

Motion-Picture Camera Design and Selection

A TUTORIAL PAPER

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The components of the motion-picture camera are analyzed by the various ways of designing each component. The purpose is to help the camera designer provide the capabilities that will be most beneficial to the cinematographer. The cinematographer should also be helped to select a camera having the features that will be most useful to him for his particular type of work.

THERE are a number of criteria to consider in selecting or designing a motion-picture camera which will bring together the proper combination of components to form the most useful tool for the cinematographer. The designer is usually confronted with a general problem; he has no specific photographic problem in mind but is trying to produce a tool that will be useful under a number of situations. The cinematographer, however, is trying to select a tool which will meet his specific requirements. Both should be aware of certain limitations inherent in the design of many of the components of the camera. In general, the selection of the camera depends upon two broad sets of requirements or limitations:

First is the use to which the film will be put when the production is finished and the film is ready for projection. Included in this category there are:

- (a) image size to be used in finished projection (8mm, 16mm, 35mm, 70mm)
- (b) viewing area (Will the film be shown in the living room, or a large auditorium?)
- (c) special requirements, such as television use.
- (d) nature of audience (This requirement might separate the amateur from the professional.)
- (e) special requirements for scientific purposes (when the camera is used as a research tool).

Second is the area of limitation in camera design which can be considered under the general heading of "Production Problems":

- (a) weight problems (hand-held vs. tripod operation)
- (b) sound requirements (Will sound be recorded while the camera is operating?)
- (c) accuracy of composition (Will parallax between the lens axis and the viewfinder axis cause a problem in composing the picture?)
- (d) steadiness requirements and frameline position
- (e) size limitations in hand-held or crowded shooting areas

(f) camera drive (What power is available?)

(g) speed of operation — normal live action, single frame, high speed, etc.

(h) film loading requirements would cover such considerations as limiting the reloading time when a large crew is working on a sound stage; quick changeability for newsreel or sports use, or so-called self-threaded cameras for amateur use.

Economy considerations must always play a part in camera design. It is probably fair to assume that if a camera is designed to be built for a certain price, some compromise must be made with many of the above-mentioned criteria. With these points in mind, let us now examine the various components which must be considered in motion-picture camera design.

FILM PULLDOWN MECHANISM

An ideal film transport would provide successive frames of identical registration; that is, there would be no displacement of the image formed by a stationary object in either the vertical or horizontal direction when the camera remains steady. In addition to image steadiness, the movement should provide accurate and consistent frameline placement in successive scenes. This means that there should be a positive registration between the pulldown mechanism and the camera aperture. Vertical steadiness refers to the ability of an intermittent movement to keep the same object point in adjacent frames from being displaced vertically. The required steadiness of a movement depends on the size of the projection screen and the size and critical nature of the audience. Beyond a certain point, improved steadiness is difficult and expensive to achieve. A small improvement might be apparent to only a trained observer.

There are several types of intermittent movement currently in use and it should be noted that primary considerations in the design of these movements are mechanical precision and balance, economy, noise level, and in special cases, speed and acceleration.

Single-Claw Pulldown

With this type of movement, the shut-

ter is closed during the pulldown part of the cycle and open the time that the claw returns. Shutter timing is depicted in Fig. 1. This movement is probably the least expensive to manufacture and is found on most amateur cameras.

An improved variation of this movement has the pulldown mechanism operating with sinusoidal acceleration, which means that the pulldown claw, after catching the perforation, gradually increases its speed until the middle of the pulldown. It then decreases speed until the pulldown comes to a gradual stop at the bottom while the claw is retracting. This greatly reduces strain on the perforations.

Single-Claw Pulldown With Rectangular Motion

This movement operates very much like the one described above, except that the pulldown claw traces a rectangular pattern, rather than an oval movement, reducing film breathing. A more sophisticated version of this movement has the pulldown claw dwelling while it is still engaged in the film. At this point, the shutter opens and the claw completes its cycle during the exposure of the frame, returning to readiness for the next exposure. This results in an extremely stable film transport. The only difficulty lies in the fact that the movement must accelerate and decelerate at a faster speed since the shutter is closed for a relatively shorter time.

There is a great deal of variation in the design of movements relative to horizontal steadiness. The most economical way to build a camera is to have side rails between which the film runs. The clearance between the film and the rails must be very small. This may vary between different makes of cameras and even between cameras made by the same manufacturer. Horizontal steadiness can be improved by spring loading a pressure rail on one side to hold the film against the opposite rail.

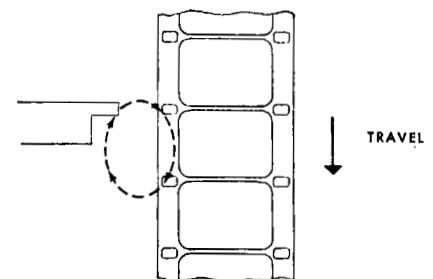


Fig. 1. Shutter timing cycle with single-claw pulldown.

A contribution by Jack Behrend, Behrend's, Inc., 161 E. Grand Ave., Chicago 11, Ill., first submitted on May 11, 1962, to SMPTE Tutorial Papers Committee Chairman Walter I. Kisner, and in final form on November 18, 1963.

Rectangular Pulldown Mechanism With Movable Registration Pin

The pulldown mechanism with this type of movement operates very much like the one described above. As the claw retracts from the perforation after the pulldown, a movable tapered registration pin engages a perforation as close as possible to the frame being exposed (Fig. 2). In some cameras, a double registration pin is used where the film is perforated on both sides. Usually, spring-loaded side pressure rails are used with movements of this type to provide horizontal steadiness. This should result in an extremely steady image, and the frame lines should be in the same position whether the camera is running backward or forward. This is particularly important where superimposed images may be needed, such as in title work and many areas of "trick" photography. It should be noted that since vertical steadiness is dependent upon the registration pin and not the tension of the pressure plate, this tension can be greatly reduced. This leads to the possibility of using a considerably longer gate, resulting in the reduction of weaving, better horizontal steadiness, and a more uniform film flow.

Rectangular Pulldown Mechanism With Fixed Registration Pins

This type of movement was originally used in the Bell & Howell 2709 Camera (Unit I shuttle). Because it is quite noisy, the movement was discontinued for most live action shooting with the introduction of sound to pictures, inasmuch as the camera proved to be very difficult to blimp properly. Today this type of movement is used mainly in animation cameras, optical printers and aerial projectors as used on animation stands.

It operates as follows: The film is carried between two vertical slides driven back and forth by a cam. A claw mechanism pulls the film down between these slides, and at the bottom of the pulldown the entire assembly (slides and film) is pushed back over two fixed registration pins. In the case of some special 16mm movements, only one registration pin is used; however, more stable operation can normally be obtained with the use of double-perforated film and two registration pins. Wherever the utmost accuracy of registration is required, this type of movement should be given careful consideration.

Rotating Prism Movement

These movements are normally used in high-speed cameras (up to 30,000 frames/sec) where the inertia of the film and the mechanism precludes the use of an intermittent pulldown. A prism rotates between the lens and the film. The prism is driven through a simple gear train by the single drive sprocket.

Light going through the lens is deflected by the prism, the angle of deflection depending upon the attitude of the prism. As the sprocket turns, the image follows the area of film being exposed until the light is cut off by the aperture of the prism. At this point, the light starts to fall on the following area of film. Cameras using this type of movement are capable of surprisingly good image quality, the most serious problem being the lack of uniformity of image brightness. Since light travels farther at the edges of the frame than it does in the center, the edges of the frame receive light, and consequently there is a noticeable fall-off between the edges of the frame and the center of the frame. For research purposes, however, this is a negligible factor. This problem can largely be corrected by the use of a two-sided prism rather than a four-sided prism, which of course necessitates a reduction in the maximum speed of the camera inasmuch as the prism must turn twice as fast for a given frame rate.

PRESSURE PLATE DESIGN

Since most photographic optics are carefully designed to insure maximum flatness of field, it is essential that the film be held flat while it is being exposed. This is usually done by raised horizontal and vertical stages around the aperture and either corresponding stages on the pressure plate or a solid flat plate which presses the film against the raised stages around the aperture.

The pressure plate in every case should be electrically conducting so as to help discharge static build-up and thus prevent static marks. Also, if the pressure pad is too tight there would be a great danger of scratching. Indented pressure plates are used chiefly for reason of providing greater strength and rigidity, and to trap foreign particles to minimize scratching.

It should be noted that pressure plate design always involves a compromise between two conflicting principles:

- (1) Film needs maximum support behind the aperture to keep it flat.
- (2) The less metal touching the film, the better.

Some solid flat pressure plates have caused trouble because they were too smooth. Under some conditions the base of the film made optical contact with the pressure plate, resulting in molecular attraction and excessive pressure by the pulldown claw, and considerable unsteadiness. While any part in contact with the film should be smooth, in order to avoid scratching, it should not be *that* smooth. A ribbed or pebbled design may be an intelligent compromise, but only if tension against the film is held to a minimum.

Some cameras utilize a movable pressure plate; while the film is being pulled

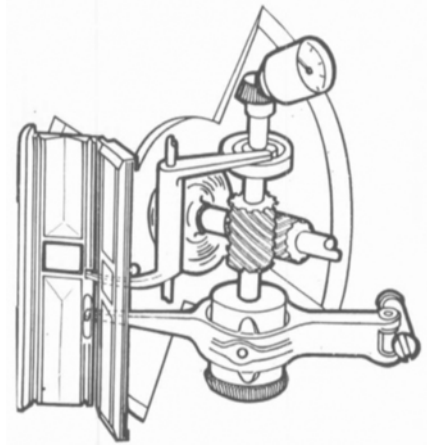


Fig. 2. Rectangular pulldown mechanism with movable registration pin.

down, pressure between the gate and the pressure plate is released to reduce the possibility of scratching. When film is in position to be exposed, a heavy pressure is applied to the pressure plate, which insures flatness of the film about to be exposed. In one recent design, the plastic memory of the film is utilized to help achieve a steady movement. The distance between aperture and pressure plate is 0.007 in. Since most film has a thickness of 0.0055 in., there is freedom of movement when the film is threaded in the gate. This film is held against the pressure plate, however, by its own tendency to curl in the direction it was wound on the supply reel.

In the foregoing discussion it is assumed that there is a definite fixed relationship between the aperture and the film mechanism. This is not necessarily the case. In some magazine-load cameras the pulldown mechanism is a part of the camera, while the aperture is a fixed part of the magazine. The magazine is usually held in place by locating pins, but the relationship between the pulldown mechanism and the aperture is, in this type of design, quite likely to vary. This results in some variation in the position of the frameline if the mating parts are not held to close tolerances.

An entirely different problem is encountered in the design of self-blimped cameras. To achieve quietness of operation, the film drive, film movement, and all internal moving parts in the camera are insulated from the exterior case of the camera. The vibration of the film-handling mechanism is damped out by some type of shock-absorbing material so that it will not be transmitted to the camera case. Since vibration can be transmitted from the pulldown mechanism through the gate to the aperture and the lens seat, the aperture assembly must be insulated from the rest of the camera. This means that the pulldown mechanism must be kept as a completely separate unit from the aperture-turret assembly; therefore, relationships between the pull-

down mechanism and the aperture may vary slightly.

In discussing relationships between the location of the aperture, frame-line and perforation holes, it should be made clear that there are more variables involved than the design of the camera. As a general rule, 16 mm projectors have the same type of movement as that described in preceding paragraphs — that is, the pulldown claw describes an oval or rectangular trace and horizontal steadiness is provided by spring-loaded edge guides. Thus the film is located in the projector approximately as it is in the camera.

Some optical printers and professional cameras on the other hand locate both the vertical and horizontal references by careful positioning of the perforations. It should be noted, therefore, that in most cameras and projectors the edge of the film determines horizontal position of the image, while in some other equipment the perforations may determine the horizontal position of the image. If there is any irregularity in the slitting of the film so that the edge of the film is not exactly straight, there will be side-weaving, even though the camera is steady. The same effect will be obtained if the edge of the film is straight but the perforations wander in a lateral direction.

FINDERS AND CRITICAL FOCUSING SYSTEMS

Positive Finder Objective With Aerial Image

Since this type of finder can be constructed with a single-element objective lens and a single-element eyepiece, it can be very inexpensive. Normally, it is mounted on the camera door, and the focal length of the finder objective ap-

proximately matches the focal length of the taking lens. As accessories, positive and negative adapter lenses can be supplied to make the finder match accessory objective lenses available for the camera.

This system can be considerably improved with the use of better optics in the finder objective lenses as well as in the finder eyepiece. It is a simple matter to correct for parallax in this type of finder since the eyepiece can be moved toward and away from the camera with a calibrated screw. In some cameras with turrets, where three finder objectives must be used to match three taking lenses, a coupling arrangement is provided so that the proper finder objective is always lined up with its matching taking lens. This can be accomplished by coupling the finder objective lenses in a turret driven by the taking lens turret, or by mounting the finder objectives in the main turret. **The latter should lead to a more accurate positioning of the finder objectives with respect to the taking lenses.**

So far we have discussed finder designs. A related problem is that of critical focusing which is usually taken to mean focusing, while observing the image formed by the camera lens. It is a simple matter to design an optical system whereby the turret of the camera can be rotated, permitting the operator to focus the image on a ground glass.

This system gives the camera operator a good check on depth of field, whereas reliance on calibrated depth of field markings may not produce the desired effect.

Studio Ground-Glass Finders

This finder, like the first one described above, provides a separate optical system so that the operator can see a facsimile of the film image. It differs,

however, in that a real image is formed on a large ground-glass screen. This enables the operator to stand back from the finder to observe the image, and it even allows more than one person, such as a cameraman and a director or a client to observe the image at the same time. Usually, this type of finder is provided with either a matte or movable cross hairs to enable the operator to match the image size to the focal length of the taking lens. Since this type of finder is normally used in studio production, it is necessary to have automatic parallax correction. Sometimes this is done by a movable member of the finder itself which is manually adjusted by the operator to correspond to the accurate distance from the film plane to the subject. In some of the more elaborate systems, the finder is coupled directly to the focusing ring of the lens. This makes parallax correction automatic and greatly simplifies operating procedures.

Critical focusing of the lenses can be done by a mechanism used on many cameras. The entire film-moving mechanism of the camera is shifted to one side so that the film is moved away from the aperture, and in its place a ground glass is positioned which in turn is in line with a microscope at the rear of the camera. Looking through the microscope, the operator can critically focus the lens on the ground glass and then rack the camera back so that the film is in taking position. Since different magnifications can be used in the microscope, this method of critical focusing allows extremely accurate adjustment of the taking lenses. The only difficulty with this system is that in moving-camera work critical focus cannot be maintained while the shot is being taken, as it is possible to rack over and check the critical focus only before and after the shot.

It should be pointed out that for a camera with rackover capabilities it is necessary to design a very rigid frame and a very accurate tracking mechanism so that the alignment between aperture and film and aperture and ground glass is always the same. The designer imposes a penalty in the form of additional weight and additional cost when he specifies this type of camera mechanism.

Mirror Systems for Critical Focusing

There are several critical focusing systems that permit the same technique on the part of the cinematographer as the rackover design described above. In one design, the light path between the lens and the aperture is blocked by the insertion of a mirror set at a 45° angle. This diverts the light to a ground-glass screen and microscope at the back of the camera, permitting critical focusing and framing of the image formed by the taking lens (Fig. 3). In operation, of course, this is similar to the rackover method. However, a lighter-weight cam-

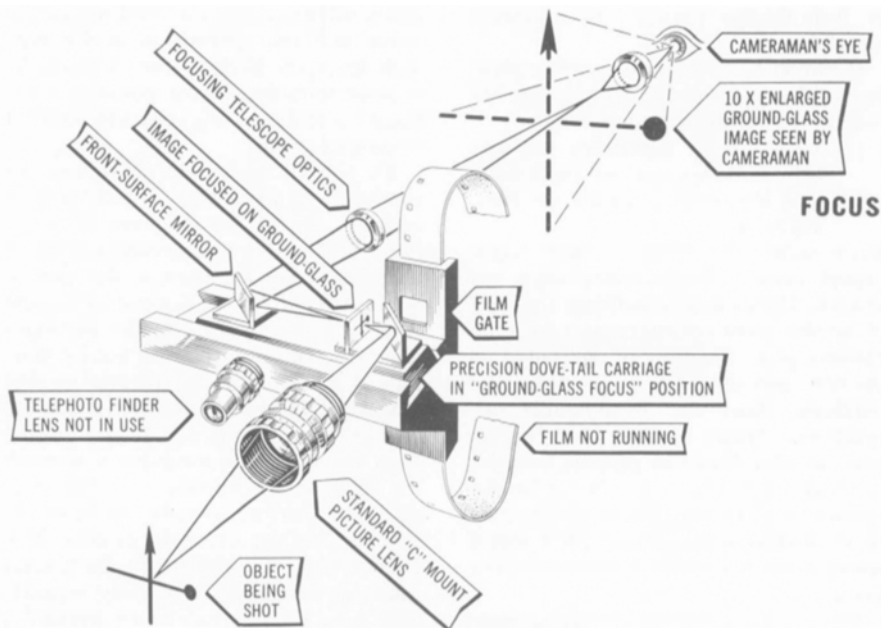


Fig. 3. A mirror system for critical focusing (Bach-Auricon, Inc.).

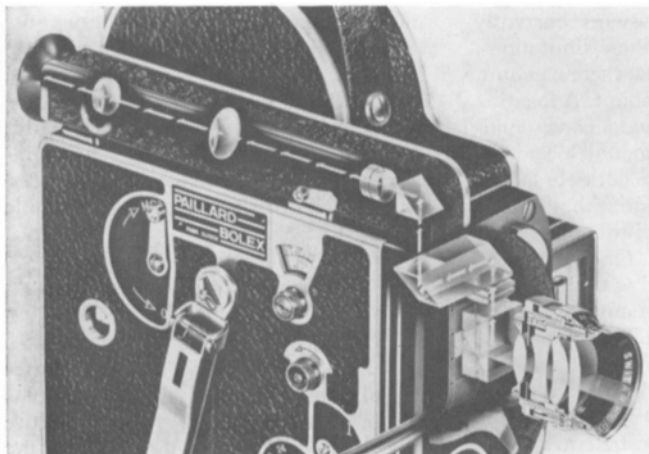


Fig. 4. A beamsplitter system (Paillard Inc.-Bolex).

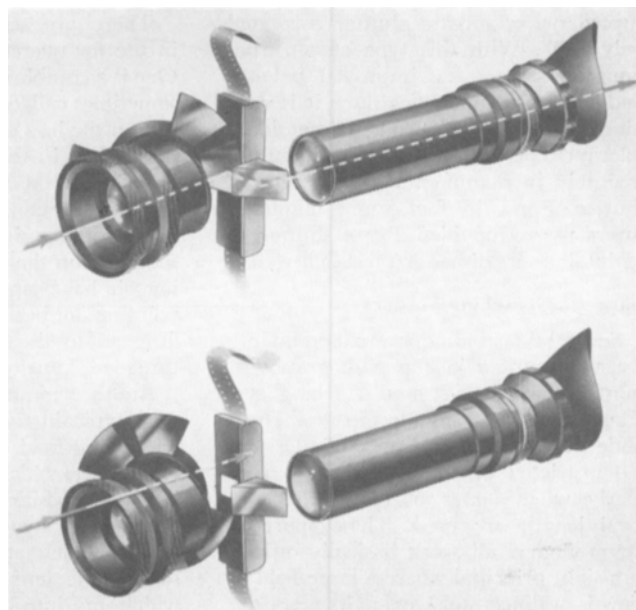


Fig. 5. A shutter mirror light system (Arriflex Corp. of America).

era frame is possible here since there is no shifting of the whole film-moving mechanism. The only difficulty presented is that the mirror system must be in almost perfect alignment or an improper focus will occur. A similar arrangement is used in a high-speed camera where focus is obtained on the emulsion of the film itself through a hole in the main sprocket. This image is transferred by mirrors to an eyepiece at the rear of the camera. With neither of the above-mentioned mirror systems can the operator make his focus adjustment while the camera is running.

Another system which employs a beamsplitter to divert a small percentage of the light to a finder allows the cameraman to focus critically and frame the image formed by the taking lens while the camera is operating (Fig. 4). This of course has several distinct advantages. In a shot where a subject is moving either toward or away from the camera, critical focus can be maintained at all times by direct observation of the image seen by the film. All parallax problems are eliminated as the cameraman is able to see the subject exactly as it appears to the film. Depth of field is clearly visible as well as the exact framing of the subject. Common errors in photography are eliminated, such as adjusting the viewfinder for a lens having wrong focal length, filming with the wrong lens, mistakes in focusing, bad mistakes in the diaphragm setting, off-center pictures, filming with wrong filter, filming with lens cap on taking lens, and incorrect positioning of turret. It should be pointed out that if the beamsplitter is in front of the shutter, a continuous image is transmitted to the eyepiece. That is, there is no flicker associated with this type of finder.

One disadvantage of this system is that a certain percentage of the light which would otherwise reach the film is diverted for use by the finder. This means that the diaphragm of the lens must be opened

slightly. If the lens is stopped down to a very small opening (as it would be with high-speed film), since only a very small portion of the total light is going to the finder, the resultant finder image is quite dim. The same type of system is built into many zoom-type lenses now in use, where the finder is not part of the camera but is actually a part of the lens. A small prism built into the rear of the lens reflects a small percentage of the light, which, after going through an optical system, can be seen through an eyepiece on one side of the camera. The same problems and advantages mentioned above would hold true for this zoom-lens finder.

To maintain the advantages described above for beamsplitting reflex finders and to eliminate most of the disadvantages, shutter-mirror light systems are designed into some of the finer cameras now available. Here the shutter is set at a 45° angle and its front surface has a mirror surface. The light reflected by the mirror goes through an optical system and a ground-glass image is observed through a magnifying eyepiece (see Fig. 5). All the available light goes to the film when the shutter is open. When the shutter is closed, all the light is transmitted to the ground glass, so that an extremely bright finder image is obtained even when the lens is stopped down. Generally speaking, if there is enough light available to expose film, a good image is obtained in the finder.

There are several variations currently available in shutter-mirror systems. Principal differences are construction of the shutter and location of the ground glass.

It was found by one manufacturer that when the ground glass was placed next to the shutter at right angles to the aperture, light from the taking lens was reflected by the ground glass to the film when the shutter was open. This resulted in some washing out and fogging under certain

conditions. To remedy this, louvres were placed at right angles to the ground glass.

For a later model camera, it was felt desirable to circumvent this problem by moving the ground glass toward the eyepiece. To do this, an elaborate optical system was required so that a highly corrected image of the same size could be moved back to a position immediately in front of the eyepiece (see Fig. 6). This method of construction has the distinct advantage of eliminating the stray-light problem.

There are two basic methods of shutter construction currently in use and a choice between them relates both to cost of construction and the problem of a flickering image in the finder. Since the light for the finder image is reflected by the rotating shutter, each time the shutter opens the image disappears. When the camera is running at a low speed, say in the order of 5 to 8 frames/sec, the resulting low-frequency flicker can be quite distracting. If the light to the finder can be broken faster, that is, with more interruptions per second, the apparent flicker will be greatly reduced.

The simplest and cheapest method of building the shutter is to provide a 180° semicircle which is stamped or machined from metal with a mirrored front surface. With this type of construction, almost half of the time required for the shutter to make a revolution can be used to transport the film as described previously. The strain imposed on the film and the movement is not severe, and the shutter components are not critical with respect to their manufacturing tolerances. A more sophisticated shutter is shown in the attached figure. Here, the shutter consists of two 90° segments, with a black stripe painted down the center of each mirror segment, doubling the number of interruptions so that with each frame exposed, the image is inter-

rupted twice, and the shutter is rotated only 180°. With this type of construction the shutter has improved balance and noise characteristics since it is running at only half-speed. Dimensional tolerances become much more difficult to maintain in manufacturing this type of shutter—and in fact some manufacturers use a moulded Pyrex shutter to maintain more dimensional stability.

Target or Tracking Finders

Several types of finders are used mainly for such outdoor jobs as photography of sports, news events, and tracking systems for aircraft and for missiles. These finders are used where normal finders are too restricted in angle of view, particularly when lenses of extremely long focal length are used. These sport or target finders all work basically on the gun-sight principal where a large field of view is outlined and cross hairs mark the center of the image. In most cases, the cameraman is not concerned with the composition of the subject except that there is a certain object he is looking for which he hopes to keep in the center of the field. These finders can be as simple as a wire ring with a bead in the middle or as complex as an optical system with optically inserted crosshairs. They all, however, seek to achieve the same purpose.

LENS MOUNTS

Since most manufacturers of cameras do not make lenses, there are two basic approaches to take toward the subject of lens mounting. One is to use a standard mount in which many lenses are already available, and the other is to design a mount best suited to the camera and then work with one or two particular manufacturers with the idea of having them design a lens for that mount.

The closest approach to a standard lens mount is the threaded "C" mount commonly used in amateur and some professional 16mm cameras. The C mount has the distinct advantage of being available from virtually all lens manufacturers; therefore, any camera designed with this type of mount can accommodate an extremely wide range of lenses. One other advantage is that the lens mount is very shallow, making turret design simple.

Disadvantages of this type of lens mount are as follows: There is quite a limitation on the weight of the lens that can be supported by the fine threads utilized; and the dimension of the rear element of the lens is limited by the diameter of the threaded portion of the mount. One other difficulty encountered with the C mount is that, since it is a screw mount, lenses may not always come to rest with the engraved index mark in a convenient position. Therefore, it may be difficult to see the aperture and focus graduations.

There are several systems currently in use for overcoming these limitations. One is a combined bayonet screw mount, sometimes called an S mount. A locating pin on the lens proper and a corresponding groove in the lens mount locate the index marks on the lens accurately so that the operator can be sure that they will be in the same position each time the lens is mounted on the camera. Once the locating pin has been meshed with the corresponding slot in the lens mount, the lens is fastened to the camera by means of a threaded, knurled ring.

Another mount, of the true bayonet type, typically utilizes a slip-in design, the lens being held in place by two spring-loaded ears which engage in a slot in the lens. The position of the index mark is maintained by a locating pin in the mount which engages a corresponding slot in the lens. The base of the lens which fits into this mount is normally $\frac{5}{8}$ to $\frac{3}{4}$ in. long, enough to support even a long heavy lens in a very stable manner. Another advantage of bayonet mounts is that they have comparatively large rear diameters, making possible the use of extremely wide angle lenses; therefore, the range of available lens designs is greater with these bayonet mounts.

One disadvantage of this type of lens mount is that extension tubes are quite difficult to use since the lens must be completely seated in order to lock. If an extension tube is used, the rear of the lens must be moved ahead of the front of the turret. Therefore, the shortest possible extension tube is in the order of $\frac{3}{4}$ in. long. With short focal-length lenses this is entirely too long for any practical application.

A fourth general category of lens mount currently in use consists of the lens mounted on a large flange with slotted or round holes. When screwed to the face of the turret and adjusted, this type of mount gives a very stable support for heavy lenses. Since the rear diameter is quite large, short focal-length lenses can be used without the necessity of using "reverse telephoto" designs. One particular advantage of this type of design lies in the field of animation cameras where a camera must be tracked on a column so that the center line of the aperture always lines up exactly with the center of an animation field. This tracking can be done by minor adjustments of the lens itself by shifting it in slotted holes in the flanged mount, a much simpler operation than shifting the entire camera.

It is sometimes considered desirable to have a filter or matte slip in between the lens and the film. It should be noted that this necessitates a change in design that requires moving the lens mount out slightly to provide more clearance between the rear element of the lens and the film plane. With the lens mount

moved out it is necessary to either use lenses of long focal length or resort to lenses of the reverse telephoto type. The addition of a second or variable shutter of course would aggravate this problem. Accessories of this type, including optical elements for a finder, seriously limit the range of available lenses.

SHUTTER DESIGN

Semicircular Disc or Cone Shutter

This is the simplest type of shutter design, consisting merely of a semicircular disc or part of a conic section. Exposure time is determined by the angle of the opening and the speed of the shutter.

Semicircular Disc With Movable Second Blade

In operation, this type of shutter works much like the one described above; however, there is a second disc underneath the main shutter which is movable. The angular opening can be changed at will either manually (in some camera designs) or with an automatic shutter advance. Since the angle can be either preset or shifted while the camera is in motion, the exposure of the film can be changed and scenes can be made to fade out or fade in at will. This shutter is useful in photographing high-speed subjects as the exposure time can be reduced to make the images on the film sharper.

Mirror Reflex Shutters

A description of this shutter ties in very closely with the description of the shutter-mirror reflex finder described earlier. Something should be said, however, about the design of the shutter itself since the alignment of the image in the finder with respect to the image on the film is dependent upon the dimensional stability of the shutter, among other things. It is important that the shutter be set in the camera to extremely close tolerances and the material that the shutter is made of should hold these tolerances under all operating conditions of temperature, moisture and vibration.

In some cameras, the shutter is made of a metal casting polished to a high degree and then silvered or chrome-plated. Sometimes the shutter is made of Pyrex glass with a front surface mirror finish applied. Pyrex, of course, has the characteristics of having good dimensional stability under many temperature conditions.

To conserve space and to reduce cost, mirror reflex shutters are usually of stamped or cast metal when variable secondary shutters are incorporated in the camera design. This does not provide the dimensional stability of Pyrex and it is difficult to get as good a mirror finish on metal as on glass. When a variable blade is added, it is usually done in conjunction with a 180° shutter segment;

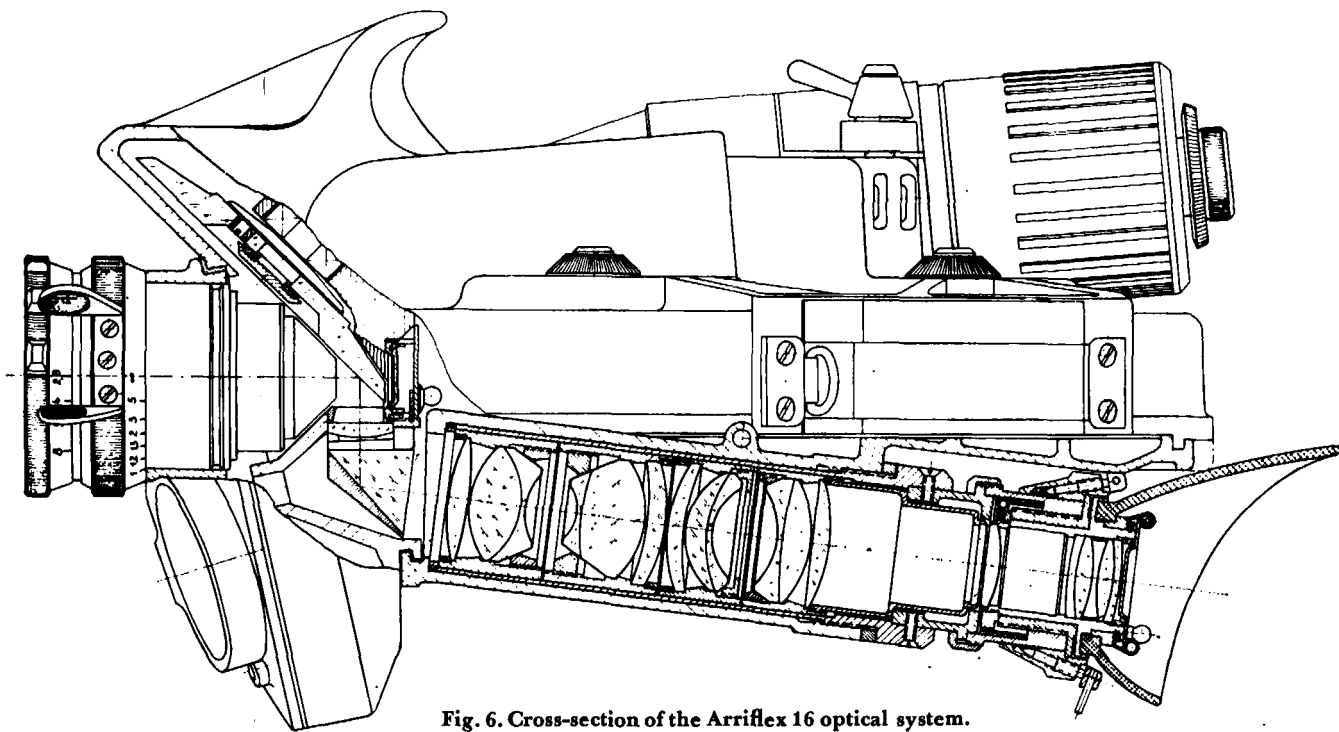


Fig. 6. Cross-section of the Arriflex 16 optical system.

therefore, a price is paid in the form of increased noise and reduced shutter balance.

If sound is to be recorded while the camera is in operation (i.e., lip-sync shooting), the noise level of the camera must be considered when a camera is selected. Perhaps the camera should be self-blipped — completely silent in its operation. Sound level is one of the most important considerations in the design of a camera. All details of the design, construction and materials used in a camera are dependent on the sound level requirement of the finished camera. If it is intended to blimp the camera, the complexity of the blimp — its sound deadening requirements — are also determined by the maximum noise level of the camera.

CAPACITY

Since cameras are used under a variety of conditions, the ideal camera would be capable of utilizing 100-ft rolls for hand-held shots of fast-moving subjects or 400-ft magazines for work on the sound stage or in the field where there is no time for reloading. Under some conditions it is desirable to use even larger magazines, such as kinescope recording of a half-hour or one-hour television show, live action shooting where very long takes are necessary, and certain types of productions shot under normal live conditions where continuous filming is necessary. For such uses, 1200-ft or larger magazines may be required.

The design of large magazines poses some interesting problems. For example, the torque required for taking up the film with an empty magazine is far less than the torque required when the magazine is nearly full and yet many

take-up devices are of the constant-torque type.

DRIVE MECHANISMS

The type of drive selected for any camera depends on how the camera will be used. Spring motors are capable of running from 14 ft up to 40 ft of 16mm film with one winding of the spring. This variation may play a part in the selection of a camera to do a particular job. Most professional cameras have motor drives, and again the selection of the type of motor depends on how the camera will be used. On a sound stage, a synchronous motor is used so that the camera will be in sync with recording equipment. Sometimes it is necessary to vary the speed of the motor to accomplish certain effects. If a camera is to be used outdoors or where 110-v a-c power is not available, it is useful to have a low-voltage d-c drive motor, powered by batteries. D-c motors are available in both variable-speed and governor-controlled designs. Since several of these motors may be used with the same camera, it is desirable to have the camera designed in such a way that the motor can be quickly and easily changed in the field. If a "wild" motor is to be used, it is almost essential to build a tachometer into the camera.

The advent of lip-sync sound recording on $\frac{1}{4}$ -in. portable tape recorders with sync heads creates new problems and opens new possibilities for camera drives. If driven by a governor-controlled motor, it can be very helpful to have a 1-v a-c 60-cycle generator either built into the camera (preferable) or built into the motor. The signal produced by this generator can then feed the sync head on the recorder so that high-

quality, double-system sync sound can be recorded where no a-c power is normally available.

An improvement over this system would have a tuning fork or crystal oscillator control the speed of the drive motor, and a matching unit in the recorder generate the signal which is placed on the tape; thus any number of remote cameras could all be in sync with each other and with any number of recorders, all without connecting wires.

A well-designed camera should be easy to thread, and once threaded, it should run smoothly and resist jamming. This means that the magazine drive must be nicely balanced to the operation of the camera, and the camera should be capable of handling standard film under a wide range of conditions.

The camera should be easy to clean and oil. Small cramped areas within the body of the camera invite dirt and film chips which eventually can cause trouble. Any piece of mechanical equipment is eventually going to need service, and a well-designed camera should be easy to disassemble and service. More than one well-designed camera has been doomed to failure because of inadequate field-service facilities. This, of course, is a distribution problem, not a design problem.

In conclusion, it is hoped: first, that the camera designer has been given an appreciation of the problems that the cinematographer has in the field and that the list of design features needed in a camera will help solve these problems; and, second, that the cinematographer will be acquainted with certain design features that may help him in his work.