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Daniels

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[54] **PNEUMATIC SPREADING OF FILAMENTS**

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[51] **Int. Cl.** **D01d 11/02**

[58] **Field of Search** ..... 19/65 T, 66 T; 28/1 CF; 226/7, 97; 239/424; 138/37, 38, 40

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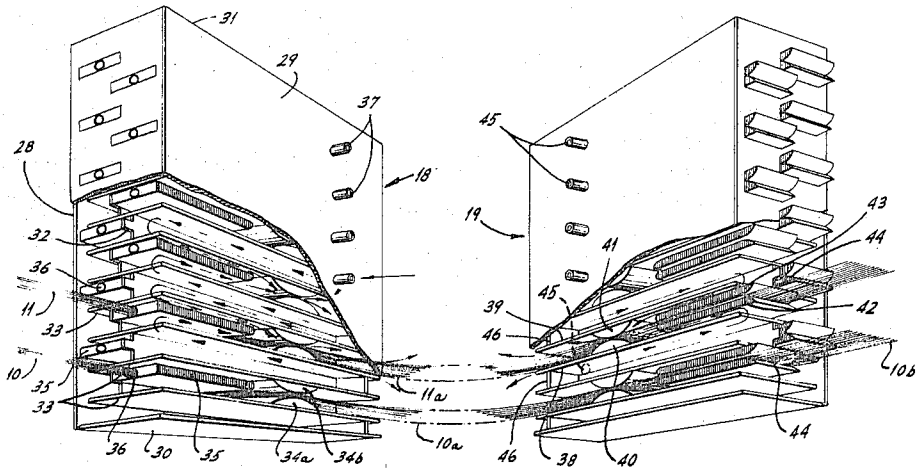
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[57] **ABSTRACT**

Process and apparatus for pneumatically spreading thin graphite or other carbon filaments from a tow bundle to form a sheet or tape in which the filaments are maintained in parallelism. The process includes passing the tow through at least one slot venturi spreader in which the tow is pulled through the spreader in a direction opposite to the direction of primary air flow through the venturi. For certain purposes use is made of first and second spreader units. Each of these units may have at least two side-by-side rows of slot venturies and at least two stacked modules whereby to process a plurality of tow bundles simultaneously.

6 Claims, 6 Drawing Figures



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SHEET 1 OF 2

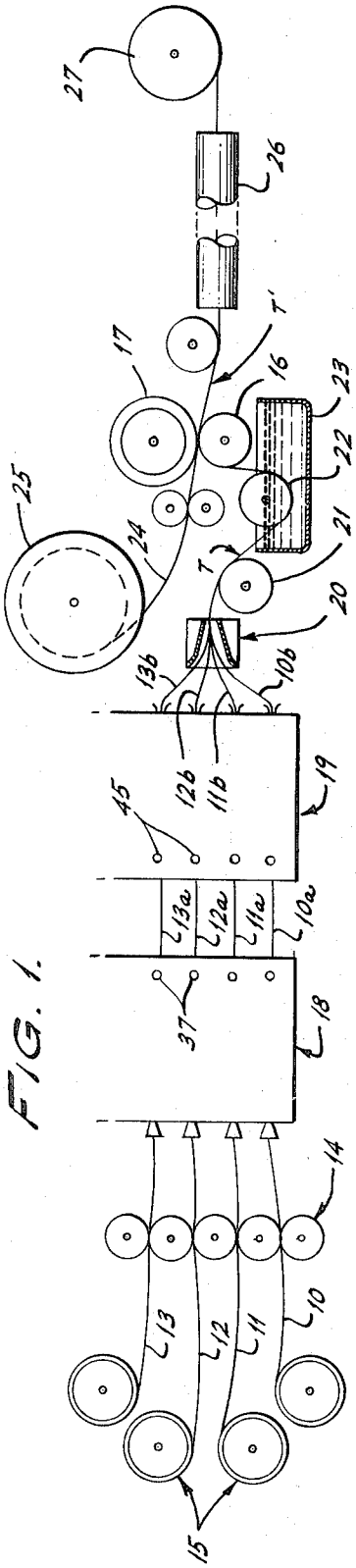


FIG. 1.

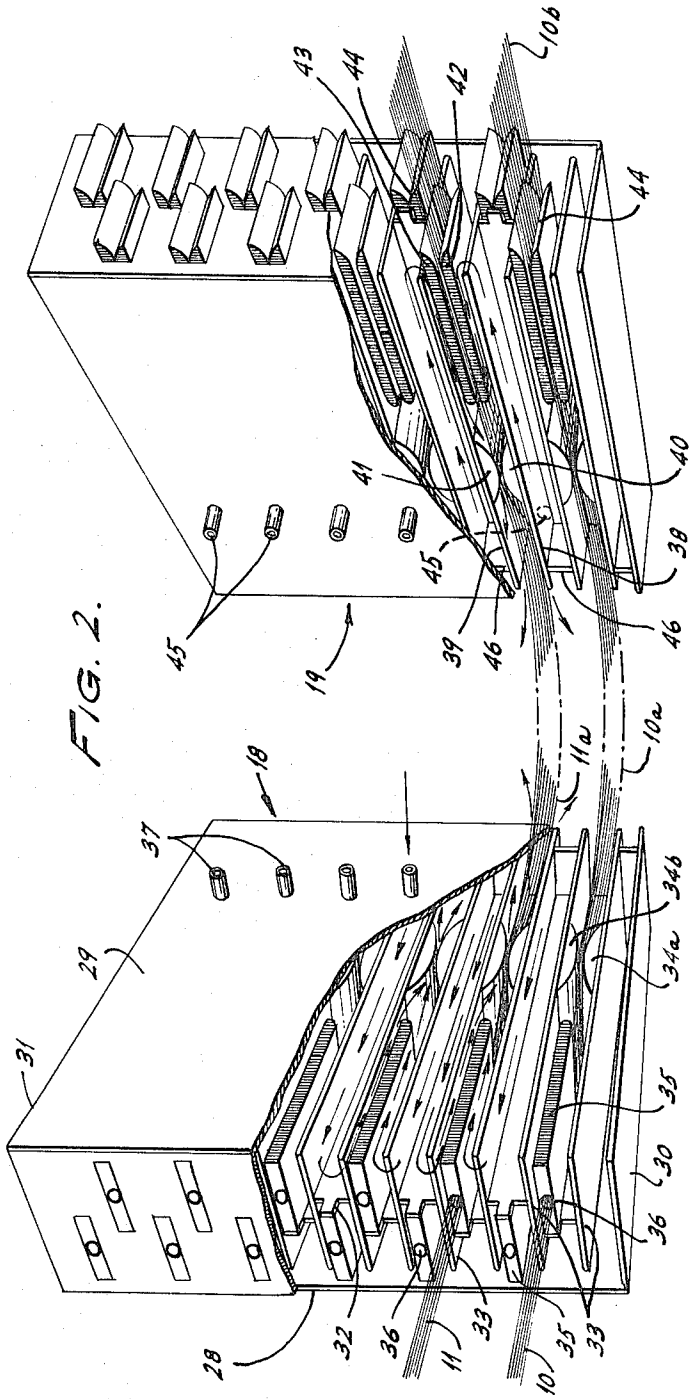


FIG. 2.

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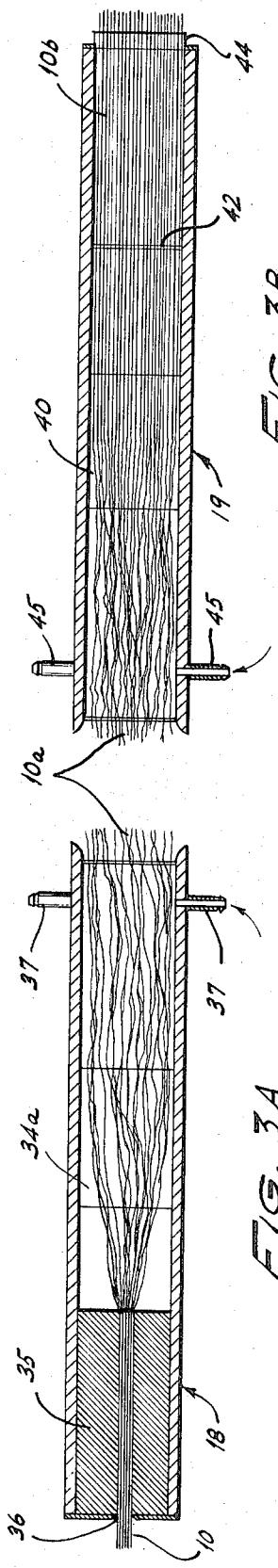


FIG. 3B.

FIG. 3A

DIRECTION OF TOW MOVEMENT

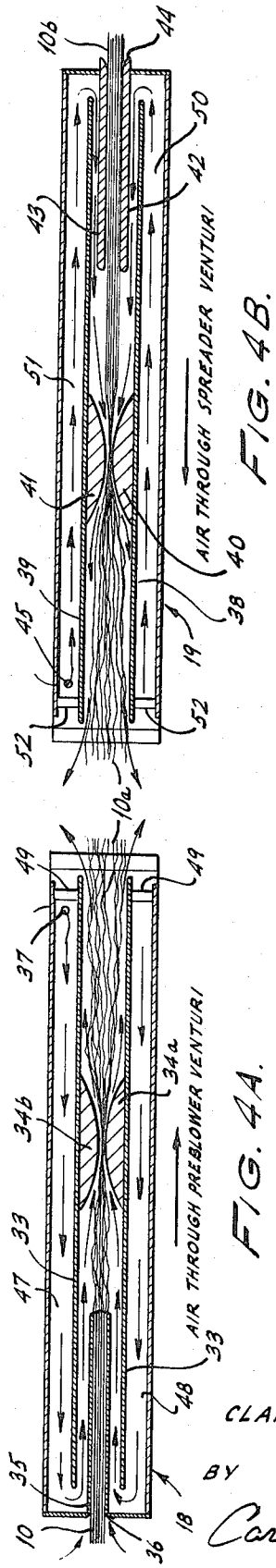


FIG. 4B.

FIG. 4A.

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PNEUMATIC SPREADING OF FILAMENTS

BACKGROUND OF THE INVENTION

It is known in the art to utilize venturi jets to "fluff" or lay open bundles of fibrous strands, commonly known as "tow," such, for example, as filaments of viscose rayon for textile purposes, or crimped cellulose fibers of the kind used in the manufacture of cigarette filters. In such prior art the filaments are separated for a number of purposes such as to desulphurize, wash, bleach or dry them or, in the case of cigarette filters, to increase the filtration efficiency. For such purposes there is no rigid requirement for uniform unidirectional laying-down of the fibers in such a way that the end product is of exact and predetermined thickness. Particularly lacking in the prior art is teaching of utilizing venturi jet means for spreading a tow of graphite, or other carbon filaments, in order to form a heat resistant sheet or tape of extreme thinness and great strength, and which is well adapted for the manufacture of structural components subjected to high temperature and stress, for example missile components, wing panels, or tail assemblies of aircraft and the like.

Graphite filaments, per se, have been developed with high strength and stiffness characteristics which are well adapted for use in laminated, reinforced, plastic structural components. Usually such graphite filaments have been manufactured for use by the textile industry, utilizing pyrolysis of synthetic fibers (rayon, polyacrylonitrile, etc.). Such fibers are available in loosely twisted continuous tow bundles having a large number of individual filaments, for example from 2,000 to 40,000 filaments which may be about 0.00025 or 0.0003 inch in diameter, the tow being packed in bales or on spools. It has been my endeavor to provide for the utilization of such graphite filaments in the manufacture of laminated plastic components. For such use, the filaments must be combined unidirectionally into uniform, ultrathin sheets or tapes, in order to achieve maximum strength with minimum weight. Previous attempts to combine the filaments in the manner needed to make such components have not been notably successful, principally because of difficulties encountered in collimating the individual filaments of the tow without formation of gaps and angular overlaps.

SUMMARY OF THE INVENTION

With the foregoing in mind it is the primary object of the present invention to provide for production of very thin sheets or tapes of truly parallel graphite filaments, which tapes may be several inches wide, of the order of a thousandth of an inch in thickness, and almost completely free of gaps or regions of angular overlap.

More specifically, my invention makes it possible to combine graphite filaments into uniform thin sheets formed of unidirectional filaments, and which sheets may, for various applications, have considerable variation in thickness. By way of example, thicknesses from about 0.001 to about 0.008 inch are very useful. In accordance with an aspect of my invention it is possible to form sheets from a batch of tapes of predetermined length corresponding to the desired sheet length, or if desired to form tape-like sheets by a continuous process in which a plurality of extended tapes are formed simultaneously.

In summary, this invention is featured by the fact that it is possible to make graphite sheets an order of magnitude thinner than has previously been possible, with unusual uniformity of filament dispersion, and with minimum damage — such as results from breaking, fuzzing, or knotting — during the manufacturing process.

In achievement of these objectives, I utilize spreader means comprising a self-contained unit, preferably although not necessarily including a plurality of modular, slot-type venturi jets, and from which unit the tow is pulled in a direction opposed to the direction of primary air flow through said jets. Preferably, in the continuous process, I utilize separate preblower and final spreader units and, in at least the final unit, the tow is pulled in a direction as mentioned just above.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 is a diagrammatic view of a machine constructed in accordance with the principles of this invention and adapted to form sheet-like tapes by a continuous process, in which a plurality of tapes are formed simultaneously and then combined into a single sheet or tape and stored for use;

FIG. 2 is an enlarged, perspective view, with housing portions broken away to facilitate illustration, showing modular preblower and final spreader units of the kind preferably employed in the machine of FIG. 1;

FIGS. 3A and 3B are sectional views of a single venturi module included, respectively, in the preblower and the final spreader illustrated in FIG. 2, FIG. 3A being a section looking at a single module of the preblower in the direction of the thickness of the tape being fabricated, and 3B being a section looking at a single module of the final spreader in the direction of the thickness of the tape; and,

FIGS. 4A and 4B are sectional views corresponding, respectively, to FIGS. 3A and 3B, FIG. 4A showing the preblower module as it would appear if viewed in the direction of the width of the tape, and FIG. 4B showing the spreader as it would appear if viewed in the direction of the width of the tape.

It should be understood that FIGS. 3A through 4B illustrate venturi modules which gave very good results in practice and that the actual modules were about three times the scale of these figures. In the interest of clarity in illustration the thickness of the tapes is shown greatly exaggerated in FIGS. 4A and 4B.

DETAILED DESCRIPTION OF THE INVENTION

With initial reference to FIG. 1 several graphite tow bundles, in this case four, are shown at **10, 11, 12** and **13** being drawn by suitable friction rollers, for example rollers of soft rubber, from separate supply spools. The rollers, designated generally by the reference numeral **14,** may be driven by any suitable means (not shown), and the supply spools appear at **15.** The tapes, in response to the pull of roller means **16** and **17** (right-hand portion FIG. 1), at least one of which is surfaced with friction material, are drawn through the apparatus shown in the mid-portion of the figure. In a preferred continuous process this apparatus comprises a first slot-type venturi spreader **18,** which serves as a preblower for separating and effecting partial alignment of the individual filaments of tow passed therethrough, and a second or final slot-type venturi spreader **19** which is specially designed to collimate the individual filaments

of the spread tow to form them into a smooth and regular tape of predetermined width and thickness, and the filaments of which are substantially devoid of gaps or angular overlaps. As is explained below, the second slot venturi spreader is featured by the provision of air flow therethrough in a direction opposite to the direction of movement of tow through the venturi of said second spreader. As will be explained later ith reference to FIG. **2**, both the preblower **18** and the spreader **19** comprise slot venturi devices. Preferably a plurality of such devices are arranged in modular array, in order to process the tape bundles **10** to **13** simultaneously. In the region between the units **18** and **19**, where the tow bundles have been partially fluffed or spread, said bundles are designated by the numerals **10***a*, **11***a*, **12***a* and **13***a* and are shown as feeding into the ingress end of the final spreader **19**. In the latter unit the spread tow is formed into very thin sheets of truly parallel graphite filaments in which form they leave the final spreader, as shown in FIG. **1** at **10***b*–**13***b*, as thin ribbons the width of the exit openings. In this particular case four tapes have been formed simultaneously and they are combined into a single tape of predetermined width and thickness, by passing them through a simple device having a combining passage, for example the device shown at **20**, after which the resultant single tape T passes over an idler roller **21** and is fed to a roller **22** which is submerged in a bath of suitable impregnating material contained within a tank **23**. Impregnating materials of a variety of types can be used, depending upon the specifications of the particular sheet or tape being fabricated. Usually the material will be of plastic resin, epoxy, phenolic, or polymide type, and the resin may be applied in a dip tank immersion process, as shown, or by other processes, as desired. The combined tape, after passing through the treatment tank **23**, still subject to the pull of friction rollers **16** and **17**, is joined to a carrier tape **24** which may, for example, comprise parchment paper drawn from a storage roll **25**. The final tape is shown at T', after it has been combined with the paper carrier which is applied merely to facilitate handling and packaging. The impregnated final product is then passed through suitable drying means, for example the drying tube shown at **26**, through which warm air is caused to flow. The excess solvent is removed from the resin by the drying operation. It will be understood that multiple or elongated drying tubes may be utilized if additional drying time is required. The impregnated tape mounted on the carrier paper exits the drying tube and is wound on a reel **27** for storage and shipment.

It should be understood that while a machine has been described for practicing a continuous process in which a plurality of tapes of extended length are formed simultaneously, the invention is primarily concerned with the nature of the venturi units **18** and **19** and with the manner in which they are used. In one aspect of my invention, it is contemplated that use may be made of only a single spreader through which the tape and the primary air move in counterflow arrangement. Generally, in such practice of the invention, repeated passes of tow would be made through the venturi device. In accordance with this aspect of the invention a plurality of tapes of predetermined length may be formed separately, after which they may be positioned in side-by-side relation to form a sheet of any desired width and then treated with plastic resin. This may readily be accomplished by pouring the resin on the sheet and spreading the same in any convenient manner, as for example by applying a roller to the sheet to spread the impregnating material uniformly thereover. Preferably, however, I utilize both a preblower unit **18** and a spreader unit **19** in the practice of a continuous process of the kind described with reference to FIG. **1**.

FIG. **2** illustrates the preblower and spreader of the invention in more detail, the view showing two passes of tow traversing the preblower and spreader units, which units have been angled somewhat in the figure to facilitate illustration. While the invention may be embodied in, and described with reference to a single venturi module, as has been done in FIGS. 3A to 4B, units of the kind contemplated by the invention preferably comprise the FIG. **2** arrangement of a plurality of venturi devices stacked in modular array. While the processing of four tapes in the apparatus shown diagrammatically in FIG. **1** indicates that each of the devices **18** and **19** includes four modules, it should be borne in mind that the number of modules is a matter of convenience. In one embodiment of my invention I have found it convenient to provide twelve venturi modules in each of the preblower and spreader units, this being accomplished by combining two adjacent rows of venturi units each of which is six units high.

Considering first the preblower unit **18** of FIG. **2**, it will be seen that this device is of rectangular box-like shape having side walls **28** and **29**, bottom and top walls **30** and **31** and intermediate partitions **32** which extend vertically, as the unit is viewed in FIG. **2**, to subdivide the housing into two stacks of six units. It should be understood that the housing would include a left end wall extending throughout the height thereof. This wall has been broken away in the lower portion of FIG. **2** — as has the right end wall of the spreader unit **19** — to show the details of interior construction. A plurality of parallel plates **33** extend through the length and width of the housing, and each pair of confronting plates is provided with partially cylindrical segments **35***a* and **34***b* which bridge the space between the side walls **28 29** of the housing, and preferably extend through the intermediate partition structure **32**. Each confronting pair of segments defines the throat of a slot type venturi through which the tow is moved during the spreading operations. Each subcompartment, or module, is provided with a thicker plate or block **35** which is provided, at **36**, with an aperture extending throughout the length thereof and through which inletted tow (see **10** and **11**) is fed toward the slot venturi where it is fluffed and separated into individual filaments. The tow, after fluffing or spreading in the venturi throat passes out of the housing of unit **18**, as is represented at **10***a* and **11***a* in FIG. **2**. Each subcompartment is provided with an air inlet conduit, and several such conduits are designated with the numeral **37**. As will be explained below, with particular reference to FIGS. 3A through 4B, air under pressure is inletted to the space above and below the feed block **35** and passes in laminar flow across the length of the block and toward the throat of the slot venturi. In the preblower **18** this air flow is in the direction of movement of the tow.

Now with particular reference to the right hand portion of FIG. **2**, that is the portion which illustrates the final spreader **19**, it will be seen that this device, into which the tow **10***a* and **11***a* is fed from the preblower

18, is similar in external configuration and general interior layout to the preblower 18. When considered specifically, however, it will be seen that the spreader is significantly different in several respects. The tow enters the spreader through the open space between adjoining plates. A pair of such plates are shown in this figure at 38 and 39, and it will be seen that these are of the same size and general configuration as the plates employed in the device 18.

After entry between the confronting surfaces of plates 38 and 39 the partially spread tow (see tow 11*a*) moves to and through the slot venturi passage defined by confronting segments 40 and 41 carried by plates 38 and 39. The tow then passes between a pair of closely spaced plates 42 and 43, the right hand end of which plates form an exit opening 44.

In particular accordance with this invention, air, which is inletted under pressure through passages 45, is constrained by a dam or wall 46 to flow toward the right hand end of spreader 19, thence around the free edge of the confronting plates (see for example plate 39) after which it flows between the surface of said plate and the confronting surface of the plate 43 which defines an exit. Air moving in this way then flows through the slot venturi defined by segments 40 and 41 and exits from the left hand end of the housing of unit 19. This pattern of air flow, as well as that which prevails in the device 18, has been indicated by arrows in the drawing.

It will be noted that in each spreader device each module has a feed opening at one end and a diverging or expansion chamber toward the other end. Also, in both devices, there is a slot venturi and upper and lower sheets of air are introduced for flow therethrough. It is important to note that in the spreader 19 the partially spread tow enters the expansion chamber, or converging part of the venturi against the flow of air through the venturi device. The tow is further fluffed as it approaches the restriction of the venturi nozzle and, after it passes through the nozzle, fluffing and collimating continues as it encounters sheets of air flowing in direction opposite to the direction of tow movement. The tow is then virtually perfectly collimated into a thin sheet of fiber as it is pulled through the final slit opening 44, for example by the drive rollers shown at 16 and 17 in FIG. 1. It is this movement of tow, in countercurrent to the direction of air flow through the spreader, which particularly characterizes practice of this invention.

In order further to facilitate understanding of the two spreaders, that is, the preblower 18 and the final spreader 19, reference will now be had to the single modules illustrated, on a larger scale, in FIGS. 3A through 4B. As will now be understood, a plurality of modules similar to those shown in these figures comprise the stacked arrays shown in FIG. 2.

FIG. 3A illustrates the preblower spreader unit in section looking in the direction of the thickness of the tape being fabricated, that is, FIG. 3A shows the width of the fluffing tape developing, for example, from tow bundle 10. FIG. 4A is taken at right angles to FIG. 3A and shows the apparatus looking in the direction of the width of the developing tape 10*a*, that is FIG. 4A shows the thickness of the tape (exaggerated). Referring more particularly to FIG. 4A, it will be seen that air under pressure is entering a pair of plenum spaces 47 and 48 which lie outwardly of and are partially defined by confronting plates 33. Air, after entering at 37, is constrained by the walls 49 to flow rearwardly in the module, that is toward the left end as viewed in FIG. 4A, where it turns reversely and flows between the plates 33 and the block 35 through which the tow is being introduced. The venturi-defining segments 34*a* and 34*b* also appear in this drawing, and the direction of tow movement has been labelled on the drawing. With regard to FIG. 4A it will be seen that a laminar flow of air occurs between the two plates 33 and the confronting surfaces of block 35 from whence the air passes through the throat of the slot venturi in the direction of tow movement. The flowing air "picks up" the tow bundle and converges with it into the slot venturi throat. As the air diverges, in passing out of the venturi throat, it causes the filament bundle to expand with the air (see central part of FIG. 3A), and the fluffed bundle 10*a* exits at the right end of device 18 and enters the left end of the spreader device 19. In the transitional phase between the two devices, as appears to best advantage by comparing FIGS. 3A and 3B, it is seen that the tow while considerably fluffed or spread, is not yet collimated. Collimation of the tow occurs in the spreader 19, largely in the venturi throat, as will now be described in greater detail. However, it should again be pointed out that while use of the spreader, and the particular construction thereof, is characteristic of the broader aspect of my invention, my preferred continuous tape-producing process utilizes both the spreader and the preblower.

In the spreader (FIGS. 3B and 4B) the partially cylindrical segments which define the slot-like throat of the venturi have again been identified, at 40 and 41, and the air is inletted under pressure through passages two of which appear at 45. As was described with reference to FIG. 2, the confronting plates within the module bear numerals 38 and 39 and their adjacent faces carry the segments 40 and 41. The outboard sides of these plates define a pair of plenum chambers designated 50 and 51. The air is confined by the dams shown at 52 and constrained to flow in each of the plenums 50 and 51 across the outboard faces of the plates 38 and 39, whence the air returns in laminar flow across the exterior surfaces of plates 42 and 43, the interior surfaces of which form the exit opening 44 for the collimated tow 10*b*. This air flows backwardly through the venturi throat, in countercurrent to the direction of tow movement, and exits at the left end of the spreader 19 as that device appears in FIG. 4B.

In summary regarding the operation of the final spreader, the fluffed and partially aligned tow 10*a* enters the unit 19 opposing the air flow direction in the venturi chamber. Since the tow is flowing in the opposite direction, it must be pulled through the spreading gun by the roller 27. As it passes through the venturi restriction, it is recombined vertically, but not laterally, resulting in a very thin ribbon the width of the exit orifice. While shown of exaggerated thickness in the drawing, the actual thickness of the collimated tape would be about 0.001 inch, a dimension which is governed by choice of the gap at the venturi throat, the width of the exit orifice, and, to some extent, by the spacing between plates 42 and 43.

As the collimated tow enters the slot exit channel, defined by plates 42 and 43, it leaves the primary air stream, although there occurs a slight air flow through and out of the channel along with the tow. This "back"

air flow, in the same direction as the tow ribbon, is a very minor flow as compared with the primary flow back through the venturi, but further aids in collimating the filaments.

I have found that much improved results, from the standpoint of the tape smoothness, collimation and thinness of a graphite tape are achieved when the primary air passes through the spreader in a direction opposite to the direction of movement of the filaments therethrough. In the spreading of a tow consisting of approximately 10,000 graphite filaments of a diameter in the region of 0.0003 inch, to make a tape 3 inches in width, and 0.001 inch in thickness, the following structural dimensions and air pressures have yielded very good results. In this apparatus, the tape should be withdrawn from the spreader at a rate from about 25 to about 60 feet per minute.

In a system which proved to be very satisfactory certain dimensions, as well as the input air pressures, are applicable to both the preblower spreader and the final spreader modules. In modules of both types the length of the modules was approximately 16 inches, the tow exit orifices were 3 inches wide (FIGS. 3A and 3B), although widths as small as ½ inch are useable depending on the desired tape width. Air pressures between 20 and 100 psi, measured at ¼ inch diameter air inlet orifices, were found satisfactory. The air pressure is adjusted by the operator until proper spreading is achieved, which depends primarily upon the degree of initial tangle in the tow, the desired spread width, and to some degree upon the humidity. The main interior plates, which extend substantially throughout, the length of modules of each type, were about 15½ inches in length typically ⅛ inch thick, and were spaced from the top and bottom module walls to provide plenum chambers ½ inch high, as those chambers are viewed in FIGS. 4A and 4B. The spacing between confronting surfaces of these plates was ⅞ inch, and in each type of module the slot of the venturi throat was a ⅛ inch gap, presented between partially cylindrical segments having a radius of about 3½ inches and which segments make contact with the plates through a distance equal to 3¼ inches.

In the preblower module (FIGS. 3A and 4A) the most restricted section of the slot-like throat was spaced 9⅝ inches from the end of the module at which the tow is inletted, and the inlet block was 5/16 inch thick, leaving a 9/32 inch airspace between each side of said block and the confronting surface of the main plate which cooperates to form the plenum. The tow passage through the inlet block was 0.230 inch in diameter, and the block extended into the module 5 inches toward the venturi. The main interior plates were spaced ½ inch from the end wall of the module, at the tow inlet end.

In the final spreader module (FIGS. 3B and 4B) the restricted venturi throat was spaced 9⅝ inches from the tow outlet end of the module. The plates which form the exit opening of the final spreader were ¼ inch in thickness, spaced apart ⅛ inch, and they extended from the outlet end 5 inches toward the venturi. The gap for air flow between each of these latter plates, and the confronting plates which cooperate with the module wall structure to define the plenum, was equal to ⅛ inch. The main interior plates were spaced ½ inch from the end wall of the module at the tow outlet end.

I claim:

1. In apparatus for spreading a tow of filamentary material to form a thin tape of collimated continuous filaments, means defining a slot venturi through which the tow is passed, passage means through which air is inletted for flow through said venturi, and co-extensive, spaced plates disposed to opposite sides of said slot venturi, said plates further extending upstream and downstream of the latter and being so cooperably disposed with respect to said passage means and sad slot venturi as to direct the inletted air over said tow as it is caused to pass between said plates and through said slot venturi.

2. In apparatus for spreading a tow of filamentary graphite material to form a thin tape of substantially parallel continuous filaments, a slot venturi spreader through which the tow is passed, means for pulling the tow through the venturi of said spreader during the tow spreading operation, passage means for inletting air to said spreader, and means for establishing a laminar flow of air and for causing such air to flow through the venturi in a direction opposite the movement of tow therethrough, said last means comprising a pair of plates spaced one from the other and each disposed to an opposite side of said slot venturi, said plates being coextensive with one another along the path of movement of said tow, to regions upstream and downstream of the slot venturi, said plates further being so cooperably disposed with said passage means for inletted air as to direct inletted air across oppositely facing surfaces of said plates, thence across confronting surfaces of said plates and into the slot venturi.

3. Apparatus in accordance with claim 1, and further characterized by the inclusion of an elongated housing having openings at either and thereof in provision for passage of tow therethrough, said pair of plates being spaced from one another in said housing to accommodate passage of the tow therebetween, and spaced from the housing walls to define air passages, confronting faces of said spaced plates having means defining the slot venturi.

4. Tow spreading apparatus for use in the simultaneous fabrication of a plurality of thin tapes of parallel continuous filaments comprising:

confronting wall structure defining a generally rectangular housing having a plurality of spaced, generally parallel, plates extending therethrough and defining a plurality of elongated, superposed, tow-treating modules each of which has means extending across its width and defining in said module a slot type venturi;

structure defining openings in two opposed portions of said housing to accommodate movement of a tow bundle into each said module, passage of the bundle through the venturi of each module, and exit of the spread tow from the module; and

means for inletting air to each module and for promoting laminar flow of such air through the venturi of the module.

5. In a process for spreading a tow of filamentary material to form a thin tape of substantially parallel continuous filaments, the steps of: spreading and effecting partial alignment of the individual filaments of the tow by passing the tow to a first venturi type spreader while causing air to flow through the venturi of said first spreader while causing air to flow through the venturi of said first spreader in the direction of movement of tow therethrough; and collimating the individual fila-

ments of the spread tow to form them into a smooth and regular tape the filaments of which are substantially devoid of gaps or overlaps, by passing the spread tow through a second venturi type spreader while causing air to flow through the venturi of said second spreader in a direction opposite to the movement of tow through said second spreader.

6. For use in apparatus for spreading a tow of graphite filaments caused to move along the line of length of such filaments to form a thin tape of substantially parallel continuous filaments: a first slot type venturi spreader for fluffing and effecting partial alignment of the individual filaments of tow as it is moved therethrough; means providing for flow of air to the venturi of said first spreader in the direction of movement of the tow therethrough; means disposed to receive the fluffed tow as it is moved from said first spreader and for collimating its individual filaments to form them into a smooth and regular tape the filaments of which are substantially devoid of gaps or angular overlaps, said last means comprising a second slot venturi spreader through which the tow is moved; and means providing for flow of air through the venturi of said second spreader in a direction opposite to the movement of tow through said second spreader.

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