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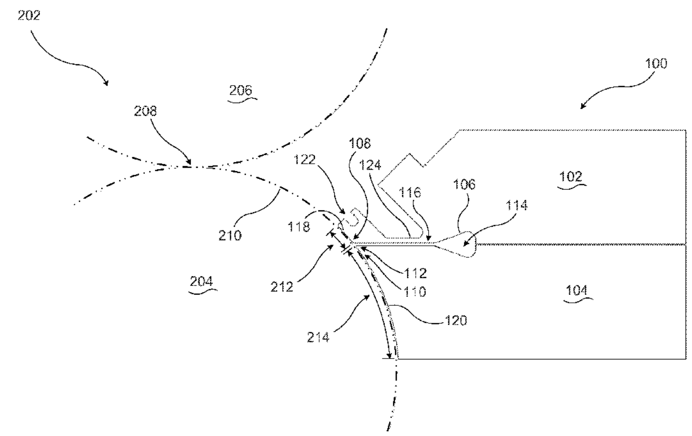

FIG. 2

(57) Abstract: An extrusion device includes a sculpted extrusion die (100) comprising a pair of mating die lips (108, 110) having sculpted surfaces (118,120) and defining a die exit (112) for an extrudate. The contour of the sculpted surfaces (118, 120) is substantially similar to the contour of a juxtaposed surface (210) configured for receiving the extrudate from the die exit (112) of the sculpted extrusion die (210). The sculpted extrusion die preferably comprises a die lip adjustment mechanism (122) for adjusting a thickness of the extrudate exiting the die exit (112) and the thickness of the extrudate received on the juxtaposed surface (210). The air gap between the die exit (112) of the sculpted extrusion die and the juxtaposed surface (210) preferably is substantially eliminated by adjusting the distance between the sculpted surfaces (118,120) and the juxtaposed surface (210). A method of adjusting a thickness of a substantially continuous sheet of extrudate formed using an embodiment of the sculpted extrusion die (210) is also provided.

WO 2013/013033 A1

SCULPTED EXTRUSION DIE AND METHOD OF ADJUSTING THE THICKNESS OF AN EXTRUDED SHEET

TECHNICAL FIELD

[0001] The present invention relates to an extrusion device and more particularly to an extrusion die for extruding thermoplastic material.

BACKGROUND

[0002] An extrusion die is used to extrude molten thermoplastic material into a relatively thin film or sheet. Conventional extrusion dies have a die cavity with the general shape of a coat hanger. These extrusion dies have been generally referred to as coat hanger dies. Typical coat hanger dies include an inlet, an inlet manifold, a generally triangular shaped preland channel, a final land channel, and a die exit or gap. In some embodiments, a back edge of the preland channel includes linear edges that form a taper converging towards a die entrance. In alternate embodiments, the taper converges away from (or diverges towards) the die entrance. The preland channel provides a resistance to flow that varies over the width of the die to uniformly spread the thermoplastic material across the entire die.

[0003] The rheological characteristics of the molten thermoplastic materials and the pressure these thermoplastic materials exert on the die bodies sometimes result in clamshelling, or non-uniform deflection. Clamshelling results in uneven flow of the thermoplastic material through the die exit. These or other nonuniform patterns are undesirable for the production of flat sheet materials. The nonuniformities can be corrected by adjusting the height of the die exit. Most extrusion dies are equipped with some form of die lip adjustment mechanism to adjust the height of the die exit. If a particular die is used to form a large quantity of a single layer of material, and the extrusion process is not subject to any interruptions, then the adjustment of the height of the die exit is an acceptable method of removing or at least addressing these nonuniformities. However, since the performance of an extrusion die is influenced by a number of factors including flow rate, temperature, the nature of the thermoplastic materials, and the like, the use of a lip adjustment mechanism to remove or minimize these nonuniformities may not always be completely effective where a die is to be used for short runs to produce different products. For each production change, the die lips may be adjusted to the new conditions. This results in a loss of production time and a waste of material as off-specification product is produced during start up.

[0004] When extruding thermoplastics using a conventional die, the molten polymer exits the die and travels through an air gap prior to contacting the surface of a roller receiving the extrudate. As is well known in the art, as the extrudate flows across the air gap and is pulled away from the die by the rotating roller, stress can be induced in the web. Additionally, variations in the web's gauge (or thickness) can occur, particularly at the edges, which become thicker as the web narrows. Little can be done to control the flow of the extrudate in the air gap. Furthermore, die lines are formed if the extrudate drags along one of the die lips. These and other nonuniformities in the extrudate can be exacerbated by the air gap between the die exit and the surface of the roller receiving the extrudate. Such defects are unacceptable in most extruded products, but are particularly troublesome in products that require good optical properties. Accordingly, die builders are asked to minimize the air gap.

[0005] In the past, die builders have typically attempted to decrease the air gap by angling the die such that the die exit is positioned as close to the roller as possible. However, this approach weakens the die and mechanical limitations become challenging. Other proposals to address these problems have included the design of different manifold configurations. In one such design, the back line of the preland portion is structured to be a uniform distance from the die exit. While this particular design may minimize the above problems, there are concerns relative to maintaining the flow through the die without creating areas of substantially higher residence time, which over time could lead to degradation of the thermoplastic material.

[0006] Accordingly, there exists a need for an extrusion device with essentially no air gap for extruding low stress sheet and film with acceptable optical properties, minimal die lines, and minimal edge bead formation, without compromising the mechanical integrity of the die.

SUMMARY

[0007] In accordance with an embodiment of the invention there is provided a sculpted extrusion die juxtaposed with a roller of an extrusion device. The sculpted extrusion die comprises a pair of mating die lips each having a sculpted surface and bounding a die exit for extrudate. The contour of the sculpted surfaces, in an embodiment of the invention, is substantially similar to the contour of a juxtaposed surface configured for receiving extrudate from the die exit of the sculpted extrusion die. Accordingly, the radius of curvature of the sculpted surfaces is substantially equal to the radius of the roller. Preferably, the sculpted extrusion die further comprises a die lip adjustment mechanism for adjusting a thickness of the extrudate exiting the die exit and the thickness of the extrudate received on the roller. As such, the air gap between the roller and the extrusion die is eliminated or minimized by adjusting the distance between the sculpted surfaces and the juxtaposed surface. In an embodiment of the invention, the die exit is devoid of any sharp corners or edges and/or catch

surfaces that would interfere with the smoothness of the exiting extrudate. In some embodiments, the sculpted extrusion die is juxtaposed with a casting roller. In other embodiments, the sculpted extrusion die is juxtaposed with one of a pair of cooperating rollers defining a nip of a calender.

[0008] An extrusion device, in accordance with some embodiments of the invention, includes a roller and an extrusion die, wherein the die includes a manifold and a die exit, and wherein the die exit is in fluid communication with the manifold. The die includes first and second die lips between which the die exit is located. The die lips have sculpted surfaces shaped so as to have a contour substantially matching a perimetrical shape of the roller, such that the sculpted surfaces are configured to be operatively positioned alongside the roller so as to provide substantially no air gap between the die and the roller.

[0009] An extrusion die, in accordance with certain embodiments of the invention, includes a manifold and a die exit, wherein the die exit is in fluid communication with the manifold. The die includes first and second die lips between which the die exit is located. The first die lip includes a sculpted surface shaped so as to have a concave contour with a radius of curvature, and the second die lip includes a sculpted surface shaped so as to have a concave contour with the radius of curvature.

[0010] A method of adjusting a thickness of a substantially continuous sheet of extrudate formed using an embodiment of the sculpted extrusion die of the invention includes extruding a polymer from an extrusion die to form a sheet, wherein the extrusion die includes a die exit defined by a pair of mating die lips. The die lips include sculpted surfaces having a contour substantially similar to that of a circumferential surface of a rotating roller operatively juxtaposed with the sculpted surfaces. Next, the sheet is passed through a curved passageway between one of the sculpted surfaces and the circumferential surface of the rotating roller. At least one lip of the pair of die lips is a moveable flexible lip. Accordingly, the method includes altering a thickness of the sheet by moving the flexible lip. In some embodiments, altering the thickness of the sheet by moving the flexible lip involves altering a height of the die exit in that the movement of the flexible lip is directed towards or away from the other of the pair of die lips. In other embodiments, altering the thickness of the sheet by moving the flexible lip also involves altering a height of the curved passageway. Altering the height of the curved passageway involves the sculpted surface of the flexible lip moving towards or away from the circumferential surface of the rotating roller. In yet other embodiments, altering the thickness of the sheet by moving the flexible lip involves simultaneously altering a height of the die exit as a result of the flexible lip moving towards or away from the other of the pair of die lips; and altering a height of the curved passageway as a result of the flexible lip moving towards or away from the circumferential surface of the rotating roller. The method further includes altering the thickness of the sheet by moving the circumferential surface of the roller towards or away from the extrusion die. The roller is one of a pair of rollers of a calendar. The calender defines a nip, and the method includes passing the sheet through the nip. In accordance with the method, the polymer moves along a path of extrudate travel that extends from a manifold of the die along a narrow channel and to the die exit, at which point the path of extrudate travel turns and extends along the curved passageway. In some embodiments, the turn in the path of extrudate travel is a turn of greater than 30 degrees. In other embodiments, the turn in the path of extrudate travel is between a straight extent of the path of extrudate travel and a subsequent extent that follows the curved passageway. After extending along the curved passageway, which is defined between one of the sculpted surfaces and the circumferential surface of the rotating roller, the sheet moves on the roller and away from the die. In some embodiments of the invention, the extrusion die is configured, and is juxtaposed with the rotating roller, such that there is substantially no air gap between the die exit and the rotating roller. In other embodiments of the invention, the extrusion die is configured, and is juxtaposed with the rotating roller, such that the extrudate emanating from the die exit does not travel across an air gap prior to contacting the rotating roller. In yet other embodiments of the invention, the extrusion die is configured, and is juxtaposed with the rotating roller, such that the sheet is substantially devoid of die lines. In certain embodiments of the invention, the extrusion die is configured, and is juxtaposed with the rotating roller, such that the sheet is substantially devoid of edge bead

[0011] In accordance with another embodiment of the invention, there is provided an extrusion device comprising an extrusion die juxtaposed with a roller, wherein the extrusion die includes a manifold in fluid communication with a die exit defined by a pair of die lips. In an embodiment of the invention, the die lips include sculpted surfaces that are contoured into shapes that substantially match a perimetrical shape of the roller. The sculpted surfaces of the extrusion die are configured for placement alongside the roller such that during operation there is substantially no air gap between the sculpted surfaces of the extrusion die and the roller.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a schematic of a sculpted extrusion die in accordance with an embodiment of the invention;

[0013] FIG. 2 illustrates the sculpted extrusion die of FIG. 1 juxtaposed with a circumferential surface of a roller of a calender;

[0014] FIG. 3 illustrates the sculpted extrusion die of FIG. 1 juxtaposed with a circumferential surface of a casting roller; and

[0015] FIG. 4 shows extrudate flow in an alternate embodiment of a sculpted extrusion die juxtaposed with a circumferential surface of a roller of a calender.

DETAILED DESCRIPTION

[0016] While selected embodiments of the instant invention are disclosed, alternate embodiments will be apparent to those skilled in the art given the present disclosure as a guide. The following detailed description describes only illustrative embodiments of the invention with reference to the accompanying drawings wherein like elements are designated by like numerals. It should be clearly understood that there is no intent, implied or otherwise, to limit the invention in any form or manner to the preferred embodiments described herein. As such, all alternatives are considered as falling within the spirit, scope and intent of the instant invention.

[0017] Sculpted extrusion die 100, in accordance with an embodiment of the invention, is illustrated in FIGS. 1-3 wherein like elements are indicated by like numerals. The illustrated extrusion die 100 comprises upper and lower die body portions 102 and 104, respectively, which together form a pair of mating die body portions defining manifold 106. Upper and lower die body portions 102 and 104, respectively, include (e.g., define) upper and lower die lips 108 and 110, which together form a pair of mating die lips defining die exit 112. Here, a single integral body defines a first of the die body portions and a first of the die's sculpted surfaces, while a separate second integral body defines a second of the die body portions and a second of the die's sculpted surfaces. As an alternative, a single die body could define both die body portions 102 and 104 of the die, including respective upper and lower die lips 108 and 110.

[0018] Manifold 106, having cavity 114, is illustrated as being a standard coat hanger type die manifold as is well known in the art. Alternatively, other manifold designs that are also well known in the art could be used including, but not limited to, "T" manifolds, fishtail manifolds and variations of coat hanger type die manifold 106. In some applications, the die manifold includes one or more restrictor bars.

[0019] As illustrated, flow channel or passageway 116 extends from manifold 106 to die exit 112, thus providing fluid communication between cavity 114 and die exit 112. As such, flow channel or passageway 116 defines, at least in part, a path of extrudate travel extending between manifold 106 (or cavity 114) and die exit 112. In the illustrated embodiment, the path of extrudate travel extends along a straight line from manifold 106 (or cavity 114) to die exit 112. Additionally or alternatively, flow passage 116 extending from manifold 106 to die exit 112 can comprise an elongated channel section wherein the confronting interior channel walls (defined respectively by the mated upper and lower die body portions 102 and 104, respectively) are parallel or substantially parallel to each other over an elongated distance (optionally along the entire elongated channel section), as shown in the figures. This, however, is not strictly required. The extrudate supplied to manifold 106 flows along flow channel or passageway 116 and exits extrusion die 100 through die exit 112. In some embodiments, as is well known in the art, flow channel or passageway 116 includes a secondary manifold, as described below with reference to FIG. 4, between manifold 106 and die exit 112. In such cases, the section of flow channel 116 between manifold 106 and the secondary manifold may be referred to as the preland section, and the section of flow channel 116 between the secondary manifold and die exit 112 may be referred to as the land section. As is also well known in the art, the exact structure of manifold 106, cavity 114, the land and preland sections, as illustrated in FIG. 4, and any secondary manifold (not shown in FIGS. 1-3) can be varied and may conform to any of a number of different conventional designs for a coat hanger type extrusion die.

[0020] In FIGS. 1-4, manifold 106 is not adjacent to an extruder screw. For example, there is no extruder screw projecting into the manifold. Here, the illustrated die body does not house or surround (e.g., is devoid of) an extruder screw.

[0021] In the embodiment illustrated, manifold 106 has a triangular shape in cross section. (The cross section here is taken in a plane perpendicular to the roller's axis of rotation.) In such cross section, the noted triangle includes two leading angled sides and a base side, with an apex of the triangle being defined between the two angled leading sides.

Here, neither of the leading sides are perpendicular to the base side. Rather, the two leading sides each converge toward the other. The illustrated flow passageway 116 emanates from an apex of the triangle, which apex points towards the die exit. Here again, these details are by no means required in all embodiments.

[0022] In accordance with an embodiment of the invention, sculpted extrusion die 100 differs from many prior art extrusion dies in that the upper and lower die lips 108 and 110, respectively, comprise sculpted surfaces 118 and 120. Each of the illustrated sculpted surfaces 118, 120 has a curved (e.g., concave) or arcuate configuration. In the embodiments illustrated in FIGS. 1-3, die body portion 102, upper die lip 108 and sculpted surface 118 are all defined by a first single integral body such that upper die lip (or flexible lip) 108 is integral to die body portion 102; and die body portion 104, lower die lip 110 and sculpted surface 120 are all defined by a second single integral body. In an alternate embodiment wherein a single die body defines both die body portions 102 and 104, both upper and lower die lips 108 and 110 and their respective sculpted surfaces 118 and 120 are defined by the same single (or "integral") die body such that upper die lip (or flexible lip) 108 is integral to the die.

[0023] As described below with reference to FIGS. 2 and 3, the contours of sculpted surfaces 118 and 120 are substantially similar to (e.g., match) the contour of an operatively juxtaposed surface configured for receiving the extrudate exiting die exit 112. In an embodiment of the invention, the juxtaposed surface is that of a roller. In another embodiment of the invention, the juxtaposed surface is a circumferential surface. In yet another embodiment, the juxtaposed surface is a perimetrical surface. In an alternate embodiment of the invention, the juxtaposed surface is that of a polygon. In another embodiment of the invention, the juxtaposed surface is that of a cylinder. All alternative embodiments of a juxtaposed surface configured for receiving the extrudate exiting die exit 112 are considered as falling within the spirit, scope and intent of the instant invention. In the interest of brevity, simplicity and understanding, all such alternate embodiments of juxtaposed surfaces configured for receiving the extrudate exiting die exit 112 are hereinafter referred to as perimetrical surfaces and/or extents in the description and the appended claims.

[0024] In certain embodiments, the extrusion die is (e.g., lips 102, 104 thereof are) nested against (e.g., sculpted to) only a single roller. For example, as in FIGS. 2-4, the extrusion die can advantageously have arcuate surfaces 118, 120 that are only juxtaposed with (e.g., carried against) a single roller 204, 302. In embodiments like those shown in FIGS. 2 and 4, the system includes two rollers 204, 206, but the die is only sculpted to one of the rollers 204. In such embodiments, the die lip closet to the other roller 206 is spaced substantially away from that roller 206.

[0025] FIG. 2 illustrates sculpted extrusion die 100 as used with calender 202 in accordance with an embodiment of the invention. Calender 202, as is well known in the art, comprises a pair of cooperating rollers 204 and 206 defining nip 208 therebetween. As shown, the contours (or curvatures) of sculpted surfaces 118 and 120 of upper and lower die lips 108 and 110, respectively, are substantially similar to (e.g., they may match) the contour of circumferential (or perimetrical) surface 210 of operatively juxtaposed roller 204 onto which the extrudate exiting die exit 112 is received. As such, sculpted surfaces 118 and 120 of upper and lower die lips 108 and 110, respectively, are operatively juxtaposed with circumferential surface 210 of at least one roller 204 of calender 202 such that a first circumferential (or perimetrical) extent 212 of roller 204 is nested against sculpted surface 118 of upper die lip (or flexible lip) 108, and second circumferential (or perimetrical) extent 214 of roller 204 is nested against sculpted surface 120 of lower die lip 110. The resulting arrangement can optionally be such that the distance (or gap) between the confronting die and roller surfaces is substantially constant at all locations between roller 204 and sculpted surface 118.

[0026] In an embodiment of the invention, second circumferential (or perimetrical) extent 214 is greater than first circumferential (or perimetrical) extent 212. This, however, is not required. In some embodiments, the arithmetic ratio of second circumferential (or perimetrical) extent 214 to first circumferential (or perimetrical) extent 212 is greater than or equal to two, greater than or equal to three, or greater than or equal to four. This is not required either.

[0027] FIG. 3 illustrates sculpted extrusion die 100 as used with a single roller 302 (e.g., a casting roller) in accordance with an embodiment of the invention. As shown, the contours (or curvatures) of sculpted surfaces 118 and 120 are substantially similar to (e.g., match) the contour of circumferential (or perimetrical) surface 304 of operatively juxtaposed roller 302 onto which the extrudate exiting die exit 112 is received. As such, first circumferential (or perimetrical) extent 306 of roller 302 is nested against sculpted surface 118 of upper die lip (or flexible lip) 108, and second circumferential (or perimetrical) extent 308 of roller 302 is nested against sculpted surface 120 of lower die lip 110. In an embodiment of the invention, second circumferential (or perimetrical) extent 308 is greater than first circumferential (or perimetrical) extent 306. In some embodiments, the arithmetic ratio of second circumferential (or perimetrical) extent 308 to first circumferential (or perimetrical) extent 306 is greater than or equal to two, greater than or equal to three, or greater than or equal to four. Again, this is not required.

[0028] As illustrated in FIGS. 2 and 3, sculpted surfaces 118 and 120 preferably are characterized by a curve having a radius that is substantially equal to (or equal to) a radius of roller 204 or 302. In other words, the radius of curvature of sculpted surfaces 118 and 120 is substantially equal to (or equal to) a radius of roller 204 or 302. While this will commonly be preferred, it is not strictly required in all embodiments.

[0029] Preferably, one of the sculpted die lips 108, 110 is equipped with lip adjustment mechanism 432. When provided, lip adjustment mechanism 432 preferably is adapted to move (e.g., bend) the flexible die lip 108 so as to change the thickness of the web produced by the system.

[0030] In FIGS. 1-3, the illustrated upper die lip 108 includes a die lip adjustment channel 122 configured for accepting any of a number of conventional die lip adjustment mechanisms, as are well known in the art. One such embodiment is described below with reference to FIG. 4. The illustrated upper die lip (or flexible lip) 108 is connected to first (or upper) die body portion 102 by a narrow neck 124 serving as a thin flex hinge. The flex hinge provides a certain degree of flexibility, thus making the upper die lip 108 a flexible lip, such that in moving upper die lip (or flexible lip) 108 with the die lip adjustment mechanism, narrow neck 124 flexes (e.g., bends) to facilitate such movement of upper die lip (or flexible lip) 108. Preferably, the neck 124 is a thin metal web, such that the lip can move relative to the die's body portion by virtue of the web flexing (e.g., bending). The configuration of die lip108, however, can be varied to accommodate many different die lip adjustment mechanisms. Thus, the related details shown in the attached drawings (e.g., the flex hinge, die lip adjustment channel 122, etc.) are not limiting to the invention. As illustrated, lower die lip 110 is a fixed lip (defined by the single integral body forming die body portion 104 itself), rather than being a flexible lip. In an alternate embodiment (not shown), lower die lip 110 is a flexible lip and upper die lip 108 is a fixed lip. In another embodiment (also not shown), both upper and lower die lips 108 and 110 are flexible lips.

[0031] In an embodiment of the invention, the die lip adjustment mechanism is used for moving the flexible lip (i.e., upper die lip 108, which is rendered flexible by the flex hinge) so as to change (or alter) the distance between sculpted surface 118 of upper die lip (or flexible lip) 108 and the juxtaposed circumferential (or perimetrical) surface 210 or 304, respectively, of operatively juxtaposed roller 204 or 302. Such adjustment effectuates (or affects) the thickness of the extrudate after it exits die exit 112. In another embodiment of the invention, the die lip adjustment mechanism is used for moving the flexible lip, i.e., upper die lip 108, so as to change (or alter) the distance between the pair of upper and lower die lips 108 and 110 without movement of the lower die lip (or fixed lip) 110. Such adjustment changes (or alters) the height of die exit 112 and accordingly effectuates (or affects) the thickness of the extrudate as it exits die exit 112. In fact, the die lip adjustment mechanism may be used for adjusting both the thickness of the extrudate at die exit 112 and the thickness of the extrudate on circumferential (or perimetrical) surface 210 or 304. Accordingly, in yet another embodiment of the invention, upper die lip (or flexible lip) 108 is movable so as to simultaneously change (or alter) both the distance between upper die lip (or flexible lip) 108 and lower die lip (or fixed lip) 110, and the distance between sculpted surface 118 of upper die lip (or flexible lip) 108 and circumferential (or perimetrical) surface 210 or 304, respectively, of operatively juxtaposed roller 204 or 302. Further, the thickness of the extrudate on circumferential (or perimetrical) surface 210 or 304, respectively, can also be adjusted by moving roller 204 or 302 towards or away from sculpted surface 118.

[0032] The air gap between sculpted extrusion die 100 and operatively juxtaposed roller 204 or 302 preferably is substantially eliminated (or eliminated) by adjusting the distance between sculpted surfaces 118 and 120 and circumferential (or perimetrical) surface 210 or 304. In an embodiment of the invention, roller 204 or 302 is operatively juxtaposed with sculpted extrusion die 100, i.e., with sculpted surfaces 118 and 120 of sculpted extrusion die 100, such that there is substantially no air gap between sculpted extrusion die 100 and roller 204 or 302. In such cases, the extrudate emanating through die exit 112 of sculpted extrusion die 100 preferably does not travel across an air gap prior to contacting roller 204 or 302.

[0033] In an embodiment of the invention, die exit 112 and/or flow channel or passageway 116 is devoid of any sharp corners, edges, catch surfaces, etc. that would interfere with the smoothness of the extrudate, disrupt extrudate flow, or both as the extrudate flows along the path of extrudate travel and exits sculpted extrusion die 100. Preferably, this is the case along the entire path of extrudate travel extending from manifold 106 and along the narrow flow channel or passageway 116 to die exit 112, as well as through the turn at die exit 112, and extending to the end of the curved passageway between sculpted surface 118 of upper die lip (or flexible lip) 108 and the circumferential surface 210 or 304 of adjacent roller

204 or 302. Accordingly, the confluence of sculpted surface 118 and an upstream surface of flow channel or passageway 116 extending from manifold 106 preferably is contoured and not abrupt. Stated alternatively, a surface, e.g., that of flow channel or passageway 116, extending from manifold 106 through die exit 112 and along sculpted surface 118 of upper die lip (or flexible lip) 108 preferably is a geometrically continuous surface devoid of any corners, edges, catch surfaces, etc. For example, where the extrudate turns a corner at the die exit 112 (and/or adjacent to where the extrudate first contacts the rollers 204, 302), there preferably is no corner projecting into the flow passageway.

[0034] In the embodiments illustrated, upon reaching die exit 112 (i.e., upon reaching roller 204 or 302), the path of extrudate travel takes a directional turn at the beginning of the passageway between sculpted surface 118 of upper die lip (or flexible lip) 108 and circumferential (or perimetrical) surface 210 or 304 of operatively juxtaposed roller 204 or 302. Here, the turn in the path of extrudate travel at die exit 112 is between a straight extent of the path of extrudate travel defined at least in part by flow channel or passageway 116 and a subsequent extent that follows a curve defined by sculpted surface 118 of upper die lip (or flexible lip) 108 and circumferential (or perimetrical) surface 210 or 304 of operatively juxtaposed roller 204 or 302. In the arrangements shown, this turn in the path of extrudate travel away from lower die lip (or fixed lip) 110 is characterized by the direction of extrudate travel turning by an acute angle, preferably being greater than 5°, greater than 10°, greater than 15°, greater than 20° or greater than 30°, while being less than 75° or less than 60°.

[0035] In an embodiment of the invention, die exit 112 is of uniform height 126 (e.g., has a constant height) across the width of sculpted extrusion die 100. In such cases, the extrudate exiting die exit 112 will be of uniform or substantially uniform thickness (e.g., over the entire width, or substantially the entire width, of the extruded sheet). In other cases, die exit 112 is of non-uniform height 126 across the width of the die 100. In such cases, the extrudate exiting die exit 112 will be of non-uniform thickness. The desired thickness of the extrudate (e.g., locally or across the whole die width) preferably is maintained by using a die adjustment mechanism, as described herein.

[0036] As illustrated in FIGS. 2 and 3, the path of extrudate travel extends from manifold 106 along flow channel or passageway 116 to die exit 112, and thereafter along the curved passageway between sculpted surface 118 and circumferential (or perimetrical) surface 210 or 304. The illustrated curved passageway between sculpted surface 118 and circumferential (or perimetrical) surface 210 or 304 spans the first circumferential (or perimetrical) extent 212 or 306 of roller 204 or 302.

[0037] As is perhaps best seen in FIGS. 2 and 3, when the flexible lip 108 of the illustrated die is in a default operative position (i.e., when the lip 108 is nor being flexed), the gap distance between the juxtaposed roller surface and the sculpted flexible lip 108 is substantially uniform (e.g., constant) over the entire length of the curved passageway. In such embodiments, the extrudate pressure may remain substantially constant in moving further along the curved passageway. Thus, the curved passageway may be devoid of a pressure chamber where the extrudate experiences substantial pressure increases as it moves further along the curved passageway.

[0038] In use, extrudate from manifold 106 travels along flow channel or passageway 116 towards die exit 112 whereat the extrudate exits sculpted extrusion die 100 and is directed onto (e.g., immediately contacts) circumferential (or perimetrical) surface 210 or 304, respectively, of operatively juxtaposed rotating roller 204 or 302. In an embodiment of the invention, roller 204 or 302 rotates in a counter-clockwise direction (as seen in the attached figures) such that the extrudate exiting die exit 112 passes through the curved passageway between operatively juxtaposed sculpted surface 118 and circumferential (or perimetrical) surface 210 or 304 of adjacent roller 204 or 302. While passing through this curved passageway, one of the extrudate's two major faces contacts the roller, while the extrudate's other major face simultaneously contacts sculpted surface 118. Rotating roller 204 or 302 facilitates movement of the extrudate deposited thereon, and the extrudate, in the form of a continuous sheet of polymer, passes through the curved passageway between sculpted surface 118 and circumferential (or perimetrical) surface 210 or 304. The sheet of extrudate next travels along with roller 204 such that one of the extrudate's major faces is carried against the roller, while its other face is exposed until reaching and passing through nip 208 between rollers 204 and 206 of calender 202. As can be seen, nip 208 is defined by calendar 202 of which rollers 204 and 206 are a part. (Nip 208, of course, is not present when only a single roller 302 is used.) As described above and below with reference to FIG. 4, the thickness of the sheet of extrudate exiting the curved passageway between sculpted surface 118 and circumferential (or perimetrical) surface 210 or 304 can be adjusted (e.g., changed) by using a die adjustment mechanism to change (or alter) height 126 of die exit 112 and/or to change (or alter) the distance between sculpted surface 118 and circumferential (or perimetrical) surface 210 or 304.

[0039] In the illustrated embodiments, a single integral body (e.g., formed of metal) defines the die's upper body portion 102, the flexible upper lip 108, and the narrow neck 124. Here, the body 102 that defines the whole sculpted surface of the die's flexible lip 108 also defines one of the confronting surfaces that extend from the manifold 106 to the die exit 112. Thus, the body 102 that defines the entire arcuate surface 118 of the flexible lip 108 is not a separate component attached to the upper die body, but rather is integral to the die body.

[0040] In accordance with an embodiment of the invention, FIG. 4 illustrates extrudate flow path 434 through sculpted extrusion die 200 wherein sculpted surfaces 118 and 120 of upper and lower die lips 108 and 110, respectively, are operatively juxtaposed with circumferential (or perimetrical) surface 210 of roller 204 of calender 202. As can be seen, the embodiment of sculpted extrusion die 200 shown in FIG. 4 is substantially similar to the embodiment of sculpted extrusion die 100 shown in FIGS. 1-3. Accordingly, like elements are indicated by like numerals and the following description in reference to FIG. 4 is primarily directed to features and elements of sculpted extrusion die 200 that are different from those previously described in reference to FIGS. 1-3 for sculpted extrusion die 100.

[0041] Sculpted extrusion die 200 comprises upper and lower die body portions 102 and 404, which together form a pair of mating die body portions defining manifold 106 and cavity 114. As illustrated, flow channel or passageway 416 extends from manifold 106 to a die exit 112, providing fluid communication between cavity 114 and die exit 112. As such, flow channel or passageway 416 defines, at least in part, path of extrudate travel 434 extending between manifold 106 (or cavity 114) and die exit 112. The extrudate, represented by the dark regions, supplied to manifold 106 flows along flow channel 416 and exits extrusion die 200 through die exit 112. In the embodiment of sculpted extrusion die 200 shown in FIG. 4, flow channel 416 includes secondary manifold 406 between manifold 106 and die exit 112. As such, section 428 of flow channel 416 between manifold 106 and secondary manifold 406 may be a preland section 428, and section 430 of flow channel 416 between secondary manifold 406 and die exit 112 may be a land section 430. As is well known in the art, the exact structures of manifold 106, cavity 114, secondary manifold 406, flow channel or passageway 416, and land and preland sections 430 and 428, respectively, can be varied and may conform to any of a number of different conventional designs for a coat hanger type extrusion die.

[0042] In FIG. 4, sculpted extrusion die 200 is shown comprising die adjustment mechanism 432 which, as previously described, can be used for adjusting both the thickness of the extrudate flowing through or exiting die exit 112 and the thickness of the extrudate between sculpted surface 118 of upper die lip (or flexible lip) 108 and circumferential (or perimetrical) surface 210 of operatively juxtaposed roller 204. Many alternative die adjustment mechanisms are well known in the art and can be used in the present invention. Thus, the details of the die adjustment mechanism 432 shown in FIG. 4 are merely exemplary and therefore should not be considered as being limiting in any respect.

[0043] Generally, die adjustment mechanism 432 engages die lip adjustment channel 122 and is operated to change (or alter) height 126 of die exit 112 and/or to change (or alter) the distance between sculpted surface 118 of upper die lip (or flexible lip) 108 and circumferential (or perimetrical) surface 210 of roller 204. As shown, upper die lip 108 comprises a relatively narrow neck 124 serving as a thin flex hinge. The flex hinge provides a certain degree of flexibility, thus making the upper die lip 108 a flexible lip, such that in moving upper die lip (or flexible lip) 108 with die lip adjustment mechanism 432, narrow neck 124 flexes to facilitate such movement of upper die lip 108. Since many different die lip adjustment mechanisms can be used, the related details shown in the attached drawings (e.g., the flex hinge, die lip adjustment channel 122, etc.) are not limiting to the invention. In the embodiment illustrated, lower die lip 110 is a fixed lip, rather than being a flexible lip.. Here, the die lip 110 that a given point on the circumference of the juxtaposed roller 204 passes under before passing under the other die lip 108 is the stationary die lip, while the other die lip 108 is the flexible die lip. This is also the case in the embodiments of FIGS. 1-3.

[0044] As illustrated in FIG. 4, path of extrudate travel 434 extends from manifold 106 (or cavity 114) along flow channel or passageway 416 to die exit 112 and thereafter along the curved passageway between sculpted surface 118 and circumferential surface (or perimetrical) 210. At die exit 112, the extrudate is directed (e.g., immediately) onto circumferential (or perimetrical) surface 210 of rotating roller 204. Rotating roller 204 facilitates movement of the extrudate along extrudate flow path 434 and the extrudate, in the form of a continuous sheet of polymer, passes through the curved passageway between sculpted surface 118 and circumferential (or perimetrical) surface 210. The sheet of extrudate continues traveling with roller 204 along extrudate flow path 434 until reaching and passing through nip 208 between rollers 204 and 206 of calender 202. (This, of course, is not the case when only a single roller 302 is used.)

[0045] The embodiments disclosed herein generally pertain to extrusion dies for extruding sheets of polymer, such as thermoplastic film, and foam sheets with substantially reduced or minimal irregularities in the extruded product. However, the invention also extends to other extrusion applications wherein a sculpted die is juxtaposed with a roller taught by the present disclosure. For instance, embodiments of extrusion dies, such as those described herein for example, can be polymer extrusion devices provided in combination with at least one polymer, wherein at least some of the polymer is located in the manifold of the die. Reference is made to FIG. 4. In certain embodiments, the present system produces an extruded polymer web of a thickness that is substantially uniform (e.g., constant) along the width of the web. Thus, the extruded web can have opposed upper and lower surfaces that are parallel or substantially parallel to each other all along the width of the web.

[0046] The basic components of an extrusion die are well known in the present art. Additionally, the basic methods of manufacturing extrusion dies are well known in the art, and therefore need not be described here. Furthermore, the basic procedures for operating extrusion dies, components and procedures for controlling the flow of extrudates, die lip adjustment mechanisms, apparatus and methods for scraping the one or more lips of the extrusion dies, etc., are well known in the art, and are therefore not described here. By way of example, such information is included in the following co-owned U.S. Patents and U.S. Patent Application Publications, all of which are incorporated herein by reference in their entirety: 7,056,112, 5,770,240, 6,663,375 6,206,680, 6,352,424, 6,109,592, 6,367,776, 6,682,333, 7,074,030, 2007/0273068, and 2007/0045904.

[0047] The processes for manufacturing a conventional extrusion die are well known to the person of ordinary skill in the art. In view thereof, a few extra steps would be necessary for manufacturing the sculpted extrusion die in accordance with the various embodiments of the instant invention. For instance, curved surfaces 118 and 120 are sculpted (or machined) using a standard computer numerical control (CNC) milling machine. Additionally, sculpted surfaces 118 and 120 preferably are polished to a mirror-like finish using techniques and methods well known in the art, including manual polishing, and combination of surface grinding and manual polishing.

[0048] Embodiments of extrusion dies, such as those described herein having sculpted surfaces and juxtaposed with a rotating roller, preferably are configured such that the extrudate emanating from the die exit (and the web produced by the present system) is devoid of, or is substantially devoid of, die lines, edge beads, etc. Accordingly, preferred methods of using such embodiments of extrusion dies will produce an extrudate devoid of, or substantially devoid of, die lines, edge beads, etc. Thus, the present extrusion device preferably is configured to produce (and the present method can produce) extrudate having substantially no die lines (or no die lines). Additionally, the present device and method can be configured to produce extrudate having substantially no edge bead (or no edge bead).

[0049] Various modifications and additions may be made to the exemplary embodiments described hereinabove without departing from the scope, intent and spirit of the instant invention. For example, while the disclosed embodiments refer to particular features, the scope of the instant invention is considered to also include embodiments having various combinations of features different from and/or in addition to those described hereinabove. Accordingly, the present invention embraces all such alternatives, modifications, and variations as within the scope, intent and spirit of the appended claims, including all equivalents thereof.

CLAIMS

We claim:

1. An extrusion device, comprising
a roller; and
an extrusion die, said die comprising
a pair of mating die body portions defining a manifold; and
a pair of mating die lips defining a die exit in fluid communication with said manifold, said die lips including sculpted surfaces wherein a contour of said sculpted surfaces is substantially similar to that of a circumferential surface of said roller, said roller being operatively juxtaposed with said sculpted surfaces.

2. The device of claim 1, wherein the contour of said sculpted surfaces is characterized by a curve having a radius that is at least substantially equal to a radius of said roller.

3. The device of claim 1, wherein both of said die lips and said sculpted surfaces are defined by the die itself.

4. The device of claim 3, wherein a first single integral body defines a first of said die body portions and a first of said sculpted surfaces, and a second single integral body defines a second of said die body portions and a second of said sculpted surfaces.

5. The device of claim 1, wherein at least one lip of said pair of die lips is a flexible lip adapted to be moved so as to effectuate a thickness of an extrudate produced by said die.

6. The device of claim 5, wherein said flexible lip is integral to the die.

7. The device of claim 5, wherein said flexible lip is connected to a first of said die body portions by a narrow neck serving as a flex hinge, such that in moving said flexible lip the narrow neck flexes to facilitate such movement.

8. The device of claim 5, wherein said flexible lip is movable to change a distance between the sculpted surface of said flexible lip and said circumferential surface of said roller.

9. The device of claim 5, wherein said flexible lip is movable so as to simultaneously change
a distance between the sculpted surface of said flexible lip and said circumferential surface of said roller; and
a distance between said pair of lips.

10. The device of claim 5, wherein said flexible lip is movable to change a distance between said pair of lips so as to change a height of said die exit.

11. The device of claim 5, wherein a surface extending from said manifold through said die exit to said sculpted surface of said flexible lip is a geometrically continuous surface.

12. The device of claim 11, wherein said geometrically continuous surface is devoid of any sharp corners or edges.

13. The device of claim 5, wherein the device is configured such that a path of extrudate travel extends from said manifold, then along a narrow channel, and to the die exit, at which point the path of extrudate travel turns and extends between the sculpted surface of said flexible lip and said circumferential surface of said roller.

14. The device of claim 13, wherein the other of said lips is a fixed lip, and wherein following said turn in the path of extrudate travel, the path of extrudate travel moves away from the fixed lip.

15. The device of 13, wherein said turn in the path of extrudate travel is a turn of greater than 30 degrees.

16. The device of claim 13, wherein said turn in the path of extrudate travel is between a straight extent of the path of extrudate travel and a subsequent extent that follows a curve.

17. The device of claim 13, wherein after extending between the sculpted surface of said flexible lip and said circumferential surface of the roller, the path of extrudate travel extends away from the die along said roller.

18. The device of claim 5, wherein the other of said lips is a fixed lip, and wherein
a first circumferential extent of said roller is nested against the sculpted surface of said flexible lip; and
a second circumferential extent of said roller is nested against the sculpted surface of said fixed lip.

19. The device of claim 18, wherein said second circumferential extent is greater than said first circumferential extent.

20. The device of claim 18, wherein an arithmetic ratio of said second circumferential extent to said first circumferential extent is greater than or equal to two.

21. The device of claim 1, wherein the device is configured such that a path of extrudate travel extends in a straight line from the manifold to the die exit.

22. The device of claim 1, wherein a flow passageway extending from the manifold to an exterior of the die is devoid of any catch surfaces that would disrupt extrudate flow through said die.

23. The device of claim 1, wherein said roller is operatively juxtaposed with said extrusion die such that there is substantially no air gap between said roller and said extrusion die.

24. The device of claim 1, wherein said roller is operatively juxtaposed with said sculpted surfaces such that extrudate emanating from said die does not travel across an air gap prior to contacting said roller.

25. The device of claim 1, wherein said manifold is a coat hanger type manifold.

26. The device of claim 1, wherein said extrusion device is a polymer extrusion device that is provided in combination with at least one polymer, some of said polymer being located in said manifold.

27. The device of claim 1, wherein said roller is part of a calender, said calender defining a nip.

28. The device of claim 27, wherein said sculpted surfaces of said die lips are operatively juxtaposed with a circumferential surface of at least one roller of said calender.

29. The device of claim 1, wherein said roller is a casting roller.

30. The device of claim 1, further comprising a die lip adjustment mechanism.

31. The device of claim 1, wherein said extrusion die is configured, and is juxtaposed with said rotating roller, such that an extrudate emanating from said die exit is substantially devoid of die lines.

32. The device of claim 1, wherein said extrusion die is configured, and is juxtaposed with said rotating roller, such that an extrudate emanating from said die exit is substantially devoid of edge bead.

33. A polymer extrusion method, comprising

extruding polymer from an extrusion die to form a sheet, the extrusion die having a die exit defined by a pair of mating die lips, said die lips comprising sculpted surfaces having a contour substantially similar to that of a circumferential surface of a rotating roller operatively juxtaposed with said sculpted surfaces; and

passing said sheet through a curved passageway between one of said sculpted surfaces and said circumferential surface of said rotating roller.

34. The method of claim 33, wherein at least one lip of said pair of die lips is a moveable flexible lip, the method comprising altering a thickness of said sheet by moving said flexible lip.

35. The method of claim 34, wherein said altering the thickness of said sheet by moving said flexible lip involves altering a height of said die exit in that said movement of said flexible lip is directed towards or away from the other of said pair of die lips.

36. The method of claim 34, wherein said altering the thickness of said sheet by moving said flexible lip also involves altering a height of said curved passageway.

37. The method of claim 36, wherein said altering the height of said curved passageway involves the sculpted surface of said flexible lip moving towards or away from said circumferential surface of said rotating roller.

38. The method of claim 34, wherein said altering the thickness of said sheet by moving said flexible lip involves simultaneously

altering a height of said die exit as a result of said flexible lip moving towards or away from the other of said pair of die lips; and

altering a height of said curved passageway as a result of said flexible lip moving towards or away from said circumferential surface of said rotating roller.

39. The method of claim 38, further comprising altering said thickness of said sheet by moving said circumferential surface of said roller towards or away from said extrusion die.

40. The method of claim 33, wherein said roller is one of a pair of rollers of a calender, said calender defining a nip, the method comprising passing said sheet through the nip.

41. The method of claim 33, wherein the polymer moves along a path of extrudate travel that extends from a manifold of the die along a narrow channel and to the die exit, at which point the path of extrudate travel turns and extends along said curved passageway.

42. The method of claim 41, wherein said turn in the path of extrudate travel is a turn of greater than 30 degrees.

43. The method of claim 41, wherein said turn in the path of extrudate travel is between a straight extent of the path of extrudate travel and a subsequent extent that follows said curved passageway.

44. The method of claim 41, wherein after extending along said curved passageway, which is defined between one of said sculpted surfaces and said circumferential surface of said rotating roller, said sheet moves on the roller and away from the die.

45. The method of claim 33, wherein said extrusion die is configured, and is juxtaposed with said rotating roller, such that there is substantially no air gap between said die exit and said rotating roller.

46. The method of claim 33, wherein said extrusion die is configured, and is juxtaposed with said rotating roller, such that the extrudate emanating from said die exit does not travel across an air gap prior to contacting said rotating roller.

47. The method of claim 33, wherein said extrusion die is configured, and is juxtaposed with said rotating roller, such that said sheet is substantially devoid of die lines.

48. The method of claim 33, wherein said extrusion die is configured, and is juxtaposed with said rotating roller, such that said sheet is substantially devoid of edge bead.

49. An extrusion device comprising a roller and an extrusion die, said die having a manifold and a die exit, said die exit being in fluid communication with said manifold, said die comprising first and second die lips between which said die exit is located, said die lips having sculpted surfaces shaped so as to have a contour substantially matching a perimetrical shape of said roller, such that said sculpted surfaces are configured to be operatively positioned alongside said roller so as to provide substantially no air gap between said die and said roller.

50. An extrusion die having a manifold and a die exit, said die exit being in fluid communication with the manifold, the die comprising first and second die lips between which said die exit is located, the first die lip having a sculpted surface shaped so as to have a concave contour with a radius of curvature, and the second die lip having a sculpted surface shaped so as to have a concave contour with said radius of curvature.

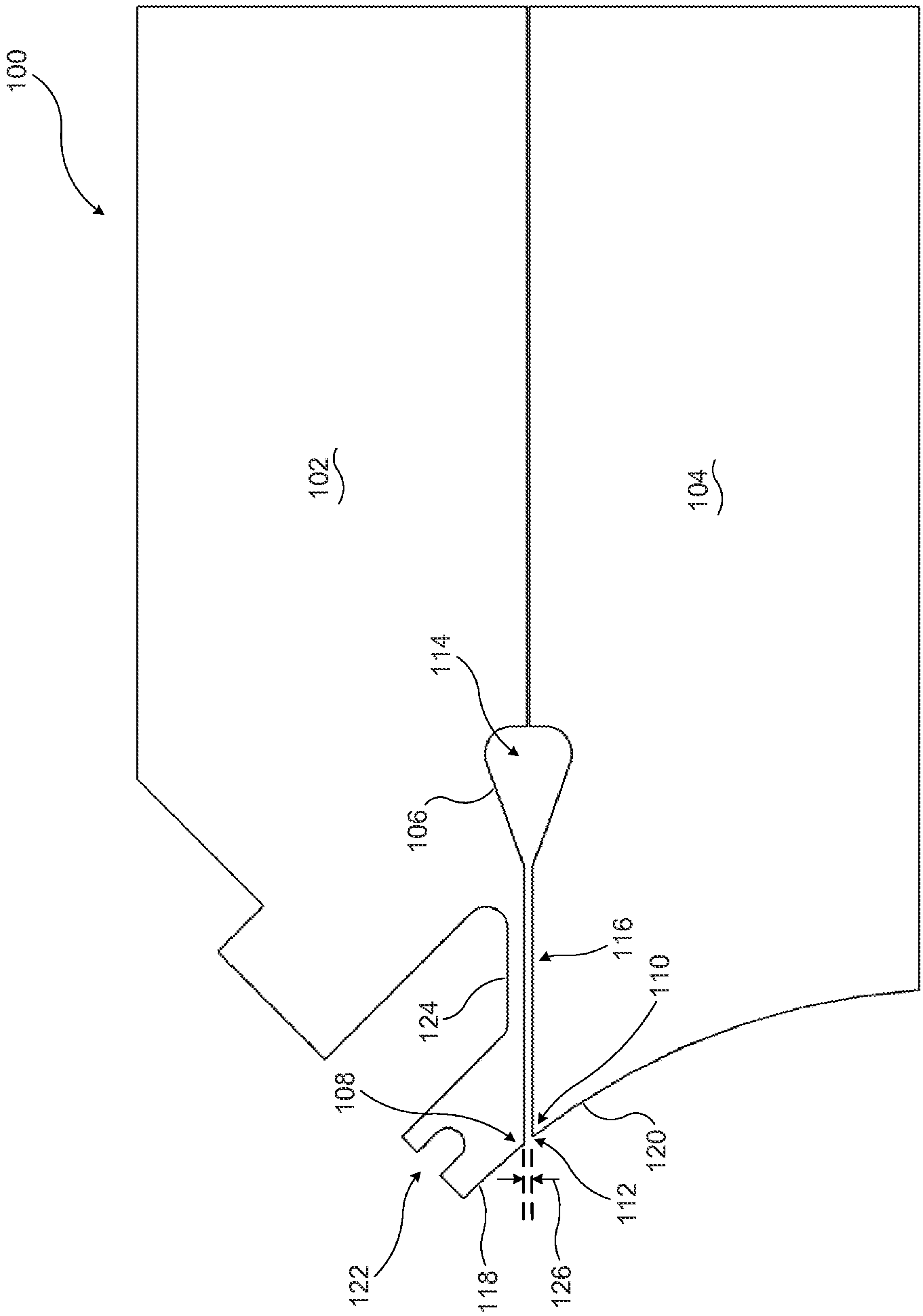

FIG. 1

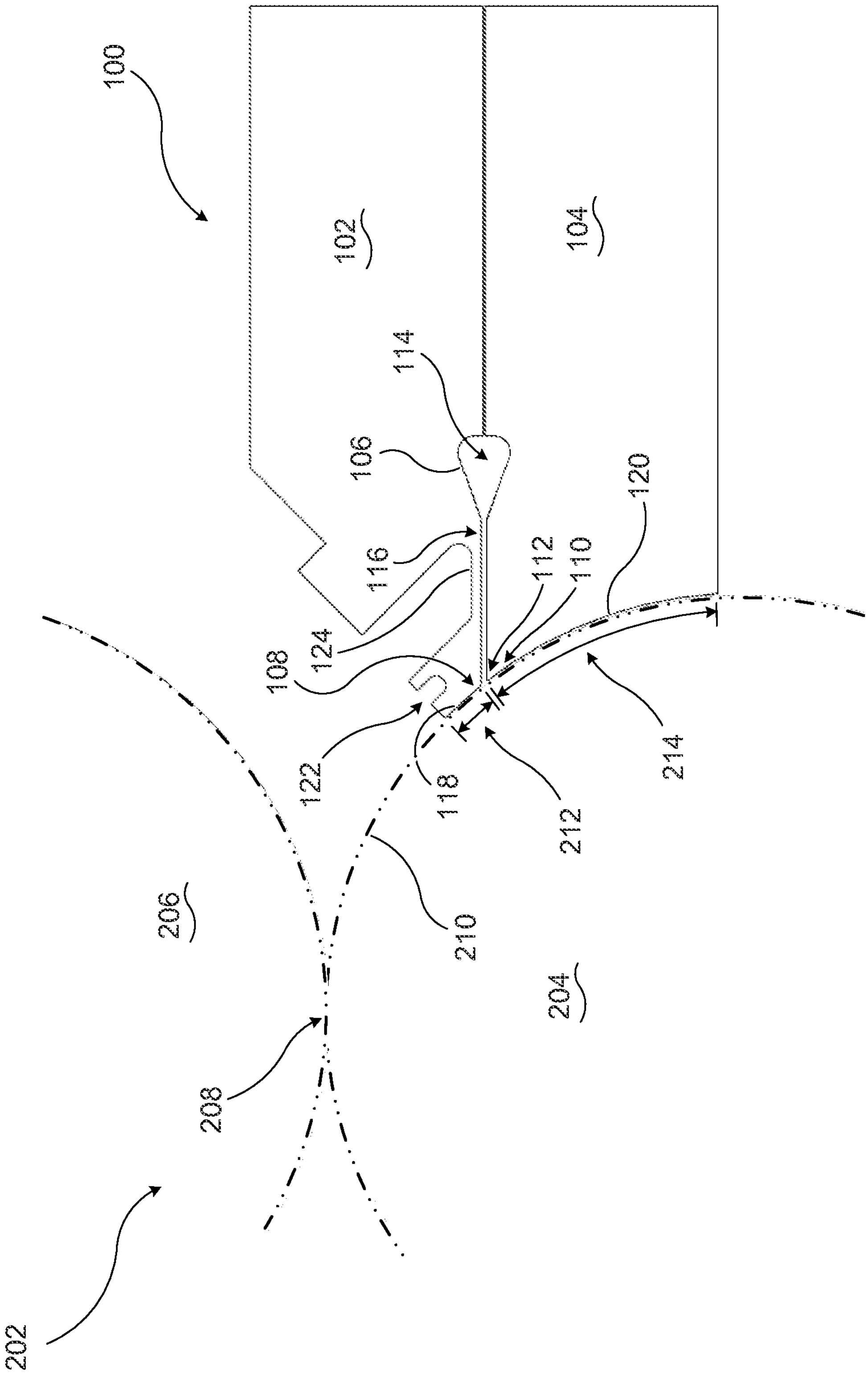
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FIG. 2

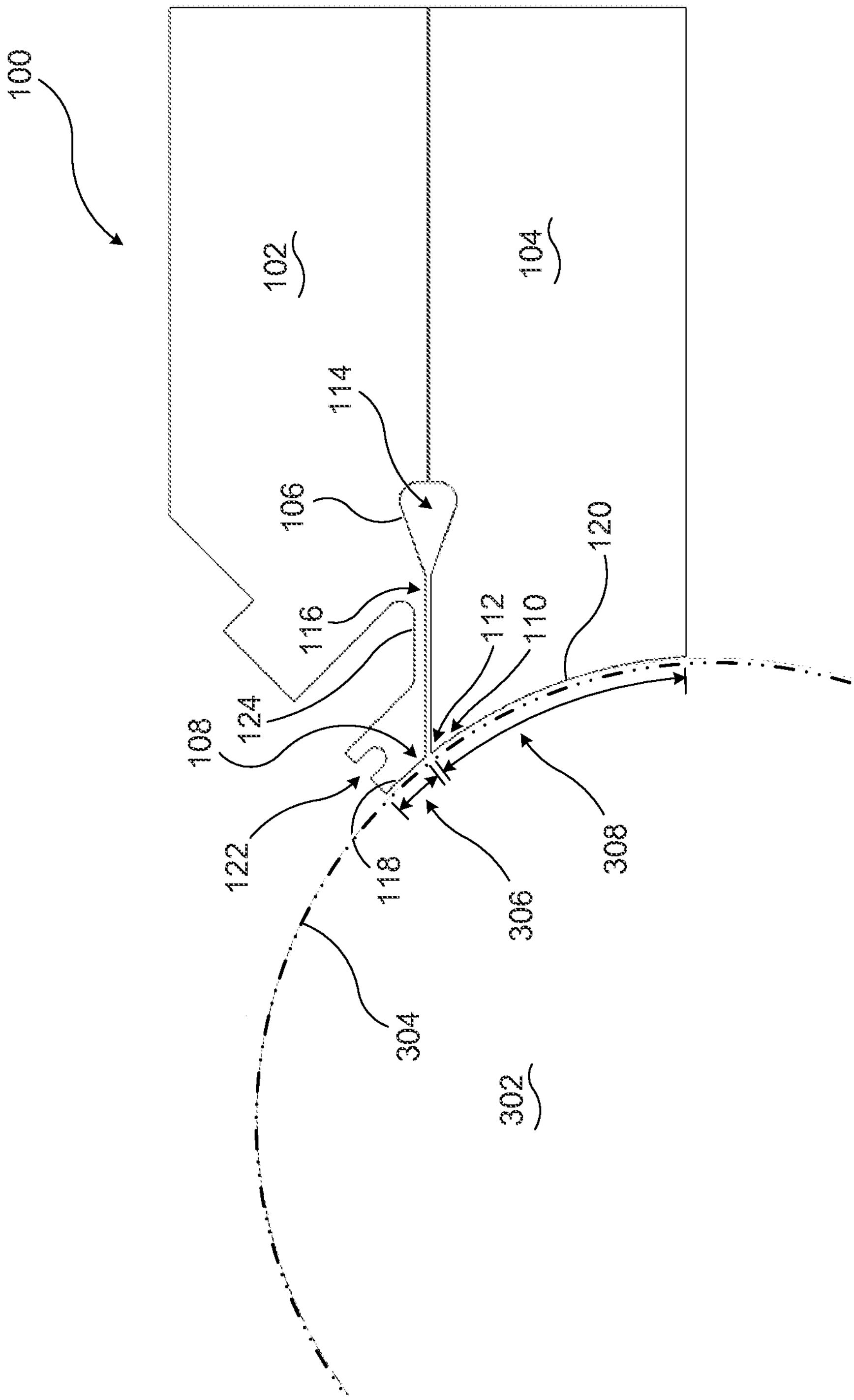
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FIG. 3

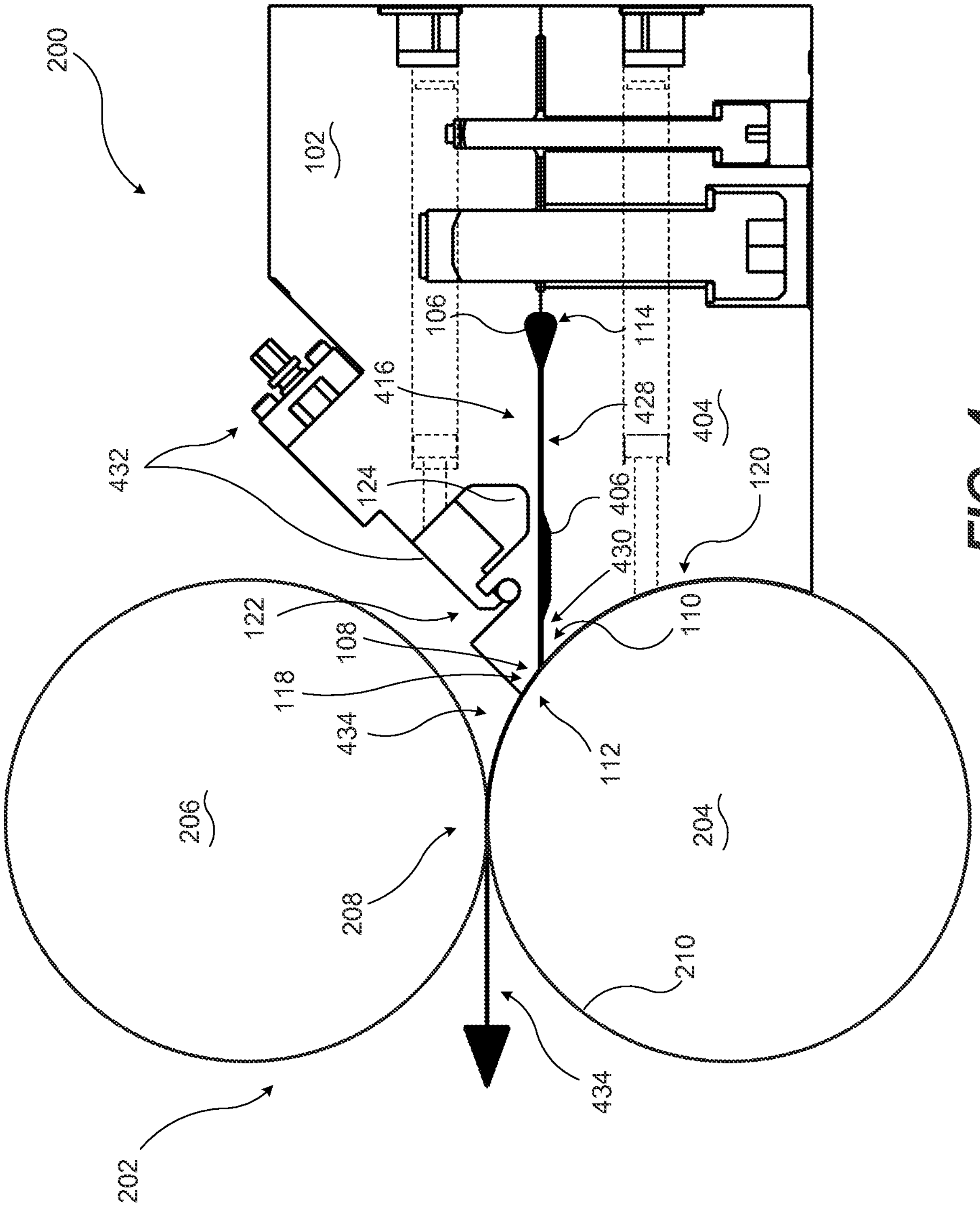
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FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/047388

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C47/32 B29C47/16 B29C43/24
ADD. B29C47/92 B29C47/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B29C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 249 518 A (TROESTER MASCHF PAUL [DE]) 13 May 1992 (1992-05-13) abstract page 4, line 17 - page 6, line 8 claims 1-8 figures 1-3 -----	1-18, 21-46, 49,50
X	US 3 871 810 A (GEYER PAUL) 18 March 1975 (1975-03-18) abstract column 2, lines 20-22 column 4, line 33 - column 5, line 9 claims 1-2 figures 1, 2, 17,18,19 ----- -/--	1-6,8,9, 11-20, 22-33, 41-50

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 October 2012	30/10/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ngwa, Walters

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/047388

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	EP 0 484 721 A2 (ROEHM GMBH [DE]) 13 May 1992 (1992-05-13) abstract column 4, lines 52-58 figure 1	1,5,33, 49,50
X	US 4 281 980 A (HOAGLAND JOHN C ET AL) 4 August 1981 (1981-08-04) abstract figure 4	1-5,13, 33

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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