and the first row of circuit breakers on the Control Panel are not tripped, the first row of lighted pushbuttons may be used to apply power, respectively from left to right, to the + 24V utilities-control power supply on the Main Breaker Panel and also the drain-purging timer, the power to the engine, Cabinets #1, 2 and 3, the computer, the cardpunch and the teletype.

Next, given the +24V, the four lighted pushbuttons in the next row may be used to respectively turn on (1) the vacuum pump, (2) the low-pressure air system, (3) the medium-pressure system (compressor and dryer), and (4) the high-pressure system (compressor and dryer and main high-pressure valve and auxiliary high-pressure air dryer in utilities cabinet). They are turned off by pressing the respective button a second time.

Provided the illumination circuit breakers are not tripped, and all the first row of pushbuttons except the +24V is off, the illumination buttons can be used to turn the left and right main and reticle arc lamps on and off. When the required lamps are on, the first row of pushbuttons may be actuated. Normally, closed relays on the various power lines connected to the first row of pushbuttons allow this. The left and right film cooling is also turned on by the main lamp buttons. If the cooling fails, pressure and/or vane switches douse the corresponding lamps and light the console alarm lamp.

The drain purging timer, every 4 hours, activates a time-delay relay which holds the left and right drain-purging solenoids on for 10 seconds.

The Film Control Units in Cabinet #1 activate the normally closed left and right air-pressure and vacuum valves. When the film is clamped, the air-pressure valve closes and the vacuum high-pressure air valve opens. When the film is unclamped, the opposite occurs. If the pressure drops under a value yet to be determined, or the vacuum drops below 20" Hg on a given stage, the corresponding pressure or vacuum switches opens the left or right film drive and stage readout interlock. Each of the stage support pressure switches opens when the high-pressure air pressure drops below 70 psi on the given stage, and stops the left or right stage through the Stage Limit Relay Assemblies in Cabinet #1.

The high-pressure and medium-pressure systems are monitored by pressure switches, and the vacuum system has a vacuum switch, all of which operate the Alarm Lamp. The vibration isolator also has a pressure switch which lights the alarm lamp when the pressure falls below 40 psi.

REFERENCES

Task 34 - Utilities, Vacuum and Air Systems

(1) III, pages T34-1 to T34-2, and Appendix T34-F (Utilities Schematic Drawing No. SK-353).

(2) XI, pages T34-1 to T34-4.

TASK 35

VIBRATION ABSORPTION AND LEVELING

I. Introduction

The vibration isolation system is designed to isolate the machine proper from ground.

II. Summary

The extent of the isolation required and the eventual design of the system was based on a computer study (1) which investigated all of the rigid body modes of the detail structural design of the Stereo Comparator, the threshold of sensitivity of the Stereo Comparator, and the Freidin and Ney Associates Vibration Study Report #1348.

The computer study and report entitled, "Dynamic Analysis of Barry Controls 9001147 Isolation System for Nuclear Research's Stereo Comparator WD-495" was performed and submitted by our vibration consultants, Barry Controls, a Division of Barry Wright Company, and is included as a part of this final report in Appendix T35-A.

III. Conclusions:

The vibration isolation system will satisfactorily isolate vibrations as described in the Freidin and Ney report # WD-495.

REFERENCES

Task 35 - Vibration Absorption and Leveling

(1) XI, page T35-1.

TASK 36

OVERALL ASSEMBLY

I. Introduction

This task covers the development and production of drawings, parts list, etc., required to assemble and interconnect all of the items in the Stereocomparator system.(1)

II. Summary

In general, the other tasks in the project require detail, sub-assembly and assembly drawings for that particular task. As the project developed it was necessary to inter-assemble tasks to make a feasible assembly as well as to insure complete interface of all assemblies.

III. Conclusion

Overall assembly drawings start at the level of Right and Left Stage assembly where the following items come together:

- Task 9 Granite and Ways
- Task 10 Air Bearings
- Task 11 Stage Drives
- Task 12 Film Transport
- Task 13 Film Clamp

The "top" assembly is the floor plan with the Measuring and Optics Assembly, Electronic and Utilities Cabinets, Console and chair, Card Punch, and Teletypewriter shown in their recommended positions.

Other drawings at this level show electrical and pneumatic lines arrangements, floor loading, electrical power and air requirements.

Parts lists and assembly information is included in these drawings.

A 1/12 scale - three dimension model of the Stereocomparator system was made, as part of this task, and delivered to the customer for approval.

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REFERENCE

(1) XI, pages T36-1, 2.

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TASK 37

RADIO FREQUENCY NOISE SUPPRESSION

I. Introduction

The requirements for radio frequency noise suppression in the Stereocomparator are twofold: First, it is imperative that the machine does not itself radiate, either to cause interference with other equipment located in the same area as the machine, or to produce decipherable data which might be susceptible to detection; secondly, it is necessary that the Stereocomparator be shielded against electrical disturbances caused by other equipment which might interfere with its operation or accuracy.

II. Summary and Discussion

Means for accomplishing these ends have included the design of various shielding elements around critical areas of the machine. The low level stages in the interferometers are perhaps most susceptible to outside RF disturbances, and in order to prevent adverse effects from external fields, we have designed the interferometer assembly with heavy shielding. Another critical area in the machine lies in the analog-to-digital converter because the low signal levels encountered are susceptible to noise. RF shielding and bypass elements on the power supplies for this system have been included and a "Mecca point" or "holy place" grounding scheme has been adopted in the external circuitry in order to prevent the possibility of RFI pickup through ground loops. The chassis used in all servo amplifiers are constructed of steel in order to shield the low level circuitry from electro-magnetic fields. The digital equipment drawers are also constructed of steel in order to prevent radiation of detectable signals from the digital gating circuits.

The equipment cabinets themselves are constructed of rather heavy gage steel sheet metal, and welded construction insures good electrical grounding of the cabinets in order to prevent RFI radiation or pickup. Shielded cables are used for most of the servo and feedback system devices in order to minimize noise pickup which might impair the accuracy of the stage drive or optical servomechanisms. Shielded cable is also being used for the arc lamp power wiring in order to prevent radiation of RF hash which might upset nearby equipment. Arrangements have been included whereby the entire frame of the machine and all motor frames are grounded in order to prevent noise radiation. The entire platen illumination system is also RFI shielded.

III. Conclusion

Great care has been taken in the design of the Stereocomparator electronic circuitry to insure that the equipment will not radiate signals which might be disturbing for nearby equipment or be a security problem. Maximum rejection of unwanted signals caused by RFI/EMI fields is assured by careful adherence to proven shielding and grounding methods.

It will be necessary for the customer to supply a high quality earth ground near the system in order to allow effective grounding of the various equipment cabinets and machine frame.

TASK 38

ENVIRONMENTAL CONTROL

The performance of this Task is being handled by the customer. See Appendix IV-B, Item III - Support Equipment.

TASK 39

RELIABILITY ANALYSIS

I. Introduction

The Stereo Comparator is designed to operate, under normal conditions, for 5000 hours with only minor maintenance, due to normal mortality of expendable replacement parts. The following is a discussion by task of the life expectancies of the individual components of the Stereo Comparator.

II. Technical Discussion

The expendable parts used and their expected lifetimes are listed in the following table:

Parts	Hours
Arc lamp, main illumination, 2 required	2000 ea
Incandescent projection lamp, 2 required	4000 ea
Computer logic modules, many required	4000 total
Interface logic modules, many required	100,000 total
Indicator lamps, control console and utilities control panel	1000 ea
Air filter cartridge	Undetermined

Table T39-1

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A discussion of life expectancy of non-expendable parts is given below by task:

Task 7, 8, and 9: The main frame, skin and granite stageways are constructed of very durable materials and do not contain moving parts nor parts under electrical strain.

Task 10: The air bearings, being of course constructed to prevent any friction between solid materials and being of non-corrosive metal, have lifetimes very much in excess of the machine lifetime.

Task 11: The stage drive system contains, of course, moving parts in the form of the linear actuator. Accelerated testing, as described in the April 1967 monthly report, indicates a useful life for the linear actuators under average use of 5000 hours. This is based on a 79-hour maximum speed test.

The stage-drive motors are rated for 5000 hours at 3600 rpm.

The stage drive tachometer is rated for 183,000 hours at a 1 ma load and 3600 rpm. The device in this application is used within these ratings.

Task 12: The film drive motor and tachometer are rated the same as the stage drive units.

Task 13: The film platen and clamping has no components subject to appreciable wear.

Task 14: The film cooling involves nothing of short lifetime, being merely passive pneumatic structures.

Task 16: The viewing optics are constructed of very long life material and contain no parts of appreciable mechanical or electrical wear.

Task 17: The arc lamps for main illumination are listed as expendable (see Table T39-1). The supplies for these lamps have an MTBF of 20,000 hours. Each igniter contains only high-reliability capacitors and transformer and a spark gap, and so will have a life far greater than the 5000 hours for the machine.

Task 18: The reticle lamps are listed as expendable items in Table T39-1.

Task 20: The platen lamp has an average life of 10,000 hours. The platen illumination power supply consists of a motor-driven autotransformer having a very long life under expected usage, three relays good for 10 million operations, and a high-voltage step-up transformer of lifetime much beyond machine life.

Task 21: The optical bridge contains only structural members and wiring, and therefore presents no reliability problem.

Task 22: The laser and power supply are good for approximately 10,000 hours.

Task 23: The optics drive motor tachometer is rated for 1000 hours at 8500 rpm. During slewing, the motor may run at up to 10,000 rpm; while during tracking, usual situation, it will run at much less than 8500 rpm.

Task 25: The image dissector is good for many years, and the electronic correlator has much greater than 5000 hour expectancy, based on the MTBF of its circuit cards.

Tasks 26, 27, and 28: The digitizing logic, metric readout and output and interface logic use standard logic cards incorporating integrated logic modules rated at a 200,000 MBTF with the 5-volt supply used. Actually, due to noise limitations, the effective MTBF may be considerably less than this figure, but well above 5000 hours.

Task 29: The cabling is done to superior commercial standards and has a lifetime far in excess of the 5000 hour machine life.

Task 30: The key switches on the control console are snap-action with lifetimes on the order of 1,000,000 operations. The joystick potentiometers are good for 2,000,000 rotations.

The trackball incremental encoders are rated at 27,000 hours at 3000 rpm.

Task 32: The internal computer used has an MTBF rating of 4000 hours. The logic modules and indicator lamps are expendable items, while the other computer components have quite long life expectancies.

Task 33: The electronic racks and control cabinets are not subject to deterioration.

Task 34: The life expectancies of the components used in the utilities are not available, but are much greater than 5000 hours. The Asco valves used are rated at 1 million operations.

Task 35: The vibration and level control unit has a life expectancy well over two years.

III. Summary and Conclusion

The reliability discussion above demonstrates that the various non-expendable parts of the Stereo Comparator have life expectancies greater than 5000 hours. Various lamps, logic modules and air-filter cartridges may need replacement during this period.

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TASK 41

STEREO COMPARATOR MOCKUP

I. Introduction

The Stereo Comparator mockup has been an extremely useful and many purposed tool. The complete machine including one full electronics cabinet has been built primarily from wood.

II. Summary

At first the main frame and granite were constructed and fitted for "X" and "Y" axis movement to check clearances three dimensionally. (1) The optical bridges, control console and chair were built and assembled to check the human engineering aspects of operator comfort, vision and control functions. (2)

The skin was then attached to produce a pleasing shape and to check primarily for optical train covering and skin interface to maintain the three-optical bridge structures independent of each other.

With the skin satisfactorily attached, the machine color scheme was introduced eventually resulting in a finished machin e mock-up that graphically represents 3-dimensionally the final size, shape and general color scheme intended for the operating Stereo Comparator. In addition the color scheme for the support equipment and the general room area have been studied.

III. Conclusion:

The mockup has been completed and is representative of the overall appearance and size of the stereo comparator.

REFERENCES

Task 41 - Stereo Comparator Mockup

(1) V. Page T41-1; Appendix T41-B and XI, Page T41-1; Appendix T41-F and T41-G

(2) I. Page T41-1, Para. I and Page T41-2, Para. III.

TASK 42

BREADBOARDS AND TEST SERVICES

I. Introduction

The purpose of the breadboard is to construct physical assemblies in order to examine certain parameters of the system which cannot be determined other than by experiment[1].

II. Summary

Test procedures for examining these parameters[2] and collecting test data[3] have been detailed. Test data results and conclusions have been collected [4][5][6] verifying operation of the stage systems.

A final test on the repeatability of the stage position accuracy has been performed and is submitted with this report.

III. Conclusion

All testing performed in the breadboard confirms the operation to specifications of the stereo comparator stage drives, interferometer system, air bearings, granite & ways, general platen illumination, and metric readout.

TEST OF STAGE POSITION ACCURACY

Purpose: To determine repeatability of stage position accuracy.

Procedure: Mechanical indications of the stage position were obtained by using a Sheffield air gage, least count 1/4 micron. The metric readout counter was set to zero, the stage was moved away from the indicator and then returned to zero on the indicator, and the difference on the metric readout counter was recorded.

Results:

Mechanical Indicator Reading	Metric Counter	Readout Reading	Difference Microns	Stage Traverse Length Microns
0	+0.2	+0.3	0.1	20736.4
	+0.2	+0.4	0.2	
0	+0.2	+0.4	0.2	41472.7
	+0.2	+0.3	0.1	
0	+0.2	+0.4	0.2	82944.8
	+0.2	+0.4	0.2	
0	+0.2	0.3	0.1	165889.9
	+0.2	0.4	0.2	

Based on the above results, the average difference from start to return is 0.16 micron up to traverse length of 165889.9 microns.

This is within the basic accuracy of the metric readout counter (0.25 microns)[7] insuring that no counts have been lost and that the stage position is repeatable to within 0.25 micron.

REFERENCES

Task 42 - Breadboards and Test Services

(1) III, T42-1, para. I.

(2) V, T42-4 through T42-9.

(3) VI, T42-6 through T42-9.

(4) VIII, T10-3, IX, Appendix T10.

(5) X, T42-1 (3 pages)

(6) XI, T42-1 (3 pages)

(7) Task 27 - Final Report (Testing)

TASK 43

COMPUTER PROGRAMMING

I. Introduction

At the time of the final contract negotiation a work statement had been prepared defining the various tasks. Task 43 was defined as follows:

Task 43 - Computer Programming and Services - The computer program will be developed to:

1. Control the settings of the controllable elements in the optical trains.

2. Control the positions of the two axis stages.

Note that the computer program will thus provide "error signals" to continuously maintain an optical presentation of a stereo model for operator viewing.

The program will be designed around the available facts, i.e., types of photography to be handled (frame, pan and strip), stage speeds, correlation limits, optical elements and control, etc., and will be designed in conjunction with a computer program consultant and outside computer services as required.

The first part of this work statement was stated more explicitly in the first progress report(1), which included as the opening paragraph under Task 43:

"A small general-purpose digital computer will be used to translate signals from the operator's controls into settings for the stage positions and the various optical elements. The computer will be programmed to determine corresponding points on the two photographs and to compare the immediately surrounding regions for (1) scale factor, (2) amount of tilt distortion, and (3) orientation. It will then generate incremental signals for the stage drives and for the optical elements (zoom lenses, anamorphic lenses, and image rotators) so as to bring the projected images into proper stereo correspondence. Thus, the apparent effect of the operator's controls will be to shift the viewpoint and the scale factor of the stereo model without causing the images to diverge. In mathematical terms, the two images will be continuously adjusted as to exhibit what is often called zero Y-parallax. The concept of zero Y-parallax is well known in photogrammetry and its mathematical implications were described in Appendix 3 of the final report under Contract [redacted] STAT

Alternative approaches in comparing the two photographs for scale factor and degree of anamorphic correction required were outlined in the next two paragraphs of the same report[2]:

"Three methods are available for comparing small regions of the two photographs to determine the relative scale factor and amount of tilt distortion. One method uses TV scanners and an elaborate (six-signal) correlator to produce analog measures of the lack of correspondence. A second method requires successive settings of the two measuring reticles on four adjacent, corresponding points in the two pictures. The digital computer then computes relative scale factors in two directions (i.e., four parameters) from the four sets of X-Y coordinates. A two-signal correlator makes setting on corresponding points a nearly automatic process. The third method involves direct computation from the known geometry of the two photographs.

The first two of these methods do not provide sufficient information to establish a stereo model initially (since the direction of the flight base remains unknown). They can, however, approximately maintain a stereo model which has been initially established by manual control of the optical elements, and continue to do so as the stereo model is moved around in response to operator control signals. The third method requires numerical values for the location and orientation of the two camera stations (hence, the flight base) and, theoretically, can be used to establish a stereo model without requiring manual control of the optics."

II. Summary

In the process of obtaining a design for a correlation system (see Task 25) it ultimately developed that a six-signal correlator rather than a two-signal version would be used. The design developed [redacted] showed a capability of correlating on many, but not all, photographic pairs or regions of a photographic pair. Under conditions such that correlation failed, the failure was complete and the Itek design could not provide two-signal correlation where it

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couldn't also provide six-signal correlation. For this reason, the second alternative mentioned above, i.e., computing the relative scale factors in two directions from the measured coordinates of four nearby corresponding points, was abandoned as of no value. The first and third alternatives mentioned above have both been implemented however, and the third may be used either with or without the assistance of the first.

Testing of the computer program(3)(4)(5)(6) demonstrated that a substantial part of the program could operate in floating point arithmetic without exceeding the available time to circulate through the complete set of computations. This eliminated some problems in scaling and accuracy which would have occurred if the whole program had had to operate in fixed point arithmetic as was originally expected(7). The testing also verified that the real time program (in fixed point arithmetic) could be written so as to run in a sufficiently short time to permit circulating through it 120 times per second. (This number is a desirable sampling rate for smooth stage control.) An independent estimate of running time was contained in a report submitted [redacted] STAT
[redacted] (8) STAT

Charting of the computer program was initiated [redacted] STAT
personnel(9)(10)(11), but was completed by means of a subcontract to Informatics Inc.(12) The final computer flow charts are part of the computer specifications written by [redacted] These can STAT
probably be more easily followed, however, if studied in conjunction

with the simplified flow charts which were furnished by [redacted] STAT
[redacted], as the basis for the much more detailed charts they STAT
made. These simplified charts are included in Appendix T43-A of this report.

Similarly, the basic mathematics was outlined by [redacted] STAT
furnished [redacted] who then incorporated it into the specifications which they wrote for the computer program. This mathematical outline is included in Appendix T43-B of this report.* STAT

III. Conclusion

The subcontract to [redacted] resulted in their writing a 193-page document entitled, "Computer Program Specifications and Instructions" which is delivered separately from this Final Report, but as part of the same contract. This document spells out a computer program to be written partly in Fortran and partly in DAP (DAP is the name of the assembly language for the Honeywell 516 computer.). "Programs" written in these two languages can be translated by the computer itself into actual machine code programs. This program specification breaks the complete program into twenty-five subroutines which are called as needed by one of two executive programs. Each subroutine and each of the executive programs is separately described with individual flow charts for most of them. In addition, the specification describes a number of tables for storage of data and various constants. STAT

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*This outline, as well as the program flow charts, are included here since they have been revised to some extent since the last editions which were included in the monthly reports.

The final debugged program will probably be capable of residing in 12,288 words of computer memory. Debugging will be considerably simplified, however, if the computer has sufficient memory to allow storing, not only the basic program which will finally emerge, but also some debugging aids which are included in the specification and the standard Honeywell software for compiling and debugging programs. Hence, it is recommended that the computer be purchased with 16,384 words of core storage.

IV. Discussion

Many of the conventions and details of the program specification are explained in the first two sections of the specification itself. As stated there, however, "Although the programs are defined in detail, study of other related documents is required for a thorough understanding of the system. The mathematical methods are defined in detail, but the development of the methods is not described. An understanding of these methods will probably be helpful in writing the computer program." The other related documents referred to are those included in Appendices T43-A and T43-B of this report and the Final Report of the feasibility study [redacted] which was written a little over two years ago. These documents are basically an application of the principles of analytical photogrammetry -- extended to panoramic and strip types of photography[13] -- to the control problems

STAT

of the Stereocomparator.

The documents mentioned above are largely self-explanatory. Some notes are in order, however, regarding the "Non-Real Time Computations" (Appendix T43-B). The following comments refer specifically to the items in the latter document as referenced by number.

1.1.8 The angle β is here treated as though general. It is actually zero in all present known cases.

1.2.1 The stage coordinates, as referred to here, are specifically for the Honeywell computer (whose program is being specified). Corresponding coordinates can, at the operator's option, be read to the card punch or directly to the external computer. The latter coordinates are BCD and can be arbitrarily labeled x or y with either direction considered positive.

1.6 The system given here breaks down for latitudes close to the north or south pole. A means remains to be devised for dealing with this special case.

1.6.2 and 1.6.4 The formulas given here are first order approximations of the formulas implied (though not all stated explicitly) in the Manual of Photography. It appears that the accuracy of these approximations should be adequate for all presently known cases. If future systems have appreciably higher camera speeds and/or altitudes then better approximations may be needed for those systems.

1.6.5.1, 1.6.5.2, and 1.6.5.3 These "rotations" give the direction of the flight base with respect to the ground system. The flight base is taken as the x axis direction of the "Image Coordinate

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System" describedin 2.2.1 of the program specifications.

1.7.7, 1.7.8 and 1.7.9 These three rotations provide a correction for the convergence of the lines of equal longitude as these approach the north (or south) pole.

1.7.11 on -- See Appendix I of the Final Report on the feasibility study for an explanation of the notation (Tensor) which is used here.

1.8 through 1.10 These formulas are used to compute a ground plane when the REORIENT button is set.

1.11.1 through 1.11.4 Three different transformations are given for 3 different types of photograph on the slave stage. The explicit form of these is the same for the three different types of photograph on the master stage, but different substitutions are used for ($x^{a} - x^{a}_{1}$) (see 1.12).

1.11.5 Photograph coordinates are transformed to stage coordinates.

1.11.6 The matrix X^{σ}_{a} is theoretically the first order derivatives of the transformation formulas given in 1.11.2 - 1.11.4. The results of generally differentiating these formulas are very complex. Hence, the approximate method given here is used as a substitute for the formally correct method. The tracking matrix is the equivalent of X^{σ}_{a} but expressed in stage coordinates.

1.12.1 - 1.12.3 The results stated here are given in the auxiliary documents referred to above[13]. Note that the subscripts and superscripts used there (m,n.... and r,s....) correspond to (α, β ..... and σ, τ .....) as used here.

2.1 These are general formulas giving $(x^j - x^j_{10})$ as functions of $(x^\alpha - x^\alpha_1)$ and of t. They are the basis for the actual computations outlined in 2.2.

2.2 These formulas can rather readily be turned into corresponding Fortran expressions which are substituted as called for in 2.1.

2.3 These approximate derivatives are used as coefficients in the optical tracking portion of the real time program (see 3.5.6 of the program specification). Their values are computed, as outlined here, in the non-real time program (see 3.7.1.5 of the program specification). The program makes two types of transformation in the process of computing and using these matrices: (1) convert from photo coordinates to stage coordinates (3.7.1-2 - 7A) and (2) convert from floating point numbers to fixed point numbers (3.7.1-2 - 9B). The program specification uses different symbols for the results before and after each of these transformations - hence it is somewhat confusing to follow.

2.4.1 - 2.4.6 The method for deriving these formulae was given in the feasibility report but the symbolism was slightly different.

2.4.4 and 2.4.6 Two angles differing by $\pm\pi$ are specified in each of these. The Stereocomparator optical servos select one or the other of these angles so as to avoid the discontinuity which any one angle has in going from $\pm\pi$ to $\mp\pi$.

2.4.7 and 2.4.8 The formulas outlined here must be spelled out explicitly in the program specification. Doing so involves straight forward applications of elementary calculus. These quantities are shown in F 6 and G 1 of the "Notes for Computer Flow Charts" (Appendix T43-A).

REFERENCES

Task 43 - Computer Programming

(1) I, page T43-1

(2) I, pages T43-1 and T43-2

(3) II, pages T43-1 through T43-4

(4) IV, pages T43-1 through T43-7

(5) VII - Appendix T43-H

(6) IX - Appendix T43-P

(7) II, page T43-2

(8) X, (Informatics Report - T43-19 through T43-39)

(9) VII, pages T43-1 through T43-5

(10) IX - Appendix T43-O

(11) X - Figure T43-1, Fig. T43-1.1 through T43-1.7

(12) X, page T43-1

(13) Photogrammetric Engineering - Vol. XXXIII, No. 11, pages 1290 - 1298, Skiff, Edson W. "Analytical Treatment of Strip and Pan Photos".

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- I January 9 through February 24, 1967.
  Pages T1-1 to T1-2
- XI October 28 through November 24, 1967.
  Pages T1-1 to T1-3

Task 2 Scheduling and Planning

- I January 9 through February 24, 1967.
  Pages T2-1 to T2-2

Task 4 Management, Administration and Supervision

- I January 9 through February 24, 1967.
  Pages T4-1 to T4-2
- II February 24 through March 31, 1967.
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- VI July 1 through July 28, 1967.
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- VIII August 26 through September 29, 1967.
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- X September 30 through October 27, 1967.
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- IV May 1 through May 31, 1967.
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- V June 1 through June 30, 1967.
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- VIII August 26 through September 29, 1967.
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Task 17 Viewing Illumination

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VIII August 26 through September 29, 1967.
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IX Appendix T16,17-C Optical Vendor Progress Report #1 (English Translation)
IX Appendix figure 1 following Report #1
IX Appendix T16,17-D Optical Vendor Progress Report #2
IX Optical drawings #4610, #4616, #4619, #4620, #4618, #4617 & #4611 following Report #2
X September 30 through October 27, 1967.
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Task 18 Reticle Projector

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Task 20 Platen Illumination

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Task 28 Output Logic, Interfaces and System

Task 30 Control Console

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VIII August 26 through September 29, 1967.
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IX Appendix T30-M Control Panel Lay-out Drawing D 4552
XI October 28 through November 24, 1967.
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Task 33 Racks and Control Cabinets

VIII August 26 through September 29, 1967.
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IX Appendix T33-N Electronic Equipment Cabinet #1 Drawing D5740

Task 34 Utilities

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Pages T34-1 to T34-2
Appendix T34-F Utilities Schematic Drawing SK 353
VI July 1 through July 28, 1967.
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Task 35 Vibration Absorption

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Task 36 Overall Assembly

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Task 41 Stereo Comparator Mock-Up

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VI July 1 through July 28, 1967.
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Task 42 Breadboards and Test Services

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IV May 1 through May 31, 1967.
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PART IV

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PART IV

PHASE II FABRICATION

I. Introduction

The requirement for assembly of a breadboard for testing critical components and for a full-size mockup of the Stereocomparator during Phase I has provided experience which will be invaluable during Phase II. It has proven the capability of [redacted] equipment and manufacturing personnel to fabricate, assemble and test many of the critical components of the machine. STAT

II. Summary

It is the intent of [redacted] to manufacture in house as many of the Stereocomparator sub-assemblies as is practical, considering the problems of the short schedule and economic feasibility. STAT

At this time [redacted] does not plan to fabricate in house the following components: STAT

1) The Optical System
2) The Optical Bridge
3) Granite and Ways
4) Image Analysis System
5) Computer
6) Electronic and Utility Cabinets
7) Isolation System

It is planned to assemble the optics to the optical bridge at the optical vendor's plant. The initial checkout and testing of the optics will likewise be performed at the optical vendor's plant.

The assembly and checkout of the Stereocomparator as a whole system will be performed at the [redacted] plant. In addition, complete STAT performance tests will be made at the [redacted] plant for customer acceptance. STAT

After disassembly and reinstallation at the customer site, a further series of acceptance tests would be performed.

III. Discussion

Except for minor sequence revisions to accommodate time phasing and provide a more even shop load, the manufacturing sequence will be:

1) Assembly of the Main Frame and Isolation System, both of which will be outside purchase.

2) Install Base Granite which has been purchased, but will be drilled and plugged for bracketry installation [redacted] STAT

3) Line and level the Base Granite, install the saddle and stage assemblies and air bearings, assemble and install drives.

4) The Optical Bridge and bridge supports will then be installed and checked for alignment. (During the sequence listed, all components will be drilled and pinned to assure alignment when re-assembled.) After a complete alignment check, the Optical Bridge will be disassembled and, with the supports, shipped to the Optics subcontractor. All internal

components of the Optical System will be installed and checked at the Optics subcontractor's plant.

5) With the Bridge removed, the check-out and test for alignment of stages, bearings, and stage drives will be conducted. At this time, all power connections will be made to the electronics racks which have been in production during mechanical assembly.

6) When the Optical Bridge and the installed components are received from the Optical Subcontractor, the final assembly test and checkout will be made.

Details of the fabrication and assembly schedule and sequence are more complex than the steps outlined above. The basic plan, however, will not deviate from this outline.

ULTRA HIGH PRECISION STEREOCOMPARATOR

STATEMENT OF WORK

The statement of wo rk requires the fabrication, test and installation of an ultra-high precision operating prototype Stereocomparator.

GENERAL DESCRIPTION

The Stereocomparator consists of a high performance stereo viewing and stereomeasuring (X and Y axis) comparator.

The instrument is adaptable to cut film and up to 500 foot rolls of 70mm to 9-1/2" wide roll film.

The optical system accommodates to large differences in scale between conjugate images.

A continuously variable optical system with two magnification ranges, 10X to 100X and 20X to 200X provides scanning and measuring over an area of 9-1/2" by 20".

The optical system and stages are arranged for three modes of positioning - manual, computer programmed and computer programmed with automatic electronic stereo correlation.

The motion of the photo carrying stages is under operator control through the use of individual stage trackballs and a joystick.

The Stereocomparator includes a light table feature whereby the entire film format may be viewed directly by the operator.

DELIVERABLE ITEMS

1. One operating prototype High Precision Stereocomparator per Drawing No. E4585, designed in conformity with the parameters: "Specifications for the Ultra High Precision Stereocomparator dated January 26, 1968."

2. Checkout of the sub-assemblies and final assembly and the performance of operational tests.

3. Updated fabrication drawings to an "as built" condition.

4. The work scheduled is described by Drawing No. E6828.

5. Installation of the Stereocomparator at the customer's ground floor site.

6. Training of operators in the use of the instrument.

7. Operating manual and procedures.

8. Recommended spare parts list.

9. Site preparation, with provision of utilities, services and environmental conditioning, will be by the customer.

January 26, 1968

PERFORMANCE SPECIFICATIONS for the ULTRA HIGH PRECISION STEREOCOMPARATOR

I. INSTRUMENT

A. Mechanical

1. Overall dimensions and weight

a. Length - 13 feet

b. Width - 7-1/2 feet

c. Height - 7 feet

d. Weight - 28,000 lbs.

2. Vibration Absorption

a. Specially designed coaxial pneumatic-hydraulic shock isolation

b. Servo leveled

c. Resonant frequency - less than 2 CPS

3. Main Base

a. Monolythic granite

b. Flat - within 50×10^{-6} inches

c. Thermal coefficient of expansion - 4×10^{-6} inches/deg. F

4. Stages

a. Air bearing lift-off - 4 microns

b. Stiffness - 15 lbs./micron liftoff/sq.inch of pad area

c. Stage drive

(1) Drive Speed

(a) maximum 3 inches/second

(b) minimum - 10 microns/second

(2) Drive acceleration maximum - 10 inches/second^2

(3) Positioning - ± 0.1582 microns, least count

(4) Servo-controlled

(5) Threadless leadscrew

(6) Frequency response - 5 Hz.

(7) Steady state tracking speed on two identical photographs - 10mm/second at 10 magnification with the displacement error less than 1/2% of the field of view

(8) Correlation time - less than 1.5 seconds at the maximum pull-in range of 5% of the field of view

d. Film Platen

(1) Subplaten cooling - 3 SCFM air

(2) Low expansion glass - 23-1/2" long, 15" wide, 1-1/4" thick

(3) Viewing area adjustable from 70mm to 9-1/2" wide by 20" long

(4) Above platen cooling - high velocity air jet less than 160 SCFH

e. Optical Bridge

Three section, arranged with the moveable elements in collimated light regions to minimize the effects of thermal expansion and vibration.

f. Film Drive

(1) Drive speed - 2-1/2 to 250 FPM - 500' film reel size.

(2) Film thickness - .002" - .007"

(3) Servo controlled capstan drive - emulsion wound either in or out.

(4) Joystick controlled

(5) Film tension held to ± 10% of preset value.

g. Film Clamping

(1) Vacuum clamping at more than 23 Torr.

(2) Clamping time from 3 to 20 seconds

(3) Adjustable for 70mm to 9-1/2" wide film x 20" long

B. <u>Optical Assembly</u>

1. Illumination System

a. Light Intensity Control

(1) Counter - rotating dual filter disc assembly, range 0 to 5 density

(2) Photoelectric sensing to a preset servo-controlled light level.

b. Film Density

To accommodate film up to 3.0 density

c. Color Filter

Remotely controlled, removable filter, yellow-green 546 millimicrons median transmission wavelength

d. Condenser

(1) Remotely controlled - focal length to conform to switching of main objectives

(2) Matches the main zoom system setting over its 1:10 variable magnification range

e. Air cooled infrared filter

f. Light source

(1) Osram XBO 450 watts

(2) High pressure Xenon arc lamp

(3) $\sim 5000^{\circ}$ K color temperature

2. Objective System

a. Focusing of Objectives

(1) Two objectives, 40mm and 80mm focal length, installed in a remote controlled rotating turret

(2) Fine focusing over 1/16" range with maximum image wander of 1/2 micron

3. Beam Splitter and Corner Prisms

Anti-reflection coated

4. Reticle Projector

a. Bright round spot projected to eyepiece center

b. Variable in brightness - 50:1 range

c. Variable in size from approximately diffraction limited to 4X diffraction limited

d. Filter holder for changing the spot color

e. Zoom range - $\sqrt{10}$ to $\frac{1}{\sqrt{10}}$

f. Anamorph range - 2:1 to 1:1

g. Reticle rotation range for anamorph matching axis - infinitely variable

h. Lamp - Osram XBO 75 watt

5. Main Anamorph System

a. Prism Type

b. Range 1:1 to 1:2

c. Anamorph rotation range - infinitely variable

6. Main Zoom System

Zoom range - $\frac{1}{\sqrt{10}}$ to $\sqrt{10}$

7. Main Image Rotator

Infinite rotation in either direction

8. Eyepieces

a. Adjustable interpupillary distance - 50 to 75mm

b. Magnification - 10X

c. Eye relief - 20mm

d. Angular field - 40^{o}

e. Convergence adjustment - 6^{o} horizontal

f. Vertical adjustment - 2^{o} (squint angle)

g. Exit pupil - 1mm diameter

h. Eyepiece brightness level control range - 10:1

i. Eye protection shutter - 2 milliseconds operating speed. Triggered automatically when the actual brightness at the eye exceeds the preset brightness level by 50%.

j. Manual switching between stereo, binocular left stage and binocular right stage and reverse stereo.

9. Laser Interferometer

a. Twyman green interferometer

b. Measuring @100,000: 1 scale, one least count on film, or 0.10 micron equals 10mm or 0.39" on object

c. To the viewer @200X 0.10 micron equals .000787"

d. One least count is on the threshhold of visability

e. Laser frequency servo stabilized ± 1 MHz per day per degree C at constant barometric pressure at 6328 angstroms (Helium-Neon)

f. X and Y reflecting mirrors carried by the stage, flat to approximately 1/4 wavelength, Sodium D light/2" of length

10. Resolution EXPECTED

a. White light from a Xenon arc

	Linepairs/mm	
Objective focal length	40mm	80mm
10X Magnification		55
20X Magnification	110	
100X Magnification		500
200X Magnification	900	

b. Yellow-green filtered Xenon arc light

Objective focal length	40mm	80mm
10X Magnification		60
20X Magnification	100	
100X Magnification		500
200X Magnification	1000	

See Part II Page 6 for Contracted Resolution

c. The resolution degradation between the center of the field of view and at one third of the distance toward the edge of the field of view, is less than 10%.

C. <u>Electronic</u>

1. Electronic Correlator

   a. Image dissector type scanning tube, computer integrated.

   b. Six-signal output

2. Computer

   a. Honeywell DPD 516

   b. 16-bit word length

   c. Approximately 16,000 word memory core

   d. Memory cycle - 0.96 microseconds

   e. Words transfer - 1.92 microseconds

   f. Teletypewriter input and output

3. Metric Readout

   a. Metric readout of stage position converted from 1/4 wavelength of He-Ne laser light to 0.1 micron least count

   b. Counting rate of measuring system - 1 MHz

4. Optical Drives

   a. Optical element servo-controlled drive frequency response - 3 Hz

   b. Full travel of optical elements in 3 seconds

5. Control Console

   a. Centralized operation by pushbutton selection

   b. Stage motion X and Y controlled by joystick and trackballs

   c. Trackball sensitivity

      (1) Low speed setting - 360° of trackball rotation causes 20 microns of stage movement

      (2) High speed setting - 360° of trackball rotation causes 1280 microns of stage movement

   d. Manual adjustment of optics by remote control from the control console panel

   e. Optical elements are provided with transducers which read out the optical settings to indicators on the panel of the control console

   f. Stage position X and Y readout on control panel in tenths of microns

   g. Operating modes for stereo viewing

      (1) Manual settings

      (2) Computer control

      (3) Computer control with electronic correlation

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II. ANCILLARY EQUIPMENT

A. Teletype - I.T.T., ASR 35

B. Cardpunch - I.B.M. 526

C. Electronic Cabinets - Two-bay type with front and rear doors, 3 units

D. Electronic and Pneumatic Utilities Control Cabinet - Two-bay type with front and rear doors, 1 unit

E. Control Console - Centralized keyboard operated

F. Operator's Chair - Adjustable for height, angle and position

III. SUPPORT EQUIPMENT

A. Air Compressor - 170 lbs., PSIG

B. Environmental Air Conditioning - Clean room with sub-micron particle filtration, temperature control - 72° F $\pm 0.5^{\circ}$ F. Humidity control - 55% RH $\pm$ 5 to -15% RH.

C. Vacuum Pumps (2) - 24 CFM at 23 Hg vacuum

D. Conditioned compressed air - Cooled and dehydrated for film cooling

E. Equipment Cooling - Dry air supply, 50 SCFM at 100 PSIG

F. Approximately 11 HP Motors

G. Stereocomparator and Control System Power Requirement - 20KW

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