New Fluorescent Lamp and Ballast Design For Rapid Starting

By A. E. LEMMERS
W. W. BROOKS

This paper presents technical material which led to the rapid-start lamp and ballast. Lamp and ballast characteristics have been integrated in a manner to produce a fluorescent lighting system with unusual characteristics. It combines the desirable features of both of the two older systems, switch start and instant start. It eliminates the less desirable features of both.

THE NEW rapid-starting fluorescent lamp and ballast system described in this paper offers the lighting industry new concepts in high quality, rapid-starting, fluorescent lighting with considerable reduction in materials used in the ballast. This has been brought about by taking advantage of certain lamp characteristics and making a new lamp and a ballast which were integrated.

The idea back of this development was to make use of everything possible in both lamp and ballast characteristics to the end that a fast starting system might be made which would have the smallest, most efficient ballast consistent with high quality lighting using mass produced fluorescent lamps.

The present instant start systems suffer mainly in weight and overall efficiency. Even with this against them the advantages of starter elimination and fast starting have caused a growing acceptance. Lesser disadvantages are shorter life, higher loss, and a condition at the end of life which can cause ballast failure in some cases. All the ballast disadvantages of the instant start systems stem from the high voltages and volt-amperes needed for satisfactory starting.[1] Any reduction in volts and volt-amperes needed to start lamps improves the economics of fluorescent lighting. The new system is much closer to the theoretical minimum volt-amperes for starting than any of the older instant-starting systems.

The complex inter-relations between lamps and ballasts have been explored in relation to a reduction in starting volt-amperes for many lamp sizes. They can roughly be broken down to the following: 1. What happens to the starting voltage of ordinary lamps when cathode heat is supplied simultaneously with the voltage. 2. What happens to the starting voltage when starting aids are built into the lamps. 3. How the cost of supplying the cathode heat is made practically negligible.

Starting Volts — Cathode Heat Relation

In Fig. 1 the starting volts for 40-watt T12 fluorescent lamps have been plotted against cathode heating current under several lamp conditions. The same lamps were used in curves A, B and C. Ionization of the lamp atmosphere as well as cathode fall changes appear to be the cause of the abrupt drop. At the lower voltage end of the curves, glow has set in. Curve A is for lamps several feet removed from adjacent conductors. It seems evident that under these conditions cathode heat at 0.6 amperes has reduced starting volts by about 150 volts.

In curve B a starting aid in the form of a conductive stripe 2 to 3 mm wide was painted on the lamps lengthwise. In curve C the stripe was connected to one end of the lamp. Note how the effect of the starting aid, when connected, has added greatly to the effect of cathode heat. In curves B and C, as indicated by tests, the starting without cathode heat is damaging while the starting with heat is not.

This lowering of starting volts, however, has cost about 6 watts per cathode. To take advantage of the reduction in starting volts some means of reducing the cathode heat after the lamps start must be found. Such a preheat current, if left on, is both wasteful and destructive during operation. Our work proceeded in two directions: doing what was possible with ordinary lamps and changing lamps so that full advantage of starting aids and cathode heat could be taken.

Present Lamps and Their Limitations

Examine the voltages needed to start ordinary lamps. Under many circumstances starting volts would be approximately as shown in curve C, Fig. 1. This would be for lamps in grounded metal fixtures

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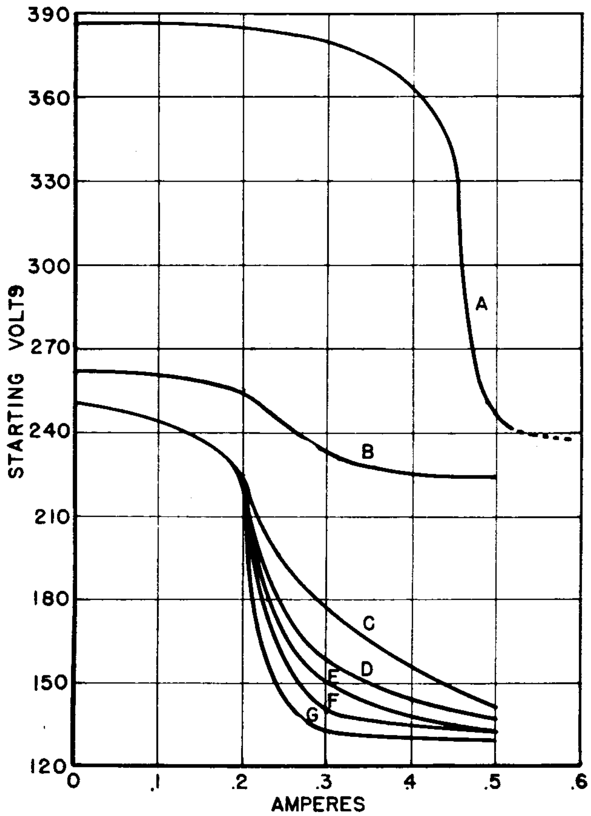

Figure 1. These curves show how cathode heat and starting aids are related and how they lower starting volts in 40WT12 lamps. Text explains conditions.

at relative humidities less than 80 per cent. However, under high humidity or in the absence of a metal fixture, the starting volts would be as shown in curve A, Fig. 1. At 90 per cent or higher relative humidity, the starting volts on new lamps could be much higher. Such a condition is shown in Fig. 2. Here the humidity effect and the effect of residual gases present in lamps which have been burned but a few minutes are shown to be additive.[2] Residual gases do not permanently clean up until several hours of burning. These gases are mainly nitrogen from nitrogen-mercury compounds.

Considering these factors, one would set the nominal starting volts with cathode heat at about 330 volts for 40WT12 lamps. When open-circuit volts are raised this high to overcome such adverse conditions we find that under favorable conditions this high voltage starts the lamps before the cathodes are sufficiently heated. This shortens life and produces early end darkening. Not only can we lose the benefits of a "fixture-type" starting aid under high humidity but damage results under good starting conditions if the ballast open-circuit volts are high enough to obtain starting under adverse conditions. For good results we either have to make sure the starting aid is not nullified or is never present.

The first condition cannot be met without redesigning the lamp. The second, however, can to some extent be had by making the mid-connection in the auto-transformer ballast the same potential as the fixture or starting aid. This reduces the effect of the starting aid and makes the starting more dependent upon cathode heat and end glow. Such an arrangement permits at least a 25 per cent reduction in starting volts under most humidity conditions (80 per cent or less). If non-starting at lower humidity (60 per cent) were permitted, a 40 per cent reduction is possible. With the first arrangement giving reasonable starting, a reduction of 25 per cent to 30 per cent in life may be experienced. In the second set of conditions normal life may be experienced but non-starting will frequently occur.

To get this type of starting (that is, without starting aid) an end glow at the cathodes is needed. Regular 40-watt lamps will have an end glow if heated with approximately 0.6 amperes through the cathode. A current of such magnitude if left on during lamp operation, causes the cathode spot

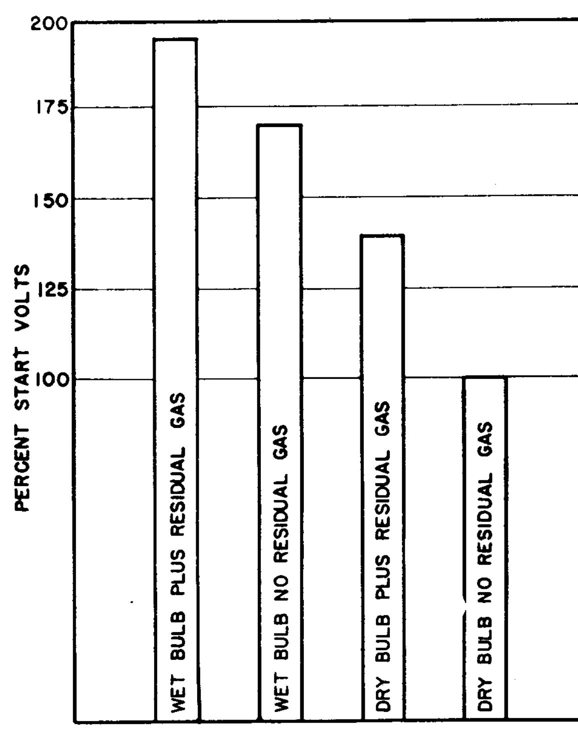

Figure 2. An example of how lowered bulb resistance, due to humidity, and the residual gases, which return in lamps during storage, act together to raise lamp starting volts when used with a grounded fixture and with cathode heat. Comparing this diagram with the curve in Fig. 4 will show that the humidity causes an effect greater than that due to removal of starting aid.

to overheat, resulting in early end darkening, shorter life, and increased wattage loss. This cathode current is, however, easily reduced by several methods as shown in ballast circuits in Fig. 3. Circuit A uses a filament supply transformer with its primary across the lamp. Here the cathode heat is reduced by the change of open-circuit volts to lamp volts.

With circuits B, C, and D there is a reduction in cathode heat by neutralization, caused by an opposing voltage after the lamps start. Perfect neutralization is difficult to obtain. The vector relations of the various circuit elements of a practical ballast do not yield any two elements 180° out of phase. Thus, only partial neutralization is possible unless the lead-lag type as in D is used. Ballasts incorporating all these various neutralizing schemes have been made and tested. None is impractical of manufacture. The particular one used would depend on the lamp size, type of service, and economics of both manufacture and use. There are only two reasons for neutralizing the preheat current. These are to prevent cathode overheating and to conserve watts.

In trying to apply these starting techniques to the regular lamps two factors prevent the full benefits of reduced ballast size and cost. One is the absence of a lamp starting aid needed under humid conditions. The other is the increased size and cost of a ballast employing the cathode heating and neutralizing elements. The best compromise also gives some reduction in lamp life. The new lamp has been designed to overcome these disadvantages.

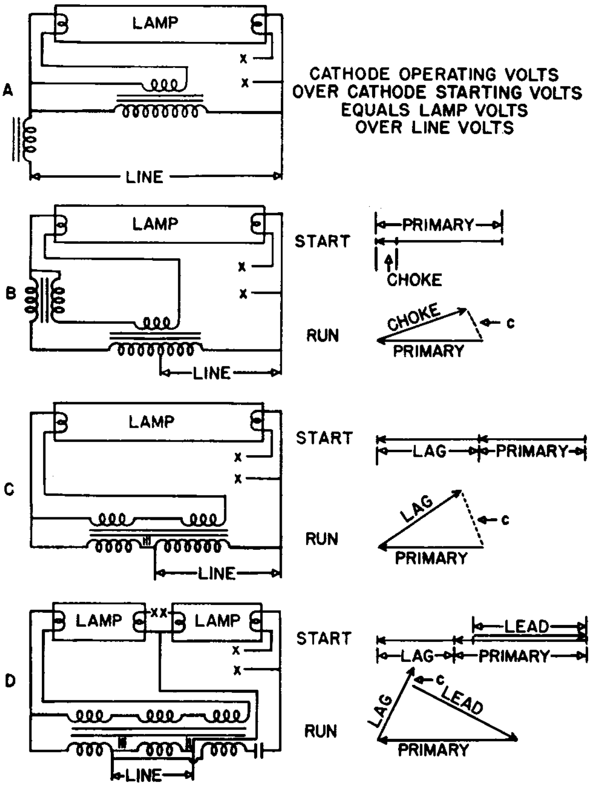

Figure 3. These circuits show the various ways in which cathode preheat may be reduced. The xx points indicate a connection is to be made to a cathode heater circuit which was omitted for clarity. The vector diagrams indicate in a general way how the voltages in the cathode heater circuits swing about at run to cause neutralization. The C indicates the magnitude of the cathode load.

Design Features of New Lamps — Aids

Let us examine the results of the new lamps which employ starting aids. Curves C, D, E, F, and G, Fig. 1 show how five different starting aids lower starting volts when used in conjunction with cathode heat. Curve C shows the effect of the grounded stripe. Curve D shows the effect of a grounded fixture. Curve E is for an outside grounded transparent conductive coating, as compared with an inside conductive coating in Curve F. Last and most effective, Curve G, a transparent conductive coating with a potential difference of at least 150 volts to either cathode.

The action of all of these starting aids is similar. All have the effect of reducing the cathode heat needed to obtain the greatest reduction in starting volts. The choice of any of these starting aids is, of course, determined first by whether they reduce the starting voltage sufficiently for the application in mind, and second, by economic and manufacturing considerations. For 40-watt T12 48-inch lamps, all of them reduce the starting volts enough to make use of the most economical and efficiently designed ballast. Economically, the use of the grounded fixture is a good choice. This requires the lamps to be coated with a water repellent material such as Dri-Film.* Instant-start lamps are presently so coated. The effect of these starting aids in conjunction with cathode heat has been investigated in lamps of all the sizes commonly available. Fig. 4 shows the increase in starting voltage when starting aids are not employed for various lengths of T12 lamps.

Cathode Heat — Demand and Effect on Ballast

The cathode heat alone in all sizes has given a reduction in starting voltage of 80 to 125 volts without end glow. The variation is believed to be due to differences in work function at different temperatures between different cathodes. A cathode abused by a few hundred cold starts will give less reduction of starting volts upon being heated. Burning for some hours will frequently return it

*Reg. General Electric Co. Trade Mark.

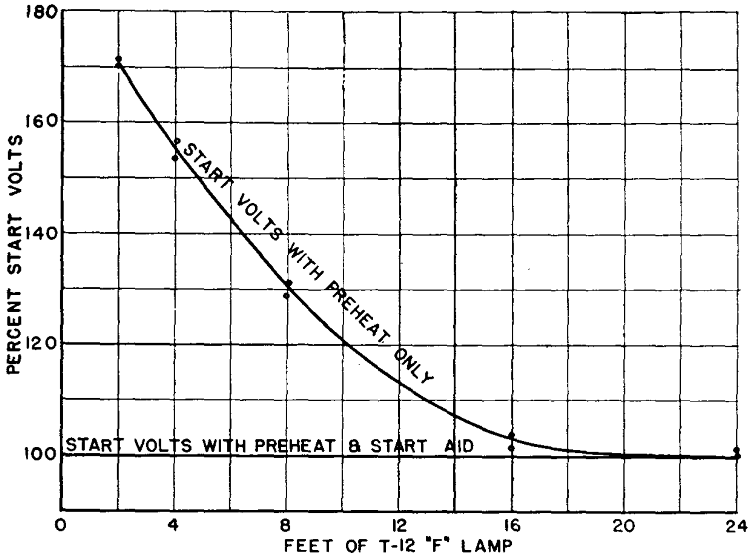

Figure 4. Here the effect of removing a starting aid in raising starting volts on lamps with heated cathodes is shown in relation to length of lamps in 1½-inch diameter. The well seasoned lamps were suspended by strings in the center of a room and the starting aids were applied and removed. The 16- and 24-foot points are made up of lamps in series.

to its original condition. The cathode temperatures corresponding to the 0.3-ampere point in Fig. 1 is an incipient red heat (500 to 550° C). It is in this temperature range, with a starting aid, that under limited current conditions a faint glow suddenly appears as a streamer from a cathode.

If the cathode heat supply is designed to stabilize the cathodes at this temperature very slow starting results. If, however, the cathode heater supplies additional current, starting will begin as the cathode passes through this minimum temperature. On the 40-watt cathodes about 0.380 amperes will cause starting in less than one-half second. At 80 per cent of nominal line volts it will still heat the cathode to the minimum starting temperature, but starting will be slower. At rated line volts the preheat wattage per cathode will be approximately 2.6 watts. In a 40-watt lamp the two cathodes would consume about 13 per cent of lamp watts. After starting, simple bucking current would take this down to about half of this value. In two-lamp ballasts lead-lag neutralizing reduces this to a very few per cent. The 0.380 amperes do not overheat these cathodes during operation, but neutralization is employed only for reduction of watts loss.

A very interesting phenomenon occurs as one applies heat to the cathode while it is operating at rated current. The temperature of the cathode spot actually decreases as one increases the average cathode temperature. The cathode spot becomes more diffuse and spread out. With excessive cathode heating, however, the cathode spot again increases in temperature. If lamps are operated above the normal hot-spot temperature earlier end darkening and shorter life occur. Below this point long life and a reduction of radio noise are experienced.[3] Radio noise may be reduced to as little as 1/200 of that normally experienced.

New Cathode To Simplify Ballast

Wattage loss from leaving cathode heat on without neutralization is high primarily because of cathode resistance (wire size and length). Cathode wire size is mainly determined by the arc current, while the length or total cathode resistance has mainly been determined by the older requirements of establishing end glow with switch-type ballasts. This has resulted in cathodes which, if heated with the currents indicated for this new type of starting, have a voltage between 7 and 8 volts. We have used shorter cathodes having from 2 to 4 volts at the desired preheat current. Results as shown in Fig. 5, Curve A, indicate the 3.5-volt cathodes of an instant-start type,[4] carrying an emission material quantity approximately the same as the longer cathodes, yield perfectly normal life (7500+ hours). There is also evidence that such lamps may also give normal life on regular switch-start ballasts (Curve B).

With these shorter cathodes the loss due to preheat, fast-starting circuits, is low enough to ignore, even when no neutralizing is used. This effects an appreciable reduction in ballast complexity and cost. Theoretically the loss in the 40-watt size is about 1.2 watts per cathode. This does not, however, appear in the final result. The watts expended in the cathodes lower the lamp volts by reducing cathode fall. If lamp current is the same for cathodes with heat on as with heat off the lumens are the same even though the lamp voltage is lower.

It is extremely difficult to measure lamp watts with any certainty in such a circuit. Because of

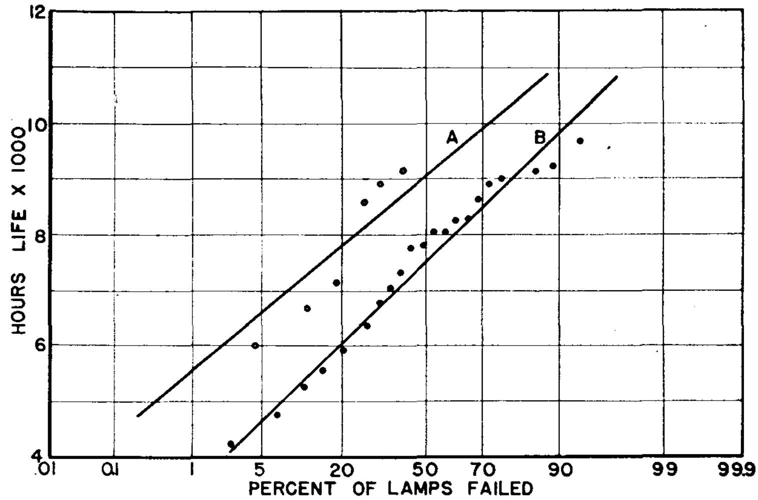

Figure 5. Curve A is the result of a 14-lamp test of mixed lots of lamps with a small 3.5-volt cathode and Dri-Filmed bulbs burned in overhead factory fixtures with 3 hrs. per start. The ballasts were a preheat, rapid-start type. Curve B is the result of 25 lamps made the same as for Curve A but burned in fixtures equipped with switch-start type ballasts and No Blink starters.

this we prefer to measure input watts and lumen output. With such measurements we find that in the 40-watt two-lamp ballast the cathode heat for two lamps can cause less than 3 watts increase in watts input for the same lumen output. Twenty-watt lamps in these circuits have shown on occasion no change in input watts for equal light output when cathode heat is left on during operation.

These starting principles can be applied with advantage by modifying any ballast circuit now used, such as low reactance, high-reactance, lead-lag, or the series type. In industrial lighting where sometimes three-phase ungrounded supply systems are used, the 40- and 100-watt lamps in single or lead-lag form of ballasts might not start if a ground exists on the phase connected to the black lead. Special longer lamps or series operation of lamps circumvent this condition. In the series type additional benefits are obtained because the cathode heat permits very low starting current without lamp damage. In a series circuit each lamp has its starting volts reduced by approximately 100 volts due to cathode heat. Thus even in long lengths of lamps where the starting-aid effect is less, considerable reduction in starting volts, without lamp damage, is possible using these preheat, fast-starting principles. In single lamps or lamp combinations up to 8 or 10 feet a starting aid is quite essential.

In the interest of ballast simplicity, low cost, and in lower wattage loss, a low voltage type of cathode is needed.

Summary

Lamps made as outlined and operated in the preferred systems discussed yield rated lumen output with fast starting, at an increase in total watts over preheat switch starting of from zero to 5 per cent. In present instant-start systems this loss is approximately 10 to 15 per cent.

Major savings, however, show up in ballast cost,

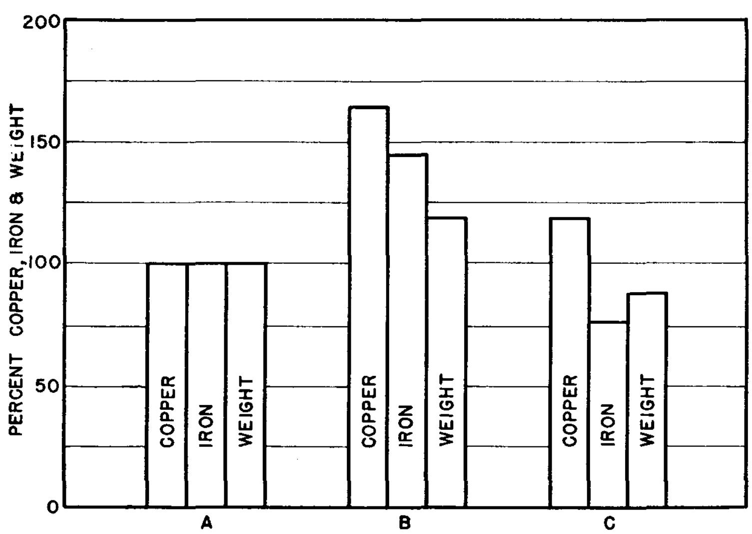

Figure 6. Bar graph of relative copper, iron, and total weights for three 40-watt, two-lamp commercial ballasts. A is a standard switch-start type ballast. B is a series instant-start and C the new rapid-start ballast.

material and weight. As a general rule the preheat fast-starting ballasts cost approximately the same as equivalent preheat ballasts plus starters and starter sockets, except in sizes where no ballast transformer is needed. Ballasts for operation of certain lamps and combinations in series can be lower in cost per lamp than existing preheat switch-start models.

Specifically consider what this means in terms of material and weight for a two-lamp 40-watt ballast. When compared to a switch-start ballast the new rapid-start ballast uses 18 per cent more copper but 23 per cent less steel (Fig. 6). This weighs 12 per cent less. The series instant-start ballast uses 64 per cent more copper and 45 per cent more steel than the switch-start ballast. This weighs 18 per cent more.

There is still one more advantage apparent at this time. With this type of lamp and ballast combination, ballast life is not reduced by the abnormal currents and voltages which may occur in high-voltage, instant-start systems at the end of the life of a lamp.

This new system offers the lighting industry new values and concepts of low cost, high quality, and rapid starting fluorescent lighting.

The authors wish to express their appreciation for the help they have received from their respective groups and in particular A. Kovach and C. E. Strecker.

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DISCUSSION

DR. J. N. ALDINGTON*: I thought it might be of some interest to comment on the authors' paper by comparing the new fluorescent lamp and ballast design, described by the authors, with our practice in Great Britain.

The preferred circuit, if I have understood the authors aright, provides rapid starting by the provision of cathode preheat from secondary windings on the current limiting reactors. The lamps are coated with a water repellent material. In Great Britain the so-called instant start circuit which has been in use for a number of years, employs cathode preheat by secondary windings on the reactance but due to our 200-250-volt mains no voltage step-up is necessary except that provided by the summation of the secondary windings to the mains voltage. This results in a very simple item of control gear and the current through the electrode is kept to a minimum, as soon as the lamp strikes, by suitable design of leakage characteristics of the cathode heater windings.

The lamps used on the instant start circuits are standard in all respects except that after manufacture an electrically conducting stripe is provided running the whole length of the lamp and coated on the outside of the bulb; arrangements being provided for this stripe to be earthed.

In our experience we are able to confirm the various beneficial factors mentioned by the authors except in one instance, on page 591 the authors mention some reduction in lamp life if the circuit is designed for normal lamps. This result is contrary to our laboratory and field experience in Great Britain. We can, however, confirm the reduction in the average cathode temperature on this circuit, the reduction in radio noise, and the long life and good starting under adverse temperature conditions. As a matter of fact, it is the practice of at least one manufacturer in Great Britain to use only instant-start lamps and ballasts in fluorescent street lighting fittings. Good performance has been reported over many thousands of lamps in such fittings during several winters.

G. K. HARDACRE*: It is very refreshing to see new developments constantly coming along that improve lighting, and, hence, advance the application of new lighting principles and improve the lighting market. This paper describes one such outstanding development which seems to offer opportunities for high quality, rapid starting, fluorescent lighting with a considerable reduction of materials used in the ballast.

Ballast weight and ballast losses have always been handicaps in promoting fluorescent lighting. The fact that this new concept materially reduces these two factors is encouraging. As pointed out in the discussion of other papers, favorable economics always in the long run advances the interest of the profession and industry.

One disturbing factor in fluorescent lighting systems is the starter maintenance problem. The new concepts described in this paper tend to eliminate this handicap.

It is interesting to note in Fig. 5 of this paper that there is some possibility of using these new type lamps on conventional circuits. We need always to simplify our lighting equipment; and, while new lamps tend to do this, they also complicate the problem unless they replace old ones. I hope the time is not too far off when this new lamp will entirely replace standard preheat type fluorescent lamps.

This paper confines itself with the 40-watt lamp; however, indications are that this same principle might be applied to any fluorescent lamp, in which case it might well lead the way to higher wattage fluorescent lamps which cannot be economically justified in many cases under present designs. Higher wattage lamps have always been stimulants to the lighting business and particularly to the expansion into new fields of fluorescent lighting.

Regardless of the future developments along these lines, this particular development is indeed a shot-in-the-arm, as it will very much help stimulate the fluorescent lighting market which has been sagging the past few months. Any new bona fide development tends to do this, and this particular lamp looks like "just what the doctor ordered."

H. E. BACHMAN**: The step-by-step development of a fast starting and economical fluorescent lamp and ballast combination, as presented by Mr. Lemmers and Mr. Brooks, was

*Siemens Electric Lamps & Supplies Ltd., Preston, Lancashire, England.

*Public Service of Northern Illinois, Chicago.
**Westinghouse Electric Corp., Lamp Division, Bloomfield, N. J.

extremely interesting. Undoubtedly this system, or some variation thereof, presents the fluorescent lighting industry with new values and concepts of improved lighting.

Unfortunately, as is usual with most new ideas and developments, there are some very distinct disadvantages and serious problems presented by this system. It is our firm conviction that the ultimate consumer must be adequately forewarned of these as possible pitfalls and, even more so, possible reasons for ultimate non-acceptance. Firstly, there is a very definite non-starting condition on a sizeable percentage of present lamps when utilizing 106 volts line. *It is possible* that the lamp starting voltage can be reduced by up to 15 volts by a slight reduction in lamp gas fill pressure. This design change would have a relatively insignificant effect on lamp life and lumen maintenance. I would, therefore, like to question the authors as to whether this possibility was considered in the design of the rapid-start lamp.

A second drawback of this new system is the imminent danger of high resistance contacts, also causing non-starting of lamps. This resistance may arise from the filament connections inside the lamp, lead-wire to base-pin contact, or in the lamp sockets, particularly after dust and corrosion set in. This one single item of resistance is a challenge to both lamp and socket designers.

Thirdly, because of the physical interchangeability of the 48-inch bipin instant-start lamp with the present rapid-start lamp, a very serious ballast overheating problem *may* exist when the 48-inch bipin instant-start lamp is used erroneously in this type service. Theoretically, it appears that the ballast may burn out in a relatively short period of time after the preheating windings are short-circuited. Have the authors taken this into account and is the condition of any serious consequence?

Because of the numerous maintenance disadvantages of the series-sequence type of circuit, we question the advisability of using this type of circuit in conjunction with rapid-start. Since the lead-lag circuit can be as easily and economically applied, we urge its use.

As a last question and comment I would like to ask what effect ambient temperature has on the starting voltage curves of Fig. 1, or more specifically what safety factors are needed for reliable starting at 40F and 50F?

Notwithstanding all the enumerated deficiencies of rapid starting as it now exists, we feel the information presented is a definite step in the right direction, especially if the indicated improvements are effected and a single lamp can be used for both preheat and rapid-start service.

H. U. Hjermstad*: This paper represents an evolution of technical improvement in which it has become possible to design a lamp ballast system having several desirable features. I personally feel that the use of this system will be extended to several sizes and types of lamps in the next few years.

I wish to point out that the circuits shown in Fig. 3 are not actually employed with rapid-start lamps. The circuits shown in Fig. 3 all are of a type in which the voltage of the cathodes reduce the moment that the lamp ignites. In the new design of the rapid-start lamp, as I understand it, the cathodes have been designed so as to permit continuous application of the cathode voltage. Once the cathodes have reached emission temperatures, the voltage required to start the lamp is then lower and the arc then can be struck. Since the starting voltage of the rapid-start lamp is much lower than that of an instant-start lamp, care must be exercised in ballast design so that the peak voltage of the ballast will not cause the lamp to instant-start rather than rapid-start. By the same token, close tolerances must be maintained on the striking voltage of the lamp or else the lamp will fail to start if the striking voltage becomes too high: *i.e.*, higher than the open circuit ballast voltage. Care in manufacture has to be exercised by both ballast and lamp manufacturers to make a compatible combination.

Most of the circuits actually employed are series sequence ballast designs similar to the early sequence-start ballasts for instant-start lamps with the addition of cathode windings. With this type of circuit, ballasts will run at very low V.A. (hence very cool) under abnormal conditions (with either lamp out). Incidentally, they will run cool if either lamp should act as a half-wave rectifier. Several designs provide for excellent regulation maintaining lamp wattage and light output over a wide range of primary voltage.

The lower starting voltage makes it possible to design a ballast having a relatively low peak to rms value of operating current. This should be very helpful toward lamp life since it has been shown in preheat type lamps that ballasts having lower crest factor will provide a longer lamp life.

I believe a very desirable feature of the rapid-start lamp is that the radio frequency noise generated at the cathode will be materially reduced. This should be extremely desirable as no doubt, this system will be used greatly in home lighting.

Since the cathodes of the rapid-start lamp will maintain the emission temperature without regard to the lamp current, it will become practical to design ballasts with a dimmer arrangement. This again, for home lighting might prove to be rather interesting.

The method of lamp wattage measurement that has been proposed on this system is rather involved. There is great need for a more accurate voltage wattage method of measurement. I sincerely hope that it will not be too long before there can be industry agreement on a more practical solution to this problem.

I have a question — When lamp #2 (the one shunted by a starting capacitor) in a series sequence circuit fails, the current through lamp #1 will drop to just a few milliamperes. Will continuous operation under this condition change the electrical characteristics or harm or shorten the life of the #1 lamp in any manner?

E. F. Lowry*: After a careful study of this paper which is of considerable interest, particularly in view of recent commercial announcements, I find a number of statements which, to me at least, are very confusing.

(1) The authors refer to Curve C, Fig. 1, in one instance as applying to the case of a grounded metal stripe and again as referring to lamps in grounded metal fixtures. Which is correct?

(2) Quite a point is made of the deleterious effects of instant starting. Is instant starting with these new lamps and ballasts any more severe than with other well known instant start circuits now in common use? It is my understanding that instant start lamps today are lasting about 7500 hours which is in excess of their economically useful life.

(3) At the top of page 590, column 2, the authors state: "For good results we either have to make sure the starting aid is not nullified or is never present." This startling state-

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*Sylvania Electric Products, Inc., Salem, Mass.

ment is made even more confusing by the discussion which follows, wherein we are led to believe that we must expect either: (a) a reduction of 25 to 30 per cent in life, or (b) a situation where non-starting will frequently occur.

(4) On page 589, we are led to believe that Fig. 1 applied to ordinary 40-watt lamps. On page 591 we are given to understand that this same figure represents data obtained on the new rapid-start lamps. If these same curves are equally applicable to both types of lamp, why do the numerous objections and difficulties recited in regard to starting aids and cathode heating in the case of standard lamps not apply with equal force to the new lamps?

(5) Is it not a fact that the use of a grounded fixture and a water-repellent coating on the lamps are the features which assure satisfactory starting at high humidities with reasonable voltages? If so, what new features are involved? Grounded metal fixtures have been recommended for years. Water-repellent coatings to eliminate the adverse effects of high humidity on starting were introduced commercially some six or seven years ago.

(6) Is it not a fact that the chief — if not the *only* — purpose of the new low resistance cathode coil is to reduce the heating power necessary to properly operate these cathodes?

(7) The only two-lamp circuit which the authors discuss is the lead-lag arrangement shown in D of Fig. 5. The ballast recently made commercially available by their company is a series-sequence type. Some information on the relative merits of the two types would certainly be of considerable interest, particularly in view of the fact that series operation of fluorescent lamps has several obvious disadvantages.

At this point I would like to make it perfectly clear that I have nothing against the general idea behind this so-called rapid-start operation of fluorescent lamps. On the contrary, I have been in favor of this method of operation ever since 1939 when I used the same circuit arrangement shown in A of Fig. 3 to operate fluorescent lamps and a similar circuit to start and operate two lamps in series. Others have also employed similar circuits at one time or another.

Let me say then — that there are many advantages to this method of operation. Several of these have been indicated by the authors. However, there are also disadvantages which all should recognize. There is not time to discuss them all but I would like to mention one of the most important. That is the matter of contact resistance. The filamentary cathode which we are discussing here has a hot resistance of about 9 ohms. Suppose an additional resistance of the order of 5 ohms is inserted, by poor mechanical contact, pin or socket corrosion or by some other mischance, then the effective resistance of the filament will be increased to 14 ohms and the heating current reduced from 380 ma to 250 ma. This is the region where unreliable starting is to be expected. Tests in our laboratories have shown that this is exactly what we may expect. Actually, there has been difficulty in the field with trigger start operation of circular lamps using 12-14-volt filament windings for this reason.

There are other difficulties to be overcome such as proper and positive grounding of both the transformer and the metallic reflector.

There is no doubt that these and other problems will be solved. When these objectives have been accomplished, we have before us an excellent method of fluorescent operation.

E. H. Salter*: Again, I am intrigued by the presentation of a new lamp and a new ballast. And again, a comparison of the new with the old would serve to evaluate the progress that has been made.

There is an age-old saying to the effect that we really know little about a given device or characteristic of a device until we can measure it or measure its effect. The authors state that: "It is extremely difficult to measure lamp watts with any certainty in such a circuit." I believe that I might add that it is extremely difficult to measure lamp watts with any certainty in any discharge lamp circuit. It has taken nearly 15 years to reach that conclusion, but I am sure that those who are close to this problem will agree with my statement.

Nevertheless those working with fluorescent lamps have been making measurements of what has been called lamp watts. Such measurements make it possible to assign intrinsic efficiency values to the lamps alone and to evaluate the performance of ballasts as such. In fact, specifications are written around those measurements. The difficulty of measurement is acknowledged.

Now we are told by the authors that: "Because of this we prefer to measure input watts and lumen output." I will grant that these measurements should serve to indicate what the user will have to pay for in the way of electrical energy used and what he will receive in light output. Nevertheless, I enter a plea that an all-out effort be made to develop or establish a means of reliably measuring the watts delivered to the lamp by the ballast so that lamp efficiency and ballast effectiveness may be evaluated independently.

R. D. Bradley*: Perhaps it is not widely recognized that today there are at least seven ballasting circuits in common usage, these circuits all pertaining to multiple lamp operation. Very recently there has been another ballast and circuit added, namely the rapid-start circuit for lead-lag operation.

In doing some experimental testing on the rapid-start lead-lag ballast, it was discovered that starting was very erratic when the fixture was ungrounded.

I assume that this problem has been considered by the designers and manufacturers of this ballast and that there are some definite reasons for its use. I would greatly appreciate the authors touching on this subject.

W. P. Lowell**: At the I.E.S. Conference in Washington last year, a paper was presented by Hinman, Keiffer and Strecker† which provided the necessary data to help clear up a most unfortunate industry situation, namely, the trouble which had been encountered with the series-sequence ballast. In discussion on that paper, I suggested that the entire lighting industry should learn a lesson from that experience and that we should not jump too fast into untried fluorescent ballast circuits. The same comment applies here.

This ballast circuit appears to have considerable merit, but our customers must recognize at least the following four items:

(1) It will now be necessary for manufacturers, wholesalers and some consumers and dealers to stock 48 kinds of a "40-watt" lamp (4 lamp styles multiplied by 12 colors).

(2) The consumer must be *sure* that he is using the

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*Day-Brite Lighting, Inc., St. Louis, Mo.
**Lighting Division, Sylvania Electric Products Inc., Salem, Mass.
†Published October 1951 issue, Illuminating Engineering, pp. 560-566.

proper lamp; otherwise, lamp trouble or ballast trouble will develop.

(3) Luminaire manufacturer and consumer must insist that the ballast have high enough open circuit voltage *and* a grounded ballast can and fixture *and* a reflector or other grounded metal must be within one inch of the lamp to aid in proper starting.

(4) Most important — all electrical joints must be good ones and all lampholder and lamp contacts must be kept clean, because the addition of even a slight resistance anywhere in the filament heater circuit will result in non-starting of lamps and may possibly damage the lamps.

W. H. Kahler*: The authors state that the fixtures employing rapid start lamps must be grounded. The writer understands that a grounded component of the fixture must be parallel to the lamp within a distance of one inch. Is this the case? If so, it imposes definite design limitations on equipment for four or more lamps. There is a definite trend toward all-plastic shielding on fixtures and the outer lamps on four-lamp equipment may be six inches or more from the center channel which would be the grounded component. Do the authors have any suggestions in the way of lamp or ballast design that would eliminate this design limitation?

It is also recommended by the authors that a series type of two-lamp ballast will produce the most reliable starting. The elimination of starters is a step toward easier fluorescent maintenance but series ballasts complicate the maintenance problem. With the series type of ballast, the maintenance man cannot readily determine which lamp should be replaced when one lamp reaches end of life. Experience with series slimline ballasts has emphasized this difficulty. Therefore, I hope that the ultimate design of ballasts established in the industry will be of the lead-lag type for rapid start lamps.

W. W. Brooks**: We are particularly fortunate to have heard of the several years of experience in Great Britain with an instant-start circuit which is very similar to our rapid-start circuit.

Dr. Aldington stated that, because of the high line voltage, no voltage step-up is necessary in the ballast. This point is salient when the practice in Great Britain is compared with the rapid-start circuit. In the circuit used in Great Britain it was necessary to incorporate a separate transformer to supply cathode heating current. This arrangement, without further complication, automatically reduced the cathode heating current after the lamp started. Therefore, it was possible and practical to use lamps with standard cathodes. However, with voltages in common use in the United States the cathode heating current could not be reduced after the lamp started without complicating the ballast circuit.

Mr. Bachman has correctly indicated that it would be possible for anyone servicing a rapid-start fixture to insert a 48-inch bipin, instant-start lamp in the lampholders, despite the fact that "rapid-start" is clearly marked on the lamp.

That problem has been investigated. We have found that properly designed rapid-start ballasts will not fail even after prolonged operation with instant-start lamps.

Furthermore, the ballasts have been submitted to Underwriters' Laboratories, Inc. and Underwriters' Laboratories, Inc. has ruled that the ballasts are not a fire hazard when operating instant-start lamps.

Mr. Hjermstad has very ably indicated some of the effects on ballast design which may be brought about by the development of the rapid-start lamp. The circuits which provide constant cathode heating current were not included in the paper because of space limitations.

The comments by Mr. Salter point up a very perplexing problem connected with the rapid-start circuit. We can assure him that we are aware of the need for a means of reliably measuring the watts delivered to the lamp by the ballast, and we will continue to work on the development of such a means.

A. E. Lemmers*: As I listened to Dr. J. N. Aldington discuss this paper I was moved by both satisfaction and I must also confess some envy. Satisfaction in the successful application of similar principles of lamp starting in England which he referred to and which confirms my results, and envy that the distribution systems and other conditions of his country so favored the application of these principles that they could proceed to commercialization so rapidly.

Dr. Aldington and Dr. Lowry have made reference to an embryonic form of the rapid-start system. The system used in Britain, while comparable, is not applicable to general lighting in this country. A short history of this development will help in understanding the differences.

In 1939 at the New York World Fair among the groups of fluorescent lamps installed was one group of ten lamps which were started by use of cathodes being preheated in conjunction with a starting aid. The starting aid was a platinized stripe on the 18T8 bulb. The cathode heat was furnished by heater coils coupled to a choke in a resonant circuit. The resonant circuit raised the 118 supply voltage to a starting voltage and furnished cathode heat until the lamp started and then fell out of resonance. This ballast just could not compete with the switch-start ballasts as they were developed. It was too far out of line in size, weight and cost. In addition we had found at this early date that lamp life was damaged on such a ballast because of frequent instant starting without waiting for cathode heat, due to switching transients producing a higher voltage.

Through the war years our attention was on other matters but in 1945 I again started work on this type of starting of fluorescent lamps. The elimination of the uneconomical ballast bulk and the improvement of lamp performance when these principles were applied to our 118-volt systems were the major problems.

It is this difference in distribution systems which accounts for our need of the new cathode. When lamps are operated from supply sources of sufficient voltage so that no step-up is used, instant starting due to transient surges at switching in and above normal peak to rms voltage from transformers, is avoided.

I have found no way of circumventing these conditions in the step-up type of ballast without undue increase in ballast cost. However, the new cathode has much greater tolerance to instant starting than the older cathode. One of the several functions of the new cathode is its ability to deliver nominal life even when there is an appreciable degree of instant starting present.

Among comments of Mr. Hardacre is a very accurate

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**Co-author. (See also rebuttal by A. E. Lemmers, starting in next column.)

*Co-author. (See also rebuttal by W. W. Brooks, starting in previous column.)

prophecy as to the extending of these rapid-start principles to larger wattage lamps. You probably noted I mentioned in this presentation the extension of rapid-start to the new 100-watt 72T12 lamp which our Lighting and Rectifier Division is making excellent use of in their new street lighting fixture.

I am quite certain Mr. Bachman has based his conclusions of non-starting at 106 volts on entirely too small a sampling of lamps. Unfortunately I also suspect he has obtained some lamps of very early manufacture which might be troubled with residual gas as shown in Fig. 2. If the non-starting is for the first start only as reported by Mr. Bachman to one of my associates, this certainly is the case. A few minutes of burning would permanently cure the starting difficulty at minimum line volts. Lamp quality is not affected. No starting trouble at normal line volts is involved. A few more minutes seasoning at the factory eliminates the condition. Under these circumstances a reduction of gas filling pressure would have little effect.

I would like to remark here that if we insisted on starting under all adverse starting conditions taken at the same time, we would hardly ship any standard instant start lamps. Yet we have sold these lamps for many years with negligible complaints on starting. The same will be true I am quite sure for the rapid start lamps. Tests have been obtained which show the rapid-start lamps to have a greater percentage starting at low line volts under adverse conditions than did the instant start lamps.

Although I reply to others on this question of resistance in the cathode heater circuit I must remark that Mr. Bachman has mentioned the only two points of connection in the circuit which ever cause trouble. We very early detected these trouble sources and corrected them. They are the cathode to lead connections and the lead to base pin connection. We use a certain soft inner lead which cures the first possible trouble and a crimped pin which eliminates the second.

Mr. Brooks, I believe, has answered the lamp interchangeability question as regards to ballast damage.

As so many ask for rapid start series versus lead lag comparison I will give it for all at the end of these comments.

In reply to H. U. Hjermstad, no damage occurs to the remaining lamp in the rapid-start series ballast when lamp #2 fails even though it remains in the low current condition for many many hours.

Dr. Lowry has presented us a list of questions. It is certainly very helpful and I will attempt to answer them to his satisfaction.

(1) Curve C, Fig. 1 is actually for a connected stripe lamp. It was referred to in the text as approximating the condition for a lamp on a grounded fixture. This is so as we consider the differences between curves C and D to be insignificant. However, it is the authors' fault for not being more explicit. Fig. 1 was originally two figures which were combined.

(2) I believe the text is clear that the comparisons of damage due to instant starting were for ordinary preheat type lamps. The way out of the dilemma was to change the lamp cathode to a type that would tolerate instant starting. The rapid-start lamps with the new cathode have shown on instant-start test to equal the instant-start lamps if the pins are shorted.

(3) Inasmuch as Dr. Lowry has stated the conditions with 100 per cent accuracy, I am at a loss to understand why he is confused. This section of the paper deals with ordinary lamps. The condition (a) as listed by Dr. Lowry is the present trigger ballast. It operates regular lamps. Regular life tests for the past several years yield the results given. Condition (b) was never offered to the public because of the frequent non-starting due to humidity.

(4) The answer to question 1 has partially answered this. Curve A and Curve D under *low humidity* are the only curves that apply to regular lamps. All the other curves are described in the text as lamps specially equipped with starting aids.

(5) One of the new features is a starting voltage over 40 per cent less than heretofore obtained. It is obtained by having cathode heat in addition to the water repellent bulb and a grounded fixture. Curve D most effectively shows this where the extreme left portion of the curve is applicable to lamps operated as Dr. Lowry suggests and the right hand portion is representative of rapid-start. The text also mentions life damage to lamps started as indicated on the left side of the curve and normal life for starting as indicated on the right hand side of the curve.

(6) The new low resistance cathode has several major functions. Each feature, however, has a specific purpose and all taken together give us a superior cathode more nearly universal than any previously available. Any of the previously available cathodes may be shortened to make for low resistance but life is also shortened. The proportioning geometry and coiling of this cathode which, while not fully covered in the paper, but which I showed and discussed in the presentation at the Conference, constitute one of the best ways to achieve full life at rated current yet having low resistance.

(7) As several have asked a similar question I will give later a comparison of the series versus lead-lag rapid-start ballast.

Dr. Lowry points out that resistance in the cathode heater circuits may cause non-starting and as an example uses a value of 5 ohms.

We certainly are in the "Dark Ages" of Electrical Engineering if we are unable to make connective devices which for currents less than one ampere have resistances in the order of ohms. Although I must admit that my measurements and experience are limited to the various types of sockets made by one manufacturer I find that the usual contact resistanec is in the order of hundredths of an ohm. One exceptional case was found wherein a socket mounted on a board standing on end and stored for over a year in a corner of a laboratory showed upon use a temporary resistance of about 1 ohm. This socket through the year had been dirtied by scrub water probably several times and was quite dirty and corroded and probably coated with detergents. The fact that it had an abnormal resistance was only noted because upon use in a circuit with meters it was observed that the heater current to that socket was .040 amperes less than to the adjacent socket. Turning the lamp twice in the socket caused the resistance to permanently disappear. Now this temporary resistance of approximately one ohm did not inhibit lamp starting at normal line volts at all. If we take the lowest line voltage and a ballast at the lowest permissible open circuit voltage we can tolerate as much as 0.5 ohms resistance and still start the lamp. This is a resistance about ten times what is ordinarily experienced. In the thousands of lamps we have handled in testing this general type of circuit in the past seven years we have never experienced difficulty with resistance in the socket as long as the lamps were actually in the socket. Service tests in places of abnormal humidities, vapors, and vibration have shown no trouble. We have, however, experienced difficulty in the cathode heater circuit which we corrected more than a year ago. I refer to the connection of the outer lead of the lamp to the pin of the base. In the past these have always been soldered. We have found, however, that in mass production there are short periods of manufacture when due to various circumstances high resistance solder jobs may be produced. Although external appearance is good and immediate contact is good, these particular solder jobs may develop into a poor contact with time. You will note that the rapid-start lamp as made by us has what we call a crimped pin. This type of connection has never shown a high resistance contact with many sampling measurements from several million bases. The field difficulty mentioned by Dr. Lowry on trigger start operation of circular lamps at least in our lamps was traced solely to poor solder due to an iron outer lead used because of metal emergency supply conditions.

In view of the fact that millions of radio tubes using even lower cathode heater voltage than the rapid-start lamp have been in service for many years, I am just slightly puzzled why Dr. Lowry should become so concerned. Certainly the engineers in the lighting industry have designed as well as those in the radio industry. The cathode heater circuit of the rapid-start lamp is essentially the same as for vacuum tubes.

In reply to Mr. Bradley, so many have asked for lead-lag versus series rapid-start information that I will cover this at the end of the discussion.

Mr. Lowell's comment about jumping into untried ballast circuits is quite to the point. For that very reason we have spent the last two and a half years of this development in testing the ballasts and lamps we are offering the public today. There have been hundreds of lamps on life and service tests and thousands of lamps handled in various other types of testing such as starting under abnormal humidity, temperature, fixture combinations, storage effects, etc. We have tested this product longer than any fluorescent lamp we previously brought out. We know of no major difficulties with the lamp or ballast as we offer it.

(1) It is my opinion that while for the present the kinds of lamps stocked have been increased, eventually this lamp will be used in all circuits.

(2) This statement is only partially true.

For example the rapid-start lamp can be placed in switch-start sockets and in all probabilities the consumer would get normal service.

If placed in instant-start sockets the same results would be had as though a regular preheat-start lamp had been inserted.

If switch-start lamps are placed in rapid-start sockets, starting is only possible with full supply volts and low humidity.

If instant-start lamps are put in rapid-start sockets they do not start at all. If left in position with power on, no ballast damage results in many hours.

(3) The voltages in the G.E. ballasts have ample safety factor and the values have been given to the industry. Where necessary the G.E. ballasts provide the conditions essential for operation even with an ungrounded fixture. The reply to W. H. Kahler covers the fixture problem.

(4) I have been under the impression that good electrical connections have for many years been common practice. As far as a slight resistance is concerned it apparently means different values to Mr. Lowell than to myself. I consider half an ohm in a supposed good connection to be large. Measurements indicate values less than one tenth of this. Service tests indicate the same. Our British friends' experience as reported by Dr. Aldington, indicates likewise and our own radio experience concurs.

Mr. Kahler is correct in the assumption that, for reliable starting over the range of humidity and temperature usually specified for fluorescent lamps, the fixture should be grounded and should be at least within one inch of the lamp. The authors, however, have some very definite suggestions for operation of four-lamp fixtures which with plastic shielding may make the above requirement difficult to meet.

(1) Do not use single lamp ballast on multiple fixtures.

(2) If lead-lag ballasts must be used good results can be had if the lead lamps are mounted next to the fixture and the lag lamps in the outer positions. With lamps on three-inch centers or less the lead lamps will always light and act as a starting aid for the lag lamps.

(3) With a series ballast there is no problem, however, the lowest starting volts may be had by placing the capacitor shunted lamp on the outside (red lead).

The above have been proven by test on General Electric components only.

Maintenance of rapid-start series ballasts has never presented any difficulty in the two and a half years it has been under test. I have always found the failed lamp to be the one with a very dark end. It is of such an appearance that it can be seen by a casual look before climbing up to change lamps. Because several have asked for a comparison of the rapid-start series and lead-lag ballasts I will answer this later.

Rapid-Start Series To Lead-Lag Comparison

An explanation of the part played by the starting aid in starting lamps will help in understanding some of the results that follow. If the starting aid has a potential of approximately 150 volts or more in relation to one of the lamp cathodes, a feeble glow will be initiated between the cathode and starting aid as soon as the cathode warms. By cumulative ionization this grows to full current if the potential between the starting aid and electrode is great enough. If this potential between starting aid and electrode is less than 150 volts, no starting occurs unless the potential across the lamp is so high that instant starting occurs. Under such a condition the ballast loss would be up and cathode heating is superfluous. This value of 150 volts between electrode and aid is approximately the value needed for argon-filled lamps regardless of length.

In lead-lag and single-lamp ballasts about 225 volts are across the lamp electrodes. All that limits the current through the lamp after the glow current is established is the lamp and ballast effective resistance. Thus starting is characterized by a very brief interval in which the electrodes heat, then glow is established, followed by a very quick shift to full current. Tests on many lamps yield an average starting time to full current of about 30 cycles.

In the series ballast about 285 volts are across two lamps. One lamp is by-passed with a small capacitor. Here at zero current practically 285 volts are across the lamp that is not by-passed. Even if the cathodes are cold, a glow is established but the current is limited to less than 1 mil. This low current produces no damage, as it is so low, and the cathode is large enough to take it as a cold cathode glow without blackening or damage. As the cathode, however, heats up due to current from the heater circuit, the cathode fall drops and the current through the by-pass capacitor and thus the voltage across it rises until it is high enough to start the glow in the second lamp. This usually happens before the cathodes are at full temperature and although the current increases, it does not get to full value until the cathode fall has been reduced to 20 volts or less. Until this happens the lamps' resistance plus the ballasts' reactance hold the current down as there is only about 143 volts per lamp available and lamp voltage is but little less.

This causes a start characterized by practically instantaneous light at a low level which rapidly builds to full brightness. Average time is from about 45 to 100 cycles from closing the switch to full current. Many people have expressed a preference for this starting as it produces less visual shock.

Because of the conditions described, the series rapid-start ballast is less dependent upon a starting aid than the lead-lag rapid-start. The lead-lag should insure fixture grounding with a resistor from white lead to case of about 2 megohms. When the ballasts are served from ungrounded systems such as a three-phase delta, a grounding of the phase serving the black ballast lead puts the lead-lag ballast in a non-starting condition because less than 150 volts will be between the high potential cathode and the grounded starting aid. The line voltage has been subtracted from the total. In the series ballast, no matter which side of the primary is grounded, there is still more than 150 volts between the starting aid and cathode.

When I speak of 150 volts for this condition, please keep in mind I mean an rms voltage with essentially a sine wave. As the peak to rms is made greater the value of voltage needed decreases. In the lead-lag ballast we must avoid a high peak to rms. If we get a high enough peak we initiate glow before the cathodes are hot and lamp resistance and ballast reactance are insufficient to hold the current low enough to prevent destructive cathode fall. In other words instant starting occurs to a damaging degree. This result has long been observed even on preheat switch start ballasts. The series ballast on the other hand is hardly affected by high peak volts, as the by-pass capacitor and ratio of lamp to ballast volts hold the current in check so that the cathodes are heated in the main by current conduction and not by ion bombardment.

We have tested both types for about two and a half years. We did not market the lead-lag because of its inability in the 40-watt lamp size to cope with conditions on ungrounded systems. We understand a large part of the industry is so served. If the lead-lag is modified to take care of this situation for 40-watt lamps, one only gets into shorter life and more ballast loss. For higher voltage lamps, however, lead-lag ballasts do not have this difficulty.

Our tests have shown strobe, maintenance, and outage of two lamps at once to be, in my opinion, mostly imaginary flaws. J. H. Campbell has shown strobe to be of no consequence under usual conditions. If a man can see an all-black end on a lamp he can find the failed lamp. If two lamps go out you lose about 5,000 lumens. With an incandescent installation which is still not unusual for high level lighting, one 300-watt lamp outage produces the equivalent lumen loss. This loss of lumens then is not an unusual situation.

If, as lighting engineers, we are sincerely interested in reducing the ballast losses and thus improving the lighting economics, the series rapid-start ballast offers us the best opportunity I know of. We can use it without any loss of life or potential damage to ballast if failed lamps are not quickly removed. Life is such that, in my opinion, group replacement can be used most effectively. The percentage of failed lamps at replacement time will be much smaller than with other systems.

My own feelings are that we should not stop at two lamps in series. Three and even four can do a better job. You will recall that in the presentation I showed a four-lamp series circuit and mentioned that the ballast loss was about 12 per cent of the lamp load. This is an improvement of more than 50 per cent in cutting ballast loss and can be even more in the ballast cost per lamp.

In conclusion we wish to thank each gentleman for his interest, time and effort in presenting a discussion on our paper. It is evident that most are quite enthusiastic about the rapid-start lamp and ballast. A few believe it to be a good general scheme but have some doubts as to whether certain features may not cause trouble under some conditions. To these latter I hope our answers to their questions have resolved their doubts. In addition to our answers, mayhap the comments of Dr. Aldington on the superbly satisfactory experience in Britain of a comparable "System" may have allayed their fears. If not, I am sure that a little more personal experience will better acquaint them with the benefits to be derived from the new lamps and ballasts.