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# OPTICAL AND MECHANICAL CHARACTERISTICS OF 16-MILLIMETER MOTION-PICTURE PROJECTORS

By Robert E. Stephens

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# PREFACE

This circular provides the prospective purchaser with information to assist in the selection of satisfactory 16-millimeter motion-picture projectors. The performance of projectors is described in terms of characteristics which can be measured objectively. Procedures for making these measurements are described in detail. Values of the important characteristics that are representative of those obtained with the better class of projectors are given. Some constructional characteristics and features are discussed.

Lyman J. Briggs, *Director*.

# OPTICAL AND MECHANICAL CHARACTERISTICS OF 16-MILLIMETER MOTION-PICTURE PROJECTORS

By Robert E. Stephens[1]

ABSTRACT

Ten 16-millimeter motion-picture projectors, furnished through the courtesy of five manufacturers, were tested to determine typical values of the important characteristics. The characteristics tested were resolving power, illumination of the image, jump and weave, film life, and durability. Typical results obtained were: resolving powers of 64, 64, 22, and 16 lines per millimeter, at positions in the field 0, 2.5, 5 and 6 degrees, respectively, from the optical axis; illumination of 19 lumens per square foot at a magnification of 120 times; jump of less than 3/16 inch and weave of less than 3/32 inch at a magnification of 120 times.

These results may be used in the preparation of specifications governing the procurement of projectors with the assurance that such performance is now accomplished by the better projectors.

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## I. INTRODUCTION

Modern motion pictures are produced by projecting on a screen, in rapid succession, a series of pictures each of which differs slightly from the preceding one. Sixteen to twenty-four pictures are projected per second. The screen is dark during the interval required for changing from one picture to the next, but, because of the persistence of vision, the dark interval is not noticed, one picture following another in such rapid succession that the illusion of a single moving picture is produced.

[1] The research upon which this paper is based was done while the author was research associate for the Committee on Scientific Aids to Learning of the National Research Council at the National Bureau of Standards.

The pictures projected are carried on a long strip of transparent film made of plasticized cellulose derivative. Sixteen-millimeter film is made of a slow-burning type and is called "safety film". The pictures are positive transparencies 10 by 7.5 mm. They are placed edge-to-edge along the film, with the 7.5-mm dimension lengthwise and the 10-mm dimension crosswise. There is a 3-mm margin along each edge of the film. One of these contains perforations by which the film is propelled; the other contains the sound record for talking pictures.

The motion-picture projector consists of an optical system similar to that of a lantern-slide projector for throwing enlarged images of the pictures upon a screen, and a mechanism for rapidly changing the pictures.

## II. DESCRIPTION OF PROJECTOR

The external parts of a typical sound-on-film projector are shown in figure 1. *A* is the supply reel, on which the unused portion of the film is carried. *B* is the feed sprocket. Its function is to pull the film from the supply reel and maintain a free loop of film just ahead of the gate, *C*. Here the film is held in the proper position for projection. *D* is the objective, a system of lenses which projects on a screen greatly magnified images of the pictures on the film. *E* is the sound head. Here the sound track on the film intercepts a beam of light which, after passing through the film, falls on the sensitive surface of a phototube for the production of sound. *F* is the take-up sprocket which pulls the film through the sound head and feeds it to the take-up reel. *G* is the take-up reel, on which the film is wound after it has passed through the projector. *H* is the lamp house, in which the projection lamp is located.

The film passes through the gate with an intermittent motion. It is stationary while each picture is being projected, then the light is shut off, and the film is pulled forward quickly until the next picture is in place. The light is then turned on and the picture projected. This cycle is repeated 16 to 24 times per second. On machines which reproduce sound-on-film, the frequency is 24 pictures per second and is kept constant by means of a governor.

## III. OPTICAL SYSTEM

A diagram of a typical optical projection system is shown in axial section in figure 2. The frame of film to be projected is shown at *A*. It is illuminated by light from the lamp, *C*. Light, after passing through the film, is collected by objective *B* and thrown on the screen, forming a greatly enlarged image of the picture on the film. *D* is the condenser which directs the light, so that light from all parts of the film enters the objective. The concave mirror, *E*, is placed with its center of curvature at the middle of the lamp filament. It catches light emitted by the back of the lamp filament, which would otherwise be lost, and reverses its direction, thus adding to the illumination of the film. This reflected light also tends to fill the spaces between the coils of the filament, and contributes to the uniformity of illumination.

The objective is a system of lenses designed to form good images at a large aperture. The aperture must be large to pass enough light to make the images sufficiently bright. Most of the objectives used

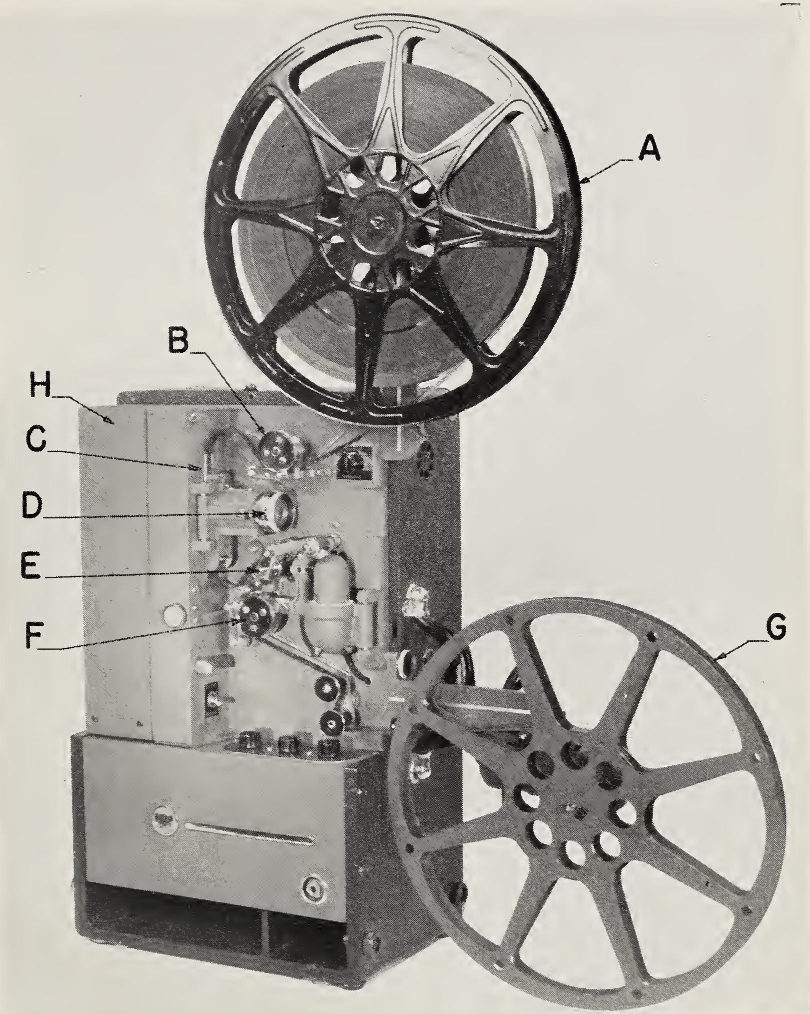


Figure 1.—*Typical sound-on-film motion-picture projector.*

on 16-millimeter motion-picture projectors are of the Petzval type, which is capable of producing excellent images if the angular width of the picture is not too great. In projecting 16-millimeter film with a 2-inch lens, the total field to be covered is only 12.5 degrees, and this form of objective gives good results. Objectives are not all alike in performance, however, even at the same price. In order to be satisfactory, an objective should be capable of resolving almost all of the detail likely to be present on a film. This is discussed more thoroughly in section VI.

The clear diameter of the objective as seen from the front of the projector is called the "aperture." The aperture, expressed as a fraction of the equivalent focal length, for example $f/1.6$, is called "relative aperture." The ratio of the aperture to the equivalent focal length, for example 1/1.6, is called "aperture ratio." For the same light source and the same image size the illumination of the image is proportional to the square of the aperture ratio, regardless of the focal

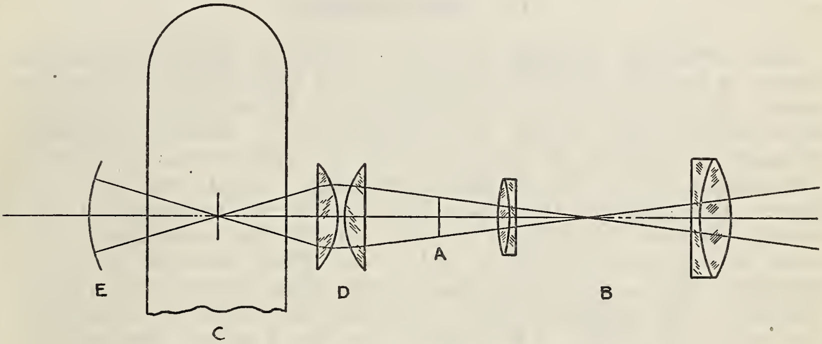


FIGURE 2.—*Diagram of the optical system of a projector.*

*A*, film bearing the picture to be projected. *B*, objective or projection lens. *C*, lamp. *D*, condenser. *E*, concave mirror. *F*, image of lamp filament formed by condenser.

length. These quantities are no indication of the quality of an objective in any other respect.

If the condenser were omitted, light from the lamp passing through the center of the film would fall on the objective, and an image of the center portion of the picture would be as bright as with the condenser. This would not be the case, however, for the light incident on the edges of the picture. It would travel in a direction inclined with respect to the optical axis, and most of it would miss the objective. The image would therefore be dark at the edges. The function of the condenser is to direct the light from the lamp in a manner such that after passing through any part of the picture on the film it enters the objective. Thus the objective can form a bright image of the entire picture. This is illustrated in figure 2 by dotted lines representing those rays which are emitted by the center of the filament and pass through opposite corners of the frame at *A*.

The components of the optical system are aligned along a common optical axis. The components should be fastened in place in a way such that they can be removed for cleaning and replaced without disturbing the alinement.

The objective can be moved in the direction of the optical axis so that images can be focused sharply on a screen at any desired distance. This motion is usually provided with two speeds, one for coarse adjustment, the other for fine. The coarse adjustment is not of much use, however, and its omission is not serious. Some means of locking the objective in place after the correct adjustment has been found should be provided. This is necessary if one wishes to be able to open the gate for threading a new film without having to refocus.

All projectors use lamps with some kind of prefocus base. This allows replacing the lamp without the necessity for adjusting its position. There are, however, minor differences in the positions of the filaments in different lamps, and slightly better results can be obtained if a slow-motion sidewise adjustment of the lamp socket is provided. Some projectors have the lamp socket fixed but have a lateral adjustment on the concave mirror. It is preferable that the mirror be fixed and the lamp socket be adjustable.

## IV. MECHANISM

The motion of changing from one picture to another takes place during a period one-sixth to one-ninth of the time for a complete cycle. During the rest of the cycle the film is stationary in the gate. This intermittent motion is accomplished in most 16-millimeter projectors by a two- or three-toothed claw which enters the perforations and pulls the film downward through the gate one frame at a time. The motion of the claw is produced by two cams, one of which moves the teeth of the claw into and out of the perforations. The other cam moves the claw up and down. These motions are so synchronized that a downward stroke occurs while the teeth are engaging the film. The upward stroke occurs after the teeth have been withdrawn from the film. The distance the film is moved depends upon the spacing of the perforations rather than upon the stroke of the claw. In some projectors the intermittent motion is transmitted to a sprocket over which the film passes. It is doubtful that there is any superiority of one type over the other. The advantage, if any, is likely to be with the one having fewer parts.

The intermittent mechanism is a critical part of a projector. If it does not function properly the pictures may jump, that is, there will not be perfect registry of successive pictures, or there may be excessive wear on the film at the perforations. Because of the complexity and rapidity of the motions, the pressures between the cams and their followers may be great, with resultant rapid wear and short life.

It is necessary for the light to be cut off while the film is being moved. This is accomplished by a shutter, which usually is a sectored disk rotated by gears connecting it with the intermittent mechanism so that the two will operate in synchronism. The shutter interrupts the light not only while the film is being moved but also two additional times while the film is stationary. This increases the flicker frequency three times and reduces the subjective effect of the flicker.

The sprockets and sprocket guards of a projector may contribute greatly to the wear and tear on the film. Only three or four teeth of the sprocket should be allowed to engage the film at a time, because the spacings of the teeth and of the perforations are not identical.

The teeth are made somewhat narrower than the perforations. This allows for some difference in spacing if not more than three or four teeth are allowed to engage the film at one time. Actually, only one tooth at a time is pulling the film. The film should lie firmly against the body of the sprocket. This can be accomplished in two ways: either the film loops around the sprocket and the tension pulls it against the sprocket or the sprocket guard presses it against the sprocket. The first method seems far more conducive to long film life. On some projectors one sprocket is used twice, with the film running in opposite directions on diametrally opposite sides of the sprocket. With this arrangement, the film must be held against the sprocket by guards.

The gate consists of two metallic plates, between which the film is held for projection. Both plates contain apertures through which the light that forms the image passes. One of these apertures is smaller than the other, and it forms the frame around the picture being projected. The back plate is fastened to the body of the projector, whereas the front, or pressure, plate is movable, being pressed by springs against the film, which in turn is pressed against the back plate. The force applied is sufficient to hold the film flat while it is being projected but weak enough that the film can be pulled through the gate easily. These plates are undercut so that the parts of the film carrying the picture and the sound track do not touch them. Contact between the film and the plates occurs only on three narrow strips, one on the edge outside the perforations, another between the perforations and the picture area, and the third between the picture area and the sound track. Any abrasion of the film as it passes through the gate takes place only on these areas. These parts must be made of a very hard material to resist wear. Generally, they are made either of solid stainless steel or of a softer metal plated with a heavy coat of chromium. Either of these is quite satisfactory.

As the film comes out of the gate, its motion is intermittent. When it gets to the sound head, it must move with nearly constant speed. This is accomplished by a roller over which the film passes as it goes through the projector. This roller is attached to a flywheel and is driven only by the film. The inertia of the flywheel tends to maintain a constant speed of rotation. In order that the roller may rotate with constant speed while the speed of the motor and sprockets fluctuates slightly, there must be some storage of film on both sides of the roller which can be added to or drawn upon as necessary. In some machines this has been provided for by having a light idler roller pressed by a weak spring against the film between the inertia roller and the take-up sprocket. In other machines the only storage of film is at bends where, because of the elasticity of the film, there is a slight flexure beyond the rollers over which the film passes. On some projectors the constant-speed mechanism includes some friction provided by stationary parts over which the film slides. It is doubtful if this friction makes a worth-while contribution to the smoothing of the speed, and moreover it imposes an undesirable extra strain on the film at the perforations, where the sprocket teeth must pull harder to overcome the added resistance.

The take-up reel is rotated either by the projector motor through a belt or by a separate motor. In either case there is a friction coupling between the motor and the take-up spindle, which may slip while transmitting enough torque to wind the film. Because of this, the speed of rotation adjusts itself, becoming smaller as the diameter of the winding increases as the reel fills.

Some means is usually provided to adapt the torque to take-up reels of different sizes. The control may be manual, automatic, or a combination of both. Where a separate motor is used for take-up, it is partly automatic, since the torque of a universal motor decreases as the speed of rotation increases. One make of projector is equipped with a mechanism in which the magnitude of torque transmitted by the slipping device is regulated by the weight of the take-up reel and the film wound on it. The control afforded by this means is sufficient to allow the use of any reel from a 50-foot spool to a 1,600-foot reel and is entirely automatic. A two-step pulley on the take-up spindle is often provided so that the speed may be adapted to large or small reels. The control of the torque by this means is not very great unless the slipping device is between the motor and the step pulley, since the torque transmitted by the slipping device is almost independent of the rate of slip. However, the wear of the slipping device is reduced by the use of the proper pulley.

If too great a torque is transmitted to the take-up spindle, small reels cannot be used. One make of projector examined by the author had so much torque that when the use of a 400-foot reel for take-up was attempted, the tension on the film was so great that it caused the film to come off the take-up sprocket. This machine operated quite satisfactorily with a 1,600-foot reel for take-up.

The projection lamp emits a great quantity of radiant energy, of which only a small part leaves the lamp house. Most of it is absorbed by the walls of the lamp house and by the glass envelope of the lamp. In order to prevent softening of the glass and overheating of the projector, a stream of air is forced through the lamp house by a blower. This blower is directly on the shaft of the projector motor so that failure of a belt cannot stop the flow of cool air. The switches which control the projector are so connected that the lamp cannot be lighted unless the motor is running.

Some provision is made on most projectors for rewinding film by power after projection. There are many different ways of doing it, and all of them accomplish the desired result satisfactorily. There is, however, a great difference in the ease with which the operation of rewinding is performed. Some require changing belts; some require the manipulation of several levers, push buttons, or switches. The number of operations required for rewinding may be of considerable importance if the machine is to be operated by unskilled persons.

When belts are used to rotate the reels for take-up and rewind, they are made of steel coil springs. These are sometimes unreliable; some may last for hundreds of hours, others may break in a few hours. The kind having ends which screw together are especially bad; those whose ends link together usually last much longer. A projector on which spring belts are used should be so constructed that a belt may be replaced without taking anything apart. The user of the projector should keep a spare belt on hand.

Most projectors have a rubberized fabric belt between the motor and the projector mechanism. These belts, if they are adequately proportioned, are satisfactory and will last for a long time.

An adjustment is provided on modern projectors for framing the picture so that the edges do not show on the screen. The picture on the film lies in a definite position with respect to the adjacent perforation, and this position may be slightly different on films exposed in different cameras or printers. The claw of the projector leaves successive perforations of the film at exactly the same place in the gate, and this place must be such that the picture on the film is centered in the frame.

The adjustment of the framing is accomplished in different ways on different projectors. One way is to have the whole intermittent mechanism movable vertically so that the position at which the claw stops is adjustable. Another way takes advantage of the fact that the field that can be satisfactorily projected by the objective is a little larger than the frame and the aperture plate is made movable in the vertical direction. A third method depends upon the fact that the illuminated area of the film is larger than the frame. The objective and aperture plate move together in a vertical direction for framing. The second method suffers from the disadvantage that the image area moves with respect to the screen during adjustment. This may necessitate compensatory adjustment of the projector tilt to prevent part of the picture from falling off the screen. The first method is entirely free from this fault and the third practically so.

## V. EXTRA FEATURES

Some projectors are so equipped that they can be used for other functions in addition to the fundamental one of projecting silent or sound motion pictures. Some have a clutch by which the film-transport mechanism can be stopped while the blower and lamp continue, allowing a single frame of the film to be projected for an indefinite period. Some are provided with a switch by which the direction of rotation of the motor can be reversed, thus reversing the entire mechanism so as to project in reverse for humorous effect or in preparation for repeating a scene.

When a projector is used for projecting stationary pictures from single frames of the film, an absorbing screen falls between the lamp and the film to reduce the intensity of radiation incident upon the film and prevent burning. This reduces the brightness of the image greatly; in fact, unless the screen is placed close to the projector and the image size greatly reduced, the picture is not bright enough to be seen even with a 750-watt lamp and an $f/1.6$ objective.

In spite of the absorbing screen, the intensity of radiation upon the film is enough to warp the film permanently in a few seconds, and during this period the film is bending and receding from the usual focal plane. As a result, the picture cannot be projected satisfactorily as a still even for a very short period.

Even if it were possible to get enough light through a single frame for satisfactory projection, the result still would be disappointing because of the poor definition of the image. A motion picture always seems much sharper than any single picture on the film. The reason for this is partly psychological; one does not expect to see as much detail in a moving object as in a stationary one. It is also partly

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physical, because the average of a sequence of pictures actually contains more detail than any of the pictures individually.

For some research purposes, it might be very useful to project single frames, and for such purposes the lamp could be replaced by one of lower power to prevent damage to the film. However, for educational purposes, the use of a motion-picture projector as a substitute for a lantern-slide projector is entirely unsatisfactory. It is better that the still-projection feature be omitted entirely so that there will be no danger of damaging the film by accidental stopping of the film transport mechanism.

For educational purposes, it might be desirable to reverse the projector and rewind some of the film in order to repeat a scene immediately. The humorous effect of reverse motion is probably undesirable but can be avoided by turning out the lamp while the reverse action is taking place.

Silent projectors can be reversed by simply reversing the driving motor if a belt or other means of turning the supply reel backwards is provided. The cost of such provision is small, and all the silent projectors inspected by the author have been so equipped.

Reverse operation of a sound projector is a more difficult matter, since an additional sprocket may be necessary to pull the film through the sound head in the reverse direction. The extra cost of such construction may be considerable; also the desirability of the reversal feature may be less than for a silent projector. The prospective purchaser is advised to make sure thant the extra cost of a satisfactory reversal feature is justified by the use which will be made of it.

Some projectors are equipped with so-called safety devices, such as trigger clutches which stop the machine if the loop near the gate is lost by slippage of the film past the claw or the teeth of a sprocket. A prospective purchaser should not be unduly influenced by the presence or absence of such devices. It may be that the machine so equipped needs the device to make up for poor design of some fundamental part. Well-designed machines will handle film with decided imperfections without loss of loop.

## VI. REQUIREMENTS AND TESTS

### 1. NATURE OF REQUIREMENTS

A projector to be considered satisfactory must fulfill certain requirements. Fundamentally these requirements are of a subjective nature. For example, the image must be sharp, full of detail, and must be bright enough that the detail in the picture on the film can be seen, but not so bright as to be tiring to the eye which is adapted to the low average brightness of the room; stationary objects in the picture must not jump around; and, for talking pictures, speech must be intelligible and music clear and free from waver.

In spite of the subjective nature of the requirements, it is desirable that objective tests be used, when possible, to judge the relative merits of projectors. For many of the characteristics this can be done, because the objective values necessary for good performance have been determined by experiment. The advantage of objective tests is that different persons testing the same type of machines will get nearly the same results regardless of individual differences of judgment or prejudice.

When specifications governing the procurement of projectors are being prepared, it is desirable that they be based upon performance characteristics rather than constructional details. If possible, these performance characteristics should be specified in terms of the objective tests which will be used to determine compliance.

At the present time, the values specified for performance characteristics should be determined by consideration of what the better class of projectors can accomplish rather than by theoretical considerations.

## 2. PICTURE SIZE

Some of the requirements, notably the light output and the focal length of the objective, depend upon the picture size. For this reason the picture size should be determined before the projector requirements are considered.

There is, for any individual spectator, a correct position for viewing a picture. This position is the one at which both the width and height of the picture subtend the same angles at the eye of the spectator that the width and height of the actual scene subtended at the lens of the camera. When viewed from this position, the apparent sizes of near and distant objects are the same in the picture as they were from the position of the camera when photographed. If the picture is viewed from any other point, it is not a true picture of the scene, since the perspective is distorted.

The angular width of the scene photographed for 16-millimeter motion pictures is about 22 degrees. The projected picture will be seen with that angular width from a point 2.5 times the width of the picture away from the screen and on a line perpendicular to the screen at the center of the picture. Obviously this position cannot be occupied by a spectator, since it would obstruct the beam of light from the projector. However, the distortion is not serious for viewpoints within a considerable space around this point.

The picture size should be so chosen that the correct viewpoint is somewhere near the front of the audience. The usual choice is to make the width of the picture equal to half the distance from the screen to the nearest spectator (see fig. 3). This places most of the audience behind the correct viewpoint. There are two reasons for this: first, the distortion of perspective resulting from having the angle of view too small is less noticeable than that resulting from having the angle of view too large; second, because of lack of sharpness of the image, no spectator should be closer to the screen than twice the width of the picture. If a person is too close to the screen, he can see the defects of the image resulting from the residual aberrations of the camera, printer, and projector lenses, and the graininess of the film. His eyes continually change their accommodation in an effort to see the picture better than it is, and eyestrain may result.

The most distant row of spectators should not be farther from the screen than about six times the picture width. Because of foreshortening, no spectator should be so placed that he sees the screen at an angle greater than 25 degrees from the normal.

After the picture size has been decided, it must be ascertained whether or not available projectors can furnish enough illumination. With a beaded screen an illumination of 4 or 5 lumens per square foot is sufficient, with a matte screen 8 to 12 lumens per square foot is desirable. These values are based on the assumption that the room is completely dark except for the light from the projector. If not enough light is available, the picture size must be somewhat reduced, it being more important that the illumination be sufficient than that the perspective be correct.

In applications where the projector is in the same room as the audience, the standard 2-inch objective will usually be the proper choice.

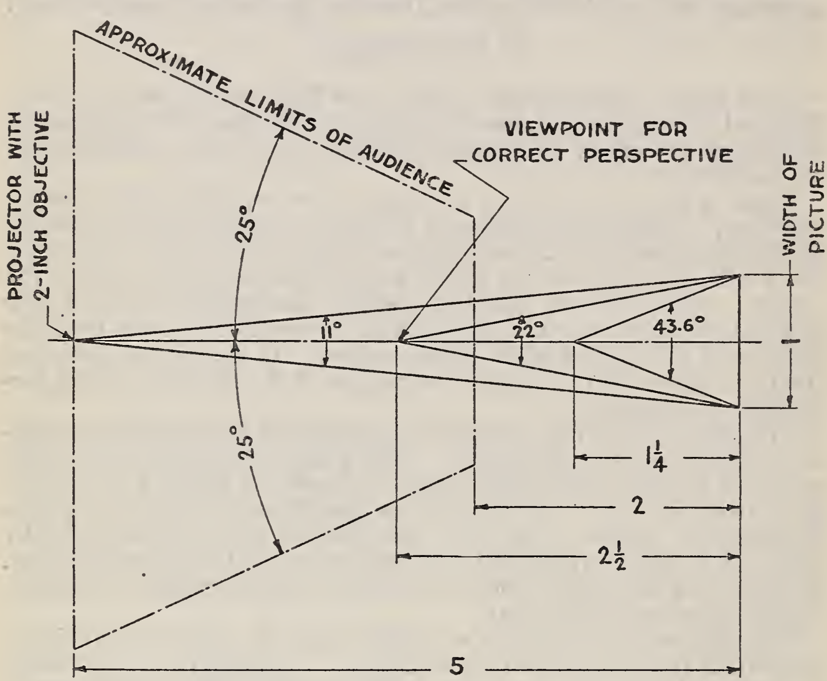


Figure 3.—*Angle of view in relation to positions of projector and spectator.*

A spectator viewing the picture from a position midway between the projector and the screen sees a picture with an angular width of 22 degrees in which the perspective is true to life. Angular widths of 11 and 43.6 degrees are seen from twice and half the correct viewing distance, respectively, and the perspective is distorted in opposite senses.

A spectator seated away from the line of projection sees a picture one dimension of which is foreshortened, while the dimension at right angles to the first is the same as though he were on the line of projection and at the same distance from the screen.

With this the correct picture size is obtained almost automatically if the projector is placed near the last row of spectators; see figure 3. If the projector must be placed in a booth considerably behind the audience, an objective of longer focal length must be used. If it must be placed in front of the audience, a shorter focal length will be necessary. The distance of projection measured in picture widths for several focal lengths is given in table 1.

TABLE 1.—*Projection distance as a function of the equivalent focal length of the objective*

| Equivalent focal length of objective (in inches) | Projection distance (in picture widths) |
|---|---|
| 1 | 2.5 |
| 1.5 | 3.75 |
| 2 | 5 |
| 2.5 | 6.25 |
| 3 | 7.5 |
| 3.5 | 8.75 |
| 4 | 10 |
| 4.5 | 11.25 |

## 3. IMAGE QUALITY

The quality of the image depends upon both its definition and brightness. These will be treated separately.

### (a) DEFINITION OF THE IMAGE

Definition of the image means the content of fine detail, such as the mortar between bricks, twigs on trees, etc. This depends partly upon the quality of the film and partly upon the projector. The extent to which the projector is responsible for the definition is dependent upon the resolving power of the objective and the precision with which the film, while being projected, is held in the proper position with its plane perpendicular to the optical axis of the objective.

The prospective purchaser of a projector is more concerned with the performance of the complete projector than with the properties of any component separately. It is desirable, therefore, that a method of testing the image quality be adopted by which the complete projector is tested rather than one by which the several contributing factors are tested separately.

It has been found practicable to describe the definition of the image in terms of the resolving power of the projector. A specially prepared film on which resolution-test patterns have been photographed is projected, and the finest lines of the film that are clearly resolved in the image are the measure of resolving power.

The test film is prepared by photographing, on a special fine-grained film, a chart made up of resolution-test patterns. The pattern is illustrated in figure 4. The chart which is photographed is shown in figure 5. The patterns in the horizontal row are placed so that when the film is projected with a 2-inch objective they are approximately 0, 2.5, and 5 degrees off the optical axis. The rectangle, the width of which is marked "36 inches", is for adjusting the magnification during projection. Its use is described in section VI–3(b).

The parallel lines on the resolution-test patterns are of such size that when photographed they are spaced approximately 64, 45, 32, 22.5, 16, 11, 8, and 6 lines per millimeter on the film. All the lines are well defined on the film. The film is developed to a high degree of contrast, since it is easier to reproduce this way than it would be if it were necessary to have a definite low contrast. There are two groups of lines of each spacing. In one group the lines are parallel to a line from the center of the field to the pattern and in the other they are perpendicular to this line.

Sixty-four lines per millimeter on the film corresponds to finer detail and sharper definition than is possible with the films regularly used for 16-millimeter motion pictures, since they will resolve only about 50 lines per millimeter and even then only with greatly reduced contrast. As a consequence, if an objective resolved 64 lines per millimeter at all parts of the field, its performance would be considered practically perfect. However, if films of higher resolving power than those used at present should become generally available, an objective of greater resolving power would be desirable. Most of the 2-inch *f*/1.6 objectives tested by the author have had resolving powers greater than 64 lines per millimeter at the center of the field, but none of them was that good at the corners.

The resolving power of a projector is measured by projecting the test film upon a screen. The focus is adjusted carefully to produce

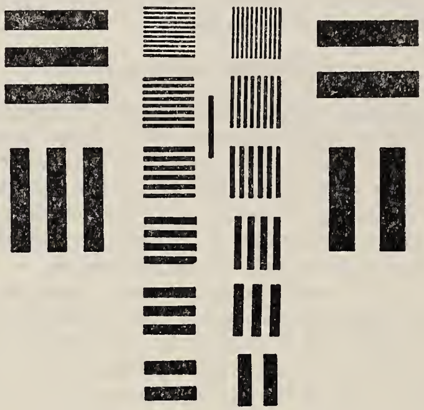

FIGURE 4.—*Resolution-test pattern.*

A group of these patterns placed as shown in figure 5 was photographed to make a film for testing resolving power of projectors. The spacings of the lines on the film were approximately 64, 45, 32, 22, 16, 11, 8, and 6 lines per millimeter.

the sharpest images possible. Generally it is necessary to focus for maximum sharpness at the center of the image. Although it is usually possible to improve the sharpness of the image at the corners by making a slight sacrifice of central sharpness, an undesirable unsteadiness is sometimes introduced at the central and most important part of the picture by this procedure.[2] While the test film is being projected, the observer approaches the screen until he is close enough to see all the detail present in the images and records the finest lines which are clearly resolved in each pattern, both radial and tangential. At any position in the picture, the finest lines that are resolved both radially and tangentially are a measure of the resolving power. The magnification used for this test is unimportant as

[2] When the focus is imperfect, a point on the film is imaged on the screen as a small disk, called the circle of confusion, instead of as a point. The light falling on different parts of this disk comes from corresponding parts of the objective. The projector shutter is not in the focal plane. For this reason a shadow of the shutter edge runs across the circle of confusion and produces an apparent movement of the image every time the shutter opens or closes.


FIGURE 5.—*Resolution-test chart.*

The test film described herein was made by photographing this chart on special fine-grained 16-millimeter, motion-picture film. When this film is projected by a 2-inch objective, the patterns lie approximately 0,2.5, 5, and 6 degrees from the optical axis.

long as it is easy to decide which are the finest lines resolved. The resolving power of a projector should be at least as great as that given in table 2.

TABLE 2.—*Minimum resolving power of a projector with 2-inch, f/1.6 objective*

| Position (in degrees) | Minimum resolving power (in lines per millimeter) |
|---|---|
| 0.0 | 64 |
| 2.5 | 64 |
| 5.0 | 22 |
| 6.0 | 16 |

During this test the observer should look for colored edges on the larger lines. These should not be noticeable from a distance of two and one-half times the width of the picture. A special Kodachrome test film may be used to test the chromatic aberration, but usually this is not necessary.

### (b) BRIGHTNESS OF THE IMAGE

To the spectator, it is important that the motion picture on the screen be bright enough for good seeing. The light-flux output of the projector, the size of the image, and the characteristics of the screen all contribute to the brightness of the image. This circular is concerned only with the performance of the projector.

The light-flux output measured in lumens is a desirable quantity for rating the performance of a projector. Its use is, however, subject to certain difficulties; an integrating-sphere photometer or some other suitably calibrated integrating photometer is necessary for its accurate measurement, and it alone is not sufficient, since it tells nothing of the distribution of the light over the picture area. A quantity which is easily measured with simple and widely available apparatus, and which gives sufficient information, is the illumination (incident flux per unit area) of the image. This is measured with the projector running but with no film in the gate.

In order to obtain results which can be used for comparative purposes, a definite magnification should be used when the illumination of the image is measured. This can be obtained approximately by adjusting the projection distance until the width of the picture is a prescribed value. This method is not very satisfactory, however, because the apertures at the gates of different makes of projectors are not identical in size and, also, the edges of the aperture are out of focus and their images are indefinite when the focus is correct for the plane of the film. A better way is to have a film on which there is an interval of known length so that its image on the screen can be measured and adjusted to the correct length for the desired magnification. An interval for this purpose is included on the film used at this Bureau for testing resolving power. The frame whose width is marked 36 inches (fig. 5) is photographed so that its width on the film is 0.300 inches. When this is projected to a width of 36 inches on the screen, the magnification is 120 times. The dimensions of the picture at a magnification of 120 times are approximately 45 by 33 inches.

It is not necessary to use a regular screen when measuring illumination; in fact, a solid smooth wall is much better, and a slate blackboard is excellent. The use of a dark surface prevents the incident light from being scattered around the room and partly returned to the picture, thus adding illumination which is not useful in forming the picture.

In order that differences between individual lamps may not prejudice the results obtained in the illumination test, the test should be repeated several times, using a different lamp each time, and the results averaged. The lamps of the group should be acquired from different sources or from the same source at different times, since a number of lamps purchased in one group seem to be nearly identical but somewhat different from those of other groups.

The lamps used for the illumination test should be burned only while measurements are actually being made. The adjustment of magnification and the focusing should be done with another lamp. It has been found that the output of a lamp (750w, 115v) remains sufficiently near constant when burned at its rated voltage to allow its use for illumination tests for about 2 hours.

The voltage supplied to the projector must be controlled carefully during the illumination test, since the light output of a lamp increases rapidly as the voltage is raised. A voltage fluctuation of about 1 percent can be tolerated. For comparative purposes it is not necessary that the lamp be operated at its rated voltage, and its useful life may be increased greatly by operating it at a lower voltage.

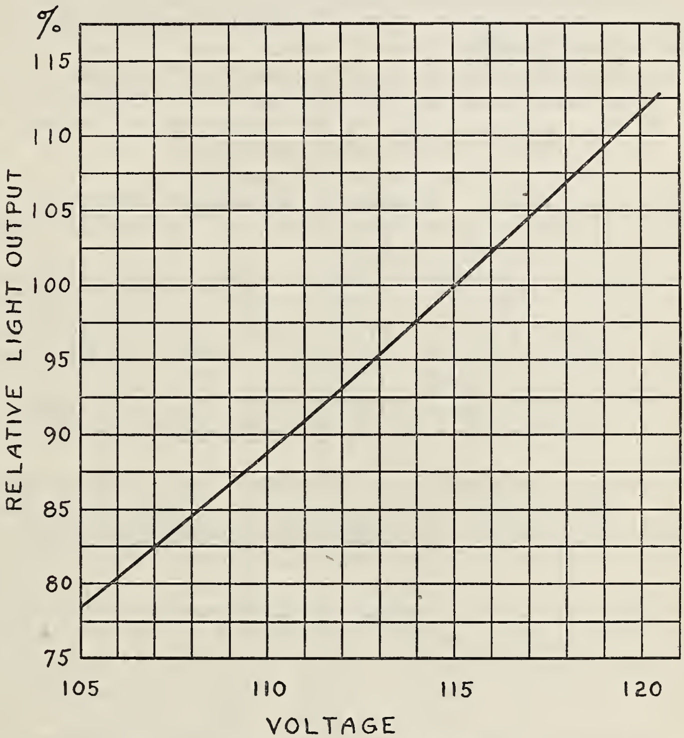


Figure 6.—*Graph of percentage light output as a function of voltage for 750-watt 115-volt projection lamps with C–13D filaments.*

The results obtained by measurements of several lamps obtained from different sources were so nearly alike that they were averaged to produce this graph. Actual values for any individual lamp probably do not differ from those on the graph by more than ±2 percent.

A lamp to be used for testing illumination may be calibrated so that afterward it may be used for tests at a voltage below its rating. The illumination at rated voltage may then be computed by multiplying the values obtained during the test by a factor determined by the calibration. In figure 6 is a curve which shows the average percentage output of some representative lamps as a function of voltage. These are plotted with the output at the rated voltage (115 volts) taken as 100 percent. The factor to be used if a test is to be made at a voltage other than the rated voltage is the reciprocal of the percentage output at that voltage.

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Any photometer which is sufficiently portable may be used for measuring the illumination. Those of the photoelectric kind are most convenient and are sufficiently accurate. A Macbeth Illuminometer is more accurate but more difficult to use. The sensitive surface, if a photoelectric photometer is used, or the white plate, if a visual photometer is used, should be placed in the beam. The unit of illumination is the lumen per square foot. In engineering circles, this is called "foot-candle." Thus many instruments for measuring illumination are called "foot-candle meters." The unit of illumination (incident flux per unit area) should not be confused with the candle per square foot, a common unit of brightness (emitted flux per unit area per unit solid angle).

The illumination should be measured at several places in the picture area. It has been found that five positions are sufficient, one at the center, and one near each edge on the horizontal and vertical center lines. If a magnification of 120 times is chosen for the test, suitable positions are center, 18 inches to right and left of center, 12 inches above and below center. Measurements at these positions give information on the illumination of three zones and on the horizontal and vertical symmetry of the illumination.

There should be no visible differences of brightness or color over the picture area to within 2 or 3 inches of the edge when the beam is thrown on a uniform screen. This test must remain a subjective one, since the number of objective measurements that would be necessary for satisfactory interpretation is too great. The ratio of the illumination at any of the edge positions to that at the center should be at least 0.70. With some projectors this ratio may be as high as 0.85 to 0.90.

The following procedure is recommended for making an illumination test. The projector to be tested is set up on a table about 20 feet (for a 2-inch objective; distances for other focal lengths in direct proportion) from a wall upon which to project. As was mentioned before, a blackboard is excellent for the purpose, not only because of its low reflectance but also because the positions at which the illumination is to be measured may be marked directly on it. The lenses and concave mirror should be clean. Some means should be provided for controlling and measuring the voltage of the power supplied to the projector. If the line voltage is greater than necessary, a rheostat of about 5 ohms resistance capable of handling 10 amperes or more will do for the control. A Variac variable transformer is very convenient for this purpose if the power supply is alternating current. The test film should then be projected and the magnification adjusted to 120 times by moving the projector nearer to or farther from the wall, always keeping the axis of the beam perpendicular to the wall. After the correct magnification has been obtained and the image is in good focus, the objective should be locked, so that the focus will not change, and the film removed from the projector. The lamp to be used for the test is then inserted, the machine started, and the voltage adjusted. The room must be totally dark except for the light from the projector. The positions at which the illumination is to be measured should be marked on the wall, that is, the center of the image area, 18 inches to the right, 18 inches to the left, 12 inches above, and 12 inches below. The photometer should then be placed at each of these positions in succession and the illumination measured. The surface of the photometer should be kept parallel to the wall. The series of five measurements should be made two or three times and all the results for each position averaged to get the final results.

Different makes and models of projectors, all with the same apertures, *f*/1.6, and the same lamp power, 750 w, give illuminations which differ greatly. The author has seen some as low as 14 lumens per square foot and some as high as 26 lumens per square foot measured at the center of the field.

The makers claim various advantages gained by sacrifice of image illumination. Among those claims are: better average light efficiency over a range of interchangeable objectives of different focal lengths, less wear on film because of slower transport through the gate, longer life of the intermittent mechanism when designed for slower transport. While these claims may seem reasonable, they are not always realized in practice.

## 4. JUMP AND WEAVE

The motion-picture projector is required to locate each successive picture of the film in the same place in the gate, so that the pictures projected on the screen register, and stationary objects in the picture do not jump around. This cannot be accomplished perfectly, and there is always a little motion of stationary objects. The motion in the vertical direction is called "jump" and that in the horizontal direction is called "weave." The jump and weave should be so small that the spectator will not see it, or at least not be annoyed by it.

The jump and weave of a projector can be measured by the use of a film specially prepared for this purpose. This film is made by a machine which clamps a piece of unperforated film and then simultaneously punches a sprocket perforation along the edge and another small hole in the middle. Then it moves the film forward the distance of successive perforations (0.300 inch) and punches a pair of holes again. This process is repeated until a film of sufficient length is prepared.

This film is prepared by the Bell and Howell Co. and is theoretically correct only for testing projectors in which the perforation adjacent to the leading edge of the picture is the one which is placed in position by the claw (on most projectors the claw is displaced from the aperture by one or two perforations). However, it has been found that this film gives smaller values of jump and weave for all machines tested than any other film tried for the purpose, and therefore it is assumed that it is more nearly perfect.

When this film is projected, the jump and weave are magnified and can be measured on the screen. The platform on which the projector is standing for this test should be very rigid to prevent jumping of the image because of vibration. At a magnification of 120 times, neither the jump nor the weave should exceed 3/16-inch. Jump and weave of 1/16 to 1/8 inch are to be expected in the better projectors, and usually the weave is only about half as large as the jump.

## 5. TRAVEL GHOST

If the shutter should be out of step with the intermittent mechanism, part of the motion of the film through the gate will take place while the shutter is open. This results in a blurring by the addition of vertical tails to objects in the picture. This effect is called travel ghost.

The shutters normally used allow light to fall first on one edge of the picture and cut it off, last at the opposite edge. As a result, if travel ghost is present it is most apparent at these edges of the picture.

Sometimes the shutter of a projector is deliberately so proportioned that it opens at one edge of the picture before the film has stopped moving and closes at the other edge after the film has started moving again, thus permitting faint travel ghosts near the edges in order to get maximum light output.

A film for testing for travel ghost should have a few small clear spots on a dark background near the edges of the frame. The film previously described for testing jump and weave is excellent for this purpose because of the great contrast between the hole and the surrounding area. When a projector is tested by this means, no travel ghost should be visible from the position of the nearest spectator (approximately two times the picture width from the screen).

## 6. DURABILITY

A high-grade motion-picture projector represents an investment ranging from something over $100 for a silent projector to something over $400 for a sound-on-film projector, and the purchaser has a right to expect a long period of trouble-free service. Few prospective purchasers can make tests in advance of a purchase to determine how a machine stands up in service. They should, therefore, insist on written guaranties from the manufacturers calling for free replacement of any parts which become defective within a year of the date of delivery or before 400 hours of use, whichever represents the shorter period. It should be specified that this guaranty be made only after suitable tests by a disinterested laboratory have shown that a long period of trouble-free service can be expected from the type of projector so guaranteed. The user of a projector wants to avoid interruptions in service, even though repairs are eventually made free of charge.

There are several components that are often short-lived. A projector should be constructed so that these parts can be replaced easily. When spring belts are used to rotate the reels, it should be possible to replace them, in case of breakage, without taking the machine apart. These belts may last for hundreds of hours, but such life should not be expected, since they are likely to break after as short a life as 25 hours. A supply of spares should always be at hand.

The governors which control the speed of sound projectors are another source of trouble. Part of the current which drives the projector motor goes through the rotating governor, and this is carried to and from the governor by brushes and slip rings. Some of these brushes wear away rapidly. The construction of the machine should be such that the governor is easily accessible and the brushes are easily replaceable. New brushes should be kept on hand.

If the motor uses brushes, they will probably not have to be replaced as often as the governor brushes, but they do wear out and replacements should be handy.

## 7. WEAR ON FILM

There is always some wear and tear on a film when it is run through a projector. Part of this is contributed by the strain imposed on the film by the sprockets and claw, part by the front and back plates of the gate and other surfaces over which the film slides, and part by the flexure of the film at various places where it is bent as it passes. In some machines, twists which are introduced in the film also contribute to the wear. Although some of this wear and tear is unavoidable, it can be reduced considerably by careful design.

Ordinarily only one tooth of a sprocket or claw pulls the film at a time, even though three or four may be inserted in perforations. This is because the spacings of the teeth and of the perforations are unlikely to be identical. The force exerted by this tooth depends upon the friction retarding the motion of the film. For this reason the amount of sliding of the film over stationary parts should be reduced to a minimum. The film has to slide as it passes through the gate, so the force of the spring pressing against the film should be as small as possible and still hold the film in its proper place. Some machines have other surfaces over which the film must slide, such as stationary sound heads and slides to introduce friction for the purpose of aiding in obtaining constant speed through the sound head. Some machines have stationary guides over which the film must slide. It has been found that the abrasion produced by such surfaces is of less consequence than the strain at the perforation introduced in overcoming the friction.

On some machines the sprocket tooth in entering a perforation pushes against the edge of the perforation with a sliding motion which tends to tear the leading edge of the perforation away from the film. After a film has been run through about a hundred times, close examination reveals small cracks in the film starting from the corners at each end of the leading edge of a perforation. After a few hundred more times through, these become so large as to render the film useless. The claw may do this same thing to the film, especially after the cams in the intermittent mechanism have become worn by several hundred hours of use.

The detrimental effect of bends and twists depends upon their sharpness. It would be difficult to determine just what curvature or rate of twist is serious. On one machine examined by the author the ultimate destruction of the film seems to be the result of repeated flexure, but only after 3,000 to 5,000 passages. On another machine (the only one examined which twists the film) a sharp twist seems to be the cause of the destruction after only 200 to 500 passages.

If inspection of the mechanism of a projector reveals the presence of certain of the above-mentioned causes of damage to film, that alone is not to be considered as disqualifying. The decision on this should depend upon the outcome of a test, since it is probable that the life of projected film will be sufficient in spite of the defect.

A satisfactory test for the life of film in a projector can be made by running an endless loop of film through the machine until it is ruined and counting or estimating the number of times it has gone through. In order that the test be made in a reasonable time, there should be only 3 to 5 feet of film in the loop. The projection lamp should not be lighted during the test. The film will probably break near the splice several times before the rest of the film is ruined, so the splice should be replaced as often as necessary and the test continued until the film is so badly worn that it will no longer feed through the machine. Of course, if abrasion of the picture or sound-track areas should spoil the film before it fails to feed through, the test should be terminated as soon as that occurs. It is not likely, however, that the film will be ruined by abrasion. The test should be repeated several times.

There are great differences between the different makes and models of projectors with respect to film life as shown by the above test. Film life ranges from about 500 passages to about 5,000 passages, with breakages at splices occurring every 100 to 1,000 passages approximately.

For many applications a film life of 500 projections may be entirely adequate, and a prospective purchaser must decide for himself whether or not a short film life obtained with a certain projector is outweighed by desirable features in other respects. Judging from the performance of the better projectors, however, it is reasonable to demand a film life of at least 1,000 times through, and that, on the average, splices should not have to be replaced oftener than once every 500 times through.

## 8. MISCELLANEOUS

Some characteristics of projectors cannot easily be tested objectively but should nevertheless be considered when purchase is contemplated. The more important ones are flicker; heating of film and external parts of the projector; control of tilt; and difficulty of setting up, threading, and rewinding.

Most of the 16-millimeter projectors on the market today have shutters which interrupt the light beam three times per picture, the durations of the three interruptions being equal and the durations of the three open periods also being equal. The dark and light periods are not necessarily of equal duration. The flicker produced by such shutters is negligible at the brightnesses ordinarily used for motion pictures. The writer of specifications can be assured of getting projectors which are satisfactory with respect to flicker if he specifies a shutter such as that described above or one which is demonstrably better.

Although numerical values can not be assigned to the flicker, the following method can be used to compare the flicker of two machines. The machines to be tested are set up to project on adjacent areas of the same screen, at distances such that the illuminations from the two are equal and about 20 lumens per square foot for a matte-surfaced screen. The speeds should be adjusted to 16 frames per second. The machines are then run simultaneously, without film. If there is a significant difference in flicker it can then be detected.

The external parts of a projector are always heated to some extent by the projection lamp. Although this does not adversely affect the performance of the projector, it is undesirable that the parts that are touched while threading become uncomfortably hot. Specifications should contain a paragraph that will enable the prospective purchaser to reject a machine if the lens barrel, sprocket guards, or aperture plates become too hot for comfortable manipulation during ordinary operation.

The film is always heated as it passes through the projector, and this probably contributes to its deterioration. However, tests made at this Bureau indicate that there is no great difference in the life of test loops of film whether the tests are made with the projection lamp lighted or with it dark. The film loops used in these tests had lengths such that they went once around in about 45 seconds. This means that in projectors available at the present time, other factors contributing to the deterioration of the film are of greater importance than the heating. As film is used in practice, it always has time to cool and partially recover its moisture content before being projected again. This makes the heating of even less importance than it is for test loops.

It would be difficult to prescribe a satisfactory test for the heating of the film as it passes through the projector and to determine the detrimental effect of such heating. The temperatures of the metal parts with which the film comes into contact are almost irrelevant, since the predominant part of the heat acquired by the film is the result of absorption of radiant energy at the aperture.

Adjustment of the framing device on some machines dislocates the picture on the screen. Such machines should have tilt controls which can be manipulated easily with one hand in order that compensation can quickly be made for the dislocation of the picture while framing.

There are considerable differences between the various makes of projectors in the difficulty of setting up, threading, and rewinding. These difficulties are of little importance if the operator has learned the procedure and operates frequently; but where the machine is to be operated by unskilled persons, it is desirable that these operations be as simple as possible.

## VII. CONCLUSION

A knowledge of the characteristics of various makes of projectors as determined by the tests described above should enable a prospective purchaser to select the one which most economically satisfies his requirements.

Where purchases are made through a purchasing agent, it is necessary to specify in advance the minimum values of each characteristic which will insure satisfactory performance. In order to satisfy requirements of simplicity of operation, it may be necessary to specify a few constructional details. Since there is always the possibility of some bidder submitting a cheaply made machine which will satisfy all the prescribed requirements but is likely to be worn out shortly after the expiration of the guaranty, all specifications should include a paragraph stating that all materials used in the construction of the machine shall be entirely suitable for the purpose. This will allow the rejection of machines in which there are obvious defects which were not anticipated when the specifications were written.

The following values of performance characteristics, suggested as the minimum acceptable, are sufficient to assure excellent service within the limitations of 16-millimeter equipment, and are within limits now attainable by the better class of projectors.

*Resolving power:*

| | | | | |
|---|---|---|---|---|
| Position in field | 0° | 2.5° | 5° | 6° |
| Resolving power in lines per millimeter | 64 | 64 | 22 | 16 |

*Illumination:*

At a magnification of 120 times (linear), the projector, running without film, should furnish at least 19 lumens per square foot at the center of the field and at least 0.70 of the central illumination at each of the marginal positions 18 inches to right and left of center, and 12 inches above and below center.

*Jump and weave:*

When measured at a magnification of 120 times, the jump should not exceed 3/16 inch and the weave should not exceed 3/32 inch.

*Travel ghost:*

No travel ghost should be visible from a distance of two times the width of the picture when the jump-and-weave test film is projected.

*Film life:*

A small test loop of film should run through the projector at least 1,000 times before it is rendered unfit for further use. One break at the splice per 500 times through is allowable.

*Durability:*

A good projector should show negligible wear after 500 hours use except for motor and governor brushes. Each brush should last at least 400 hours.

A guaranty calling for replacement without charge of any part becoming defective before 400 hours' use should be expected of the manufacturer.

WASHINGTON, December 5, 1941.

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