1978

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Recommended Citation

Davidhazy, Andrew, "Streak, strip and scanning photographic systems - an overview of historical and current technologies" (1978). Accessed from
http://scholarworks.rit.edu/article/448

What follows below is the text only of a manuscript that I started to prepare in the mid 1970s and which includes figures and illustrations and is laid out more clearly than what you see here but this is provided to give you a glimpse into what may someday come about as a complete publication. So, I hope you live with the shortcomings of this material and appreciate it for what it is ... or was, in 1978! I found the typewritten text as prepared by my secretary and recently (in 2003) OCRd it and that is how this version came to be today. It is given here with erros included so you will have to use a bit of ingenuity to figure out what some formulas mean. However, helpful suggestions are always welcome! Send to me at andpph@rit.edu
 - Andrew Davidhazy

Streak, Strip and Scanning Photographic Systems - an overview of historical and current technologies

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Although this manuscript concerns itself primarily with streak, slit, or smear or scanning recording, it is appropriate that the fundamental characteristics of a focal plane shutter be quickly reviewed in order to better understand a system that is basically patterned after focal plane shutter design and operation.

FOCAL PLANE SHUTTERS

Exposure

As is generally known, a focal plane shutter consists of a variable aperture slit passing in front of a stationary film. The assumption that photographs taken with this kind of a shutter are ³instantaneous² is only accurate to the extent that in the time frame of most common events, the real and measurable transit time of the slit from one side of the film gate to the other is insignificant. However, as events become short lived or if they assume a different shape in a short time or if the image of the event moves from one point on the film plane to another during the transit of the slit across the film gate then the focal plane shutter delivers a distorted reflection of reality.

This happens because it does not uncover or cover the whole film at the same time, or instantaneously, but it does so rather in a sequential manner.

(Figure 1)

Referring to Figure 1, the bold rectangle represents the film gate and C1 and C2 the leading and trailing curtains that make up the edges of the slit which travels across the film in a specific time primarily determined by such variables as spring tension, curtain inertia, etc. At T=2 the first curtain C1 has already exposed a short section of the film while curtain C2 is waiting for the specific length of time set on the shutter speed dial before it is released. At T=3 curtain C2 just starts to cover up those areas on the film which were first uncovered by the first curtain. At T=4 both curtains are moving across the middle portions of the frame while at T=5 the first curtain has reached the right edge of the gate and it remains for curtain C2 to complete the exposure by covering up the rest of the frame.

For a constant curtain velocity the exposure time is basically determined by the slit width. It is the length of time it takes the slit to move a distance equal to its width, or the time interval between the uncovering and covering of a given point on the film.

Efficiency

However, the effective exposure time of two shutters that have the same total exposure time may differ considerably. This difference is caused by variations in shutter efficiency. The efficiency of focal plane shutters depends on the numerical aperture of the lens in use, the width of the slit and the distance from the slit to the film plane.

As shown in Figure 2, these factors are related as follows:

A E = ------------- (d) A + ----- N

Where E = efficiency A = slit width D = slit distance from film N = f number of lens in use

When the slit width is just the same as the diameter of the cone of light from the lens reaching a point on the film, then the efficiency of the shutter is 50%. Decreasing the size of the aperture or increasing the size of the shutter slit achieves higher efficiencies. The slit width can be made larger for a given exposure time by increasing the speed of the curtains. Thus, fast curtain speeds contribute to increased efficiency of focal plane shutters, as long as the distance between the film and the moving slit remains the same. The nearer the curtains are to the surface of the film the greater the efficiency.

Finally, while for a pupil, diaphragm or leaf shutter total time is constant and effective time changes with aperture, just the opposite is the case for the focal plane shutter.

Distortion

Consider, as shown in Figure 3A, a focal plane shutter in which the slit (assumed here to very narrow) is moving from left to right at an even speed so that it is located at equidistant positions T1, T2, T3, and that the elapsed time between each position is the same. Then, the image of a horizontal bar moving upwards, also at a constant speed, will be recorded by the moving slit at positions L1, L2 and L3. Since the curtain is continuously moving across the film plane it successively records the image of the horizontal bar so that the final image appears as shown in Figure 3B.

If the bar had been moving at a constant speed but the slit of the focal plane shutter had accelerated, then the image would appear as in Figure 3C and if it had decelerated then the image of the bar which was straight as it moved up on the film plane would appear curved as shown in Figure 3D.

Conversely, if the shutter maintained an even velocity across the film plane but the bar accelerated as it went up the frame, the resulting photograph would appear as in Figure 3D and if it had slowed down as it went up it would look like Figure 3C.

(Figure 3) From knowledge of the vertical speed of the image across the film plane an estimate of the camera¹s shutter speed is possible. This is similar to using a television receiver as a shutter tester.

Conversely, the speed of the bar¹s image across the film plane can be determined if one knows the shutter curtain speed. Multiplying this speed by the camera¹s reduction factor gives the speed of the real bar in front of the camera. Without knowledge of the shutter slit speed this determination is impossible and even a guess as to the true shape of the bar as it crossed the field of view of the camera would be hard to make.

Further, consider the situation of a square object imaged at the film plane of a camera equipped with a focal plane shutter. When the square is at rest, the moving slit records the square with a height to length ratio of 1:1. Then, if as in Figure 4A the speed of the slit and the image are the same then either one long stretched out image with the correct height results on the film if the square was imaged on the slit as it moved across the frame or no exposure at all results if a portion of the square happened not to coincide with the position of the open slit at any one time. When as in Figure 4B the image of the square moves in the same direction as the slit but at one-half its speed, then by the time the slit reaches the point where the right edge of the square was at the time the slit first uncovered the left edge, the right edge will have moved a distance equal to one-half its length to the right. As the square continues to move to the right so does the slit and it finally catches up to the right edge of the square after it has moved over a distance equal to its original length, and therefore the image recorded on the film does not present the original 1:1 height to length ratio but a 1:2 ratio.

It is interesting to note that when the direction of travel of the image of an object with a height to length ratio of 1:2, as in Figure 4C is moving in a direction opposite but equal to the speed of the focal plane shutter then the object is compressed exactly by a factor of 1/2 so that now it appears to be as high as it is long. The alteration of the proper height to length ratio of an image by virtue of the motion of the image with respect to the moving slit can be determined from the following relationship:

$$\text{slit velocity ML} = \overline{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad} \text{ absolute speed difference between image and slit}$$

where ML is the amount the proper length of an image is magnified.

In this case it is assumed that the size of the slit is of negligible dimension.

Using the example of Figure 4D, the velocity of the slit is 1, the velocity of the image in the opposite direction is .5. Then, ML is 1/1.5, which makes ML equal to 2/3. This means that the proper image length is multiplied by 2/3 to arrive at the length of the distorted image (in this case the result is a compressed image).

Another situation is illustrated in Figure 3f where the motion of the image is at right angles to that of the moving slit. This results in the leading and trailing edges of the moving subject to appear slanted instead of being reproduced their proper relationship to the subject¹s other two sides.

Going further, if the subject is stationary but spins in place it will sequentially show a different aspect or edge view to the moving slit and may reproduce as a ³bow tie² as shown in Figure 3g.

The examples mentioned above assume that the curtains in a focal plane shutter travel at constant speeds as indicated by the equidistant positions of the slit in these diagrams. Unfortunately, this is not so and further distortion of a more complex nature is introduced into the final results by the acceleration of the slit as it moves across the film gate.

In summary, keeping in mind that moving objects are distorted due to the fact that focal plane shutters expose the film sequentially, it would be most questionable and almost impossible to make accurate real shape determinations of moving objects using cameras equipped with this type of a shutter.

The only reason that they are widely used in cameras is that they have many advantages that outweigh the possibility that images made with them might exhibit distortion. The reason that this distortion associated with focal plane shutters is generally not a problem is that the curtains in modern shutters move across the focal plane at a rate at least an order of magnitude greater than the rate at which most images move.

To see pictorial examples of what can happen when focal plane shutters move too slowly see the section on slit-scan photography discussed later in this book.

STREAK and STRIP PHOTOGRAPHY

Introduction

Streak, slit, smear or scanning recording cameras have two general features in common with focal plane shutter cameras. One is a slit shutter, the width of which can be varied to set a desired effective exposure time and the other is that recording takes place sequentially over a finite amount of time. The difference is that with streak/strip photography the slit shutter remains stationary and open all the time and sequential exposure is achieved by moving the film behind it at some desired speed.

Streak and strip recording cameras can generally be divided into two groups. The first of these, streak cameras, includes making of records of subjects that, without moving, change some characteristic that one wishes to track, and those that move in a direction parallel to the slit built into the camera. The second group, strip cameras, deals with the photography of subjects that move in a direction perpendicular to the slit and parallel to the direction that the film moves.

Streak Cameras

These include those cameras that have made streak recording a most useful tool in ballistics and explosives research. These are the high speed film streak cameras and the rotating drum and rotating mirror streak cameras. They are intended primarily to provide a record of subject image displacement along the slit vs. time. The film records provided by these cameras are valuable when subject velocity or change in velocity needs to be determined.

These cameras can also be used to study the duration of one or more events such as the total time a leaf shutter is open compared to the fully open time or to determine the frequency of repetitive phenomena, such as the rate at which a fan turns or the stitching rate of a sewing machine. They are also useful for determining whether events are simultaneous or not or the temporal discrepancy of events presumed to be simultaneous.

Scanning Strip Cameras

The second group of cameras, generally probably best referred to as ³strip² cameras because invariably the images they produce are on short strips of film, deliver real looking photographs of subjects by scanning their images over time. They record subjects that travel in a direction perpendicular to the camera¹s slit shutter and parallel to the film motion direction and in the opposite direction as the film is moving behind the slit. Because of the optical system in the camera subject motion is reversed and the image of the subject thus moves in the same direction as the film. These are by far the most numerous and ³common² of the lit equipped, moving film, cameras available. They take the form of high speed synchroballistic cameras, aerial photomapping cameras, racetrack photo-finish cameras, wide angle, panoramic, scanning cameras, peripheral cameras, and others.

Strip cameras attempt to present a stationary image with respect to the moving film, as would be the case if a focal plane shutter were to photograph a motionless subject. This is accomplished by moving the object in front of the camera in such a direction and speed that when its motion is reversed and reduced by the reduction factor of the lens in use, the image travels across the slit at approximately the same speed and direction as the film is moving behind it.

Velocity Recording and Time Resolving Streak Cameras

Moving Film Streak Cameras

High speed streak film cameras sometimes are modified high speed rotating prism motion picture cameras. They are very simple and consist of a film supply spool, a lens, a slit, a film take up spool and some method of rapidly moving the film from one spool to the other. See Figure 5. As mentioned earlier, these cameras are usually intended for the study of events that move in a direction parallel to (and their image on top of) the slit in the camera. If the motion of the film is horizontal then the slit generally aligned at right angles to it and thus is vertical. Therefore, its aperture usually restricts the horizontal angle of view of the camera to a couple of degrees or less and the camera responds only to subject position changes that occur along and upon the open slit. Anything else is not recorded and thus it can be said that streak cameras are one-dimensional cameras rather than two-dimensional ones as are normal instantaneous snapshots. That is, the latter have height and length. Streak photographs only have height or dimension along the slit aperture. Most importantly, however, photographs made with streak incorporate time as the second dimension.

In order to further explain the method whereby a streak camera makes a direct record of subject velocity consider the following: As shown in Figure 6 three vertical lines, A, B and C on a film are moving from right to left behind the slit, 5, or a streak camera. At the same time a horizontal bar^{1}s image, I, is moving up along the slit. The width of the slit restricts the films s view of the bar to a small horizontal section. As each portion or line on the film moves into position behind the slit, the upward moving image appears at a different height. Since the event is continuous, and, if the object and the film had a constant velocity then the resulting photograph of the event would show a straight line crossing the film from the lower edge to the upper.

The vertical displacement per horizontal distance unit on the film is directly related to image speed along the slit and film speed past the slit. In most high speed streak cameras an attempt is made to keep the speed of the film constant over a known period of time. Then variations in velocity of the image will appear to either bend the line up if the subject accelerates or curve it in a direction parallel to the direction of film travel if it slows down. The magnification or reduction of the camera lens has to be taken into account to make accurate velocity and acceleration measurements.

In Figure 7, for example, on illustration of a streak record of a projectile in flight, its image moved from bottom to top of a strip of film. It is known that the camera had a reduction factor of 100:1. Then, a distance, which is one foot in reality, will appear to be 1/100^1 on the film or .12^2 along the slit. This can be marked-off directly along the vertical axis. If the film moves within the camera so that 1/10^2 of film passes by the slit in 1/100 of a second, then the horizontal axis can be marked off in 1/10 inch increments, each corresponding to 1/100 sec. It is now possible to calculate the velocity of an object that moves along the slit at an unknown rate by direct measurements made from the film or from enlargements made at known magnifications.

Of course, if the film is marked up before enlargement then the system from there onwards becomes magnification independent.

From the data in Figure 7 the projectile appears to have moved at a constant speed along the slit since the line recorded by the camera has a constant slope. Its speed can be determined from the following formula:

$$V = \frac{\text{change in D}}{\text{change in T}}$$

Where V is velocity, D is real distance covered by the projectile and T is the time required to move the above distance. In this example the projectile¹s image moves from one edge of the film to the other or a total of 84 inches. Allowing for a camera reduction factor of 100:1 the real distance recorded is 7 feet.

Further, The projectile¹s image travels from one edge of the film to the other in 7/100 second. Therefore, since V = change in distance / change in time = 7 / 7/100 which is 100 feet per second. Any straight line that has a steeper slope than this one will indicate that the subject is traveling faster and lesser slopes indicate the object is traveling slower than this figure. This is, of course, assuming that the rate of movement of the film behind the slit remains constant.

Obviously, quantitative results or measurements require that one know or be able to determine accurately the rate at which the film is moving past the slit or the rate at which the image of the slit is wiped onto stationary film in rotating mirror cameras discussed later.

There are various methods of determining the rate of movement of the film but one of the most common is the inclusion within the camera of a neon or LED timing light driven either by the frequency of the AC line or by a separate timing light pulse generator. Since the interval between flashes of the timing lights is accurately known, then, if the distance between marks is constant as the film moves past the open slit the film it must also be moving at a constant speed. The actual speed is easily determined from knowledge of the frequency of the pulses and the distance between them. There are many other schemes for feeding and placing timing information on the film. These range from simple mechanical means to sophisticated electronic ones.

For all types of streak cameras the rate at which the film can be moved behind the slit, or the image of the slit can be wiped onto stationary film, is usually specified as the camera¹s minimum and maximum ³writing speed² given in feet/second or meters/second. The ability of a given camera to depict small changes in time is also a function of how narrow the slit can be made. The narrower, the higher the time resolution capability of the camera. Diffraction imposes a limit on the degree to which a slit can be narroWed. However, generally, the faster the film or image of the slit can be made to move the better the time resolution that can be expected from the camera or the higher the speed of any given event can be and still be able to accurately determine its rate of change.

In case that a camera¹s writing speed is not sufficiently fast for a particular application, it may still be possible to use the camera if the distance between the camera and the subject can be increased without altering the behavior of the subject. For example, the speed of a projectile can be measured over a distance of one foot or over a distance of 10 feet, but to achieve the same horizontal displacement, the camera photographing the projectile at one foot needs a 10-fold increase in film speed over the camera that does the photography at 10 feet. NEW: In other words, for a given subject velocity, decreases in camera magnification cause the slope of the moving image across the film to become less.

A NEW FIGURE GOES HERE

Moving film type streak cameras have to accelerate in order to reach a certain film speed past the slit and generally, speed or time between equidistant points on the film changes with time. Although such changes in film velocity will be indicated by changes in the spacing of timing markers on the film, this is mentioned here simply so that it is not forgotten that this possibility must be taken into account when measurements are made from the developed film.

Rotating Drum Cameras

When higher rates of film movement past the slit are required than can be achieved by simply pulling the film from one spool to another in order to achieve greater ³time resolution² to measure events which move at greater rates of speed, then cameras with different configurations are used.

Some of the most common of these are the rotating drum streak cameras. These are illustrated in Figure 8 and Figure 9. The drum type camera typically holds a length of film wrapped around the inside or the outside of a drum that can be rotated at high speeds. Since the diameter of the drum and its rate of rotation can be accurately set and measured it is a fairly simple matter to determine the rate at which the film is moving past the slit of this particular type of streak camera.

From here on the method of determining subject velocity is the same as that described earlier for moving film type cameras. The major limitation of drum type streak cameras is that the camera can only record events that generally last less time than it takes for the drum to go around once. That is, of course, unless it is possible to allow double exposure or ³rewrite². For example, photography of projectiles in flight can usually take place over more than one revolution due to the fact that probably the image takes up only a small portion of film along the length of the slit. Or, possibly because the moving edge of the object¹s image can usually still be interpreted properly in spite of double exposure. However, drum cameras usually are equipped with a secondary, ³capping² shutter, to prevent rewrite. However, inclusion of such a capping shutter causes these cameras to lose a major advantage in relationship to synchronization.

This advantage is that when they are employed to photograph self-luminous events they are inherently ³always alert² and ready to record the event at any random time as long as light can be excluded from the scene. This capability to respond instantly and without complex synchronization schemes or devices is unlike moving film type cameras or rotating mirror streak cameras that are discussed later. With these either the event has to be made dependent on camera operation or the camera made dependent on event occurrence.

A second advantage of drum type streak cameras is the very high lens aperture systems available. A major limitation is their relatively slow writing speed capability compared to rotating mirror types. This is primarily due to mechanical stresses built up in the drums and bearings.

Rotating Mirror Cameras

These are the highest speed film type streak cameras and their configuration is illustrated in Figure 9. In these cameras the film is held stationary in an arc at the center of which is located a mirror sometimes made of high strength steel or even beryllium. This mirror can be rotated at speeds in excess of 50,000 RPM. The mirror reflects an image of the slit aperture located in front of a relay lens onto the stationary film. The camera, because of the constraint of having to operate with a relay lens system has a very low effective aperture. Under most circumstances this type of camera is used with self-luminous phenomena. A capping shutter is invariably built into the camera and synchronized to the rotating mirror in such a manner that usually only one image sweep is allowed to reach the film plane. This allows photography of opaque, reflective subjects moving across a highly illuminated field such as by transmitted light as in a Schlieren system.

In order to increase the time resolving power or writing speed of these cameras, it might seem logical to extend the optical arm of the camera. However, this soon becomes an exercise in compromises. As the optical arm of a mirror type streak camera is increased the image gets dimmer. One reason for this is that for a given diameter objective lens the longer the distance between the lens and the film the smaller the effective aperture. Since, as the aperture is becoming smaller the image is moving faster, the combination of factors calls for dramatic increases in the illumination level of the subject and this eventually limits the design parameters to a set of compromise specifications. Another approach is to make the slit width narrower but this too results in loss of light, which is generally in short supply already.

While drum type cameras are always alert, rotating mirror cameras have to be synchronized with the event to be photographed and elaborate electronic devices are built into the camera to sense the rotational speed as well as the instantaneous position of the mirror so that the time delay between event initiation and beginning of event image sweep over the 900 or so available for recording to occur at the appropriate instant.

WHAT IS THE END OF THE ABOVE PARAGRAPH ABOUT????

A number of refinements to the basic rotating mirror camera have been developed. These improvements include longer recording times made possible by imaging onto stationary film held around the inside circumference of a drum. The principle of operation and analysis, however, is the same as that used for linearly moving film or drum type streak cameras.

Timing Applications of Streak Cameras

When high speed streak cameras are not employed to photograph the linear velocity of objects then one of their most common applications is the determination of the temporal duration of an event that does not suffer from being reduced to a single dimension. Of course, this type of information is automatically recorded along with velocity information and it is only mentioned here to clearly specify that these cameras are used for event duration as well as event velocity investigations.

A common application of streak cameras in these combined roles is in the photography of spark gaps or exploding wires, Figure 10A, or something as familiar as the operation of leaf shutters, Figure 10B, or focal plane shutters, Figure 10C.

Streak cameras can also be used to photograph rotating objects to determine rotation rates, Figure 10D, or other cyclic events such as the up and down motion of sewing machine parts to determine the frequency, the speed and the direction of motion of the various components.

Streak cameras are not suitable for the photography of events that are erratic in their position or direction of motion. This might be an event such as the measurement of the speed of collapse of a bursting balloon.

Summary

The inherent advantage of a drum type streak camera is the fact that large aperture optical systems are readily available and that for self-luminous events the camera is always alert and ready to record the event. The advantage of spinning mirror streak cameras is that high writing speeds are easily attainable. Both cameras suffer from the short length of time during which recording can take place and thus the advantage of a moving film type camera is the relatively long time over which the camera is accessible to new information and the fact that capping shutters are not needed since the film only goes past the slit once.

STRIP CAMERAS

The second major group of streak cameras is by far the more numerous and we will deal with each application separately. They can, however, be grouped into five distinct categories: cameras which determine the speed of a moving object e.g. synchroballistic cameras; cameras which measure the arrival time of objects at a particular point and cameras which are stationary while recording a moving subject e.g. photofinish cameras and microfilm copying cameras; cameras which take photographs of motionless subjects but which introduce subject motion by moving the cameras, e.g. aerial mapping cameras; cameras which take wide angle or panoramic photographs and, finally, cameras intended for peripheral photography. Enlargers that are used to print streak photographs are designed after a combination of features found in most of the above five camera groups.

As explained in earlier detailed descriptions of the operation of a streak camera, the direction perpendicular to the orientation of the slit is the time axis and the axis parallel to the slit is the distance axis. Velocity recording streak cameras are used to make measurements of subject image velocity along the slit based on measurements of displacements along both these axis.

Synchroballistic Cameras

There is a way to measure subject velocity and to gain an understanding of its behavior as well by a method used primarily in ballistics research known as synchroballistic photography.

In this application the object¹s image crosses the slit shutter perpendicular to it and in such a way that its direction and speed approximate the speed of the film past the slit. The situation is analogous to a focal plane shutter making an exposure of a stationary object or one which is moving in the same (or opposite) direction as the moving slit.

Consider a situation as in Figure 11 in which the image of an object with a height to length ratio of 1:1, a square, moves at a constant speed across the slit of a streak camera. Further, assume that the speed of the film past the slit is also constant and exactly matches the speed of the image. Then, a specific point of the image will remain fixed on a particular point on the film as the two pass by the slit. As far as the film was concerned, the image was stationary during exposure and this condition renders a photograph that shows the subject having a known height to length ratio with exactly the same ratio on the film. Therefore if a photograph is made of an object the height and length of which are known but the speed of which is in question and a streak photograph taken under the above conditions shows the image to have the original¹s height to length ratio, then the conclusion is that the image of the subject and the film were traveling at the same speed Then, by simply accounting for the reduction factor of the lens system in use the true speed of the object as its image crossed across the slit can be made as follows.

Image Speed x Camera Reduction Factor = Subject Speed

For example, if the film is known to travel at 100 feet/second and that the lens has a reduction factor of 40 and a square subject appears square on the film, by simply multiplying 10 feet/second times 40, the speed of the object is determined to be 400 feet/second. With this method, the measurement of subject speed can be reliably determined and at the same time a ³real² looking image of the subject is recorded. Obviously, when making a record in this manner the assumption is made that the shape of the object has not changed while it is in front of the camera compared to its shape at rest.

Determinations of rotation of the subject while under way can be made by marking it with something as simple as a horizontal line and carefully noting its shape on the streak photograph. A curved record of a straight original line indicates that the subject was rotating in flight. Rotation rate can be estimated by noting the number of degrees displacement per unit of time.

The method even works fairly well if the subject has some motion component other than one strictly perpendicular to the slit, but then the horizontal shape of the subject will appear to be distorted.

Even when the resulting photograph does not match exactly the height-to-length ratio of the original object, a good determination of its speed can still be made by correcting the known film speed by a factor arrived at as follows:

SL Œ~ x Film Speed = Image Speed (correct this so it is right)

The subject length, 5L¹ is divided by its height, 5H¹ and the resulting number is multiplied by the number resulting from dividing the height of the image, ŒH¹ on the film by its length, ŒL~. This is the correct factor to use for multiplying the known film speed past the slit to determine the unknown image speed. When this is then further mu1tiplied by the reduction factor of the lens system, the true speed of the object in front of the camera can be calculated.

In the example in Figure 11B, the image is moving at an unknown speed, but analysis of the photographic record shows that the recorded image of the subject has a height to length ratio of 1:2 while the original¹s ratio was 1:1. The known speed of the film past the slit is 10 feet/second while the optical reduction factor of the system is 40. Subject length divided by height is 1, and image height divided by image length is _. Then, the correct factor to use is _ and the speed of the original subject is the film speed multiplied by the correction factor and further multiplied by the optical reduction factor: 10 feet/second x _ = speed of image x 40 = speed of object which is equal to 200 feet/ second. When the image of an object is traveling across the slit at a speed slower than the rate at which the film moves behind the slit, the original¹s height to length ratio will appear to be extended while if the image travels faster than the film, the height to length ratio of the original object will appear to be compressed. The magnification of the length of any subject photographed by these cameras is directly related to the ratio of the speed between the film and the image, as follows:

Length Magnification = Film speed / Image speed

Determinations of speed are irrelevant of the direction of the subject¹s motion if the slit is very narrow since horizontal dimension then is only dependent on slit transit time. The only differences between an object which moves in the opposite direction rather than the same direction is, one, that it will be less sharp since image points traveling in a direction opposite to that of film travel are exposed on different film points over the time it takes them to go from one side of the slit to the other and two, that the image will appear reversed from left to right compared to the original subjects orientation. The first effect can be minimized, but not eliminated, by making the slit as narrow as possible thus making the total exposure time for a point on the film as short as possible, but the reversal in subject orientation is inherent to the system.

This is caused by a reversal in the order in which subject image points are recorded compared to the order in which they are recorded when image and film are moving in the same direction. As shown in Figure 11C when the film and image move together the arrowhead is imaged and recorded first and thus the film record shows the arrow as it was on the original subject. When, as in Figure 11D, the film and image move in opposite directions the arrowhead is still recorded first and its record has been moved by the film past the slit edge by the time the tail is recorded. This yields a film record in which the arrow orientation is reversed as compared to its orientation on the original subject.

Generally, exposure time for streak cameras is the reciprocal of the slit width in mm. divided into the speed of the film past the slit also in mm. or, in other words, the time it takes the film to move from one edge of the slit to the other. Efficiency depends, just as with focal plane shutters, on the numerical aperture of the lens used, the slit width and the distance between the slit and the film or image plane. It is not unusual to find that with very narrow slit widths some streak cameras operate at efficiencies close to 50%.

When the absolute speed difference between film and image is zero the subject appears as sharp as possible. When the image moves faster or more slowly than the film but in the same direction, the motion stopping ability of the slit shutter can be increased by reducing the slit width to produce a shorter total exposure time. When the image moves in the opposite direction to that of the film a much greater reduction in slit aperture is needed to achieve the same degree of sharpness. For example, when film and image travel in the same direction at 9 cm/sec. and 11 cm/sec respectively their absolute speed difference is 2 cm/sec. and an exposure time of, let¹s say, 1/100 second produces a blur of 2/10 mm. in the image. When the image moves in the opposite direction, however, the speed difference between the two is 20 cm/sec., thus a 1/100 sec. exposure would yield a 2 mm. blur in the image. The slit size has to be reduced to yield an exposure time of 1/1000 second in order to reduce blur to the same degree as when the film and image move in the same direction.

When streak cameras do not achieve fast enough writing speeds, electronic imaging devices that scan an area in a manner similar to streak cameras but at a much faster rate are used. These electronic cameras can exceed writing speeds of 100 inches/microsecond and have become invaluable tools, particularly in explosives research.

Elapsed Time Cameras

With synchroballistic cameras the objective is usually to determine the speed and attitude of an object traversing a particular area in space.

Low speed applications of this same system generally are intended to determine differences in the time of arrival at a particular spot of a number of objects. A particularly good example of this type of camera is the photofinish cameras in-stalled at most racetracks.

Although their basic operation is the same as that of synchroballistic cameras described earlier, photofinish cameras have been misunderstood by most laymen and even many photographers so we will review their operation here.

A photofinish camera, shown in Figure 12, consists of a film supply chamber, a take up chamber, a vertical slit (the leading edge of which is lined up with the edge of the finish line on the racetrack) and some means of transporting the film at an even speed behind the slit. In addition to these requirements most of these cameras have rotating segmented shutters included near the edges of the film that record the position of the finish wire as a series of vertical lines. The distance between these lines corresponds to a known time interval for a particular rate of rotation of the shutter in the camera. Some cameras have independent timing lights incorporated to establish elapsed time between edge markings.

Referring to Figure 12, as the horses approach the finish the camera operator sets the film in the camera into motion. When the first horse crosses under the wire, its nose is the first part to be recorded by the camera. As the image of the horse¹s nose moves across the slit it does not move with respect to the area on the film that first recorded the nose since the speed of the film is made to closely match the average speed of the image of the horse across the slit. After the nose, sequentially, the rest of the horse is recorded onto the moving film. By the time the second horse¹s nose arrives at the finish wire, the image of the winning horse¹s nose or length is already recorded on the film and its recorded image has moved away from the slit.

Again, referring to Figure 12E, horse number eight has not arrived at the finish wire by the time number five¹s nose is starting to be imaged on the moving film and should it eventually not cross under the wire, the photofinish camera will not show that horse number eight was ever a participant in the race.

The horizontal axis in a photofinish record is interpreted directly as elapsed time between the orders of arrival of the horses. If the speed at which the film is moved within the camera is not exactly constant the photofinish camera still accurately indicates the order of finish although the horses might look distorted at various points along the film. Measurements of elapsed time between the order of finish of the various horses can also be obtained independent of the rate of movement of the film with reasonable accuracy as long as the time base generator, whether segmented shutter or timing light, is delivering accurate timing marks on the film edges.

Photofinish photographs cannot be interpreted as ³real² since the horizontal dimension does not correspond to ³width² as in a snapshot but rather to ³time.²

When viewing a photofinish picture it should be remembered that the

³finish line² seen in published prints is added after the fact for measurement purposes only and most of the time simply for esthetic reasons since the fans expect to see a finish line.

It is interesting to note that pictures for first, second or third place all show the horses in the same position except that the ³finish line² has been moved to just touch the nose of the first, second or third horse. See Figure 13A,B, C.

This further emphasizes the fact that in a photofinish print the finish line is not any particular line, but that any vertical line from one end of the print to the other is the finish line. Another way of saying this would be to refer to the whole print as a record of the finish line.

In order to preclude the possibility of one horse covering up the order of arrival of another situated further away from the camera, a mirror is placed on the opposite side of the track from the camera. In this manner the camera records the horses, as they cross the finish line, from both sides. The mirror image can usually be seen on the top quarter of the photograph.

Another useful variation of this technique is in the microfilm-duplicating field. The duplicating streak or more generally known as strip camera is aimed at a moving stage upon which are placed the documents to be recorded. The speed of the stage is adjusted to equal the film speed in the camera multiplied by the camera reduction factor. For example, if the film moves in the camera a 10 ips and the subject is being reduced by a factor of 10 then the stage is adjusted to provide a speed of 100 inches per second. The reason for a constantly moving duplicating system is the speed with which copying can be performed since nothing has to come to a halt and as long as images pass in front of the camera¹s lens the moving film will record them. The system is particularly suitable for applications where a very large number of originals need to be microfilmed in a short period of time.

Aerial Mapping Cameras

In a photofinish camera the camera and, therefore, the position of the slit in space are stationary. When the camera is set in linear motion then the area that the slit in the camera is responsive to continually changes. Cameras that employ this variation of strip recording are primarily aerial photomapping cameras. The optical geometry of this type of a camera is not unlike that of duplicating cameras and is described in Figure 14. The camera is aimed at the ground so that the orientation of the slit is perpendicular to the direction of motion of the airplane. Aerial cameras are usually focused at infinity since the distance between them and the ground is so great. Once proper altitude is achieved by the plane the film in the camera is set in motion in the same direction that of the airplane and at a speed which is determined by the ground speed of the airplane. The proper speed of the film is determined by:

$a=A$

Where A is the subject speed past slit or the ground speed of the plane

R is the reduction factor of the optical system a is the film speed past slit

In aerial photography the appropriate film speed in inches per second for a particular mapping mission would be determined as follows:

Film speed =

ground speed(mph) x 5200(ft/mile) x 12(inches/ft) = 3600 sec/hr x camera reduction

Therefore, if the optical system of an aerial camera has a reduction factor of 10,000 and the plane is flying at 600 mph, the film has to be adjusted to run at:

a = 600 x 5280 x 12 = 1.056 inches per second 3600 x 10,000

In practice most aerial cameras of this type have an electronic interlock between the planes¹ ground speed measuring system and the rate at which the film moves in the camera so that changes in the velocity of the plane over the ground will immediately alter the speed of the film within the camera and sometimes also change the lens aperture to maintain the same effective exposure throughout the film run. Changes in altitude are generally ignored because at large overall distances from the ground the change in the reduction factor of the lens hardly affects the rate at which the film speed has to be changed in order to maintain the proper imaging characteristics of the camera.

One of the most famous strip photographs of this kind was a photograph made in 1957 by the Air Force in which a continuous record of the U.S. was made in less than three hours of a strip of land 20 miles wide by 3,200 miles long extending from New York City to Los Angeles.

A novel application of this linear motion streak technique is its use in recording subjects at a closer range. A case in point would be the photography on one piece of film of all the homes along a street or a row of cars parked in a lot.

Consider, as in Figure 16A, the situation where a single camera is first used to record instantaneously the appearance of a number of cars lined up in a parking lot, and then the appearance of the same subject made with a moving streak camera.

In the instantaneous record the sides of cars off the optical axis are clearly visible. The marker lines between cars become obscured by the cars off to the side. The cars located behind the first row appear smaller. Parallel lines converge towards one point. These are direct consequences of the photograph obeying the rules of perspective.

When a linearly moving streak camera records the same subject it instantaneously records only that part of the total subject that lies on the axis established by the slit and lens. Since the slit limits the horizontal view of the subject only a small vertical segment is recorded at any particular time. As the camera is, however, moving these individual segments are continuously recorded and the final record appears as in Figure 16B. In this photograph there are no sides of cars visible. The marker lines between cars are all clearly visible. These parallel lines moving away from the camera do not converge, however. The cars located behind the first row appear as tall as in the previous instantaneous record but they are just as wide as the cars in the front row. This is caused by the camera responding to changes in subject distance from the camera as changes in magnification. However, subject length is recorded only as a function of film speed past slit and image speed over the slit. That is, a 10 foot long subject will appear the same length on the film regardless of distance from the camera.

The camera thus can only properly render the height to length ratio of an object at one specific distance from the camera At other distances the original ratio will be expanded if the subject is further away than the distance the film speed is set for and at closer distances objects will have their ratio compressed.

Thus, linearly moving streak cameras eliminate perspective clues in a direction parallel to that of film travel. If a strip camera with a vertical slit moves horizontally, then the photographs will lack horizontal perspective.

In order to determine the speed at which the streak camera must move in front of a stationary subject to photograph the subject so that the image on the film will retain the original¹s height to length ratio, the following tables and equations are

used. They are given to help in quickly relating to each other the parameters of camera to subject distance, optical reduction, rate of film movement in the camera and speed of the camera past a stationary subject or of the subject past a stationary camera. These tables are particularly useful applied to ³home² built or modified equipment described later.

Table 1 – Approximate speed in mph the camera must move past subject or subject past camera when camera reduction factor and camera film speed are known.

REDUCTION Factor of lens	100:1	200:1	300:1	400:1	500:1	1,000:1	10,000:1	
Film speed in camera in inches/sec								
.125	.7	1.5	2.2	2.8	3.6	7	70	Speed of camera
.25	1.5	2.8	4.5	6	7	15	150	Past subject or
.5	2.8	6	9	12	15	30	300	Subject past
1.0	6	12	18	25	30	60	600	camera in MPH

For reduction factors and in camera film speeds not given above the required camera speed past the subject is given by the following formula.

$A = .057 Ra$

Where A = Camera speed in miles per hour past subject or subject speed in miles per hour past subject

R = reduction of lens a = speed of film in camera in inches/second

.057 = constant relating inches per second to miles per hour

This equation is a simplified form of the one given earlier for determining the ground speed of a plane doing aerial mapping.

As is evident from Table 1, the greater the reduction factor of the lens being used to photograph and the greater the speed at which the film is pulled past the slit in the camera, the greater the speed of the camera past the stationary subject in the case of aerial or similar photography or the greater the speed of the –subject past the camera must be in applications such as microfilm copying or photofinish cameras.

Since most calculations used with strip cameras include the reduction factor of the camera lens being used the following table is given to quickly indicate the reduction factors achieved with various common lenses at specific distances from a subject.

Table 2 – Distance in feet from camera to subject with various lenses for specific reduction ratios.

REDUCTION Lens Fl	100:1	200:1	300:1	400:1	500:1	1,000:1	10,000:1	
7.5 mm	2.5	5	7.5	10	12	25	250	Distance
20mm	6.5	13	20	26	33	66	660	in feet
35mm	11	22	33	44	55	110	1100	between
50mm	17	33	50	66	83	170	1700	subject
200mm	65	130	195	260	325	655	6500	and camera

For lenses and magnifications not given above approximate camera to subject distance for desired reduction factor with a known focal length lens is given by the formula:

R (D – fl) x 305 ilL

Where R = reduction desired D distance from lens to subject in feet focal length of lens in use in mm.

305 = constant to convert distance from mm to feet Sometimes it is impossible to measure the distance from camera to subject but a good approximation of subject height can be made. For this case the reduction factor of the lens being used can also be estimated as shown in the following table and equation.

Table 3 - Height of subject that will be 24mm high (the image height using 35mm film) at certain subject reductions regardless of lens focal length used.

	100:1	200:1	300:1	400:1	500:1	1000:1	10000:1
Subject height in feet	8	16	24	32	40	80	800

Camera reduction factor	100:1	200:1	300:1	400:1	500:1	1,000:1	10,000:1
Subject height in feet	8	16	24	32	40	80	800

For reduction factors not included in this guide, the approximate subject height that will just fill a 24 mm high frame is given by the following equation.

$H= .08R$

Where

H = subject height in feet

R = reduction

.08 A constant relating frame height in nun to subject height in feet

In most technical applications it is desirable to keep the direction and speed of film and image coincident and the slit perpendicular to the edge of the moving film. However, when the slit is not perpendicular to the film motion and the film and image move parallel to each other but their speeds are different then the shape of the resultant image will appear slanted to the right or left depending on the slit slope and the difference in speed between the film and the image.

Assume that, as shown in Figure 17, the slit in the streak camera is inclined at an angle of 45 degrees to the direction of travel of the film, the film moves at an even speed past the slit and the vertical subject¹s image moves at _ the film speed. The moving image arrives at the slit and starts to be recorded at the bottom edge of the film first. As the image of the bar pro-gresses from left to right the portion of it which the film records progressively moves towards the top edge of the film. At the completion of its transit from point T1 to point T2 the recording of the bar is complete. Since in the same length of time the area on the film which first recorded the arrival of the image has moved twice as far to the right as the bar¹s image, the resultant record appears as a diagonal line with a slope exactly opposite that of the slit in the camera.

The resultant slope of the image for a given slit slope is determined by the following equation:

1= S 5

S ~ (~)

Where I~ ‹S ‹S

Iv resultant image slope slit slope film speed past slit image speed past slit

This indicates that when film and image speed are the same, verticals in the subject will appear vertical regardless of the slope or shape of the slit. However, when speeds are unequal, then the faster the image speed in relation to the film speed the more closely the image slope will tend to match the slit slope.

Another case occurs when subjects which are vertical and which are photographed by a camera moving in a linear fashion but in such a manner that the slit is not parallel to the vertical subject, then these originally vertical subjects will appear inclined in the photograph recorded by the camera. A good example of this would be a streak camera mounted in a car with film parallel to the motion of the car attempting to photograph build-ings built along a street going up or downhill.

Conversely, if the slit and the camera are made to be vertical in the above example, thus matching the building orientation then horizontal features on the ground, such as rooftops, will appear inclined. The horizon line in each case would, however, remain horizontal and parallel to the film edge. See Figure 18A, 18B.

Changes in the shape of the slit present another avenue for creative experimentation and technical control. S shaped slits, offset slits, double slits and other shapes and combinations can be constructed to achieve a variety of effects. Along with changes in slit shape, changes in slit width provide yet another dimension for the creation of unusual images.

As long as the distance from one edge of the slit to the other in a direction parallel to film motion remains the same, exposure time from one edge of -the film to the other will also be the same and consistent. Exposure time then is determined by the transit time for a given point on the film across the slit. However, when slit width is specified as the perpendicular distance between the edges, then exposure time is dependent on this distance and the angle of the slit at any point with respect to the direction of film motion.

Exposure time for inclined slits is determined by the follow-ing relationship:

DE=VE 1 sin a Where: DE = exposure time with inclined slit

V ~e Exposure time when same size slit is perpendicular to film travel a = angle at any point between slit edge and direction of film travel

From this equation it can be determined that a curved slit where the perpendicular distance between edges remains constant will produce uneven exposure from one edge of the film to the other.

The second way of specifying slit width, and the easiest to make, does not yield changes in exposure in a direction perpendicular to film motion. This kind of slit is made by drawing the desired shape on the opaque slit material and cutting the two pieces apart along the drawn line. Then the two are separated exactly the amount one desires the slit width to be. Since this automatically causes the perpendicular distance between the two edges to change according to the angle of the slit and thus maintains the horizontal distance, or the one parallel to film travel, the same, exposure remains the same from one edge of the film to the other.

Panoramic Cameras

Streak photography is particularly useful in applications requiring wide-angle pictures due to the sequential exposure nature of the system. The camera placed on a turntable or other rotating support is turned in a direction perpendicular to the slit orientation and opposite to that of film travel. In general the axis of rotation of the-camera, should be around the rear nodal point of the lens. In more practical terms, it can be between the lens and the slit or even behind the slit. It should not be wound a point in front of the lens. These cameras resemble the moving lens and moving slit with stationary film panoramic cameras such as the Widelux and the old Kodak ³Cirkut² panoramic cameras made specifically for photography of large groups of people. See Figure 19.

The wide angle scanning strip camera is shown diagrammatically in Figure 20. The lens on the camera determines the vertical angle of view of the camera, or the angle parallel to the orientation of the slit. The lens in use in turn determines the length of film which must pass by the slit for every complete revolution, or every 360 degrees perpendicular to the slit, (or portion thereof if smaller than full panoramas are desired) recorded by the camera.

Assuming that the film frame is the normal 35mm film gate aperture, then the vertical angle of coverage of the lens is first determined from manufacturer-supplied data, from available tables or mathematically determined. The vertical angles of coverage for six common lenses on a 35 mm camera are given below:

7.5mm Fisheye	180 degrees
20 mm	65 degrees
35 mm	37 degrees
50 mm	26 degrees
100 mm	13 degrees
200 mm	7 degrees

The vertical angle of coverage of any lens for the short dimension of the 35mm format can be approximately determined by dividing the focal length of the lens into 1300.

The exact vertical angle of coverage for non-distorting lenses is given by the following formula.

Optical L = 2 tan1 (24)

From knowledge of the time it takes the camera to turn a full revolution, the amount film that must be advanced in the streak camera in the same time can be determined as follows:

(H x 24 Film required for 360 degree coverage (V

The vertical to horizontal angle of coverage ratio must first be determined and then multiplied by the height of the frame. For example, assuming that a 35mm panoramic streak camera will be using a 35mm lens, then the vertical angle of coverage, 37 degrees, divided into 360 degrees (which will be the horizontal angle), is 9.7. Then, since the 35mm camera has a frame height of 24mm and it is for this frame height that the angles of cover-age are given, 24mm is multiplied by the previously found factor to arrive at a required length of 233x~im. Therefore, if the camera turns at the rate of one revolution every ten seconds, then the camera must advance 233mm also in 10 seconds, or 23.3mm per second, in order for the photograph to appear as a correct panoramic representation of the subject surrounding the camera. In actuality this would be the length required regardless of the film size used as long as the lens remained the same.

It is appropriate to mention here that while the above discussion seems make sense it is not the most appropriate method for determining the amount of film required for a 360 degree panorama. For most practical purposes the amount of film required is equal to the circumference of a circle whose radius is equal to the focal length (or image distance if the lens is focused on a nearby subject). So, the required length is simply:

2 x f x pi or about 6.28 times the focal length of the lens

For coverages less than the full 360 degree panorama a fractional amount
is required that reduces the above amount by the number of time the angle of coverage fits into 360 degrees. A discussion related to the difference between the two methods will be included here.

Generally, when taking panoramic photographs it is important to keep the axis of rotation of the camera vertical. If the camera does not rotate around a vertical axis the horizon line will appear to be higher at one point of the panorama than at the opposite point along the 360-degree circle. Tilting the camera down or up will just raise or lower the horizon line.

If the camera is tilted from left to right, then the only effect will be that vertical subjects will appear to be tilted in a direction opposite to that of the camera tilt.

The primary disadvantage and difficulty with wide-angle photographs made with streak panoramic cameras is the large length to height ratio that is usually inherent to them.

For example, if one wishes to see a print of a complete 360-degree view in which the vertical angle is 37 degrees (taken by using a 35mm lens on a 35mm panoramic camera) the height to length ratio of the print must be 1:9.7. This means that if we wish to make the vertical dimension of the print 10 inches, the print would measure over 8 feet in length. When a 200mm lens is mounted on the camera the ratio is 1:52 and a 36-exposure roll would cover slightly more than a full 360-degree panorama.

The advantage of using a long focal length lens for wide-angle pictures is that objects at a distance can be recorded over a wide horizon angle, such as in photographs of boats or mountains, without including a large amount of foreground or sky. Photographs taken this way may be more economical since the camera essentially becomes a large format camera but only uses that part of the film that is really useful. Panoramic distortion is evident when a wide-angle photograph taken with these cameras is viewed as a flat print. All horizontal lines in the original subject appear curved towards the horizon line of the final flat photograph.

A practical way of looking at these photographs and eliminating panoramic distortion is to place the viewer at the center of the photograph, essentially assuming the position of the camera at the time the exposure was made. Thus, the photographs become self-correcting in terms of ³panoramic² distortion. See Figure 22.

When viewing sections of a 360-degree view, as long as the curvature remains the same as that which the complete view would have had and the viewer is looking at the print from the center of curvature, the print will have proper perspective and appear essentially distortion-less. Photographs made with a regular camera of this print from the center of curvature appear exactly the same as if the picture had been taken of the original subject regardless of the focal length of the lens used on either the panoramic camera or the copy camera.

It is interesting to note that if a panoramic camera is used for architectural photography tilting the camera up in order to take a whole building will not result in the building appearing to ³fall backwards² as when a regular camera is tilted for this purpose. Instead, the camera will automatically correct for this kind of distortion at the expense of some loss of sharpness in some portions of the pictures. Making the slit size narrower can minimize this. The reason for this is that as explained earlier the camera records equal angular displacements as equal distances along the film. Since the slit is vertical with respect to the direction of movement of the film every vertical line in the subject will appear vertical on the film. The camera only records one vertical portion of the subject at a time.

Since the edges of a vertical building are vertical the streak camera will record each edge as such when the slit arrives at each edge of the building. Therefore, since both sides are recorded as vertical lines the building appears not to be tilted backwards. See Figure 23. However, since the top of the building is farther away than the bottom it will be ³stretched out² by the streak camera. The stretching out and blurring are caused by the fact that there is a real speed difference between the rate at which the bottom part of the building goes by the slit and the rate at

which points near the top go by the slit. Because the streak ~camera can only accommodate one particular image speed properly, and that is the one which matches the rate of film travel past the slit, any image point moving at a different rate will suffer from blurring due to relative motion between image and film while in transit over the slit aperture.

The fact that the top of the building appears curved is caused by panoramic distortion, which as discussed earlier, causes parallel horizontal lines in the subject (perpendicular to slit orientation) to appear to curve towards the horizon when the panoramic photograph is viewed as a flat print.

In order to photograph ³everything² surrounding the panoramic camera, a fisheye lens could be attached to it. Since this lens has a 180 degree coverage along the diameter of the circular image lined up along the slit, and the rotating streak camera takes care of the 360 degree horizontal coverage, the resulting photograph covers 180 degree vertically and 360 degree horizon-tally and that should include everything surrounding the camera. See Figure 24.

This image, however, suffers from pronounced distortion along the top and bottom. It is essentially the same kind of distortion that is evident in Mercator projections of the globe. This causes equal horizontal angular displacements along the poles (top or bottom) and the equator (middle of photograph) to record as equal distances along the horizontal axis of the photo-graph. Since this is not the case in reality, the circumference of the sphere being shorter at the poles of a globe than at the equator, in this kind of wide-angle photograph there is consider-able blurring along the top and bottom of the image.

The blurring and distortion are caused by the large angle of view of the fisheye objective. It is not experienced when narrower angle of view, rectilinear, lenses are used and as long as the camera is kept level.

A special situation occurs if a camera equipped generally with a very wide-angle lens is tilted so that the angle of view of the lens extends beyond the axis of rotation of the camera. Then the lens delivers onto the slit an image that includes subjects both in front of and behind the axis of rotation of the camera and the camera will make a graphic record or interpreta-tion of INFINITY. See Figure 25A & B. That is, if infinity can be defined as the distance at which the poles of a sphere are projected when its surface is tangent to the inside of a cylinder and the sphere¹s polar axis is coincident with the axis of the cylinder.

Photographs taken under the above conditions show extreme blurring along the ³infinity line². The records of objects located behind the axis of rotation appear upside down and 180 degrees out of phase with their own records when located in front of the axis of rotation. Left to right image reversal is also evident.

Peripheral Scanning Cameras

Panoramic cameras take 360-degree photographs while looking out at a subject. They can be turned inwards to take peripheral or 360 degree photographs of the surface of a subject. Usually these peripheral cameras find application in archeological studies (generally known as cyclographs), piston and cylinder wear records and in forensic photography for rifling comparisons of bullets.

The main reason for anyone wishing to make a peripheral photograph is the desire to be able to see all sides of a subject at once on a flat piece of paper. It is far easier to mail a photographic record of all sides of an object than to mail the original three-dimensional object, especially when it is large or valuable.

Basically there are two ways of making peripheral photographs. The first is analogous to taking pictures of a moving subject with a focal plane shutter. This method is particularly useful with a restricted range of subjects that are mostly cylindrical in shape.

Although the method is widely used it is somewhat more difficult to execute properly with improvised equipment than the second method discussed in detail later.

The camera, usually of a 1arge format, 4x5 or 5x7, has a focal plane shutter consisting of an adjustable width slit which can be made to move across the film plane in synchronization with the image of a rotating subject placed in front of the camera. This can be accomplished by a set of pulleys and belts. Figure 26. As was explained earlier, if a subject¹s image moves at the same speed and direction as the slit in a focal plane shutter camera the image will be spread out over the whole frame. The one variation by which the peripheral camera prevents this from happening is that while the subject moves across the field of view of the lens it 4so rotates. Therefore it presents a different subject area to the film while the moving shutter sequentially uncovers the film. The camera is set up so that a little over one revolution of the subject in front of the camera will be recorded over the width of the film plane.

There are at least two factors that must be taken into account when round objects are photographed by this camera. First, one must make sure that one revolution of the object can be properly accommodated onto the available film surface. For this, the subject¹s height to circumference ratio is first deter-mined and the camera is set at such a distance from the surface of the object that the height to length ratio of the subject matches the height to available frame width of the camera.

Second, the subject cannot exceed certain circumference and height specifications because of the mechanical interlocking between the moving rotating subject stage and the camera. The one advantage of this system is that the image is recorded onto one piece of sheet film.

Unusual photographs can be taken with a camera of this kind when applied to subjects not moving at the same speed or direction as the moving slit. When the shutter scans vertically, a vertical rotating subject will appear as a corkscrew The top of the photograph may show one side of the subject and so may the bottom, but points in between will be intermediate views including the back view at the middle of the photograph. Placing the slit in front of the camera and opening the shutter of the camera can simulate a slow moving slit at the focal plane. Thus the film will only be exposed as the slit traverses through the angle of view of the lens. Figures 27A and 27B.

The second method of taking peripheral photographs is by far the most practical and it lends itself to the greatest variety of applications.

The only requirement beyond a variable speed scanning strip camera is a turntable, also variable in speed if possible.

The essentials of the system call for the slit, lens and turntable to be lined up along the same axis so that the axis of rotation of the turntable falls directly onto the slit in camera.

Obviously, for most applications a vertical slit will be used. Thus, the surface of the turntable will be horizontal. The turntable should turn at an even speed and its size should be appropriate for the subject it will be holding.

There is a direct relationship between turntable speed and speed of film past the slit. They are essentially related by the magnification of the optical system. Thus, knowing the surface speed of the object on the turntable and the reduction factor of the lens on the camera the speed at which the film must move past the slit can be determined from the following formula:

.4

Fv= Sv

4

Where Fv = film speed past slit in camera R = vertical reduction factor

Sv subject surface speed (circumference x RPS of turntable) Subject surface speed in inches per second is given by multiplying the subject circumference in inches by its speed in revolutions per second. Then, dividing this speed by the optical reduction factor of the lens, the speed at which the film needs to be moved past the slit is determined. From here on it is simple matter of dividing the slit width in inches by the Li speed in inches per second to arrive at the exposure time Lion¹ that particular transit rate of the film. A standard light meter reading is taken of the rotating subject and the f-stop is ad-justed to give proper exposure for that exposure time.

As the camera and subject are independent of each other, many different subject diameters can be accommodated with ease. When very small objects are photographed one must align the rotating subject with care, especially when as in ballistic comparison photographs, two different subjects will be compared to each other.

It is interesting to note that if one is willing to tolerate some distortion, the subject does not have to be a perfect cylinder but it can have depressions or protrusions. Parts that protrude from the average circumference of the subject will appear com-pressed and those that are depressed will appear spread out. By this technique, full 360-degree portraits can be taken. See Figure ??

The subject is placed on a rotating turntable with the slit aimed at the center of rotation of the head. When these photographs are later displayed on rotating cylinders a close approximation to reality is achieved since the viewer tends to ignore the straight vertical sides of the cylinder and concen-trates mainly on the changing features of the portrait.

Interesting distortions can be made by having the subject off center or changing expressions as the camera is recording the back of the head or having the subject move laterally at the same time, or turning while being imaged on the streak camera¹s slit. Photographs bearing a strong resemblance to cubist vision have been made this way.

Peripheral cameras have also been used to photograph the interior walls of cylinders by placing a mirror at 45 degrees inside the cylinder and then imaging the moving reflection onto the slit of a streak camera.

In this context, the peripheral camera is more of a panoramic camera in that the camera looks out by way of a mirror to cover a 360-degree view of the wall of the cylinder. However, instead of rotating the camera as in a panoramic photograph, the subject is made to rotate and the camera is kept stationary. In any event, the result is the same as if a panoramic photograph had been taken.

Enlarging Streak Photographs

As mentioned in the section dealing with panoramic cameras, wide angle and peripheral photographs tend to be very difficult to handle and use because~ their height to length ratio is usually unwieldy. In order to make prints with an acceptable vertical dimension, the horizontal dimension often would necessitate an enlarger capable of holding at least ten inches of film and an easel capable of accepting paper up to 10 feet long.

The answer to this constraint is to use an enlarger that operates basically as a streak camera in reverse. The enlarger is identical to a microfilm-copying camera with a moving stage except for the fact that a lamp-house is fitted above the moving film.

As shown in Figure 30, the film and paper move in opposite directions and at such a speed that there is no relative motion between the image projected by the lens and the moving paper below. The proper speed relationship between the film and the paper are simply determined from knowledge of the magnification that the particular lens on the enlarger is set to. The speed of the film past the slit is multiplied by the magnification factor of the lens and that is the speed at which the paper must be moved on the easel.

The advantage of this system is that the length of the image becomes relatively unimportant as long as it is not so long that when the height of the streak record is enlarged to fit the width of the paper, the paper length required does not exceed the length of the paper roll available.

The main disadvantage is that there is an obvious difference between the time that one edge of the enlargement is exposed and the time the exposure is completed at the other end.

Consider that if a certain light source is used to enlarge a strip of 35mm film 5² long in a 4x5 enlarger and the Proper exposure for a print 40² x 17 feet is ten minutes, then after the ten-minute exposure time the print can be developed.

However, assuming that the 5² long strip is printed by a streak enlarger the total time from beginning of exposure to end increases considerably.

When a 4x5 enlarger is used each image point on the paper receives an exposure for ten minutes; therefore, the same must be true in the streak enlarger. If the slit size is assumed to be 1/10 inch, it will be enlarged to be 4² in size when the slit is enlarged to fill a 40² roll of paper from edge to edge. This is an enlargement of 40X linear. The paper must be pulled, then, at the rate of 4² every ten minutes so that every point along the paper is exposed for ten minutes. Then, it will take ten minutes times 17 feet divided by 4² to complete the exposure of the en-largement. In this case it would be 10 x 50 = 500 minutes or over eight hours!

Obviously, one solution is to use a wider slit width in the enlarger, but this requires that film and paper movement speeds increase in accuracy. Another is to use a brighter light source, but there are practical limits to this as well. In any case, it is still the most practical way of making large enlargements and it is possible to feed the roll of paper directly from the en-larger into a chemistry train so that shortly after the print is completely exposed it is also fully processed.

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9/78

DOUBLE SLIT VELOCIMETRY

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