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Phase Report

HIGH-SPEED CINEMATOGRAPHY

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LIST OF FIGURES

ABSTRACT

The principal subject matter of this report is presented in two sections. One section deals with the general principles of high-speed motion pictures, and the other section lists and describes basic camera types.

The fact that a motion picture is a physiological effect is stressed, and this is differentiated from a mere sequence of pictures. The necessary requirements of a motion picture are discussed and examples are given.

The matter of time and space resolution, so necessary to technical analysis, is considered, and a logical approach to this subject is worked out.

Cameras are classified into basic types by the method of operation. Examples are given. The information-taking rate, which is a fundamental measure of a camera's capability for assessing information, is presented as a basic concept.

OBJECTIVE

The objective of this report is the presentation of the basic concepts of high-speed motion pictures and a classification and description of typical high-speed motion-picture cameras.

INTRODUCTION

The purpose of this report is to present information that has been collected on the subject of high-speed motion pictures. The work is an outgrowth of a study done for the U. S. Army Ordnance Dept. in the field of shock and vibration. The need for improved instrumentation techniques in this field has provided the basis for this investigation of high-speed motion pictures, and while this method of analysis has already been used in ballistic research, a systematic approach to the problem, based on background and analysis, is lacking.

Devices for producing the illusion of motion based on the persistence of vision effect have been known for a long time; in rudimentary forms, they can be traced as far back as the time of Ptolemy (A.D. 130). In 1833 W. G. Horner patented a device called the Zeotrope (wheel of life) which produced motion-picture effects of printed figures on the inside of a drum when the figures were viewed through slots in the side of the rotating drum.

It is interesting to note, however, that the first motion pictures (of the modern type) were taken as a means of analyzing motions that were too fast for the human eye to follow and not for the purpose of entertainment. This is still the basic purpose of high-speed motion-picture photography. The first motion pictures were taken by Edward Muybridge in California in 1872. His work developed from arguments concerning the nature of the gait of a horse, arguments in which several prominent figures of the time, including Gov. Leland Stanford, were involved. Muybridge's work settled the argument about the horse, and established the value of motion pictures in scientific analysis.

The progress of developments followed both scientific and commercial paths after Muybridge's work. Thomas A. Edison was prominent in the commercial developments, and was instrumental in standardizing the 35-mm commercial film size. Scientific progress was steady, marked by the brilliant developments of Bull and Jenkin's in the early twentieth century. The character of the developments until about 1930 was based on refinements of mechanical and optical methods instead of on new principles. In the 1930's several new techniques appeared. These included the use of electro-optical shutters and strobe lamps as components of the process.

Since 1940, image conversion and the principle of image dissection have been applied as components of the process. These last two factors have already provided for great improvements in camera capabilities, and it appears that many refinements are yet possible which will further increase their usefulness.

In spite of the many developments in the field, there is yet lacking a system which combines large capability with economy and simplicity. Developments which would combine and enhance these factors would without doubt be warmly received.

The subject of lighting equipment which forms an intimate part of the array of equipment is not taken up in this report. The presentation of this subject is planned for a subsequent report.

GENERAL DISCUSSION

The process of taking motion pictures necessarily involves cameras, films, and lights, and while these are the primary tools of the art, they must be used with intelligence and imagination if their maximum potentialities are to be realized. In analyzing a photographic problem, it is natural and convenient therefore to divide the problem into considerations of camera equipment, lighting facilities, and subject matter. These divisions are not completely separate and the analysis of one part of the problem must be made in relation to the others.

GENERAL PRINCIPLES OF MOTION PICTURES

Before moving on to the analysis of separate components, it may be helpful to dwell at some length on the basic aspects of motion-picture photography. On this level there is a question that ought to be asked (and answered) concerning what actually constitutes a motion picture.

Aside from the evident features such as frames, picture resolution, etc., it appears that a motion picture involves a scene-sampling process. More accurately, a motion picture is the result of examining the scene sampling in a particular way. The usefulness of the process is based on the assumption that all visual phenomena are continuous within certain time or space intervals.

Motion-picture processes therefore use either a time- or space-sampling technique. This is in principle; in practice, physical limitations dictate that each basic technique partake of characteristics of the other. In the usual terminology, then, framing cameras sample a scene primarily with respect to time, and the streak cameras sample primarily with respect to space. In either case, the gradients in the scene (either timewise or spacewise) dictate the degree of resolution necessary in the process.

However, we need to examine the basic idea of the motion picture more thoroughly. It must be recognized that a motion picture is a physiological effect. A mere sequence of photographs does not constitute a motion picture. It is only when these photos are examined by successive replacement at a certain rate that the illusion of motion appears. The motion of the scene is thereby recreated by an illusory effect. This may appear to be belaboring a definition to excess, but it is important to certain following ideas. Since the motion picture involves the recreation of the motion of a scene, it is necessary to examine in some detail what is meant by scene motion. This again has physiological implications. A good way to consider this effect is in relation to the motion of the hands of a clock. If the hour and minute hands are viewed casually, no apparent motion is observed. The hands appear to be fixed, although by deduction they are known to be in motion. The sweep second hand, however, is easily seen to be moving.

How much slower the second hand could move and still appear to be in motion is questionable and the acceptable rate would probably vary among individuals, but it is apparent that it is moving at a rate not greatly in excess of the minimum needed to show apparent motion. A little thought will reveal that the matter rests on the rate of angular displacement of an object relative to the observer. Returning to the example of the clock sweep second hand, and considering a typical case as being a clock one foot in diameter and 10 ft away, it is apparent that the top of the hand moves from top to bottom of the face in 1/2 min. This represents an angular rate of change of about 10°/min. Any angular rate much less than this would not appear as motion. On the other hand, there is also a maximum rate. This is harder to determine, but an upper limit is imposed by the persistence of vision effect, and if the clock hand were revolving about 20 turns/sec, it would appear as a solid fixed circle and would no longer exhibit motion. The rate of angular change is now about 5000°/min. A larger clock face viewed from the same distance would result in a larger maximum value for the rate of angular change. Eventually, however, when the face is made large enough, the whole circular motion of the hand tip cannot be observed anyway, and this effect finally limits the maximum value of the observable angular rate in this direction. Experiment is needed to establish the accurate values of this limit, but as a rough approximation the value 10,000°/min will suffice. It is thus seen that observable motion occupies an angular rate of change of from about 10° to 10,000°/min, a ratio of 1 to 1000.

These ideas have implications for the concept of the motion picture. For any event to be reviewed as motion, its angular rate of change as seen from the viewer's position must be within the above limits.

By taking pictures at one rate and showing them at another, the motion-picture system is able to increase and decrease angular change rates so that events which do not normally lie in the range of observable motion are seen to have motion. This is part of the basis of the great utility of motion pictures in scientific research.

There is another requirement which a process must meet to be classed as a motion picture. The time duration of the scene has a minimum limit. This is again a rather indeterminate factor, but Schardin[1] has fixed the minimum time at about one second. Any scene observed for less time than this will not be seen as motion, but will appear fixed. Thus the minimum requirements for a motion picture call for 16 sequential pictures to be shown in one second with the apparent angular rate of displacement of the subject lying between approximately 10-10,000°/min.

In addition to the above subjects, the matters of time and space resolution must be dealt with. Returning to the example of the clock and considering the minute hand, suppose that a sequence of pictures is taken of this hand at a rate of one per minute. In one turn of the hand we will have taken 60 or 61 photographs depending on how the matter is viewed. Using the round number of 60, and viewing these pictures in sequence at 16/sec, the scene will be found to occupy about 4 sec. The hand will appear to make one rotation in 4 sec. This generally qualifies as a motion picture. However, it is evident that if this process were used as a means of technically checking time, we would never know the exact position of the minute hand and the related time more precisely than to within one minute mark. The time resolution of the process is one minute regardless of how it is viewed. In this particular case smaller time intervals could be interpolated based on the assumed uniform motion of the hand, but this will not work in general.

If the above procedure is repeated, but if instead of as before, the pictures are taken every second, then a sequence of 3600 pictures will be obtained. If these are viewed in sequence at a rate of 960/sec, the same motion-picture effect will be observed as before. In this case, however, the inherent time resolution is 1/60 minute mark rather than one minute mark. We are now sure of the hand location to within 1/60 minute mark and the time to within one second. This latter sequence could be viewed at the rate of 16/sec without noticeable flicker, but now the apparent motion of the hand is one turn in 230 sec and is too slow to be observable as motion. It is apparent from this that a particular time resolution and observable motion are not always compatible in a particular scene. This state of affairs has no particular bearing on the use of the film sequence for technical frame by frame analysis. The time resolution exists and can be made use of, but the latter scene is not a motion picture when viewed at the standard projection rate.

There is some bearing here on the nomenclature of cameras. Sequence photographs are frequently taken for analysis purposes where there is no intention of using them to recreate motion effects. Cameras taking this picture can hardly be called motion-picture cameras. Indeed, since the motion picture is in fact a physiological phenomenon and depends entirely on the manner of viewing the picture sequences, it can be argued that there is no device properly classified as a motion-picture camera. The term properly applies to the projector. All cameras of this type are sequential picture cameras. The term "motion-picture camera" exists, however, and undoubtedly will continue to exist despite all such argument, and so the term will be generally used here.

One additional point on the matter of time resolution may be made. It was assumed in making the clock picture that the photograph was taken instantly. In the practical device such is not the case. Some exposure time must be allowed, and during this time the hand will move and blur the picture.

This introduces an element of uncertainty into the question of the location of the hand, and, while generally slight, must be accounted for in a technical analysis of the camera and will be discussed more thoroughly in the section dealing with the camera.

On the subject of space resolution, it can be said that it depends primarily on the characteristics of the optical system and the photographic emulsion, but must be evaluated according to the properties of the eye. That the eye plays an essential role is evident when it is considered that the final evaluation of any photographic process is nearly always with the eye. The whole subject of resolution is indeed difficult and extensive and is only partly understood in many of its aspects and implications. Resolution is perhaps best understood when it describes the performance of microscope and telescope objective lenses, especially the latter. Owing chiefly to the small fields of view covered, the performance of these lenses is limited primarily by diffractional effects and is fairly predictable. Camera objectives, on the other hand, attempt to cover wide fields and suffer from several abberations which impair the image quality. A technical definition of resolution based on a generally accepted convention for lens systems is not necessarily significant in relation to the eye. Indeed, the exact meaning of resolution as related to the eye is difficult to define. It is frequently stated, for instance, that the limit of resolution of the eye is about one minute of arc. This means that the eye can distinguish between points whose angular separation as seen from the eye is one minute of arc. The writer was able to substantiate this figure in one case, by having several individuals view a ten-line black-and-white halftone plate and judging the distance at which individual dots were no longer visible. The distance among the individuals tested averaged about 25 ft, and a few computations show the angular separation of the clots to be about 1.10 minutes of arc. Several 10-line plates of varying density were tried, and it was found that the plate on which the black dots covered 30% of the total area afforded the maximum resolution. The resolution was increased slightly by increasing the level of illumination. When the same experiment was tried with a 65-line plate, the results failed to correlate the tests on the 10-line plate. The minimum angular separation resolvable by the eye turned out to be about 2 minutes of arc in this case. This difference in results is not readily explainable, but some idea of the cause was gained by viewing the 65-line plate with a magnifying glass. When the 65-line dots were magnified to appear as large as the 10-line dots, the former were seen to be much less precise and perfect than the 10-line dots. Furthermore, the roughness of the paper relative to the size of the dot was much greater in the case of the 65-line dots.

This is an example of the difficulties involved in defining resolution in general and eye resolution in particular. A difference in resolution is noted in this case which may be related to the effect observed in the magnifying glass, and to the level of illumination. It may be related to other unassessed variables. At any rate, the geometrical, optical, and physiological factors are so complex that a precise mathematical analysis is impractical, and the exact contributions to eye resolution of the several variables cannot be assessed.

When a lens and an emulsion are used to produce a photograph, the quality of the final image (with respect to fine detail) depends on the resolution capabilities of both film and lens. Generally this is about all that can be said about the matter. There is a natural tendency to express the resolving power of lenses and of emulsions as separate factors so that the expected results from different combinations can be predicted.

There is no doubt that this scheme works in a general sort of way, but it cannot be depended on to predict quantitative results. The usual way of evaluating line resolution is to arrange the lens as a telescope objective and to view a test pattern or other object (double star) with a magnifying eyepiece. By increasing the power of the eyepiece, a point will be found where further magnification discloses no additional detail. The size of the minimum observed detail and its distance away from the telescope determines an angular resolution limit of the lens. The resolving power of a film is obtained by photographing a test pattern through a highly corrected lens. The effects of the lens are always present, but can be made fairly small; for instance, the theoretical resolving process of a 6-in.-diameter, 60-in.-focal-length (f10) telescopic objective is 3700 lines/in. at the focal point, and this figure will be approached near the center of the field with a high-quality lens.

Since film resolution normally ranges around 1000/in., the lens probably causes little error in the test. Combinations of lenses and emulsion used to produce photographs do not ordinarily give resolutions that correlate closely with their separately measured values. Typical values for the combinations working together with practical operating conditions can be given, however, and these values do have significance. These are the values normally tabulated when high-speed camera characteristics are listed.

Finally, when the photograph has been taken, processed, and is in hand, the question arises as to how to describe the resolution, or more generally, the quality of the picture, in quantitative terms. The system normally used for describing resolution refers to this matter in terms of information lines/in., or lines across the entire field.

This system relates back to the number of lines which can be reproduced from a test pattern photographed by the lens-film combination. The picture itself could, however, be compared for definition with a plate printed from a halftone screen. The resolution of a halftone plate is definite since it is a geometrically precise defice with dots spaced on a square grid. By comparing the photograph with a halftone screen of equal definition, an equivalent resolving power in terms of lines/in. could be obtained. There is, of course, no regular pattern of dots and spaces on a photograph, but only an irregular spacing of grain clumps. Whether the equivalent resolution as obtained above would precisely check the value obtained by the test-pattern method is not known, but it is believed unlikely.

The preceding discussion of resolution is not intended to deny the value of this concept, but is presented with the idea that it will reveal the limitations and approximations in the system and thus provide the basis for a realistic approach to a photographic problem.

To an approximation, resolution and picture detail may be related as follows as judged by the eye at normal reading distance.

Picture Definition	Picture Resolution
excellent	500 lines/in.
average	250 lines/in.
poor	125 lines/in.

An example of how to use resolution in planning a photographic analysis will now be given. Suppose a scene contains the printed number 5, and it is printed to be one inch high. (Assume it to be the numeral 5 on the face of the clock previously used as an example.) It is wished to photograph the scene to be able to distinguish the printed 5 as a minimum feature. Assume further that the lens-film combination can resolve 250 lines/in. It is now necessary to make some guesses about the problem and this is proper since the entire matter is partly subjective. The printed 5, it will be seen, can be suggested with a sort of a code of dots as follows (Fig. 1) and is drawn to scale. There is a question about the exact number of dots needed to distinguish a 5 from all other characters, but the illustration shown will suffice. In the figure the minimum dot spacing is about 0.35 in. If the minimum resolvable dot spacing on the film is 1/250 in. (obtained from the assumed resolution), then a size-reduction factor of 87.5 is allowable between the scene and the film. If, for instance, the camera lens has a focal length

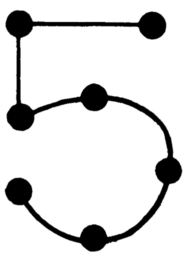

Fig. 1. Representation of printed figure by dot code.

of 6 in., then the 5 can be photographed and distinguished at any distance out to 43.75 ft. The further the scene is from the camera, the larger will be the field covered, and if the film is 1 in. square, then the field covered will be 87.5 in. square at the maximum distance for resolving the printed 5.

While the resolution needed to resolve some particular detail is largely subjective, there will usually be some aspect of the scene which can be used as a basis for planning, as above.

HIGH-SPEED MOTION-PICTURE CAMERA EQUIPMENT

The high-speed motion-picture cameras that are commercially available are limited to perhaps a half-dozen basic types. These types cover a fair range of application, but there is a need for additional commercial development. The present state of affairs in this respect has led to the development of camera systems on an individual basis that are primarily intended to study a single problem. This has not produced cameras having much flexibility or a wide range of application. Indeed it appears that nearly all the high-speed-camera developments are a by-product of some investigation into natural phenomena. The investigator is therefore required to become expert in the field of high-speed photography as well as in his field of investigation. This may not always be considered desirable.

The situation seems ripe for rapid commercial development and this may be expected to occur, but meanwhile any investigator of high-speed phenomena must contend with the situation as it presently exists. It is the purpose of this section to try to present in usable form some information relative to the high-speed-camera field as it exists today. On this basis, it may then be possible for the investigator to plan a more direct approach to his photographic problem; to decide, for instance, whether to purchase or to construct a camera system.

An investigation of high-speed camera equipment reveals that there are many individual examples to consider. The total number has not been determined, but it probably runs into the hundreds. The consideration of all examples relative to some problem would be a discouraging prospect, but fortunately, as with most things, the individual types tend to be similar in some respects and this leads to the possibility of classification to simplify the problem of making a choice.

High-speed cameras may be classified in several ways, as, for example, by framing rate and by method of film transport, but the method based on sampling techniques is fundamental and furthermore leads to a smaller number of subclasses. We can begin, therefore, by distinguishing two classes. These two classes include the streak cameras which primarily sample a scene with respect to spatial dimension, and the framing cameras which sample primarily with respect to time. Beyond this, the next most fundamental relationship appears to be the motion of the image with respect to the film. In this respect it is either moving or stationary. Thus the frame cameras divide into two subclasses: those in which the image moves relative to the film while the picture is being taken, and those in which it does not. The streak cameras possess only one subclass at this level of classification. In their subclass the image moves relative to the film. The basic nature of the streak camera seems to exclude the other (stationary) classification.

The third level of classification is not so simply arranged. For instance, if we consider the class of framing cameras with stationary image-film relationship, there is a strong temptation to subdivide this class into those needing image-film motion compensation and those that do not. The former could be further subdivided on a basis of how this is accomplished. Such a method of classification, while logically attractive, leads to a highly subdivided and unbalanced system and this tends to nullify the real advantages of classification. Thus ideality gives way to practicality, and the subclassification into basic types is ended at the third level. Further subclassification amounts to variation more than to additional types and is so called.

The classification scheme is shown graphically in Fig. 2 and the headings are believed self-explanatory. The classification number assigned to each variation is not intended to have any significance beyond convenience in this paper. This method of classification is similar to the one developed by Naslin;[2] the principal difference lies in the subclassification.

Whatever the value of classification (the present scheme has already revealed points in the technique which might be further developed),it is without meaning except in terms of the specific example which it classifies. Therefore the particular examples listed by classification number will be described, but before this is undertaken several basic camera characteristics should be discussed.

On considering the cameras, it will be noted that, in addition to using certain operating principles, they possess various characteristics such as frame rate, picture size and resolution, number of pictures in a sequence, effective relative aperture, exposure time, etc. For any particular camera, these factors result in some interesting and useful parameters and some discussion of these parameters is in order.

A short glossary of terms, applicable to the "art," follows:

- Frame rate - F - the number of separate pictures taken per second.
- Frame interval - tw - the reciprocal of the frame rate (sec/picture).
- Exposure time - tp - the time the scene image is actually displayed on the film.
- Exposure factor - Q - frame interval/exposure time.
- Frame definition - K_2 - the total information contained in the image expressed as resolvable points in the image.
- Weighted frame rate - $K_1 = F \cdot Q^{2/3}$ - the frame rate weighted by the two-thirds power of the exposure factor.
- Frame sequence - N - the number of separate pictures taken by the camera in one run.
- Weight frame sequence - K_3 - $N \cdot Q^{2/3}$.
- Focal ratio - f - if given in effective values, has the same significance as in simple cameras.

Three of the above terms may need some explanation. If cameras are compared which have the same frame interval but different exposure times, and are otherwise equivalent, the camera with the shortest exposure time will give the best image. This is a common experience, for even in single-exposure cameras it is necessary to take short exposures to get sharp pictures of moving objects. The result is, therefore, that the short exposure-time camera presents more useful information than the long exposure camera. Its time resolution is in effect greater. If we wish to compare the two cameras on an equivalent basis, it is convenient to assign to the short exposure camera a higher effective framing rate than to the long exposure camera.

This fictitious framing rate is termed the weighted frame rate. Similar considerations give rise to the weighted frame sequence. These concepts are due to the work of Schardin[4] who has developed the idea further to include the effects of image compensation.

In some cameras the optical system is so complex that the basic idea of focal ratio has little meaning. It is noted that, for a simple lens with a focal ratio of 0.5, the image formed is as bright as the object from which it comes (neglecting transmission losses). Thus if the image brightness in a particular camera is, say, 1/4 as bright as the object, then the effective lens speed is f1.0. The mathematical relation is

$$\frac{\text{Object brightness}}{\text{Image brightness}} = (2f)^2 ,$$

and once the relative image-object brightness for a particular camera is measured, an effective f number can be computed.

In general, with reference to a particular photographic problem, it is necessary to examine all the characteristics of a camera system to determine its suitability. There are, however, certain parameters which strongly differentiate cameras with respect to their capability.

One of these parameters is the information-taking rate. Consider a camera that takes a picture having a quality of 1000 information lines across and from top to bottom of the picture. There will be 10^6 information points on this picture. Furthermore, if the camera effectively takes 10^4 pictures/sec, its information taking rate is 10^{10} information points/sec. If the camera takes a frame sequence of 100 pictures, the total information possible is 10^8 points. This is another important parameter. In particular,

$$\text{information-taking rate} = K_1 \cdot K_2 \;;$$

$$\text{total information possible} = K_2 \cdot K_3 \quad .$$

The information-taking rate is a parameter of prime importance in camera characteristics since it combines the two basic concepts of time resolution and space resolution. The total information possible is a closely related parameter since it determines the time duration of information-taking.

It will be noted that cameras designed for the highest taking rate do not use film magazines and therefore are able to present only a limited amount of film to the scene. The consequences of this is that the total information that can be taken is limited to some maximum numbers of points. Furthermore, with this as a limit, the information-taking rate may be balanced between time resolution and space resolution. Thus the character of the scene and the degree to which it need be analyzed both timewise and spacewise determine the required information-taking rate. The total duration of the scene analysis is limited by the total information possible and the information-taking rate. A camera system must meet these requirements if it is to produce the expected results.

Two factors which favor a camera usefulness are the information-taking rate and the number of frames in a sequence. An undesirable factor is a large focal ratio. If it is assumed that the problem of illumination is a linear one, then it is reasonable to take the square of the focal ratio as representing its contributions as an undesirable factor. The above terms can be combined into a single value which is given the name "Over-all Capability Factor," OCF.

$$\text{OCF} = \frac{\text{information-taking rate x number of frames}}{(\text{focal ratio})^2}$$

This term is rather general, but it is a measure of a camera flexibility and range of usefulness. It remains to be seen what general utility it will have, if any, but the OCF should serve as a guide in making a selection between several cameras, any of which may be able to do a certain particular job.

A comment about film properties may be useful here. In computing an exposure, the f number of the camera, the exposure time selected, and the film speed are related to the amount of illumination available. Much has been said about the failure of the reciprocity law at the very short exposure time found in high-speed cameras. This effect probably is present, but apparently is not so important as has been generally thought. Tupper[3] has shown that, in most cases, the necessary increases in exposure amounts to a factor of about 2 at the highest speeds encountered.

CAMERA EQUIPMENT BY BASIC TYPES

CLASS 1. STANDARD AND HIGH-SPEED 16- AND 35-MM CAMERAS

Most standard motion-picture cameras have some capability of providing time magnification. The usual limit is 128 frames per second. The limit is relatively low because the method of operation involves an intermittent feeding of the film. The strength of the film is insufficient to withstand the acceleration imposed by a much higher frame rate. Refinements in design have raised the upper limit of this type to about 300 frames per second. The Debrie 35-mm camera is possibly the best known of the special types.

Characteristics of Debrie 35-mm Camera, Class I

Framing rate - 300 pps
Exposure factor - 5
Framing sequence - magazine
Picture size - 18 by 24 mm
Resolution per picture - 640,000 points (700 x 900 lines)
Focal ratio - 3.5

CLASS 2. VARIABLE PERSPECTIVE

An example of this type is the Marley camera. The Marley camera essentially consists of a number of separate cameras arranged in a circle so that a rotating slit plate alternatively uncovers the successive cameras and exposes them (Fig. 3). The actual camera accomplishes this by having several slits in the rotating plate, but the principle is the same. The camera also has a set of matching hole plates placed over the slit plate. The set serves as a capping shutter to prevent multiple exposures. Each individual camera looks at the scene from a slightly different perspective, which is a disadvantage, although probably not often a serious one.

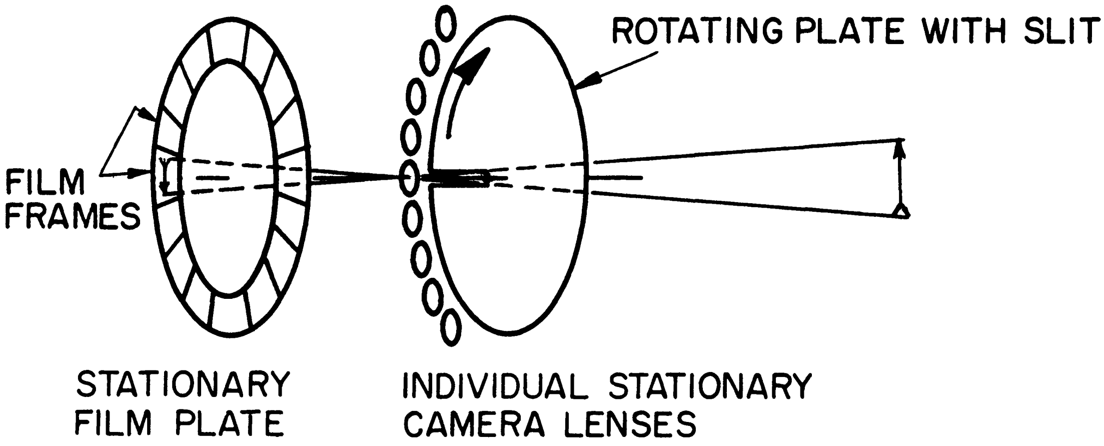

Fig. 3. Principle of Marley camera.

Characteristics of Marley Camera

Framing rate - 100,000 pps
Exposure factor - 2
Framing sequence - 59
Picture size - 30-mm diam
Resolution per picture - 1.13×10^6 points (1200 lines)
Focal ratio - 27

Another variable perspective arrangement is the Cranz-Schardin system. This system is not practical for taking reflected light pictures, but for those applications involving transmitted light, the system works well and gives the highest quality images. The principle is shown in Fig. 4.

The field lens directs the light from a particular spark source into a corresponding camera. Thus by discharging the sparks in succession, the separate cameras will take successive pictures of the object. Since the process works by transmitted light, it is useful only for silhouette, Schlieren, or possibly interferometric work.

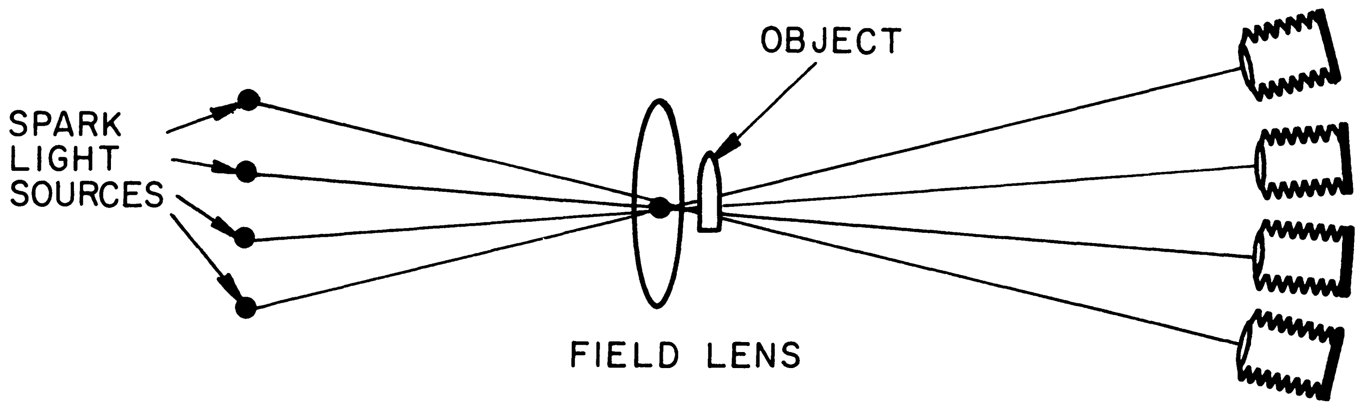

Fig. 4. Cranz-Schardin system.

Characteristics of Cranz-Schardin System

Framing rate - 10^6 - 10^7 fps
Exposure factor - 1-3
Frame sequence - 30
Picture size - 40-mm diam
Resolution - 5 x 10^6 points (2500 lines)
Focal ratio - 14

CLASS 3. FIXED PERSPECTIVE, OPTICAL IMAGE TRANSPORT

In this system, the optical image is transported from a portion of the film to another portion by reflection of a mirror or refraction of a prism. Some form of image compensation is necessary to reduce the image smear on the film. This camera has been produced in a variety of forms, so that it is difficult to present typical characteristics. The Beckmann and Whitley Model 189 camera (which is commercially available) is thought to be fairly representative of the type, and its characteristics are described. The principle of operation is shown in Fig. 5. This camera uses a rotating mirror, but the principle is similar to using a rotating prism in place of the mirror.

In this camera, the main objective lens forms a real image of the object on the rotating mirror. The mirror in turn sweeps this image along the film strip since the rotation changes the angle of reflection. The relay lenses serve two functions. They re-image the primary image onto the film strip as a secondary image, and they provide the image compensation. The image compensation follows from the basic nature of a lens. If conjugate points are considered, it is noted that the direction of the ray does not influence the points of focus. Rays aiming at any portion of the lens from a conjugate point are in all cases returned to the other conjugate point. This idea is illustrated in Fig. 6. It is evident that a change of path

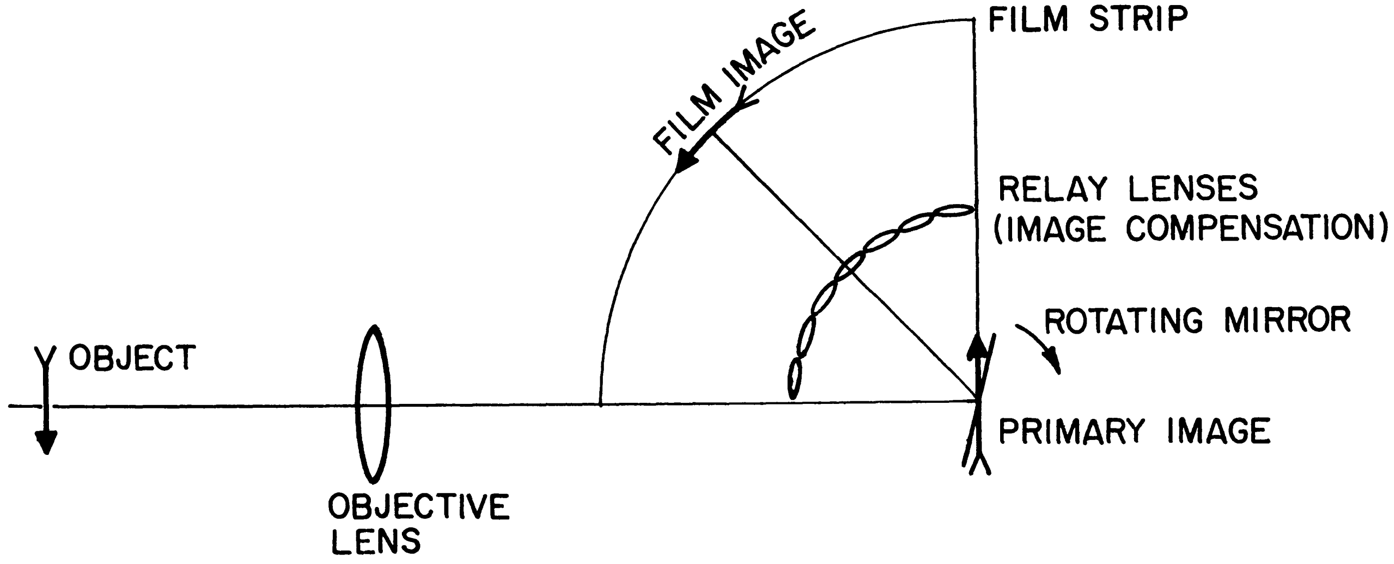

Fig. 5. Principle of rotating mirror camera.

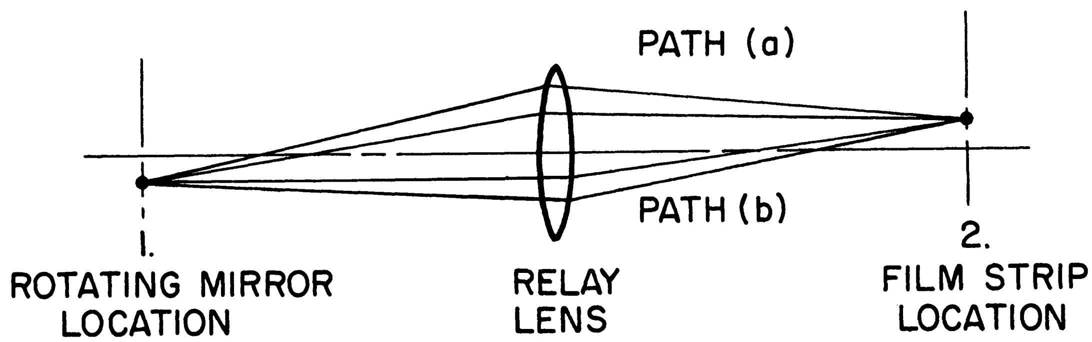

Fig. 6. Image compensation by relay lens.

angle at point 1 causes the path to shift to a different part of the lens, but the final focus is unchanged at point 2.

The relay lens serves this function. The mirror by its rotation changes the path angle of the light rays to the relay lens. The imaging point, however, is unchanged. When the image is swept completely across a relay lens, the action is repeated at the next.

Characteristics of Beckman and Whitley Model 189 Camera

Framing rate - 4,000,000 fps
Exposure factor - 2.8
Framing sequence - 25
Picture size - 10 by 25 mm
Resolution - 320 x 800 lines per picture (250,000 points)
Focal ratio - 14

CLASS 4. FIXED PERSPECTIVE IMAGE CONVERTER

It should be noted that the image converter is properly an adjunct to an optical system. It operates on electron beams in a manner analogous to the effect of a lens on light. The image converter possesses two important advantages over the optical system. These are its ability to intensify the brightness of the image and its ability to shift rapidly the location of the image on the screen. The image converter is diagramed in Fig. 7.

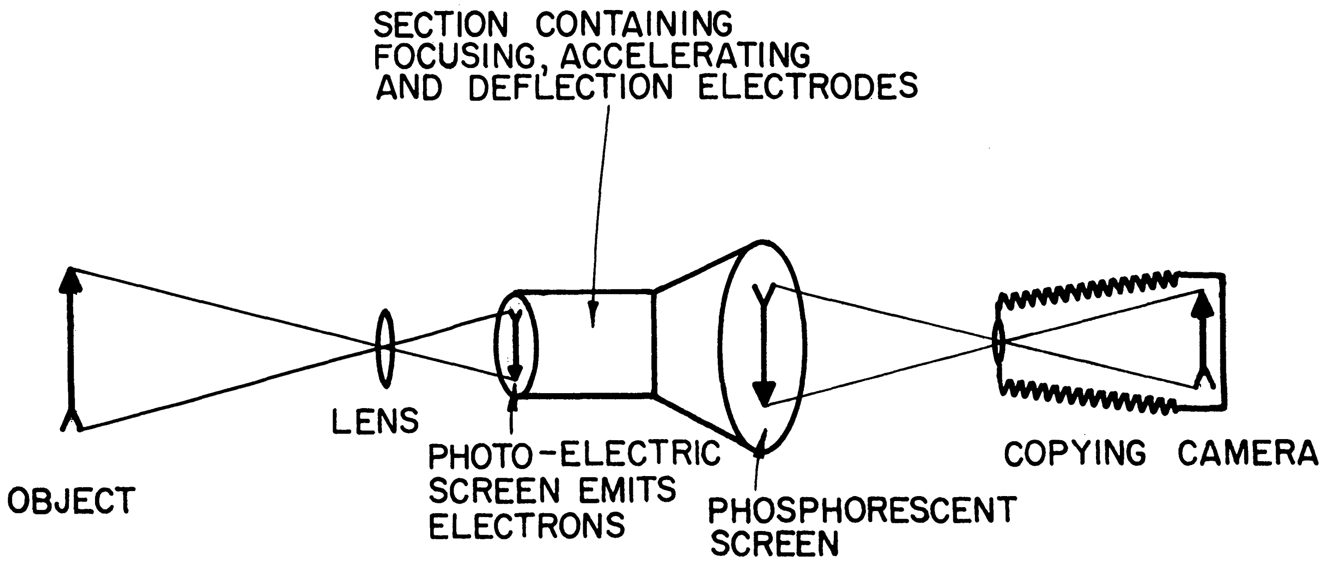

Fig. 7. Principle of image converter.

The principle of operation is fairly simple. A conventional optical lens forms an image on the photoelectric screen in one end of the tube. Electrons are emitted from the screen in amounts proportional to the local intensities of the image. The electrical system of the tube accelerates and focuses the electrons onto the phosphorescent screen, forming a second visible image of the object. The size as well as the intensity of the second image is controllable. Furthermore the position of the second image can be moved about the screen by use of the deflection coils.

By rapidly shifting the position of the image about the face of the screen, a sequence of pictures of an event may be produced. These images are recorded by the copying camera so adjusted as to image the entire phosphorescent screen of the converter tube.

The image-converter system is still a relatively new device. Its potentialities seem to be very great, but have not yet been realized. Specific information on the device is not plentiful, but the following description is believed to be representative of the present state of development.

Characteristics of Image Converter

Framing rate - 250,000 fps
Exposure factor - 1 (frame interval/exposure time)
Resolution - 1,000,000 points (total in one sequence of exposures)
Frame sequence - 10 (actually no fixed number)
Area of screen - 75 sq cm
Picture size - 27 by 27 mm (based on frame sequence of 10)
Resolution per frame - 100,000 points (315 lines x 315 lines)
Focal ratio - image-intensification factor of 10 (over-all depends on optics used)

CLASS 5. ROTATING PRISMS

The Wollensak Fastax camera is the primary example of this type. It has been brought to a high degree of perfection and is probably the best known of the high-speed cameras. Originally developed at the Bell Telephone Laboratories, this camera has been available in various modification for about 25 years. The camera is now available in 35-mm, 16-mm, and 8-mm frame size. Figure 8 shows the operating principle of the camera, and the characteristics of the 16-mm size are given.

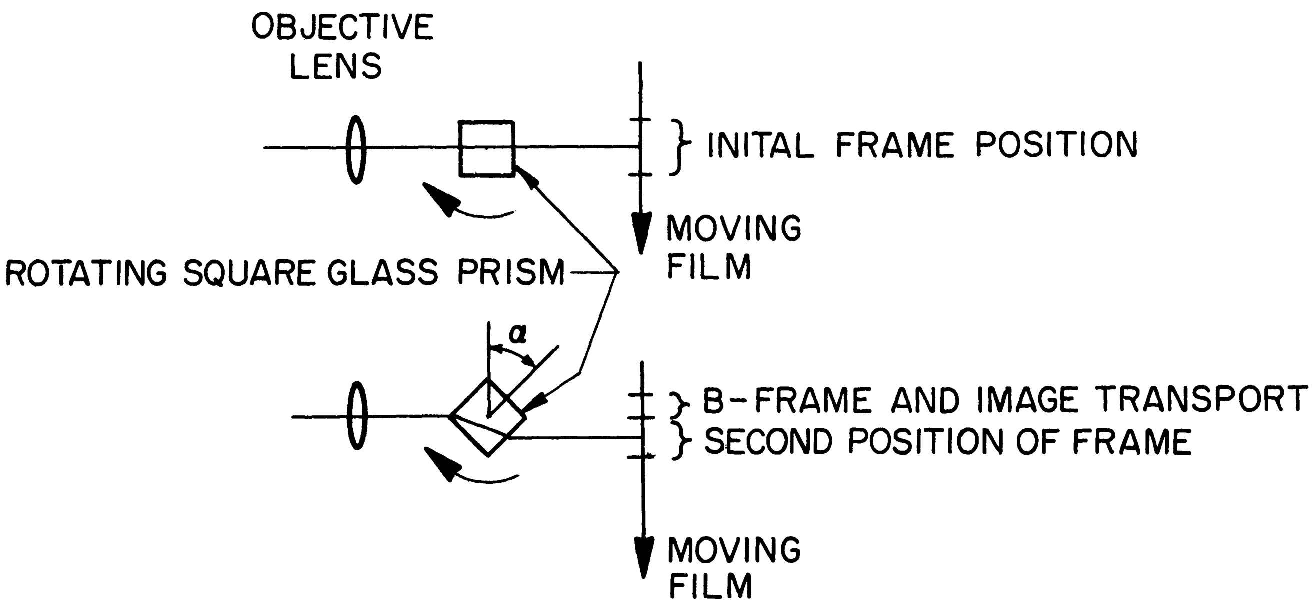

Fig. 8. Principle of rotating prism camera.

The 16-mm camera uses 100-ft rolls of perforated film and a complete roll of film is normally used for each shot. In this camera, the film travels continuously, and the rotation of the prism is geared to the film motion in such a way that when the prism rotates through the angle α (Fig. 8), the film is transported the distance B. The size of the prism is selected so that, when rotation α has occurred, the light ray has also been transported the distance B. This image transport occurs because of the nature of the prism. Having parallel sides, it displaces the emergent light ray relative to the incident ray without changing its direction. Of course, this only occurs when the incident ray is not normal to the surface of the prism, as when the frame is directly behind the prism face.

Characteristics of Rotating Prism Camera (Fastax 16 mm)

Framing rate - 7000 fps
Exposure factor - 5
Frame sequence - 4000
Picture size - 7.5 b 11 mm
Resolution - 40,000 points
Focal ratio - approx. 6

CLASS 6. ROTATING MIRROR

There is no great distinction between the rotating prism and rotating mirror cameras. The optical compensation is accomplished by reflection from a mirror instead of by the refraction of a prism. Otherwise, the two cameras are quite similar. This applies to their operational features as well as their characteristics. The rotating mirror principle is shown in Fig. 9. In this camera, the rotation of the mirror causes the reflected ray to be carried along with the film. The gearing between the film transport sprocket and the mirror (M) is arranged so that the image travels at the same rate as the film. Successive faces of the mirror bring about the framing action of the camera.

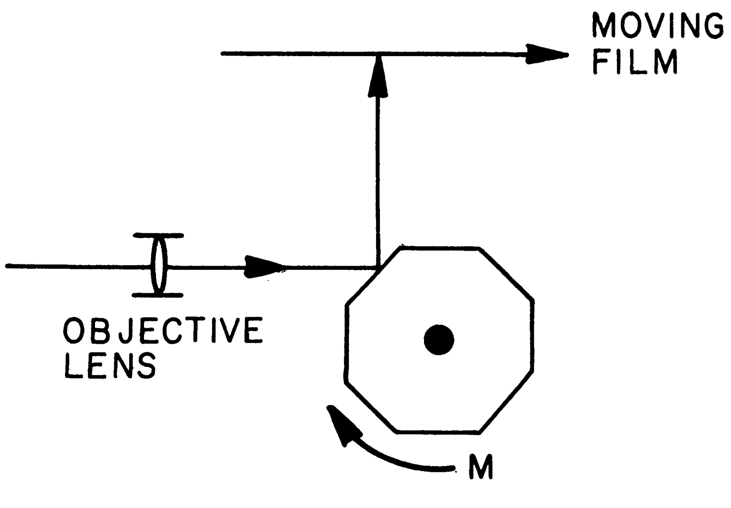

Fig. 9. Principle of rotating mirror camera.

This type of camera is made by the Zeiss Company in 35-mm and 16-mm sizes. Characteristics of the 16-mm size are given below.

Characteristics of Rotating Mirror Camera (Zeiss 16 mm)

- Framing rate - 3000 fps
- Exposure factor - 1
- Frame sequence - 4000
- Picture size - 7.5 by 11 mm
- Resolution - 40,000 points
- Focal ratio - approx. 6 (max)

CLASS 7. TRANSLATING MIRROR

The translating mirror affords another means of optical compensation. This device is the basis of the Miller Isotransport camera, and operates according to the principle illustrated in Fig. 10.

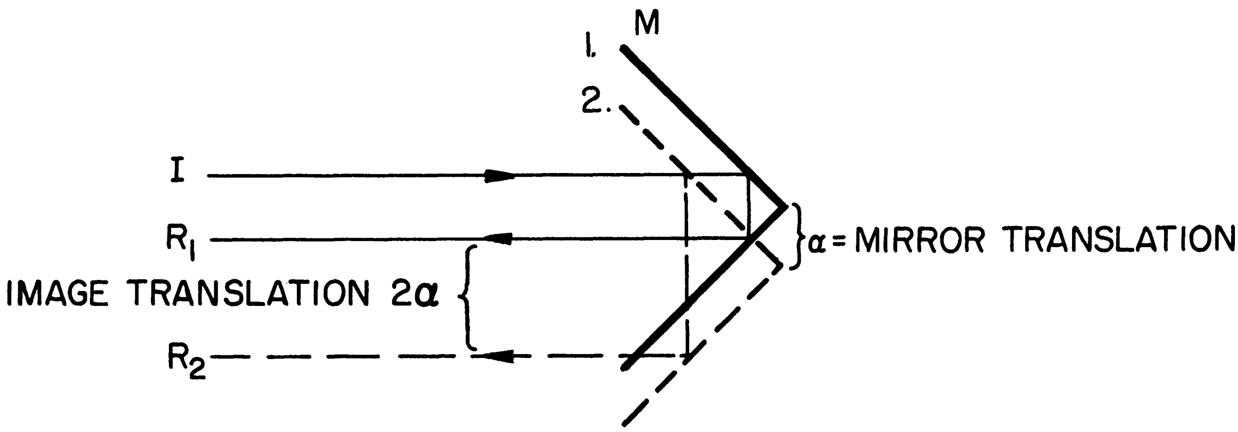

Fig. 10. Principle of translating mirror.

The incident ray I strikes the mirror when it is in position 1 and is reflected as R_1. After the mirror moves the distance α and is at position 2, the incident ray is reflected as R_2. Geometric considerations show that the reflected ray is translated by twice the movement of the mirror. The way this property is used in a camera system is illustrated in Fig. 11.

The incident ray I is focused as an image on the translating mirror by objective D. The mirrors cause a translation of this image that is twice the translation of the drum. The film is translated with the drum and at the same rate as the drum. Since the film is on the opposite side of the drum from the primary image, it is translated in the opposite direction to the image. The relay lens R matches the secondary image to the film in both direction and speed. If the primary image is moving downward, the secondary

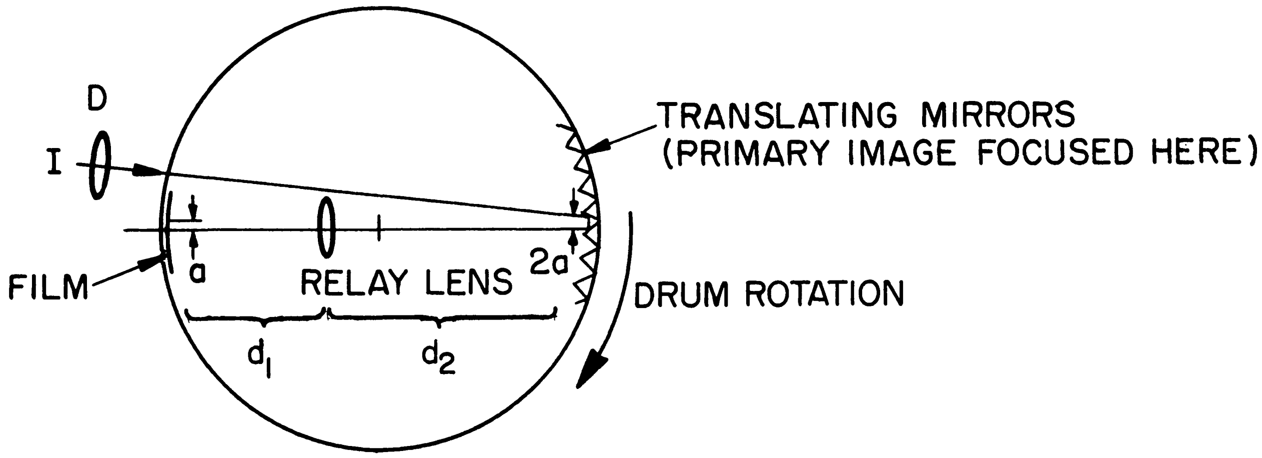

Fig. 11. Principle of Miller Isotransport camera.

image formed on the film by the relay lens will move upward, in accordance with the film movement. By making the conjugate points of the relay lens have the ratio $d_2/d_1 = 2$, the secondary image is made to move in the same direction and at the same speed as the film. The optical system of the actual Miller camera is more complex than this one (the mirrors are on the outside of the drum) but the principle is as shown.

Characteristics of Translation, Mirror Camera (Miller Isotransport)

Framing rate - 100,000 fps
Exposure factor - 1
Frame sequence - 500
Picture size - 3.8 by 5 mm
Resolution - 60,000 points (100 x 60 lines)
Focal ratio - 10 (estimated)

CLASS 8. THE MOVING LENS CAMERA

This type of camera was developed around 1910 by Charles F. Jenkins in substantially the form used at present. Jenkins' camera could take about 3000 pictures per second and used standard 35-mm magazine film. Cameras of this type were developed by Heape and Grills in England around 1925. Their camera used a film drum and could take 5000 pps in stereoscopic pairs on 35-mm movie film. The modern example of this type is the Wyckoff camera which has probably not yet reached the maximum attainable refinement.

The moving lens camera uses the lens to obtain film-image motion compensation. The manner of doing this is shown in Fig. 12. The camera consists of a lens wheel holding a number of objective lenses and arranged to rotate in front of the moving film. The wheel and the film are geared

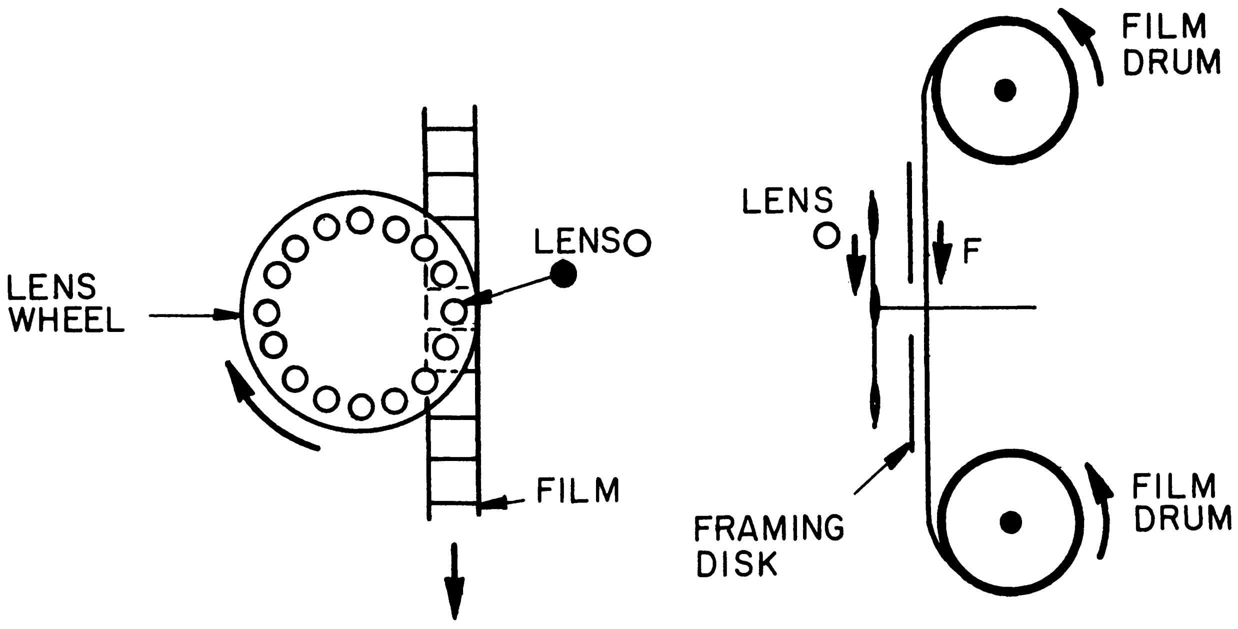

Fig. 12. Principle of moving lens camera.

together in such a way that the lens O moves across the framing mask at the same rate as the film. The image cast by the lens O thus follows the film during the period of exposure.

The image actually follows a slightly curved path while the film follows a straight line. This imparts a particular defect to the compensation which is evident in the pictures taken. Small moving objects appear to be crescent-shaped.

The Wyckoff camera eliminates the difficulty, but introduces other problems which nevertheless are better handled.

The Jenkins' camera was at one time manufactured for sale, but is not available now.

Characteristics of Moving Lens Camera (Wyckoff type)

Framing rate - 2350 fps
Exposure factor - 2-10 (adjustable)
Frame sequence - 3300
Picture size - 18 by 24 mm
Resolution - 1.08 x 10^6 points (900 x 1200 lines)
Focal ratio - 9

CLASS 9. ELECTRICAL SHUTTER

When a camera system operates without film-image motion compensation, it is necessary to control the image smear by resorting to very short exposure times. This can be done by shuttering, and electrical devices exist for doing this. At least three are known. These are the Kerr Cell, the magneto-optic glass, and the image converter. No example of the application of the last two devices as motion-picture shutters is known, but they could be applied for this purpose.

K. D. Froome has used the Kerr Cell in a sequential picture camera. The Kerr Cell consists of two electrodes separated by a liquid (usually nitro benzene) which becomes optically active when a voltage is applied to the electrodes. The Kerr Cell rotates the plane of polarization of light rays, and when placed between two crossed light-polarizing plates, it can rotate the plane of polarization so that light will pass through the combination (Fig. 13).

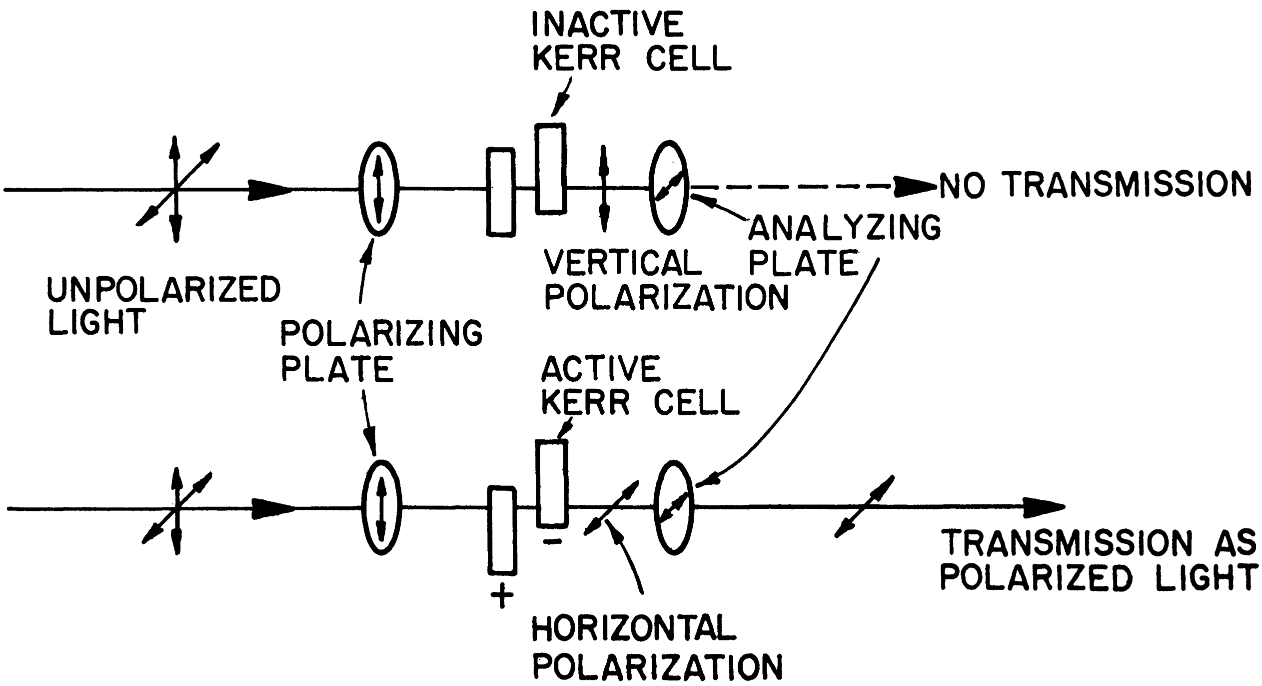

Fig. 13. Principle of Kerr Cell shutter.

The entire arrangement becomes a shutter which can work at extremely short exposure times of the order of 0.1 microsecond, but it can transmit at most about 5% of the incident light. The operation can be repeated by repeating the voltage applied to the electrodes. The system of Froome (Fig. 14) hardly constitutes a motion-picture camera since the pictures are not adapted to projection, but they could be used this way by retaking the pictures with a regular movie camera on a frame-by-frame basis. The purpose of Froome's camera is to study the development of the cathode spot of a metallic arc.

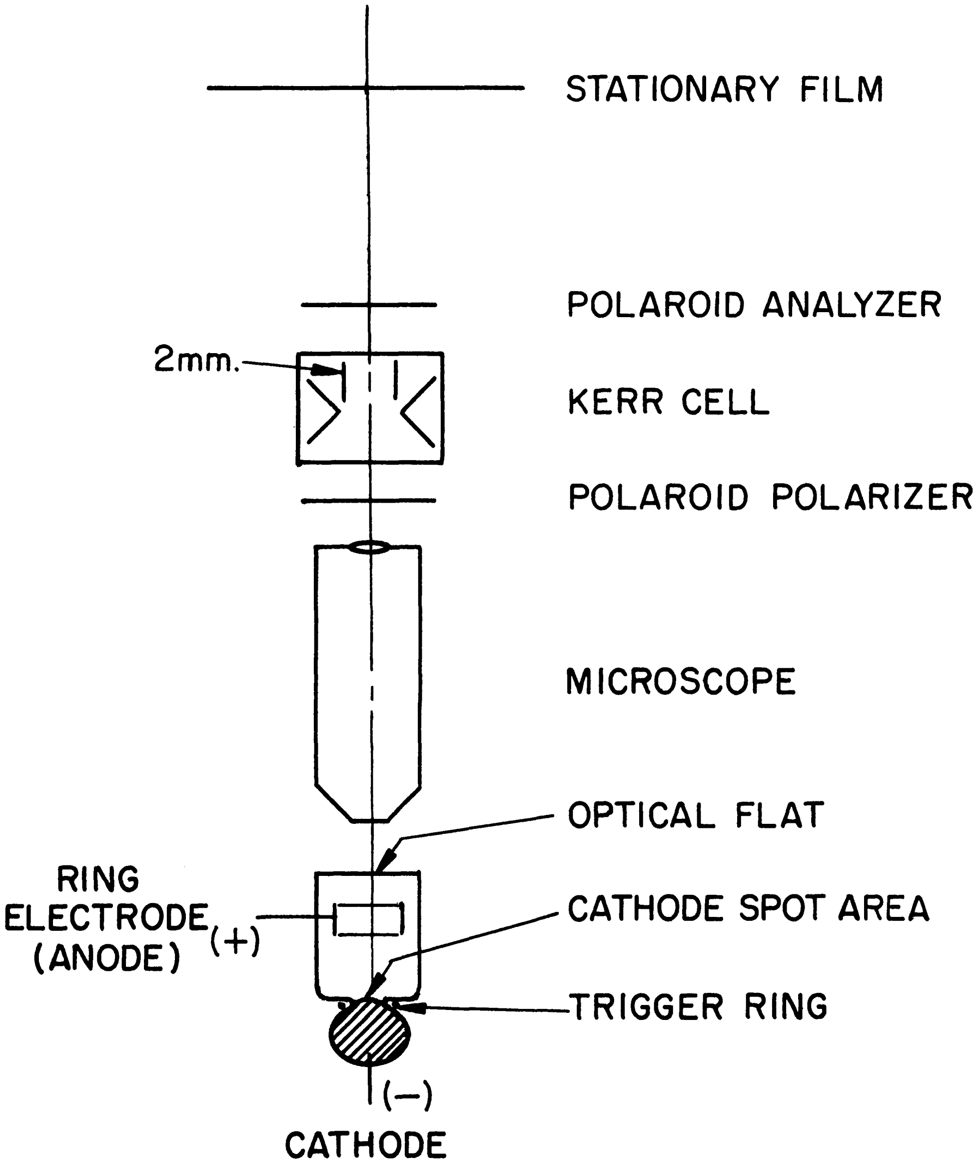

Fig. 14. Froome-Kerr Cell camera.

This camera operates on the basis of the movement of the cathode spots. These are moved by means of a magnetic field but they also move naturally. Movement of the spot causes the image of the spot to move across the film. The Kerr Cell is shuttered simultaneously with the image motion by a suitably applied voltage, and sequential pictures are thus obtained.

Characteristics of Electrical Shutter Camera (Froome)

Framing rate - 2.5×10^6 fps
Exposure factor - 1-4
Picture sequence - no exact number
Picture size - no exact size
Resolution - 40 lines/mm (estimated)
Focal ratio - 72 (approx.)

There is no basic reason why the Kerr Cell cannot be applied to conventional movie cameras, but it compares poorly to mechanical shutters in this application. It may find application in other types of high-speed cameras, however.

The magnetic-optic glass replaces the Kerr Cell in the shutter - described above. A cylindrical slug of extra dense flint glass becomes optically active when placed in a strong magnetic field. The slug is wound with several turns of wire and a heavy pulse of electrical current is applied.

During this time, the glass rotates the polarized beam and the shutter opens. Edgerton and associates have devised a one-shot still camera using this device, but no application to sequence cameras is known.

The image converter has been mentioned before but as an image-transport device. It is also able to work as a shutter by applying the necessary electrode voltages. No example of the use of the image converter as a shutter in a motion-picture camera is known, but the possibility seems rather attractive.

CLASS 10. FLASHING LIGHT CAMERA (GENERAL RADIO)

When the scene to be photographed is to be illuminated by applied artificial lighting, the possibility exists of shuttering the light between the source and the subject instead of between the subject and the film as is usually done. Such shuttering might be electrical or mechanical, but in any case if a continuously operating source is so shuttered, a large portion of the energy producing the light is wasted. This happens during the time the shutter is closed.

The development in recent years of gas discharge tubes having large light output of short duration affords a different approach to light-shuttering. The method is used to take motion pictures by continuously running the film behind the objective lens and in the image plane. The light is flashed repeatedly and at such intervals as will allow the film to advance one frame length between flashes. The light flash is of such short duration that the image smear is negligible under the conditions used. A disadvantage of the system comes from the limited amount of light available which restricts its use to fields of the order of a few square feet of area. An advantage lies in the relative simplicity of the mechanical and optical system (Fig. 15).

Characteristics of General Radio Camera

Framing rate - 1500 fps
Exposure factor - 200 (of doubtful significance in determining weighted frame data)

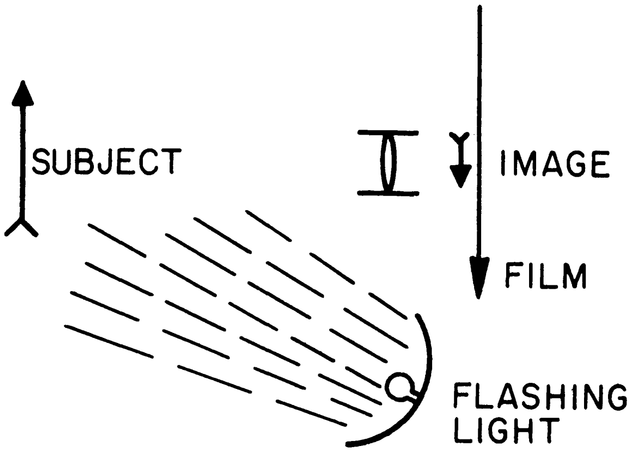

Fig. 15. General Radio camera.

Frame sequence - 1600
Picture size - 18 by 24 mm
Resolution - 430,000 points (360 x 1200 lines) (estimated)
Focal ratio - 2.0

CLASS 11. MECHANICAL SHUTTER

Mechanical shutters may be used to obtain relatively short exposure times and thus reduce image smear in cameras which do not have image-film motion compensation. The mechanical shutters cannot operate at the speeds of the electrical shutters, but they have the advantage of greater simplicity. The ordinary cinema camera, of course, uses a mechanical shutter, but the requirement in this case is not especially severe since the framing rate is relatively low, and there is no relative film-image motion to cause smear. That is, the motion in the scene is the only source of image smear.

The Bowen Ribbon frame camera is an example of a relatively low-speed camera which uses a mechanical shutter to control image smear. The camera (Fig. 16) consists of a drum over which film is drawn from one magazine into another. There is a framing mask ahead of the film drum and just ahead of this another drum with slits is arranged. The film is drawn continuously over the film drum, and the slitted drum rotates at such speed that successive slits arrive in front of the framing mask as often as the film advances one frame. The arrangement is in effect a focal plane shutter. The Bowen camera has a frame that is wide but not very high. It was designed this way to accommodate actions in similarly shaped scenes.

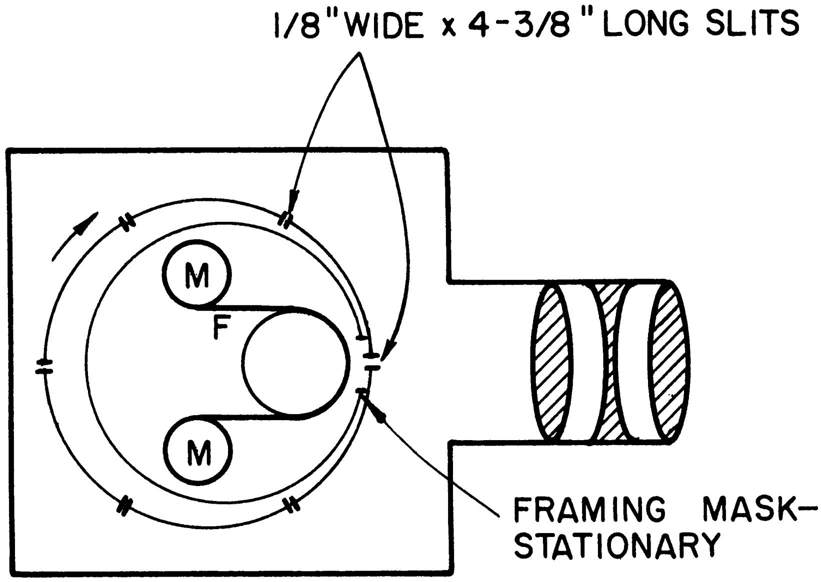

Fig. 16. Bowen Ribbon frame camera.

Characteristics of the Bowen Ribbon Frame Camera

Framing rates - 30, 60, 180 fps
Exposure factor - 340, 170, 57
Exposure time - 97 microseconds
Frame sequence - 1200, 2400, 6000
Picture size - 1.00, 0.50, 0.17 in. high by 4-3/8 in. long
Resolution - 300, 150, 50 lines by 4250 lines (estimated)
1.27×10^6, 0.64×10^6, 0.21×10^6 points (estimated)
Focal ratio - 3.5

CLASS 12. IMAGE SAMPLER - FOCAL PLANE SCANNING - TUTTLE, SULTANOFF

With this class, we take up the streak cameras or image dissectors. These interesting cameras represent a fairly recent development in the field. Their operation is based on the following ideas.

Ordinarily, a picture is considered to be made up of point or line elements. These elements are normally immediately adjacent to one another, and the eye is not able to distinguish where one begins and another leaves off. Suppose now that the point elements that make up a picture are separated from each other by a relatively large distance. It is obvious that the picture will now cover a larger area. It is also apparent that there will be spaces between the point elements which contain nothing but, say, the white paper. If a mask full of holes is placed over the paper so that the holes let the point elements show through, then the picture will be seen as before, provided the viewer moves far enough away so that the individual points are not individually seen. Use can be made of the blank spaces between the points. For instance, the elements of a different picture could be printed in these blank spaces, and if the mask were registered properly, the second picture could be seen but not the first. In a practical case, this idea can be expanded so that many pictures can be recorded in the same surface and then sorted out by proper adjustment of the mask. The same argument can be made relative to line elements of pictures.

Tuttle has applied this idea to a type of camera that uses a focal plane scanner. This camera is not very different from an ordinary view camera, but in addition to the usual features, a mask or scanner is placed over the emulsion plate. This mask is composed of alternate slits and opaque portions, the opaque portions being rather wide relative to the slits (Fig. 17).

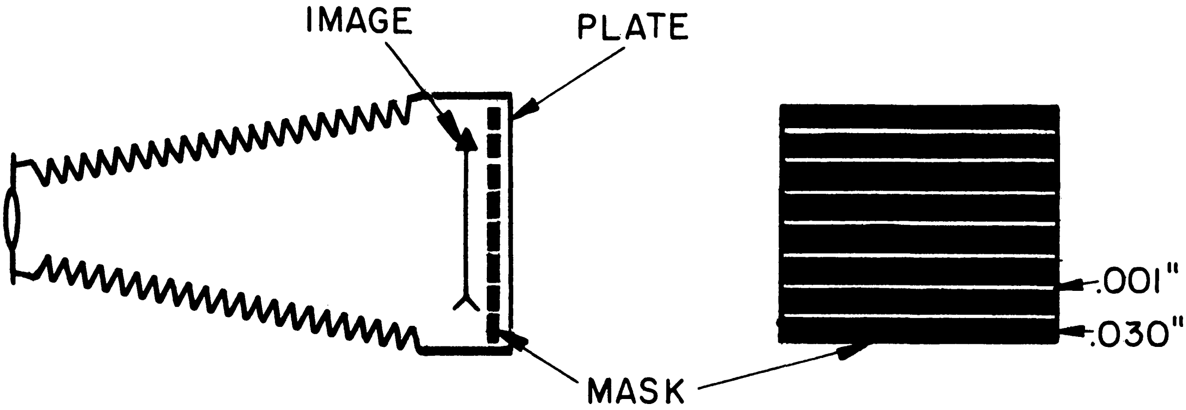

Fig. 17. Focal plane scanner (Tuttle).

In the Tuttle camera, the width of the opaque portions of the mask is 0.030 in., and the slits are 0.001 in. wide. The plate size is 4 by 5 in. It is apparent that, with the mask placed over the plate, only about 1/30 of the plate is actually exposed. A picture can be taken this way and then the mask may be moved slightly (0.001 in.) so as to uncover new emulsion and another picture may be taken. This may be carried on for a total of 31 pictures. In practice, the number of pictures possible is modified by a good many factors related to emulsion resolution, diffraction effects, image spread, lens resolution, etc., but the number of pictures based on geometric effects alone is representative.

It is readily apparent that the mask may be moved steadily and similar results obtained. In this case there is no lens shutter needed during the time of motion of the mask. A so-called capping shutter is placed over the lens to prevent multiple exposure which will begin to occur after the mask has moved the 0.030 in. After the plate is developed, it is returned to the camera. A uniform light is admitted through the camera lens, and the scanner is moved slowly. By this procedure, new pictures are continuously seen until the scanner has moved 0.030 in., after which the sequence repeats. The time magnification is proportional to the quotient of the scanner speed during the taking period by that during the viewing period. It is apparent that quite high taking rates may be accomplished by this method. For instance, if the scanner moves 10 fps (not a difficult problem) the picture-taking rate is about 120,000/sec, since the movement of the scanner takes 1000 pictures for each inch of motion.

The resolution of the pictures obtained is not well balanced, since the resolution parallel to the slit is about as good as that of the basic camera (say 50 lines/mm), while the resolution across the slits is only 30 lines/in. or roughly 1 line/mm. On a 4- by 5-in. plate, this amounts to a resolution of 150 x 4000 lines.

Characteristics of Image Dissector - Focal Plane Line Scanning - Tuttle

Framing rate - 16,000 pps
Exposure factor - 1
Exposure time - 60 microseconds
Frame sequence - 100
Picture size - 4 by 5 in.
Resolution - 150 x 4000 lines (600,000 points)
Focal ratio - 4.5

Tuttle has extended the idea of the slit scanner to a point scanner. The same general idea is followed as with the slit scanner, but in this case, a disc is substituted for the slitted mask as a scanning device. This disc is perforated with many holes arranged in multiple Nipkov spirals. A portion of this disc is placed over the plate and the disc is continuously rotated (Fig. 18). A special shutter is also arranged to start and stop exposure so as to present multiple exposures or overlapping.

When the disc is rotated at 5000 rpm, the picture-taking rate is approximately 10^6/sec. This camera has a better balance in resolution, giving 240 x 300 lines on the plate.

Characteristics of Image Dissector - Focal Plane Point Scanning - Tuttle

Framing rate - 10^6 fps
Exposure factor - 1
Exposure time - 1 microsecond
Frame sequence - 900
Picture size - 4 by 5 in.
Resolution - 240 x 300 lines (72,000 points)
Focal ratio - 4.5

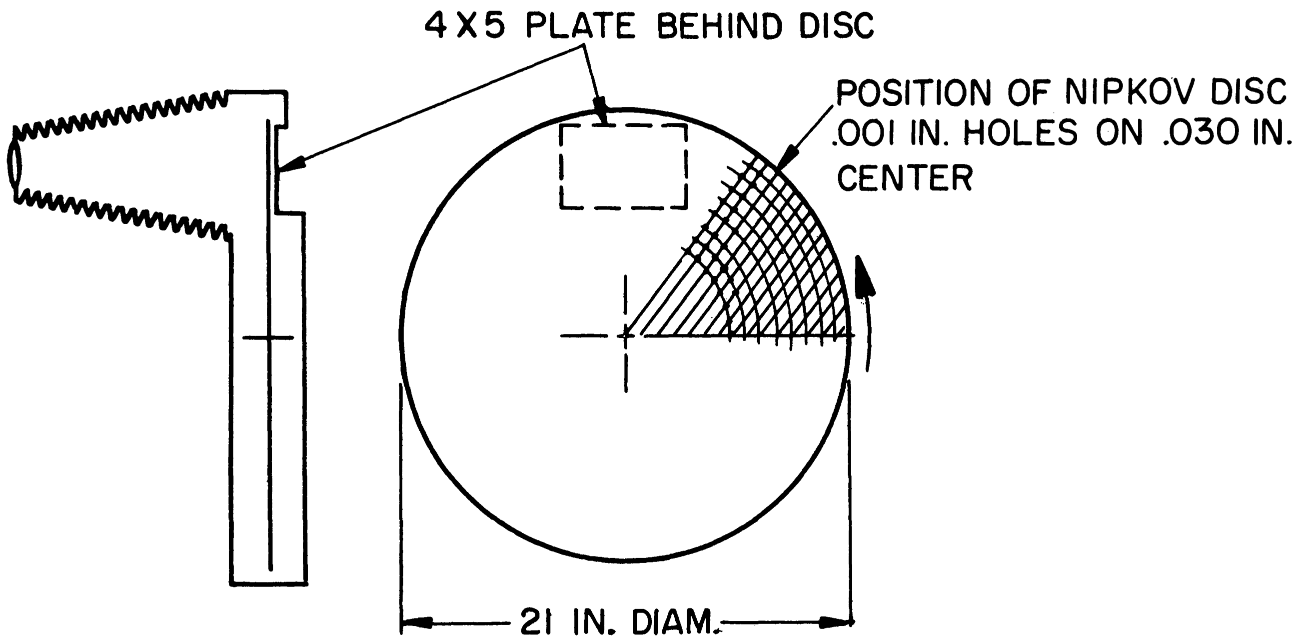

Fig. 18. Nipkov Disc as used in Tuttle "point" scanner.

Sultanoff has extended the Tuttle line-scanning idea in a camera that can take pictures at a rate of 10^8 pps. Instead of using a mechanical scanner, the Sultanoff camera accomplishes this function by optical means (Fig. 19). In this camera, an objective lens forms an image of the scene on a stationary dissection plate which is ruled with 250 transparent lines 0.0005 in. wide and 0.015 in. apart. The relay lens and the rotating mirror form an image at unity magnifications on the 4- by 5-in. photographic plate. Since the primary image is dissected into line elements by the dissection plate, there will be a dissected similar secondary image displayed on the photographic plate. The position of this image may be changed by rotation of the mirror, and moderate mirror rotational speeds account for a fast

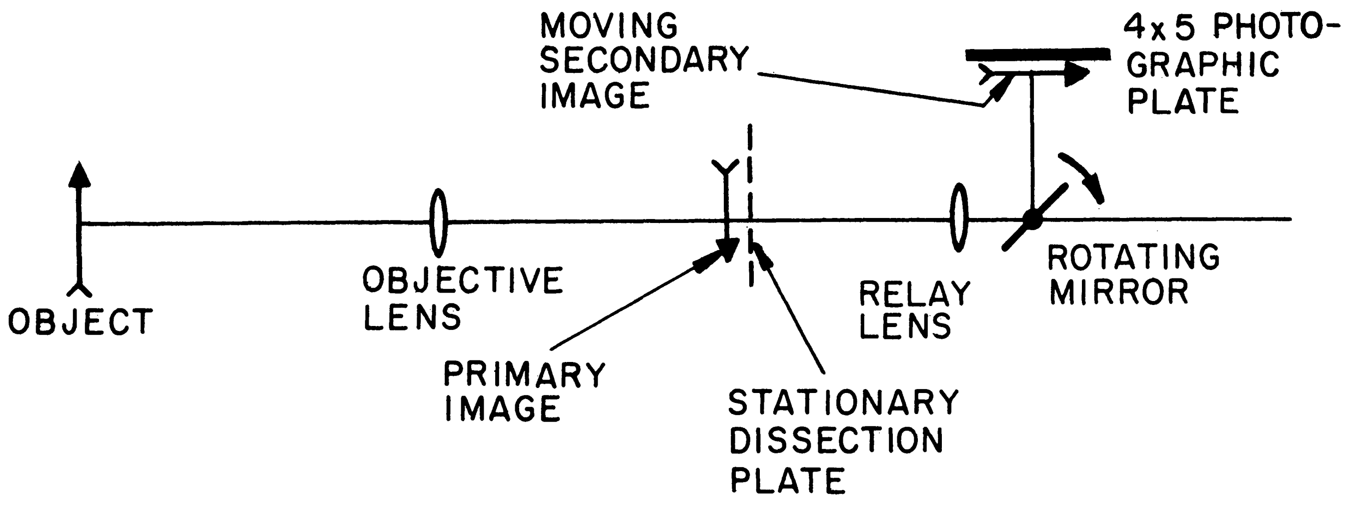

Fig. 19. Principle of Sultanoff focal plane scanner.

sweep rate of the "optical" grid across the photographic plate. As was seen before, moderate grid sweep rates give very large framing rates with the result that the Sultanoff camera can take pictures at an enormous rate. It should be noted again, however, that as is common with the highest speed cameras, the utility is limited by poor definition and by the need for generally unattainable levels of illumination. Synchronization of the camera to the event is a difficult problem, and the over-all result is that this camera is useful only for studying explosions at its highest framing rate.

Characteristics of Image Dissector - Optical Focal Plane Line Scanning - Sultanoff

Framing rate - 10^8 fps
Exposure factor - 1
Exposure time - 10^{-8} microseconds
Frame sequence - 30
Picture size - 4 by 5 in.
Resolution - 250 x 1000 lines (250,000 points) (estimated)
Focal ratio - 18 (estimated)

CLASS 13. OBJECTIVE SCANNING IMAGE SAMPLER - COURTNEY-PRATT

Courtney-Pratt has applied the principles of image dissection to a point-scanning camera that works in a somewhat different way from the Tuttle camera. Courtney-Pratt makes use of what is termed a lenticular image-dissection plate. This plate is so constructed that it effectively consists of numerous (80,000) small lenslets spaced on square centers over a 4- by 5-in. area. These lenslets have very short individual focal lengths. The actual camera (Fig. 20) resembles, and is in general similar to, an ordinary view camera of large aperture. In use, the image-dissection plate is placed just in front of the 4- by 5-in. emulsion plate. In addition, a small movable aperture (stop) is placed over the main lines. The system is arranged so that each lenslet forms an image of the stop on the part of the photographic plate that is behind it.

If the position of the stop is moved about, the position of its image moves on the plate behind each lenslet. The stop is made small enough so that its images on the photographic plate approach the smallest dimension that can be recorded by the emulsion and the optical system. In addition, the system is further arranged so that the main objective lens forms the image of the scene on the front surface of the lenticular plate. Further thought reveals that the scene image is unaltered in position by changes in the movable aperture position.

With the movable stop held in one position, it is apparent that its multiple images on the photographic plate will be of varying intensity de-

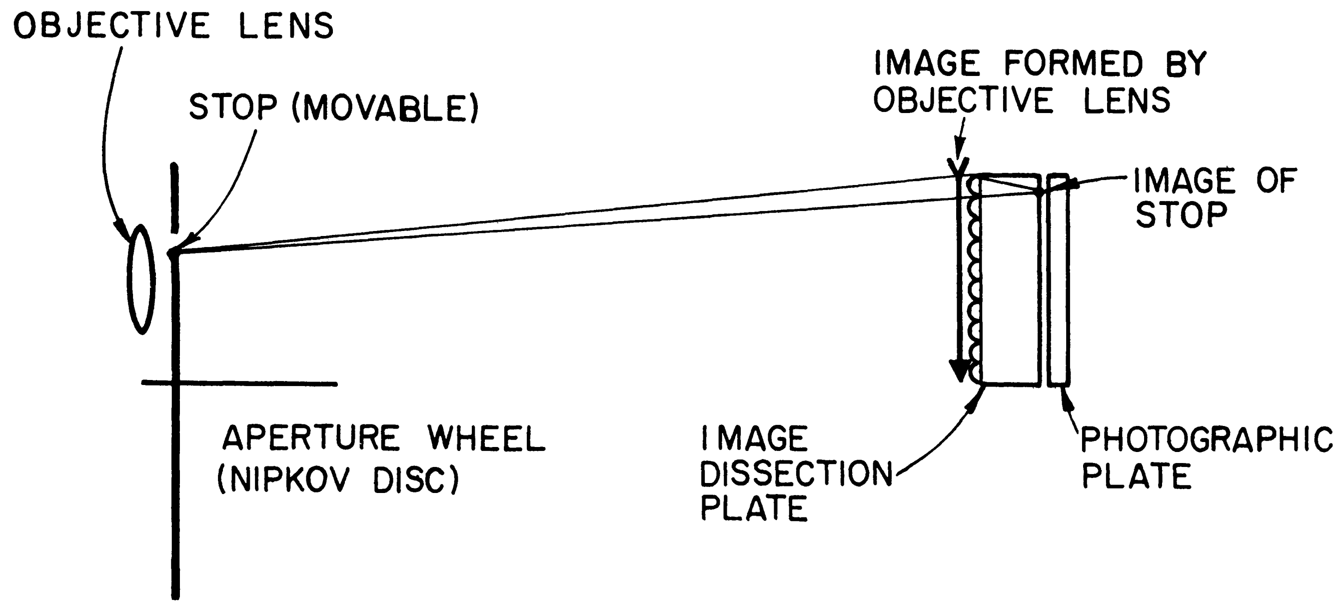

Fig. 20. Courtney-Pratt-600 camera.

pending on the local degree of shading of the scene image. In other words, if the scene image shows a bright spot in front of a lenslet, the image of the stop that is behind the lenslet will be brightly illuminated and conversely for a dark spot in the scene image. A picture can be taken this way and, after the plate is developed and processed, it may be returned to its position behind the lenticular plate. With the stop at the same position as before, a light is projected into the main camera lens. This light will eventually reach the photographic plate by passing through the stop and by being focused by the lenslets so that it falls on and only on the previously exposed and darkened spots. If the plate is viewed from behind, a photographic negative of the scene will be seen.

Now, if after taking the first picture, the stop is moved across the main lens to a new position, another picture may be taken since the images of the stop formed on the plate behind the lenslets have been shifted to a new part of the photographic plate. If the plate is processed and returned to its position behind the lenticular plate, two pictures may now be seen, one for each of the two selected positions of the stop. This reasoning may be carried further so that in the case of the CP-600 camera, between 200 and 300 pictures may be recorded. It is not necessary that the movable aperture be arrested while taking pictures, but if in continuous motion, it will form continuous streak images of variable density along the streak when the scene is in motion. This system does not gain something for nothing. It is noted that the quality of the picture (280 x 350 line resolution) is really not equal to that of a good 16-mm frame which covers a film area of about 0.125 sq in.

It is seen that it should be possible to get $4 \times 5/0.125 = 160$ exposures of 16-mm size and quality on a 4- by 5-in. plate. It is therefore reasonable to get an equivalent of 200-300 pictures of less than 16-mm quality on a 4- by 5-in. plate using the CP system.

The movable aperture is actually a series of spertures arranged on a rotating disc in a Nipkov spiral (Fig. 21).

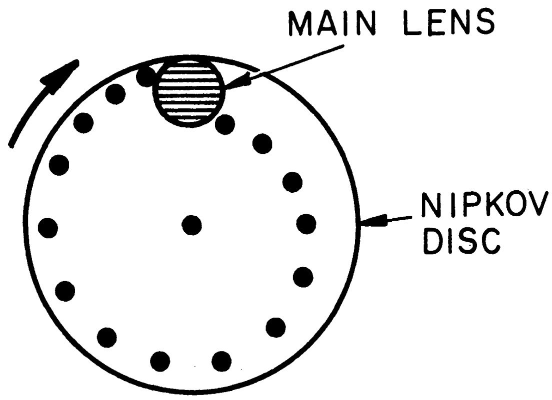

Fig. 21. Nipkov Disc used in CP-600 camera.

The holes in the disc are spaced tangentially and radially in such a way that, as the disc rotates, each hole traces out a path across the main lens. As soon as one hole clears the lens, another hole starts across on a path adjacent to the preceding one. In the CP camera, the apertures are about 0.1-in. diameter and there are approximately 8 holes in the spiral, but the spiral is double.

A so-called capping shutter is also used which covers the entire main lens and is open only during the picture-taking sequence. The purpose is to prevent multiple exposures and to reduce the effects of stray light.

The CP camera has a relatively fast optical system despite the small (0.1-in.) lens stop used. This is on account of the focusing effect of the small lenslets which reduce the pencil of light striking them to a very small point. The effect is as if all the light coming through the aperture were focused on a piece of film of about 16-mm size. The effective relative aperture is about 6.3.

Characteristics of Image Dissector - Objective Scanning - CP-600 Camera

Framing rate - 250,000 fps
Exposure factor - 1
Exposure time - 4 microseconds
Frame sequence - 200-300
Picture size - 4 by 5 in.
Picture resolution - 255 x 315 lines (80,000 points)
Focal ratio - 6.3

CLASS 14. IMAGE SAMPLING - LINE DISPLACEMENT - O'BRIEN AND MILNE

O'Brien and Milne have applied the principle of image dissection or sampling in a novel and, for some applications, powerful manner. Their camera samples the image by lines instead of by points. The principle on which the camera operates can be approached as follows (Fig. 22).

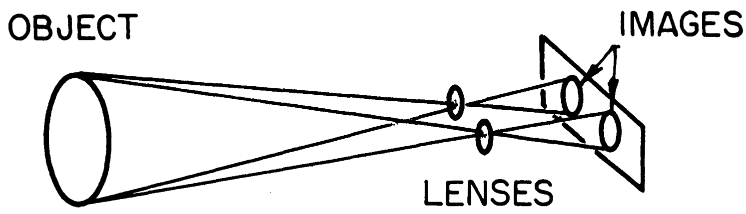

Fig. 22. Principle of line displacement image dissector.

If several cameras are placed side by side, viewing the same scene, similar images will be formed on their screens or plates. A mask having a slit is now placed over each camera screen, the slits having a different relative position on each mask.

If a picture is taken with all the cameras simultaneously, there will be a narrow portion of the scene shown on each plate, and if a number of cameras are used, the picture portions can be reassembled into a composite picture of the whole scene. It is apparent that the principle of variable perspective enters into the operations to some extent. If now the camera lenses are left open, and the film is drawn behind the masks, a continuous line-element trace will be exposed on each film. By combining the corresponding elements on each film, a series of pictures may be composed from the elements. The principle is developed in the O'Brien and Milne camera by using a number of lenses placed side by side and exposing through a slit into a 16-mm film strip (Fig. 23).

The film itself is placed on a rotating drum so that it may be rotated and exposed at high speed. Each frame is taken during the time it takes the film to move the width of the slit (1/100 mm), and as seen before, this can account for very high framing rates. At 400-fps film speed (maximum attainable), the film is moving 12,000,000 slit widths/sec. The actual framing rate for the camera is given as 10^7 fps. The 2-ft-long film strip allows about 24,000 exposure or frames to be taken. One version of the camera uses 30 lens elements, so it is apparent that the resolution across the slit is no better than 30 lines across the field. Parallel to the slit (across the film), the resolution may amount to about 1/30 of 900 lines or 30 lines. It is seen that the resolution or information content of each frame is very low. This would be expected owing to the large number of frames taken on a small film area (2 ft of 16-mm film).

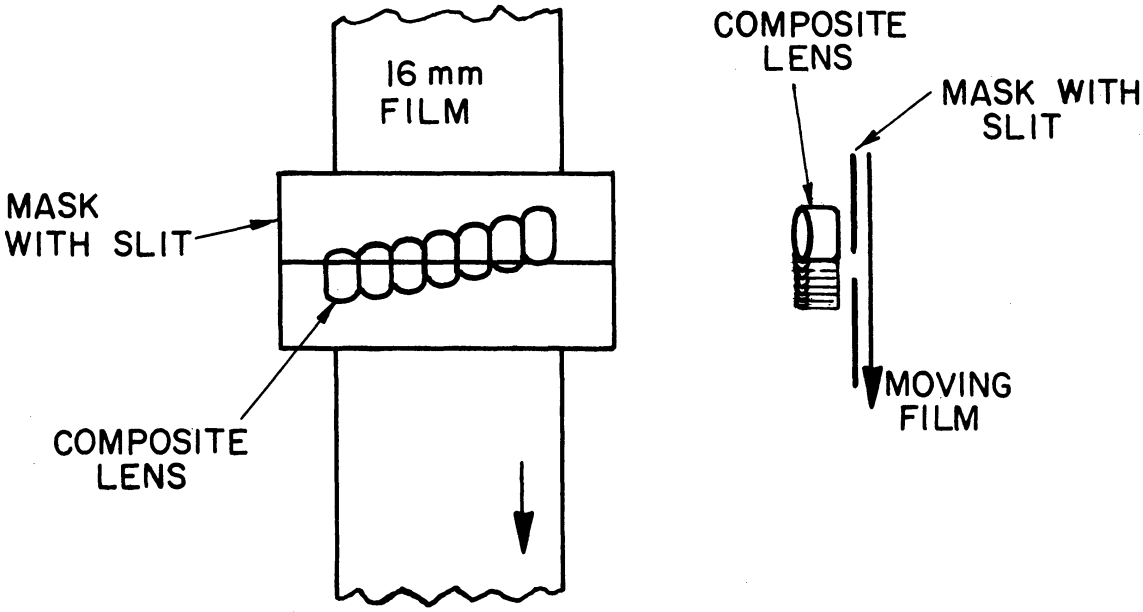

Fig. 23. O'Brien and Milne line displacement image dissector.

The picture is recomposed by projecting a light through the film, through the slit and the composite lens. The recomposed image is formed on a screen or it may be photographed.

Characteristics of Image Sampler - Line Displacement - O'Brien and Milne

Framing rate - 10,000,000 fps
Exposure factor - 1
Exposure time - 10^{-7} seconds
Frame sequence - 24,000
Picture size - 0.3 by 0.3 mm (equivalent size)
Picture resolution - 30 x 30 lines (900 points)
Focal ratio - 4.5 (estimated)

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