United States Patent [19]

Rosenthal et al.

[11] **3,736,493**

[45] **May 29, 1973**

[54] FILM TREATING PROCESS

[75] Inventors: **Louis A. Rosenthal**, Highland Park; **Donald A. Davis**, Somerville, both of N.J.

[73] Assignee: **Union Carbide Corporation**, New York, N.Y.

[22] Filed: **Jan. 14, 1971**

[21] Appl. No.: **106,377**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 862,307, Sept. 30, 1969, abandoned.

[52] **U.S. Cl.** .....**321/45 R**, 204/312, 250/49.5 GC, 250/49.5 TC

[51] **Int. Cl.**.....**H02m 7/48**

[58] **Field of Search** .....250/49.5; 321/45, 321/45 C; 204/312

[56] **References Cited**

UNITED STATES PATENTS

3,514,393	5/1970	Eisby	204/312
3,303,406	2/1967	Bedford	321/45 R
3,496,092	2/1970	Fraser	321/45 X
3,294,971	12/1966	Von Der Heide	250/49.5
2,969,463	1/1961	McDonald	250/49.5
3,047,789	7/1962	Lowry	321/45
3,263,153	7/1966	Lawn	321/45 C
3,391,314	7/1968	Carter	317/262 A

OTHER PUBLICATIONS

Principles of Inverter Circuits, Bedford & Hoft, John Wiley & Sons, Inc., New York, London, Sydney, 1964, pp. 141, 165, 166, 184–186, 208, 263

"A Silicon-Controlled Rectifier Inverter with Improved Commutation", W. McMurray & D. P. Shattuck, reprint from Communication & Electronics, Nov., 1961. Principles of Inverter Circuits, Bedford & Hoft, John Wiley & Sons, Inc., New York, London, Sydney, 1964, pp. 90–92.

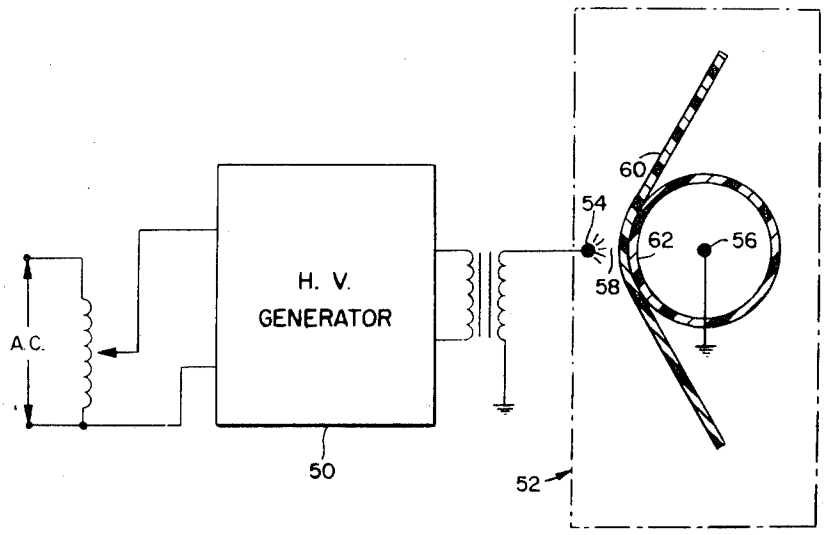
Primary Examiner—William M. Shoop, Jr.

Attorney—Paul A. Rose, Gerald R. O'Brien and Aldo John Cozzi

[57] **ABSTRACT**

A process is disclosed for the surface treatment of a plastic body, employing an alternating voltage of high intensity accompanied by corona discharge, which comprises exposing said surface to high frequency alternating voltage and accompanying corona discharge, the frequency of said alternating voltage being adjusted to effect surface treatment under optimum loading conditions at any selected constant voltage level.

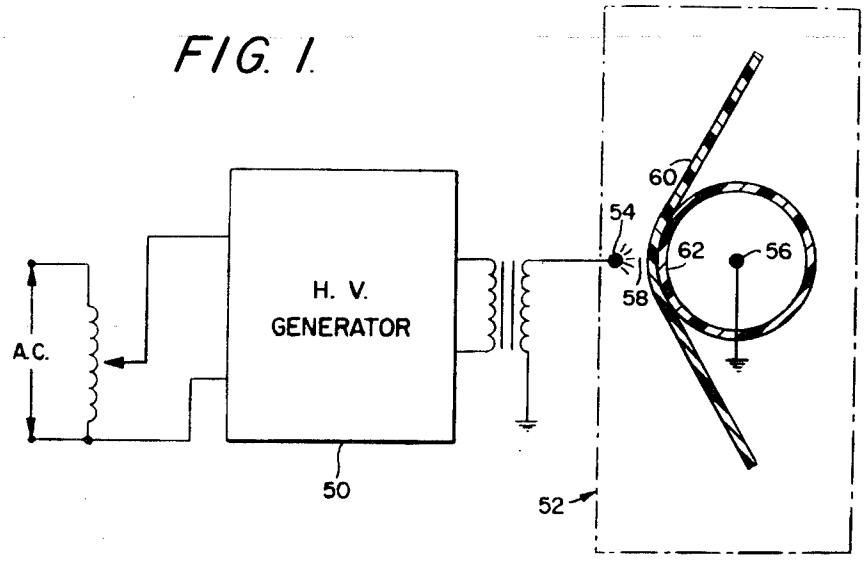
4 Claims, 8 Drawing Figures



Patented May 29, 1973 3,736,493

7 Sheets-Sheet 1

FIG. 1.



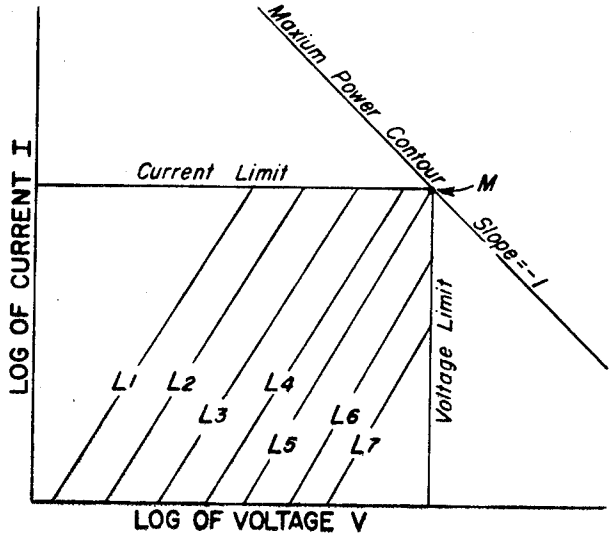


FIG. 4.

INVENTORS
Louis A. Rosenthal
Donald A. Davis
BY
ATTORNEY

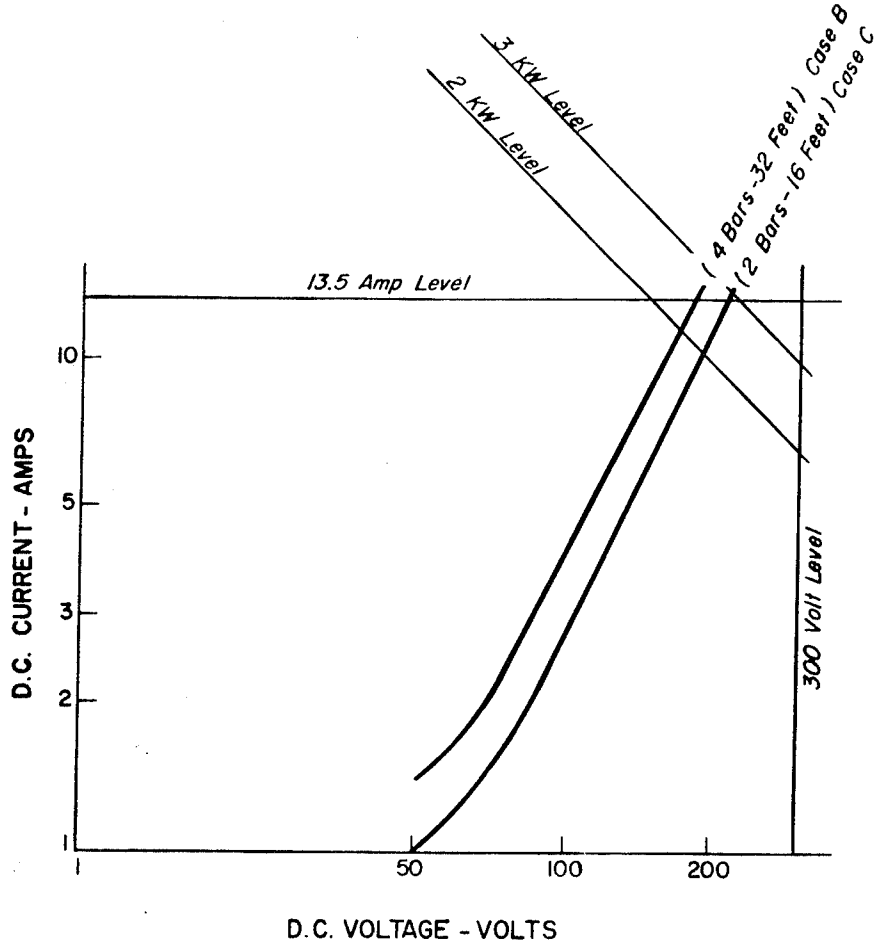


FIG. 2.

INVENTORS
Louis A. Rosenthal
Donald A. Davis
BY
ATTORNEY

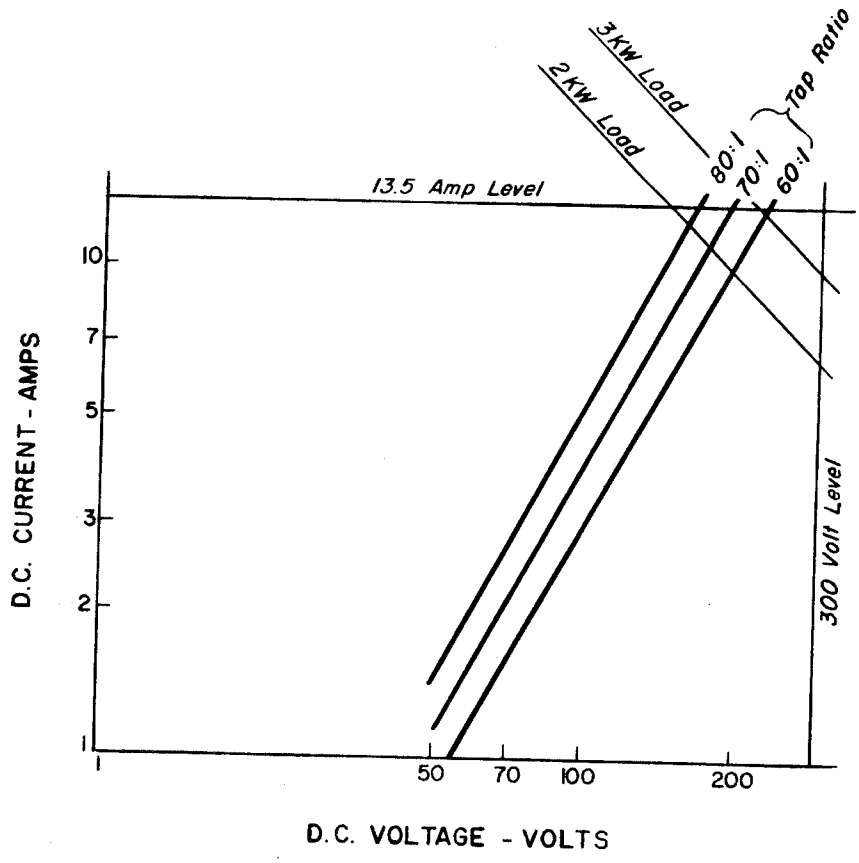


FIG. 3.

INVENTORS
Louis A. Rosenthal
Donald A. Davis

BY

ATTORNEY

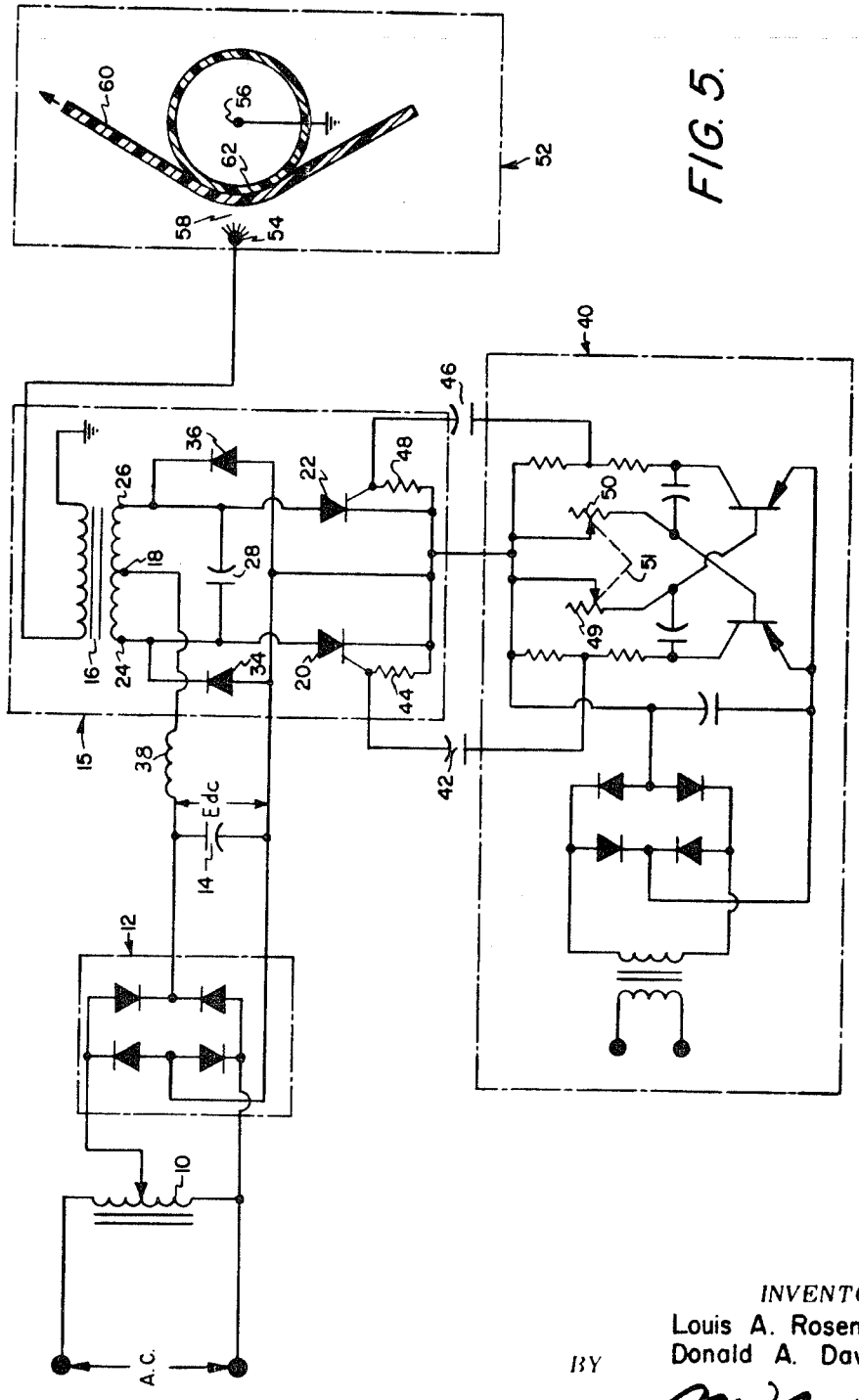


FIG. 5.

INVENTORS
Louis A. Rosenthal
Donald A. Davis

BY

ATTORNEY

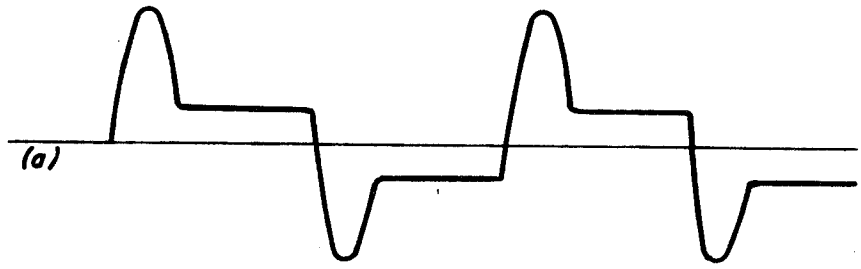
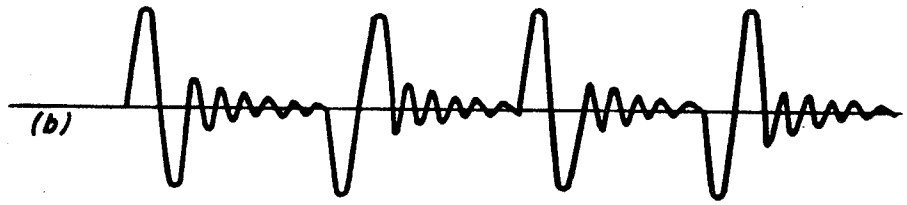


FIG. 6.





INVENTORS
Louis A. Rosenthal
Donald A. Davis

BY

ATTORNEY

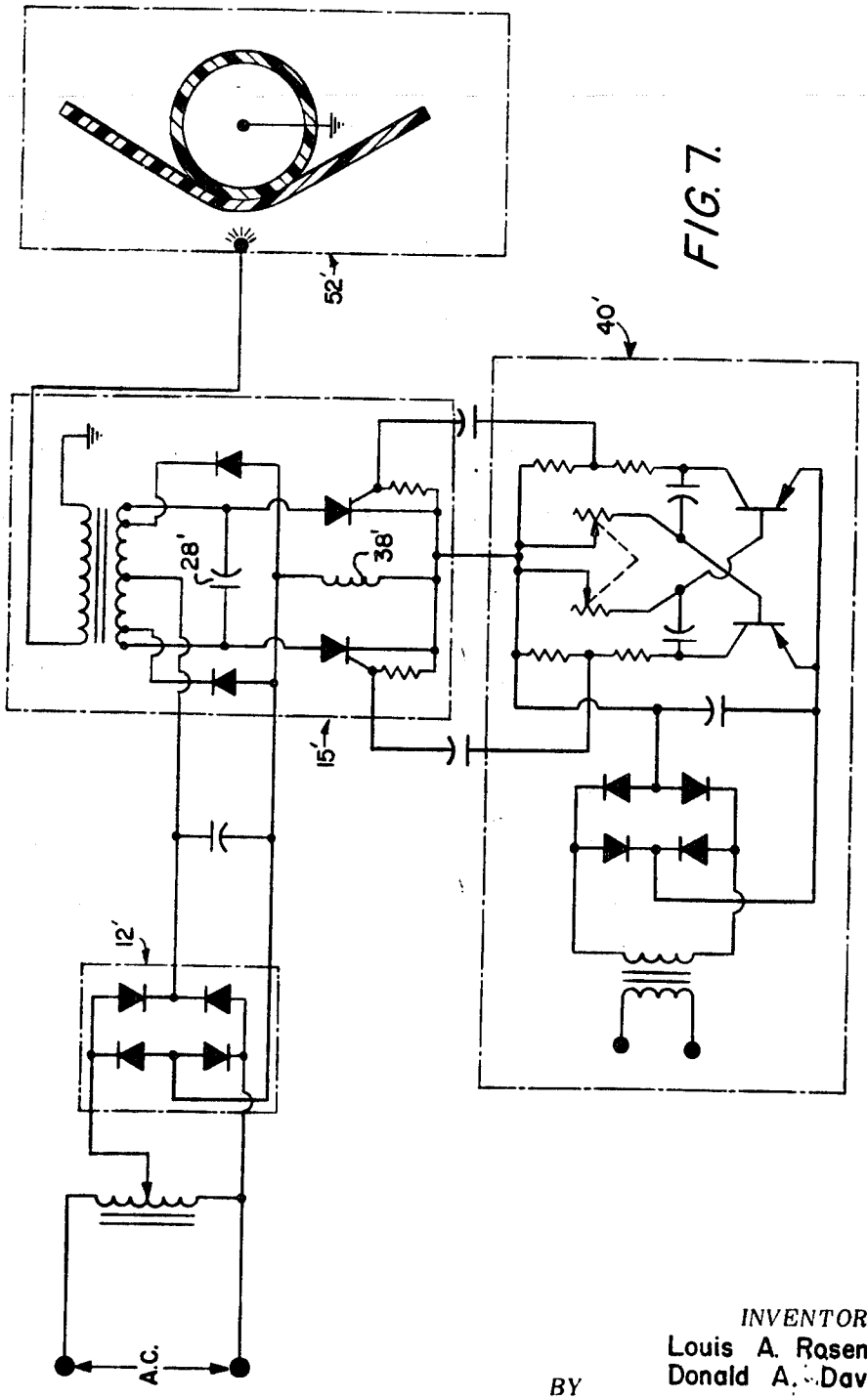


FIG. 7.

INVENTORS
Louis A. Rosenthal
Donald A. Davis

BY

ATTORNEY

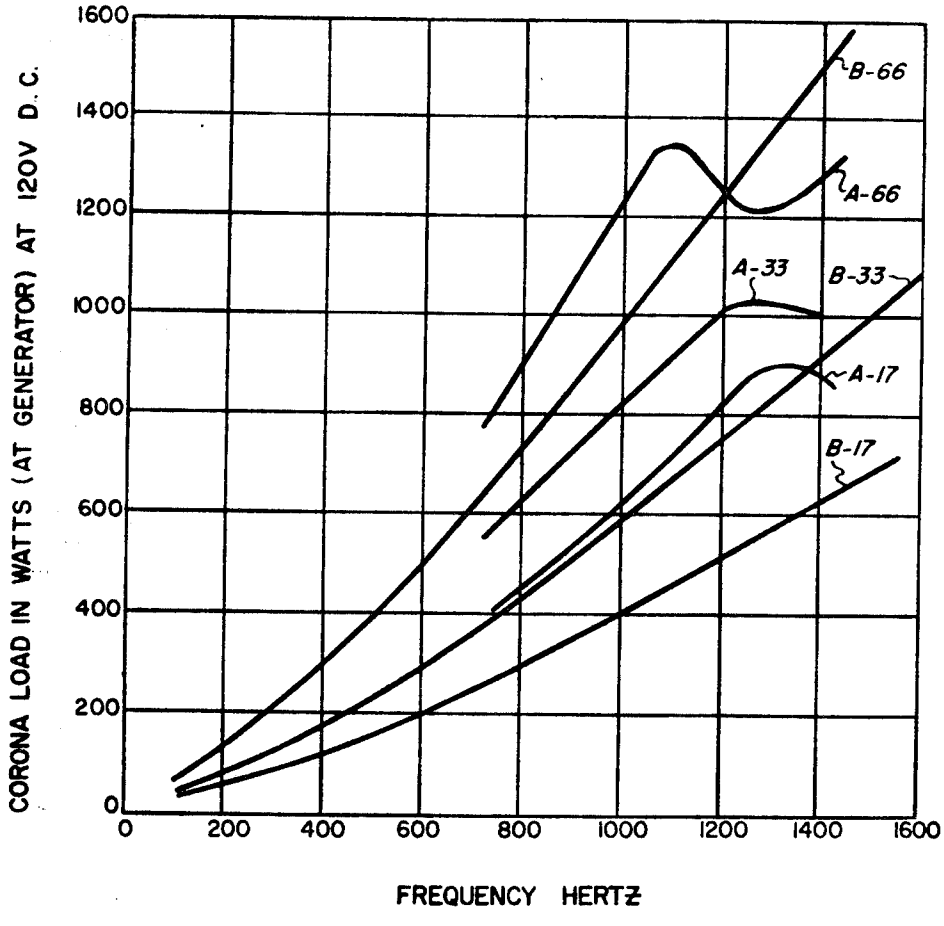


FIG. 8.

INVENTORS
Louis A. Rosenthal
BY Donald A. Davis
ATTORNEY

FILM TREATING PROCESS

This application is a continuation-in-part of application Ser. No. 862,307, filed Sept. 30, 1969, and now abandoned.

BACKGROUND OF THE INVENTION

Exposing the surface of a polymer body, such as polyethylene film, to a high voltage gaseous discharge having corona characteristics is known to improve the affinity of the surface for adhesives, inks and other polar substrates. The treatment zone of a typical system comprises a relatively large ground electrode separated from one or more relatively sharp high voltage electrodes by two and preferably three dielectrics. The essential dielectrics are an ionizable gaseous dielectric, normally air, and the polymeric body to be treated. Normally, the ground electrode is covered with a "buffer" dielectric, such as rubber or a polyester film, which acts to preclude an arc from bridging the gap at weak points in the polymer body. The high voltage electrode, which may consist of one or more treater bars in series or in parallel, runs the length of the ground electrode and is in circuit with a high voltage generator.

Most commercial treating systems employ alternating current supplied at frequencies up to 500 kHz or more. Gap voltages up to 15 kv or more are employed to effectively treat a polymer film which is continuously passed through the gap at speeds up to 500 feet per minute or more. In practice, an energy density-to-film surface of the order of about 1 watt-minute per square foot of film surface or more is sought to achieve good surface adhesion characteristics.

While every component of a film treating system has come under investigation from time to time, the high voltage generator has generally been neglected. The spark gap generators and motor alternators now in use are inefficient and suffer from many inherent deficiencies.

In addition to interfering with radio reception, due to the presence of radio frequencies in the spark gap generator output wave, that generator has a short duty cycle. The range of output power for a given generator is severely limited since the gap breakdown voltage sets the minimum voltage.

The motor alternator, on the other hand, is cumbersome in size and subject to frequent mechanical failure. Further, its output is sinusoidal which is far from the ideal waveform.

It is apparent that an improved film treating process is one in which a more efficient control and adjustment of input power to the load is effected.

In the drawings:

FIG. 1 is a simplified schematic view of high voltage apparatus circuitry for the treating of plastic film;

FIGS. 2, 3 and 4 are graphical representations of the load characteristics (on a log-log scale) for a corona discharge load circuit having varying loads;

FIG. 5 is a schematic view of apparatus circuitry capable of use in the practice of the process of the invention;

FIG. 6 (*a*) and (*b*) are schematic representations of the treating circuit voltage and load current waveforms, respectively, for apparatus of the type shown in FIG. 5;

FIG. 7 is a schematic view of modified apparatus circuitry capable of use in the practice of the process of the invention; and

FIG. 8 is a graphical representation of the relationship between treating load power and frequency employed for varying waveforms and electrode lengths in the process of the present invention.

A typical high voltage film treating system is schematically shown in FIG. 1 of the drawings. As is there shown, an alternating current line voltage is fed to a high voltage generator and the generator alternating output is fed through an output transformer to the treating circuit load.

It is of major importance to note that the load should be viewed as a lossy capacitor wherein the electrodes, in their area and spacing, define the capacitance and the dielectric is a composite made up of an air gap, the film and the buffer dielectric all in series. As the corona voltage threshold level is reached, the losses of this system vary in a nonlinear manner. It is the loss component which is effective in treatment and the recognition of the capacitive reactive behavior of the load is important.

The typical conventional treater generator has limited provision for delivering optimum power to a corona discharge load. Practically, the bar length, the bar width, the buffer dielectric, and even the film thickness, can make a generator incompatible with the load. The capability of transferring up to maximum power to the load can optimize the entire operation. For example, a fixed frequency generator can be rated at 1.5 KW. It would be impossible to deliver this power to a 1 foot electrode since the voltages required would be prohibitively high. Likewise, it would be impossible to deliver this power to a 15 foot electrode since the current would be excessive for this generator example. Any given generator has both a voltage and current limit and it is our object to optimize the product.

By taking a load characteristic on an actual film system, rather than a simulated load, we can examine the criteria for proper generator loading. This observed data is shown in FIGS. 2 and 3 as log-log plots. In FIG. 2, the corona load non-linearity is apparent and the current varies in the useful region as:

$$I = k\ V^{1.8}$$

The power input would, accordingly, follow:

$$P_{in} = k\ V^{2.8}$$

This means that a 10 percent increase in dc input voltage would result in a 28 percent increase in input power. Loading is very sensitive to voltage for a gaseous discharge (i.e. corona) system. The generator has two constraints. The current in this example is limited by the design to 13.5 amperes and the voltage is limited to about 300 volts by the line supply (when rectified). Optimum loading would pass the corona load through this maximum point labelled M in FIG. 4. It is to be noted from FIG. 2 that two bars (16 ft.) produced better loading than four bars (32 ft.), i.e., Case C vs. Case B. Contours of constant power level are superimposed and in theory this generator should be capable of supplying about 4 KW with the proper load.

A tapped output high voltage transformer provides an additional degree of freedom as shown in FIG. 3. The corona voltage is closely the dc voltage multiplied by the tap factor. For the two-bar system a 50:1 tap

ratio would have provided higher power input. Once a proper load is designed, the variable autotransformer in the solid state treater supply allows one to move up and down the optimized curve in a continuous manner which is non-linear with respect to output power. This concept will be generalized with reference to FIG. 4.

The point M corresponding to maximum output power is apparent. For maximum loading the load line must pass through the point M. Only load L5 accomplishes this optimization. Loads L6 and L7 are voltage limited (current flow is too light at maximum voltage) and loads L1, L2, L3 and L4 are current limited (current flow is too heavy at less than maximum voltage). To go from load L7 to load line L1 the following parameters must be increased:

a. transformer tap ratio,

b. electrode width,

c. electrode total length.

Parameter "c" is generally limited by web width considerations and parameters "b" and "c" compositely describe the electrode capacitance. The significance of parameter "a" is obvious.

The cross-sectional shape of the electrode reflects in the effective width of the electrode. Although the currents and voltages were measured at the primary input, they can be related to the secondary voltage and current. Electrode shape scales the current magnitude and, in addition, controls the voltage sensitivity.

The load line is fixed once a particular electrode geometry and output transformer turns ratio is selected. In a flexible system, an optimum match to a wide variety of electrodes cannot be obtained by voltage control or electrode geometry alone.

SUMMARY OF THE INVENTION

Following these tests, the concept of variable frequency was recognized as the all important parameter for load adjustment and optimization. Looking at the corona treating region as a lossy capacitor system, the power at constant voltage would be proportional to frequency just as for a given input voltage the current entering a capacitor is linear with frequency. Consider a periodic waveform wherein the waveshape is fixed (i.e. pulse wave, sine wave, square wave, trapezoidal wave, etc.) and all voltage amplitudes are constant. A resistive load such as a lamp or heater would draw a constant power independent of the frequency. If the load is a lossy capacitor wherein the current is limited by the capacitive reactance, the current will be directly proportional to the frequency. As an example consider, a sine wave voltage of the form:

$$e = E_{max} \sin 2\pi ft,$$

wherein f is the frequency in hertz. The peak current (ip) that would flow in a resistor (R) would be:

$$i_p = E_{max}/R.$$

Replacing the resistor with a capacitor (C) would result in:

$$i_p = E_{max}\, 2\pi fC$$

or the peak current is linearly related to frequency f. A corona load is unusual in that it behaves primarily as a capacitance.

Accordingly, this invention relates to the surface treatment of a plastic body, employing an alternating voltage of high intensity accompanied by corona discharge, wherein the treatment zone constitutes a capacitive load which for a given input voltage provides a linear relationship between frequency and current, comprising exposing said surface to an alternating, adjustable frequency, selected constant voltage in the sonic frequency range and accompanying corona discharge and adjusting the frequency of said selected constant voltage to effect surface treatment under optimum loading conditions, i.e., the capability of transfer of up to maximum power to the treatment zone.

It has been found that a broad range of sonic frequency (20–20,000 Hz) treating voltages may be employed, the range from about 20 to about 5000 Hz being preferred as most practical commercially.

It is to be understood that, within the scope of the present invention, the waveform of the alternating, high variable-frequency treating voltage is not critical for operability and may be of sinusoidal, square, pulse or other waveshape.

Referring specifically to the system of FIG. 5, a suitable direct current source is provided comprising a variable autotransformer **10** having an alternating current supply, the output of which is rectified by a full wave rectifier **12** and filtered by capacitor **14** connected across the output terminals of rectifier **12.** The dc voltage output E_{dc} which is a direct function of the applied autotransformer voltage is fed to the high voltage pulse output circuit **15.** Polyphase rectifiers and the like can also be used to provide adjustable dc voltages. It should be noted, however, that the employment of means for varying input voltage and consequent selected output voltage to a desired constant level constitutes merely an apparatus convenience but does not constitute a point of criticality or novelty in the present invention.

The high voltage pulse output circuit **15** comprises a high voltage transformer **16** having a high voltage secondary winding and a low voltage primary center tapped at **18** where voltage E_{dc} is applied. At least two power thyristors **20** and **22** are coupled at their cathodes and respectively connected at their anodes to the end taps **24** and **26** of the primary of the transformer **16.** As described in the article "Thyristors: Semiconductors for Power Control" by V.W. Wigotsky in *Design News*, Vol. 22, No. 18, page 26, which is incorporated by reference, thyristors are super switches for electrical power as is their function in the solid state high voltage generator of this invention. The preferred power thyristors are silicon controlled rectifiers but any solid state device or combination of devices which function equivalent to a thyristor or switch can be used. Ordinarily, a thyristor, particularly a silicon-controlled rectifier in a high conductive state, continues to conduct after the gate signal is removed until the anode current is interrupted or diverted for a time sufficient to permit the rectifier to regain its forward blocking condition.

At least one capacitor **28** is connected across the end taps **24** and **26** of the primary of the transformer and consequently between thyristors **20** and **22.**

The high voltage transformer **16** is an important integral part of the high voltage pulse generator circuit. It is center-tapped with end return taps in the primary while the secondary is a high potential winding. Its core must not saturate at operating frequencies and voltages.

At least one pair of diodes **34** and **36** are, respectively, connected at their cathodes to the end taps **24** and **26** of the primary of the transformer **16.** The anodes of diodes **34** and **36** are commonly connected to the cathodes of thyristors **20** and **22.** Inductor **38** is positioned between filtering capacitor **14** and pulse output circuit **15.** The diodes **34** and **36** act as anti-parallel or reverse conduction diodes to allow for reversed current flow.

The rate at which power thyristors undergo gating is controlled by a timing circuit **40** which is typically a multivibrator, preferably a free-running, astable, solid state oscillator or a unijunction, astable oscillator which generates trigger pulses of any desired frequency. If coupled with another triggering circuit, monostable and bistable oscillators may also be used. The multivibrator **40** is coupled to the gate of thyristor **20** by a capacitor **42** and resistor **44** and to the gate of thyristor **22** by capacitor **46** and resistor **48** networks, respectively.

Variation of the output frequency of the multivibrator circuit **40** is obtained by the employment of variable resistors **49** and **50** (ganged at **51**) which are, respectively, positioned in each of the base circuits of the transistors. Control of multivibrator output frequency produces a consequent controllable output from the pulse output circuit **15** which results in output frequency control of power delivered to the treating load circuit **52.**

The output of the transformer, thyristor section of the high voltage generator is essentially a pulsed wave of variable frequency. Such output is produced by sequentially gating thyristors **20** and **22** by timing pulses applied to the gates thereof by the timing circuit **40.** More particularly, when thyristor **20** is closed, thyristor **22** is maintained in a blocked or open condition and current from the power supply will then flow through the inductor **38** and one half of the transformer. The capacitor **28** is across the whole transformer. This series combination of inductor **38** and capacitor **28** oscillate (at a frequency higher than the gating frequency) to provide a single cycle of oscillation. The thyristor **20** is self-extinguished during the time that diode **34** is conducting (i.e., the negative portion of the cycle). Each thyristor is independently turned off by this procedure.

When thyristor **22** is closed, the same sequence occurs using the other half of the transformer in a sequential manner. By this action, current from the power source alternately flows through the two sides of the transformer primary as the thyristors are sequentially fired.

Since the direction of current flow through the two halves of the primary is opposed, an alternating, variable frequency, pulse wave output having an amplitude of about $[N_2/N_1]\ 2\ E_{dc}$, wherein N_2 is the number of windings on the secondary of the transformer and N_1 is the number of windings on each half of the primary, will be created in the secondary having the waveform shown schematically in FIG. **6**(*a*) of the drawings. This voltage is applied to the treater circuit load and produces a treater load current having a pulse waveform as shown schematically in FIG. **6**(*b*) of the drawings.

The waveshape of the voltage output from the secondary of the transformer is an alternating pulse superimposed on a residual pedestal. This pedestal is due to the charge remaining on the system capacitance at the end of each pulse. The load current in the treater circuit has the waveform of a series of alternating-directional, sonic frequency, single oscillation pulses. There is a natural resonant ring due to the transformer following the useful load current burst. This ring does not contribute to corona. Comparing the waveforms of FIGS. **6***a* and **6***b* in proper time sequence one can see that the current (**6***b*) is a derivative function of the voltage (**6***a*).

The solid state high voltage generating system disclosed herein is especially suited for use in polymer film treating systems. As shown schematically in FIG. **5,** the system as a whole consists of the high voltage generator whose output is connected to the film treating work cell **52** comprising a treater electrode **54** which is normally separated from ground electrode **56** by an air gap **58,** the polymeric film **60** and a buffer dielectric **62.**

To effectively modify or treat the surface of a polymeric film, the solid state, adjustable frequency, high voltage generator must cause a rapid sequence of high voltage gaseous discharges to occur in gap **58** during passage of a polymeric film therethrough.

The frequency adjustment in the generator to effect optimum loading conditions (up to maximum loading conditions) in the treatment zone is carried out as follows:

1. Surface treatment of the plastic body is commenced by running the plastic body to be treated through the treating zone;

2. the operator ascertains the plastic body surface throughput rate (ft.²/min);

3. the operator then selects the desired energy density (watt-min/ft.²) necessary for treatment. This selection is based on prior treating experience with any given resin. With conventional film resins, slip agent and other additive content of the resin controls the energy density necessary for adequate treatment. For example, the higher the content of slip agent the higher the energy density required. For conventional medium-slip polyethylene films, an energy density in the range of from about 1–2 watt-min/ft.² is typical; and

4. With the voltage at some selected constant level, preferably maximum, the frequency is varied to provide an independent control of the current up to the desired energy density, which can be determined by known empirical testing procedures.

Referring specifically to the film treating system of FIG. **7** of the drawings, another generator is there disclosed which provides as an output a variable-frequency alternating-directional, sonic frequency electrical voltage having a square waveform.

Elements of the system of FIG. **7** have been assigned primed reference numerals identical with the reference numerals of corresponding elements of the pulse waveform embodiment of FIG. **5.** In the embodiment of FIG. **7** the basic circuit functions of the circuit components are not merely equivalent to those of the FIG. **5** embodiment. The circuit changes, occasioned by the repositioning of inductor **38** as **38'**, result in the production of an entirely different mode of generator operation to provide a square output waveform, rather than the pulse output waveform of the embodiment of FIG. **5.**

It is additionally possible to employ a generator providing an alternating high frequency treating voltage in the sonic range having a sinusoidal waveform. Such

variable frequency sinusoidal waveform generators are well known in the art.

In carrying out treating tests in accordance with the present invention, a high slip polyethylene film 70 inches wide, 1.5 mil thick, traveling at 50 feet per minute, was exposed to the corona discharge provided by both the pulse generator of FIG. 5 and the square wave generator of FIG. 7. The latter generator employed the same components as the former generator (i.e., 1 mfd capacitor etc.) but was rearranged to provide a square wave rather than pulsed output voltage. The voltage fed to the corona generator was maintained at 120 volts dc and the input current varied with variations in frequency as a criterion of loading. By taking the product of dc voltage and dc current, the power input to the generator is indicative of loading.

The observed data is presented as the curves of FIG. 8. For the square wave case (A), a load range of 2:1 was utilized.

In the curves of FIG. 8, the number following the A or B designation indicates the length (in inches) of the electrode employed for treating.

With the pulse circuit arrangement the curves labelled B were obtained. The power delivered to the load is continuously controllable down to essentially zero.

Tests were carried out at desired energy densities and the treatment was satisfactory for ink adhesion at commercial levels.

The term "high voltage gaseous discharge", as used herein applies to the discharge phenomenon observed during the treatment of polymer films. Although essentially a suppressed arc which possesses aspects of corona glow and arc discharges, the predominant visual indicia is the corona which has caused the art to term the phenomenon a "corona discharge."

To generate the high voltage discharge in the gap 58, the high voltage generator is capable of supplying to a sharp knife-edge electrode at least 2,000 volts ac. Commercial units with larger radius electrodes require from about 5,000 to 50,000 volts or more ac which for a dc power supply having an output up to about 120 volts dc will require a transformer having at least 20, preferably 70 or more, windings for each half primary winding. It will be appreciated, however, that the number of secondary windings could vary depending on the magnitude of the selected supply voltage. The solid state high voltage generator should also be capable of providing a power output of from about 5 to about 25 watts per linear inch of electrode 54 to effectively treat the surface of a polymeric film.

Since polymer film treating systems operate at gap film speeds in order of about 100 to 200 feet per minute or more, the astable timing circuit should preferably operate at a frequency of about 20 to 5,000 Hz to closely space the discharges on the film surface. As used herein, the term Hz, or Hertz, is the currently accepted abbreviation for cycles per second.

While not critical to the operation of a polymer film treating system, gap spacings in the order of about 1/16 to 3/16 inch are most commonly employed and contemplated within the ambit of this invention.

In addition to an efficient duty cycle, and the ability to obtain maximum loading conditions through frequency control, the solid state high voltage generator of the invention possesses several characteristics which are deficient in prior generators.

Radio frequency interference is essentially nonexistent because the fundamental waveshape is lacking in radio frequency components. This avoids the use of expensive shielding devices and allows its use in areas where regulations have forbidden the use of other generators.

dc Input voltage variation offers a convenience over existing units. Since the timing circuit operates independently of the voltage supply, output voltage is not dependent on the frequency of the timing circuit and any desired output voltage is available at any selected frequency of operation of the timing circuit by variation in dc input voltage. Therefore, for any selected dc input voltage, the output voltage of the generator will be constant and independent of frequency variation.

What is claimed is:

1. A process for the surface treatment of a plastic body with an alternating voltage of high intensity accompanied by corona discharge, wherein the treatment zone constitutes a capacitive load which for a given input voltage provides a linear relationship between frequency and current, comprising exposing said surface to an alternating, adjustable frequency, selected constant voltage in the sonic frequency range and accompanying corona discharge and adjusting the frequency of said constant voltage to provide surface treatment under optimum loading conditions.

2. A process in accordance with claim 1, wherein said frequency is in the range of from 20–5000 Hz.

3. A process in accordance with claim 1, wherein said alternating voltage has a square waveform.

4. A process in accordance with claim 1, wherein said alternating voltage has a pulse waveform.

* * * * *