Film-Tech

This paper reflects work done on, and is applicable to, acetate film base only. It does not apply to modern polyester film base.

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Society of Motion Picture and Television Engineers
595 Hartsdale Avenue
White Plains, New York 10607
www.smpte.org

Effect of Winding on the Projection Performance of 35mm Motion-Picture Film

By PAUL H. PREO
and ERIC A. YAVITZ

Projection performance depends greatly upon the diameter to which the film has been wound on a reel or core prior to projection, and the effect is more obvious for film wound emulsion-out. Screen-image quality differs considerably between the head and core ends of a theater print, but if the film is kept wound emulsion-in, the focus stability is substantially improved, particularly in the larger, higher-intensity installations. These effects have been examined in a continuous series of practical studies. Extrapolations are suggested from the 35mm experiments to all projection formats.

As previously reported by Kolb,[1] an accelerated projection test utilizing short loops of film is used routinely in Kodak Park to evaluate the projection performance of release print films. It will be recalled that a curve of the type shown in Fig. 1, with little change in optimum focus of the film, is indicative of potentially satisfactory projection performance. Numerical values relating to focus position were omitted on the vertical axis of this, and all the subsequent figures, because they are directly related to the conditions under which the film is projected. The general shape of the curve and its position relative to the zero axis are the dominant factors to be illustrated.

A curve of the type shown in Fig. 2, however, with a large change in optimum focus and excursion from negative to positive focus, is indicative of poorer performance. This large shift in focus position is readily observed on the screen as a transition from good image quality to flutter, followed by in-and-out of focus, and finally as a sharp central image with the periphery excessively out of focus. It will be further recalled that particular image degradation, in the form of flutter and in-and-out of focus, is encountered when the focus position is at, or near, the zero, or neutral axis. Since the severity of the test can be varied at will by changes in projector arc intensity,[2] ambient relative humidity, length of loop and other factors, it is difficult to establish an accurate correlation between the loop test and actual theatrical projection. Nevertheless, the test is an excellent tool in directly comparing the projection performance of different types of film. It is further a good presumption that the film which survives the harsh loop test should present no problem in the theater, where projection conditions are much less stringent.

In addition to the evaluation of various release positive materials, the accelerated loop test has been used as an experimental tool to study factors which affect the projection performance of films.[3] It is through further understanding of factors which cause projection problems that we may hope some day to alleviate these problems.

In one such series of correlative tests, the loop test results have been compared directly with the performance of "trade rolls" which contain the same film and are projected as standard release reels of approximately 1,800 ft each.

During the projection testing of these trade rolls, it was noted that there was a focus drift from the head of the reel to the tail end of the reel. Because trade rolls are focused at 100-ft intervals during these tests, the culminating effect of the drift was not noticeable on the screen. Further studies, however, indicated that the focus drift was considerable and could indeed affect screen image quality during the projection of a full theater reel. There was also an overall day-to-day drift toward the threshold at which screen image quality could become degraded.

Similar effects have been reported by some projectionists; although since it is, of course, more difficult to control the many variables in a theater, the projectionists have not had as fortunate opportunities to explore the problem in depth. It is the purpose of this report to describe some new information recently obtained on factors not previously recognized as having an effect on the projection performance of motion-picture films. These factors are the roll diameter and the orientation in which the film is wound prior to projection.

Effect of Film Format

Although this experimental work was done with 35mm film in theatrical equipment, the results are applicable to all projection of motion-picture film in all sizes and formats. Of course, the magnitudes of the effect observed will depend upon the magnitudes of the important dimensions.

Forces affecting the performance of film in the gate at the instant of projection have their origin in the heating of the image. Previous work has shown that this heating is a function of the radiant flux density[1,4] and of the relationship between the spectral energy distribution of the light beam and the spectral absorption of the film image.[5] Although it is customary to think of projection light sources in terms of their total output, such concepts may be misleading as the sole indication of radiant flux density. If no other changes are made than in the size of the film itself, for example, the same projection arc might supply a certain level of radiant flux density in the center of a 35mm "wide-screen" aperture, only 65% of that flux in the center of a CinemaScope aperture, and only 22% in the center of a 70mm Todd-AO aperture. On the other hand, a projection light source with only 6% of the output of that arc would provide an equivalent flux in the center of an 8mm aperture. In like manner it is necessary to consider the absorption characteristics of the film image *in direct relation to the energy distribution in the projection beam.* Inasmuch as a variety of sources is used commercially, and these are further "filtered" by various means both inside the lamp-house and outside — and since the effective image absorption is further shifted by concurrent usage of metallic, toned and dye images, the practical extrapolation of these data to other projection conditions in which the deforming forces may be different is sometimes complex. This does not, of course, detract from the relative simplicity of the basic laws.

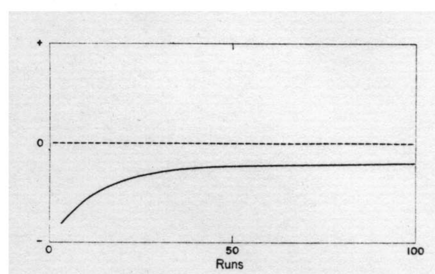

Fig. 1. Optimum focus during each run indicating potentially satisfactory projection performance.

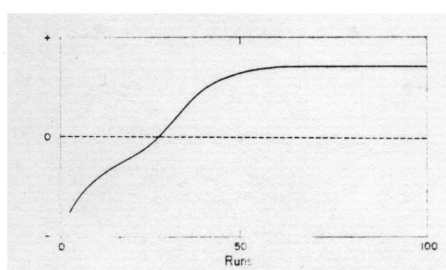

Fig. 2. Excessive focus excursion during repeated projection indicative of poorer performance.

Presented on March 30, 1965, at the Society's Technical Conference in Los Angeles by Paul H. Preo (who read the paper), Eastman Kodak Co., Kodak Park, Bldg. 35, Rochester, N.Y. 14650.
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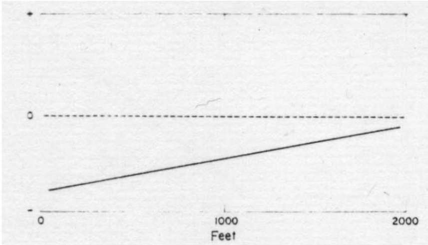

Fig. 3. Change in optimum focus position from head to tail of a 2000-ft reel.

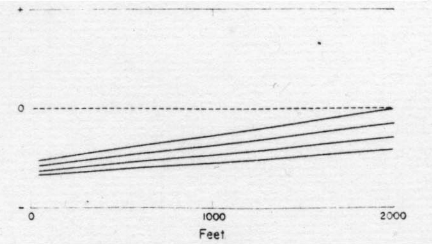

Fig. 5. Day-to-day focus drift towards the zero axis as a result of the continuing projection of the same reel of film.

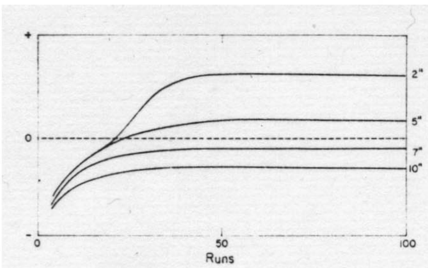

Fig. 4. Effect of winding diameter on the focus position and projection performance of 35mm film wound emulsion-out.

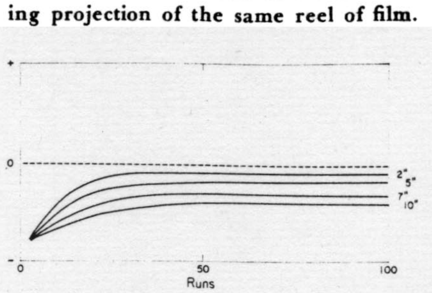

Fig. 6. Effect of winding diameter on the focus position and projection performance of 35mm film wound emulsion-in.

Magnitude of film motion during the instant of projection depends upon both the forces involved and the rigidity of the film (in conjunction with any restraining forces that may be acting). Film rigidity is described to a first approximation by the basic formulas of mechanics defining the deflection of beams and plates under load. The significant dimensions in these relationships show that the amount of deflection is directly proportionate to the square or cube of the span, and inversely proportional to the square or cube of the thickness. Comparisons among 70mm, 35mm, 16mm and 8mm are therefore related to the size of the image. The most significant format dimension seems to be the width of the film area left unsupported between the normal projector side rails, or in some cases the diagonal of the image area subjected to radiant flux. In normal projection the film thickness is relatively constant throughout these formats, although in a few special-purpose projection systems both thinner and thicker films may be involved. Accordingly, straightforward mathematics can give a reasonable prediction of the relative film movement to be expected for any projection format of interest and provide adequate answers for most preliminary design problems.

The film focus effect, however, depends ultimately upon the visibility of the phenomena upon the screen and, therefore, upon the degree of uncertainty in film positioning that is permitted by the depth of focus of the projection optics. It has long been observed in regular theater operation that lenses of short-focal length are less tolerant of film positioning than those of long-focal length, that a high-aperture lens is less tolerant than a low, and that a lens of high definition and excellent correction is more critical than one of lesser perfection. When these same characteristics are compared in the extreme — for example, between 70mm projection with a 5.0-in. $f/1.8$ lens and 8mm projection with a 15mm $f/1.2$ lens — it becomes immediately obvious that an uncertainty in film positioning that is unnoticed in one system may represent complete failure in another.

This discussion on the relation of projection effects and image format emphasizes that we do have the understanding to make valuable qualitative predictions and that problems of image quality are not characteristic of a single system but are universal. The expansion of motion-picture projection applications and the application of new technologies have, in fact, brought us closer to the point where equivalent situations exist in all formats.

The remainder of this paper will be written specifically in terms of 35mm for greater simplicity and clarity of discussion.

Test Results

In preliminary tests, it was often observed that during the normal projection of a 2,000-ft reel of film, the optimum focus position tends to change continuously to some extent. This change is represented in Fig. 3 which contains a plot of focus position as a function of projected footage. Although the amount of change in focus varies with many factors, the change is observed to be always in the positive direction as the tail end of the reel is approached. If, then, the same reel is projected tail first, the focus change reverses itself and the various portions of the film still focus at the same position as they did during head-first projection. This fact indicates that the change in focus from head to tail of a reel occurs over and above any changes which may be caused by the heating of the projector gate and optics and, indeed, that the focus is determined by some physical properties inherent in the piece of film being projected at any given moment. This then suggests that a piece of film at the tail end of a 2,000-ft reel may have different projection properties than a piece of film at the head end of the same reel.

To examine this suggestion, accelerated loop projection tests were performed on lengths of film taken from different sections of the same reel. Test results are shown in Fig. 4. It is clearly seen that as the diameter of winding becomes smaller, the projection performance deteriorates, even though all the samples in the test are from the same strip of film wound in the same roll. This test shows that whereas the film at the head end of a roll may undergo only a small change in focus on repeated projection, the tail end of the same roll may undergo a much greater focus change during the same number of projections. The freshly processed film samples were wound on 2-in. cores and on film rolls of the indicated diameters. Shortly before testing, the samples were made up into 22-ft loops and projected at 30% RH and with a mean net flux of 0.5 w/sq mm. It should be observed that, as the diameter increased, the performance of the film improved. The results clearly indicated the effect of the changing curvature, or set, on the projection performance and screen image quality of the film. Continuing projection of the same samples also showed a day-to-day drift toward the positive side of zero focus. This condition can show itself in the theater in a number of ways, some of which have been occasionally experienced in the trade.

(1) A gradual change in optimum focus from head to tail of a reel can cause the picture to go gradually softer, requiring constant vigilance and periodic refocusing on the part of the projectionist. This effect is encountered occasionally in theaters using high-intensity projection.

(2) As the tail end of a roll changes its optimum focus with repeated projection, it may eventually approach the zero or neutral axis, where projected image quality is sharply degraded by "flutter." In such cases, no amount of refocusing can bring the projected image into sharp focus. This condition is encountered only rarely in present-day theatrical projection.

(3) Since the head end of the roll also changes focus with repeated projection, albeit at a slower rate than the tail

end, it too can become subject to the image degradation which is encountered when the focus approaches the zero axis. Such gradual changes in focus behavior from day to day are represented by Fig. 5.

While these problems of image quality are not matters of universal concern, it is obvious that an increase in the amount of total light available on projection screens has many significant advantages. Accordingly, there will always be a number of installations in which the projection system is pushed to its maximum capability — and basically it is these high-performance theaters that must be most alert to every detail of projection. It is inevitable that more attention and more skill will be required to meet higher standards.

It becomes evident as a result of this work that some physical action due to winding — perhaps a result of plastic flow or "core set" within the wound film — has a major influence on projection performance. As a result of this factor, the projection properties of a roll of film deteriorate sharply as the winding diameter becomes smaller.

To study further the effect of plastic flow, a similar set of tests was run on lengths of film from various portions of a roll wound emulsion-in, contrary to present practice. The results are shown in Fig. 6. It will be noted that although there is still some slight deterioration in quality as the winding diameter becomes smaller, this deterioration is dramatically less than in a roll of film wound emulsion-out. In fact, the projection performance of film wound emulsion-in is shown to be markedly superior to that of the same film wound emulsion-out.

It was further found that the effects of winding orientation are reversible. A roll of film which has been wound emulsion-out and shows the characteristic deterioration of projection performance can be rewound emulsion-in, and in time, because of plastic flow, it will assume the superior projection performance characteristics of emulsion-in winding. Since flow is a reversible, time-dependent phenomenon,[6] the effects of plastic set in film are reversible over a long period of time. We have also found experimentally that these particular plastic changes affecting image definition can also be "erased" in rather short order by immersion of the film in moderately hot water. The plastic set which results when film is wound on a reel for some time can be removed by immersing the film in 110 F water for about 5 min. The film then has no "memory" of any previous winding history and is in a virgin, or unwound, state.

The startling effect of the erasure of plastic memory on projection performance is evident in the test shown in Fig. 7. A sample of film which had been kept in an emulsion-out winding was projected in a short loop and produced the portion of the curve shown on the left. The film went through zero focus and produced flutter and in-and-out of focus before projection was terminated. One-half of the film in the loop was then treated by a short immersion in 110 F water and dried. The treated sample was then spliced back into the loop with the untreated sample and projection was resumed. The two curves on the right of Fig. 7 graphically show the results of the treatment and the effect of erasing the plastic set or memory in the treated portion of the film. After treatment, the film not only returned to the same focus position it had when the test started, but also it showed distinctly better projection properties and resisted the tendency toward in-and-out of focus which it displayed prior to treatment. The untreated portion, on the other hand, continued to display poor projection.

The difference between the treated and the untreated portions of the film is apparent, incidentally, only upon projection. Careful examination and measurement of the normal physical characteristics of the two films show them to be indistinguishable. The changes occurring during repeated projection that are responsible for the differences in focus behavior do not correlate with measurements of curl, shrinkage, moisture content, or any other of the many physical characteristics — and the reversal produced by immersion in water is likewise not identifiable by measurements other than those made during actual projection.

It was also found that equal erasure of plastic memory or set could be obtained by longer immersion in water of lower temperature. For example, immersion in 70 F water for 20 min (simulating immersion during photographic processing) is as effective in eliminating plastic set as a shorter immersion in 110 F water.

One final experiment was run to demonstrate the effect of winding orientation on projection performance. A length of processed film was treated by water immersion in order to eliminate any plastic set which might have been present as a result of previous winding history. This length of film was then divided into three sections. One section was wound emulsion-out on a 2-in. core and a second section was wound emulsion-in on a similar core. The third section was not wound at all, but simply allowed to lie flat on a bench top.

These three samples were kept for several weeks at normal room temperature in order to allow plastic flow or set to occur in the samples which had been wound on cores. After that time, the standard projection performance test was used, producing the dramatic results shown in Fig. 8. The sample which had not been wound at all showed the best projection performance of the three. The sample wound in the emulsion-in orientation showed projection properties which were only very slightly poorer than the unwound check. The sample wound emulsion-out (in the standard manner) showed substantially deteriorated projection performance.

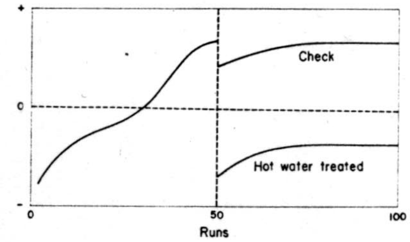

Fig. 7. Effect of hot water treatment on a film sample which had exhibited poor projection performance after 50 runs.

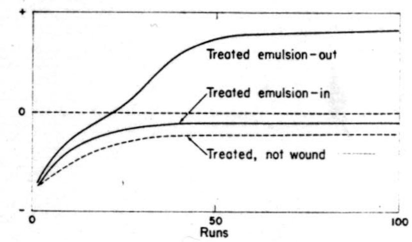

Fig. 8. Comparison of projection performance between an unwound film sample and two samples from the same strip wound emulsion-in and emulsion-out.

Discussion

It can therefore be stated from the results of all these tests that film wound emulsion-out has poorer properties than the same film wound emulsion-in, and that this difference is greatly accentuated as the winding diameter becomes smaller.

The work presented here indicates that winding diameter and emulsion orientation have a profound influence on the projection performance of current release positive film. The test results have clearly demonstrated the virtues of emulsion-in winding of processed film as a means to improve projection performance. Unwound film, which is relaxed and without plastic memory, performs best. The condition of film as it comes off the processing machine achieves this status as a result of the similarity of the process to the 70 F water treatment. The subsequent winding orientation helps determine the type of projection performance that the film will provide. Emulsion-in winding will maintain the good projection properties of unwound film. Emulsion-out winding, however, will cause a deterioration in projection performance.

According to current trade practices,

processed film is wound emulsion-out when it leaves the processing machine, and is kept in this orientation almost exclusively throughout its entire history — the very orientation which is detrimental to projection properties.

The significant advantage of emulsion-in winding is not only that it improves the projection performance of a reel of print film but also that it minimizes the difference in projection performance between the head and the tail end of the reel. This means that it minimizes changes in focus during the projection of a single reel. This problem has been encountered in some theaters using high-intensity arc projection, and relief from it would benefit projectionists and theater owners.

Although emulsion-in winding should not be looked on as a panacea for all projection problems, it certainly enhances the film's resistance to projection and makes possible improved performance by increasing focus stability from head to tail of a reel and from one day to the next.

One other ramification of the work described herein should be explored briefly. It has been shown that proper immersion and the resulting erasure of plastic set has not only a preventive but also a remedial effect on the projection properties of film. In other words, a given piece of film which may, after repeated projections, become susceptible to projection problems such as flutter and in-and-out of focus, can be treated by immersion. Its projection properties would then revert to the satisfactory level that the film had when first projected. On this basis, one could treat a print which has run into projection problems in the theater and restore much of its original projection quality. Of course, the rejuvenation would be only a temporary remedy, since subsequent emulsion-out winding will once again cause a slow deterioration in the projection properties of the film.

Another factor which comes to mind in contemplating emulsion-in winding is its effect on other physical properties of the film. The property which is most likely to be affected by a change in winding is the curl level of the film involved. With emulsion-in winding, one would expect an increase in positive curl. Indeed, measurements made in conjunction with this work did show a moderately increased positive curl. This increased curl is not sufficient to cause problems, however, and is not considered a deterrent to the adoption of emulsion-in winding as a universal practice.

Present Practice in Handling Release Prints

The current practice of handling release prints, under normal conditions, begins in the processing laboratory. After processing, and inspection, the prints are shipped to the exchanges, usually as 2,000-ft rolls wound emulsion-out on 2-in. cores, and packed in individual metal cans. Upon receipt at the exchange, the rolls are mounted onto 2,000-ft shipping reels emulsion-out, and the necessary splices are made between the A & B sections of the roll when applicable. The reels making up the complete release are then packed into shipping cases to await shipment. When the print receives a play date, the vault card is drawn, the shipping cases are labeled and the print is shipped. If this is the very first booking, or if the print has been inspected prior to shipment, it is received by the theater head-out and wound emulsion-out, ready to project. If no inspection has been made, however, the print could be either head-out or tail-out, with either winding orientation. In any event, the projectionists in most first-run houses take the print on delivery and rewind the film onto their own special house reels. After projection, the film which was wound emulsion-in during take-up, is rewound emulsion-out and head-out preparatory to the next projection. After the last run of an engagement, if house reels have been used, the print is either rewound onto the shipping reels emulsion-out and head-out, or it may have been taken up in the projector on shipping reels emulsion-in and tail-out. The print is then shipped back to the exchange, or possibly directly to the next theater. At the exchange, the incoming print could remain unattended for some length of time before inspection and the next booking. Because of these many possibilities it would be difficult to keep a strict check on the winding orientation. A new, top feature release, however, would get preferential treatment and its winding orientation could be checked and maintained because of its greater commercial import.

Practical Application in the Trade

The following practical benefits of emulsion-in winding should be emphasized:

(1) The screen image quality would be greatly improved throughout a full reel with a minimum risk of focus drift, flutter, and in-and-out of focus. Flutter describes a condition in which the film in the aperture does not conform to a smooth, normal negative drift, (toward the lamphouse) but rather becomes overly relaxed, assuming random positions in the aperture. This condition is not extreme, but it does prevent sharp focus on the screen because the film excursion exceeds the depth of focus of the projection lens. In-and-out of focus is a more violent and erratic form of flutter. The film in the aperture moves violently from negative to positive, or vice versa. The motion of the film is excessive and erratic, so the projection lens cannot cope with it. The resultant screen image is alternately in focus, or out of focus in a random fashion.

(2) The erasable nature of plastic flow suggests the possibility of rejuvenating release prints during the course of their booking schedule. Occasional treatment may prevent or remedy possible projection difficulties and extend the useful life of the film in the theater.

(3) Because the emulsion-in wind minimizes plastic flow and the accompanying adverse effects of incident radiant energy, a moderate increase in screen illumination could be tolerated while still maintaining a high level of projection performance.

In order to obtain in practice the full benefits indicated by the work reported here, it would be necessary to change the current film winding practices in the motion-picture industry. It would be mandatory for processed motion-picture print films to be always kept wound in an emulsion-in orientation. Since plastic flow is a time-dependent phenomenon, it would be necessary to begin the emulsion-in winding orientation as soon as the film comes off the processing machine in the laboratory. Since plastic flow is also a reversible phenomenon, it would be advisable not to wind the film in an emulsion-out orientation at any subsequent time. By the same token, short periods of time spent in an emulsion-out winding will not be completely ruinous to the film's projection properties since subsequent emulsion-in winding will eventually remedy the situation; however, it does appear that the deleterious effects of emulsion-out plastic flow are produced quite rapidly and the improvement through emulsion-in plastic flow takes very much longer! The ultimate objective, therefore, would be for the film never to be wound emulsion-out. Implementation of such practice is a formidable task. It requires maximum interest and cooperation in the laboratory, in the film exchange, and in the projection room.

A limited survey undertaken some time ago to determine winding practices in processing laboratories shows that the universal practice is to take up film on a 2-in. core and in an emulsion-out winding as it comes off from the processing machine. It is apparent that here, at the origin of the release print, the procedure would have to be altered to conform with the emulsion-in winding orientation. A half twist in the film, or a change in the direction of rotation of the take-up spindle would be needed, along with changing of old habits among the operating personnel. This would probably be the easiest phase in the implementation of the emulsion-in winding.

A more comprehensive survey of the film exchanges throughout the country indicates in some cases that only small mechanical modifications would be required. Modifications to some film inspection machines would be deemed advisable in order to facilitate splicing of film coming off an emulsion-in reel. Film exchange personnel point out that a change in winding orientation would not be completely foreign to them, since they are occasionally called on at the present time to handle film in both winding orientations with no apparent hardship. Nevertheless, there would be extensive re-education to be done among exchange personnel, together with an emphasis upon the importance of winding orientation.

The one area which has not been investigated, except for a few local contacts, is the theater, or more specifically, the projection room. The actual change in technique involved here seems to be relatively simple. It merely involves putting the reel in the upper film magazine so that the film comes off in a clockwise rotation from the front of the reel rather than from the back as in current practice. The film would then be wound normally in the projector take-up magazine. In rewinding the reel, the projectionist would have to go straight across from reel to reel rather than from bottom to top. This procedure presents no problem in manual rewinds, and probably little, or no problems on motor driven rewinds. The addition of an idler roller in the upper magazine of some projectors would be recommended in order to minimize the chance of film abrasion in the magazine, but otherwise, no change or modification is needed to the projection equipment.

The major problem here, as in other areas, would likely be the re-education of personnel involved. The large number of projectionists scattered in so many places in the United States and abroad would make the task a difficult one in itself. This fact, coupled with the difficulty of breaking long-ingrained habits, and the risk of mistreated, mislabeled and mishandled prints make the assignment of changing film winding practices look formidable indeed.

Of course, it is equally apparent that the major benefits from such a proposed change in practices might well be observed in a relatively few theaters where special showmanship is paramount. It is, therefore, conceivable that the change might be made first in such a limited market, with the benefits to be spread more gradually throughout the rest of the industry as re-education and re-emphasis became practical.

The work described offers not only a means for improving projection performance, but also some basic new knowledge which may be useful in understanding and explaining the actual mechanisms producing uncertainty in positioning of the film, during high-intensity projection. The widespread recognition of the facts, together with the difficulties of a consistent hypothesis, serve to make the problem the more intriguing!

Conclusions

As a result of the work described in this paper along with the surveys made in relation to this work, the following conclusions are evident:

(1) The diameter at which a film sample is wound has a great effect on its projection performance. Generally, the head of the reel has projection properties superior to those of the tail.

(2) Film wound emulsion-out amplifies the effects of winding diameters and is more susceptible to projection problems such as focus drift, flutter and in-and-out of focus, whereas film which has been kept wound emulsion-in reduces these projection problems.

(3) The winding effects are reversible, time-dependent and erasable.

(4) Better projection performance will result if the prints are kept wound emulsion-in from the time that they come off the processing machine.

(5) Although the phenomena have been studied in 35mm format, the conclusions are applicable in degree to projection in all formats.

(6) The acceptance of the new winding orientation could benefit the trade only if the laboratories, exchanges and theaters were aware that cooperation must be complete.

(7) The difficulty in achieving an overall change in film-handling techniques should not be minimized, but the realization of that purpose has great potential rewards.

Acknowledgment

During the course of the investigation leading to the presentation of this paper, the authors received assistance from many colleagues. Particular mention should be made of the contributions by Robert S. Battey and Frederick J. Kolb, Jr.

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