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J. G. SOLA
TRANSFORMER FOR STARTING AND OPERATING
METALLIC VAPOR DISCHARGE DEVICES
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Fig. 1.

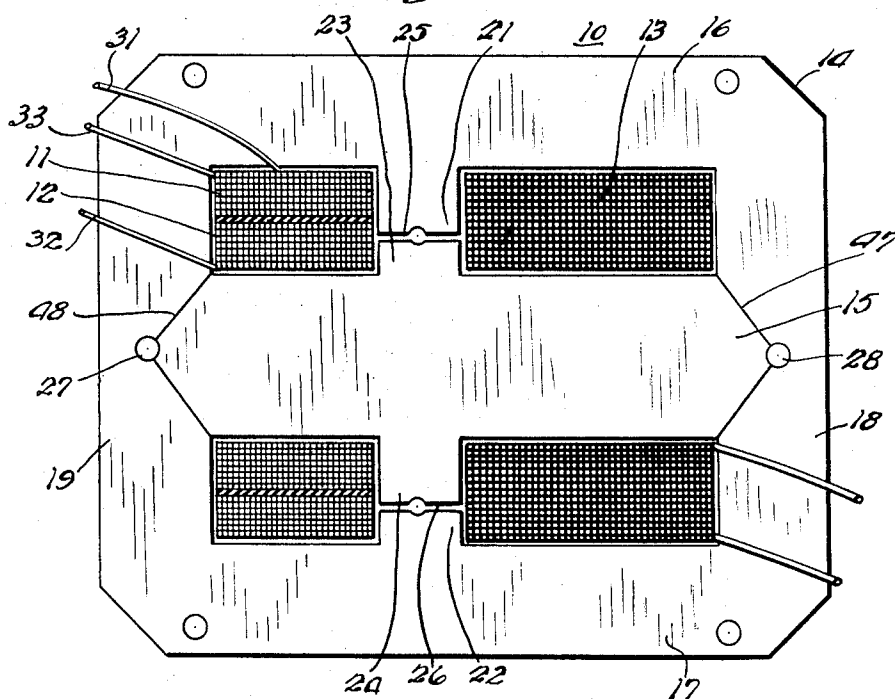


Fig. 2.

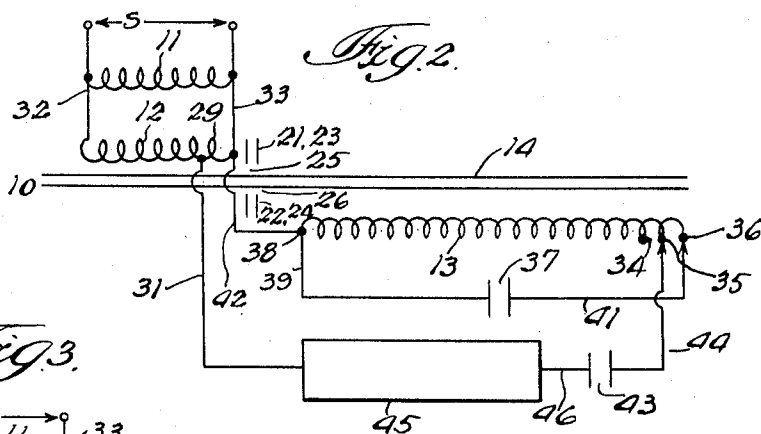
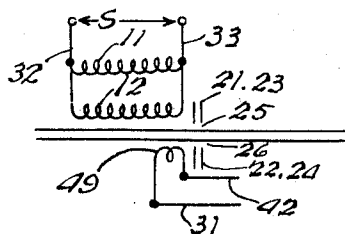


Fig. 3.



INVENTOR.

INVENTOR.
Joseph G. Sola.
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Okan, Mecklenburger, van Hout,
Pendleton, & Newman. 1871 5.

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TRANSFORMER FOR STARTING AND OPERATING METALLIC VAPOR DISCHARGE DEVICES

Joseph G. Sola, River Forest, Ill., assignor, by mesne assignments, to Basic Products Corporation, West Milwaukee, Wis., a corporation of Wisconsin

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8 Claims. (Cl. 323—61)

This invention relates to alternating current power supply apparatus to be connected between a source of voltage and a negative resistance discharge device for starting and operating thereof, and it is an object of the invention to provide improved apparatus of this character.

While the invention will be described in connection with a negative resistance discharge device of the type which may be designated as a relatively high pressure mercury vapor lamp useful in street lighting applications, it will be understood that this is exemplary and that the invention may have application to other types of metallic vapor discharge devices irrespective of the internal pressure or metallic vapor involved.

Mercury vapor lamps for street lighting applications, for example, require a relatively high voltage for starting and a considerably lower voltage for operating, the starting voltage, starting current, operating voltage, operating current and wattage consumed by the lamp being specified by the manufacturer. A typical mercury vapor street lighting lamp of the type involved in this invention and with respect to which the invention will be described is that known as type E-H1 which is rated as follows: 400 watts, 300 volts for striking, 135 volts for operating, approximately 5 amperes starting current and 3.2 amperes operating current. The ratings, however, apply for a nominal lamp and, as manufactured, lamps actually comprise three categories, known as high lamps, nominal lamps, and low lamps. High lamps would operate at a voltage of about 145 to 150 volts with correspondingly increased wattages, and low lamps would operate at about 120 to 125 volts with correspondingly decreased wattages, since, in each case, the lamp current remains at 3.2 amperes.

In mercury vapor discharge lamps of the character described, it is also considered essential that the wave shape of current in the lamp during operation be of a certain form, which is to say that undesired peaks in the current are to be eliminated. The measure of such wave shape of current is designated as the ratio of peak current to root mean square (R. M. S.) current and should be less than a certain maximum in order to obtain from such lamps the requisite number of hours of operating life with the quantity of light output being substantially maintained. The said ratio will be referred to throughout this specification as the crest factor, and the upper limit thereof specified by certain manufacturers of lamps is 1.85, and by other manufacturers it is specified as 1.7. For best results with such mercury vapor lamps the crest factor should not be greater than, and preferably should be less than, these values, and it is an object of the invention to provide an improved ballast or transformer for starting and operating mercury vapor discharge lamps at the rated wattages, voltages and currents and with the crest factors of operating current substantially less than 1.7.

Ballasts or transformers for starting and operating mercury vapor discharge lamps of the type referred to are well known. Such ballasts are designed for operating a

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nominal lamp—that is, one having a starting voltage of 135 volts—and may operate the lamp satisfactorily with a current crest factor equal to 1.7 or less. However, when such a ballast is connected to a low lamp—that is, one requiring 120 to 125 volts to strike—the lamp will operate with a crest factor greater than 1.7 which is not considered satisfactory by some manufacturers of lamps.

Certain other available ballasts or transformers utilize bridge gaps of substantial size in the iron cores linking their primary and secondary windings for control of the flux in such cores in order to maintain the crest factor of the lamp current below the limit specified. This results in such ballasts using large amounts of iron and copper and consequently becoming quite bulky and expensive. Accordingly, it is a further object of the invention to provide improved apparatus of the character indicated, resulting in a desired crest factor for current, which is productive of substantial savings in iron and copper.

It is a further object of the invention to provide an improved ballast or transformer for starting and operating mercury vapor discharge lamps at the rated wattage, voltage, current, and crest factor, irrespective of whether the lamp being supplied is a nominal, high, or low lamp.

It is a further object of the invention to provide an improved ballast or transformer for starting and operating mercury vapor discharge lamps which eliminates the need for special starting windings, and the like.

In carrying out the invention in one form, alternating current power supply means for starting and operating negative resistance discharge devices of the relatively high pressure metallic vapor type from a source of predetermined voltage and frequency is provided comprising a transformer having a core of magnetic material, a primary winding on said core adapted for connection to said source, a secondary winding on said core and adapted to be connected in circuit with such negative resistance discharge device of predetermined starting and operating voltage, and a high reluctance magnetic shunt magnetically disposed between said primary and secondary windings, the portions of said core linking said primary and secondary windings being free of any non-magnetic gaps of significant magnitude, the winding portions of said core having a cross-sectional area such that the flux produced by said primary winding, when connected to said source, effects a condition of substantial saturation in said winding portions, the ratio of turns of said secondary winding to said primary winding being such that the transformation voltage of said secondary winding, at the voltage and frequency of said primary winding, is normally insufficient by a substantial amount to start said device, a first capacitor connected across said secondary winding, a second capacitor, and a winding member associated with said primary to develop a voltage therefrom, said second capacitor, said secondary winding and said winding member being connected in a series circuit with each other and being adapted to include in series such negative resistance discharge device, said winding member being connected in said series circuit such that its voltage is opposed to the voltage of said secondary winding therein for providing a predetermined crest factor of current through said device during operation, said first capacitor having a magnitude for developing a voltage principally at the third harmonic frequency of said source which, in combination with the fundamental component provides a certain R. M. S. voltage sufficient to start said device in said series circuit, and said second capacitor having a value of capacitance relative to the constants of said secondary winding at the frequency of said source to maintain the R. M. S. voltage across said secondary winding substantially greater than turns ratio value but less than said certain voltage and for maintaining the wattage in

said device substantially constant at the rated value thereof throughout a rated range of voltage variation of said source.

Further objects and advantages of the invention will appear as the description proceeds.

For a better understanding of the invention, reference should be had to the accompanying drawing, in which—

Figure 1 is a plan view, partially in section, of one form of transformer which may be utilized in carrying out the invention.

Fig. 2 is a circuit diagram of apparatus embodying the invention, showing the electrical connections of the transformer illustrated in Fig. 1, together with certain other circuit components, and

Fig. 3 is a fragmentary circuit diagram illustrating a modified form of the invention.

Referring to the drawing, the invention is shown comprising the combination of a transformer 10 and capacitors 37 and 43.

The transformer 10 is shown including the primary windings 11 and 12, a secondary winding 13 and an iron core 14. The iron core is shown as being of the shell type having a central leg 15 and an outer shell consisting of side legs 16 and 17, and end legs 18 and 19. In the form shown, the side legs 16 and 17 and end legs 18 and 19 may be integral with each other in forming the outer shell, although other forms of construction may be used—such, for example, as forming the side and end legs of separate pieces and stacking them together. The core may be formed of laminations punched from suitable transformer sheet steel in the form of the outer shell comprising the legs 16, 17, 18 and 19 and punching therefrom, in substantially the same operation, the laminations forming the central leg 15. A suitable number of laminations are assembled together to give a stack of desired thickness.

The windings 11, 12 and 13 which may be form-wound are disposed on the central leg 15 and the resulting assembly is pressed into the assembled stack of outer laminations.

Disposed between the primary windings 11 and 12 and secondary windings 13 there are high reluctance shunts consisting of portions 21 and 22 formed integrally with the side legs 16 and 17, respectively, and portions 23 and 24 formed integrally with the central leg 15. The portions 21 and 23 are separated by a nonmagnetic gap, shown as an air gap 25, and the portions 22 and 24 likewise are separated by a nonmagnetic gap, shown as an air gap 26. The high reluctance shunts 21, 23, 25 and 22, 24, 26 provide a leakage flux path whereby portions of the fluxes of the primary and secondary windings may link the respective windings individually to the exclusion of the respective other windings. In this manner, the core provides a high leakage reactance for each of the primary and secondary windings. Other well-known constructions for obtaining the necessary high leakage reactance may be utilized, such, for example, as relatively thin and elongated windings placed side by side on a core.

With the shunt portions 23 and 24 formed directly on the central leg 15, a convenient arrangement is had for positioning the windings on the central leg prior to its assembly into the outer shell. To be certain that the laminations forming the central leg 15 are oriented correctly, the shunt portions 23 and 24 are of different lengths, the shunt portions 21 and 22 being of appropriate length to cooperate respectively with shunt portions 23 and 24. Since the laminations forming the central leg 15 are first punched from the outer shell laminations and are assembled and then pressed into an assembly of outer shell laminations, the fit of the central leg 15 into the outer shell is tight and good magnetic contact is had at the junctures 47 and 48 between the ends of the central leg 15 and the end legs 18 and 19. To hold the laminations together, rivets 27 and 28, or the like, may be provided at the ends of the central leg for holding it to the outer shell.

As may be seen more clearly in Fig. 2, which is a circuit diagram of apparatus embodying the invention and including diagrammatically the transformer of Fig. 1, the primary winding 12 includes a tapped portion 29, from which tap extends a conductor 31. The primary windings 11 and 12 are shown connected in parallel in Fig. 2 and to conductors 32 and 33 which may be connected to a source S of alternating current having a predetermined nominal voltage and frequency such, for example, as 115 volts at 60 cycles.

If desired, the primary windings 11 and 12 may be connected in series, as is well understood in the art, in order that a source S of double voltage, for example 230 volts, may be used while still developing the same voltage at the secondary winding for supplying the load.

The secondary winding 13 is shown provided with a series of taps 34, 35 and 36 adjacent one end thereof. A capacitor 37 is connected to one terminal 38 of secondary winding 13 by means of conductor 39 and to the tap 36 at the other end of the secondary winding by means of conductor 41. That end of primary winding 12 which is connected to conductor 33 is connected by means of conductor 42 to terminal 38. A capacitor 43 is connected to tap 35 by means of conductor 44 and to one terminal of a relatively high pressure metallic vapor discharge device 45, for example, the E-H1 lamp already referred to, by means of conductor 46. The other terminal of the discharge device 45 is connected to conductor 31.

As will be more fully explained, the combination of the secondary winding 13 and the capacitor 37 forms a starting arrangement for the discharge device or lamp 45, and the combination of capacitor 43, secondary winding 13 and primary winding portion 29 forms an operating arrangement for the discharge device after starting thereof.

While conductor 41 is shown connected to tap 36 and the conductor 44 is shown connected to tap 35, this is by way of example of one possible form of structure. The capacity values of capacitors vary within certain manufacturing tolerances and different capacitors may produce different voltages when connected to the same winding. In order to arrive at the optimum desired voltages, the taps 34, 35 and 36 and, if desired, others are provided in order that the taps which will give the desired voltages with particular capacitors in the circuit, may be utilized.

The operating circuit of the discharge device 45 may be traced as follows: From the left-hand end of discharge device 45 through conductor 31, primary winding portion 29, conductor 42, secondary winding 13, tap 35, conductor 44, capacitor 43 and conductor 46 to the right-hand end of the discharge device. In this operating circuit the primary winding portion 29 is connected so that its voltage opposes or bucks the voltage provided by secondary winding 13. The starting voltage of discharge device 45 is provided by the combination of secondary winding 13 and capacitor 37 and is applied to the discharge device through the operating circuit just described. Because the primary winding portion 29 bucks the voltage of secondary winding 13, the starting circuit must provide sufficient voltage to overcome the voltage of primary winding portion 29 to start the discharge device.

It is an important aspect of the present invention that the magnetic circuit or iron path linking the primary and secondary windings be as good a magnetic circuit as is practically obtainable—that is, the magnetic circuit which links these two windings should be free of any significant air gaps or reductions in cross-sectional area which would significantly interfere with flux from linking both windings. In Fig. 1 the magnetic circuit or iron path which links both windings consists of the central leg 15, the end legs 18 and 19 and the side legs 16 and 17. In following any continuous path, including the full length of central leg 15 and the appropriate portions of outer legs 18 and

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19 and side legs 16 and 17, there are no significant air gaps or reductions of cross-sectional area—such, for example, as slots of tangible width cut transversely into these members or holes formed directly therein. The junctions 47 and 48 between the ends of central leg 15 and the end legs 18 and 19, respectively, are as good magnetic junctions as are practically obtainable and are intended to be substantially metal-to-metal contact with no air gap therein. Such gaps as may exist here are of the form obtained with good butt joints or lapped joints. In this manner that portion of the primary flux which is not intended to be by-passed through the high reluctance shunts 21, 23, 25 and 22, 24, 26 links the secondary winding 13 and is a factor in enabling the core and coils to be reduced to as small a size as possible with resultant economy of iron and copper.

A portion of the flux generated by the primary windings 11 and 12 of course passes through the high reluctance shunts and therefore does not link the secondary winding 13. These high reluctance shunts include the air gap portions 25 and 26 which, however, are not in the iron or magnetic pathway linking the primary and secondary windings.

Further description of the invention and its operation may be best understood by considering that the negative resistance discharge device 45 requires a high voltage to strike or start it and a substantially lower voltage for operating it. This difference in starting and operating voltages is provided by the ballast effect of the transformer and circuit described. In addition to the voltage reduction and current limiting through the discharge device, the transformer or ballast must provide an appropriate wave shape of current through the discharge device during operation, already defined herein as the crest factor.

It is characteristic of gaseous discharge devices that the crest factor of current tends to be poorest when, in the operating circuit, the ratio of voltage available to strike the device to the operating voltage across the device after striking, is high. Many efforts in the art are devoted to avoid this effect such as by providing starting switches, etc. In apparatus according to the invention the initial voltage available in the operating circuit is reduced substantially below the voltage necessary to start or strike device 45 by reducing the number of turns in winding 13, i. e., reducing the turns ratio. The starting or striking voltage is provided by the starting circuit comprising secondary winding 13 and capacitor 37, which voltage consists of a high percentage of odd harmonics, particularly the third harmonic. The starting voltage drops to a low value after the device starts and thus does not influence the operation substantially.

The turns ratio of secondary winding 13 and either of primary windings 11 and 12 in the parallel combination shown is of such a low value that the steady state R. M. S. voltage developed by winding 13, in the absence of capacitor 37, is normally insufficient to start the discharge device 45. In one practical structure according to the invention, the induced voltage of the secondary winding 13, when a 115-volt source was connected to the primary, was approximately 205 volts. The voltage of 205 volts was slightly less than the product of the ratio of turns and the primary voltage, namely, 219 volts, inasmuch as the high reluctance shunts 21, 23, 25 and 22, 24, 26 diverted a slight amount of flux prior to the flow of current in the secondary winding.

Since the primary winding portion 29 is connected in opposition to the voltage of winding 13, the voltage available across discharge device 45—that is, between conductor 31 and tap 35—from winding 13 is reduced by the voltage of primary winding portion 29, which reduction in the practical structure referred to was 30 volts. Accordingly, the initial or open circuit voltage available in the operating circuit of the device, due to transformation by the transformer, was only 175 volts,

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the E-H1 mercury vapor lamp requiring 300 volts in order to be certain that striking will take place during all conditions. This deficiency in starting voltage is supplied by the starting circuit of secondary winding 13 and capacitor 37.

The capacitive reactance of capacitor 37 and the effective inductive reactance available at the terminals of the secondary winding 13 to which said capacitor is connected are related to each other so that at odd harmonic frequencies with respect to the frequency of source S, notably the third harmonic, a harmonic component of voltage of substantial magnitude is obtained. When the harmonic component of voltage is added to the fundamental component of voltage also available, a combined voltage is obtained between terminal 38 and tap 36 of a magnitude substantially larger than the turns ratio voltage. The combined voltage diminished by the voltage of primary winding portion 29 appears across conductors 31 and 46 and has an R. M. S. magnitude made sufficient to start the discharge device 45. Prior to the actual striking of the discharge device, there is no current therein, and the external load circuit is virtually open circuited. In the practical structure referred to, the voltage of winding 13 under starting conditions—that is, with condenser 37 connected in circuit—was 300 volts R. M. S. and comprised a fundamental component of assumed 100 percent magnitude, a third harmonic component of approximately 85 percent of the fundamental, a fifth harmonic of approximately 10 percent of the fundamental and a seventh harmonic of approximately 3 percent of the fundamental. The capacity value of capacitor 37 under the conditions indicated had a value of 4.32 mfd.

It will be evident from the harmonic percentages given that the striking voltage is substantially the resultant of the fundamental and the third harmonic, the fifth and seventh harmonics adding substantially nothing.

The odd harmonic component voltages, and notably the third harmonic, are by-products of the magnetic saturation which exists in the transformer core, which saturation is produced as a result of flux created by the primary winding. That is to say, the voltage appearing across terminal 38 and tap 36 to which capacitor 37 is connected must contain the harmonic components of voltage, and the capacitor 37 can then be selected to effect a voltage rise because there are inductive effects associated with the secondary winding. The constants of the core and coils are so selected that sufficient saturation occurs in the core at the lower end of the primary voltage range within which the device is intended to operate so that the odd harmonic components of voltage may be obtained in the secondary winding with reasonable sizes of capacitors 37.

In the practical structure according to the invention it was found that the voltage across terminal 38 and tap 36 of 205 volts and 115 volts was applied to the primary winding and the capacitor 37 was absent had a fundamental or sixty cycle component of an assumed magnitude of 100% and relative thereto the third harmonic component had a magnitude of approximately 7%, the fifth harmonic component had a magnitude of approximately 3%, and the seventh harmonic component had a magnitude of approximately 1%. Thus, it may be seen that the third harmonic component of approximately 7% was amplified to approximately 85% through the use of a capacitor 37.

It was also found in the practical structure that when the primary winding had only ninety volts applied to it, which is substantially below the operating range of primary voltages there was substantially no saturation in the transformer core and the odd harmonic rise in voltage was insufficient to start the device.

Within the operating range of primary voltage, varying the microfarad value of capacitor 37 varies the amount of harmonic component voltages obtained. Thus,

by increasing the microfarad value of capacitor 37 a higher harmonic component voltage may be obtained giving a higher voltage across terminal 38 and tap 36 for striking the discharge device, but this is unnecessary in the actual structure since a greater voltage is not needed. However, increasing the microfarad value of capacitor 37 beyond a certain magnitude causes the voltage rise suddenly to collapse and insufficient voltage is thereafter available for striking the discharge device. In the practical structure described, the upper limit of capacitor 37 was about 8.25 mfd. Also, reducing the microfarad value of capacitor 37 results in decreasing the magnitude of harmonic component voltages in winding 13, and below about 4 mfd. in the practical structure no substantial rise in voltage was obtained when the primary was supplied with 115 volts. Accordingly, it is evident that an optimum value of capacitor 37 will exist for a particular core and coils which will provide the desired amount of harmonic component voltages within the operating range of voltages applied to the primary winding.

Within the operating range of primary voltages after a particular value of capacity has been selected for capacitor 37 the voltage thereacross in the practical structure was greater at 115 volts than at 100 volts and less at 130 volts than at 115 volts.

Utilizing the harmonic component voltages enables a smaller capacitor 37 to be used to bring about the voltage rise and at the same time enables the number of turns in the secondary winding to be reduced. The size of the transformer 14 is thus enabled according to the invention to be made smaller and more efficient.

The relationship between capacitor 37 and the inductance within the transformer core to which it responds is somewhat delicate in that slight variations in the capacity value due, for example, to manufacturing tolerances, may cause substantial changes in voltages appearing across capacitor 37. These effects are minimized, if not completely eliminated, by selecting the appropriate type of winding 13 for capacitor 37. The full voltage of the harmonic starting circuit may differ slightly from that applied to the discharge device at starting in view of the fact that the conductor 44 may be connected to a different tap than conductor 41, but the number of turns between these taps is small.

After the discharge device 45 has started and current is flowing therein, the harmonic voltage developed across the secondary winding 13 and capacitor 37 decreases, and after the discharge device has come up to operating temperature the harmonic voltage decreases substantially and the current through capacitor 37 decreases to a small value. Accordingly, little energy is lost in the harmonic circuit after the discharge device starts. The drop in harmonic voltage is due, evidently in part, to the increase in resistance of the discharge device thereby causing damping of the harmonic voltage. In the practical structure the harmonic component voltages across capacitor 37 prior to the striking of the discharge device 45 dropped to a negligible value after striking thereof and a substantial sixty cycle or fundamental frequency voltage having a magnitude of 268 volts appeared across capacitor 37.

In the operating circuit described, the capacitive reactance of capacitor 43 is so related to the effective inductive reactance available at the terminals 38 and 35 of the secondary winding to which said capacitor 43 and discharge device 45 are connected, both at the fundamental frequency of said source S, that an operating condition throughout the complete device having certain definite advantages is established, which advantages are enhanced by the presence of the bucking portion 29 of the primary winding. The secondary winding 13, primary windings 11 and 12, capacitor 43, discharge device 45 and the capacitor 37 and the primary winding portion 29 contribute their part to the said operating con-

dition at the fundamental frequency to bring about the advantages according to the invention. Thus the current through the discharge device 45 and the voltage thereacross are maintained at an optimum value—that is, at a desired R. M. S. value with proper crest factor or wave shape—whereby the light output of the discharge device, as measured by the wattage consumed thereby, is maintained substantially constant in spite of fluctuations in voltage of source S over the rated range, namely, from 100 to 130 volts for a device having a nominal primary voltage rating of 115 volts. Moreover, high power factor, 90 percent or better, is obtained at the input conductors 32 and 33 along with reduced size of the device and high efficiency of operation.

The optimum conditions described are obtained even though the voltage across the winding 13 is at a substantially higher value than the turns ratio voltage after the discharge device is operating. The increased voltage across the secondary winding is associated with the stable operating condition of the discharge device and is believed due to the saturated magnetic flux condition of the core. The saturated flux condition of the portion of the central leg 15 inside of the secondary winding 13 is greater than the saturation of that portion of the central leg 15 inside of primary windings 11 and 12. The capacitor 43 in taking a leading current, causes the aforesaid increase in flux density in the secondary portion of central leg 15 and, by virtue of the resultant saturation, brings about the regulating condition of the device whereby the wattage of the discharge device 45 is maintained substantially constant over a range of variation of primary voltage. In the practical structure the capacitor 43 had a value of 37 mfd., the voltage across the terminals 38 and 35 was substantially 268 volts as compared with 205 volts of induced voltage, and the voltage across discharge device 45 was substantially 137 volts.

The microfarad value of capacitor 43 is selected with a particular core and coil to produce the desired wattage consumed by discharge device 45 and to effect a condition of saturation in the secondary portion of the core whereby that wattage remains substantially constant over the operating range of the transformer. As compared with such an optimum value of capacitor, a larger capacitor will produce larger wattages in discharge device 45 and a larger magnitude of R. M. S. current therethrough. The wattage regulation of the device will stay good and may improve and the crest factor of the discharge device current will not change greatly. Using a smaller than optimum value of capacitor 43 will produce lower wattages in discharge device 45 and lower R. M. S. currents therethrough. The wattage regulation and the crest factor may not change greatly but the transformer may permit the discharge device to go out near the lower end of the permissible range of primary voltage variations. Reducing the microfarad value of capacitor 43 to still lower values—for example, to less than 30 mfd. for the practical structure described—may result in certain unstable conditions in the operating circuit, wherein poor lamp performance is obtained.

The presence of the primary winding portion 29 in bucking relationship to the voltage of secondary winding 13 improves the wave shape or crest factor of operating current through discharge device 45 substantially over arrangements in which the primary winding portion 29 is eliminated and the secondary winding 13 alone supplies the voltage in the operating circuit to the discharge device 45 through capacitor 43. Particularly the presence of the bucking voltage produced in the primary winding portion 29 enables a desired low value of crest factor to be obtained, even though the operating voltage of random selections of discharge devices 45 may vary downwardly or upwardly between the range of approximately 120 to 150 volts for E-H1

type devices, the nominal operating voltage E-H1 devices being 135 volts. As indicated hereinbefore, certain manufacturers of such lamps indicate that the proper crest factor of current therethrough should be not greater than 1.7, whereas certain other manufacturers designate this factor as 1.85. According to the present invention, crest factor values of about 1.5 are obtainable irrespective of whether the discharge devices of the E-H1 type have nominal operating voltages or high or low operating voltages. In the practical structure described, during operation at 115 volts primary, the crest factor was 1.54 and when the operating voltage was increased to 130 volts, the crest factor increased somewhat, but did not exceed the value 1.7, and for the lower value of primary voltage equal to 100 volts, the crest factor decreased below the 1.54 value.

The amount of bucking voltage obtained from the primary winding, such as by a winding portion 29, cannot be increased indefinitely without producing undesired operating results in so far as the discharge device 45 is concerned. Within limits, as the bucking voltage from primary winding portion 29 is increased from zero upwardly, the crest factor of discharge device current improves. The microfarad value of capacitor 37 must be increased along with each increase of voltage from primary winding portion 29 in order to maintain the striking voltage of the discharge device. A point is reached, however, where, even though the crest factor is improved, it is impossible to maintain proper wattage in the discharge device.

In the practical structure described, when the voltage from primary winding portion 29 was zero, the crest factor of current in discharge device 45 had a value of approximately 1.85; when the voltage of the primary winding portion 29 was 30 volts, the said crest factor had a value of 1.54; when the voltage of primary winding portion 29 was 45 volts, the crest factor had a value of 1.46. In the instances referred to, rated wattage, or slightly greater, was supplied to the discharge device, the capacity value of capacitor 43 being adjusted to bring this about. When the voltage in primary winding portion 29 was increased to 60 volts, the said crest factor had a value of 1.4 approximately, but the wattage of discharge device 45 was slightly less than the rated value of 400 watts.

Also, as the amount of bucking voltage obtained from primary winding portion 29 is increased, the drop-out voltage of the ballast or transformer is reduced. Thus, for example, while the apparatus is intended to function over the range of primary voltage of from 100 to 130 volts, the apparatus will continue to function even though the primary voltage decreases to 70 volts when the bucking voltage is zero. When the bucking voltage is increased to about 60 volts, the drop-out voltage is near the lower limit of the operating range. Accordingly, an optimum value of the bucking voltage may be found and has a value of about 30 volts for the device described.

It has been found advantageous to reduce the number of turns of the secondary winding and, therefore, the voltage produced thereby to a relatively low value, in order to reduce the size of the transformer and consequently to effect economies in iron and copper. The saturation conditions necessary to the operation of the device are produced by the primary winding in so far as the odd harmonic starting voltage is concerned and are produced in the secondary portion of the core by virtue of the leading current through the capacitor 43. The transformation ratio of the transformer could be increased whereby a lower capacity value of the capacitor 43 would be required to give the desired wattage and current and the wattage regulation of the device would improve. However, the crest factor of the discharge device current would be worsened and greater amounts of bucking voltage from the primary winding

would be necessary to bring this ratio within acceptable limits. If lower than optimum values of transformation ratio are used, higher capacity values of capacitor 43 are needed, the wattage regulation would worsen, but the crest factor of the current should improve. However, the drop-out value of the device would tend to become critical. Accordingly, it has been found that an optimum value of turns ratio may be determined giving an over-all smaller size of transformer and improved crest factors with resultant increased life of the discharge devices.

The operating circuit will maintain the discharge device operating with optimum light output, even through the voltage of the source drops to the lower limit of the rated range of variation. This may occur even if the capacitor 37 of the harmonic starting circuit is removed. However, at still lower values of the source voltage as indicated, there is a likelihood that the discharge device will be extinguished in the absence of capacitor 37. The presence of the capacitor 37 not only provides the odd harmonic starting voltage, but provides, in combination with the capacitor 39 and the winding 13, a voltage condition such that when the voltage of the source drops below the lowest point of the rated range of variation by a substantial amount, the discharge device 45 will remain in satisfactory operation. Apparently under this latter condition, if the discharge device has a tendency to be extinguished, the odd harmonic high starting voltage tends to be re-established with the result that the discharge device continues to function.

Devices according to the invention, as indicated throughout this specification, include an iron core linking the primary and secondary windings which is substantially free of any significant nonmagnetic gaps, and saturation conditions for starting and operating. The relatively small size of the transformer occurs in part because of the high flux densities used and from the optimum selection of values for the various components. The combination of the foregoing with the bucking voltage obtained from the primary winding produces the advantageous results described.

Throughout this specification all references to a practical form of structure are by way of example only and are to the same device which was rated at 400 watts and in which the following applied: Each of the primary windings 11 and 12 had 154 turns of No. 17½ copper wire. The secondary winding 13 had 293 turns of No. 15 copper wire. The primary winding portion 29 consisted of 44 turns, the cross-sectional area of the central leg 15 was approximately 2.8 square inches and the cross-sectional area of each of the side legs 16 and 17 and the end legs 18 and 19 was approximately 1.97 square inches. The width of the central leg was 1.25 inches and the stack thickness was 2.25 inches.

The laminations making up the core were of 24 gauge cold reduced steel, designated as type M-22 electrical steel by the manufacturers thereof. The flux densities in the primary and secondary portions of the central leg 15 utilizing a stacking factor of .9 were approximately 110,000 lines per square inch and 136,000 lines per square inch, respectively. This device, when operated at a primary voltage of 115 volts, produced an input power factor of approximately 100 percent.

The total cross-sectional area of the outer legs is substantially greater than that of the inner leg, whereby stray fields surrounding the core are substantially eliminated.

Throughout this specification, the E-H1 form of discharge device referred to comprises a mercury vapor discharge lamp for lighting applications having ratings as hereinbefore indicated. The invention has application to devices of this E-H1 type and similar metallic vapor devices wherein the internal pressure during operation is considered to be relatively high, being in the vicinity of 1.2 atmospheres for E-H1 devices. In such relatively high pressure devices the lamp is a substantial short cir-

cuit across the source of voltage at the instant of starting and thus the ballast or transformer supplying them must provide a current limitation as specified by the lamp manufacturers. As the lamps heat up, the pressure therein increases and the resistance of the device thereby increases until some stable value is reached at the operating temperature of the device. When such lamps are extinguished, they must be allowed to cool before they can again be restarted at the intended voltage. Accordingly, it is desirable in devices according to the invention that the supply voltage may drop to lower than rated values without permitting the lamp to become extinguished.

While the invention has been described in connection with the E-H1 type of lamp, it will be understood that it has application to other metallic vapor discharge devices of the relatively high pressure type—for example, pressures of upwards of one-half of atmosphere.

Referring to Fig. 3, a modified form of the invention is shown in fragmentary form, which is similar in all respects to that shown in Fig. 2 except that the bucking voltage applied in the circuit comprising conductors 42 and 31 which are connected to the same circuit as shown in Fig. 2 is obtained from a winding 49 which is closely coupled to the primary windings 11 and 12 rather than being a part thereof.

While particular embodiments of the invention have been shown, it will be understood, of course, that the invention is not limited thereto since many modifications may be made, and it is, therefore, contemplated by the appended claims to cover any such modifications as fall within the true spirit and scope of the invention.

The invention having thus been described, what is claimed and desired to be secured by Letters Patent is:

1. Alternating current power supply means for starting and operating negative resistance discharge devices of the relatively high pressure metallic vapor type from a source of predetermined voltage and frequency comprising a transformer having a core of magnetic material, a primary winding on said core, and adapted for connection to said source, a secondary winding on said core and adapted to be connected in circuit with such negative resistance discharge device of predetermined starting and operating voltages, and a high reluctance magnetic shunt magnetically disposed between said primary and secondary windings, the portions of said core linking said primary and secondary windings being free of any nonmagnetic gaps of significant magnitude, the winding portions of said core having a cross-sectional area such that the flux produced by said primary winding when connected to said source effects a condition of substantial saturation in said winding portions, the ratio of turns of said secondary winding to said primary winding being such that the transformation voltage of said secondary winding at the voltage and frequency of said primary winding is normally insufficient by a substantial amount to start said device, a first capacitor connected across said secondary winding, a second capacitor, and a winding member associated with said primary winding to develop a voltage therefrom, said second capacitor, said secondary winding and said winding member being connected in a series circuit with each other and being adapted to include in series such negative resistance discharge device, said winding member being connected in said series circuit such that its voltage is opposed to the voltage of said secondary winding therein for providing a predetermined crest factor of current through said device during operation, said first capacitor having a magnitude for developing a voltage principally at the third harmonic frequency of said source which in combination with the fundamental component provides a certain R. M. S. voltage sufficient to start said device in said series circuit and said second capacitor having a value of capacitance relative to the constants of said secondary winding at the frequency of said source to maintain the R. M. S. voltage across said secondary winding substan-

tially greater than turns ratio value but less than said certain voltage and for maintaining the wattage in said device substantially constant at the rated value thereof throughout a rated range of voltage variation of said source.

2. Alternating current power supply means for starting and operating negative resistance discharge devices of the relatively high pressure metallic vapor type from a source of predetermined voltage and frequency comprising a transformer having a core of magnetic material, a primary winding on said core and adapted for connection to said source, a second winding on said core and adapted to be connected in circuit with such negative resistance discharge device of predetermined starting and operating voltages, and a high reluctance magnetic shunt magnetically disposed between said primary and secondary windings, the portions of said core linking said primary and secondary windings being free of any nonmagnetic gaps of significant magnitude, the winding portions of said core having a cross-sectional area such that the flux produced by said primary winding when connected to said source effects a condition of substantial saturation in said winding portions, the ratio of turns of said secondary winding to said primary winding being such that the transformation voltage of said secondary winding at the voltage and frequency of said primary winding is normally insufficient by a substantial amount to start said device, a first capacitor connected across said secondary winding, and a second capacitor, said second capacitor, said secondary winding and a portion of said primary winding being connected in a series circuit with each other and being adapted to include in series such negative resistance discharge device, said primary winding portion being connected in said series circuit such that its voltage is opposed to the voltage of said secondary winding therein for providing a redetermined crest factor of current through said device during operation, said first capacitor having a magnitude for developing a voltage principally at the third harmonic frequency of said source which in combination with the fundamental component provides a certain R. M. S. voltage sufficient to start said device in said series circuit, and said second capacitor having a value of capacitance relative to the constants of said secondary winding at the frequency of said source to maintain the R. M. S. voltage across said secondary winding substantially greater than turns ratio value but less than said certain voltage and for maintaining the wattage in said device substantially constant at the rated value thereof throughout a rated range of voltage variation of said source.

3. Alternating current power supply means for starting and operating negative resistance discharge devices of the relatively high pressure metallic vapor type from a source of predetermined voltage and frequency comprising a transformer having a core of magnetic material, a primary winding on said core and adapted for connection to said source, a secondary winding on said core and adapted to be connected in circuit with such negative resistance discharge device of predetermined starting and operating voltages, and a high reluctance magnetic shunt magnetically disposed between said primary and secondary windings, the portions of said core linking said primary and secondary windings being free of any nonmagnetic gaps of significant magnitude, the winding portions of said core having a cross-sectional area such that the flux produced by said primary winding when connected to said source effects a condition of substantial saturation in said winding portions, the ratio of turns of said secondary winding to said primary winding being such that of the transformation voltage of said secondary winding at the voltage and frequency of said primary winding is normally insufficient by a substantial amount to start said device, a first capacitor connected across said secondary winding, a second capacitor, and a winding member magnetically closely coupled to said primary

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winding to develop a voltage therefrom, said second capacitor, said secondary winding and said winding member being connected in a series circuit with each other and being adapted to include in series such negative resistance discharge device, said winding member being connected in said series circuit such that its voltage is opposed to the voltage of said secondary winding therein for providing a predetermined crest factor of current through said device during operation, said first capacitor having a magnitude for developing a voltage principally at the third harmonic frequency of said source which in combination with the fundamental component provides a certain R. M. S. voltage sufficient to start said device in said series circuit, and said second capacitor having a value of capacitance relative to the constants of said secondary winding at the frequency of said source to maintain the R. M. S. voltage across said secondary winding substantially greater than turns ratio value but less than said certain voltage and for maintaining the wattage in said device substantially constant at the rated value thereof throughout a rated range of voltage variation of said source.

4. Alternating current power supply means for starting and operating negative resistance discharge devices of the relatively high pressure metallic vapor type from a source of predetermined voltage and frequency comprising a transformer having a core of magnetic material including a central leg and two outer legs, one each of which is disposed on each side of said central leg, a primary winding on said central leg and adapted for connection to said source, a secondary winding on said central leg and adapted to be connected in circuit with such negative resistance discharge device of predetermined starting and operating voltages, and a high reluctance magnetic shunt magnetically disposed between said primary and secondary windings, the portions of said core linking said primary and secondary windings being free of any nonmagnetic gaps of significant magnitude, said central leg having a cross-sectional area such that the flux produced by said primary winding when connected to said source effects a condition of substantial saturation therein, said outer legs having a total cross-sectional area substantially greater than that of said central leg, the ratio of turns of said secondary winding to said primary winding being such that the transformation voltage of said secondary winding at the voltage and frequency of said primary winding is normally insufficient by a substantial amount to start said device, a first capacitor connected across said secondary winding, a second capacitor, and a winding member associated with said primary member to develop a voltage therefrom, said second capacitor, said secondary winding and said winding member being connected in a series circuit with each other and being adapted to include in series such negative resistance discharge device, said winding member being connected in said series circuit such that its voltage is opposed to the voltage of said secondary winding therein for providing a predetermined crest factor of current through said device during operation, said first capacitor having a magnitude for developing a voltage principally at the third harmonic frequency of said source which in combination with the fundamental component provides a certain R. M. S. voltage sufficient to start said device in said series circuit and said second capacitor having a value of capacitance relative to the constants of said secondary winding at the frequency of said source to maintain the R. M. S. voltage across said secondary winding substantially greater than turns ratio value but less than said certain voltage and for maintaining the wattage in said device substantially constant at the rated value thereof throughout a rated range of voltage variation of said source.

5. Alternating current power supply means for starting and operating negative resistance discharge devices of the relatively high pressure metallic vapor type from

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a source of predetermined voltage and frequency comprising a transformer having a core of magnetic material, including a central leg and two outer legs, one each of which is disposed on each side of said central leg, a primary winding on said central leg and adapted for connection to said source, a secondary winding on said central leg and adapted to be connected in circuit with such negative resistance discharge device of predetermined starting and operating voltages, and a high reluctance magnetic shunt magnetically disposed between said primary and secondary windings, the portions of said core linking said primary and secondary windings being free of any nonmagnetic gaps of significant magnitude, said central leg having a cross-sectional area such that the flux produced by said primary winding when connected to said source effects a condition of substantial saturation therein, said outer legs having a total cross-sectional area substantially greater than that of said central leg, the ratio of turns of said secondary winding to said primary winding being such that the transformation voltage of said secondary winding at the voltage and frequency of said primary winding is normally insufficient by a substantial amount to start said device, a first capacitor connected across said secondary winding, and a second capacitor, said second capacitor, said secondary winding and a portion of said primary winding being connected in a series circuit with each other and being adapted to include in series such negative resistance discharge device, said primary winding portion being connected in said series circuit such that its voltage is opposed to the voltage of said secondary winding therein for providing a predetermined crest factor of current through said device during operation, said first capacitor having a magnitude for developing a voltage principally at the third harmonic frequency of said source which in combination with the fundamental component provides a certain R. M. S. voltage sufficient to start said device in said series circuit, and said second capacitor having a value of capacitance relative to the constants of said secondary winding at the frequency of said source to maintain the R. M. S. voltage across said secondary winding substantially greater than turns ratio value but less than said certain voltage and for maintaining the wattage in said device substantially constant at the rated value thereof throughout a rated range of voltage variation of said source.

6. Alternating current power supply means for starting and operating negative resistance discharge devices of the relatively high pressure metallic vapor type from a source of predetermined voltage and frequency comprising a transformer having a core of magnetic material, including a central leg and two outer legs, one each of which is disposed on each side of said central leg, a primary winding on said central leg and adapted for connection to said source, a secondary winding on said central leg and adapted to be connected in circuit with such negative resistance discharge device of predetermined starting and operating voltages, and a high reluctance magnetic shunt magnetically disposed between said primary and secondary windings, the portions of said core linking said primary and secondary windings being free of any nonmagnetic gaps of significant magnitude, said central leg having a cross-sectional area such that the flux produced by said primary winding when connected to said source effects a condition of substantial saturation therein, said outer legs having a total cross-sectional area substantially greater than that of said central leg, the ratio of turns of said secondary winding to said primary winding being such that the transformation voltage of said secondary winding at the voltage and frequency of said primary winding is normally insufficient by a substantial amount to start said device, a first capacitor connected across said secondary winding, a second capacitor, and a winding member magnetically closely coupled to said primary member to develop a

voltage therefrom, said second capacitor, said secondary winding and said winding member being connected in a series circuit with each other and being adapted to include in series such negative resistance discharge device, said winding member being connected in said series circuit such that its voltage is opposed to the voltage of said secondary winding therein for providing a predetermined crest factor of current through said device during operation, said first capacitor having a magnitude for developing a voltage principally at the third harmonic frequency of said source which in combination with the fundamental component provides a certain R. M. S. voltage sufficient to start said device in said series circuit, and said second capacitor having a value of capacitance relative to the constants of said secondary winding at the frequency of said source to maintain the R. M. S. voltage across said secondary winding substantially greater than turns ratio value but less than said certain voltage and for maintaining the wattage in said device substantially constant at the rated value thereof throughout a rated range of voltage variation of said source.

7. Alternating current power supply means for starting and operating negative resistance discharge devices of the relatively high pressure metallic vapor type from a source of predetermined voltage and frequency comprising a transformer having a core of magnetic material, including a central leg and two outer legs, one each of which is disposed on each side of said central leg, a primary winding on said central leg and adapted for connection to said source, a secondary winding on said central leg and adapted to be connected in circuit with such negative resistance discharge device of predetermined starting and operating voltages, and a high reluctance magnetic shunt including a nonmagnetic gap magnetically disposed between said primary and secondary windings, the portions of said core linking said primary and secondary windings being free of any nonmagnetic gaps of significant magnitude, said central leg having a cross-sectional area such that the flux produced by said primary winding when connected to said source effects a condition of substantial saturation therein, said outer legs having a total cross-sectional area substantially greater than that of said central leg, the ratio of turns of said secondary winding to said primary winding being such that the transformation voltage of said secondary winding at the voltage and frequency of said primary winding is normally insufficient by a substantial amount to start said device, a first capacitor connected across said secondary winding, a second capacitor, and a winding member associated with said primary member to develop a voltage therefrom, said second capacitor, said secondary winding and said winding member being connected in a series circuit with each other and being adapted to include in series such negative resistance discharge device, said winding member being connected in said series circuit such that its voltage is opposed to the voltage of said secondary winding therein for providing a predetermined crest factor of current through said device during operation, said first capacitor having a magnitude for developing a voltage principally at the third harmonic frequency of said source which in combination with the fundamental component provides a certain R. M. S. voltage sufficient to start said device in said series circuit, and said second capacitor having a value of capacitance relative to the constants of said

secondary winding at the frequency of said source to maintain the R. M. S. voltage across said secondary winding substantially greater than turns ratio value but less than said certain voltage and for maintaining the wattage in said device substantially constant at the rated value thereof throughout a rated range of voltage variation of said source.

8. Alternating current power supply means for starting and operating negative resistance discharge devices of the relatively high pressure metallic vapor type from a source of predetermined voltage and frequency comprising a transformer having a core of magnetic material, including a central leg and two outer legs, one each of which is disposed on each side of said central leg, a primary winding on said central leg and adapted for connection to said source, a secondary winding on said central leg and adapted to be connected in circuit with a negative resistance discharge device of predetermined starting and operating voltages, and a high reluctance magnetic shunt magnetically disposed between said primary and secondary windings, the portions of said core linking said primary and secondary windings being free of any nonmagnetic gaps of significant magnitude, said central leg having a cross-sectional area such that the flux produced by said primary winding when connected to said source effects a condition of substantial saturation therein, said outer legs having a total cross-sectional area substantially greater than that of said central leg, the ratio of turns of said secondary winding to said primary winding being such that the transformation voltage of said secondary winding at the voltage and frequency of said primary winding is normally insufficient by a substantial amount to start said device, a first capacitor connected across said secondary winding, a second capacitor, and a winding member associated with said primary member to develop a voltage therefrom, said second capacitor, said secondary winding and said winding member being connected in a series circuit with each other and being adapted to include in series such negative resistance discharge device, said winding member being connected in said series circuit such that its voltage is opposed to the voltage of said secondary winding therein for providing a predetermined crest factor of current through said device during operation, said first capacitor having a magnitude for developing a voltage at odd harmonic frequencies of said source which in combination with the fundamental component provides a certain R. M. S. voltage sufficient to start said device in said series circuit, and said second capacitor having a value of capacitance relative to the constants of said secondary winding at the frequency of said source to maintain the R. M. S. voltage across said secondary winding substantially greater than turns ratio value but less than said certain voltage and for maintaining the wattage in said device substantially constant at the rated value thereof throughout a rated range of voltage variation of said source.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,870,398

January 20, 1959

Joseph G. Sola

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 62, for "thec entral" read -- the central --; column 4, line 50, for "poriton" read -- portion --; column 6, line 56, for "and" read -- when --; column 8, line 4, for "maintain" read -- maintained --; column 12, line 12, for "second" read -- secondary --; line 70, strike out "of", first occurrence; column 16, line 62, list of references cited, for "Boucher" read -- Boucher et al. --.

Signed and sealed this 30th day of June 1959.

(SEAL)

Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents

UNITED STATES PATENT OFFICE
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