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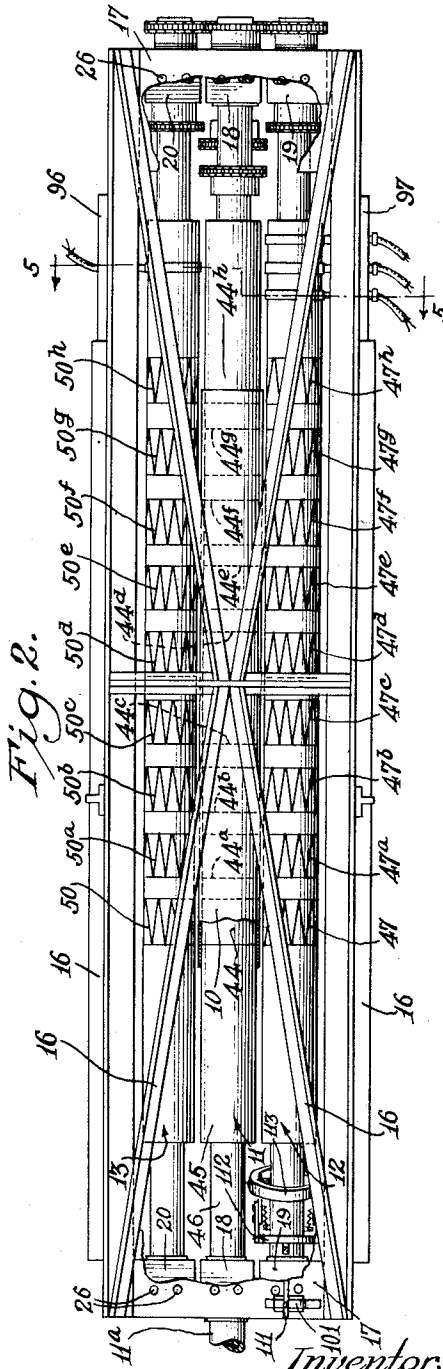
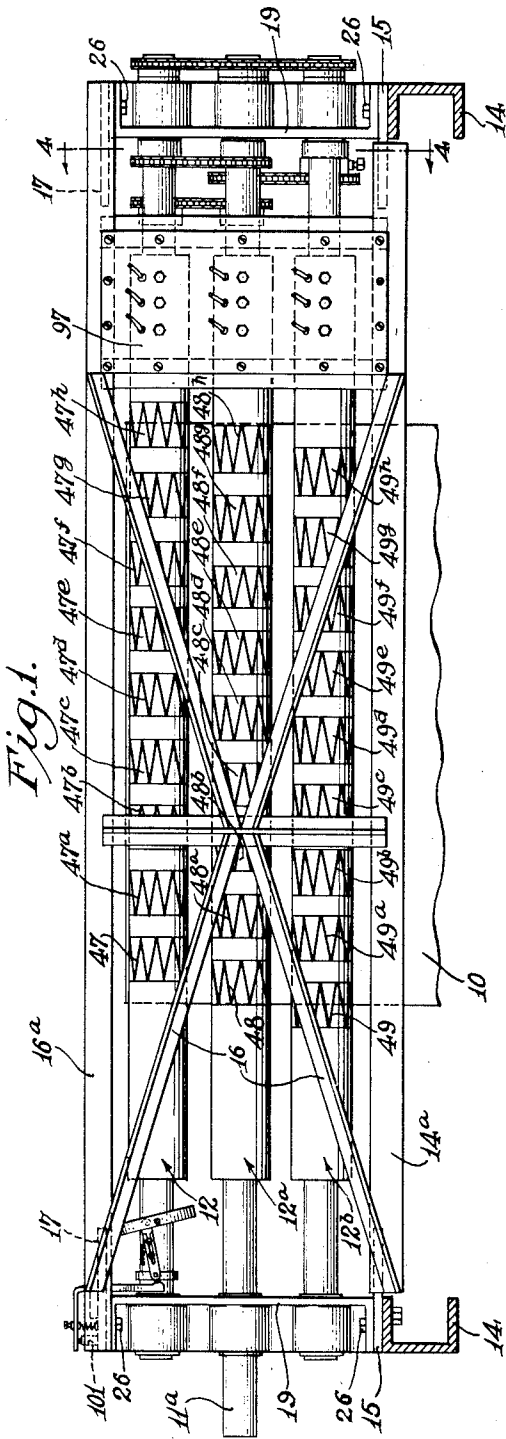
I. H. WILSEY ET AL

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METHOD AND APPARATUS FOR PERFORATING SHEET MATERIAL

Filed May 12, 1941

6 Sheets-Sheet 1



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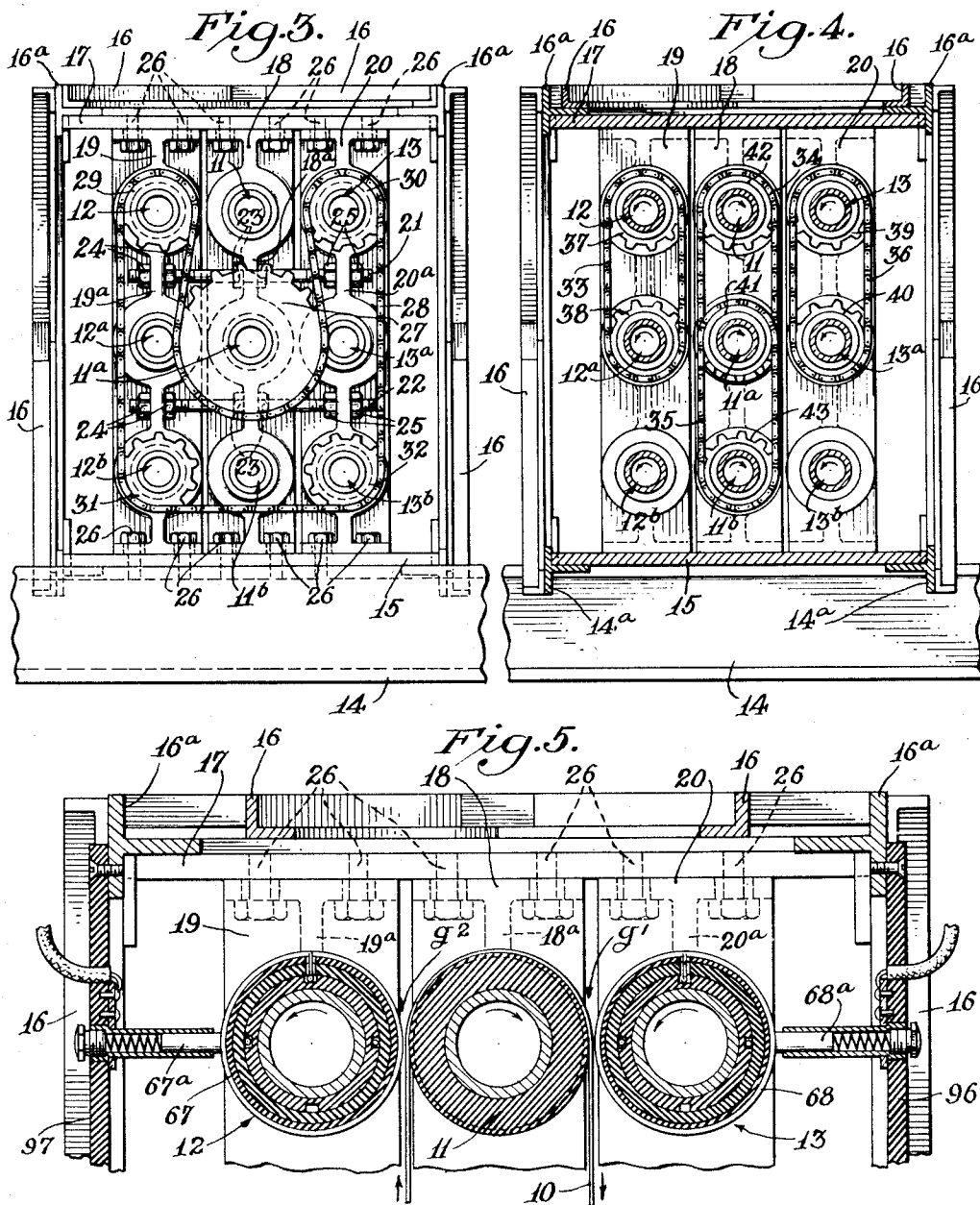
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METHOD AND APPARATUS FOR PERFORATING SHEET MATERIAL

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6 Sheets-Sheet 2



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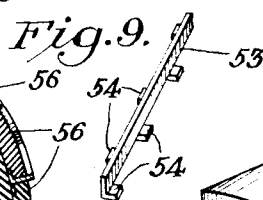
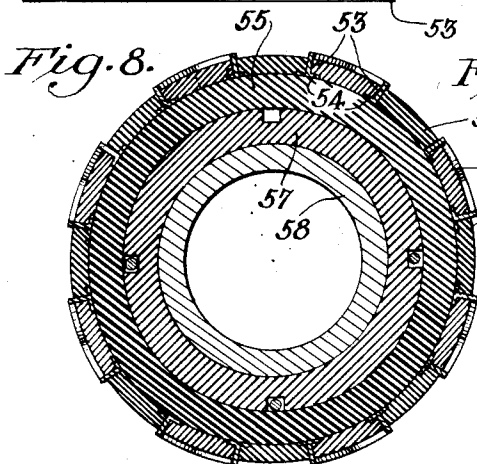
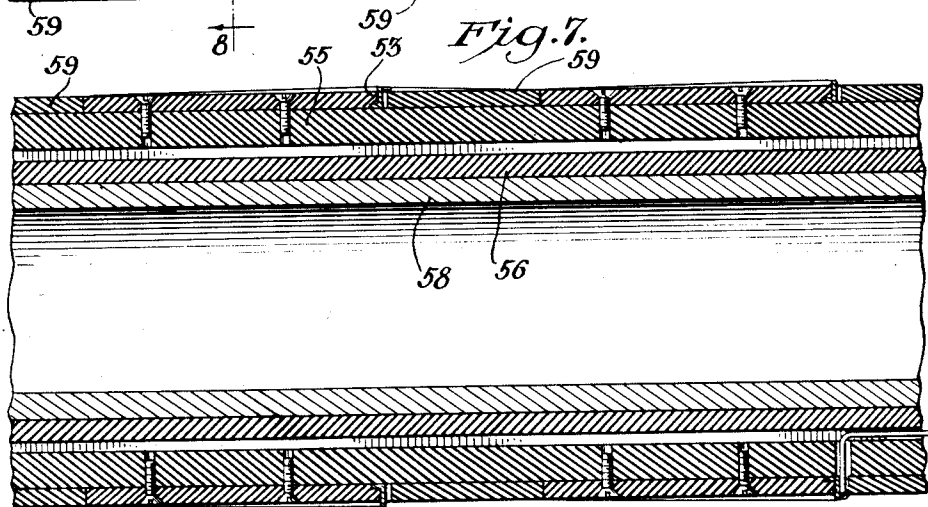
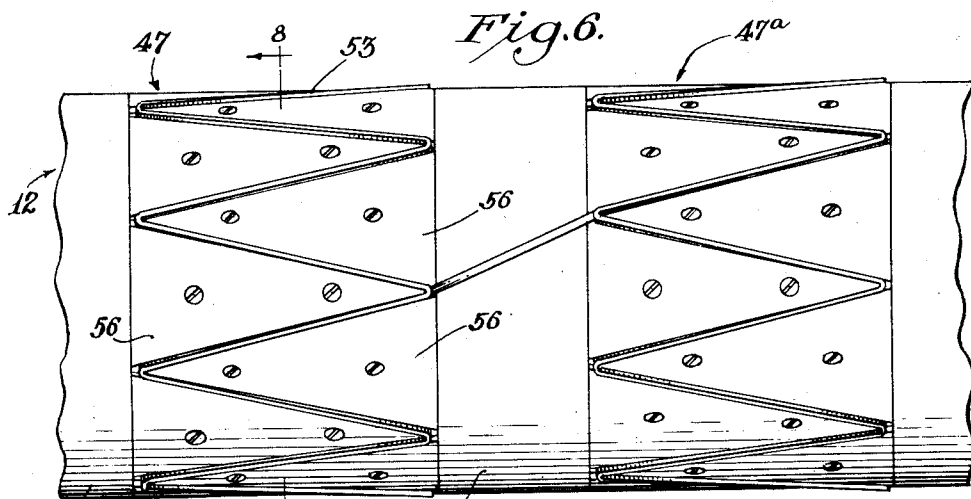
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METHOD AND APPARATUS FOR PERFORATING SHEET MATERIAL

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6 Sheets-Sheet 3



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METHOD AND APPARATUS FOR PERFORATING SHEET MATERIAL

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Fig. 14.

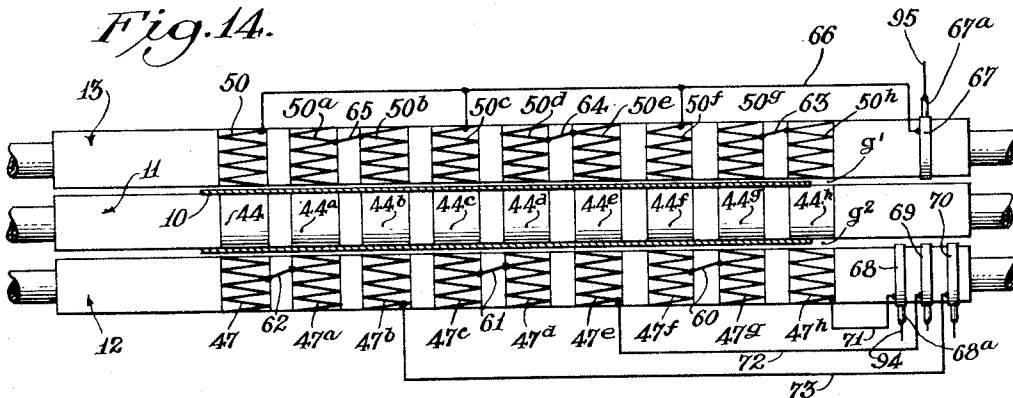


Fig. 15.

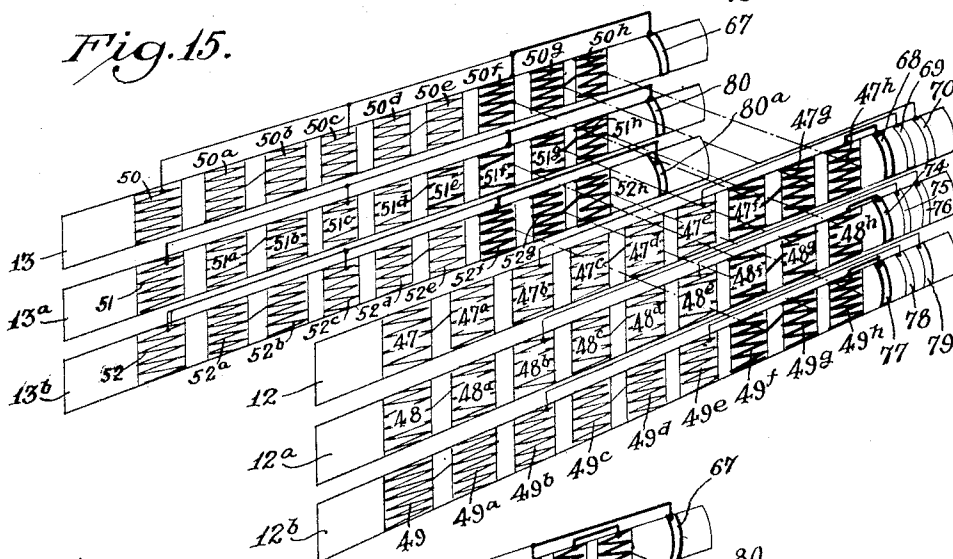
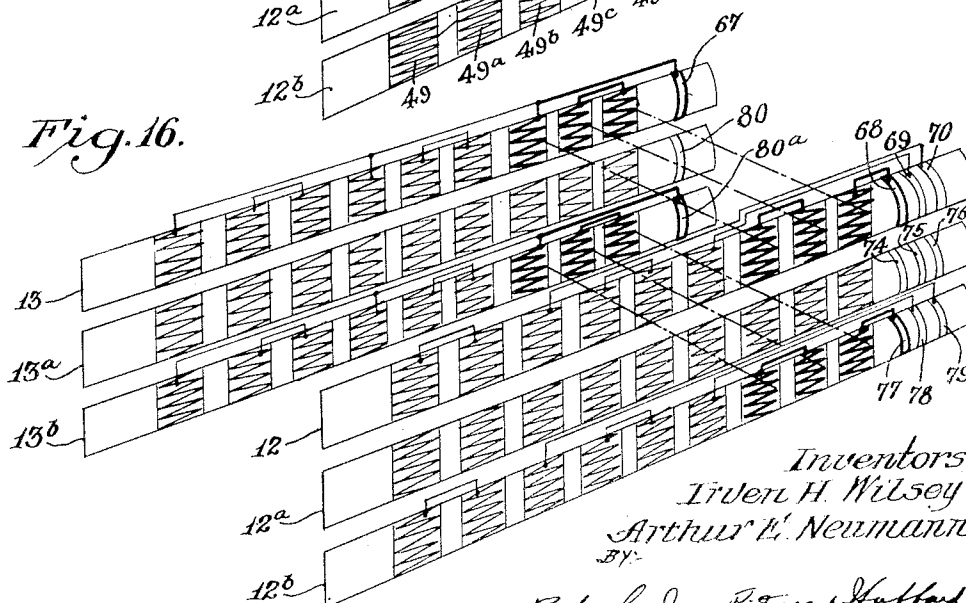


Fig. 16.



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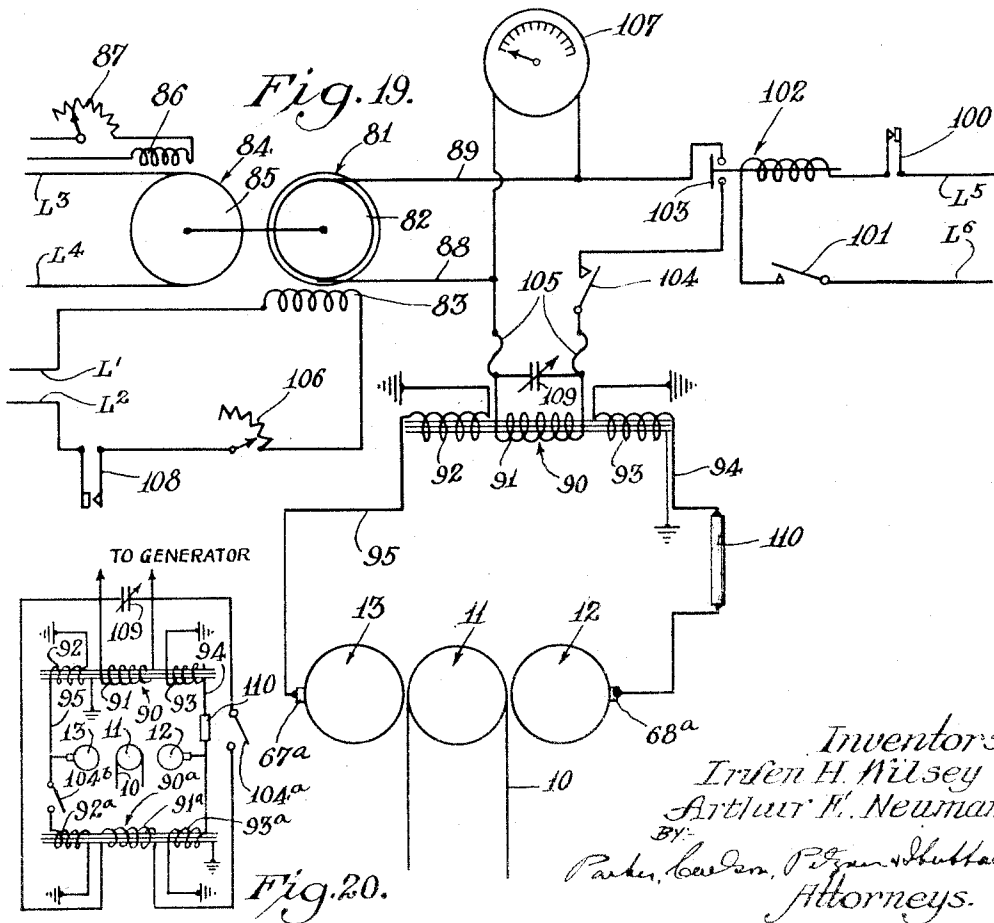
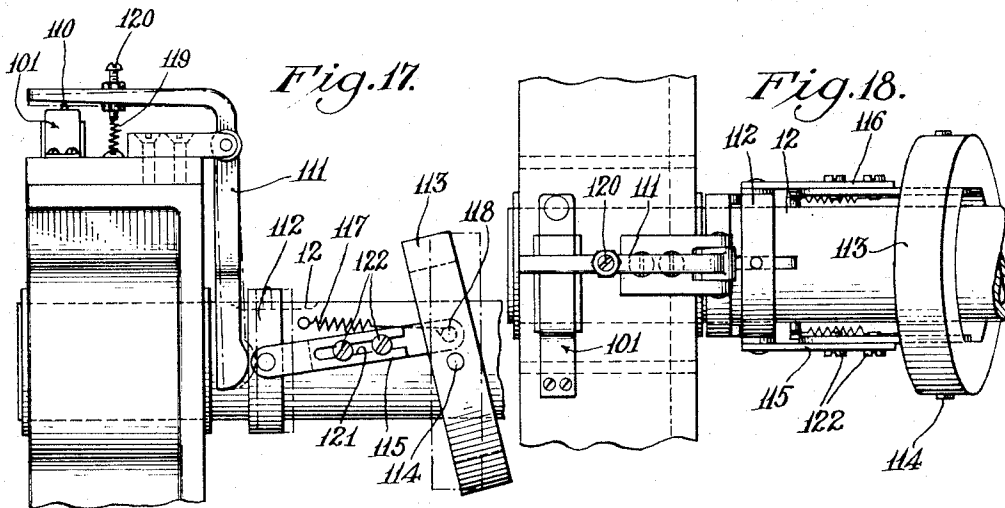
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METHOD AND APPARATUS FOR PERFORATING SHEET MATERIAL

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UNITED STATES PATENT OFFICE

2,385,246

METHOD AND APPARATUS FOR PERFORATING SHEET MATERIAL

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Application May 12, 1941, Serial No. 393,134

22 Claims. (Cl. 175—265)

The present invention relates to a novel method and apparatus for perforating sheet material and more particularly to pattern perforating such material.

The invention may be utilized in perforating a large variety of sheet materials and other articles including, for example, such dissimilar items as paper, veneer, felt and leather. The type of perforations contemplated are so small as to be nearly, if not completely, invisible to the naked eye, the perforations having a diameter of the order of 0.020 to 0.0005 inch. Sheet materials having such extremely fine perforations have been found to have large and varied fields of use. For instance, in packaging cement, flour and other such finely divided materials in valve type paper bags it is of great importance that the bag be able to "breathe." In other words, its wall structure should have sufficient porosity to permit the egress of air displaced by the contents of the bag as it is filled, and yet the wall structure must not permit the finely powdered contents to filter through. Lack of porosity causes flour or similar material to "fluff" along the side of the bag during filling and is a serious matter in valved bags. For a porous bag for such materials several factors must be carefully controlled, viz: the size of holes or perforations, the uniformity of their distribution over the sheet and the density of their distribution. Not only must these factors be controlled but in many instances should be varied to accommodate different materials.

One primary object of the invention is to provide a novel method and apparatus for pattern perforating sheet material. By "pattern" perforating is meant the aperturing or puncturing of the sheet in such manner that a preselected relative spacing and alinement of the perforations per unit area on the sheet are attained. This does not mean that the layout of holes in each unit area is an exact duplicate of that in every other area but is to be distinguished from a mere random perforating of a sheet in which the perforations fall at irregular points and the average density or number of perforations per unit area is permitted to vary.

A more specific object of the invention is to provide a novel method and apparatus for pattern perforating a sheet through the use of periodic electric arc discharges between a pair of electrodes at opposite faces of the sheet, in which the sheet and the electrodes are moved continuously relative to each other, and the perforation spacing controlled by varying the relative speed of movement between the sheet and elec-

trodes, or the periodicity of the discharges, or both.

Another object is to provide a sheet perforating machine utilizing electrical arc discharges for forming the perforations, which machine is of such character that it can be readily controlled by cutting in or out various sections to accommodate traveling sheets or webs of different widths.

Another object is to provide a machine for perforating a traveling sheet or web by electrical arc discharges, in which the discharges are effected between successive points along crisscrossing lines over the face of the web and in which a novel arrangement is provided for varying the number of such lines from which the discharges take place so as to vary correspondingly the density of the perforation pattern.

Still another object is to provide an arc discharge type perforating machine for a traveling web or sheet embodying a novel arrangement for preventing burning of the sheet in the event of undue diminution in the speed of, or stopping of, the web advance.

A further object of the invention is to provide a machine for perforating a web by electrical arc discharges which embodies a novel arrangement for variably controlling the size of the perforations formed in the sheet.

The invention also resides in the provision in the machine of various other novel features including its sectionalized control, operation-condition indicating mechanism, and electrode structure.

Further objects and advantages of the invention will become apparent as the following description proceeds, taken in connection with the accompanying drawings in which:

Figure 1 is a side elevation of a sheet material perforating machine embodying the invention and adapted to carry out the novel method herein disclosed.

Fig. 2 is a plan view of the machine.

Fig. 3 is an end elevation of the machine, taken from the right hand end as viewed in Fig. 1.

Fig. 4 is a transverse sectional view taken substantially along the line 4—4 in Fig. 1.

Fig. 5 is an enlarged, fragmentary transverse sectional view taken substantially along the line 5—5 in Fig. 2.

Fig. 6 is an enlarged detail view of one of the electrode rolls.

Figs. 7 and 8 are respectively longitudinal and transverse sectional views of the roll shown in Fig. 6.

Fig. 9 is a detail perspective view of a portion of one of the electrodes for the roll.

Fig. 10 is a detail perspective view of an insulating segment for the roll.

Figs. 11, 12 and 13 are diagrammatic views showing, respectively, various distributions of the zigzag electrodes over a unit area of sheet material.

Fig. 14 is a generally diagrammatic plan view of the machine showing the circuit connections for the top set of electrode rolls.

Figs. 15 and 16 are diagrammatic views illustrating the use of the sectionalized circuit connections for the electrode rolls.

Figs. 17 and 18 are respectively side elevation and plan views of a speed responsive switch mechanism used in the control circuit for the machine.

Fig. 19 is a wiring diagram for the machine.

Fig. 20 is a wiring diagram of a modified form of electrode supply circuit.

While the invention is susceptible of various modifications and alternative constructions, I have shown in the drawings and will herein describe in detail the preferred embodiment, but it is to be understood that I do not thereby intend to limit the invention to the specific form disclosed, but intend to cover all modifications and alternative constructions falling within the spirit and scope of the invention as expressed in the appended claims.

In the instant exemplification of the invention, the preferred procedure used includes, in brief, the following: A continuous relative movement is effected between a sheet of material, which is to be perforated, and a pair of electrodes between which it is led. Electrical arc discharges are periodically passed between the electrodes and through the sheet to perforate the latter. By controlling the periodicity of the discharges, as well as the speed and path of the relative movement noted, the relative location and spacing of the perforations are controlled. To obtain a distributed or over-all pattern of perforations on the sheet, the discharges are, in the present instance, made at spaced points along intersecting zigzag lines overlapping each other in staggered and offset relation. By varying the number of such overlapping zigzags along which the discharges take place the density of the pattern is correspondingly changed. Though the relative motion of the sheet and electrodes, etc., set forth above can be effected by hand, the great number of perforations required makes the use of an automatic machine highly desirable in carrying out the disclosed method. A more complete understanding of the method itself will be had from the succeeding description of the machine and its operation, the machine disclosed being especially adapted to carry out the method contemplated.

In the instant machine (Figs. 1 and 2) a web or sheet 10, of material to be perforated is, in general, led between a series of opposed rolls which are, in the illustrated machine, driven in synchronism with the speed of web advance. On the peripheries of these rolls are suitable electrodes, hereinafter described, and electrical arc discharges or sparks jumping between the electrodes on opposed pairs of the rolls puncture the advancing web. In the illustrative construction these electrode rolls are arranged in three superimposed sets of three. The top set (Fig. 2) comprises a center roll 11 and two side rolls

12 and 13, paralleling the center roll and arranged on diametrically opposite sides of it. Hence, if a sufficient difference in potential is established between the two side rolls 12 and 13 an arc discharge will take place in the gaps g_1 and g_2 (see Fig. 5), the center roll constituting a common or cross-over electrode for each of the series arcs. By leading the web 10 up through the gap g_2 over the top of the center roll 11 and down through the gap g_1 , it is punctured at spaced points by the two simultaneous series arcs in the air gaps g_1 and g_2 .

The other two sets of electrode rolls are substantially identical with the top set 11, 12, 13, described above and each of them is also arranged to form two air gaps for series arcs. Thus, the intermediate set of rolls comprises a center roll 11^a and side rolls 12^a and 13^a while the lower set includes a center rolls 11^b and side rolls 12^b and 13^b (Figs. 3 and 4). The entering web 10 is led upward from the bottom of the machine (Fig. 1) successively between the opposed sets of rolls 11^b, 12^b and 11^a, 12^a and 11, 12 (Fig. 3), then over the top of the upper center roll 11 and finally down through the successive pairs of opposed rolls 11, 13 and 11^a, 13^a and 11^b, 13^b. In this way the web passes successively through six air gaps between opposed pairs of rolls, and through each of which gaps arc discharges may be passed to puncture the advancing web. Suitable guide rolls (not shown) located beneath the electrode rolls exert a downward tension on the portions of the web 10 extending down from each side of the top center roll 11 so that the web frictionally engages this roll. Consequently, the web is advanced by rotation of this roll 11 and in substantial synchronism with it.

The nine electrode rolls identified above are rotatably journaled in a suitable framework of generally rectangular form. It comprises (Fig. 1) a pair of transverse bed channels 14 joined by lower longitudinal members 14^a. Paralleling the members 14^a are upper longitudinal frame members 16^a joined to each other and to the members 14^a by, respectively, top and side X-frames 16. At each end of the framework described are fixed upper and lower horizontal plates 17 and 15. Between these opposed pairs of plates are, in each case, three upright brackets 18, 19 and 20 (Fig. 3) in which are respectively journaled the vertically aligned groups of rolls 11, 11^a, 11^b and 12, 12^a, 12^b and 13, 13^a, 13^b. Each of these brackets 18, 19 and 20 comprises a vertical plate with a corresponding web 18^a, 19^a and 20^a on its inner face apertured to receive the bearings for the rolls.

To adjust the lateral spacing of the rolls in each set, and thus correspondingly vary the air gaps between them, horizontal adjustment screws 21 and 22 (Fig. 3) are arranged in registering holes in the webs 18^a, 19^a and 20^a. The central web 18^a is gripped between pairs of clamping nuts 23 on the screws 21 and 22 while the webs 19^a and 20^a are, respectively, gripped between pairs of nuts 24 and 25. By threading the nuts 24 and 25 along the screws 21 and 22, the outer brackets 19 and 20 are moved toward and away from the center bracket 18 and the air gap spacing between the laterally aligned rolls thus adjusted. This spacing is ordinarily of the order of magnitude of about three times the thickness of the sheet which is being perforated. In general, the spacing is such that the sheet or web 10 does not completely fill the gap between the opposed rolls

(Fig. 5) but instead is such that a small air gap appears between the outer face of the web and opposed peripheries of the side rolls 12 and 13, etc.

To guide the brackets 18, 19 and 20 during the adjustment operation described, and to hold them firmly in adjusted position, cap screws 26 are utilized (Fig. 3). A pair of these cap screws passes through corresponding slots in a foot on each end of each of the brackets and is threaded in corresponding holes in one of the plates 15 or 17. By loosening these cap screws the brackets are freed for transverse adjustment and after the desired adjustment has been effected the cap screws are retightened to hold the roll-supporting brackets fixedly in position.

The vertical spacing of the rolls is not particularly critical and no provision is made for its adjustment. It is great enough to permit the insertion of an operator's hand, in threading a new web or sheet into the machine, and to prevent arcing between vertically aligned rolls. It is, however, small enough to insure compactness for the machine.

In order to rotate all of the nine electrode rolls in unison a common or interconnected drive system is used for them. In the present instance power is applied through the projecting end of the center roll 11^a (Figs. 1 and 2). On the opposite end of this roll is a sprocket 27 (Fig. 3) over which is led an endless roller chain 28, which also passes over sprockets 29, 30, 31 and 32, fixed respectively on the rolls 12, 13, 12^b and 13^b. To drive the remaining rolls 11, 12^a, 13^a and 11^b, additional endless roller chains 33, 34, 35 and 36 are utilized (Fig. 4). The chain 33 is led over sprockets 37 and 38 fixed on the rolls 12 and 12^a. Similarly, the chain 36 is led over sprockets 39 and 40 fixed on the rolls 13 and 13^a while the chains 34 and 35 mesh respectively with a pair of sprockets 41 on the roll 11^a and with sprockets 42 and 43 on the rolls 11 and 11^b. The arrows in Figs. 4 and 5 indicate the direction of roll rotation. In the event that the machine is being used, for example, to perforate paper, the primary drive roll 11^a may be driven from the same unified drive system which also operates a slitter located ahead of the perforator and a reroll mechanism following it. The high speed with which the web 10 may pass through the present perforator at, for example, several feet per second, makes it possible to use the perforator in any ordinary line-up of paper making or handling machines without the necessity of slowing down the line because of the presence of the perforator.

Turning now to the details of the electrode structures of the various rolls, the center, or what might be termed the cross-over rolls, 11, 11^a and 11^b are provided with electrodes in the form of simple annular metal bands 44, 44^a, 44^b to 44ⁿ. These electrode bands may be made of copper or other suitably electrically conductive material. Each of them completely encircles the roll on which it is mounted and is fixed on the periphery of a sheath or cylinder 45 of insulating material. This sheath 45 is, in turn, telescoped on and fixed to a hollow steel shaft 46. Each of the center rolls 11, 11^a and 11^b is identical in construction except that the sets of electrode bands on them are offset longitudinally with respect to each other, for a purpose which will hereinafter appear. The amount of this longitudinal offset is the same as that shown for the zigzag electrodes on the side rolls and which is indicated in Fig. 1.

By spacing the electrode bands 44, 44^a to 44ⁿ (Fig. 2) laterally from each other along the supporting insulator sheath 45 they are effectually insulated from each other. In this way they form a series of separate and electrically insulated electrodes so that arc discharges can be passed to them from similarly spaced electrodes on the side rolls, thereby making possible a corresponding number of arc discharges through the web 10 at laterally spaced points in the latter.

On the outer or side rolls 12, 12^a, 12^b, 13, 13^a, and 13^b a plurality (nine in the present instance) of electrodes are provided at spaced points along each of the rolls and in position to cooperate with the band electrodes on the center rolls 11, 11^a and 11^b. In the case of the roll 12 the separate electrodes on it have been identified as 47, 47^a to 47ⁿ, those on the roll 12^a as 48, 48^a to 48ⁿ, those on the roll 12^b as 49, 49^a to 49ⁿ, those on roll 13 as 50, 50^a to 50ⁿ, those on roll 13^a as 51, 51^a to 51ⁿ, those on roll 13^b as 52, 52^a to 52ⁿ (Figs. 1, 2 and 15). Each of the electrodes is identical and, accordingly, a description of electrode 47 on roll 12 will serve for all. This electrode (Fig. 6) is of zigzag or wavy form and comprises a bar 53 (see also Fig. 9) of nichrome steel, or other electrically conducting material, bent in zigzag form as shown and with its ends jointed together to form a complete annulus encircling the roll.

The electrode bar 53 has feet 54 bent laterally from its lower edge and projecting alternately in opposed directions (Fig. 9) which rest on a sheath or cylinder 55 of insulating material (Figs. 7 and 8). Segments 56 of insulating material (Fig. 10) are inserted between the bends in the electrode bar 53 (Fig. 6) and overlie the feet 54, these segments being screwed to the sheath 55 so as to hold the bar 53 in place. The insulating sheath 55 is telescoped on an inner insulating sheath 57 which is longitudinally slotted (Fig. 8) to receive, and insulate from each other, interconnecting conductors between various ones of the zigzag electrodes. This inner sheath 57 is in turn telescoped over and fixed to a hollow steel shaft 58. Suitable annular insulating spacers 59 (Figs. 6 and 7) encircle the sheath 55 between the annular rows of segments 56.

It will be observed that as the rolls 11 and 12 (Figs. 2 and 5) rotate with respect to each other in the directions indicated by the arrows in Fig. 5, the point of least distance, in the air gap g_1 between the band electrode 44 on the roll 11 and the zigzag electrode 47, moves progressively along the latter electrode. When a potential is created between the electrodes 44 and 47 so that an arc discharge passes between them it will, in general, jump between the most closely adjacent points on them. Consequently, a periodically applied voltage between the electrodes 44 and 47 will cause a series of discharges between them at successively spaced points along the zigzag electrode 47. The spacing along the electrode of successive ones of these discharges will depend upon the relation between the periodicity of the discharges and the speed of rotation of the zigzag electrode. As is hereinafter explained in greater detail, advantage is taken of this characteristic to control the spacing of the arc-formed perforations in the traveling web 10.

To obtain a generally uniform or controlled patterned distribution of the perforations over the web 10 a particular geometric relation of the various zigzag electrodes, under which each portion of the web passes, is desirably used. For this purpose each of the zigzag electrodes on the

side rolls 12, 12^a and 12^b (see Fig. 1) is longitudinally offset with respect to the corresponding electrode on the next adjacent roll in this series. Incidentally, this offset has not been indicated in diagrammatic Figs. 15 and 16 in order to simplify the same. The amount of offset is, in the present instance, one-half the width of each electrode. Furthermore, each of the zigzag electrodes on the side rolls 12, 12^a and 12^b is angularly offset with respect to the corresponding electrode on the next adjacent side roll. On the other side of the machine, the zigzag electrodes on the rolls 13, 13^a and 13^b are offset with respect to each other by the same amount as those in the rolls 12, 12^a and 12^b. Thus the electrodes on the roll 13 are directly across from those on the roll 12, those on roll 13^a directly across from those on 12^a, etc. Also, the electrodes on the rolls 13, 13^a and 13^b are staggered angularly about their respective rolls, but in this case they are staggered not only with respect to each other but with respect to the electrodes on the rolls 12, 12^a and 12^b.

The details of the above geometric relation of the several zigzag electrodes will be clear upon reference to the diagrammatic illustration in Fig. 11. This figure shows a portion of the web 10 with criss-cross lines superimposed on it corresponding to the relative positions of the portions of certain of the electrodes on the rolls 13, 13^a and 13^b which the web passes successively in the order named as it moves down through the machine. The particular portion of the web chosen for illustration passes by portions of the electrodes 50^a, 51^a and 52^a on the rolls 13, 13^a and 13^b, respectively. The developed outline of the electrode 51^a has been shown in full lines, that of the electrode 50^a in dash lines, and that of the electrode 52^a in dot-dash lines, in order to distinguish them. The staggered and offset relation of these three electrodes, which is typical for all of those on the rolls 13, 13^a and 13^b, will be apparent from this development of them in Fig. 11.

This same portion of the web 10 also passes up through the three gaps on the other side of the machine, or, in other words, past the rolls 12^b, 12^a and 12 in that order and, hence, successively under the electrodes 49^a, 48^a and 47^a. These have been indicated in Fig. 12 by, respectively dotted lines, dash double-dot lines and light full lines. Thus, Fig. 12 shows the full pattern of distribution for the various zigzag electrodes as they successively overlie a single unitary portion of the web. The arc discharges, heretofore referred to, take place at successively spaced points along each of the intersecting lines so that the entire surface of the web is finally covered with closely spaced, though fairly accurately distributed, perforations.

By cutting into or out of circuit certain of the zigzag electrodes which pass over a particular portion of the web, the number of perforations can be varied, although the uniformity of the pattern of the perforations is maintained. For example, in Fig. 13, the lines for the electrodes 47^a and 50^a have been shown simply in light lines (compared to the contrasting heavier lines for those same electrodes shown in Fig. 12) so as to indicate that these electrodes are deenergized. In such case the perforation-forming arc discharges will take place at spaced points along only the heavier lines indicated for the electrodes 52^a, 51^a, 49^a and 48^a. Accordingly, homogeneity or uniformity of perforation distribution is maintained, although the density of perforation per unit area of the web is substantially diminished.

Various other ones of the electrodes may be cut into or out of circuit, by a switch mechanism subsequently described, to effect other variations in the pattern of distribution.

Similarly, but cutting into or out of circuit various ones of the zigzag electrodes along each of the rolls, the machine can be conditioned to accommodate, with maximum efficiency, sheets or webs of different widths. Thus, upon reference to Fig. 15 it will be observed that in the right hand vertical bank of rolls 12, 12^a and 12^b only the electrodes 47^f, 47^e, 47^d and 48^f, 48^e, 48^d and 49^f, 49^e, 49^d are energized (as indicated by the heavier lines in which these electrodes are drawn). Similarly, in the left hand bank of rolls 13, 13^a and 13^b only the corresponding three end electrodes, shown in heavy lines, are energized. The machine is in such case conditioned to receive a web having a lateral width equal to not more than the length of roll covered by three electrodes on each side roll. For wider sheets successive groups of the electrodes along each roll may be energized.

Even when the machine is set up for a narrow web the density of perforation distribution can still be controlled as described. Thus, upon reference to Fig. 16, for example, it will be seen that only the end group of electrodes is energized so as to accommodate a narrow web (as described above in connection with Fig. 15) but among even these end electrodes those on the rolls 12^a and 13^a are, in this instance (Fig. 16), deenergized so as to cut down the number of perforations per unit area as previously described.

In order to make it possible to cut into or out of circuit different electrodes for the various purposes set forth above, a sectionalized type of circuit is used for applying potential to the electrodes. Upon reference to the illustrative construction in Fig. 14 it will be seen that the electrodes on the roll 12 are wired in three successive groups, each group containing three adjacent electrodes. In each of these groups two of the electrodes are interconnected. Thus, in the right hand group, comprising electrodes 47^f, 47^e and 47^d, the electrodes 47^f and 47^e are interconnected by a conductor 60. Similarly, in the middle group the pair of electrodes 47^c and 47^b are interconnected by conductor 61, and in the left end group the electrodes 47^a and 47^b are interconnected by a conductor 62.

On the opposite side of the machine, that is, on roll 13, the electrodes are wired in similar circuit groups or sections and in each of these groups of three, two of the electrodes are interconnected. Specifically, the electrodes 50^e and 50^d are interconnected by a conductor 63, the electrodes 50^d and 50^c by a conductor 64, and the electrodes 50^c and 50^b by a conductor 65. On this roll 13 the electrodes are connected by a common supply lead 66 to a slip ring 67. On the other roll 12 however, three separate slip rings 68, 69 and 70 are connected to corresponding ones of the electrodes in the three sections or groups by conductors 71, 72 and 73.

With the circuit connections described above, when potential is applied between the slip rings 68 and 67 current will flow through a circuit

68—71—47^b—g₂—44^b—g₁—50^b—
63—50^c—g₁—44^c—g₂—47^c—60—
47^f—g₂—44^f—g₁—50^f—66—67

Upon tracing this circuit in Fig. 14 it will be seen that it includes a total of six air gaps in each of which an arc discharge must take place to complete the circuit. Specifically, the circuit

passes through gap g_1 three times and through gap g_2 three times. Consequently the web 10 is punctured at six different points by a single energization of the circuit.

In order to energize the next or middle group of electrodes on the rolls 12, 13 (Fig. 14) a potential difference is established between the slip rings 66 and 67. In such case a circuit is completed through

66—72—47^a— g_2 —44^a— g_1 —50^a—
64—50^a— g_1 —44^a— g_2 —47^a—61—
47^a— g_2 —44^a— g_1 —50^a—66—67

In the same way, when a potential difference is established between the slip rings 76 and 67 a circuit is completed through

76—73—47^b— g_2 —44^b— g_1 —50^b—
68—50^b— g_1 —44^b— g_2 —47^b—62—
47^b— g_2 —44^b— g_1 —50^b—66—67

Identical sectionalized energizing circuits are provided for the rolls 12^a, 13^a and 12^b, 13^b in the middle and lower sets, respectively, as indicated in Figs. 15 and 16. As terminals for these circuits on the rolls 12^a and 12^b, respectively, are provided sets of three slip rings each, viz: 74, 75, 76 and 77, 78 and 79. On each of the rolls 13^a and 13^b is provided a single slip ring 80 and 86^a, respectively.

As a means of applying potential to the various sections of the electrode circuits set forth above, a high frequency generator 81 is utilized (Fig. 19). This generator is, in general, of conventional form and comprises an armature 82 and a separately excited field 83, which is connected to suitable direct current supply lines L_1 and L_2 . The generator armature 82 is driven by a variable speed motor 84 having an armature 85 connected to alternating current supply lines L_3 and L_4 , as well as a separately excited field 86, connected to a suitable source of current through a speed adjusting rheostat 87.

To the output leads 88, 89 of the high frequency generator 81 are connected, in parallel relation to each other, a plurality of step-up transformers, one for each of the electrode sections heretofore described or, in other words, nine in number for the present machine. Each of these transformers has one of its output terminals connected to a corresponding one of the slip rings on one of the rolls 12, 12^a or 12^b and its other terminal connected to a corresponding return slip ring on one of the opposite rolls 13, 13^a or 13^b. Since these transformers are identical, and are each connected in parallel to each other in the same manner to the output leads of the generator, only one has been shown, namely, the transformer 90 (Fig. 19) for the slip rings 66 and 67 (see Fig. 14). This transformer is of the high-reactance current-limiting type and includes a primary winding 91 inductively coupled with a sectionalized secondary winding including sections 92 and 93. One terminal of each of these secondary windings is grounded and the others are connected, respectively, through conductors 94 and 95, with brushes 67^a and 68^a for the slip rings 67 and 68 (see also Figs. 5 and 14). It will be observed upon reference to Fig. 5 that the brushes are of conventional form, being resiliently mounted in insulating panels 96 and 97 secured to opposite sides of the machine framework. As indicated in Figs. 1 and 2 the corresponding brushes for all of the slip rings are mounted on these same panels.

The generator 81 (Fig. 19) may, for example,

have a rated output of 2500 cycles at 110 volts. The frequency of its output potential is of course a function of the generator speed and can be controlled by changing the speed of the variable speed driving motor 84, through the medium of the speed controlling rheostat 87. In such case the transformer 90 may be wound to step up the voltage to 10,000 volts or whatever is required to produce an arc discharge of desired intensity through the six series gaps in the electrode section which the transformer supplies. When operating at 2500 cycles, two discharges take place for each cycle, that is, one on the positive peak and one on the negative peak. Hence there are 5000 discharges per second but since there are six gaps in each electrode section there will be 30,000 separate arcs in each section per second or 30,000 perforations formed per second in the portion of the web passing through the section. There are, however, nine electrode sections in the machine shown, so that when all are operating, there will be 270,000 perforations formed per second or 16,200,000 per minute. Despite this tremendous speed with which the perforations are formed, their distribution pattern over the web is accurately controlled by the electrode arrangement heretofore described.

To initiate operation of the machine, after the generator 81 has been started, the operator closes the manual on-off switch 100 (Fig. 19) which, together with a safety switch 101 herein-after described, connects the actuating winding of a relay winding 102 to suitable supply lines L_5 and L_6 . Thereupon this relay closes its normally open contacts 103, which are interposed in the conductor 89 leading to the transformer primary winding 91. Also interposed in this conductor 89 is an individual manually operated on-off switch 104, one of which is provided for each of the transformers. By closing and opening selected ones of these individual on-off switches, the associated transformers can be cut into or out of circuit to condition the desired number of electrode sections for operation. Each of the transformers is protected by a pair of fuses 105 in its input leads. When the relay 102 drops out, due to the opening of the manual on-off switch 100, or of the safety switch 101, all of the transformers are simultaneously disconnected from the generator 81.

The physical character of the hole or puncture formed in the sheet by an arc discharge depends to some extent upon the power of the discharge or in other words upon the product of the in-phase current and voltage. As the power is increased from a point just sufficient to effect puncturing a sheet, the size of the puncture or perforation increases in more or less direct proportion. In the event that paper is being perforated, it has been found by microscopic examination of the sheets that the marginal edges of the perforations are made up of fused material. When perforations, with fused edges, are formed in even cheap rosin content wrapping paper it has been found that the strength of the paper has not been materially decreased but in many instances actually increased. This increase may be due to various causes, probably including the fusion of the edges of the perforations. As the power of the arc discharge is still further increased, from a point at which a fused edge perforation is formed, some charring at the edges of the still larger perforations appears.

Such charring is, in many instances, undesirable for various reasons in that it interferes with

subsequent printing on the sheet surface and may, if carried far enough, structurally weaken it. It will thus be clear that accurate control of power of the discharges is very desirable. Even aside from the difference in character of the perforations formed there are other reasons for controlling their size. For example the particular use to which the sheet material is to be put will frequently govern the maximum or minimum size of perforation which is desired or even permissible.

The illustrative machine comprises two distinct means for controlling the size of the perforations formed in the web 10. First, means is provided for controlling the output voltage of the generator 81, and by means of which, the power is correspondingly controlled. Second, means is provided for controlling the phase relation of the voltage and current supplied by the generator 81 and correspondingly the product of the in-phase voltage and current, or in other words, the power.

To control the output voltage of the generator 81, a rheostat 106 is connected in series with its separately excited field 83. By changing the setting of this rheostat the output voltage of the generator is changed, the mode of operation of such a generator in this respect being well known. For convenience in operation a volt meter 107 is connected across the output leads 88, 89 of the generator so that the operator is continuously apprised of the voltage applied to the network. An auxiliary manually operated on-off switch 108 is preferably interposed in a circuit for the generator field 83 so that it can be used at will to open-circuit this field and drop to zero the output voltage of the generator.

The means for varying the phase relation of the generator output voltage and current has been shown (Fig. 19) as comprising a variable condenser 109 connected in shunt with the transformer primary winding 81. The inductive reactance of the transformer and the capacitive reactance of the condenser go to make up a tuned circuit, and by adjusting the capacity of the condenser the phase relation of the voltage and current can be changed at will. A similar variable condenser (not shown) is associated with each of the transformers for the various electrode sections. This affords great flexibility of operation for the machine since the size of the holes produced by each of the sections can be varied independently by adjusting the condenser for such section. On the other hand if it is desired to make a simultaneous change in the size of the holes produced by all of the sections this can be effected by changing the generator output voltage through the medium of the adjustable rheostat 106.

To afford the operator a visual indication of the condition of operation for the various sections of electrodes, a gaseous discharge tube such as a neon lamp 110 (Fig. 19) is connected in series with each of the transformer secondaries. One such lamp is provided for each of the nine transformers. The high order of magnitude of the output voltage from the transformers is sufficient to render these tubes conductive but the voltage drop through them is very small and their current consumption is also small so that they do not materially diminish the efficiency of the system. When full load current is flowing through one of these tubes it glows, and since the tube is in series with the load on the transformer, its glow indicates that the associated circuit is func-

tioning properly. Moreover, when the power is varied the intensity and color of the light emitted by the pilot lamp changes accordingly. When the individual on-off switch 104 for any particular tube's section is opened the associated pilot tube is darkened, indicating that its section is out of service. The group of nine pilot tubes 110 may be conveniently mounted on a single panel (not shown) at any convenient point of control and the individual on-off switch 104 is desirably mounted on the same panel adjacent the corresponding pilot tubes.

In many instances it is desirable to provide separate driving means for rotating the electrode rolls and for driving the high frequency generator. In such case the driving means are desirably interlocked so that no potential will be applied to the electrodes unless the rolls are rotating at a speed exceeding a predetermined minimum. By providing such an interlock danger of badly charring or even burning the web 10 by repeated discharges through the same portions of the web is obviated. To effect this interlocking the safety switch 101 (Fig. 19) is arranged to be actuated in response to the speed of rotation of the rolls. As was heretofore noted, when this switch 101 is open, the relay 102 is dropped out and all supply of potential to the electrodes is thereby cut off.

In the illustrative construction (Fig. 1) the switch 101, which is a normally open so-called micro-switch, is mounted on the left end frame of the machine. This switch is provided with an upstanding actuating plunger 110 (Fig. 17) which must be pushed down to close the switch. Pivoted on the end frame of the machine with one arm overlying the plunger 110 is a bell crank 111. This bell crank has a bifurcated lower end embracing the roll 12 (see also Fig. 18). Keyed for axial movement on the roll is a collar 112 which is arranged to abut against the enlarged lower ends of the bell crank 111. An annular weight or ring 113 is pivoted by trunnions 114 on the shaft 12 at a point axially displaced from the collar 112. This ring 113 is tiltable in a direction transverse to the shaft axis and is connected to the collar 112 through links 115 and 116 arranged on diametrically opposite sides of the roll 12. The opposite ends of these links are pivotally connected respectively to the collar 112 and to the ring 113. In the case of the collar 112 they are connected to it at diametrically opposite points, but in the case of the ring 113 they are pivoted to it at points eccentric to its trunnions 114. Tension springs 117, anchored at their opposite ends to the shaft 12 and to pivot pins 118 which connect the links to the ring, normally tilt the ring 113 to the position shown in full lines in Fig. 17. The links 115, 116 are thus thrust endwise to the left and move the collar 112 to the full line position shown where it abuts against the bell crank 111 and swings it in a clockwise direction to release the switch plunger 110. A tension spring 119, anchored at one end of the machine frame and at its other end to a screw 120 adjustably threaded in the bell crank 111, serves to vary the cocking tension of the switch mechanism.

When the roll 12 is rotating, centrifugal force tends to swing the ring 113 into a plane transverse to the axis of shaft rotation (position indicated in dot-dash lines in Fig. 17). Such movement is yieldably opposed by the tension springs 117. When the speed of rotation for the roll 12 finally reaches a predetermined value the spring

tension is overcome and the ring 113 is shifted to the dot-dash position in Fig. 17 whereupon the collar 104 is drawn to the right, thereby disengaging the bell crank lever 111 so that the latter is pulled down by the spring 119 and the switch 101 closed. Closure of this switch 101 (see Fig. 19) conditions the relay 102 for energization upon the subsequent closure by the main on-off switch 100.

To vary the speed-responsive setting of the switch-actuating mechanism the effective length of the links 115, 116 may be altered. For this purpose each of the links is made up of two overlapping portions one of which is longitudinally slotted as indicated at 121. Screws 122 threaded in the other member and projecting through the slot releasably clamp the link portions together. Adjustment of the tension in the spring 119 also serves to effect smaller or finer adjustments in the speed setting of the mechanism.

In Fig. 20 is shown a modified transformer circuit for one set of electrodes and which may be substituted for that of Fig. 19 to obtain even greater latitude in intensity of arcing between the electrodes and, hence, in perforation size. In general, transformers 90^a are arranged to supplement the transformers 90 previously described. Each of the transformers 90^a is identical with the transformers 90 and includes a primary winding 91^a and secondaries 92^a and 93^a. The primary winding 91^a may, at will, be connected in parallel with the primary of the transformer 90, through an on-off switch 104^a, so as to be supplied from the same generator 81. Similarly, the secondaries are connected across the electrodes by a switch 104^b. When open these switches prevent feed-back to the circuit of the transformer 90. By cutting the supplemental transformer 90^a into circuit the power applied to the associated electrodes is practically doubled. Nevertheless, the condensers 109 and generator output voltage control can be used as before to vary the perforation size even with the supplemental transformers in circuit although the range through which the variations take place is correspondingly enlarged.

Brief résumé of operation

Assuming that the leading portion of the web 10 has been threaded between the rolls as heretofore described, the operator preliminarily conditions the machine for operation by opening or closing various ones of the individual on-off switches 104, the ones closed depending upon the width of the sheet to be perforated and the density of distribution desired for the perforation pattern. If a very dense pattern of perforations on a sheet of maximum width is desired, all of the switches 104 are closed so that all of the sections of electrodes will be operative. Additionally the generator driving motor 84 is started and the output voltage for the generator checked on the meter 107, any desired variations in such voltage being effected by adjusting the rheostat 106.

With the machine preliminarily conditioned as described, the main on-off switch 100 may be closed and the center roll 11^a coupled to its driving mechanism so that the rolls are set in rotation. As soon as the rolls come up to speed the safety switch 101 closes thereby pulling in the main relay 102 and connecting the selected transformers 90 to the output leads of the high frequency generator 81.

Each half cycle of voltage from the generator 81 causes six series arc discharges between the

electrodes of the selected electrode sections. The rotation of the generally spiraled electrodes on the side rolls moves them so that the point thereon in closest proximity to the center roll electrode bands (and hence the point from which a spark will jump to the center roll band since the spark travels through a path of least distance) moves progressively along the spiral or zigzag electrodes. Thus as successive cycles of voltage are applied the sparks occur at successively spaced points along the zigzag electrodes. To vary the spacing between these successive points, the relation between frequency of the voltage and speed of web advance can be changed. This can be done either by changing the frequency, through variation in speed of the generator driving motor 84, or by changing the speed of web advance by change in speed of roll rotation, or both.

To vary the size of the punctures in the web 10 formed by the discharges in any selected section of electrodes, the corresponding variable condenser 109 is adjusted. By changing its setting the phase relation of the voltage and current is altered, as heretofore explained, so that the power expended in the discharges is correspondingly changed.

In the event that the operator wishes to change simultaneously the size of the perforations formed by all of the electrode sections he changes the output voltage of the high frequency generator 81. To do this he varies the excitation of its field 83 by means of the rheostat 106.

If the modified circuit of Fig. 20 is used the range of perforation size may be further increased by closing switches 104^a and 104^b to cut in the supplemental transformer 90^a for a selected section of the machine. Thereafter the controls 109 and 106 are used as described above to vary the output of the now parallel connected transformers 90 and 90^a.

In the event that the roll driving mechanism should become stalled or the rolls stopped for any other reason the web 10 is completely protected against burning. Any such stoppage of the rolls automatically opens the safety switch 101 and thereby prevents further application of voltage to the electrodes.

From the foregoing it will be apparent that a remarkably versatile machine has been provided. Adjustment of the clearance between the rolls makes it possible to accommodate a wide variety of thicknesses of sheet material. This also aids to some extent in conditioning the machine for different kinds of material while the complete nature of the control over arc power makes it possible to obtain a desired size of perforation despite differences in the dielectric qualities of the particular materials. Coupled with this is the ability to obtain a uniform pattern of distribution for the perforations and one which is of selectively variable density. In view of this completeness and flexibility of control an extremely wide variety of materials can be handled effectually and at extremely high speeds.

We claim as our invention:

1. The method of pattern perforating a sheet of material which comprises passing electrical arc discharges through the sheet at spaced points along predetermined intersecting lines, and varying the number of such lines criss-crossing each other in unit areas of the sheet to vary correspondingly the density of the pattern of perforations.

2. The method of pattern perforating a sheet

of material which comprises passing electrical arc discharges through the sheet at successive spaced points along a plurality of zigzag lines with such lines successively overlapping the same portions of the sheet and arranged with certain of such lines offset with respect to each other laterally of the sheet and also with certain of said lines staggered with respect to each other longitudinally of the sheet.

3. The method of perforating a sheet which comprises locating the sheet between a plurality of pairs of electrodes, applying potential between said pairs of electrodes from a common source of potential to establish periodical arc discharges between such electrodes and thereby puncture the sheet, varying the output potential of said source to change correspondingly and simultaneously the size of the punctures produced by all of such discharges, and varying the phase relation between the potential and current supplied to selected ones of the pairs of electrodes to change independently the size of the punctures produced by the discharges between the selected pair or pairs of electrodes.

4. In a sheet perforating machine, the combination of power actuated means for advancing a web, a set of electrodes comprising a plurality of zigzag electrodes and cooperating electrodes spaced from the former and arranged with each zigzag electrode on the opposite side of the path of web advance from its cooperating electrode, means for causing electrical arc discharges to pass between the zigzag electrodes and corresponding ones of the spaced electrodes at spaced points along selected ones of the zigzag electrodes, and said zigzag electrodes being offset with respect to each other in a direction transverse to the path of web travel.

5. A machine of the type set forth comprising, in combination, first and second rows of electrodes arranged in parallel spaced relation; a third row of cross-over electrodes between said first and second rows disposed in closely spaced relation to the latter to receive in the resulting gaps between the first and third rows as well as the second and third rows portions of sheet material to be perforated; means electrically interconnecting predetermined ones of the electrodes in the second row which are so positioned with respect to those in the first row as to form a series circuit including in the order named an electrode in the first row, a cross-over electrode, two series connected electrodes in the third row, a second cross-over electrode and a second electrode in the first row; and means for applying a periodically varying electrical potential to the terminals of said series circuit to set up arc discharges in said gaps and through the portions of sheet material between successive electrodes in said series circuit.

6. A sheet perforating machine comprising, in combination, a center roll and a pair of parallel side rolls disposed on generally diametrically opposite sides of said center roll, said rolls being spaced apart to receive a traveling web passing through the gaps thus formed between the center roll and respective ones of the side rolls, said center roll having an electrode thereon in the form of an annular conductor encircling the same, each of said side rolls having an electrode thereon comprising a zigzag annular conductor encircling the respective roll and opposed to the electrode on the center roll, and means for periodically applying a potential between the side roll electrodes to cause an electric impulse to

pass from one side roll electrode through the center roll electrode to the other side roll electrode, the resulting arc discharges in the gaps separating the side rolls and the center roll serving to puncture the web at such points.

7. A sheet perforating machine comprising, in combination, a rotatably mounted roll having a plurality of electrodes thereon in insulated relation to each other at points spaced longitudinally of the roll, each of said electrodes comprising a zigzag annular conductor encircling the roll, a cooperating electrode structure spaced from said zigzag electrodes on the roll to receive a web therebetween which is to be perforated, and means for applying an electrical potential between the roll supported electrodes and said cooperating electrode structure, said last named means including a slip ring connection for the roll supported electrodes.

8. A sheet perforating machine comprising, in combination, a pair of parallel side rolls disposed on opposite sides of a centrally located cross-over electrode, said rolls being spaced from the center electrode to receive a traveling web passing through the gaps thus formed between the center electrode and respective ones of the side rolls, each of said side rolls having an electrode thereon comprising a zigzag annular conductor encircling the respective roll and opposed to the center electrode, means for periodically applying a potential between the side roll electrodes to cause an electric impulse to pass from one side roll electrode through the center cross-over electrode to the other side roll electrode, the resulting arc discharges in the gaps separating the side rolls and the center electrode serving to puncture the web at such points, power actuated means for rotating said side rolls in unison and the zigzag side roll electrodes being offset from each other in an angular sense about the axes of their respective rolls.

9. In a sheet perforating machine, the combination of a plurality of pairs of spaced electrodes adapted to receive a traveling web between the successive pairs, at least one electrode in each pair comprising a zigzag annulus of conducting material, power actuated means for rotating the zigzag annular electrodes in unison to bring successive points along the same into proximity with the other electrode in each pair, means for applying potential periodically between the electrodes in each pair to cause arc discharges to pass between the points of closest proximity in each pair and through the web, and said zigzag annular electrodes being offset from each other in an angular sense about their respective axes of rotation.

10. In a sheet perforating machine, the combination of a plurality of pairs of spaced electrodes adapted to receive a traveling web between the successive pairs, at least one electrode in each pair comprising a zigzag annulus of conducting material, power actuated means for rotating the zigzag annular electrodes in unison to bring successive points along the same into proximity with the other electrode in each pair, means for applying potential periodically between the electrodes in each pair to cause arc discharges to pass between the points of closest proximity in each pair and through the web, and said zigzag electrodes being offset with respect to each other not only laterally of the path of web travel but also in an angular sense about their respective axes of rotation.

11. A sheet perforating machine comprising,

in combination, a plurality of sets of revoluble rolls, each of said sets including a center roll and a pair of parallel side rolls disposed on generally diametrically opposite sides of the respective center rolls, the rolls in each set being spaced apart to receive a traveling web passing through the gaps between the center roll in each set and the respective side rolls in the set, each of said center rolls having an electrode thereon in the form of an annular conductor encircling the same, each of said side rolls having an electrode thereon comprising a zigzag annular conductor encircling the respective roll and opposed to the electrode on the associated center roll, means for periodically applying a potential between the side roll electrodes in each set to cause an electric impulse to pass from one side roll electrode in each set through the center roll electrode for such set to the other side roll electrode of the set, the resulting arc discharges in the gaps separating the side rolls and respective center rolls serving to puncture the web at such points, and said side roll electrodes in each set being offset in a direction longitudinal of the rolls with respect to the side roll electrodes in the other sets.

12. A sheet perforating machine comprising, in combination, a plurality of sets of revoluble rolls, each of said sets including a center roll and a pair of parallel side rolls disposed on generally diametrically opposite sides of the respective center rolls, the corresponding rolls in the various sets being arranged in alinement and the rolls in each set being spaced apart to receive a traveling web passing through the gaps thus formed between the center rolls and the associated side rolls, each of said rolls having an electrode thereon, means for applying an electrical potential to the side rolls in each set to cause an electric impulse to pass from one side roll in each set through the associated center roll electrode to the other side roll electrode in the set, and adjusting means for simultaneously shifting all of the side rolls located on one side of their respective center rolls and in alinement with each other toward or away from the center rolls to adjust the lengths of the gaps therebetween.

13. In a machine of the type set forth, the combination of three rolls having peripherally located electrodes thereon, means revolubly supporting said rolls in parallel spaced relation to form air gaps between said electrodes through which a web to be perforated may be led, means for applying an electric potential between the electrodes on two of the rolls to cause series arcs in the gaps between such electrodes and that on the other roll, and means for adjusting the spacing of said rolls to vary the lengths of the air gaps through which the series arcs pass.

14. In a machine of the type set forth, the combination of a revolubly mounted insulating member having a cylindrical exterior surface, an annular electrically conductive metal bar of zigzag form encircling said member and having laterally projecting integral feet resting on the exterior of said member, and means including segments of insulating material overlying said feet for fixing the conductor to said member to form an electrode encircling the same.

15. A machine for perforating a moving web comprising, in combination, a plurality of parallel revoluble rolls arranged to have a moving web threaded between them, a plurality of electrodes distributed along at least one of said rolls

at points spaced longitudinally of the latter, a cooperating electrode structure on another of the rolls lying on the opposite side of the path of web travel from said one roll, a power source for supplying a periodically fluctuating potential, and means operable at will to connect selected ones of said electrodes on said one roll in circuit with said power source to energize a plurality of said electrodes extending a distance along said one roll commensurate with the width of the web.

16. In a sheet material perforating machine, the combination of a plurality of sets of electrodes arranged to receive a sheet between them, means for applying potential periodically to a pair of electrodes in each set to pass an arc discharge between the same and through the sheet to perforate the latter, means for varying individually the power expended in the arcs in selected ones of said sets of electrodes, and means for varying simultaneously the power expended in the arcs in all of said sets of electrodes.

17. In a sheet material perforating machine, the combination of a plurality of sets of electrodes arranged to receive a sheet between them, means for applying potential periodically to a pair of electrodes in each set to pass an arc discharge between the same and through the sheet to perforate the latter, means for varying individually the power expended in the arcs in selected ones of said sets of electrodes to establish a selected differential relation for expenditure of power in the various sets of electrodes, and means operable independently of the setting of said first named control means and without disturbing the differential relation set up between the various sets of electrodes by said first named control means for varying simultaneously the power expended in the arcs in all of said sets of electrodes.

18. In a sheet material perforating machine, the combination of a plurality of sets of electrodes arranged to receive a sheet between them, means for applying potential periodically to a pair of electrodes in each set to pass an arc discharge between the same and through the sheet to perforate the latter, means for varying individually the power expended in the arcs in selected ones of said sets of electrodes, and means for varying the potential supplied to said sets of electrodes to vary simultaneously the size of the punctures produced in the sheet by all of said arcs.

19. In a sheet material perforating machine, the combination of a plurality of sets of electrodes arranged to receive a sheet between them, means for applying an alternating current potential to a pair of electrodes in each set to pass arc discharges between the same and through the sheet to perforate the latter, means for selectively varying the phase relation between the voltage and current supplied to selected ones of said sets of electrodes, and means for varying simultaneously the potential supplied by said power source to all of said sets of electrodes.

20. In a sheet material perforating machine, the combination of a pair of electrodes adapted to receive between them a sheet to be perforated, means for supplying high frequency alternating current, means for connecting the supply means to said electrodes to cause arc discharges to pass between the electrodes and puncture the sheet, said connecting means including two step up transformers having input and output circuits connected in parallel relation to each other re-

spectively to said supply means and to said electrodes, and switching means for alternatively cutting in or out of circuit one of said transformers to vary the power output to the electrodes.

21. In a machine for perforating a traveling web, the combination of a plurality of revoluble rolls arranged for the web to be led between them and about at least one of the rolls in frictional contact with the latter to advance the web upon rotation of said one roll, power actuated means for rotating said rolls in unison, at least some of said rolls having electrodes on the peripheries thereof, means for applying potential to the electrodes to pass arc discharges therebetween and through the web, and means including a safety interlock switch actuated in response to the speed of rotation of said rolls for preventing the application of potential to

said electrodes by the last mentioned means except when the rolls are rotating at a speed in excess of a predetermined minimum.

22. Method of perforating sheet material which consists in imparting movement to the sheet in the direction of one of its area dimensions while causing a multiplicity of electric arcs to simultaneously pierce a series of perforations in the sheet extending in a line across the sheet transversely to the direction of movement of the same whereby perforations are formed over an area of the sheet two dimensionally and controlling the spacing of the perforations in the direction of the movement of the sheet by varying the frequency of the discharges relatively to the speed at which the sheet is moved.

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