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Machida et al.

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[54] **APPARATUS FOR MAKING PERFORATIONS IN SHEET MATERIAL BY ELECTRIC DISCHARGE**

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[21] Appl. No.: **439,424**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 334,082, Feb. 20, 1973, abandoned.

[30] **Foreign Application Priority Data**

July 17, 1972 Japan 47-70719

[52] **U.S. Cl.** ..... **219/384,** 346/74 S

[51] **Int. Cl.** **H05b 7/18**

[58] **Field of Search** ..... 219/69, 121 EB, 383, 384; 204/312; 346/74 R, 74 S

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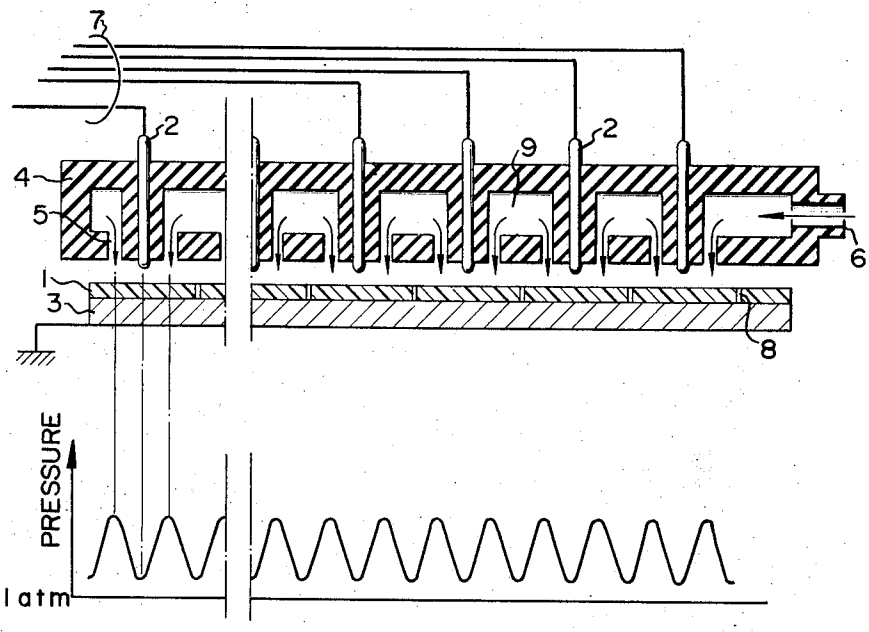
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[57] **ABSTRACT**

Apparatus for making perforations in sheet material by generating electric discharge through the sheet while passing the sheet between a group of discharge electrodes and a common grounded electrode and producing a gaseous stream in any desired amounts between and around the discharge electrodes and the surface of the sheet, thereby obtaining a perforated sheet having uniform perforation spacing and density as well as descreased scorching or blackening created around the perforations in the perforated sheet.

14 Claims, 6 Drawing Figures



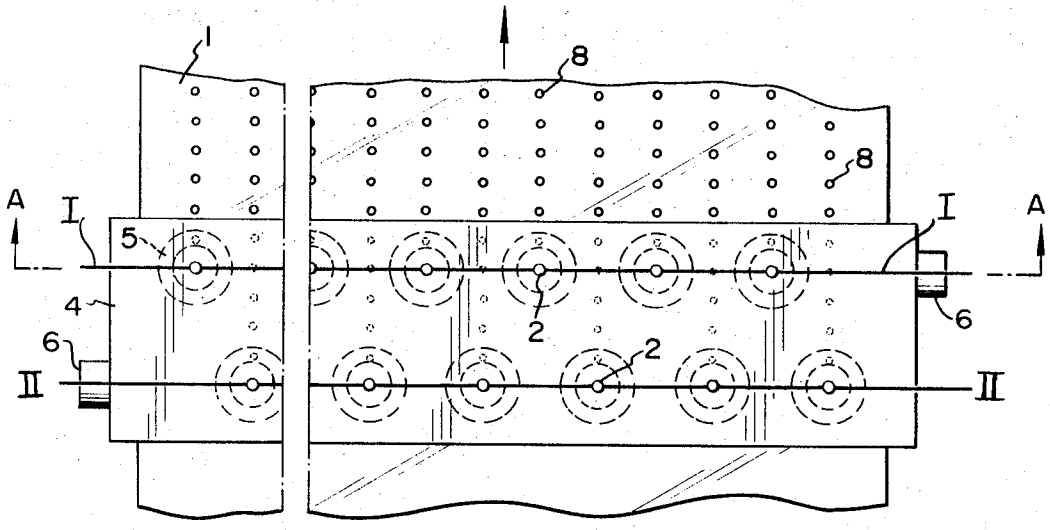


FIG. IA

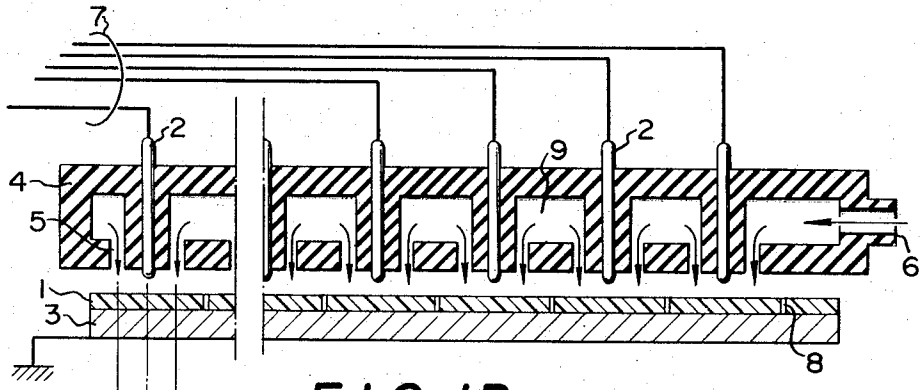


FIG. IB

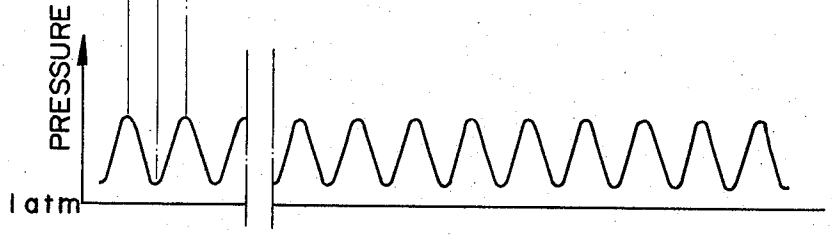


FIG. IC

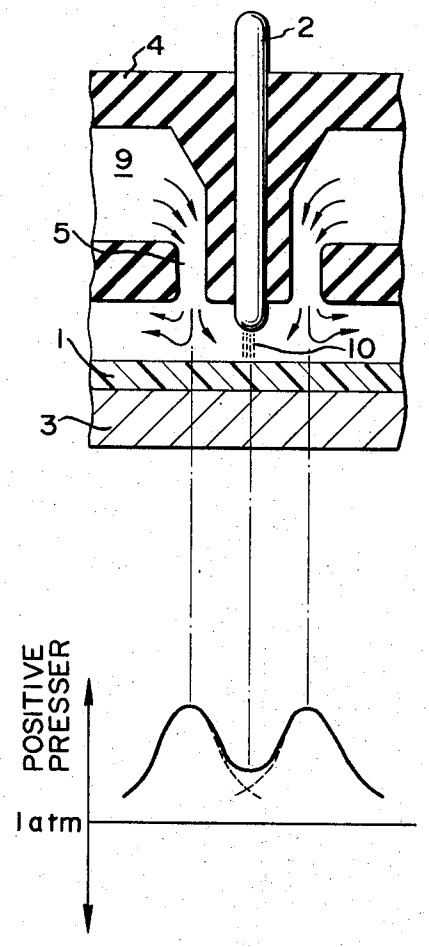

4
2
9
5
1
10
3
POSITIVE PRESSER
1 atm

FIG. 2

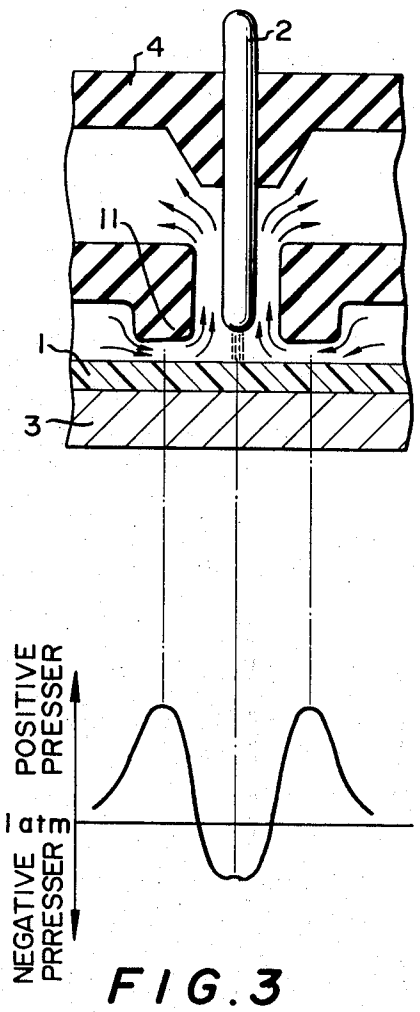

4
2
11
1
3
POSITIVE PRESSER
1 atm
NEGATIVE PRRESSER

FIG. 3

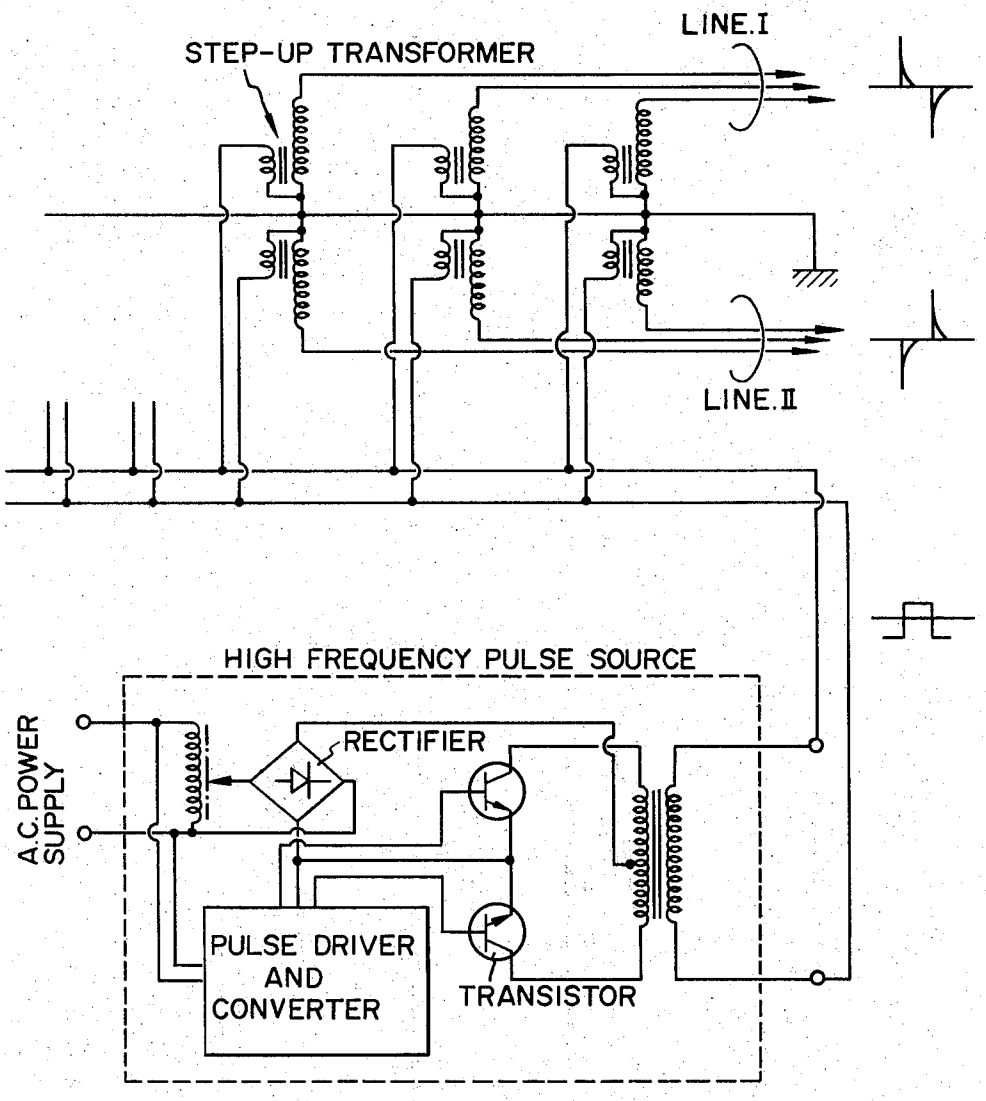

LINE.I
STEP-UP TRANSFORMER
LINE.II
HIGH FREQUENCY PULSE SOURCE
A.C. POWER SUPPLY
RECTIFIER
PULSE DRIVER AND CONVERTER
TRANSISTOR

FIG. 4

APPARATUS FOR MAKING PERFORATIONS IN SHEET MATERIAL BY ELECTRIC DISCHARGE

This is a Continuation-in-Part application of Ser. No. 334,082 filed Feb. 20, 1973, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to an apparatus for perforating a sheet made of natural or synthetic substance by utilizing electric discharge and more particularly to an apparatus for perforating a sheet made of non-porous or insufficiently porous, natural or synthetic substance by generating therethrough an electric spark or arc discharge using a plurality of discharge electrodes and a common grounded electrode positioned opposite thereto while passing the sheet through between the discharge electrodes and the common grounded electrode and ejecting or drawing any desired amounts of an air-based compressed gas from or into nozzles provided around or near the discharge electrodes to or from the discharge or the sheet. In one embodiment of this invention the discharge electrodes are each connected to an independent or separate, high frequency pulse, high voltage power source. In another embodiment, the sheet to be perforated is passed through between a group of the discharge electrodes and the common grounded electrode without contacting the discharge electrodes.

Synthetic leather, rubber sheets, rice paper for tobacco, kraft paper for cement, polyethylene-laminated paper, plastic fiber-mixed paper, laminates of paper and synthetic resin sheets, and the like sometimes need to be provided with gas-permeability and, to this end, they have heretofore been perforated by effecting electric discharge therethrough. Such conventional perforating process comprises effecting electric discharge through a sheet to be perforated while passing the sheet on a metallic roll or plate and keeping it in contact with a plurality of discharge electrodes connected to a single power source which applies a relatively high frequency pulse voltage to said electrodes. However, the conventional process has disadvantages as follows.

1. Perforations made in a sheet greatly vary in diameter since the sheet is not necessarily uniform in thickness and density at all parts thereof, that is, discharge resistances at all the parts are different from each other. Further, discharge current tends to concentrate locally, for instance, at the peripheral portions of the perforations thereby scorching and damaging said portions.

2. The sheet is liable to be mechanically damaged because of the contact of the sheet with the electrodes. Such damage will have an increasingly adverse effect on the quality of the perforated sheet as the sheet used is smaller in thickness.

3. It requires a large numer of personnel and is expensive to watch and interchange discharge electrodes because of their great wear or consumption while in use.

4. If the sheet is thin, it will not pass smoothly nor travel simultaneously with creating crease due to the resistance caused by its contact with the electrodes and, in some cases, will be torn or cut off due to the crease. This tendency has been especially remarkable with the recent realization of the speed-up of the treatment of the sheet.

5. The space between the neighboring perforations (the space being hereinafter called "perforation spacing") and the diameter of the perforations are undesirably large, and the perforation density (number of perforations per unit area) is unsuitably low.

Accordingly, an object of the present invention is to overcome the disadvantages of known prior art arrangements and to provide perforating apparatus which makes it possible to inhibit a temperature raise in the discharge portions of discharge electrodes, decrease the wear (or consumption) of the material at the tip of said discharge portions, and control perforation conditions.

Other features which are considered characteristic of the invention are set forth in the appended claims.

Although the invention is illustrated and described in relationship to specific embodiments, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without department from the spirit of the invention and within th scope and range of equivalents of the claims.

SUMMARY OF THE INVENTION

Apparatus for making perforations in a sheet includes a plurality of discharge electrodes and a common grounded electrode opposite thereto. The discharge electrodes and the common grounded electrode are disposed to allow the sheet to pass therebetween and to effect discharge therebetween through the sheet to produce perforations in the sheet. Nozzle means are arranged around the discharge electrodes such that the axes of the nozzles are directed perpendicularly to the sheet surface, whereby the nozzle means establish a gas stream in a direction perpendicular to the sheet surface, such gas stream passing between and around the discharge electrodes and the sheet to control perforation conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a partial diagrammatic plan view showing the construction of discharge electrodes of an electrical perforating apparatus according to one embodiment of the invention, showing the disposition of a sheet being perforated with respect to the discharge electrodes.

FIG. 1B is a cross-sectional view taken along the lines A — A of FIG. 1A.

FIG. 1C shows the variation in pressure in the transverse direction of a sheet being perforated utilizing an ejected gas stream as shown in FIGS. 1A and 1B.

FIG. 2 is an enlarged partial elevational view showing the construction of a discharge electrode portion according to the present invention and showing the state of flow of the gas stream ejected in the direction from around the discharge electrodes perpendicularly to the surface of the sheet being perforated and the variation in pressure exerted thereon by the ejected gas stream thereon.

FIG. 3 is a view similar to FIG. 2, but illustrating an alternate embodiment and showing the state of flow of the gas stream drawn in the direction from the surface of the sheet being perforated to around the discharge electrode and the variation in pressure exerted thereon by the drawn gas stream.

FIG. 4 is a schematic view of the electric circuits through which suitable electric power is supplied to the discharge electrodes according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to the present invention, a natural or synthetic substance in the sheet form such as a synthetic resin sheet, paper, or a paper-synthetic resin sheet laminate, is passed on a common grounded metallic roll or plate through between a plurality of discharge electrodes usually in the needle form and the grounded metallic roll or plate positioned opposite thereto to effect electric discharge through the passing or travelling sheet, while producing a forced gaseous stream between nozzles for ejecting or drawing the gas, provided around or near the discharge electrodes, and the discharge and sheet to be perforated, thereby inhibiting or controlling the generation of thermal energy and the spreading of creeping discharge on the surfaces of the sheet and controlling perforation conditions. The forced gaseous stream may be composed of air, an inert gas, steam or the mixtures thereof. The aforementioned stream is directed to such regions that the discharge is not extinguished thereby. The discharge electrodes are each connected to a high frequency pulse source via a step-up transformer to form an independent discharge circuit, and a high frequency pulse of a high voltage and small current is applied to each of the electrodes. Thus, a sharp and intense discharge is effected between the discharge electrodes and the grounded metallic roll or plate to thereby make fixedly spaced perforations over the whole width of the sheet almost at a time. Such discharge is repeated at a fixed interval of time while the sheet is travelling, thereby making perforations at a fixed space also in the travelling direction. In this process each of the electrodes is in its independent circuit and power from a power source is uniformly distributed to each of the electrodes, and electric discharge will therefore be effected almost smoothly even if a sheet to be perforated is not uniform in density and thickness. Further, the discharge from the individual electrodes will not greatly be affected by the fact that the gap between each electrode and the sheet is not adjusted to be strictly uniform.

Adjustment or control of the flow of air or other gases ejected from the nozzles under the specific discharge circuit conditions in accordance with this invention will make it possible to conspicuously increase perforation density (number of perforations per unit area), control the frequency of perforation and the diameter of perforations to be obtained, inhibit scorching and blackening possibly caused in the peripheral portions of the perforations, inhibit a temperature raise in the discharging portions of discharge electrodes and decrease the consumption of the material of the tip of the discharge electrodes. Such adjustment, in combination with the use of an inert gas such as CO_2, N_2 or steam as the ejected or drawn gas, will further be effective in preventing the scorching or blackening.

The use of a gas ejected from or drawn into the nozzles in the practice of this invention will be detailed hereunder.

In the conventional process of electric discharge in which stationary air is utilized, perforation adjustment to obtain a desired perforation spacing and diameter of perforations as well as a decrease in scorching or blackening possibly caused around the perforations is made mainly by adjusting the variables on the power source side, such as discharge voltage, discharge current and frequency, while in the process according to the present invention, electric discharge in a dynamic gas such as a forced gaseous stream composed mainly of compressed air is utilized and perforation adjustment is made by adjusting the amount of the gaseous stream ejected or drawn.

Apparatus for carrying out the present invention comprises (A) a plurality of discharge electrodes and (B) a common grounded electrode positioned opposite thereto to allow a sheet being perforated to pass therebetween without contacting with the discharge electrodes and simultaneously generate electric discharge through the sheet for perforation, said discharge electrodes (A) being each connected via a step-up transformer to a high frequency pulse source thereby forming a separate discharge circuit to apply a high frequency pulse of high voltage and small current to each of the discharge electrodes, and (C) means for passing a gaseous stream between around each discharge electrode and the surface of a sheet to be perforated, said means (C) being composed essentially of nozzles for ejecting the gas, valves for adjusting the flow of the gas, piping for feeding the gas, a compressor or vacuum pump and Bombe (or pressure container) for gas.

Turning now to the illustrated embodiments in the drawings, FIG. 1A shows a sheet **1** which is moved upwardly with respect of the drawing as indicated by the arrow symbol. A plurality of discharge electrodes **2** are disposed above the sheet **1**, in rows as indicated by the lines I—I and II—II and at a predetermined space from each other, and they are directed perpendicularly to the surface of the sheet **1**. Such disposition of the discharge electrodes **2** will permit perforations **8** to be obtained at a uniform spacing from each other across the width of the sheet **1**.

The reason why the discharge electrodes **2** are divisionally disposed in rows as indicated by the lines I—I and II—II, is as follows.

In the electrical perforation of a sheet having a fixed width, an increase in the number of rows in which discharge electrodes are disposed will permit the use of a correspondingly increased number of such discharge electrodes without unduly lessening the space therebetween, thereby obtaining satisfactory perforations at a smaller space from each other. If a fixed number of discharge electrodes are used, such increase in the the number of rows will permit the discharge electrodes to be disposed at a greater spacing from each other thereby increasing the insulation resistance of the sheet being perforated. Moreover, the discharge electrodes (disposed in rows I—I and II—II) can be supplied with voltages of opposite polarity as explained hereinafter, to thereby decrease the electrostatic capacity of the sheet between the rows I—I and II—II, and thus enabling a steep discharging pulse to be maintained.

Gas-ejecting nozzles **5** having an annular opening, are each disposed around the discharge electrodes **2** and may be provided by machining an electrode support of electrical insulating material **4** at the portion thereof opposite the sheet to form the annular opening.

In FIG. 1B, the discharge electrodes **2** are positioned out to contact with the sheet **1** and have their axes directed perpendicularly to the surface of the sheet **1**. Each of the discharge electrodes **2** is connected to a different electric supplying wire **7**. Between these discharge electrodes and a grounded common electrode **3** which is positioned beneath the sheet **1**, sharp and

high voltages are applied thus effecting the discharge perforation.

Inside the electrode support **4**, a plurality of pressure compartments are provided and supplied with gas through a nonillustrated gas supply valve disposed at one end of the support, thereby ejecting a gas stream through the opening of a gas-ejecting nozzle **5** and perpendicularly to the sheet surface.

FIG. **1C** shows the pressure variation on the sheet surface along the width thereof which is caused by the ejection of the gas stream as shown in FIG. **1B**. Such mode of generating a pressure variation is explained in more detail with reference to FIG. **2**.

In FIG. **2**, a pressurized gas is ejected from a pressure compartment **9** through the nozzle **5** having an annular opening provided around the discharge electrode **2** towards the sheet surface, and the flow directions of the gas stream are indicated by the arrows. By such ejection of the gas, there is a variation in pressure exerted on the sheet surface as shown in FIG. **2**, and thus the discharging arc **10** is enveloped with the gas stream. The gas stream may partially flow into the discharging arc, but in this case, the amount of gas supplied should be adjusted so that the aforementioned partial flow does not extinguish the arc beneath the discharge electrode.

By providing the gas ejection in such a manner as above, the path for the discharging arc is defined or confined to the spot of the sheet surface which is positioned just beneath the discharging electrode, and thus the gas stream prevents the discharging arc from expanding in all directions in the form of creeping discharge and thereby producing perforations only at said spot.

The necessity for preventing the discharging arc from expanding in all directions will be concretely explained with reference to FIG. **1A**.

The points of the sheet **1** which are directly beneath the mid points between the neighboring ones of the discharge electrodes in the row I—I have already been perforated by the discharge electrodes in the row II—II. Moreover, at the points of the sheet **1** which are downstream of the points just beneath the discharge electrodes in the row I—I, there have already been perforations made by the discharge action of the discharge electrodes in the row I—I.

Thus, if the gas stream is not produced, the discharging arcs from the discharge electrodes in the row I—I will pass through these points that have been already perforated and thus have a low insulating resistance. Accordingly, there may hardly be produced new perforations at the points that are positioned directly beneath the discharge electrodes when discharged. Such inclination or tendency becomes more conspicuous or pronounced when the sheet is of the type having more insulating resistance or when greater perforation density is desired by making narrower the spacing between the perforations to be produced.

As an alternate arrangement the discharging arc can be controlled by drawing a gas stream instead of by ejecting the gas stream to thereby conduct an efficient perforation.

FIG. **3** shows a gas stream generated by the suction of gas and also illustrating the variation in pressure exerted on the sheet surface by the stream. In this case, unlike the case of FIG. **2**, the annular opening is defined by the discharge electrode and an annular projection **11** is so constructed that the gas passes through the narrow gap between the projection **11** and the sheet surface to thereby generate a gradient of pressure exerted on the sheet surface as shown in FIG. **3**. Since the pressure compartments **9** are maintained below atmospheric pressure, the pressure variation or gradient in this case is more remarkable than that in FIG. **2**, and the gas stream flows in the direction opposite to the path for creeping discharge which might otherwise be generated along the sheet surface. Thus, the gas stream generated by suction has a more positive inhibiting effect on the formation of paths for creeping discharge and obtains a more efficient perforation than the gas stream generated by ejection.

If desired, the gap between the annular projection **11** and the sheet surface may be made smaller so that the sheet travels in sliding contact therewith, thereby further enhancing the inhibiting effect.

The electric circuit shown in FIG. **4** and through which electric power is supplied to the discharge electrodes is constructed in view of the fact that a synthetic resin sheet being perforated has a particularly high insulating resistance anad is thus difficult to perforate. The circuit comprises a high frequency pulse source and a plurality of step-up transformers, and has characteristics as follows:

1. The step-up transformer is of a high inductance type which is effective in the rapid control of electric current and in which is composed of a secondary winding which supplies a high voltage of a steep wave form when a pulse voltage is applied to a primary winding. In actual practice, an ignition coil usually for use with automobiles may be used as such. Such ignition coil is of a small size, inexpensive, of a high clurability and easily available in quantities.
2. The secondary winding of each step-up transformer may be connected to a single discharge electrode. Thus, there are necessary step-up transformers of the same number as the discharge electrodes, so that respective discharging circuits are formed independently to enable a plurality of discharge electrodes to discharge simultaneously and securely.
3. It is possible to reduce both the electrostatic capacity between lines I—I and II—II and the earth capacity. As shown in FIG. **4**, the lines I—I and II—II from the secondary winding of the step-up transformer are connected to the discharge electrodes in the rows I—I and II—II, respectively, as shown in FIG. **1A**, that is, the step-up transformer consists of a pair of ignition coils and the secondary winding is center-tapped and grounded and has the opposite ends connected to the discharge electrodes, thus applying to the discharge electrodes voltages of opposite polarity. These lines I—I and II—II comprise feeders having equipotentials, respectively and they effect a power supply of opposite polarity. Thus, enough spacing of the lines I—I and II—II from each other, and enough spacing of these lines and the earth from each other, will greatly reduce the electrostatic capacity between the lines and between the same and the earth, thereby allowing a voltage of steep wave form generated in the secondary winding to be applied to each of the discharge electrodes.

4. The high frequency pulse source is controlled by means of transisters to supply a predetermined pulse to the primary winding of the step-up transformer. This pulse source does not include any mechanically driven parts, and it can widely vary the pulse voltage and frequency.

As previously mentioned, the conventional processes give perforated sheets having a large perforation space, a small perforation density, perforations of large diameter and remarkable scorching and blackening produced in the peripheral portion of the perforations, and this tendency is greater as sheets used have higher dielectric strength. More particularly, once the travelling sheet is locally destructively perforated by effecting discharge therethrough, the discharge concentrates in said destructively perforated portions due to their rapid decrease in electric resistance and further this concentration continues for such a time that the sheet takes to travel as far as the creeping discharge is interrupted, whereby the current concentrates in said destructively perforated portions and consequentially a severer scorching or blackening is produced; while perforation pauses at other portions than the destructively perforated ones in the sheet thereby obtaining an undesirably large perforation spacing.

As is seen from the foregoing, the process of this invention which eliminates the above-mentioned drawbacks, is very effective in obtaining a reduced perforation spacing, small diameter of perforations and minimized scorching in the peripheral portions of the perforations by passing a forced gaseous stream through the arc to interrupt the creeping discharge on the surfaces of the sheet and properly control the thermal energy in the discharge. This process also makes it possible to controllably vary the perforating conditions by adjusting the flow rate of the gaseous stream.

The following Table 1 shows the effects or advantages obtained by the practice of this invention in comparison with those obtained by the conventional process.

Table 1

Type of discharge	Electric discharge in forced gaseous stream	Electric discharge in stationary air
Main method for adjusting perforation	Amount of air ejected	Applied voltage, current and frequency
Perforation spacing	Small	Large
Diameter of perforations	Small	Large
Scorching or blackening of peripheral portions of perforations	Small	Large
Wear of the tip of discharge electrodes	Small	Large
Temperature raise in the discharge portion of electrodes	Small	Large
Range of variation of permeability (or porosity) of perforated article	Large	Small

This invention will be better understood by the following examples.

EXAMPLE

As discharge electrodes there were used a plurality of tungsten wires arranged at an approximately 3-mm space. The discharge electrodes were disposed opposite to a common grounded metallic roll so that the former were several millimeters spaced from the latter, and each of the discharge electrodes was connected to a high-voltage power source capable of generating high frequency pulses. Nozzles for ejecting or drawing a gas were provided around each tungsten wire so that a stream of the gas surrounded arcs generated between the discharge electrodes and metallic roll and the flow rate of the gas was made uniform by the use of a flow-adjusting valve, thereby allowing the arc discharge to continue at every part of a sheet to be perforated. The sheet was travelled at a velocity of 120 m/min and a discharge frequency of 3 KHz while it is in contact with the grounded metallic roll and out of contact with the tungsten wires, that is, needle-like discharge electrodes. The gas used was a pressurized air. Table 2 shows a comparison between the results obtained from the test using such gaseous stream and those obtained without the use of a gaseous stream as mentioned above.

Table 2

Sheet to be perforated	Perforating conditions and properties of product	New process of this invention Electric discharge in forced gaseous stream	Conventional process Electric discharge in stationary air
Wrapping paper A (Weight 37g/m²)	Discharge voltage (KV)	7	7
	Ejecting pressure at nozzle (Kg/cm²)	1.5	0
	Perforation density (No. of perforations per unit area)	50–60	10–20
	Diameter of perforations (μ)	30–40	50–100
	Blackening at the peripheral portion of perforations	Slightly black	Remarkably black
Wrapping paper (Weight 100g/m²)	Discharge voltage (KV)	15	15
	Ejecting pressure at nozzle (Kg/cm²)	2.0	0
	Perforation density (No. of perforations per unit area)	20–30	5–7
	Diameter of perforations (μ)	50–80	100–300
	Blackening at the peripheral portion of perforations	Slightly brown	Remarkably brown
Soft polyvinyl chloride (Thickness 300μ)	Discharge voltage (KV)	15	15
	Ejecting pressure at nozzle (Kg/cm²)	2.0	0
	Perforation density	15–20	5–7
	Diameter of perforations (μ)	50–100	300–500
	Blackening at the peripheral portion of perforations	Slightly dark brown	Remarkably dark brown

What is claimed is:

1. An apparatus for the perforation of a sheet comprising a plurality of discharge electrodes electrically insulated from each other, a common grounded electrode opposite thereto, said discharge electrodes and common grounded electrode being arranged to allow the sheet to pass therebetween and effect discharge therebetween through the sheet to produce perfora-

tions in the sheet, annular nozzle means disposed around and surrounding each of said discharge electrodes, each of said annular nozzle means having their axes perpendicularly to the sheet surface, means for establishing a gas stream, said nozzle means forming said gas stream in a direction perpendicular to the sheet surface, said gas stream passing between and around each of said discharge electrodes and the sheet to control perforation conditions.

2. An apparatus as claimed in claim **1,** wherein said means for establishing a gas stream includes a compressed gas supply, said nozzle means being connected to said compressed gas supply, thereby ejecting a compressed gas stream in a direction from the nozzles perpendicularly to the sheet surface.

3. An apparatus as claimed in claim **1,** wherein each of said nozzle means includes a nozzle having an annular projection at the peripheral portion thereof opposing the sheet surface, a suction means, said annular projection being connected to said suction means, thereby generating a drawn gas stream between the sheet surface and the discharge electrodes.

4. An apparatus as claimed in claim **2,** including a stepup transformer and a high frequency pulse source, said discharge electrodes being connected via said step-up transformer to said high frequency pulse source to form an independent discharge circuit thereby applying a high frequency pulse of high voltage and small current to said discharge electrode.

5. An apparatus as claimed in claim **4,** wherein said step-up transformer comprises a pair of ignition coils, a primary winding connected to the high frequency pulse source, and a center-tapped secondary winding, the opposite ends of said secondary winding being connected to a pair of said discharge electrodes whereas said center-tapped secondary winding is grounded, thus applying to said pair of discharge electrodes voltages of opposite polarity.

6. An apparatus as claimed in claim **3,** including a step-up transformer and a high frequency pulse source, said discharge electrodes being connected via said step-up transformer to said high frequency pulse source to form an independent discharge circuit thereby applying a high frequency pulse or high voltage and small current to said discharge electrode.

7. An apparatus as claimed in claim **6,** wherein said step-up transformer comprises a pair of ignition coils, a primary winding connected to the high frequency pulse source, and a center-tapped secondary winding, the opposite ends of said secondary winding being connected to a pair of said discharge electrodes whereas said center-tapped secondary winding is grounded, thus applying to said pair of discharge electrodes voltages of opposite polarity.

8. An apparatus as claimed in claim **1** wherein each of said nozzle means is constructed and arranged to direct said gas stream in a manner to control the perforation spacing, perforation density, the diameter of the perforations formed, and any blackening and scorching which may be produced at the peripheral edge portions of the perforations.

9. An apparatus as claimed in claim **1** wherein said gas stream includes an inert gas to prevent scorching and blackening.

10. An apparatus as claimed in claim **1** wherein said discharge electrodes have discharge ends spaced from said sheet.

11. An apparatus as claimed in claim **3** wherein said annular projections on said nozzles slidably contact said sheet.

12. An apparatus as claimed in claim **1** wherein each of said nozzle means includes a nozzle arranged in circumscribing relationship about individual discharge electrodes.

13. An apparatus as claimed in claim **1** wherein each of said nozzle means includes a nozzle comprising a gas discharge passage having an axis perpendicular to said sheet, each of said discharge nozzles being centrally disposed within one of said discharge passages.

14. An apparatus as claimed in claim **1** wherein each of said nozzle means includes a nozzle having a toroidal opening circumscribing said discharge electrode.

* * * * *