April 18, 1967 R. W. BUNDY 3,314,122

APPARATUS FOR FORMING NON-WOVEN WEB STRUCTURES

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FIG. 1

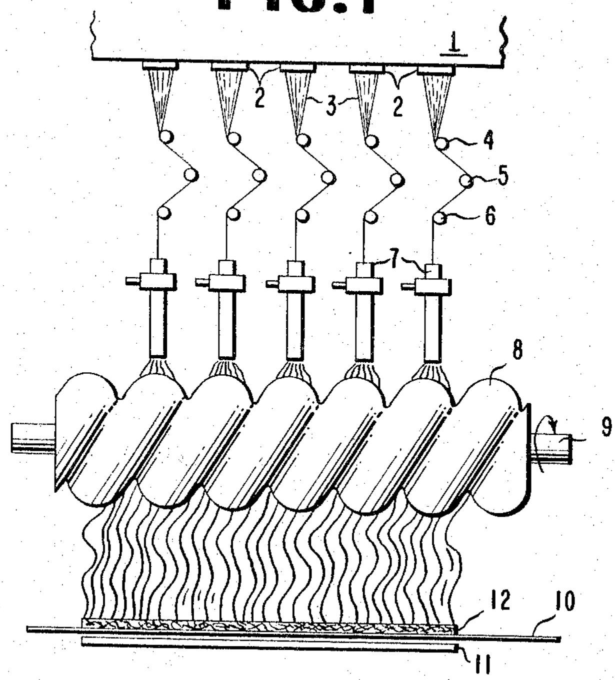


FIG. 1a

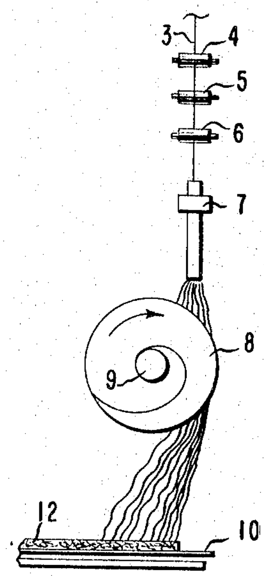


FIG. 2

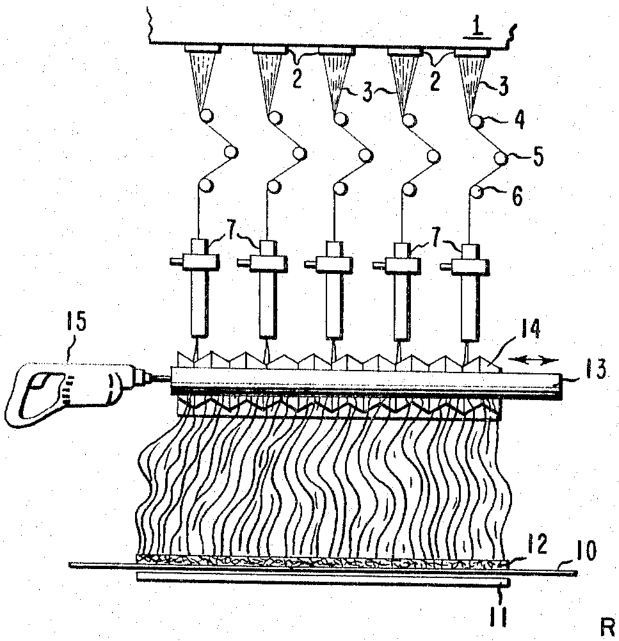
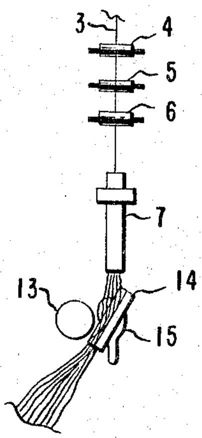


FIG. 3



INVENTOR
ROBERT WENDEL BUNDY

BY Harry C. Braddock
ATTORNEY

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APPARATUS FOR FORMING NON-WOVEN WEB STRUCTURES

Robert Wendel Bundy, Nashville, Tenn., assignor to E. I. du Pont de Nemours and Company, Wilmington, Del., a corporation of Delaware

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3 Claims. (Cl. 28—1)

This case relates to novel improved process and apparatus for handling continuously forwarded fibrous elements, especially those in the form of continuous filaments and preferably continuous filaments of synthetic organic polymeric material, which process and apparatus provide for laying down a plurality of these filaments upon a collecting surface to form a web of uniform thickness and properties comprised of the fibrous elements arranged in random non-parallel array, and still more especially, such webs of substantially wide width.

In the following specification and in the claims, the term "fibrous elements" is intended to include any filamentary material of the types appropriate to the textile art, these including any fiber, filament, thread, yarn, or filamentary structure, regardless of diameter, or composition, although in preferred form the invention relates particularly to such materials in the form of continuous filaments of synthetic organic polymeric fibrous materials.

The term "web" includes mats, batts, non-woven pile fabrics, and other interfelted, interentangled, or commingled fibrous products which may generally be described as coherent sheets of entangled fibers made without the fibers first being spun into yarns and the yarns later interlaced by weaving, knitting, braiding, or other means of yarn manipulation in which the ends of yarns of finite length must be handled and intertwined.

The production of non-woven webs of fibrous elements is an activity of growing commercial importance. These webs not only permit attainment of textile structures having properties equivalent to previously known fabrics of the woven and felted types and at a considerably lower cost, but also permit reaching hitherto unattainable structures having desirable properties and combinations of properties in terms of end use function and aesthetics.

It has been the experience of those skilled in the art that achieving a given desirable non-woven web structure requires controlling a large number of variables. Furthermore, it has been found that the controlling parameters in their desirable ranges more often than not are mutually exclusive, attaining one object in full often seems to require missing another object completely. As a result, the non-woven structures known in the present state of the art are the result of prudent although not always felicitous compromises in balancing one set of objects against another.

The problems encountered in the production of non-woven materials are particularly difficult when forming webs of substantially wide widths. These may be defined as webs exceeding in width 24 inches, and more usually extending to the range of 36 to 54 inches wide or wider. This condition largely results from the fact that the types of devices employed to produce the fibrous elements are of such a nature that a web of wide width requires the combining of a plurality of such devices. Furthermore, even where it is possible to provide a source of fibrous elements capable of producing a sufficient multiplicity of elements to lay down such a wide web, it has been found that with the vastly increased dimensions of the source, or fibrous element supply means, the uniformity of distribution has rapidly declined, defeating the original purpose. Thus, it is more common practice in the art to unite a plurality of separate fibrous element producing devices and by one means or another attempt to combine the elements produced by these in a manner producing the least disturbance of the final product.

The uniformity of the final product is best measured by basis weight which, as is well known, is a measure of weight per unit area and ordinarily expressed in terms of ounces per square yard. This then is a density measurement related to the major dimensions of a sheet-like structure. Variations in basis weight are frequently in excess of ±10%. As a result of this high variation and in combination with peculiarities of the types of fibrous element laydown arrangement hitherto employed, directionality of physical properties in the web machine direction vs. the cross machine direction have hitherto been considerably in excess of a desirable 1:1 ratio (directionality ratio) which would, of course, be isotropic. Indeed, so difficult has it been to avoid anisotropy, that a directional property ratio of 1.5:1 represents a maximum limiting condition of outstanding uniformity in the state of the art heretofore.

Another and obvious measure of uniformity is that of variation in web thickness but this, ordinarily, is reflected in variation in basis weight.

Inasmuch as the preferred form of web produced by the improved process and apparatus of the instant invention is comprised of continuous filaments laid down in random non-parallel arrangement, another significant characterization is that which denotes the degree of randomness, i.e., the absence of fiber aggregates. Structures produced by the instant invention are characterized by the substantial absence of such filament aggregates and this absence may be measured by the bunching coefficient. The bunching coefficient, designated B.C., is defined as the ratio of the number of "fiber spaces" occupied by fibers relative to the total number of "fiber spaces" available. In this measurement the term "fiber space" represents the average space occupied by a fiber, and is calculated by dividing a unit distance of the non-woven sheet structure by the total number of fibers oriented in a single direction in that unit length. The bunching coefficient concept is based on the premise that where the individual fibers disposed in the same direction are uniformly spaced from each other, each "fiber space" will contain one fiber and the bunching coefficient of such a structure will be unity. In a non-woven which contains bunched fibers, some of the "fiber spaces" will contain bundles of fibers while others will be unoccupied and the bunching coefficient of such a structure will be less than one. The greater the filament aggregation, the lower the bunching coefficient. This concept was developed by D. R. Patterson, and is described in his Ph.D. Thesis, "On the Mechanics of Non-woven Fabrics," presented to the Massachusetts Institute of Technology in 1958.

The basic equation is then:

$$\text{B.C.}=\frac{\text{Number of "fiber spaces" occupied by fibers}}{\text{Total number of "fiber spaces" available}} \quad (1)$$

Statistical analysis shows that the optimum value for bunching coefficient is approximately 0.87. The experimental determination is the same.

A process for producing non-woven webs of fibrous elements disposed in random non-parallel arrangement is described in Belgian Patent 608,646 to Kinney. That patent describes a process in which a running multifilament bundle composed of substantially continuous synthetic organic filaments is charged electrostatically in such a manner as to separate each filament from adjacent filaments and these are thereafter collected on a receiver to form a non-woven sheet product of the distinct type described.

The filaments may be charged by a corona discharge maintained in the vicinity, or by triboelectric contact with a suitably selected guide means or by other appropriate electrostatic methods. Ordinarily, such charging is accomplished while the filaments are under sufficient tension so that they do not separate until such tension is relieved, i.e., after they have been impelled toward the receiver whereupon they immediately separate and are then collected. In a preferred embodiment, freshly-formed melt-spun synthetic organic filaments are charged and are simultaneously oriented with an aspirating jet, the action of which also serves to accelerate the charged filaments to the receiver. The output of a number of such jets may be combined to produce a wider web.

This process is, of course, also applicable to filaments other than the synthetic organic type and with minor modifications may be employed with such filaments as glass and the like.

Where the output of a number of spaced parallel jets is combined to produce a wide web, electrostatic and aerodynamic interactions between the cone-like dispersion patterns of the individual jets produce nonuniformities, particularly across the web due to imperfect blending of the boundaries of the patterns.

If one attempts to employ mechanical means alone such as surfaces physically contacting the filaments for additional distributing of the charged filaments as part of the process of combining the plurality of cone-like dispersion patterns issuing from the individual jets so that the initially substantially parallel bundles of filaments, after being transformed to the cone-like dispersion patterns, are intermingled to fall ultimately as edge-blended patterns of filaments of uniform nature, a curtain of filaments; one finds that such surfaces introduce even further nonuniformities of laydown. The introduction of a surface for the purpose of distributing filaments is known in the art; for example, see the patent issued to Frickert, U.S. 2,875,503, and others of its type, in which a continuous strand is projected with a substantially high axial velocity directly against a deflecting surface and the deflecting surface is oscillated to sweep the resultant laydown of filaments across a collecting surface. In the instance where charged bundles of filaments are so manipulated, the product is not uniform but is characterized by an excessive number of ropey areas or, in terms of the precise characterizing criteria discussed, the product has a low bunching coefficient. The cause and effect relationship is one of the utmost subtlety and its uncovery resulted from a great deal of careful study. It was seen that interaction between the filaments and the redistributing surface was at fault. However, recognition of the problem did not bring with it an immediate or obvious solution. It became apparent that the distributing means to be employed must of necessity be different from those known in the art. Inasmuch as both aerodynamic interactions and electrostatic interactions are involved in practicing the art of the Kinney process, hitherto known techniques were to no avail and therefore development of the arrangements of the instant invention occurred.

The instant invention is an improvement over the prior art, and combines mechanical and aerodynamic principles to provide novel improved arrangement for the formation of wide width non-woven sheets with superior uniformity, producing wide webs economically that have bunching coefficients equal to or in excess of 0.70, combined with a maximum basis weight variation of ±10% or less and a directionality ratio of 1.5:1 or better.

Accordingly, it is an object of the present invention to provide an improved and novel process and apparatus for producing non-woven webs characterized by a high degree of uniformity. Further, it is an object to so produce a web by simple and inexpensive, yet reliable and effective, means. Additionally, it is an object to lay down a non-woven web of fibrous elements in randomly distributed non-parallel array, characterized by uniformity of basis weight and uniformity of properties measured both in the direction of machine production and across that direction.

It is a still further object of the instant invention to provide improved process and apparatus for laying down webs of fibrous elements arrayed in random non-parallel arrangement, these webs being characterized by a maximum basis weight variation of no more than about ±10%, and by directionality of physical properties in the web machine direction vs. the cross machine direction of 1.5:1 or better and by a bunching coefficient greater than 0.70.

And it is yet a still further object to provide an arrangement combining the laydown patterns of a plurality of frusto-conical dispersion patterns of fibrous elements bearing electrostatic charges of the same sign and substantial magnitude, continuously forwarded by forces including aerodynamic into a unitary non-woven web of wide width and uniform properties.

These objects are accomplished by an improved web laydown arrangement providing means for blending adjacent streams of electrostatically charged fibrous elements having parallel initial lines of direction into a web with only very minor non-uniformities, the arrangement comprising laying down a non-woven web of random non-parallel fibrous elements from a series of adjacent air jets handling electrostatically charged fibers so that the cones of dispersion of the fibers issuing from the individual jets intermingle producing a unitary curtain of filaments, by subjecting each of the substantially parallel streams of filaments to an intermittent transverse mechanical force in a given direction transverse to the initial line of direction while simultaneously exerting an aerodynamic force in a direction significantly different from said given direction and also transverse to said initial line of direction to separate the filaments from the means providing the intermittent transverse force.

The invention will be more clearly understood and additional objects and advantages will become apparent by reference to the discussion below and to the figures which are given for illustrative purposes and of which:

FIGURE 1 is a diagrammatic front elevational view of a preferred version of apparatus embodying the present invention,

FIGURE 1*a* is a fragmentary side elevational view of the arrangement shown in FIGURE 1,

FIGURE 2 is a diagrammatic front elevational view of a modified version of apparatus employing the present invention, and

FIGURE 3 is a fragmentary side elevational view of the apparatus of FIGURE 2.

Referring to FIGURE 1, a spinning machine **1** is disposed with a plurality of spinnerets **2** so that the issuing filaments **3** will be directly above charging bars **4**, **5**, and **6** and advancing and drawing jets **7**. The spinnerets **2** are arranged spaced in line parallel to the axis of screw deflector **8** which is mounted upon shaft **9** and provided with appropriate support and driving means, not shown. Jets **7** are disposed spaced in line so that their individual vertical axes are directed substantially in a plane generally tangent to the surface of screw deflector **8**. Furthermore, the spacing of jets **7** is substantially the same as the pitch of screw deflector **8**. Screw deflector **8** is spaced and disposed above collecting surface **10** which ordinarily is a continuous belt moving in a plane parallel to shaft **9** in a direction substantially at right angles to the plane containing jets **7** and the other described apparatus. Electrostatic attracting means **11** may be disposed beneath belt **10**.

Operation of the apparatus of FIGURE 1 will now be described. Spinning machine **1** is supplied with fiber-forming material in the manner well known and filaments **3** issue from spinnerets **2**, converging into a substantially ribbon-like form on charging bar **4**, and then passing in succession over charging bars **5** and **6**. As described in the aforementioned Belgian Patent No. 608,646, the triboelectric effect resulting from the separation of filaments **3** from charging bars **4**, **5** and **6**, produces a high level of electrostatic charge upon filaments **3** which are then introduced to jets **7** wherein they are advanced and drawn, jets **7** being supplied by appropriate means (not shown) with an elastic drawing and advancing fluid, ordinarily air. When discharged from jets **7**, filaments **3**, now bearing like electrostatic charges, tend to separate. Impelled in a downward direction by a combination of aerodynamic, electrostatic, and gravitational forces, filaments **3** impinge substantially tangentially against the surface of screw deflector **8** and pass through a partial arc about that surface. Inasmuch as screw deflector **8** is rotating in the direction of the arrow, the screw form of the surface tends to move filaments **3** laterally and moves or diverts the filaments laterally for a distance where the growing lateral restraining force caused by increasing elastic forces within filaments **3** exceeds the lateral moving force and filaments **3** return to their initial undistorted position. This process repeats itself cyclically. Thus, rotating screw deflector **8** generally comprises a means of subjecting the substantially parallel bundles of filaments **3** to an intermittent transverse mechanical force. Since the fluid emerging from jets **7** is directed substantially tangentially toward the curved surface of screw deflector **8**, a "coanda" action also occurs.

This principle, named for its discoverer, Henri Coanda, was first applied to a useful structure as described in U.S. 2,052,869. It describes structure for controlling the discharge into an elastic fluid atmosphere of another elastic fluid moving at high velocity wherein there are means for checking the flow located wholly on one side of the line of discharge. One aspect of the present invention involves utilizing this principle in a novel arrangement to attain a new and useful result.

Essentially, the stream of fluid e.g., air as it issues from jet **7** carrying along with it the filaments **3** flows through an asymmetric nozzle of which one wall, the surface of screw deflector **8**, is real and the other fictitious, being formed by the ambient atmosphere. See FIGURES 1 and 1*a*. The air-stream, because of its velocity, is at a pressure lower than that of the surrounding air which enables the stream to act on the surrounding air and induce it, not only by surface friction, i.e., fluid shear, but also through pressure difference to flow toward the real wall in a manner essentially perpendicular to that wall, causing the filaments to follow around the curvature essentially without touching the surface. As the kinetic energy of the stream is translated into momentum of ambient air, the filaments separate from proximity to the wall or deflector **8** and are borne downward in the induced flow of the large slower moving mass of secondary air under the influence of that flow combined with electrostatic and gravitational forces. Superimposed on this action, of course, is the result of the induced intermittent transverse oscillation caused by the screw form as previously described.

The combination of the intermittent transverse forces and the aerodynamic force upon the filaments is such that the several aggregations of filaments **3**, after emerging from jets **7** have, under action of the aerodynamic and electrostatic forces, tended to become diverted into cone-like dispersions or patterns, overlapping or edge-blended in a manner producing a curtain of filaments which are forwarded to collecting surface or belt **10** under the additional attractive action of electrostatically attractive surface **11**, to form a web **12** of randomly disposed non-parallel filaments having the desired high uniformity.

An alternate disposition of apparatus according to the invention is shown in FIGURES 2 and 3. The apparatus is generally disposed as in FIGURE 1 and only those elements which are altered physically are numbered differently. The intermittent mechanical transverse force creating means of FIGURES 2 and 3 comprises sawtooth or serrated surfaced deflector **14** which is driven in the direction of the arrows in reciprocating motion by any suitable reciprocating mechanism **15** such as the portable saber saw unit indicated in the drawings. Reciprocating deflector **14** is inclined slightly to the direction of vertical motion of the descending filaments **3** and is in close proximity with the lower end of jets **7** so that the filaments are discharged from the jets **7** at a grazing angle with the surface of sawtooth deflector **14**. Disposed in close proximity to the surface of sawtooth deflector **14** is air foil bar **13**. This cylindrical bar, in close proximity to the deflector but not touching it, produces a coanda effect similar to that described previously in the embodiment of FIGURES 1 and 1*a*.

In operation, the deflector is reciprocated rapidly at about 150–160 cycles per minute. The coanda effect resulting from the jet air emerging from jet **7** and swinging around the cylindrical surface of air foil bar **13** causes the filaments to lift out of the valleys of the deflector and float gently to the laydown surface. The reciprocating action of the deflector imparts sufficient lateral wave motion to the individual filaments to cause them to blend into a continuous uniform sheet or transverse curtain of filaments as they fall.

The process and apparatus according to the preceding descriptions employing either embodiment produces a curtain of filaments which lays down into a non-woven web-structure of extremely good uniformity. The filaments spread well and beta ray uniformities within $\pm 10\%$ are readily obtained. Similarly, directionality of physical properties in the web machine direction vs. the cross machine direction of 1.5:1 or better are achieved and the process produces non-woven webs characterized by bunching coefficients of greater than 0.70.

As described in the Kinney patent previously referred to, the products of this process are extremely useful in a great variety of end uses, not only replacing previously woven materials with an economic advantage as in substrates for tent and tarpaulin fabrics but also replacing other non-woven materials such as felts employed in filter cloths, as well as producing a variety of hitherto unobtainable non-woven structures.

The curtain of filaments produced in accordance with the process of this invention is preferably deposited on a foraminous surface, such as a cloth or wire screen. The surface may be in the form of a continuous moving belt. If desired, further control of filament deposition and isotropy of filament arrangement in the web can be obtained by the use of suction devices placed under the surface below the area of deposition in any part or all of that area.

Any departure from the procedure and apparatus described in this disclosure which embodies the principles of this invention is intended to be included within the scope of the claims below.

I claim:

1. In an apparatus for combining a plurality of laterally spaced and aligned parallel moving streams of an elastic fluid having a plurality of electrostatically charged fibrous elements dispersed therein and collecting the electrostatically charged fibrous elements from the combined streams in the form of a unitary coherent non-woven web structure having uniform thickness, density, and directional properties, the improvement comprising a stream combining and controlling mechanism, said mechanism comprising a first and second means, said first means comprising an elongated cylindrical member mounted transversely to and positioned adjacent and spaced a short distance from each of said streams in a given position, and said second means comprising a second elongated member mounted for longitudinal reciprocating motion in a position substantially parallel to said cylindrical member, transverse to and intersecting the path of each of said streams, said second elongated member provided with a longitudinal surface for deflecting each of said streams in

a given direction, said surface provided with a plurality of evenly spaced substantially parallel transversely extending stream deflecting elements for deflecting said streams in a direction substantially perpendicular to said given direction, said second means further comprising a drive means operatively connected to said second member for longitudinal reciprocation thereof in a direction transverse to the lines of movement of said streams, said first means and said deflecting surface cooperating to aerodynamically control and deflect the streams in a direction transverse to the line of stream movement and also in a direction away from the second member towards said cylindrical member.

2. In an apparatus for combining a plurality of laterally spaced and aligned parallel moving streams of an elastic fluid having a plurality of electrostatically charged fibrous elements dispersed therein and collecting the fibrous elements from the combined streams in the form of a unitary coherent non-woven web structure having uniform thickness, density, and directional properties, the improvement comprising a stream combining and controlling mechanism, said mechanism comprising a means for aerodynamically diverting each stream in a given direction transverse to the path of stream movement and for additionally diverting each stream in an oscillating manner along a general lateral line of direction transverse to the path of stream movement and substantially perpendicular to said given direction to form a single combined evenly-blended continuous laterally extending moving stream of fluid and fibrous elements, said mechanism comprising an elongated cylindrical member mounted for rotation about its axis in a position extending transversely to and generally tangent to each of said streams, said member provided with a smoothly curved peripheral surface and further provided with a longitudinally extending helical stream deflecting channel, said mechanism further comprising a drive means operatively connected to said cylindrical member for continuously rotating said member in a direction such that said peripheral surface is generally moving in the same direction as the streams in the area of tangency.

3. In an apparatus for combining a plurality of laterally spaced and aligned parallel moving streams of an elastic fluid having a plurality of electrostatically charged fibrous elements dispersed therein and collecting the fibrous elements from the combined streams in the form of a unitary coherent non-woven web structure having uniform thickness, density, and directional properties, the improvement comprising a stream combining and controlling mechanism, said mechanism comprising a member having a smoothly curved peripheral surface located in a position extending transversely to and generally tangent to each of said streams, said member aerodynamically diverting each stream in a given direction transverse to the path of stream movement and means cooperating with said smoothly curved peripheral surface and concurrently operated therewith for additionally diverting each stream in an oscillating manner along a general lateral line of direction transverse to the path of stream movement and substantially perpendicular to said given direction to form a single combined evenly-blended continuous laterally extending moving stream of fluid and fibrous elements.

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ROBERT R. MACKEY, *Primary Examiner.*