Reduction Cameras: Mechanical Design of the 3.5X and 1.4X Reduction Cameras

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I. INTRODUCTION

The 3.5X and 1.4X reduction cameras basically employ the same structural features differing only in the lenses and focal distances required to achieve the desired reductions. Both cameras have been designed as fixed-focus cameras in that no adjustment is made on individual components to optimize the focus and magnification.

The camera incorporates the following design features: (*i*) isolation of the camera from building vibrations; (*ii*) temperature compensation in the long and short conjugates to compensate for changes in the lens due to changes in the ambient temperature; (*iii*) sufficient structural mass of individual components and material conductivity to avoid local distortions due to rapid changes in ambient temperatures; (*iv*) artwork and image plates automatically positioned to within an accuracy of about one micron; and (*v*) exposure control which can be varied, with a high degree of reproducibility.

II. PHYSICAL DESCRIPTION OF CAMERAS

A rigid camera bed supports the elements as shown in Fig. 1. The camera bed is mounted on springs to provide vibrational isolation. The welded frame which supports the camera bed-spring assembly contains the pneumatic controls, lamp power supply, shutter-control electronics, and the Mask Shop Information System (MSIS) lamp and read-out supplies.

The camera bed is made of two GA50 Meehanite cast iron I-beams which are connected laterally. The faces of the I-beams have been ground flat and parallel in pairs to provide an accurate support for

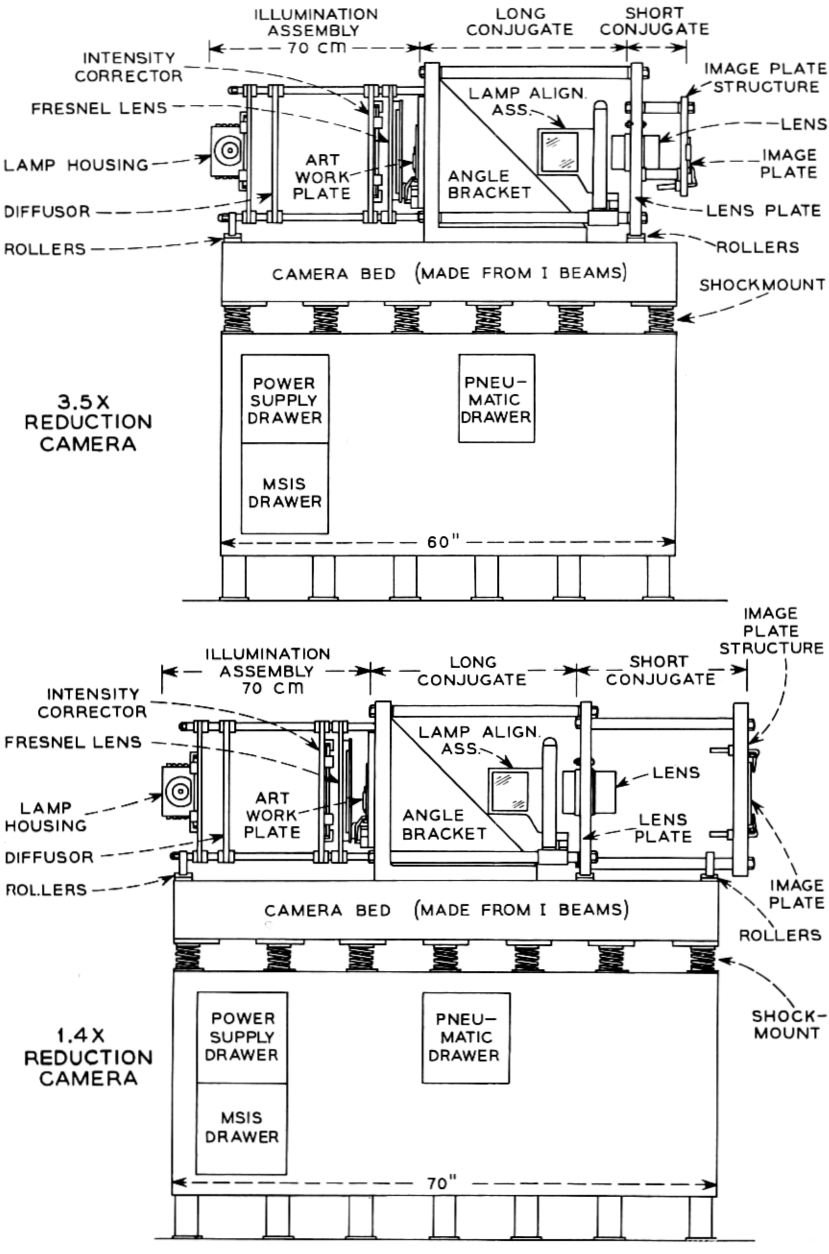

Fig. 1—Schematic of 3.5X and 1.4X reduction cameras.

the camera elements. As shown in Fig. 1, a large gusseted Meehanite angle bracket is bolted and pinned to the camera. This bracket provides the fixed support for the illumination assembly and the lens-and-image plate assembly. As will be discussed later, the rods of the conjugates are machined along with the assembled lens-and-image plates to obtain the correct theoretical lengths so as to yield the desired focus and magnification. Fine trimming of the lengths is performed utilizing a computer program until the optimum lengths are achieved (see Ref. 1).

The lens plate is mounted on rollers and is free to move along the camera bed with changes in ambient temperature. Similarly, the end of the rod supporting the illumination assembly is mounted on rollers. The illumination assembly consists of the fresnel lens, intensity corrector, diffusion screen, and lamp-housing shutter assembly.

As shown in Fig. 1, a roller support is provided for the image-plate structure of the 1.4X camera. On the 3.5X camera, this additional support is not needed because of the relatively small short-conjugate distance. Figures 2 and 3 are photographs of the 3.5X and 1.4X reduction cameras.

III. VIBRATION ISOLATION

Providing a vibration-free environment is essential if high-quality reductions are to be made. If excited, vibration of the camera bed would result in bending of the bed in many modes and thus could destroy the focus and magnification of the camera along with the alignment of its image relative to the artwork. To eliminate this, the 3.5X and 1.4X camera beds were designed to have a free-free natural frequency of 100 Hz and the bed shock mounted on springs to yield a rigid body natural frequency of 3 Hz. Reference 2 shows that if this is the case the natural frequency of the bed coupled to the springs is the 3 Hz rigid body mode with the next resonant frequency occurring at 100 Hz and other frequencies occurring from 100 Hz on up. From Fig. 4 taken from Ref. 3 one can see that if the exciting frequency ω is three times greater than the rigid-body natural frequency ω_n, the rigid body is essentially isolated from the perturbing force. Normally, for most building floor slabs one can expect floor slabs to have a resonance of from 12 to 15 Hz and the foundation (i.e., base slab or cellar) to have a resonance of around 30 Hz or higher. Hence, mounting the reduction camera bed at 3 Hz isolates it from all the disturbing building frequencies above 10 Hz. Furthermore, because of the rigidity of the camera bed, it will behave

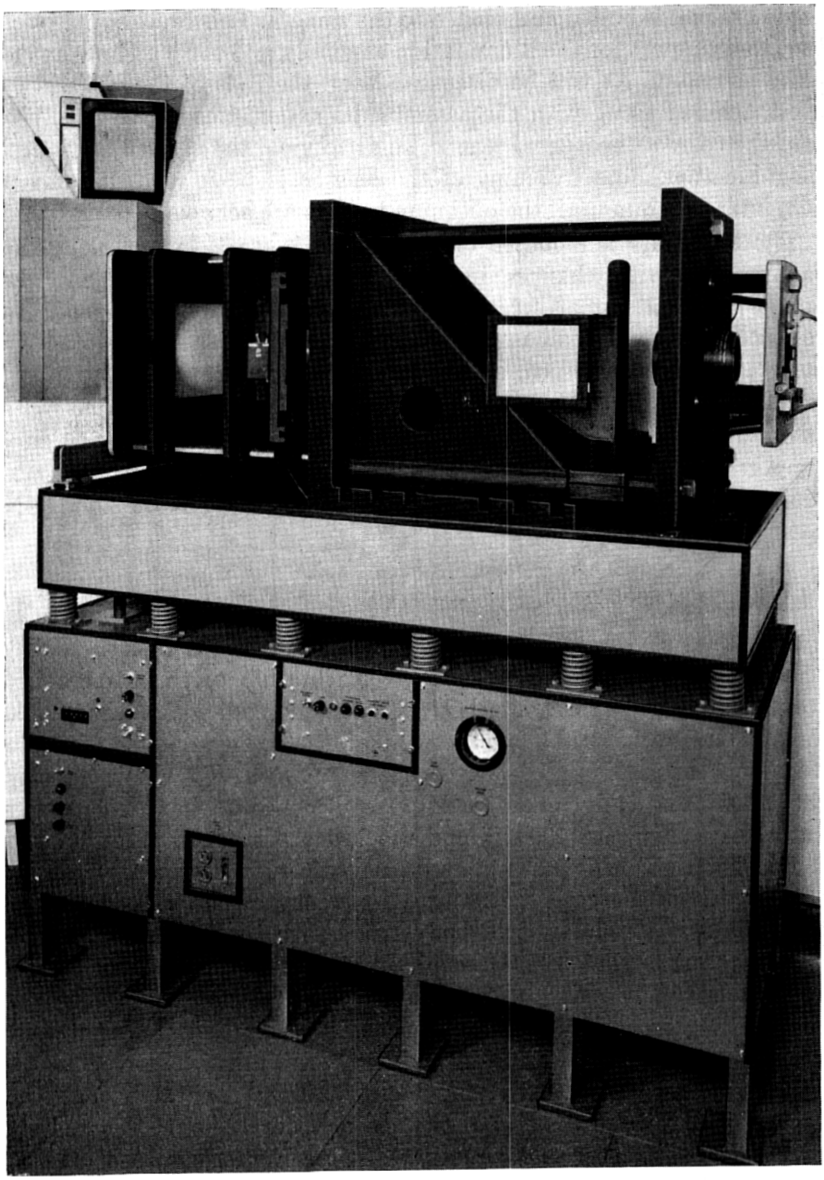

Fig. 2—3.5X reduction camera.

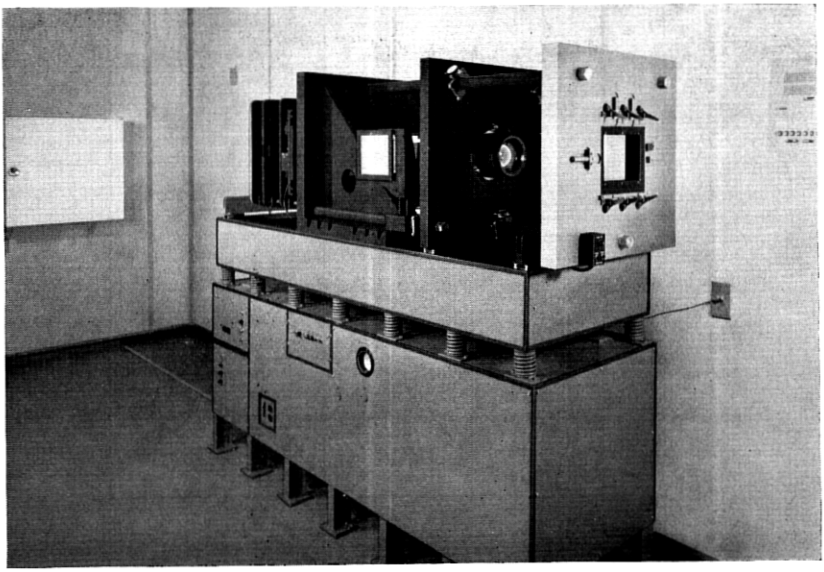

Fig. 3—1.4X reduction camera.

as a rigid body if subjected to excitation below 10 Hz. The 3-Hz shock mounts are provided with inorganic (metal mesh) damping and the camera bed I-beams have an elastomeric damping compound bounded on their webs to provide damping should the camera bed be inadvertently excited.

The frame to which this shock-mounted camera is attached was designed so that its resonant frequency is 50 Hz, hence eliminating any possibility of the support structure being the source of a rigid body excitation near 3 Hz.

The three support rods of the illumination system have a natural frequency of 40 Hz in the lowest mode which is lateral bending. The three rods of the long and short conjugates have a natural frequency of 200 Hz.

IV. THERMAL DESIGN CONSIDERATIONS

The reduction cameras are operated in a clean room which is temperature-controlled to within ±0.15°C to maintain artwork and image sizes as well as their relative positions. To further assure reproducability even under more adverse ambient condtions, additional design features were incorporated. The rod material of the long and short

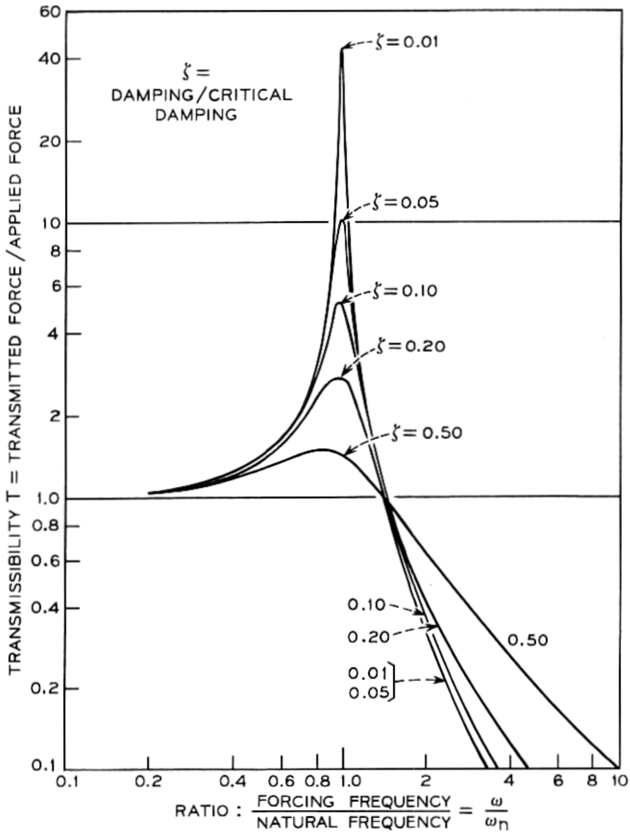

Fig. 4—Transmissibility versus frequency for a single-degree-of-freedom rigid-body system.

conjugates on both cameras was selected to compensate for both focus and magnification errors due to the effect of temperature fluctuations of the lens itself over $\pm 5°C$. The length of the long and short conjugates vary with temperature in a prescribed manner to accomplish this compensation. The variation is linear with temperature and is obtained by selecting the rod material with the appropriate coefficient of thermal expansion.

The good conductivity of the GA50 Meehanite and the large mass of the bed insures that only negligible thermal gradients through the bed structure will be encountered and, hence, bending distortion of the bed is effectively eliminated. The bed temperature will change uniformly should a change in room temperature occur, thus, preventing degradation of focus, magnification, and artwork-image alignment.

V. MATERIAL SELECTION

GA50 Meehanite was selected for the I-beams and angle bracket of the camera bed because of its good dimensional stability with time and its good conductivity. Both the I-beams and angle bracket were furnace annealed prior to rough machining and given a vibration stress relief after rough machining and prior to final machining. This was done to insure the stability of the parts.

The illumination element holders were made from ground tool plate which was annealed to avoid warpage during final machining.

The lens-holder plate and image-plate structure were made from AZ-31 magnesuim plate which has exceptionally good dimensional stability. This material provided a rigid yet lightweight structure.

For the 3.5X reduction camera, the rods of the long conjugate were made from Hastelloy X and those of the short conjugate from a 49 percent nickel iron alloy. These materials were selected because they had coefficients of thermal expansion which provided the required temperature compensation for the lens.

For the 1.4X reduction camera, the long conjugate rods were made from a composite two-material rod of Invar 36 and 49 percent nickel iron alloy, and the short conjugate made from a composite two-material rod of stainless steel and 49 percent nickel iron alloy to obtain the appropriate coefficient of thermal expansion.

VI. ADJUSTMENT OF THE LONG AND SHORT CONJUGATES

A relatively gross adjustment in the mils range (i.e., 10^{-3}″ range) has been provided on both the long and short conjugates of the reduction cameras. In addition, an adjustment in the microinch range (i.e., 10^{-6}″ range) has also been provided utilizing the technique developed for the mirror of the PPG (see Ref. 4). The gross adjustment is provided by compressing Belleville springs as shown in Fig. 5, and the fine adjustment uses elastic compression of rectangular pads into the metal surface to provide the microinch adjustment, the soft spring being the bolt itself as shown in Fig. 5.

The long conjugate is bolted to the angle bracket reference surface. This end contains the pad washers which provide the microinch adjustment. The other end of the long conjugate is bolted to the lens plate and contains the Belleville springs used for gross adjustment.

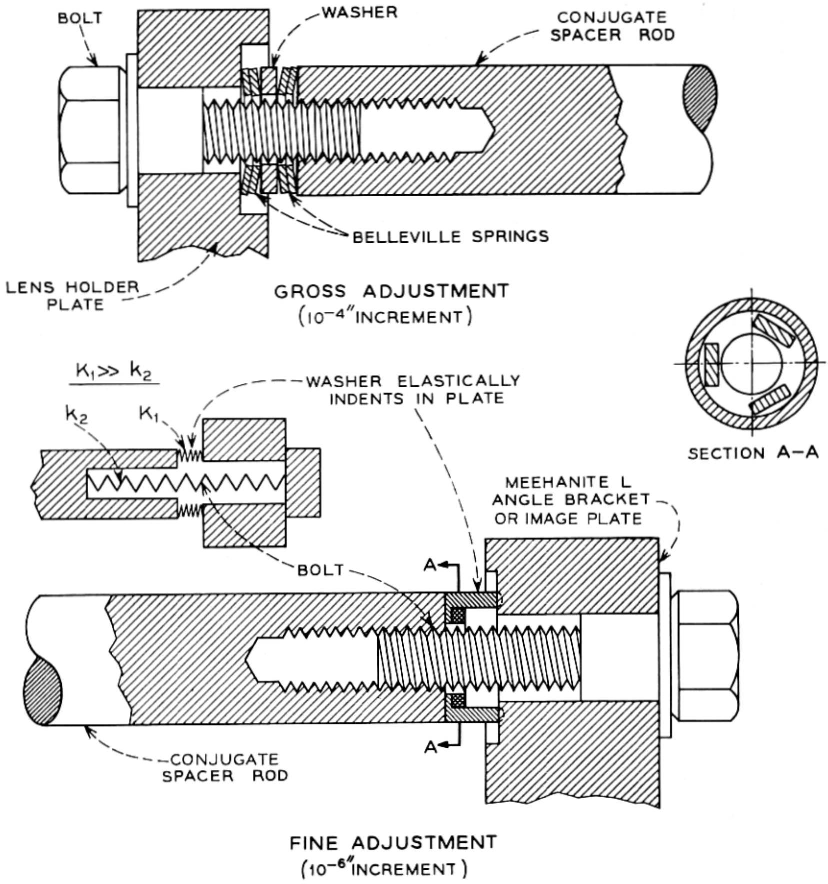

Fig. 5—Adjustment mechanism for conjugates of reduction camera.

The short conjugate is bolted to the lens plate and to the image-plate structure. The end bolted to the lens plate contains, the Belleville washers for gross adjustment and the end bolted to the image-plate structure contains the pad washer for microinch adjustment. The gross adjustment provided for each conjugate rod at the lens plate is monitored with a dial indicator (later removed) capable of being read accurately to within 0.0001″ and having a range of ±0.01″. This permits the adjustment of the long and short conjugate rods according to the computer program discussed in Ref. 1. The pad-washer end of each conjugate provides the fine adjustments in the microinch range within a range of ±0.00025″. For the current reduction cameras it was not necessary to use the microinch adjustment to bring the camera into focus and magnification.

VII. ARTWORK AND IMAGE PLATE POSITIONING

Both the artwork and image plates must be positioned reproducibly against the locating pins. The artwork plate, locating pins on the camera are positioned and constructed exactly as they are on the pattern generator. Similarly, the image plate is positioned against pins which are constructed exactly as they are on the artwork side of the step and repeat camera.

To position the artwork and image plates in the reduction camera successfully, the applied forces holding plates against their location pin must be greater than the frictional forces. A static analysis, knowing the coefficient of friction, allows one to adjust the relative forces in the horizontal, the vertical, and the axial directions, such that the plate will always seat.

The artwork is placed into a vertical holder and pneumatically held. This holder, supported on bearings, is then pushed into the camera. Upon contacting a microswitch, the plate is released from the holder and clamped against vertical and horizontal pins. The holder is ejected and the plate then located onto the axial pins (i.e., pins parallel to the optical axis). To accomplish this, a system of miniature pneumatic cylinders utilizing dry nitrogen are used (see Fig. 6). The image plate is also located pneumatically. The operations are controlled by pneumatic and electrical components in a drawer located in the bench assembly (see Fig. 7).

Artwork and image plates have been loaded repeatedly into the cameras. Statistical analysis of the data shows that the plates index reproducibly. For the nominal eight-inch by ten-inch, one-quarter-inch-thick artwork plate it was found that the plates had a mean seating error of from eight to thirteen microinches depending on the axis measured, with a standard deviation of from five to ten microinches. For the nominal four-inch by five-inch, one-quarter-inch-thick image plate, it was found that the plates had a mean seating error of from three to four microinches depending on the axis measured, with a standard deviation of from two to eight microinches.

VIII. SHUTTER

For both cameras, it was deemed desirable to be able to vary the exposure time from 30 ms to 100 s. To provide uniform exposure, it

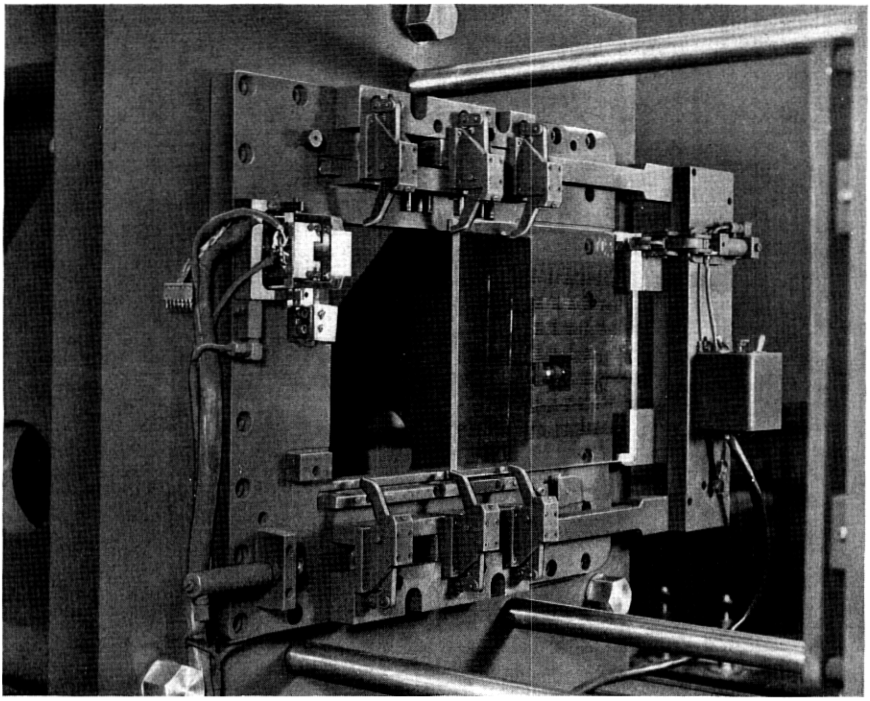

Fig. 6—Insertion mechanism for artwork.

is necessary to have opening and closing speeds which are small compared to the exposure. It was not possible to purchase a shutter having the required 6.3-cm aperture and the necessary range and precision of exposure with an opening and closing time of 10 ms.

A commercial spring-activated shutter was modified to meet this requirement. The case A and plate B were retained as shown in Fig. 8. The leaves were reinforced in the high impacted area, and the leaf-activating mechanism was designed to ride on ball bearings to reduce the frictional forces. The driving mechanism consists of an opening and closing solenoid with their armatures joined at the driving arm of the shutter. The solenoids with the shutter are mounted on the lamp housing, aligned, and pinned. At the ends of the armatures are damping cushions to reduce bounce, and at the ends of the solenoids are adjusting screws to insure that the impact force is not absorbed by the shutter leaf rotating slot. The shutter driving arm is coupled to the solenoid armatures through a slot. The slot is longer than the

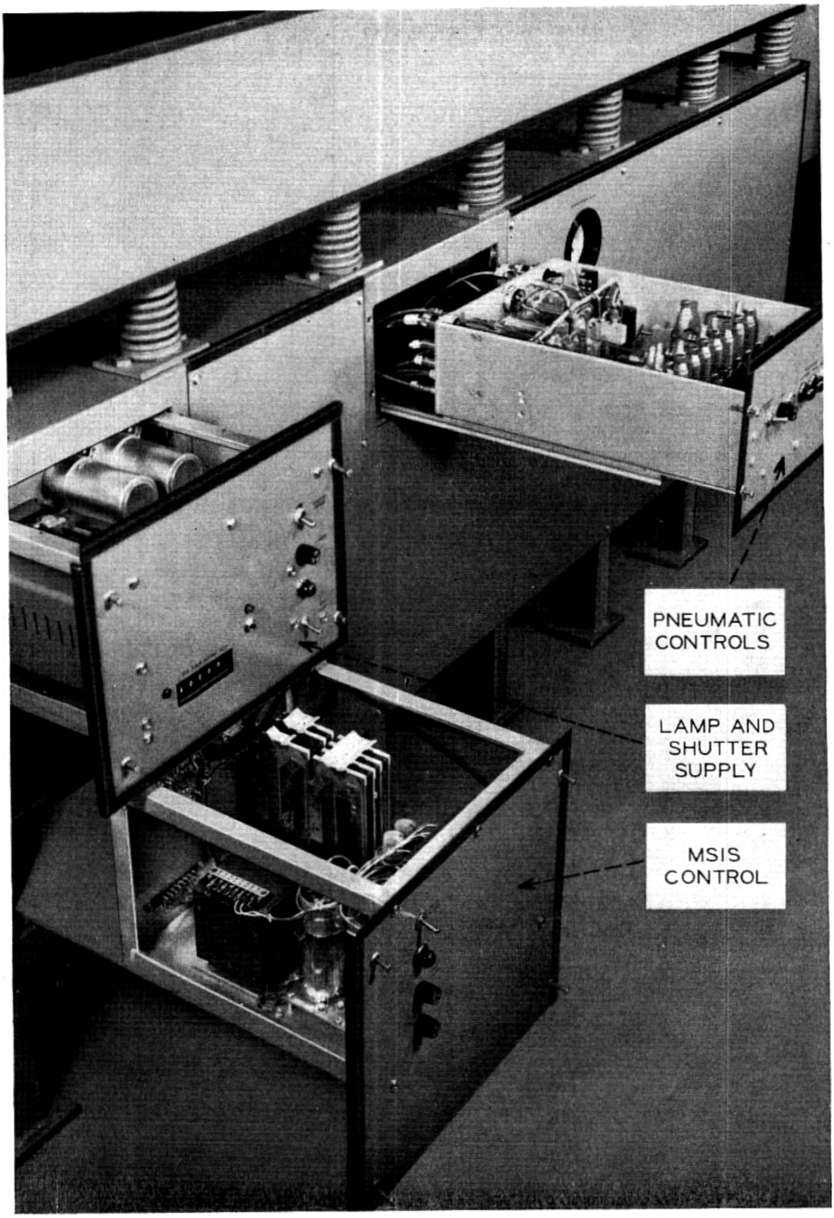

Fig. 7—Pneumatic and electrical controls.

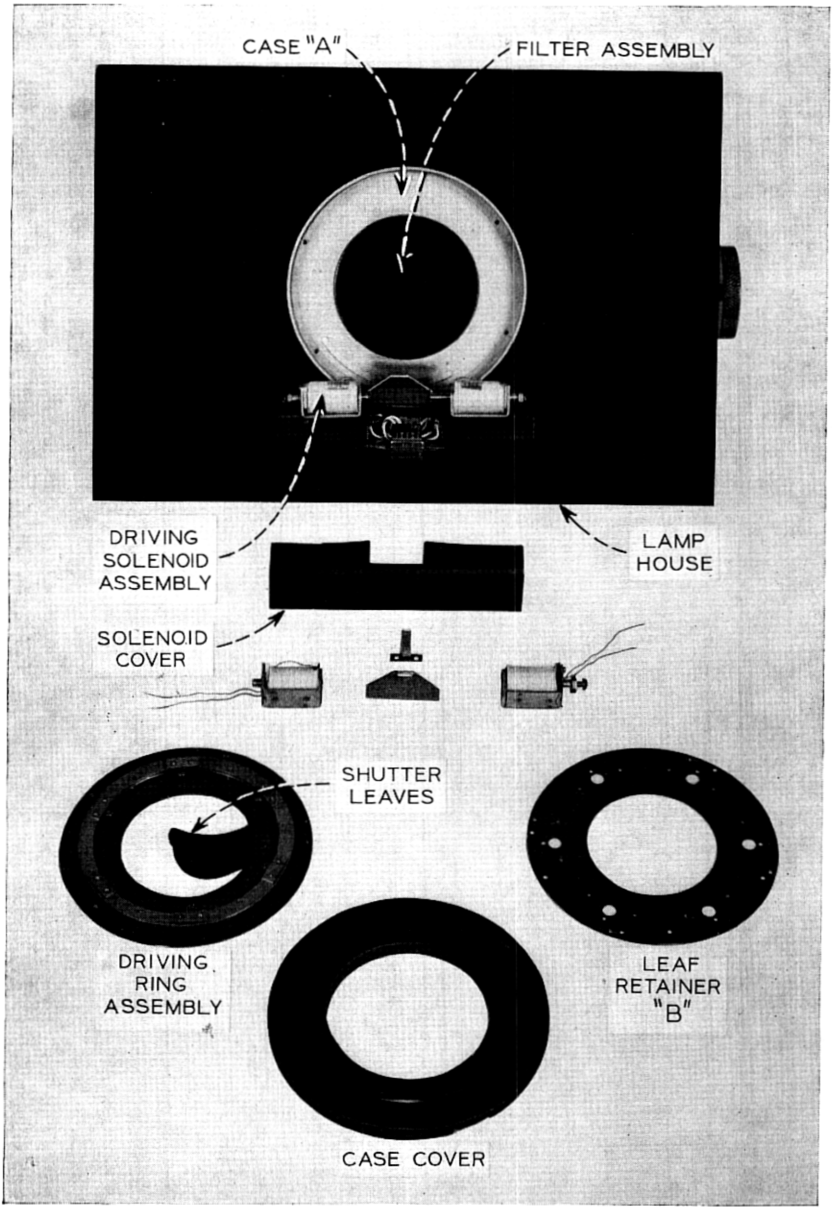

Fig. 8—Shutter assembly and components.

actuating arm is wide, providing for a 1/16″ space at one end towards the activated solenoid. The armature travels 1/16″ before contacting the activating arm, thereby accelerating without the load of the shutter mechanism. The total armature travel necessary to achieve the shutter fully open or closed is 0.188″. The opening and closing time takes 10 to 12 ms, depending on the friction in the assembly. This is accomplished by the solenoid operating at five times its rated voltage. Since the duty cycle is very low, this causes no damage. The solenoid voltage is applied for 30 ms. The additional 20 ms is necessary to keep the shutter from bouncing and to provide damping-down time. The shutter solenoids are controlled by a digital timer, consisting of a 1-kHz crystal clock oscillator, a five-decade-selector switch, and associated integrated circuitry.

All shutters are acceptance tested to 3000 cycles; life-tested shutters have run over 100,000 cycles. The life-tested shutter showed signs of wear but no signs of imminent failure.

IX. MASK SHOP INFORMATION SYSTEM

The primary pattern generator (PPG) records identification codes on the plate. This information is used both for visual inspection and for automatic identification in the reduction cameras. This consists of human-readable and machine-readable information. The machine-readable information is encoded as a series of clear or opaque rectangles located outside the primary pattern area. This binary information is read in the camera by a linear array of phototransistors and sent to the MSIS computer which verifies that the proper plate has been loaded.

The detector array is made up of 8 silicon chips, each with six phototransistors positioned in a row on a gold interconnection pattern on a sapphire substrate. This is mounted on a Bakelite assembly and attached to the artwork support structure (see Fig. 9). The diodes are located 80 mils from the emulsion side of the artwork plates. On the opposite side of the artwork plate is located a special illuminator housing consisting of lamps and condenser lenses. To prevent the artwork plate from striking the MSIS illuminator housing, it was necessary to swivel the illuminator housing out of the way during artwork insertion. This was accomplished by means of pneumatic cylinders actuated in conjunction with the plate clamping pneumatics. Since space did not permit an in-line illuminator source, the housing was set off to the side and the light beams were brought into line

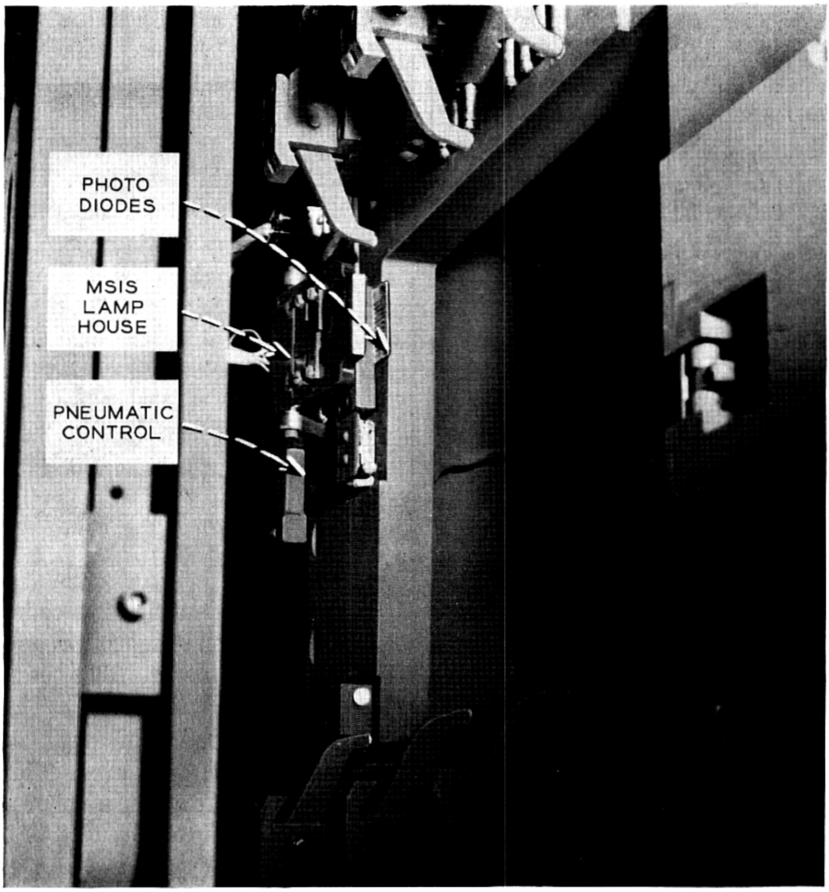

Fig. 9—MSIS assembly.

by means of a prism. Each pair of silicon chips (12 phototransistors) is illuminated by one of four lamps independently switched on by the computer. Each lamp is separated by septums to prevent interference, and each lamp has a lens to image the filament at infinity. The collimated beam is directed into the prism which reflects the light through a linear array of twelve fly-eye lenses which in turn illuminate the twelve phototransistors through the information strip on the artwork plate. The four lamps are turned on in sequence, and the information is sent to the MSIS computer.

X. SUMMARY

High-quality reduction cameras have been designed which are unperturbed by normal building vibrations and which, due to their mass, good material conductivity and temperature compensation of the conjugates are unaffected by reasonable changes in the ambient temperature. Insertion of the artwork and image is reproducible. A high-speed, wide-aperture shutter, capable of being opened or closed in 10 to 12 ms, has also been designed with a life of over 100,000 cycles.

XI. ACKNOWLEDGMENT

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