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(54) Title: POWERED AIR PURIFYING RESPIRATOR WITH NOISE REDUCING PLENUM

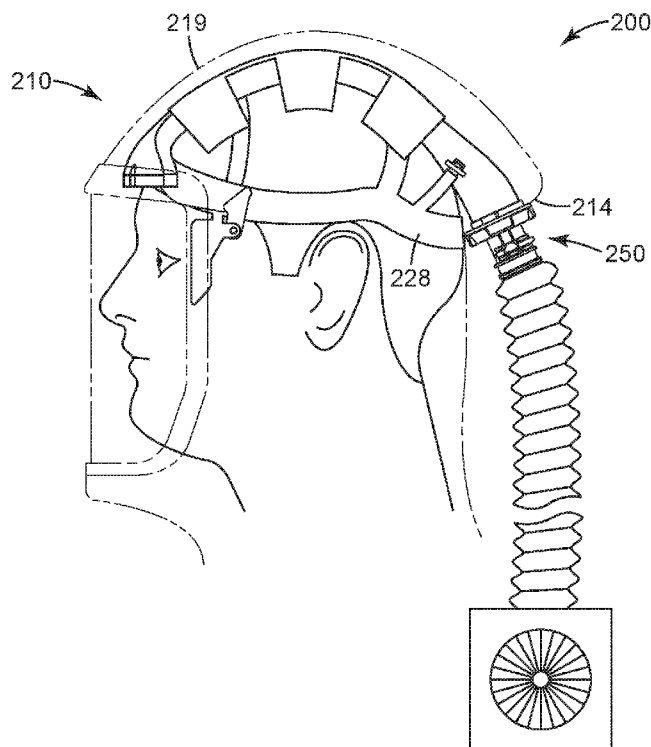


Fig. 2

(57) Abstract: The present description provides a respiratory protection device including a shell defining an interior zone around at least a portion of a head of a user and a curved air delivery plenum within the shell. The air delivery plenum includes a plenum inlet, a plenum outlet, and first and second plenum subsections positioned between the plenum inlet and outlet, the second plenum subsection having a maximum cross-sectional area (A_{max2}) and including a second plenum inlet having a cross-sectional area (A_{i2}). The air delivery plenum is curved along a longitudinal axis extending along the air delivery plenum in a direction of airflow, and (A_{max2}) > 1.5 (A_{i2}).



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POWERED AIR PURIFYING RESPIRATOR
WITH NOISE REDUCING PLENUM

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Technical Field

[0001] The present description relates to powered air purifying respirators, and particularly powered air purifying respirators including a plenum having features for reducing noise.

Background

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[0002] Respirators are well known and have many uses. For example, certain types of respirators may be used to aid a user's breathing in a contaminated atmosphere, such as a smoke or dust laden atmosphere, a mine, or a laboratory. Respirators may also be worn to prevent contamination of the surrounding atmosphere by a user, such as when working in a clean room for manufacturing sensitive electronic components.

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[0003] Various types of respirators may be used including supplied air respirators in which breathable air is delivered to a user from a supply tank or an air compressor. There are also powered air respirators that draw or drive ambient air through a filter. Systems that use a powered air source to supply clean air to the user are referred to as powered air purifying respirators, or "PAPRs." A fan may drive or draw ambient air through one or more filters to be delivered to a user. The device may further include a breathing mask, or other suitable hood, helmet, or headtop, having an inlet for filtered air.

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Summary

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[0004] The present description provides, in one exemplary embodiment, a respiratory protection device including a shell defining an interior zone around at least a portion of a head of a user and a curved air delivery plenum within the shell. The air delivery plenum includes a plenum inlet, a plenum outlet, and first and second plenum subsections positioned between the plenum inlet and outlet, the second plenum subsection having a maximum cross-sectional area (A_{max2}) and including a second plenum inlet having a cross-sectional area (A_{i2}). The air delivery plenum is curved along a longitudinal axis extending along the air delivery plenum in a direction of airflow, and $(A_{max2}) > 1.5 (A_{i2})$.

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[0005] In another exemplary embodiment, the present description provides a respiratory protection device including a curved air delivery plenum having a plenum inlet, a plenum outlet and first and second plenum subsections positioned between the plenum inlet and outlet. The second plenum subsection includes a second plenum inlet having a cross-sectional area (A_{i2})

and a maximum cross-sectional area (A_{max2}), and front and rear walls extending in a direction outwardly from a longitudinal axis and separated by a length (l_2), the longitudinal axis extending along the air delivery plenum in a direction of airflow. The air delivery plenum is curved along a longitudinal axis extending through the plenum inlet in a direction of airflow, and $2.0 \text{ cm}^2 <$
5 $(A_{max2}) < 180 \text{ cm}^2$, $1.3 \text{ cm}^2 < (A_{i2}) < 45 \text{ cm}^2$, and $1.5 \text{ cm} < (l_2) < 10 \text{ cm}$.

[0006] The above summary is not intended to describe each disclosed embodiment or every implementation. The Figures and Detailed Description, which follow, more particularly exemplify illustrative embodiments.

Brief Description of Drawings

[0007] The present description will be further explained with reference to the accompanying figures, wherein like structure is referred to by like reference numerals throughout the several views.

[0008] FIG. 1A shows a schematic side view of an exemplary embodiment of a respirator system according to the present disclosure.

[0009] FIG. 1B shows a cross-sectional side view of the exemplary respirator system shown in FIG. 1A disposed on a user's head.

[0010] FIG. 2 shows a schematic side view of an exemplary embodiment of a respirator system according to the present disclosure.

[0011] FIG. 3A is a perspective view of an exemplary air delivery plenum according to the present description.

[0012] FIG. 3B is a top view of the air delivery plenum of FIG. 3A.

[0013] FIG. 3C is a side view of the air delivery plenum of FIG. 3A.

[0014] FIG. 3D is a cross-sectional view of the air delivery plenum of FIG. 3A.

[0015] FIG. 4 is a top view of an exemplary air delivery plenum according to the present description.

[0016] FIG. 5 is a top view of an exemplary air delivery plenum according to the present description.

[0017] While the above-identified figures set forth several embodiments of the disclosed subject matter, other embodiments are also contemplated. In all cases, this disclosure presents the disclosed subject matter by way of representation and not limitation. It is understood that numerous other modifications and embodiments can be devised by those skilled in the art which fall within the scope and spirit of the principles of this disclosure.

Detailed Description

[0018] The present description provides an air delivery plenum of a respiratory protection device that reduces noise transmitted to the mask and/or headtop worn by a user. The plenum includes one or more subsections providing one or more noise reducing chambers, such as an expansion chamber or resonance chamber, and results in less noise perceived by a user. A plenum as described herein may provide an improved user experience by reducing perception of noise and/or minimizing noise associated fatigue.

[0019] An exemplary embodiment of a respiratory protection system 100 according to the present disclosure is illustrated in FIGS. 1A and 1B. Respiratory protection system 100 includes a headgear article 110 and a clean air source 170. Clean air source 170 provides breathable air to a breathable air zone 112 (FIG. 1B) defined by at least a portion of an interior zone 102 (FIG. 1B) of headgear article 110.

[0020] Headgear article 110 includes a visor 122 and a shell 111. Shell 111 provides a barrier separating an interior volume of headgear article 110, including at least breathable air zone 112, from the ambient environment, and may partially or completely cover a user's head. In an exemplary embodiment, shell 111 includes a shape-stable outer shell that has sufficient structural integrity to retain its desired shape, and/or the shape of other layers that are supported by it, under normal handling. For example, shell 111 may include a shape-stable outer shell that substantially retains its shape after any deforming forces have ceased. In various exemplary embodiments, shell 111 is a helmet configured to resist impact to provide a level of impact protection to a user of the headgear article 110 as may be desired for a particular application. Impact resistance exists where the shell absorbs at least a certain amount of mechanical energy from impact that would otherwise reach a user's head. Exemplary materials suitable for use in shell 111 include, without limitation, high density polyethylene, polypropylene, nylon, polycarbonate, ABS, styrene, aluminum, fiber reinforced plastics, laminated paper products other suitable materials as known in the art, and combinations thereof.

[0021] In various exemplary embodiments, a shell may include a hood and that may be a loose fitting face piece that covers at least a face of the user and does not provide significant head impact protection. FIG. 2 shows an exemplary embodiment of a respiratory protection system 200 having a headgear article 210 including a hood 219. Similar to the exemplary embodiment described with reference to FIGS 1A and 1B, respiratory protection system 200 includes an air inlet opening 214, suspension system 228, and clean air supply system 250 including air delivery plenum 251.

[0022] Returning to the exemplary embodiment illustrated in FIGS. 1A and 1B, visor 122 includes a transparent member which may be made of any suitable transparent material through which a user may view the surroundings. In an exemplary embodiment, visor 122 includes a generally curved lens 122a and a lens frame 122b. Lens frame 122b supports lens 122a and facilitates pivoting of the visor 122 via pivot mechanism 123, for example. Curved lens 122a may exhibit a cylindrical curvature with a spherical or an elliptical cross-section. Visor 122 includes a seal 125 attached to lens 122a and/or lens frame 122b. Seal 125 typically engages frontal area of shell 111, when visor 122 is in its lowered or closed position, for example. In some exemplary embodiments, seal 125 is fluid tight, e.g., air tight. In an exemplary embodiment, visor 122 is pivotally attached to shell 111 via pivot mechanism 123, such that the visor may have a lowered position, a raised position and various intermediate positions. Any suitable pivoting mechanism as known in the art may be provided to allow visor 122 to move between lowered and raised positions.

[0023] Referring to FIG. 1B, headgear article 110 of respiratory protection system 100 may define breathable air zone 112 in the entire interior thereof or as a subsection of interior zone 102. In an exemplary embodiment, breathable air zone 112 is located between visor 122 and the user's face, and is defined at least in part by a face seal 126 that provides a seal with the user's body, article of clothing, or other component. Outer periphery 126a of face seal 126 may be constructed to be disposed at least in part under the user's chin. Face seal 126 and/or a breathing zone seal 127 may be used to separate breathable air zone 112 from the remainder of the interior zone 102. In the exemplary embodiment shown in Fig. 1B, the remainder of the interior zone 102 resides between shell 111 and the top of a user's head.

[0024] Referring further to FIGS. 1A and 1B, exemplary headgear article 110 may include a suspension that supports headgear article 110 on the user's head such as suspension system 128. Suspension system 128 serves to mount and support headgear article 110 on a user's head, and may include a headband 128a configured to be disposed across a user's forehead.

[0025] Respiratory protection system 100 includes a clean air supply system 150 including an air delivery plenum 151 within shell 111. Air delivery plenum 151 includes a plenum inlet 152 disposed at a first location of air delivery plenum 151 and a plenum outlet 153 disposed at a second location of air delivery plenum 151. Air delivery plenum 151 includes one or more plenum subsections that may be configured to minimize transmission and/or generation of sound that could be perceived by a user, as described further herein.

[0026] Plenum inlet 152 is configured for connection to a clean air source 170 and is in fluid communication with plenum outlet 153. In an exemplary embodiment, plenum inlet 152 is

positioned at a rear of shell and air delivery plenum 151 includes one or more portions, such as subsections 191, 192, 193, 194, 195, and/or 196 that pass over and/or around portions of a user's head, for example towards visor 122, to deliver air to plenum outlet 153. Plenum outlet 153 provides one or more openings to allow air to flow out of air delivery plenum 151 into
5 breathable air zone 112. In an exemplary embodiment, at least one of plenum outlets 153 is positioned to deliver air proximate a user's face such that air entering breathable air zone 112 through plenum outlet 153 may circulate between visor 122 and a user's face.

[0027] Clean air supply system 150 may include a diverter 155 disposed at or in plenum outlet 153 and configured to allow the user to alter the direction and/or amount of air flow into
10 breathable air zone 112. In an exemplary embodiment, diverter 155 is a moveable structure disposed adjacent plenum outlet 153 and that affects the flow direction of air exiting plenum outlet 153, dependent upon the position of the structure relative to plenum outlet 153.

Accordingly, in an exemplary embodiment, plenum outlet 153 is adjustable between at least a first outlet configuration wherein the air flow from the outlet is directed in a first direction and at
15 least a second outlet configuration wherein the air flow from the outlet is directed in a second, different direction.

[0028] In an exemplary embodiment, plenum inlet 152 is in fluid communication with clean air source 170 that provides breathable air to air delivery plenum 151. Clean air source 170 may include a blower to force ambient air through air-purifying elements to plenum inlet 152. In
20 various exemplary embodiments, clean air source 170 may be a compressed air system, such as an air compressor, or other suitable clean air source 170 as may be known in the art. Clean air source 170 may be joined directly to plenum inlet 152, and integrated with or supported on headgear article 110, or may be fluidically coupled to plenum inlet 152 by an air delivery hose 160.

[0029] FIGS. 3A through 3D show an exemplary embodiment of an air delivery plenum 151. Air delivery plenum 151 includes plenum inlet 152, plenum outlet 153, a first plenum subsection 191, and a second plenum subsection 192. First and second plenum subsections 191 and 192 are positioned between plenum inlet 152 and plenum outlet 153, and have a geometry and
25 configuration such that transmission of sound waves through air delivery plenum 151 is affected.

[0030] In an exemplary embodiment, air delivery plenum 151 exhibits a curvature along a longitudinal axis, such as a longitudinal axis A. Longitudinal axis A passes through plenum inlet 152 in a direction parallel to the flow of air when the device is in use. For example, at least a portion of air delivery plenum 151 is curved along longitudinal axis A extending through
30 plenum inlet 152 such that air delivery plenum 151 provides a generally arcuate lower wall 157

of air delivery plenum 151 that may accommodate a user's head. An effective length of an airflow path between plenum inlet 152 and plenum outlet 153 is longer than it otherwise would be as compared to an air delivery plenum 151 that does not exhibit curvature along longitudinal axis A. In an exemplary embodiment, curved air delivery plenum 151 may be readily positioned in a crown space 129 of shell 111 and accommodate a user's head in a space efficient manner.

[0031] In various exemplary embodiments, air delivery plenum 151 exhibits curvature in multiple directions to further allow positioning of air delivery plenum 151 in crown space 129 of shell 111. For example, air delivery plenum 151 exhibits curvature along transverse axis B that is perpendicular to longitudinal axis A. At least a portion of air delivery plenum 151 has a convex upper surface 156 and/or a concave lower surface 157 along transverse axis B.

[0032] Air delivery plenum 151 may be permanently or removably joined with shell 111. In an exemplary embodiment, air delivery plenum 151 is removably joined with shell 111 and may be supported on a head of a user by a suspension system 128. A portion of air delivery plenum 151 extends through an air inlet opening 114 of shell 111. Shell 111 and air delivery plenum 151 are non-destructively joined such that air delivery plenum 151 may be separated from shell 111, and reused for example, without destroying air delivery plenum 151 and shell 111. In other exemplary embodiments, air delivery plenum 151 is integral with shell 111 or otherwise not separable without damaging one or both of air delivery plenum 151 and shell 111.

[0033] First plenum subsection 191 may be sized and configured as desired for a particular system. In an exemplary embodiment, first plenum subsection 191 provides an air flow path between plenum inlet 152 and second plenum subsection 192, and may have a uniform or varying cross-section. In various exemplary embodiments, first plenum subsection has a length (11) between 0.5 cm and 25 cm, and 1.5 cm and 25 cm, or 2.5 cm and 20 cm.

[0034] First and second plenum subsections 191, 192 are sized and configured to minimize transmission and/or generation of sound as air flows through air delivery plenum 151. In various exemplary embodiments, second plenum subsection 192 is dimensioned and configured as a muffler in which sound is reflected and attenuated, for example due to changes in cross-sectional area between first and second plenum subsections 191, 192. In an exemplary embodiment, best viewed in FIG. 3B, second plenum subsection 192 has front and rear walls 181, 182 separated by second subsection length (12), and upper and lower walls 183, 184. Front and rear walls 181, 182 extend generally outwardly relative to a flow of air through air delivery plenum 151 and/or from longitudinal axis A. Second subsection length (12) is thus a distance between interior surfaces of front and rear walls 181, 182, for example between second plenum subsection inlet 192i and second plenum subsection outlet 192o. Second plenum subsection 192 has a second

plenum subsection width (w_2) between inner surfaces of side wall portions 185. In various exemplary embodiments, front and rear walls 181, 182 may extend outwardly at an angle such that second plenum subsection length (l_2) varies across width (w_2).

[0035] Alternatively or in addition, second plenum subsection 192 is dimensioned and configured as a resonant chamber such that, at predetermined frequency ranges, incident sound is reflected towards the source resulting at least in part from impedance changes due to the geometry of second plenum subsection 192. Such chambers may be selectively tuned by configuring the geometry to result in a desired attenuation at one or more specific frequencies, as further described herein.

[0036] In an exemplary embodiment, second plenum subsection 192 includes a second plenum subsection inlet 192i having a cross-sectional area (A_{i2}) at front wall 181, and a maximum cross-sectional area (A_{max2}) between front and rear walls 181, 182. Maximum cross-sectional area (A_{max2}) is a maximum cross-sectional area of a cross-section of second plenum subsection 192 passing through second plenum subsection 192 transverse to the air flow direction, for example, and defined by internal surfaces of second plenum subsection 192, including for example upper and lower walls 183, 184 and side wall portions 185 between front and rear walls 181, 182. Air may flow from a direction of plenum inlet 152 through second plenum subsection inlet 192i into second plenum subsection 192.

[0037] In various exemplary embodiments, cross-sectional area (A_{i2}) is between 1.3 cm^2 and 45 cm^2 , 2.5 cm^2 and 35 cm^2 , 3.9 cm^2 and 25 cm^2 , or about 7.0 cm^2 . In various exemplary embodiments, maximum cross-sectional area (A_{max2}) is between 2.0 cm^2 and 180 cm^2 , 3.8 cm^2 and 140 cm^2 , 5.9 cm^2 and 100 cm^2 , or about 14.5 cm^2 . In an exemplary embodiment, maximum cross-sectional area (A_{max2}) is greater than inlet cross-sectional area (A_{i2}), and the ratio of maximum cross-sectional area (A_{max2}) to inlet cross-sectional area (A_{i2}) may be selected to allow for desired sound attenuation as air flows through air delivery plenum 151. In various exemplary embodiments, maximum cross-sectional area (A_{max2}) is greater than 1.2, 1.5, 2, 3, 4, 5, 6 or more times the area of inlet cross-sectional area (A_{i2}). For example, (A_{max2}) is between $1.1 \cdot (A_{i2})$ and $8 \cdot (A_{i2})$, $1.25 \cdot (A_{i2})$, and $4 \cdot (A_{i2})$, or between about $1.5 \cdot (A_{i2})$ and $2.5 \cdot (A_{i2})$. Such values and ratios of inlet cross-sectional area (A_{i2}) and maximum cross-sectional area (A_{max2}) result in a desirable level of sound attenuation without undesirable pressure drop in air pressure, as described further herein.

[0038] A length of air delivery plenum 151 and relative lengths of first and second plenum subsections 191, 192 may be selected to provide attenuation at a desired frequency range. For example, air delivery plenum 151 and first and second subsections may be dimensioned to

attenuate frequencies that may be associated with a particular PAPR blower unit used in conjunction with air delivery plenum 151, or undesirable frequency ranges otherwise present when respiratory protection system 100 is in use. Second plenum subsection length may be selected to be $(1/4*\lambda)$, where λ represents a desired wave length to be attenuated by air delivery plenum 151. In various exemplary embodiments, second subsection length (12) may be $(N*1/2\lambda)+(1/4\lambda)$, where N is an integer. For example, length (12) of second plenum subsection 192 may be 4.2 cm, and calculated to provide a maximum attenuation at a frequency (f) of approximately 1920 Hz. In various exemplary embodiments, second subsection length (12) may be between 0.5 cm and 20 cm, 2.1 cm and 8.5 cm, or about 5.7 cm.

[0039] In an exemplary embodiment, air delivery plenum 151 may further include a third plenum subsection 193 and a fourth plenum subsection 194. Third plenum subsection 193 is positioned between second and forth plenum subsections 192, 194, such that air may flow into forth plenum subsection after passing through third plenum subsection. As described above with respect to second plenum subsection 192, the geometry and configuration of forth plenum subsection may be configured to provide desired airflow and attenuation characteristics. Fourth plenum subsection 194 includes a fourth plenum inlet cross-sectional area (A_{i4}) and a maximum cross-sectional area (A_{max4}).

[0040] In various exemplary embodiments, cross-sectional area (A_{i4}) is between 1.3 cm^2 and 45 cm^2 , 2.5 cm^2 and 35 cm^2 , 3.9 cm^2 and 25 cm^2 , or about 6.7 cm^2 . In various exemplary embodiments, maximum cross-sectional area (A_{max4}) is between 2.0 cm^2 and 180 cm^2 , 3.8 cm^2 and 140 cm^2 , 5.9 cm^2 and 100 cm^2 , or about 13.6 cm^2 . In an exemplary embodiment, maximum cross-sectional area (A_{max4}) is greater than inlet cross-sectional area (A_{i4}), and the ratio of maximum cross-sectional area (A_{max4}) to inlet cross-sectional area (A_{i4}) may be selected to allow for desired sound attenuation as air flows through air delivery plenum 151. In various exemplary embodiments, maximum cross-sectional area (A_{max4}) is greater than 1.2, 1.5, 2, 3, 4, 5, 6 or more times the area of inlet cross-sectional area (A_{i4}). For example, (A_{max4}) is between $1.1*(A_{i4})$ and $8*(A_{i4})$, $1.25*(A_{i4})$, and $4*(A_{i4})$, or between about $1.5*(A_{i4})$ and $2.5*(A_{i4})$. Such ratios of inlet cross-sectional area (A_{i4}) and maximum cross-sectional area (A_{max4}) result in a desirable level of sound attenuation without undesirable pressure drop in air pressure, as described further herein.

[0041] A length of air delivery plenum 151 and relative lengths of third and fourth plenum subsections 193, 194 may be selected to provide attenuation at a desired frequency range, as described above with respect to first and second plenum subsections 191, 192. In various exemplary embodiments, length (14) of fourth plenum subsection 194 may be 4.3 cm, and

calculated to provide a maximum attenuation at a frequency (f) of approximately 1970 Hz. In various exemplary embodiments, fourth plenum subsection length (l4) may be between 0.5 cm and 20 cm, 2.1 cm and 8.5 cm, or about 4.44 cm.

[0042] The geometry and configuration of air delivery plenum 151 may be selected to provide a desired attenuation curve over a range of frequencies. In an exemplary embodiment, second and fourth plenum subsections may have a geometry and configuration to provide a maximum attenuation at the same or similar frequency. In various exemplary embodiments, second plenum subsection length (l2) is approximately equal to fourth plenum subsection length (l4).

Attenuation resulting from first and second plenum subsections may be at least partially additive at a given frequency, such that fourth plenum subsection provides additional attenuation beyond what may be achieved by second plenum subsection alone. In various other exemplary embodiments, second and fourth plenum subsection lengths (l2), (l4), are selected to be different such that peak attenuation is provided over a relatively wider range of frequencies.

[0043] In various exemplary embodiments, air delivery plenum 151 may include fifth and sixth plenum subsections 195, 196, or additional subsections, having geometry and configuration similar to that described above regarding first, second, third and/or fourth plenum subsections 191, 192, 193, 194, to provide an air delivery plenum 151 having desired airflow and attenuation characteristics as may be desired for a particular application or system.

[0044] Air delivery plenum 151 may be lined with or include additional sound attenuating materials. In an exemplary embodiment, second plenum subsection includes a sound attenuating material that dampens sound waves and/or controls flow of air through air delivery plenum 151, while second plenum subsection also acts as an expansion and/or resonant chamber that attenuates at least some sound energy present as air flows through air delivery plenum 151.

[0045] FIG. 4 shows an exemplary air delivery plenum 451 having first, second, third and fourth plenum subsections 491, 492, 493 and 494. Second plenum subsection 492 includes a width (w2), length (l2), second plenum cross-sectional area (Ai2) and a second plenum maximum cross-sectional area (Amax2), and fourth plenum subsection 494 includes a width (w4), length (l4), a fourth plenum cross-sectional area (Ai4) and a fourth plenum maximum cross-sectional area (Amax2).

[0046] FIG. 5 shows an exemplary air plenum 551 having first and second plenum subsections 591, 592. Second plenum subsection 592 includes a width (w2), length (l2), second plenum cross-sectional area (Ai2) and a second plenum maximum cross-sectional area (Amax2).

[0047] The present inventors have found that air delivery plenums as described herein may be curved and shaped to provide desirable sound attenuation, even when positioned within a shell

of a respiratory protection device, without significantly increasing pressure drop through the plenum. A plenum having a lower pressure drop facilitates a respiratory protection device having a high performance with relatively less power consumption. Exemplary air delivery plenums have subsections as described herein may result in a pressure drop through a plenum as measured according to the Pressure Drop Test that is equal to or less than a pressure drop through a plenum having a similar volume not including subsections as described herein. In various exemplary embodiments, air delivery plenum 151 exhibits a pressure drop of between 1 Pa and 250 Pa, less than 125 Pa, less than 100 Pa, less than 75 Pa, or less than 50 Pa, or less than 25 Pa, or less than 15 Pa at 200 Slpm.

[0048] A respiratory protection device including an air delivery plenum as described herein provides several unique features and advantages. Such air delivery plenums provide a reduction in noise that may be generated by a blower or other system component and/or otherwise perceived by a user. Desirable noise reduction may be attained with minimal pressure drop caused by the plenum. In this way, sound attenuation may be achieved without any substantial increase in power consumption or affect on airflow performance. Further, various exemplary air delivery plenums as described herein may be readily positioned in a headtop of the respiratory protection device, and are effective in reducing noise perceived by a user even when positioned within an interior space defined by the headtop. That is, the air delivery plenum described herein does not need to be positioned outside of the headtop in order to function effectively in reducing sound within the interior space of the headtop perceivable by a user. Noise reduction provided by an air delivery plenum as described herein also allows materials and components of a respiratory protection to be selected to provide other features and advantages, as opposed to being selected only for noise mitigation purposes.

Examples

[0049] The characteristics, operation, and advantages of the present description will be further described with regard to the following detailed non-limiting examples. These examples are offered to further illustrate the various specific and preferred embodiments and techniques. It should be understood, however that many variations and modifications may be made while remaining within the scope of the present invention.

Noise Test Procedure

[0050] Sound level may be measured during operation of a respiratory protection device according to the following procedure to provide an indication of noise that may be perceived by

a user. Unless specified herein, the procedure is conducted according to the National Institute for Occupational Safety and Health (NIOSH) protocol for noise testing of respirators as specified at 42 C.F.R. § 84.140, 84.202, 84.1139 and NIOSH Procedure Nos. RCT-ASR-STP-0111 (Rev 1.1, 20-Sept-2005) and RCT-APR-STP-0030 (Rev 1.1, 14-Jun-2005), using a mannequin as a test subject as outlined in sections 5.1 of the respective procedures.

[0051] Ambient noise levels were obtained by positioning microphones of 3M Quest NoisePro DLX-1 dosimeters, calibrated according to the manufacturer's instructions, in recesses of a rubber noise testing head form. Ambient noise levels were measured using a one minute sampling time according to NIOSH RCT-APR-STP-0030. Ambient noise levels were confirmed to be at least 10 db-A below any test measurements.

[0052] A headtop having the dimensions of a 3M VERSFLO M-400, except with a smooth inner surface to provide approximately 0.25" of additional clearance in the crown space to accommodate a plenum to be tested, was printed using a Fortus 400 FDM prototyping machine using ABS material. The headtop was positioned over the head form, and a 3M VERSAFLO TR-300 blower having a 7-blade impellor ("Blower 1"), 3M VERSAFLO TR-332 Li-ion battery, 3M BT-40 breathing tube, and a 3M TR-3710 filter were assembled. Noise level was measured with a one minute sampling time with the blower operating to obtain an average sound level (db-A).

[0053] A headtop having the dimensions of a 3M VERSFLO M-400, except with a smooth inner surface to provide approximately 0.25" of additional clearance in the crown space to accommodate a plenum to be tested, was printed using a Fortus 400 FDM prototyping machine using ABS material. The headtop was positioned over the head form, and a 3M VERSAFLO TR-300 11-blade impellor blower, ("Blower 2"), 3M VERSAFLO TR-332 Li-ion battery, 3M BT-40 breathing tube, and 3M TR-3710 filter were assembled. Noise level was measured with a one minute sampling time with the blower operating to obtain an average sound level (db-A).

Pressure Drop Test Procedure

[0054] Pressure drop of an air delivery plenum was measured by delivering air through a TSI 4040 flow meter before entering the plenum and measuring pressure at a pressure tap at the inlet using an EXTEK HD755 digital manometer. Pressure measurements were obtained with flowrates of 170 Slpm, 190 Slpm, 200 Slpm, 210 Slpm, 220 Slpm, and 230 Slpm.

Examples 1 - 3

[0055] The Noise Test and Pressure Drop Test were performed with plenums having two subsections (Example 1), four subsections (Example 2), and six subsections (Example 3), having configurations as shown in Figs. 4, 5 and 3A-3C, respectively. Dimensions of the plenums of Examples 1, 2 and 3 are provided in Table 1 below, and test results are provided in Table 2.

Table 1

	Example 1	Example 2	Example 3
Amax2 (cm ²)	14.5	13.6	16.2
Ai2 (cm ²)	7.1	6.7	8.0
l2 (cm)	4.4	4.24	4.24
w2 (cm)	3.6	3.6	3.6
Amax4 (cm ²)	-	13.6	13.6
Ai4 (cm ²)	-	6.7	6.7
l4 (cm)	-	4.44	4.44
w4 (cm)	-	3.4	3.4
Amax6 (cm ²)	-	-	16.2
Ai6 (cm ²)	-	-	8.0
l6 (cm)	-	-	4.44
w6 (cm)	-	-	3.7
Total Volume (cm ³)	336	364	397

Comparative Example A

[0056] The Noise Test and Pressure Drop Test were performed on a 3M M-400 Series Helmet Plenum. Test results are provided in Table 2 below.

Table 2

	Blower 1 (db-A)	Reduction	Blower 2 (db-A)	Reduction
Example 1	73.8	2.1	67.1	3.3
Example 2	70.9	5	67.6	2.8
Example 3	71.8	4.1	66.5	3.9
Comparative Example A	75.9	-	70.4	-

Table 3

	Pressure Drop (Pa)					
	170 Slpm	190 Slpm	200 Slpm	210 Slpm	220 Slpm	230 Slpm
Example 1	12	15	16	17	20	20
Example 2	14	17	18	19	22	23
Example 3	13	16	17	19	21	22
Comparative Example A	14	17	18	19	22	23

[0057] Examples 1 through 3 having a plenum including one or more subsections as described herein exhibited a reduced sound level as compared to Comparative Example A. The plenums of Examples 1 through 3 were thus able to be positioned in a shell to deliver air to a user while reducing noise and improving user comfort. Additionally, the plenums of Examples 1 through 3 did not add significant pressure drop that could otherwise affect system performance or power consumption, and exhibited equal or reduced pressure drop through the plenum.

[0058] The present disclosure has now been described with reference to several embodiments thereof. The foregoing detailed description and examples have been given for clarity of understanding only. No unnecessary limitations are to be understood therefrom. It will be apparent to those skilled in the art that many changes can be made in the embodiments described without departing from the scope of the invention. Thus, the scope of the present invention should not be limited to the exact details and structures described herein, but rather by the structures described by the language of the claims, and the equivalents of those structures. Any feature or characteristic described with respect to any of the above embodiments can be incorporated individually or in combination with any other feature or characteristic, and are presented in the above order and combinations for clarity only. That is, the present description contemplates all possible combinations and arrangements of various features of each of the exemplary embodiments and components describe herein, and each component may be combined or used in conjunction with any other component as desired for a particular application.

What is claimed is:

1. A respiratory protection device, comprising:
a shell defining an interior zone around at least a portion of a head of a user; and
5 a curved air delivery plenum within the shell, the air delivery plenum comprising:
a plenum inlet;
a plenum outlet; and
first and second plenum subsections positioned between the plenum inlet and outlet, the
second plenum subsection having a maximum cross-sectional area (A_{max2}) and
10 comprising a second plenum inlet having a cross-sectional area (A_{i2});
wherein the air delivery plenum is curved along a longitudinal axis extending along the air
delivery plenum in a direction of airflow, and wherein $(A_{max2}) > 1.5 (A_{i2})$.
2. The respiratory protection device of claim 1, wherein $2.0 \text{ cm}^2 < (A_{max2}) < 180 \text{ cm}^2$.
3. The respiratory protection device of claim 1, wherein $3.8 \text{ cm}^2 < (A_{max2}) < 140 \text{ cm}^2$.
4. The respiratory protection device of claim 1, wherein $1.3 \text{ cm}^2 < (A_{i2}) < 45 \text{ cm}^2$.
5. The respiratory protection device of claim 1, wherein $3.9 \text{ cm}^2 < (A_{i2}) < 25 \text{ cm}^2$.
6. The respiratory protection device of claim 1, wherein the air delivery plenum is
configured to be positioned in a crown space of the shell.
7. The respiratory protection device of claim 1, wherein at least a portion of the air delivery
plenum is curved in a direction transverse to the longitudinal axis.
8. The respiratory protection device of claim 1, wherein the second plenum subsection
comprises an upper wall and a lower wall, and the lower wall has an outer concave
30 surface.
9. The respiratory protection device of claim 1, wherein the second plenum subsection
comprises front and rear walls extending in a direction outwardly from the longitudinal
axis.

10. The respiratory protection device of claim 9, wherein the front and rear walls of the second subsection are separated by a length (l2), and $1.5 \text{ cm} < (l2) < 10 \text{ cm}$.
- 5 11. The respiratory protection device of claim 10, wherein $2.5 \text{ cm} < (l2) < 8.0 \text{ cm}$.
12. The respiratory protection device of claim 1, wherein the first plenum subsection has a length (l1), and $1.5 \text{ cm} < (l1) < 25 \text{ cm}$.
- 10 13. The respiratory protection device of claim 1, further comprising a third plenum subsection, and a fourth plenum subsection, the fourth plenum subsection comprising a fourth plenum inlet cross-sectional area (A_{i4}) and a maximum cross-sectional area (A_{max4}), wherein $(A_{max4}) > 1.5 (A_{i4})$.
- 15 14. The respiratory protection device of claim 1, wherein the air delivery plenum inlet is configured for attachment to a clean air source.
15. The respiratory protection device of claim 1, wherein the second plenum subsection has a second plenum subsection width (w2), and second subsection plenum length (l2) varies
20 across second plenum subsection width (w2).
16. The respiratory protection device of claim 1, wherein the air delivery plenum exhibits a pressure drop of less than 250 Pa at a flow rate of 200 Slpm when measured according to the Pressure Drop Test.
- 25 17. The respiratory protection device of claim 1, wherein the second plenum subsection comprises symmetrical left and right halves opposite the longitudinal axis.
18. The respiratory protection device of claim 1, wherein the air delivery plenum is non-
30 destroyingly separable from the shell.
19. A respiratory protection device, comprising:
a curved air delivery plenum having:
a plenum inlet;
35 a plenum outlet; and

first and second plenum subsections positioned between the plenum inlet and outlet, the second plenum subsection comprising a second plenum inlet having a cross-sectional area (A_{i2}) and a maximum cross-sectional area (A_{max2}), and front and rear walls extending in a direction outwardly from a longitudinal axis and separated by a length (l_2), the longitudinal axis extending along the air delivery plenum in a direction of airflow;

wherein the air delivery plenum is curved along a longitudinal axis extending through the plenum inlet in a direction of airflow, and wherein $2.0 \text{ cm}^2 < (A_{max2}) < 180 \text{ cm}^2$, $1.3 \text{ cm}^2 < (A_{i2}) < 45 \text{ cm}^2$, and $1.5 \text{ cm} < (l_2) < 10 \text{ cm}$.

20. The respiratory protection device of claim 19, wherein the air delivery plenum exhibits a pressure drop of less than 250 Pa at a flow rate of 200 Slpm when measured according to the Pressure Drop Test.

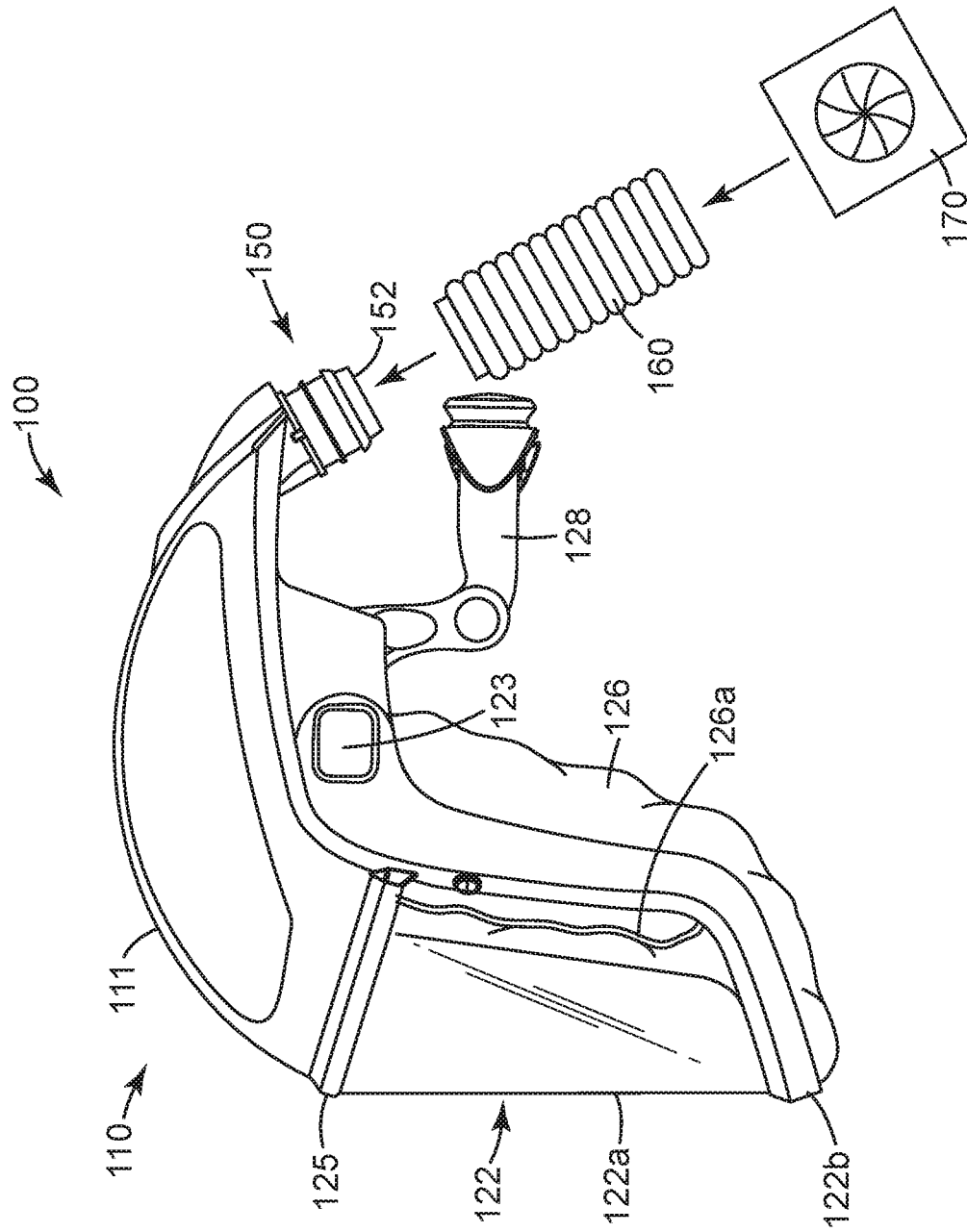
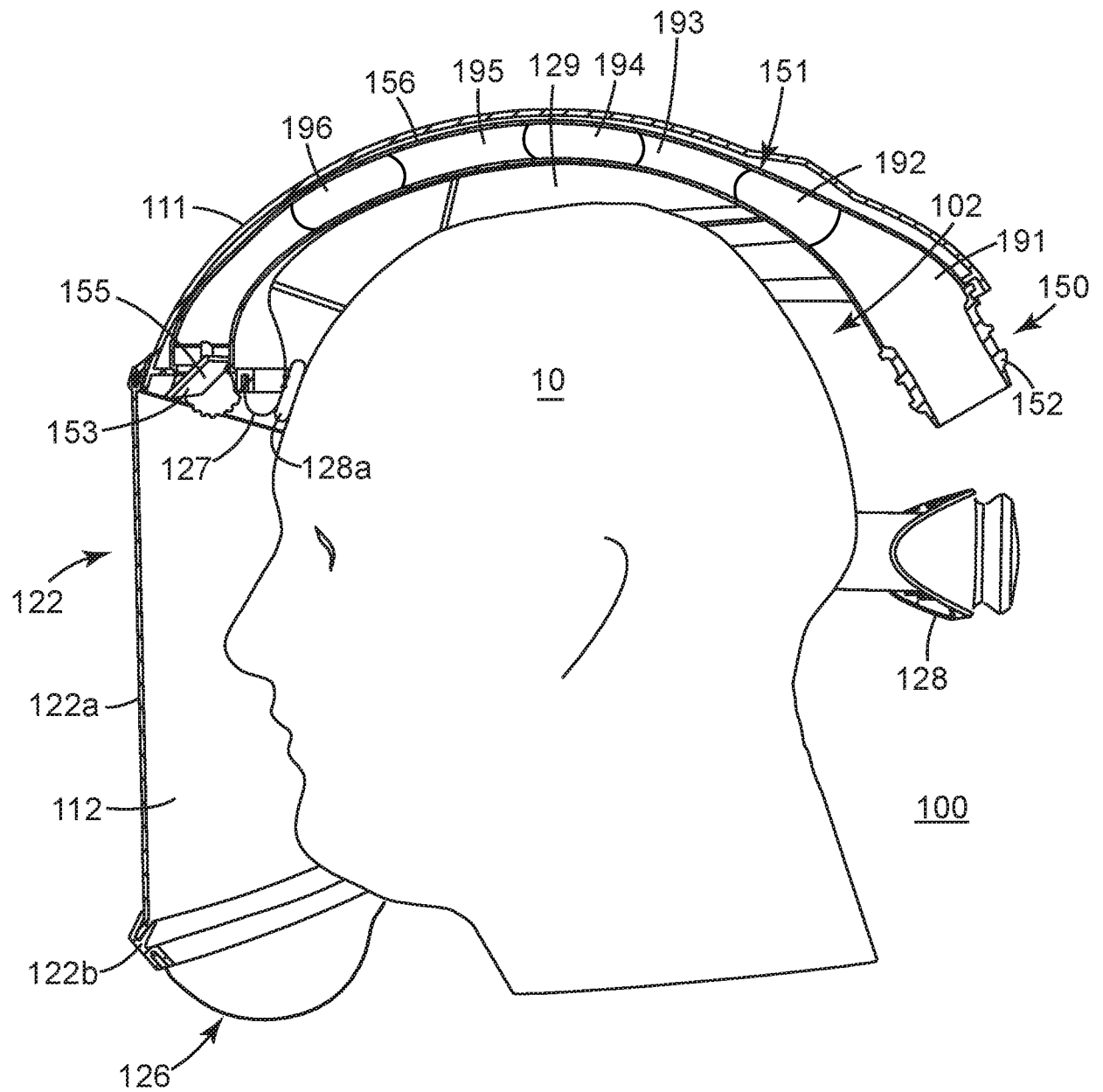


Fig. 1A

*Fig. 1B*

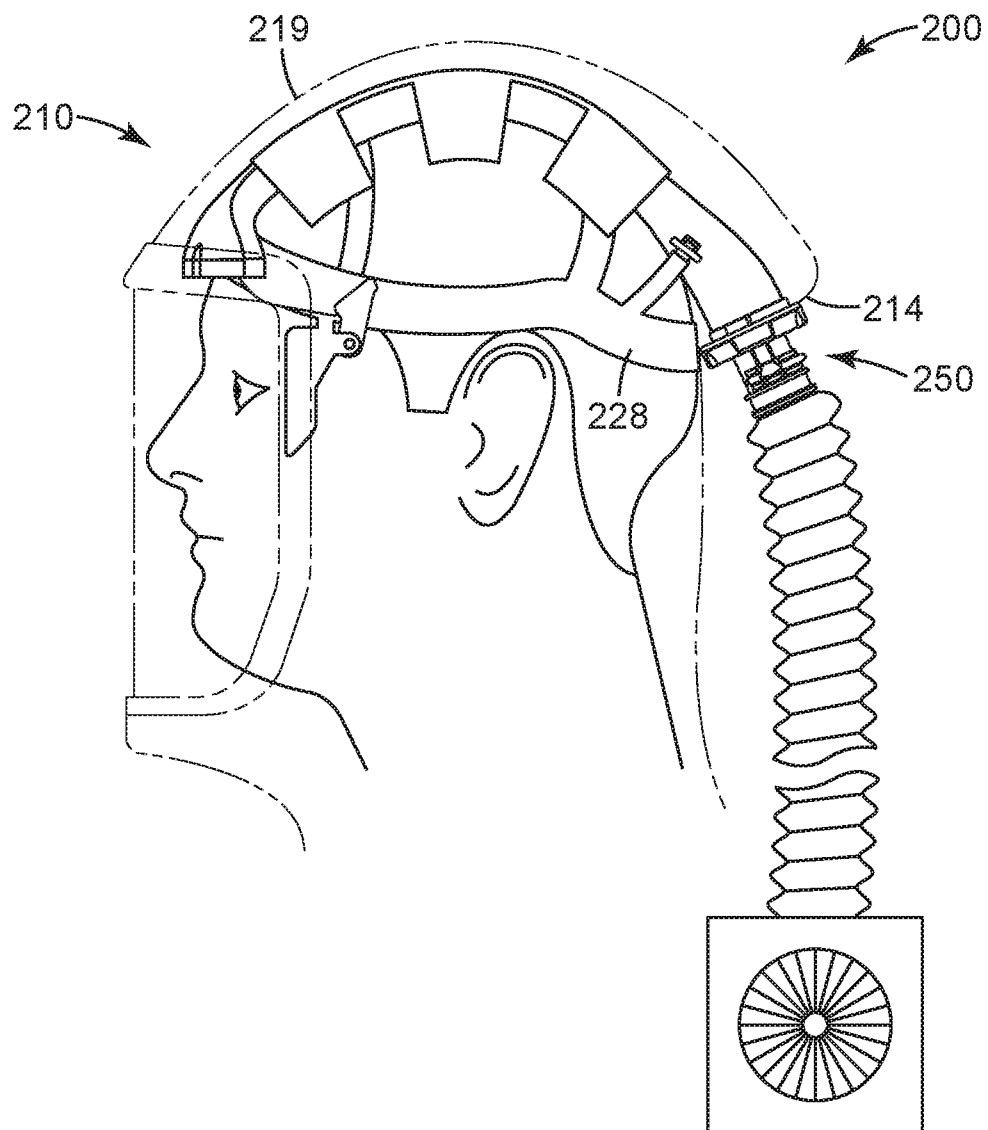
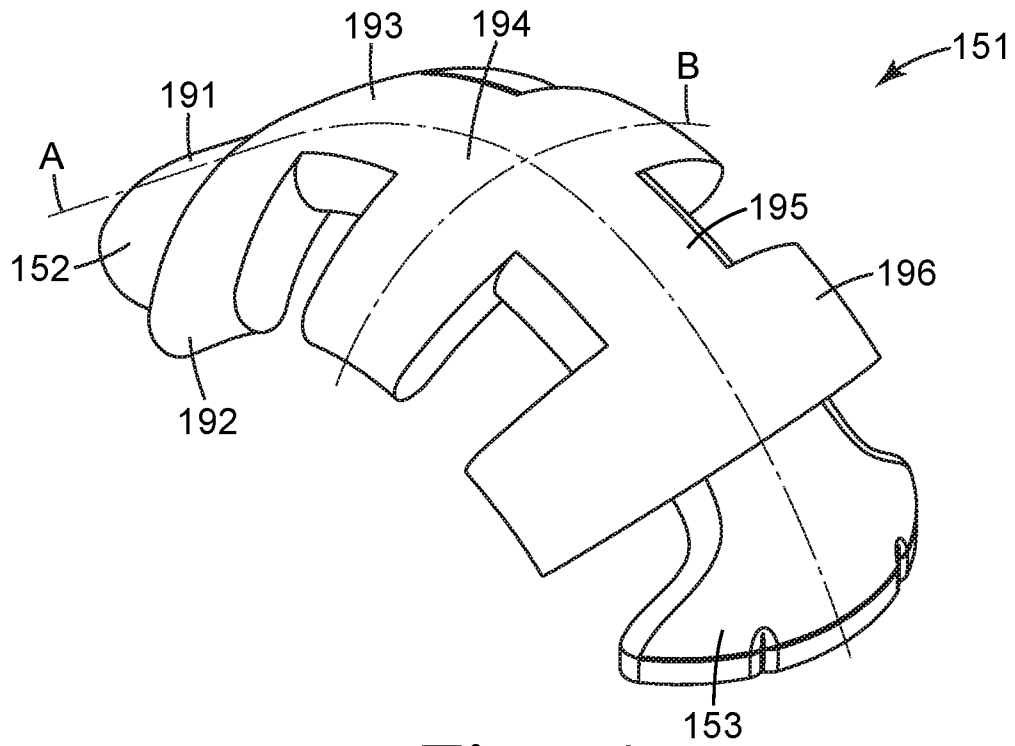
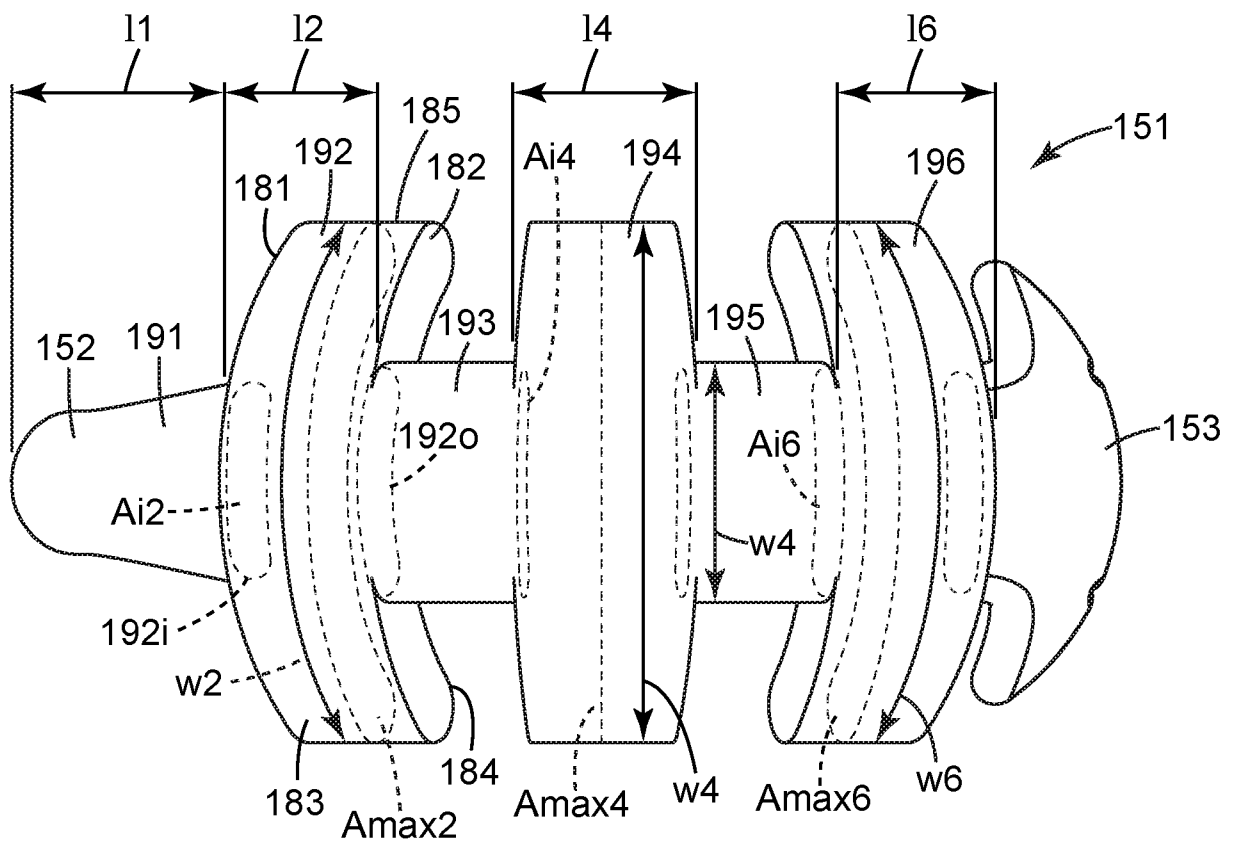
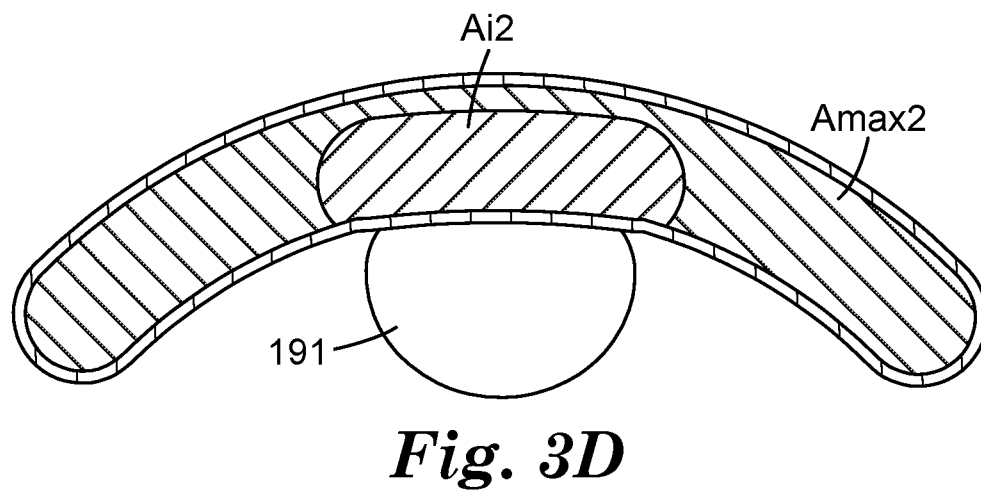
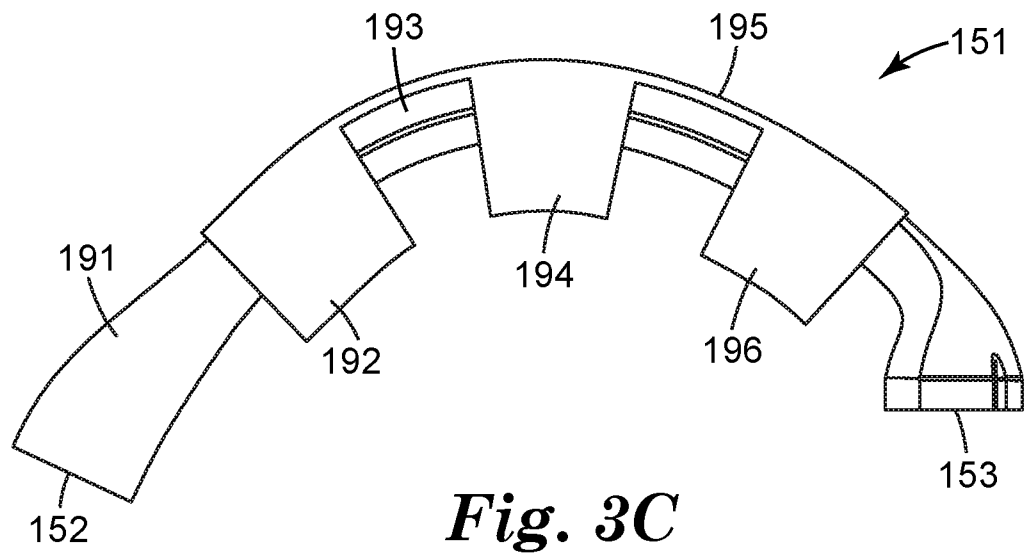


Fig. 2

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**Fig. 3A****Fig. 3B**

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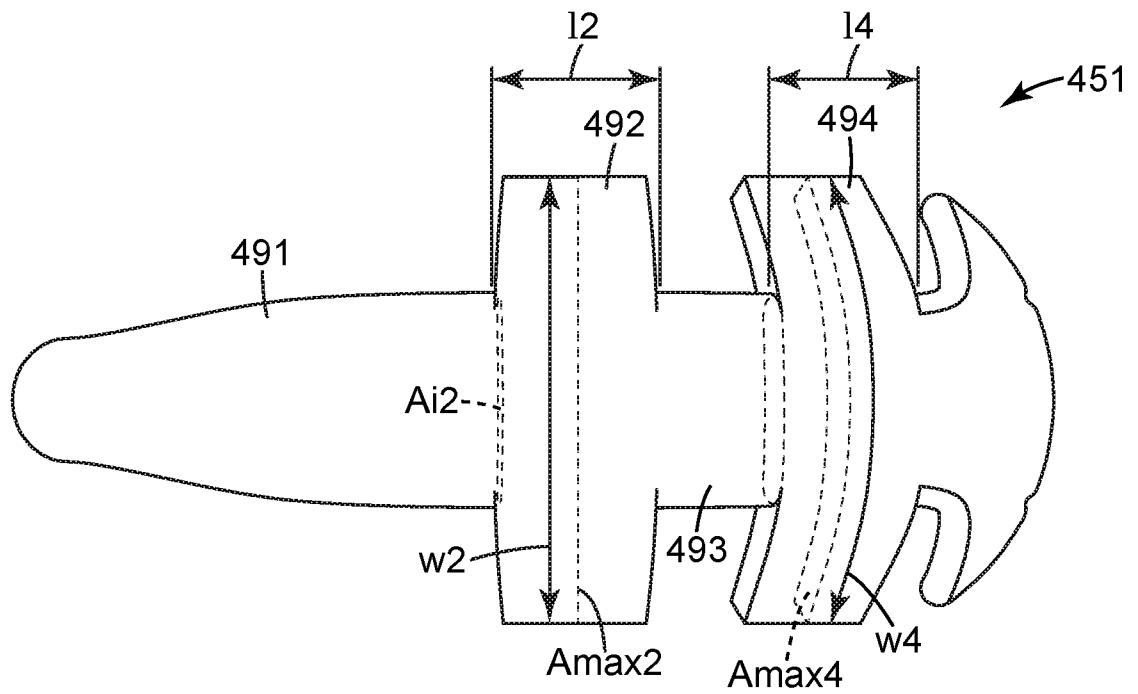


Fig. 4

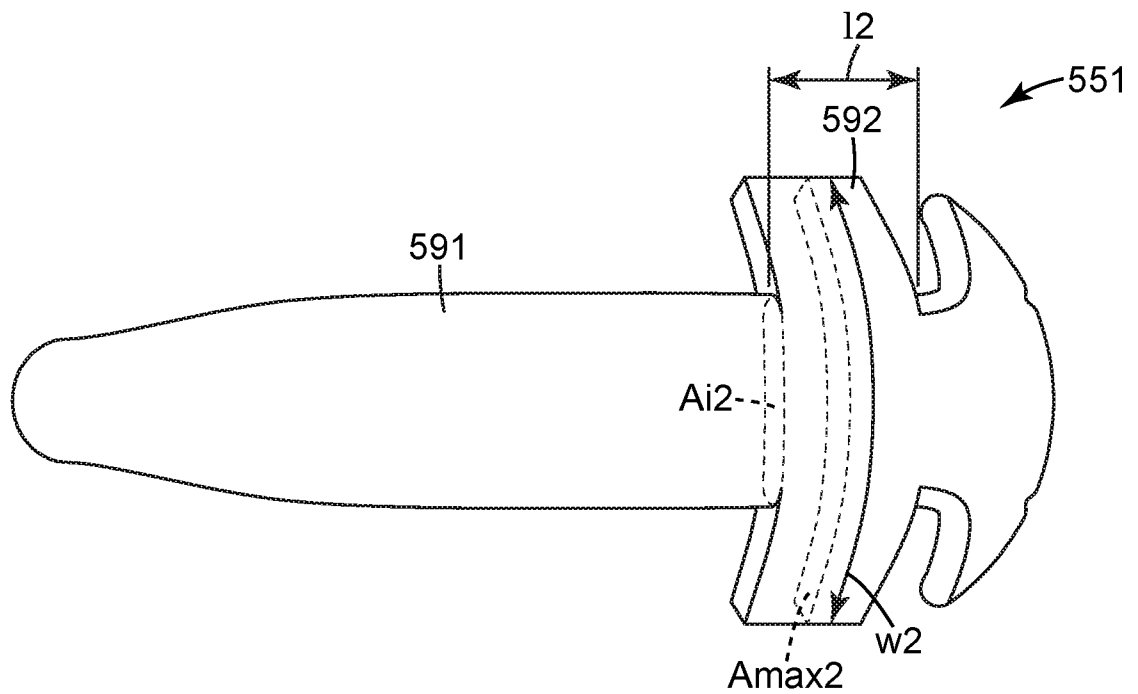


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/035010

A. CLASSIFICATION OF SUBJECT MATTER

INV. A62B18/00 A62B18/04 A62B18/08 G10K11/16 A41D13/002
A41D13/11
ADD. A42B3/28

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)

A62B A42B G10K A41D

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)

EP0-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	US 3 736 927 A (MISAQI F) 5 June 1973 (1973-06-05)	1-6,9, 12-18
Y	column 3, lines 18-44	10,11,
A	column 3, lines 60-64 figures 1-8	19,20 7,8

X	WO 2006/006819 A1 (PARK CHUN BAE [KR]) 19 January 2006 (2006-01-19)	1-8,14, 16-18
A	paragraphs [0007] - [0023] paragraphs [0035] - [0055] figures 1-8	9-13,15, 19,20

Y	DE 20 2006 013683 U1 (DRAEGER MEDICAL AG [DE]) 14 December 2006 (2006-12-14)	10,11, 19,20
A	paragraph [0007] figure 1	1-9, 12-18

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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

8 August 2016

Date of mailing of the international search report

16/08/2016

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/035010

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/127976 A1 (ACKER JARON M [US] ET AL) 5 June 2008 (2008-06-05) paragraph [0022] paragraph [0032] paragraph [0035] figures 1, 4, 5 -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/035010

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