United States Patent [19]

Crawford

[11] **3,792,310**

[45] **Feb. 12, 1974**

[54] **THREE-LAMP LEAD LAG RAPID START BALLAST APPARATUS**

[75] Inventor: **Joseph A. Crawford,** Chicago, Ill.

[73] Assignee: **Advance Transformer Co.,** Chicago, Ill.

[22] Filed: **Dec. 12, 1972**

[21] Appl. No.: **314,399**

[52] **U.S. Cl.** **315/257,** 315/278, 315/282, 315/323, 315/DIG. 5

[51] **Int. Cl.** **H05b 41/16**

[58] **Field of Search** ... 315/254, 257, 278, 282, 323, 315/DIG. 5

[56] **References Cited**

UNITED STATES PATENTS

2,436,399	2/1948	Nathanson	315/257 X
2,709,231	5/1955	Feinberg	315/282 X
3,080,505	3/1963	Eppert	315/278 X
2,996,644	8/1961	Nathanson	315/278 X
2,946,922	7/1960	Dougherty	315/257 X
3,169,213	2/1965	Shaheen	315/DIG. 5

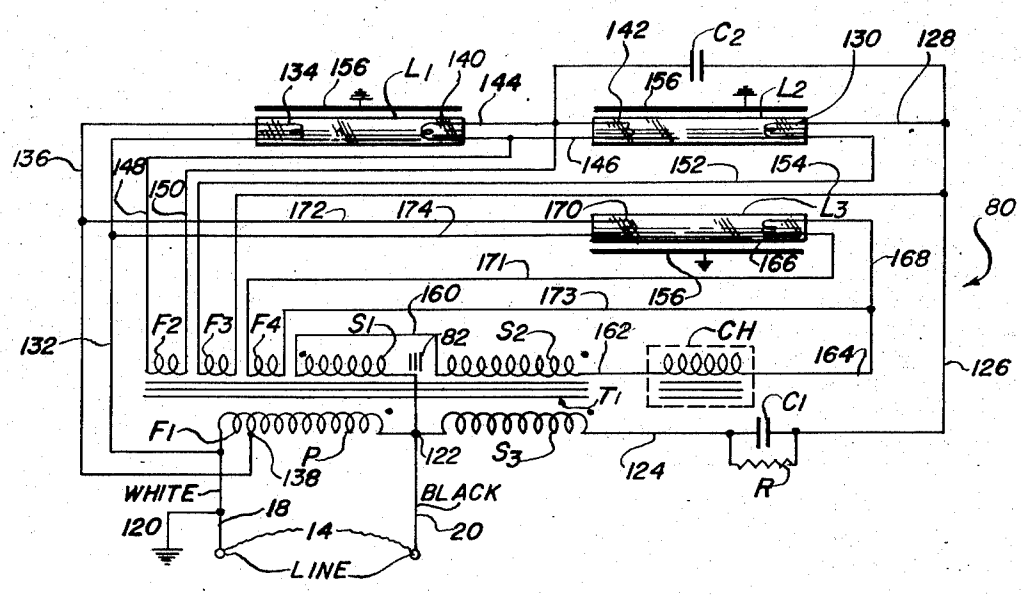
Primary Examiner—Alfred L. Brody

Attorney, Agent, or Firm—Silverman & Cass

[57] **ABSTRACT**

A ballast for rapid start gaseous discharge lamps to ignite and operate three such lamps from a source of a.c. voltage greater than the igniting voltage of the lamps comprising a lead side made up of two lamps in series with a shunting condenser across one lamp and an operating condenser in series with both lamps, the lamps and operating condenser being connected across an autotransformer including a primary and secondary winding additive and closely coupled; and a lag side made up of one lamp in series with the same primary winding and two secondary windings, the latter secondary windings being connected additive with the primary winding and together therewith in series with a choke and the single lamp. The primary and all secondary windings and filament windings are mounted on the same core with all filament windings, primary winding and one of the lag side secondary windings closely coupled to one another but loosely coupled relative to the remaining secondary windings. The latter two are closely coupled to one another. The lead side lamps start first and current flow in the lead circuit increases voltages in the lag side secondaries raising the lag side open circuit voltage to aid in the starting of the lag lamp.

16 Claims, 6 Drawing Figures



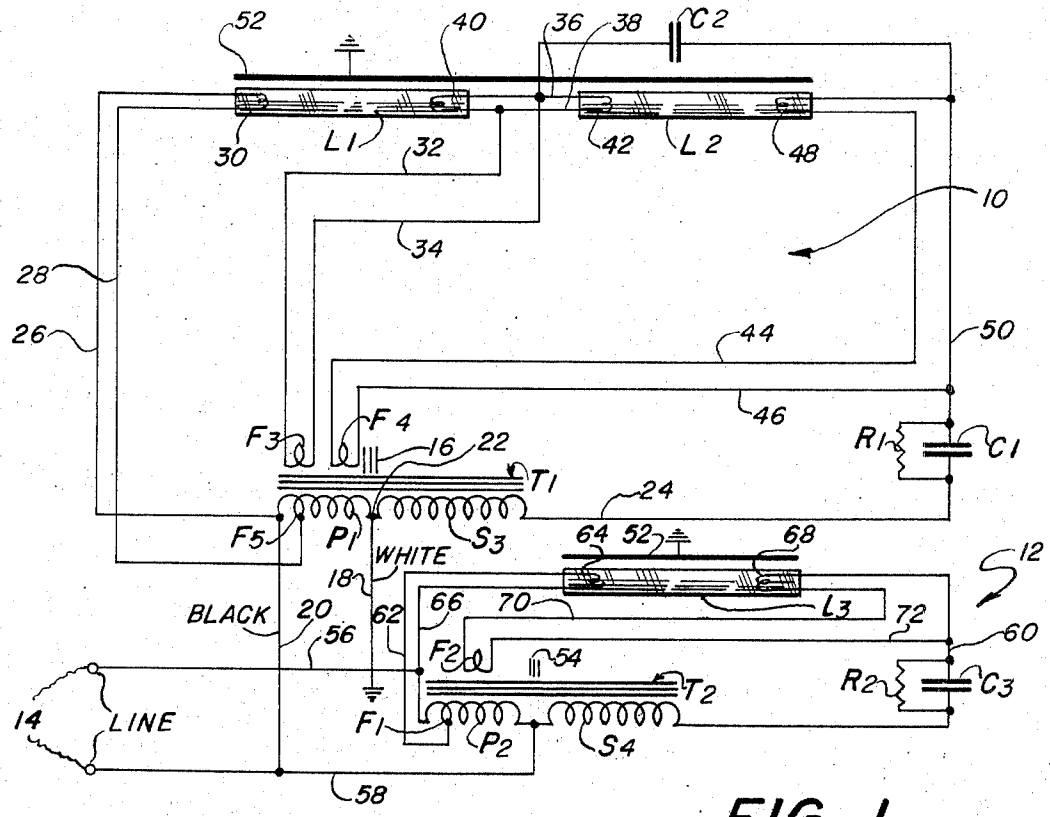


FIG. 1

PRIOR ART

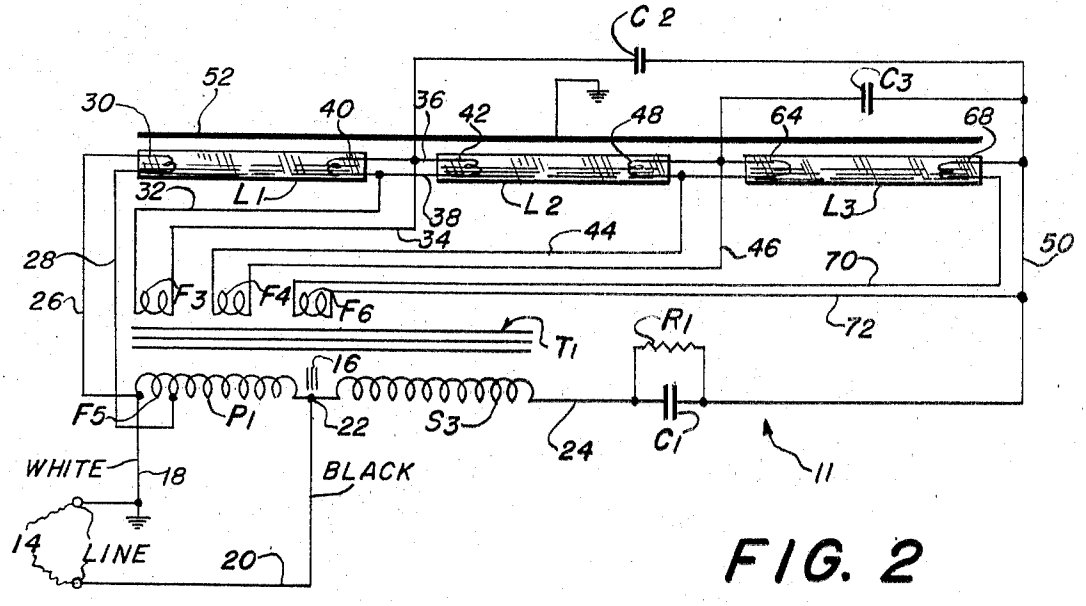


FIG. 2

PRIOR ART

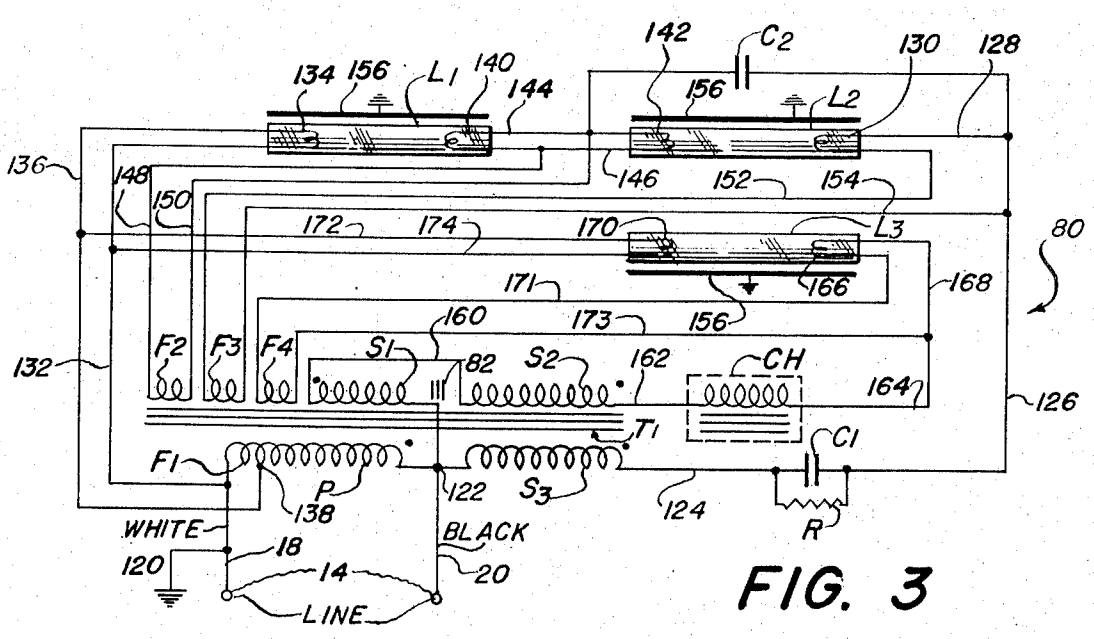

142
C2
130
128
134
156
L1
140
144
156
L2
136
148
150
146
152
154
172
174
170
L3
80
171
166
168
160
173
156
132
F2
F3
F4
S1
82
S2
162
CH
164
126
T1
C1
F1
P
122
S3
124
138
R
WHITE
18
BLACK
120
14
20
LINE

FIG. 3

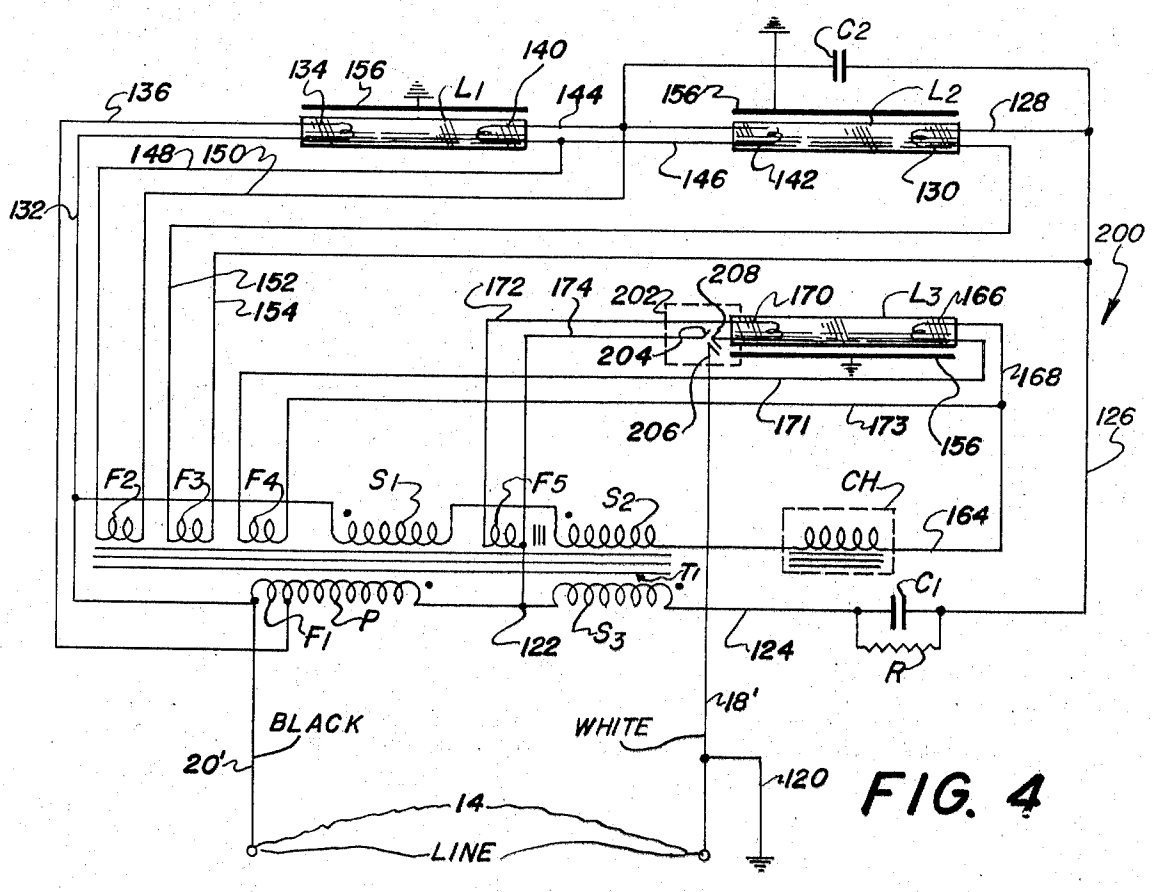

C2
140
134
156
L1
144
156
L2
128
136
148
150
146
142
130
132
200
152
154
172
174
202
208
170
L3
166
204
168
206
171
173
156
126
F2
F3
F4
S1
F5
S2
CH
164
T1
C1
F1
P
122
S3
124
R
18'
BLACK
WHITE
20'
120
14
LINE

FIG. 4

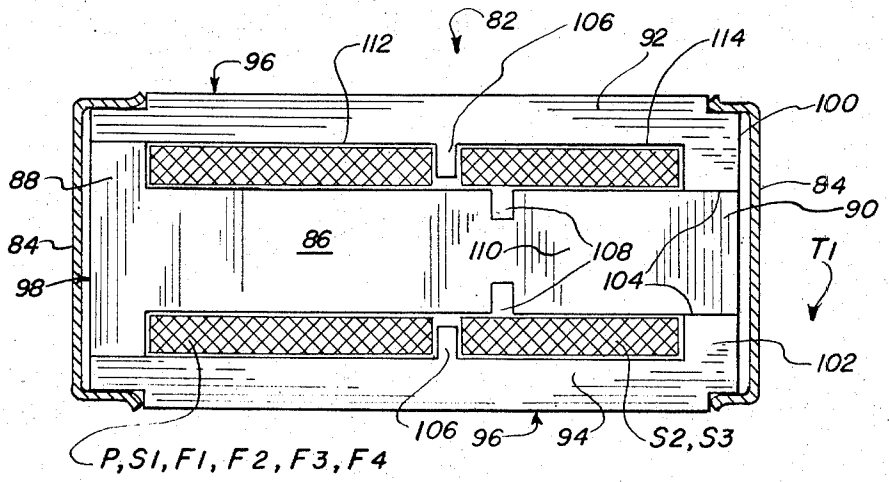

82
106
92
114
96
112
100
88
84
90
86
110
108
104
T1
84
98
102
106
96
94
S2, S3
P, S1, F1, F2, F3, F4

FIG. 5

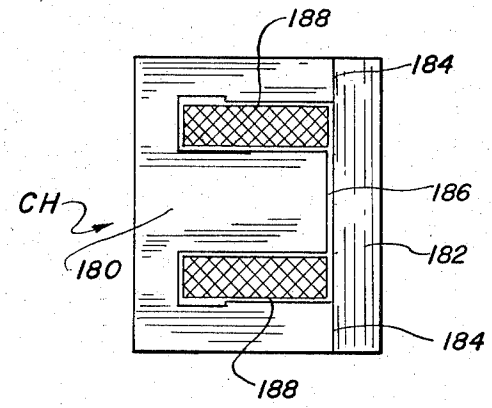

188
184
186
CH
180
182
184
188

FIG. 6

THREE-LAMP LEAD LAG RAPID START BALLAST APPARATUS

BACKGROUND OF THE INVENTION

The invention herein is concerned generally with apparatus for igniting and operating gaseous discharge devices, and specifically is directed to the provision of a novel ballast for fluorescent lamps operated by alternating electric current.

The general characteristics and requirements of ballasts for fluorescent lamps are too well-known to require detailed discussion. Suffice it to say that such lamps are elongate glass tubes having an interior atmosphere of an inert gas such as argon with a few droplets of mercury and interior phosphor coatings which fluoresce when the gas is ionized. The lamps ignite (ionize) at a higher voltage than required to operate (maintain the arc) the same and are negative resistance devices which require substantial current limitation once the lamp has ignited. The so-called ballasts which are used with these lamps are thereby required to provide three characteristics: (a) they must furnish the ignition voltage, raising the line voltage where the lamps ignite at higher voltage than available from the line or reducing it where the lamps ignite at lower than line voltage; (b) they must furnish the running or operating voltage for the lamps, this being substantially lower than ignition voltage; and (c) they must provide sufficient impedance to flow of current to prevent the lamps from destroying themselves once current commences to flow with ionization of the gases within the lamps, while maintaining sufficient flow of current to give the desired illumination, such flow of current being that specified as rated by the lamp manufacturer.

The art of ballast construction has reached a high degree of sophistication notwithstanding the fact that the theory upon which ballast construction is based depends upon certain presumptions and there are aspects of the operation of ballasts which are not precisely known. The principal presumption is that the voltages and electric currents are sinusoidal (which is only approximately true) and the aspects of ballast function which are not precisely known are those represented by the interaction between the various components. In this latter regard, it is pointed out that it is most difficult, if not impossible, to quantitatively analyze the operation of a ballast which has a plurality of windings with different degrees of coupling, each having a different ferromagnetic effect upon the iron core which carries such windings. The relative dimensions of the different parts of the iron core, the type of steel, the sizes and locations of shunts, the values of capacitive elements in the circuit, the locations of the different parts of the core with respect to the windings - all of these can have a substantial effect upon the phenomena occurring.

Certain structures have become accepted as the most economical and efficient for the operation of certain lamps. Also, the use of certain lamps has become prevalent at the present time.

A fluorescent lamp which is in widespread use today in the United States is the so-called rapid start lamp. This is a fluorescent lamp which has permanently energized filaments in its ends, and in many places it has replaced the earlier preheat start lamp and the instant start lamp. The preheat start lamp had filaments in its ends which were energized during the ignition period

of the lamp through a shunting circuit that was thermostatically opened to disconnect the filaments and, by a surge produced upon such opening, assist in the starting of the lamp. The filaments glowed during such starting period to provide clouds of electrons to reduce the ignition voltage. The instant start lamp was one which had filament-like electrodes in its ends and was ignited by means of a substantially higher than line voltage by breaking down the field between the two electrodes.

The preheat lamps were normally low voltage lamps and the circuits for igniting and operating them were bothersome. The instant start lamps required ballasts which were expensive because of the high voltages required and the lamps were not as robust as the later rapid start lamps.

Notwithstanding the need for filament windings and connections for energizing the filaments of rapid start lamps, fixtures with rapid start lamps are the most popular today.

The most common rapid start ballast circuit as of the present time is one which uses a transformer having a primary winding and a secondary winding on the same laminated steel core separated by a shunt, connected in voltage additive autotransformer relationship with a pair of rapid start lamps in series with the two windings. A condenser shunts one of the lamps and a second condenser is in series with both lamps. When the primary winding is energized, the open circuit voltage across both the primary and secondary windings appears across the lamp which is not shunted. The shunting condenser acts only to reflect the open circuit voltage through itself since there is substantially no current flowing and no voltage across the shunting condenser.

Once the unshunted lamp ignites and current flows through the shunting condenser and the unshunted lamp, a voltage appears across the shunting condenser which is sufficient to ignite the second or shunted lamp. When this lamp ignites, since its impedance to current flow is substantially less than the capacitive reactance of the shunting condenser, most of the current flows through the second lamp and thereafter current flows through the two lamps in series and through the series condenser. The purpose of the series condenser is to provide a leading current in the circuit which improves the overall power factor of the entire circuit.

Single lamp ballasts using rapid start lamps comprise autotransformers with or without series condensers. A typical ballast will comprise a primary winding and a secondary winding on a similar iron core as described above, the windings being additive and together connected in series with a condenser and a rapid start lamp. The open circuit voltage is chosen to be sufficient to ignite the lamp, the condenser not participating in the establishment of the open circuit voltage. Thereafter, when current flows, the condenser provides sufficient capacitive reactance to limit current flow to rated value while offsetting inductive reactance of the transformer to provide good power factor.

The invention herein is principally concerned with the provision of a three-lamp ballast. The problem originally attacked related to a three-lamp ballast using 40 watt 48 inches T12 rapid start lamps but the solution is not limited to the particular type of lamp. The problem is relatively acute with respect to the particular lamp. These lamps require 200 volts to start, and operate at about 105 volts.

Three-lamp fixtures using 40 watt 48 inches T12 rapid start lamps have been made in the past but with expensive components. One manner of manufacture has been to use a two-lamp rapid start ballast as described above along with a single lamp rapid start ballast as described above, both being installed in the same fixture. This arrangement is heavy, expensive, and occupies a great deal of space. Another method of constructing a three-lamp rapid start fixture has been to use a circuit not differing substantially from the two-lamp rapid start ballasts described above in which the three lamps are connected in series with suitable shunting condensers arranged across two of the lamps. For example, one condenser would shunt two lamps and another one lamp. An alternate arrangement would provide for the shunting of two lamps only by one condenser so that the sequence of starting is the unshunted lamp followed by the two shunted lamps.

The problem with this type of ballast is that minimum starting voltage required for two 40 watt rapid start lamps in series is 256 volts and for three lamps in series is 395 volts. Accordingly, the ballast for a three-lamp arrangement in which the lamps are connected in series is substantially more expensive than a two-lamp ballast because of the high voltages which must be handled.

The problems relating to high voltage insulation and, in addition, safety considerations, have channeled fixture manufacturers to the use of two independent circuits for three-lamp arrangements. As a matter of fact, due to the expense and the space involved, three-lamp fixtures are not as popular as two-lamp or four-lamp fixtures.

The invention herein solves the problems mentioned above in connection with the production of three-lamp systems by providing a ballast that is very small in size, economical, and efficient for use in a three-lamp circuit of the rapid start variety.

One of the important items of economy which results from the invention is the reduction in the cost of the operating or series condenser. The voltages are lower in the three-lamp circuit of the invention than in a three-lamp series circuit. This enables the use of a lower voltage and hence more economical capacitor than in the series circuit.

SUMMARY OF THE INVENTION

A three-lamp rapid start circuit is provided in which the overall circuit has a lead side and a lag side both energized by a single transformer. The transformer has four principal windings arranged on two parts of the transformer so that the pair of windings in one part while tightly coupled with respect to one another, is loosely coupled with respect to the pair of windings in the other part. The lag side of the circuit comprises a single rapid start lamp in series with a choke and connected in series additive relationship with the primary winding, a first secondary winding and a second secondary winding, all in series. The lead side of the circuit consists of a pair of rapid start lamps connected in series with a condenser and one of the lamps being shunted by a second condenser, both lamps being connected in series with the primary winding of the transformer and a third secondary winding of the transformer, the two windings being additive and loosely coupled with respect to one another. The primary and first secondary winding are closely coupled and the second secondary winding is loosely coupled with respect to these two windings.

The two lamps in series ignite first in sequence and due to the transformer relationship of the second secondary windings with respect to the third secondary winding provide an additional voltage to assist in igniting the third lamp.

The arrangement is such that there is high power factor reflected into the line by the transformer and some stroboscopic correction due to the alternate flashing of the lead and lag circuits.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1** and **2** are circuit diagrams of three-lamp ballast systems for rapid start lamps showing typical prior art apparatus;

FIG. **3** is a circuit diagram of a three-lamp ballast system for rapid start lamps constructed in accordance with the invention;

FIG. **4** is another circuit diagram of a three-lamp ballast system for rapid start lamps constructed in accordance with the invention but showing a modified form;

FIG. **5** is a sectional view taken through a transformer for use with either of the apparatuses illustrated in FIGS. **3** and **4**; and

FIG. **6** is a sectional view through a choke for use with either of the apparatuses of FIGS. **3** and **4**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The most important differences between the apparatus of the invention and the apparatus of the prior art lie in the space occupied, the weight and the cost. Other advantages also accrue.

In one instance, there is an integration of two circuits into one, utilizing a single transformer whose size and complexity are not much greater than those of one of the transformers of the prior art circuits.

In the second instance there is a substantial decrease in voltages and currents handled and substantial savings in component construction as a result.

The ballast of the invention runs cooler and provides better wave shape and power factor than either of the prior art circuits.

A typical prior art circuit is illustrated in FIG. **1** in which there are, in effect, two independent ballast circuits mounted in a single fixture. In FIG. **1** the circuit **10** is a typical two-lamp rapid start ballast circuit and the circuit **12** is a typical one-lamp rapid start ballast circuit. Both circuits are shown connected to the same line **14** but, except for being mounted in the same fixture, that is the only aspect that they have in common.

The circuit **10** typically utilizes a shell-type transformer **T1** having two parts defined by framed windows (not shown) separated by a shunt **16.** The primary winding **P1** is mounted in one window and connected to the line **14** by way of the white lead **18** and the black lead **20.** Connections as shown are for safety purposes. Primary winding **P1** is connected by the common connection **22** in series with the secondary winding **S3** that is mounted in the second window of the transformer **T1.** The right-hand terminal of the winding **S3** is defined by the conductor **24** and the left-hand terminal of the winding **P1** is defined by the conductor **26.** The transformer windings **P1** and **S3** are thus connected across the lamps **L1** and **L2** in series, the windings themselves being in autotransformer additive relationship.

The remaining elements of the circuit **10** are well known. A few turns of the primary winding P1 are utilized as a filament winding F5 connected by way of the leads **26** and **28** to the left-hand filament **30** of the lamp L1. A filament winding F3 closely coupled with the primary winding P1 is connected by way of the leads **32** and **34** to the common connections **36** and **38** respectively of the right-hand filament **40** of the lamp L1 and the left-hand filament **42** of the lamp L2. The filament winding F4 closely coupled with the primary winding P1 is connected by way of the leads **44** and **46** to the right-hand filament **48** of the lamp L2, the lead **46** in the course of such connection being common with the lead **50** that serves to connect the condenser C1 in series with the lamps. The resistor R1 is a leading resistor to discharge the condenser C1 when the circuit is not operating. Condenser C2 is the shunting condenser for the lamp L2.

The circuit **10** of the ballast apparatus of FIG. **1** operates in a conventional manner. When the primary winding P1 is energized, a voltage appears across leads **26** and **24** which is, in effect, transferred to be applied to the lamp L1. On open circuit conditions with substantially no current flowing through the condensers C1 and C2, there is no voltage drop to speak of across such condensers all of the voltage therefore appearing across the lamp L1. The fixture itself, represented by reference character **52**, is grounded so that there is a potential between the right-hand end of the lamp L1 and ground through the air surrounding the right-hand end assisting in the starting.

Once the lamp L1 has started, current flows through the condenser C2, this condenser being of the order of 0.05 microfarads in a circuit for **40** watt rapid start lamps so that a high enough voltage is provided appearing now across the lamp L2 between the leads **36** and **50**. This voltage ignites the lamp L2 after which current flows through the lamp bypassing the shunting condenser C2. Thereafter, current flows through the lamps L1 and L2 in series with the condenser C1, typically of the order of 4 microfarads. The circuit **10** is leading so that the overall power factor at the leads **18** and **20** approaches unity.

Now, with respect to the circuit **12**, this circuit operates substantially independently of the circuit **10**. A transformer T2 of construction similar to that of T1 having a shunt **54** mounts the primary winding P2 connected to the line **14** by way of the leads **56** and **58**. The autotransformer winding S4 is arranged additive to the primary winding P2 and together with the primary winding P2 is connected across the single lamp L3 by way of the leads **60** and **62**. The left-hand filament **64** of the lamp L3 is energized by the filament winding F1 through the leads **62** and **66** while the right-hand filament **68** of the lamp L3 is energized by the filament winding F2 through the leads **70** and **72**. The condenser C3 is a series condenser shown shunted by a discharge resistor R2.

In operation, sufficient voltage on open circuit appears across the leads **60** and **62** to ignite the lamp L3 after which current flow is limited by the total impedance of the circuit which is made leading by reason of the condenser C3.

As seen from the apparatus of FIG. **1**, two transformers are needed in energizing two independent circuits **10** and **12**. The weight, space and cost of the ballast with two such circuits is not much less than the cost of two two-lamp rapid start ballasts.

In FIG. **2** there is illustrated another prior art three-lamp rapid start ballast circuit **11**. In this circuit the three lamps L1, L2, L3 are started in sequence in the same manner as the lamps L1 and L2 of the circuit **10** of FIG. **1**. The only components added are the lamp L3 with its filaments **64** and **68**, a second shunting condenser C3, and another filament winding F6 with suitable connections. First lamp to start is L1, next is L2, and the last is L3. Condensers C2 and C3 aid in starting seriatim and are thereafter effectively shunted out of the circuit.

This circuit **11** seems simple and economical of components, but the high voltages handled and the large component of leading current make it expensive and heavy. Wave shape and power factor are acceptable but not desirable.

Reference is now made to the apparatus **80** of FIG. **3** in which similar components will be given reference characters for the same or similar components as in FIGS. **1** and **2**.

In FIG. **3**, a transformer T1 is designated by the conventional symbol comprising parallel lines, the transformer being divided into two parts by virtue of a shunt **82**. Shunt **82** may be metallic or simply comprise spacing between parts. The transformer T1 has a primary winding P, a first secondary winding S1 closely coupled to the primary winding, a second secondary winding S2 loosely coupled with respect to the primary winding P and the first secondary winding S1, and a third secondary winding S3 which is closely coupled to the second secondary winding S2. A filament winding F1 is formed from a few turns of a primary winding P and there are independent filament windings F2, F3, and F4 closely coupled with the primary winding P.

Before entering further into the discussion of the apparatus **80**, attention is invited to FIG. **5** which illustrates in section the transformer T1.

The transformer T1 comprises an iron core formed of stacks of laminations clamped together by clamps **84** to form a shell-type iron core. The construction of the transformer T1 is fairly well known at the present time. For example, the core includes a central winding leg **86**, a framing part **88** at the left end, a framing part **90** at the right end and outer elongate framing parts **92** and **94**. The individual laminations from which the core is formed are stamped with a scrapless technique disclosed in U.S. Pat., Nos. 2,892,249 and 3,023,385, and hence comprise T's and L's suitably arranged. The L's are designated **96** and the T's are designated **98**. The left end framing portion **88** is formed out of the cross member of the stack of T's **98**. The outer framing members **92** and **94** comprise the elongate portions of the L stacks **96**. The right end framing portion **90** is formed by the short legs **100** and **102** of the opposite L stacks **96** directed toward one another butting against the extreme right-hand end of the central bar or winding leg **86** of the T stack **98**. The butted joints are designated **104**.

In the process of stamping the laminations, inwardly directed tongues **106** are stamped integral with the L laminations **96** thereby producing notches **108** in the sides of the main bar or winding leg **86** of the T laminations **98** so that in effect the central winding leg **86** has a reduced cross-section portion **110**. The effect of the tongues **106** when the core is formed is to provide a shunt at **82**. When the three stacks, that is, the two L

stacks **96** and the single T stack **98**, are assembled together as shown, windows are formed at **112** and **114**, such windows being for the purpose of accommodating windings as will be described. In the description and claims, reference will be made to the transformer core having two parts. What is meant by these designations is the physical portions of the transformer on opposite sides of the shunt **82**. Thus, when windings are said to be provided on one part or in one part of the transformer, such windings would be in the window **114** and when windings are said to be provided on or in another part of the transformer, they would be in the window **112**.

According to the invention, the primary winding P of the apparatus **80**, the first secondary winding S1, and the three small filament windings F2, F3, and F4, are all mounted in the window **112**. Since the filament winding F1 is a part of the primary winding P it also is disposed in the window **112**. The two secondary windings S2 and S3 are disposed in the window **114** with the notches **108** and decreased cross section **110** of the central winding leg **86** buried within those two secondary windings.

The windings may be made by two different techniques. In accordance with one technique a single spool or bobbin of wire is made on the usual tubular paper member and in the course of applying the turns loops are formed which eventually will be pulled from the ends of the bobbin and either cut to form independent windings or connected without cutting to provide taps. The second method of forming such windings is to wind independent bobbins for the groups of windings which is going to be mounted in a single window and disposing them telescopically or axially of one another, depending upon how they are wound.

In accordance with either technique, when a plurality of windings is mounted in a single window it is intended that they will all be closely coupled with one another.

From the construction which has been described above, it will be seen that the secondary windings S2 and S3 are closely coupled with one another but are both loosely coupled with respect to all of the other windings. The latter, comprising the primary winding P, the first secondary winding S1, and all of the filament windings are all closely coupled to one another.

Adverting once more to FIG. **3** and the continued description of the apparatus **80**, it may be seen that the primary winding P is connected to the terminals **14** of the line by way of the leads **18** and **20**. The lead **18** is white in accordance with color convention used today, this being grounded as shown at **120**. The lead **20** is the "hot" line lead and is black in color. The secondary winding S3 connects with the right-hand end of primary winding P at the terminal **122**, and its right-hand end in turn is connected to the lead **124**, the series condenser C1 and the lead **126** which, of course, is a continuation of the lead **124**. Lead **126** connects by way of the lead **128** to one side of the filament **130** of the lamp L2.

The left terminal of the primary winding P which terminal is at ground potential, connects by way of the lead **132** to one of the terminals of the filament **134** of the lamp L1. The other terminal of the filament **134** connects by way of the lead **136** to the tap point **138** which defines the filament winding F1 so that in effect the primary winding P is connected to the lamp L1 while the filament winding F1 is connected to the filament **134**. Lamps L1 and L2 have their filaments **140** and **142** connected together by common leads **144** and **146**, the leads being in turn connected to the filament winding F2 by way of the leads **148** and **150**. Filament winding F2 therefore is arranged to energize the filaments **140** and **142** in parallel. The filament winding F3 connects by way of the leads **152** and **154** to the filament **130** there being a direct connection to one terminal and a connection through the leads **126** and **128** to the other terminal.

The lamp L2 is shunted by the condenser C2 which connects from the lead **126** to the lead **144**. The fixture in which the lamps L1 and L2 are mounted will include a metallic plate portion that is close to the lamps and is grounded, this being designated by the heavy lines **156**.

As thus far described the circuit **80** is very much like the circuit **10** of FIG. **1** but for the construction of the transformer T1. In operation there is a strong similarity if the action of the transformer secondary windings S1 and S2 is not considered. When the primary winding P is energized a voltage is produced from the lead **132** to the lead **124** which depends upon autotransformer action and the turns ratio of the secondary winding S3 with respect to the primary winding P. Windings are additive as indicated. Substantially all of this voltage will appear across the lamp L1 for reasons which have been explained above causing this lamp to ignite and thereafter causing electric current to flow through the condenser C2 in series with the lamp L1. Thereafter, the voltage appears across the condenser C2 which is sufficient to ignite the lamp L2, the lamp L2 ignites and the shunting circuit represented by the condenser C2 becomes ineffective. Thereafter, the circuit consists of the lamps L1 and L2 in series with the condenser C1 and connected across the windings P and S3.

For sake of convenience, this portion of the circuit **80** described above has been termed the lead side since the circuit is leading on account of the excessive capacitive reactance produced by the condenser C1 which is normally chosen to be of the order of 3.95 microfarads. This is for a **40** watt rapid start lamp circuit. It will be noted that the right-hand terminal of the condenser C1 and the right-hand terminal of the condenser C2 may be common so that both condensers may be mounted in a single canister, with a common foil having a single terminal. The condenser C2 has a capacitance of 0.05 microfarad.

The lag side of the apparatus **80** will now be described, this portion of the circuit being intended to ignite and operate the lamp L3.

The terminal **122** is connected by way of an extension of the lead **20** to the right-hand terminal of the first secondary winding S1. This winding is connected by way of the lead **160** to the left-hand terminal of the second secondary winding S2 and the right-hand terminal of the second secondary winding S2 is connected to the lead **162** through a series choke CH to the lead **164**, this latter lead in turn being connected to one terminal of the filament **166** of the lamp L3 through the lead **168**. The left-hand end of the lamp L3 has the filament **170** which is connected by way of the leads **172** and **174** to the leads **136** and **132** respectively, these leads being in turn connected to the left-hand end of the primary winding P so that the filament winding F1 in addition to energizing the filament **134** also energizes the filament **170** and provides the connection for the left

terminal of the primary winding P with the lamp L3. The lamp L3 is in the same fixture with the other two lamps and hence the grounded metal plate **156** is also shown in proximity to it for assistance in starting. The filament winding F4 serves the filament **166** through leads **171** and **173.**

The windings P, S1, and S2 are all connected in additive relationship across the lamp L3 for starting and operating the lamp with the choke CH in series to limit the flow of current once the lamp L3 is ignited.

The choke CH may be constructed conventionally as shown in FIG. **6.** Illustrated is a structure in which there is a stack of E laminations **180** and a stack of I laminations **182** butted together along the joint **184.** The usual gap **186** is provided by shortening the center leg of the E stack **180.** The window formed at **188** on opposite sides of the central leg is occupied by a single tubular winding of conventional construction. The stacks of laminations are held together by clamp means (not shown).

The operation of the circuit **80** depends upon the interrelations between the secondary windings. Integrating the lead and lag circuits so that their secondary windings assist one another, it is feasible to use a small transformer and less turns than would be expected to provide required open circuit and operating voltages for three lamps in a single circuit. The savings are of sufficient magnitude such that even the additional expense of a choke does not prevent substantial economical advantage over prior three-lamp rapid start ballasts. This benefit extends also to weight and space occupied.

The operation of the circuit **80** is best explained in conjunction with a practical device constructed and tested using commercial 40 watt 48 inches T12 rapid start lamps, the circuit being energized from a 120 volt 60 hertz source. The physical specifications of the apparatus were as follows:

The transformer core illustrated in FIG. **5** is substantially to scale with the laminations configured as shown. The overall length was 4.56 inches, the width of the central winding leg **86** was 0.82 inch, the width of the outer framing parts **92** and **94** was 0.35 inch, the width of the legs **100** and **102** and the crosshead **88** was 0.38 inch. The length of the window **112** was 2.07 inches, of the window **114** was 1.59 inches and the width and length of the projections were 0.128 inch by 0.225 inch. Other dimensions may be proportionally scaled from the figure.

Electrical sheet steel was used, containing silicon, of conventional thickness, the stacks being 0.85 inch in height.

The primary winding P, S1 and filament windings were formed into a rectangular tubular structure or assembly 2.06 inches in length occupying the window **112.**

The secondary windings S2 and S3 comprises a tubular member 1.56 inches in length occupying the window **114.** The winding composition was as follows:

P1 - 696 turns of No 24 A.W.G. copper wire with insulating enamel

S1 - 137 turns of No 28-½ A.W.G. copper wire with insulating enamel

S2 - 498 turns of No 28-½ A.W.G. copper wire with insulating enamel

S3 - 1,277 turns of No 28-½ A.W.G. copper wire with insulating enamel

All filament windings were approximatly 25 turns of 28-½ A.W.G. wire except where formed by a tap in the primary winding P1 in which case the filament winding would be out of the same gauge as the primary winding P1. The choke CH comprised a one inch long tubular coil of 1061 turns of No. 29 A.W.G. copper wire mounted on a 0.85 inch stack of E's and I's arranged as shown in FIG. **5.** The width of the E (top to bottom) was 2.04 inches, the overall length was 1.7 inches. The remaining dimensions may be scaled from the drawing which is drawn to proper proportions. The gap **186** was 0.023 inch.

The condenser C1 was 3.95 microfarads and the condenser C2 was 0.05 microfarad, both being mounted in the same canister and having suitable safe voltage ratings, but only for two lamps in series.

Standards, requirements and performance characteristics for ballasts and fluorescent lamps are established in the United States by the American National Standards Institute and the Certified Ballast Manufacturers. These are voluntary not-for-profit organizations of lamp and ballast manufacturers in the first instance and of ballast manufacturers in the second instance whose aims are to achieve the greatest benefits in safety, economy and efficiency in lighting for the public in connection with gaseous discharge lamps. Other public benefit oriented organizations, such as the Underwriters' Laboratories give substantial recognition to the policies established by the two first mentioned organizations.

Starting and operating characteristics are established by the A.N.S.I. The C.B.M. members manufacture ballasts in accordance with these characteristics.

The word "required" when used to describe a starting voltage, for example, is an artificial usage if it means the voltage which has been established as "required" by the A.N.S.I. Considering a given lamp, the voltage which is physically required for starting it may be substantially different from that "required" by the standards of the A.N.S.I. The environment and physical conditions, manufacturers' variations in the construction, etc., may result in the lamp being quite satisfactorily started at some voltage substantially below the "required" starting voltage established by the A.N.S.I.

The three voltages mentioned previously for starting 40 watt rapid start lamps, namely 200 volts for a single lamp, 256 volts for two lamps and 395 volts for three lamps are established by the A.N.S.I. These voltages are R.M.S. values, bnd the values are established as the "minimum required" starting voltages for the lamps under conditions that the ballast providing such voltages is connected to a source of 90 percent to 100 percent of line voltage. (In the case of 120 volts 60 hertz, this would mean that the starting values must be achieved in the ballast when it is connected to a source as low as 108 volts.

When the starting voltage established by the A.N.S.I. is mentioned hereinafter, it will be referred to as the "minimum required" starting voltage. Mention should be made of a "minimum practical" starting voltage which should be considered independently of the existance of any standards. Any given lamp, under favorable conditions, will have a starting voltage at which the lamp will start quickly enough to give good ionization

without creating any factors which could eventually result in the shortening of the lamp life. This voltage would be the minimum practical starting voltage.

In the United States, for all commercially available fluorescent lamps, it may be accepted that the minimum required starting voltage and the minimum practical starting voltage are the same. The purchasing public familiar with any type of lamp will expect that the ballasts which are purchased for those lamps will meet the A.N.S.I. standards and hence provide minimum required starting voltages, even if the lamps are capable of starting reliably at much lower voltages.

Reference made hereinafter to "starting voltage" will mean a voltage applied to a lamp which causes it to start, irrespective of whether it is the minimum required or minimum practical starting voltage or any other value of starting voltage. Reference to applied voltage is the voltage applied to a lamp, regardless of whether it causes the lamp to start or not.

As previously stated, the minimum required starting voltage for two 40 watt rapid start fluorescent lamps connected in series is 256 volts across the lamps together. For a single 40 watt rapid start fluorescent lamp the minimum required starting voltage is 200 volts.

With this in mind, the electrical characteristics of the practical ballast described above may be considered and used to illustrate the benefits to be derived from the invention.

At open circuit, energized from a 120 volt 60 hertz line, the following open circuit voltages were observed at 90 percent of line voltage and 100 percent of line voltage:

Across the secondary S1 20.5 volts at 100 percent of line voltage

S2 68 volts at 100 percent of line voltage

S3 177 volts at 100 percent of line voltage

CH 0 volts

Across the lamps L1 and L2 277 volts at 90 percent of line voltage

299 volts at 100 percent of line voltage

Across the lamp L3 195 volts at 90 percent of line voltage and 214 volts at 100 percent of line voltage.

The voltages generated by the ballast are required to meet the established minimum required values for the range between 90 percent and 100 percent of the line voltage for which the ballast is built. As noted from the above data, there is no problem with the lamps L1 and L2 but it appears that the open circuit voltage for igniting the lamp L3 is below minimum required starting value. Among the disadvantages of low starting voltage is decrease in lamp life. It should also be noted that too high a starting voltage is also undesirable because it forces the lamp to start before the filament has been heated (this being called "instant starting") thereby causing the filaments to be damaged by heavy ion bombardment.

Measurements were made with the lamps L1 and L2 in the circuit and the lamp L3 removed. This enables the measurement of the L3 open circuit voltage after the first two lamps have ignited to show the effect of the flow of current in the lead circuit upon the voltages generated in the secondary windings of the lag circuit. These measurements were as follows: (The lamps L1 and L2 only in operation)

Lamp current 0.421 amp.

Line current 0.838 amp.

Primary current 0.526 amp.

Watts in line 98

Primary voltage 120 volts

S1 voltage 21.7 volts

S2 87 volts

S3 217 volts

CH 0 volts

Voltage across lamp L3 207 volts at 90 percent of line voltage

Voltage across lamp L3 226 volts at 100 percent of line voltage.

Note that the voltage in the first secondary winding has increased only slightly, but that there has been a noticeable increase of the voltages in the second and third secondary windings. In the case of S2 the increase is almost 30 percent while in the case of S3 the increase is about 23 percent. The increase in open circuit voltage available for ignition of the lamp L3 at full line voltage is no 226 volts which is an increase of over 8 percent. More importantly, note that the open circuit voltage across the lamp at 90 percent of line voltage is 207 volts, which is well above the minimum requirement.

While the above-described example is a practical ballast, its open circuit applied voltage for the lamp L3 is not the minimum required at **90** percent of line voltage. It is in fact 5 volts too low. The A.N.S.I. requires that the third lamp L3 of a three-lamp ballast be capable of starting by itself, irrespective or whether the other two lamps ignite. In practically all but the most adverse of ambient circumstances **195** volts will be sufficient starting voltage for the lamp L3, but the minimum required starting voltage must be present for the ballast to be acceptable. Accordingly, the practical circuit described above will have to be varied in its physical constants to meet this requirement, as for example, by adding a few turns to the secondary winding S1. No other physical changes in the structure need be made. The example has been given to indicate that even though on open circuit the lamp L3 might not have sufficient starting voltage or minimum practical starting voltage applied to it, once the other two lamps ignited there was additional voltage available bringing the applied voltage comfortably up to minimum required and/or minimum practical starting voltage.

It is believed that the increase in open circuit voltage of the secondary windings S2 and S3 is caused by the additional flow of current in the primary and secondary windings after the lead side of the circuit has been operating, possibly affected by phase changes or flux variations resulting in higher induced voltages. From a consideration of the voltages of P, S2 and S3 in series additive relation there is a substantial difference in phase between the windings, but the resultant is now sufficient to meet the open circuit minimum required starting voltage for igniting the lamp L3 where before (i.e., on open circuit conditions with the lamps L1 and L2 not ignited) the requirement was not met.

It is emphasized that the ballast physically described above is a good practical ballast, notwithstanding it would not be acceptable by one who insists on having every requirement of the A.N.S.I. met. It was pointed out above that it could be made fully acceptable by adding a few more turns, say **20** or so, to the secondary winding S1.

The requirement that the third lamp L3 be capable of independent ignition is an artificial requirement established by the A.N.S.I., albeit done to achieve certain practical benefits to ballast and lamp users. Absent

such requirement, as for example in the case of new lamps which have not had standards and requirements established; or in the case of apparatus being manufactured for use in locations where the regulatory agencies and associations have no jurisdiction or following; or even in the case that the requirement is eliminated in this country — it should be appreciated that it is feasible to construct the ballast **80** wherein the applied voltage on lamp L3 on open circuit is even below starting voltage for the lamp, with the added voltage in the secondary windings S2 and S3 being sufficient after ignition of the lamps L1 and L2 to bring the applied voltage across L3 to minimum practical starting voltage.

In the practical example above, notwithstanding its deficiency in supplying minimum required starting voltage for the lamp L3 on open circuit, operating characteristics were fully satisfactory as indicated by the following data taken with all lamps operating:

Lamp currents were between 0.368 and 0.416 amp.
Line current 1.30 amps.
Primary current 0.771 amp
Line watts 144 watts
Coil voltages S1 21 volts
S2 76 volts
S3 205 volts
CH 152 volts
Condenser C1 274 volts
Crest Factor Lead Side 1.463
Lag side 1.581
Filament voltages 3.26 to 3.76

It will be noted that the voltages and currents within the circuit are quite moderate considering that there are three lamps to be started and operated.

An analysis of the circuit will reveal that the ballast of the invention has electrical advantages in addition to the presence of moderate currents and voltages. This latter fact can be observed from the electrical characteristics listed above for a practical device and clearly results in a cooler operating ballast.

It is believed that during operation of the ballast, the lag current in the lag side produced by the choke CH flowing in the secondary winding S2 has a phase that reacts contrary to the phase of leading current flowing in the winding S3. The lead current in secondary winding S3 produces a flux tending to saturate the core under the secondaries S2 and S3 due to the large number of turns of winding S3, but the lagging current in S2 reduces the flux and decreases the tendency to saturate. Although still leading, the flux decrease improves wave shape and hence gives better lighting. This is in addition to the improvement produced by the flux reduction due to the reduced section **110.**

As stated above, the open circuit voltage for igniting the lag lamp L3 may be deliberately made higher than need be to assure that the lamp L3 is capable of starting by itself.

If the lag lamp L3 ignites first, the open circuit voltages available for the ignition of the lead circuit are sufficient to provide rated ignition voltages for the lamps L1 and L2. Thus, although in practically all cases the lamps L1 and L2 will ignite first, followed by the lag lamp L3, if L3 comes on first L1 and L2 will follow. This can be seen by the following measurements which were taken on the practical ballast described above.

With the lamps L1 and L2 out of the circuit, only lamp L3 was ignited, when the ballast was energized from the 120 volts 60 hertz line. Recall that the open circuit voltage was well over 200 volts, the minimum required starting voltage, even though the ballast would be commercially not acceptable because its open circuit voltage applied to L3 at 90 percent of line voltage is below the minimum required starting voltage.

Lamp current in L3 0.338 amp.
Line current 0.853 amp.
Primary current 0.513 amp.
Line watts 50.1 watts
Coil voltages S1 21.2 volts
S2 55 volts
S3 154 volts
CH 138 volts
Across the lamps L1 and L2 257 volts at 90 percent of line voltage
277 volts at 100 percent of line voltage

We have seen from the previous discussion that the minimum required voltage for ignition of two 40 watt rapid start lamps in series is 256 volts from 90 percent to 100 percent of line voltage. It is apparent that even if under special circumstances and conditions the lag lamp L3 ignites first, it will not have sufficient extinguishing effect upon the components of the transformer T1 that contribute to the open circuit voltage of the lamps L1 and L2 to prevent ignition of such lamps. Accordingly, the circuit **80** is a rugged and totally reliable circuit besides being economical.

A comparison between a ballast constructed according to the invention and the smaller of the two conventional three-lamp rapid start ballasts will indicate the physical advantages of the former. The comparison ballast is a typical three-lamp series ballast as known. The lamps and ratings are the same, i.e., 40 watt T-12 rapid start lamps to be operated from 120 volt 60 hertz lines.

	Ballast As Sold Heretofor	Ballast Embodying Invention
Weight	7.46 Pounds	5.25 Pounds
Size of Canister	3.125" × 11.75" × 1.75"	2.36" × 11.75" ×1.70"
Volume of Canister	64.256 cubic inches	47.2 cubic inches
Cost of Construction	100%	Estimated 75%

Addition of a few turns on S1 to bring the 90 percent of line open circuit voltage applied to L3 up to 200 volts will have no practical effect on these figures.

The modified circuit **200** of FIG. **4** varies but slightly from the circuit **80** of FIG. **3.** The difference lies in a rearrangement of the connections of the secondary windings to have lower voltages at lamp terminals in case a person should grasp one end of a lamp and touch ground completing a circuit. As for the lag lamp L3 a disconnect socket **202** is connected at its left filament **170** and the leads **172** and **174** connect with an independent filament winding F5 that is closely coupled to the primary winding P.

Instead of grounding the left-hand terminal of the primary winding P as in FIG. **3,** this is made the "hot" side and connected to the line terminal **14** by lead **20'.** The terminal **122** is connected by the lead **174,** the contact **204,** the contact **206** and the lead **18'** to line terminal **14** which is grounded at **120.** The connection for lamp L3 is through contact **208.** The contacts **204, 206** and **208** form the disconnect socket **202** which is conventional in construction. Removal of the lamp L3 from socket **202** deenergizes the entire circuit. Grasping a terminal of either lamp L1 or L2 and touching ground

will not subject the person holding same to excessive voltage because of lower voltage to ground in this portion of the circuit.

In the discussion concerning circuits **80** and **200** above, reference has been made to lag side secondary windings S1 and S2 arranged in additive voltage series connection. It should be appreciated that the equivalent description could be a single secondary winding having a first portion (S1) on one part of the transformer T1 and closely coupled to the primary winding P and a second portion (S2) on the second part of the transformer T1 and closely coupled to the secondary winding S3. The portions of the secondary winding S1, S2 are in series and additive open circuit voltage relationship with respect to the loop circuit containing said secondary, the primary winding P, the choke CH and the lamp L3.

No comment need be made concerning the lead side except to mention that the open circuit loop contains the primary winding P and secondary winding S3 additive, together with the lamps L1 and L2 and the condenser C1 all in series.

The primary winding is common to both loops.

It is presumed in the use of ballasts for rapid start lamps that there will always be a grounded metal plate of the fixture in capacitive coupled relation to the lamps as shown at **52** and **156** for aiding in starting.

The invention is applicable to any rapid start lamp circuit for three lamps and is not limited to the **40** watt type specifically described above.

What it is desired to secure by Letters Patent of the United States is:

1. Apparatus for igniting and operating three gaseous discharge devices of the rapid start type comprising:

A. a transformer having a ferromagnetic core comprising a first part and a second part and means providing for substantial flux leakage between the parts,

B. a primary winding and first, second and third secondary windings mounted on said core, the primary winding and first secondary winding being mounted in close coupled relation on the first part and the second and third secondary windings being mounted in close coupled relation on the second part,

C. means comprising terminal leads for connecting the primary winding across an a.c. line of voltage insufficient to ignite any one of said devices,

D. means for forming with two of the devices a lead side of said apparatus and for forming with the third device a lag side of said apparatus and comprising

i. for said lead side a first condenser, a second condenser and conductors for connecting the two devices, said first condenser, the third secondary and the primary winding in series with the windings in additive autotransformer relation and said second condenser shunting one of the two devices, and

ii. for said lag side, a choke and conductors for connecting the third device, said choke, the first and second secondary and the primary windings in series with the windings in additive autotransformer relation,

E. The turns ratios and phase relations being such that on open circuit the lead side devices will have a voltage applied thereto sufficient to ignite said devices in sequence and will tend to ignite first and said lag side device will have a certain voltage applied thereto, after ignition of said lead side devices said certain voltage will be increased to assist in igniting said lag side device if it has not already been ignited, and the devices thereafter remaining ignited at substantially normal operating conditions.

2. The apparatus as claimed in claim **1** in which the voltage applied to said lead side devices on open circuit will be the minimum practical starting voltage for two devices while the said certain voltage applied to said lag side device on open circuit is less than the minimum practical starting voltage for a single device but after ignition of the said lead side devices the voltage applied to said lag side device will be increased to at least minimum practical starting voltage.

3. The apparatus as claimed in claim **1** in which the voltages applied to said devices on open circuit are the minimum required starting voltages.

4. The apparatus as claimed in claim **1** in which the primary winding, third secondary winding and one of said first and second secondary windings have a terminal end in common connected to one of said terminal leads.

5. The apparatus as claimed in claim **1** in which one of said first and second secondary windings and said primary winding have a first terminal end in common and in which said third secondary winding and primary winding have a second terminal end in common, the first and second terminal ends being opposite terminals of said primary winding and connected respectively to said terminal leads.

6. The apparatus as claimed in claim **5** in which said second terminal is adapted to be grounded and said means for forming the lag side include connections to a disconnect socket for said lag side device.

7. Apparatus for igniting and operating three gaseous discharge devices of the rapid start type comprising:

A. a transformer having a ferromagnetic core comprising a first part and a second part and means providing for substantial flux leakage between the parts,

B. a primary winding and two secondary windings mounted on said core, one secondary winding being a lead secondary winding and the other being a lag secondary winding, the primary winding being mounted on the first part of the core, the lead secondary winding being mounted on the second part of said core, and the lag secondary winding having one portion thereof closely coupled to the lead secondary winding,

C. means comprising terminal leads for connecting the primary winding across an a.c. line of voltage insufficient to ignite any one of the devices,

D. means including electrical leads and two condensers for forming with two devices and said transformer a lead loop, with the devices, one condenser, the primary winding and the lead secondary winding all connected in series, the second condenser shunting one of the two devices and the primary and secondary windings being additive, in said lead loop,

E. means including electrical leads and a choke for forming with a third device and said transformer a lag loop, with the third device, the choke, the primary winding and the lag secondary winding all connected in series, the primary and secondary windings being additive in said lag loop,

F. the primary winding being common to both loops and cooperating with said lead secondary winding to evolve a voltage on open circuit in the lead loop sufficient to ignite the unshunted device following which the shunted device will ignite and thereafter operating lead current will flow in series through said lead loop, the primary winding also cooperating with the lag secondary winding to evolve a voltage in the lag secondary winding on open circuit which is raised when said lead current flows in said lead secondary such that the combined primary and lag secondary voltages in said lag loop will be sufficient to ignite said third device, and

G. the choke serving to provide inductive reactance in said lag loop for providing lagging operating current therein.

8. The apparatus as claimed in claim **7** in which the open circuit voltage available across both devices of said lead loop is the minimum practical voltage for igniting two devices in series, and the open circuit voltage available across the third device of the lag loop is less than the minimum practical voltage for igniting a single device but is raised to minimum practical starting voltage after both devices of the lead loop are operating.

9. The apparatus as claimed in claim **7** in which the voltages applied to said devices on open circuit are the minimum practical starting voltages such that although the devices of the lead loop tend to ignite first, the third device will have sufficient open circuit voltage to ignite independently but will ignite more readily should the lead devices ignite first.

10. The apparatus as claimed in claim **7** in which the open circuit voltages available to all of said devices comprises the minimum required voltages for ignition.

11. A gaseous discharge device system comprising:

A. a high leakage reactance transformer having two ferromagnetic parts separated by shunting means, a primary winding and a step-up lead secondary winding mounted on the respective parts loosely coupled relative to one another, a step-up lag secondary winding having two portions each mounted on the respective parts in loose coupled relation to one another but in close coupled relation to the respective primary and lead secondary windings,

B. a pair of series connected gaseous discharge devices of the rapid start type and a condenser shunting one device,

C. a second condenser,

D. a third gaseous discharge device of the rapid start type,

E. a choke,

F. means for connecting the primary winding to a source of a.c. power the voltage of which is insufficient to ignite any device,

G. a lead loop formed by the series connected devices, the second condenser, the lead secondary winding and the primary winding, with the windings connected additive in said lead loop,

H. a lag loop formed by the third device, the choke, the lag secondary winding and the primary winding, with the windings connected additive in the said lag loop,

I. the turns relationships and phase relationships being such that upon ignition of the devices, a leading current will flow in the lead loop and a lagging current will flow in the lag loop.

12. The apparatus as claimed in claim **11** in which the pair of devices of the lead loop will on open circuit have a voltage applied thereto which is sufficient to ignite the devices in sequence and said pair of devices will tend to ignite before the third device, the lag secondary winding and primary winding upon open circuit applying a voltage across said third device which is raised after ignition of said pair of devices to assist in ignition thereof, if it hasn't already ignited.

13. The apparatus as claimed in claim **11** in which the lag secondary winding has a terminal common to one terminal of the primary winding and the lead secondary winding has a terminal common with the second terminal of the primary winding.

14. The apparatus as claimed in claim **13** in which said means for connecting said primary winding to a source include an electrical lead connected to said second terminal, the third device has a disconnect socket including spaced contacts in said electrical lead bridged only when said device is in said socket but otherwise open to deenergize said primary winding.

15. The apparatus as claimed in claim **14** in which said electrical lead is grounded.

16. The apparatus as claimed in claim **11** in which said devices have filaments in the ends thereof and said transformer includes a plurality of filament windings closely coupled with said primary winding and connected to energize said filaments.

* * * * *