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Nagy et al.

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(54) **RESTORABLE CRASH CUSHION APPARATUS**

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E01F 15/14 (2006.01)

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CPC E01F 15/00; E01F 15/04; E01F 15/0461; E01F 15/146; E01F 15/0423; E01F 15/143
See application file for complete search history.

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(57) **ABSTRACT**

A crash cushion apparatus broadly comprising a rail assembly, a number of dividers and a number of side panels forming a number of collapsible bays, and a number of crushable tubes. The rail assembly includes a number of anchor plates and a rail. The dividers are longitudinally spaced apart from each other and slidably entrained on the rail. The side panels link the dividers together. The crushable tubes are oriented longitudinally in spaces formed by the collapsible bays and extend between sequentially adjacent ones of the dividers. The dividers entrain the crushable tubes

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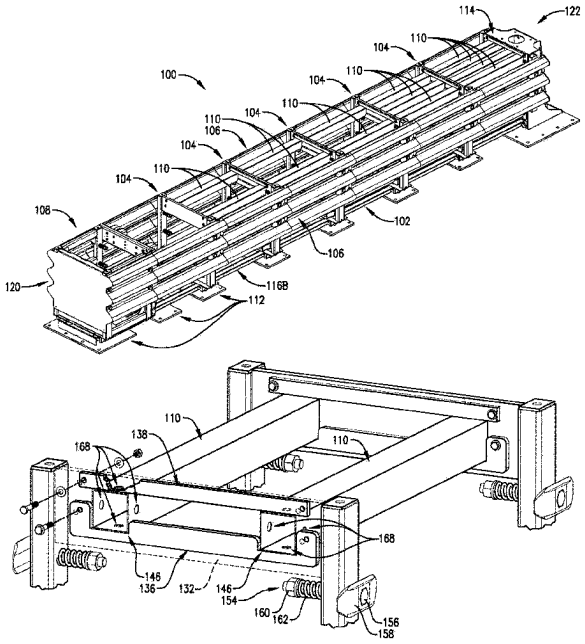

in the longitudinal orientation without the crushable tubes being fixed to the dividers. The dividers are configured to be driven rearward along the rail and crush the crushable tubes to sequentially collapse the collapsible bays.

20 Claims, 6 Drawing Sheets

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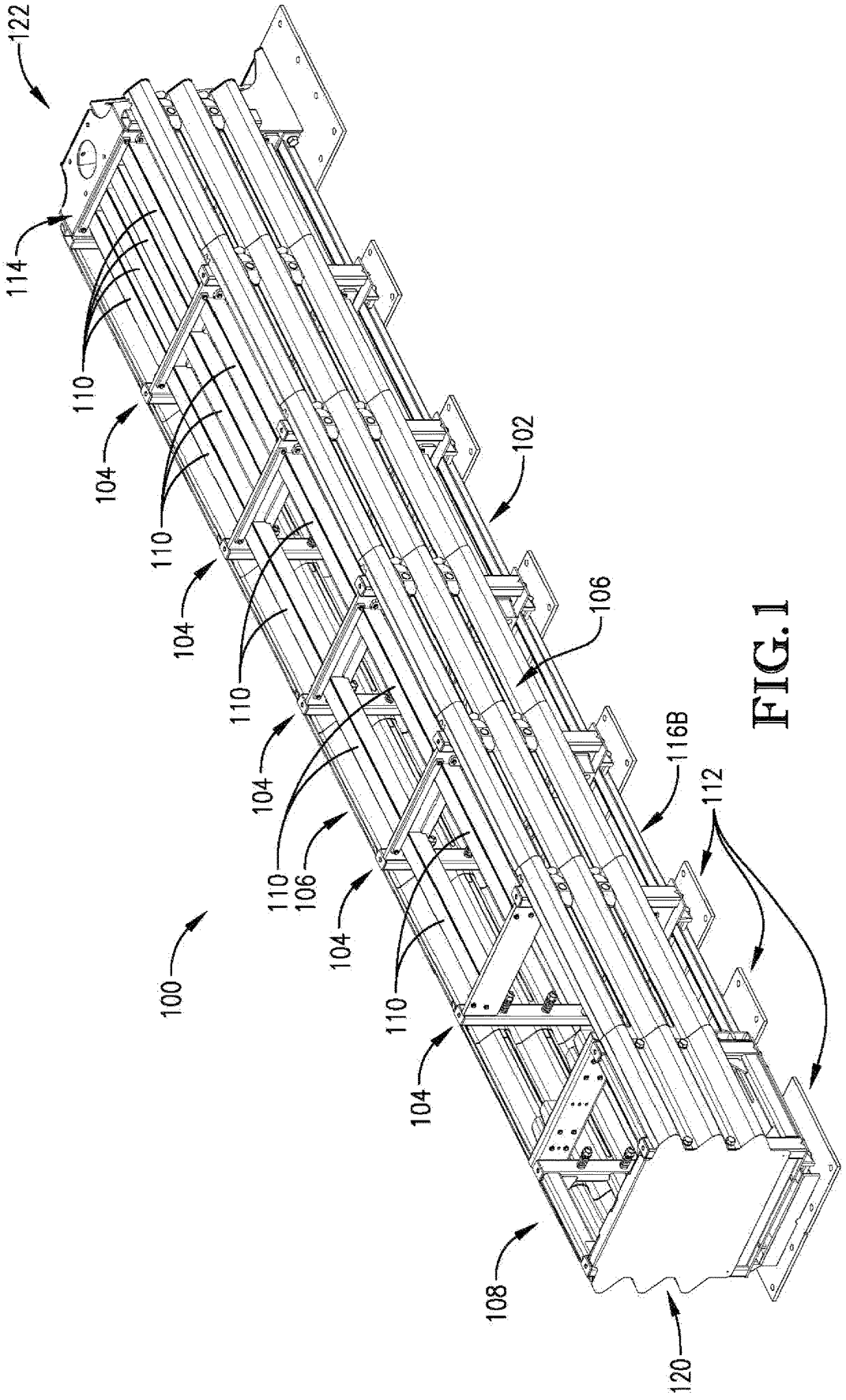
122
114
110
104
110
104
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104
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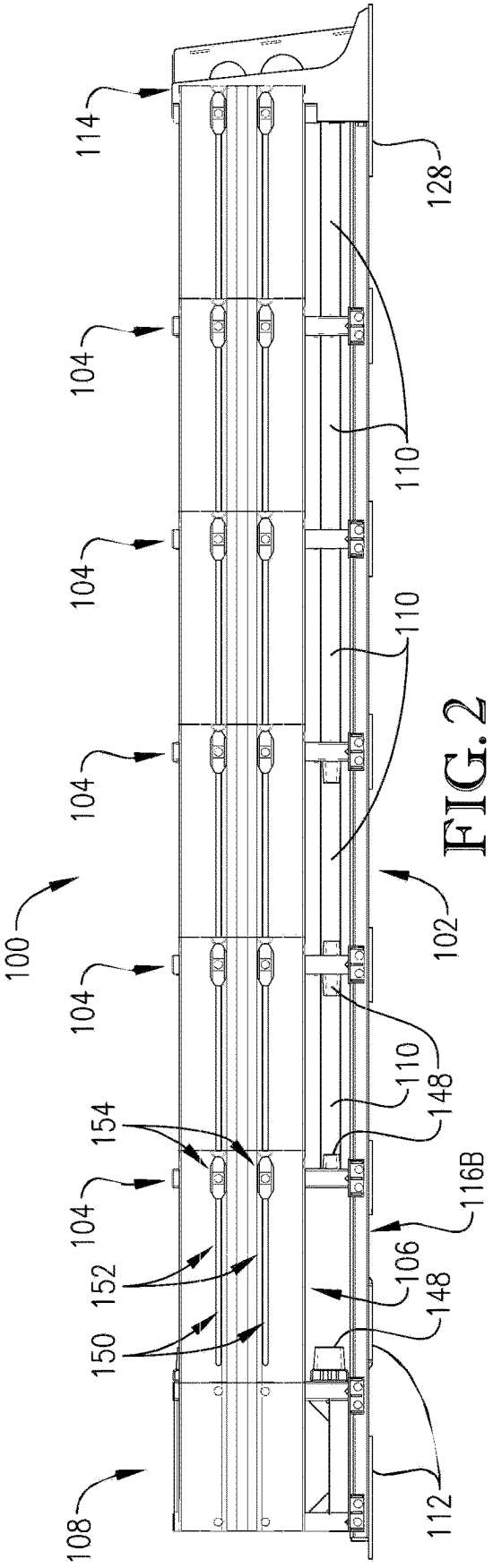
106
104
110
104
102
106
116B
112
100
108
120

FIG. 1


114
104
104
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128
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154
116B
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112
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100
102

FIG. 2

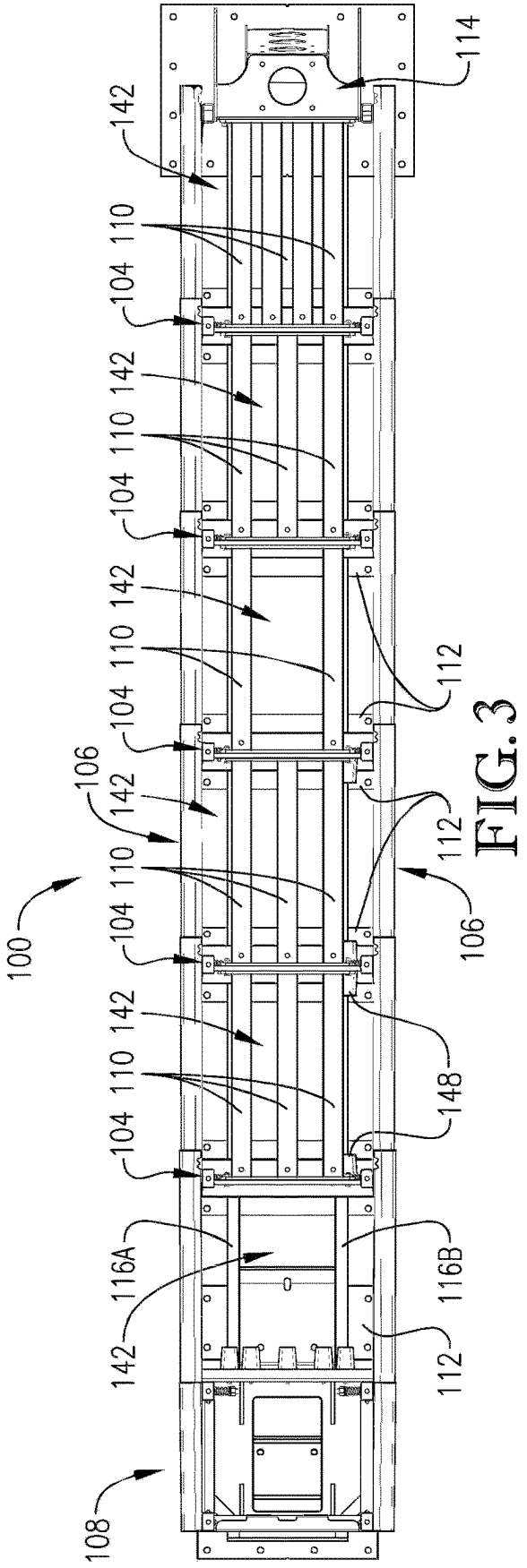
114
142
104 110
104 110 142
104 110 142
104 110 142
104 110
106
142
112
106
104 110
142
148
104 110
116A
116B
142
112
108
100

FIG. 3

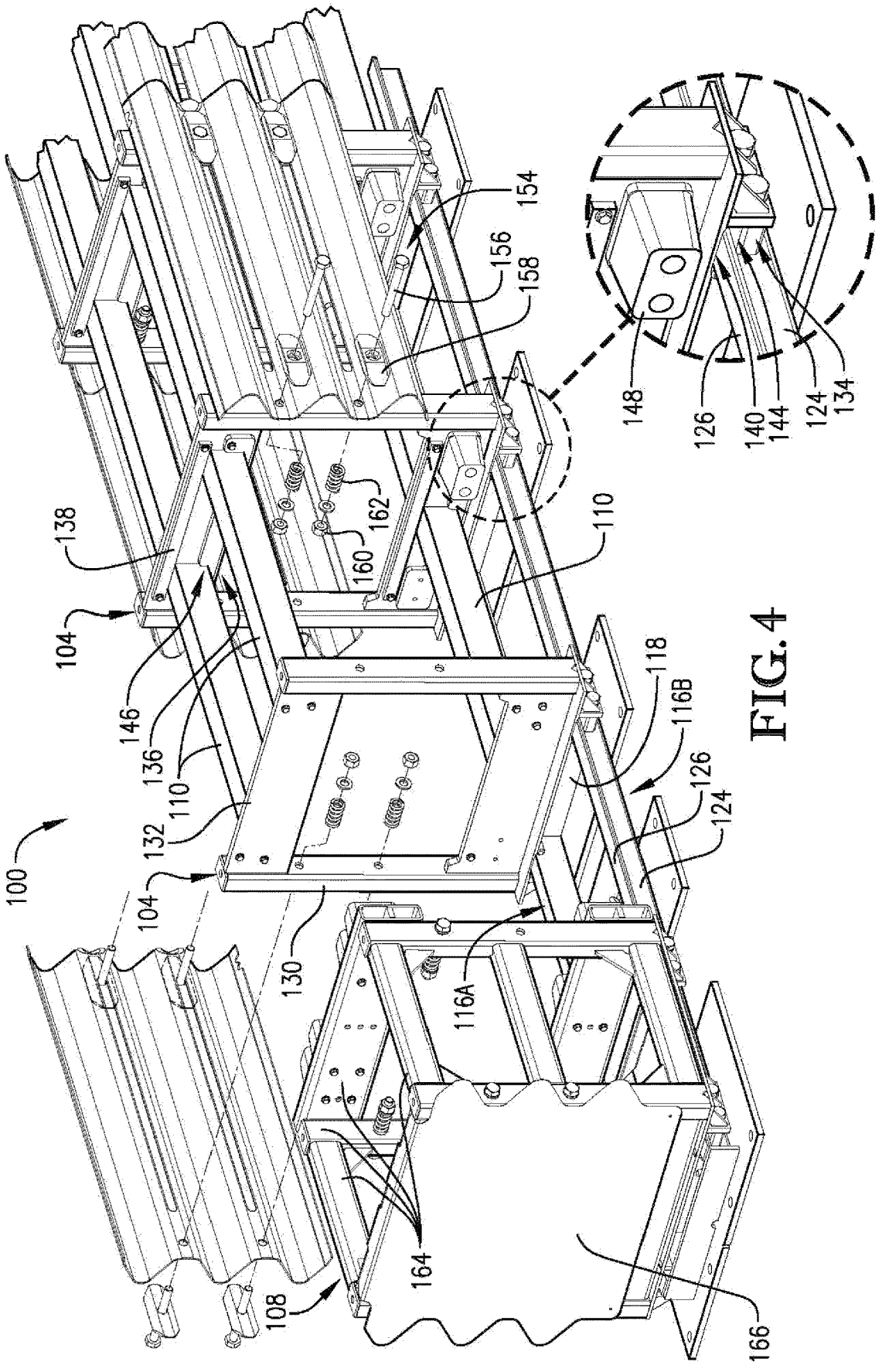
100
104
104
108
110
110
116A
116B
118
124
126
126
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FIG. 4

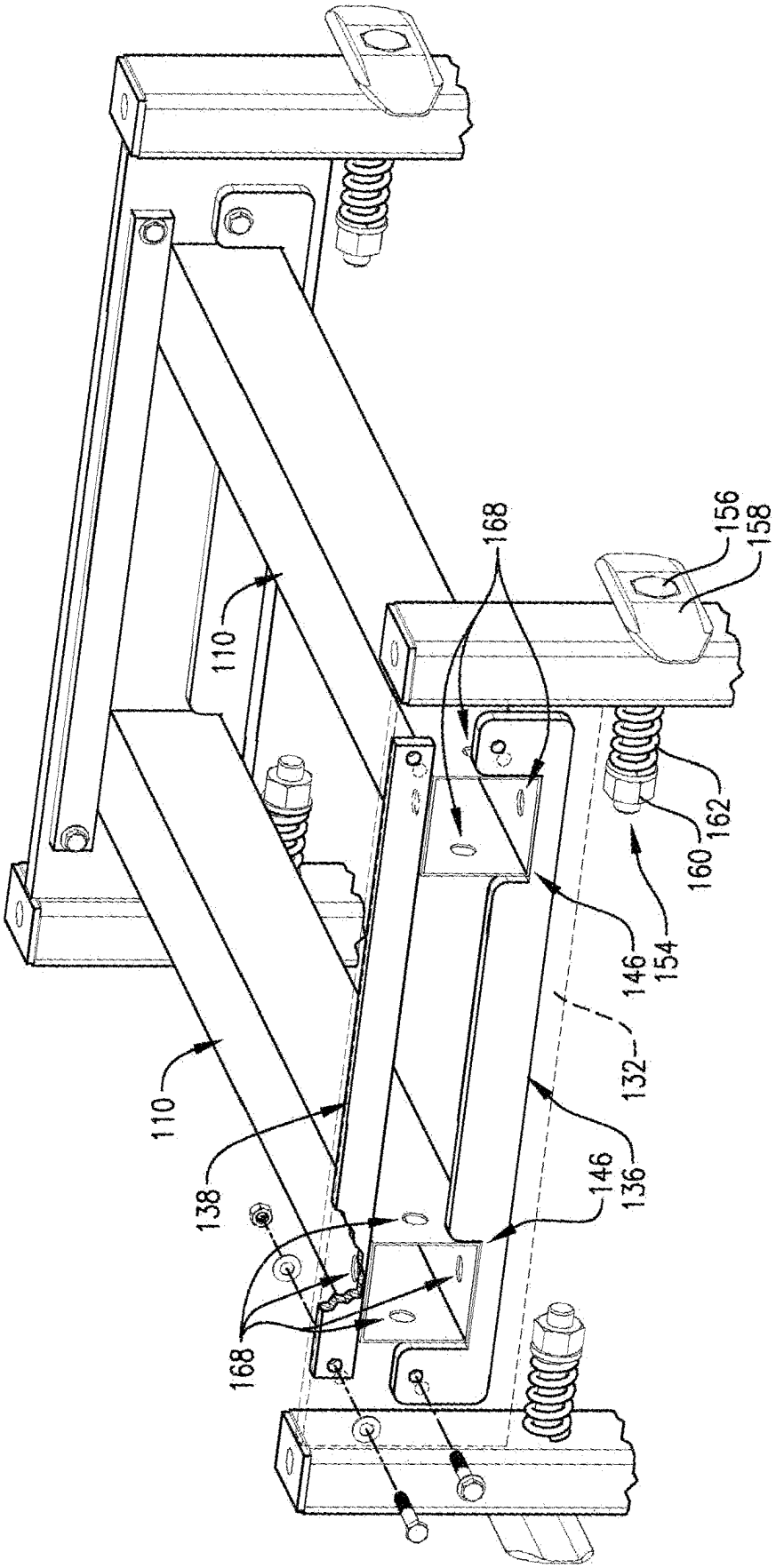

FIG. 5

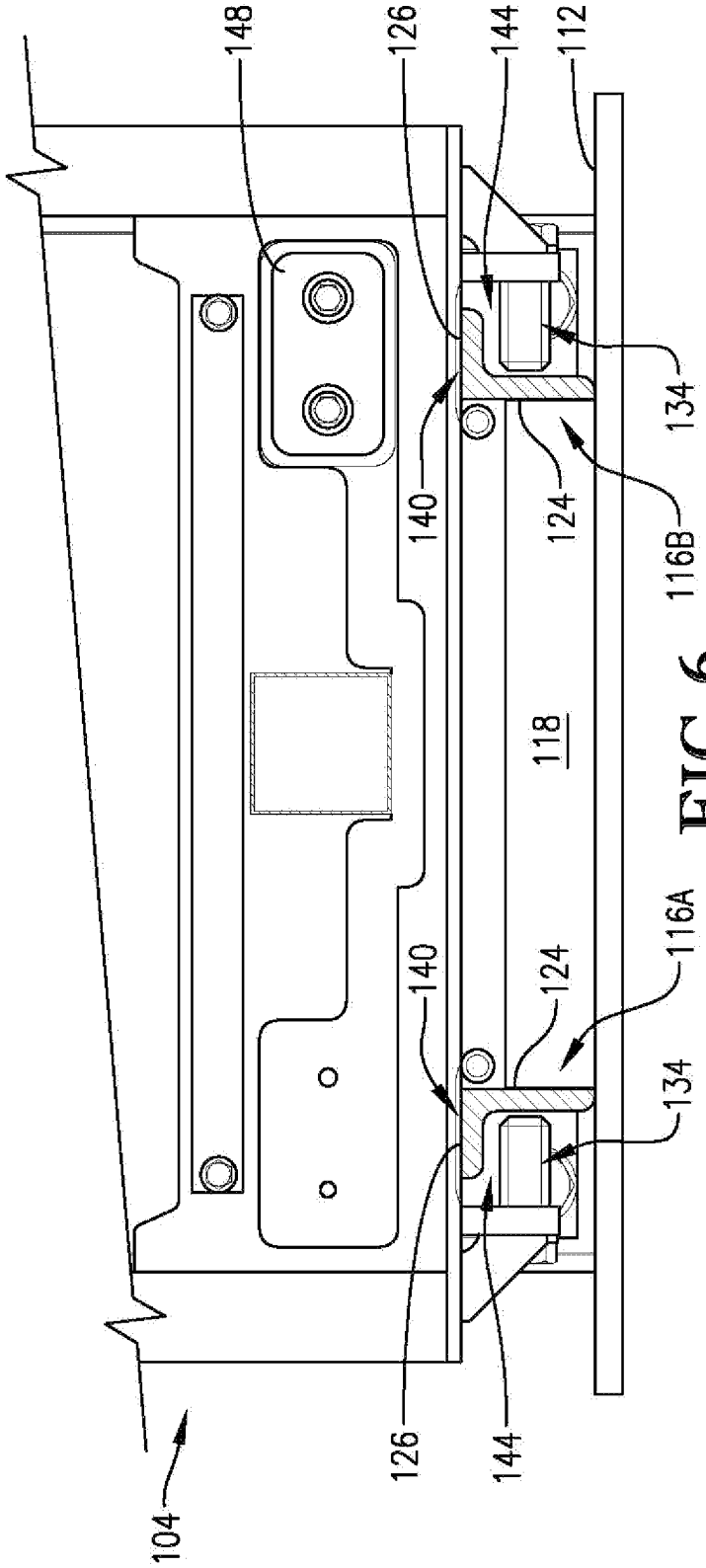
148
126
144
112
134
140
124
116B
118
116A
140
124
134
126
144
104

FIG. 6

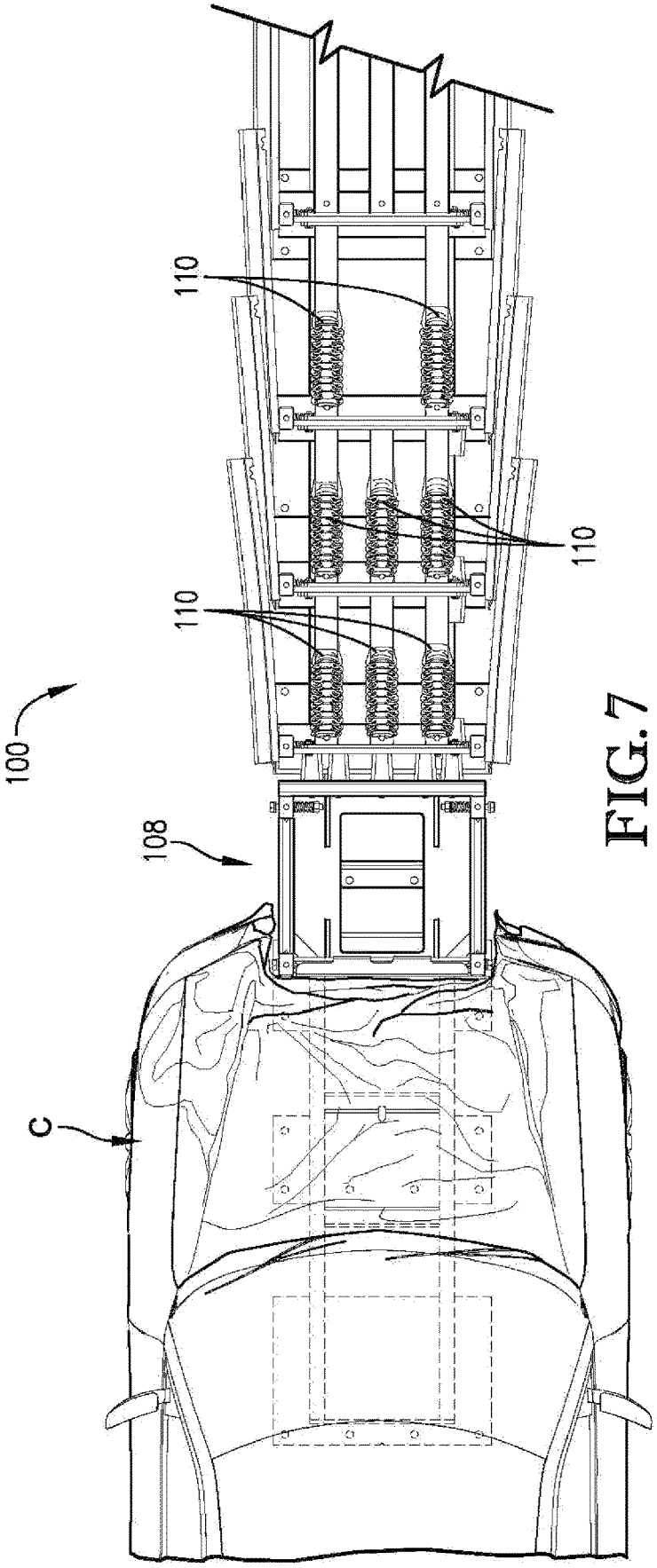

FIG. 7

RESTORABLE CRASH CUSHION APPARATUS

BACKGROUND

Crash cushion apparatuses are often placed in road medians and shoulders to safely redirect or arrest wayward vehicles. Some crash cushion apparatuses include crushable tubes affixed in collapsible bays for absorbing and dispersing impact forces. Unfortunately, the crushable tubes can be imperfectly affixed in the collapsible bays (e.g., via cracked welds or broken fasteners) in ways that are impossible or at least impractical to identify and address. The crushable tubes also often buckle and bend when crushed, which negates their effectiveness and introduces unpredictable behavior. Furthermore, slideable dividers forming the collapsible bays sometimes bind on their rails, thus preventing impact forces from reaching the crushable tubes and being dissipated from the vehicles. Crash cushion apparatuses are also difficult to inspect and restore after impact events, resulting in significant roadside hazardous exposure to workers.

SUMMARY

Embodiments of the invention solve the above-mentioned problems and other problems and provide a distinct advance in the art of crash cushion apparatuses. More particularly, the invention provides a restorable crash cushion apparatus including crushable tubes that are entrained but not affixed in collapsible bays and that have improved crushing characteristics. The crash cushion apparatus also includes slideable dividers with improved sliding characteristics. These and other features ensure more effective and predictable impact behavior.

An embodiment of the crash cushion apparatus is configured to be positioned in a road median or shoulder to mitigate head-on vehicle impacts and deflect side impacts and broadly comprises a rail assembly; a number of dividers and side panels that together form a number of collapsible bays entrained on the rail assembly; a nose component configured to be impacted by a vehicle during a head-on impact event and remain substantially intact as it is driven rearward toward the collapsible bays; and a number of crushable tubes entrained but not affixed in the collapsible bays. The crushable tubes crush longitudinally during a head-on impact event, thereby eliminating the need for tube crushing guidance structure.

The rail assembly supports the collapsible bays and the nose component and permits the nose component to be driven toward and initiate collapse of the collapsible bays. An embodiment of the rail assembly includes a number of anchor plates, opposing rails, and a number of crossmembers. The rail assembly is attached to a backstop.

The anchor plates are rigidly affixed to a substrate or ground surface via threaded bolts or other similar components so that the rail assembly does not move during an impact event. Each anchor plate is a flat plate spaced apart from sequentially adjacent anchor plates.

The backstop helps prevent an impacting vehicle from advancing further and is positioned near the rearward end of the crash cushion apparatus and includes an anchor plate affixed to the ground or road surface. To that end, the backstop is a fixed point at which tubes in the aft-most collapsible bay crush against in the longitudinal direction.

The opposing rails extend longitudinally from the forward end to the rearward end and are fixed in place via the anchor plates. Each of the opposing rails includes a riser and a ledge.

Each of the crossmembers extends laterally between the opposing rails on one of the anchor plates. This increases rigidity of the rail assembly.

The dividers are longitudinally spaced apart from each other and slidably entrained on the rails. Each of the dividers includes vertical members and horizontal members, opposing tabs, and one or more cradle members and entrainment members depending on the divider's position. Each of the dividers also includes beveled (filleted, chamfered, or tapered) surfaces.

The horizontal members extend between the vertical members and abut ends of the crushable tubes. This entrains the crushable tubes in the corresponding collapsible bays and allows impact forces to be transferred between the crushable tubes and the dividers. The horizontal members and crushable tubes are not fixed together.

The opposing tabs are spaced below the ledges of the rails by a gap and extend inwardly toward the risers of the rails to prevent the dividers from becoming derailed. The gap is a predetermined width that optimally facilitates movement between the dividers and the rails.

Each cradle member extends laterally and adjacent to one of the horizontal members of a corresponding divider and includes one or more recesses corresponding to a number of crushable tubes disposed in the corresponding collapsible bay. The cradle member supports an end of one or more of the crushable tubes and prevents lateral and vertical movement thereof.

Each entrainment member extends laterally and adjacent to one of the horizontal members of a corresponding divider and over ends of corresponding crushable tubes. The entrainment member, together with a corresponding cradle member entrains the crushable tube in a longitudinal orientation in the corresponding collapsible bay without the crushable tube being fixed to the corresponding divider.

The beveled surfaces are disposed near the rails and are configured to engage the rails during an impact event. The beveled surfaces improve movement of the dividers relative to the rails.

The side panels extend between and are attached to sides of sequential dividers and may include a number of holes and a number of horizontal slots and horizontal grooves for receiving biased fasteners. Each side panel is corrugated thereby increasing rigidity and impact reactivity for deflecting side impacts and redirecting side impact forces. The side panels overlap adjacent side panels so that the side panels slide next to (i.e., nest with) each other in an impact event.

The biased fasteners attach the side panels to the dividers via the slots and corresponding holes of adjacent panels. The biased fasteners include a bolt, a sliding guide, a nut, and a biasing element.

The bolt extends through the slot and through a fastener hole of a vertical member of one of the dividers. In some embodiments, the bolt also extends through the biasing element (particularly in the case of a helical spring). A head end of the bolt is attached to or in inter-engagement with the sliding guide.

The sliding guide is positioned on an outer side of the corresponding panel in the horizontal groove in inter-engagement with a head of the bolt. The sliding guide is elongated for guiding the corresponding panel via the horizontal groove as the panel slides relative to the biased fastener.

The nut retains the biasing element in engagement with the corresponding divider. In the case of a helical spring, the nut entrains the biasing element on the bolt.

The biasing element adds tension to the corresponding panel to keep the panel in place while allowing it to slide more freely during an impact event. The biasing element may be a coil spring, a Belleville washer, a urethane spring, a leaf spring, or the like. In another embodiment, no biasing element is used.

Some of the dividers and/or the nose component optionally include shock absorption elements for reducing spikes in energy transfer (e.g., minimize shock) between some of the dividers and other components. The shock absorption elements may be rubber or similar material. These can also be used to aid in alignment of the dividers.

The nose component includes a number of rigidly connected members, a delineation plate, a set of tabs, and a set of beveled surfaces similar to the beveled surfaces described above.

The rigidly connected members form a box frame near the forward end of the crash cushion apparatus. The rigidly connected members are sufficiently strong to transfer loads into the dividers and the crushable tubes without absorbing much energy themselves (except the energy that initiates movement of the nose component).

The delineation plate extends between some of the rigidly connected members and together with opposing side panels at least partially enclose the box frame. The delineation plate may include curved edges complementary to the corrugated shape of forwardmost side panels.

The tabs are spaced below the ledges of the rails by a gap and extend inwardly toward the risers of the rails to prevent the nose component from becoming derailed from the rails. As discussed above, the gap is a predetermined width that optimally facilitates movement between the nose component and the rails.

The beveled surfaces are disposed near the rails and are configured to engage the rails during an impact event. The beveled surfaces improve movement of the nose component relative to the rails. In other words, the beveled surfaces reduce binding between the nose component and the rails.

The crushable tubes are oriented longitudinally in the collapsible bays and extend between sequentially adjacent ones of the dividers such that the dividers (and more specifically, the cradle members and entrainment members) entrain the crushable tubes in the longitudinal orientation without the crushable tubes being fixed to the dividers.

Each crushable tube may include one or more holes near one of its ends (e.g., a forward end) for promoting longitudinal and progressive collapse of the crushable tube. Edges of the hole(s) may be between approximately 0.5 inches to approximately 3 inches from the end of the crushable tube. In one embodiment, each crushable tube includes four holes, one on each side.

The crushable tubes are distributed unevenly between the collapsible bays so that at least one of the collapsible bays has more crushable tubes than at least one other of the collapsible bays. In one embodiment, the crushable tubes increase in number per collapsible bay from the forward end to the rearward end of the crash cushion apparatus. In another embodiment, one of the forward-most collapsible bays of the collapsible bays has zero crushable tubes. In yet another embodiment, the foremost collapsible bay (nearest to the nose component includes zero crushable tubes, the next two collapsible bays include three crushable tubes each, the next collapsible bay includes four crushable tubes, the next collapsible bay includes six crushable tubes, and the aftmost collapsible bay includes eight crushable tubes. The crushable tubes may include upper crushable tubes positioned near tops of the dividers and lower crushable tubes positioned near bottoms of the dividers.

The crash cushion apparatus arrests a vehicle impacting the nose component. Specifically, the nose component is driven rearward on the rails toward the foremost divider, thus collapsing the first collapsible bay. Similarly, the side panels corresponding to the first collapsible bay are overlapped by side panels of the nose component and begin to slide rearward via the biased fasteners. The shock absorption elements reduce spikes in energy transfer (e.g., minimize shock) between some of the dividers (and particularly the foremost dividers) and other components.

The nose component continues to be driven rearward, thus sequentially collapsing corresponding collapsible bays until the vehicle is stopped. The dividers crush the crushable tubes in the collapsible bays as the dividers are driven rearward.

The above-described crash cushion apparatus provides several advantages. For example, the dividers entrain the crushable tubes in their longitudinal orientation in the collapsible bays without the crushable tubes being fixed to the dividers. This helps ensure that energy transfer between the dividers and the crushable tubes is primarily due to longitudinal rearward movement of the dividers and not from a wider array of forces transferable between fixed joints (e.g., lateral stress, bending, twisting, stretching, recoil, or the like). The crushable tubes being entrained only (and not fixed to the dividers) also ensures the crushable tubes are properly installed—it is not necessary to inspect welds or fasteners between the dividers and the crushable tubes. The entrainment members also prevent theft of the crushable tubes. Furthermore, this also facilitates safely inspecting, restoring, re-building and/or re-using elements of the crash cushion apparatus after an impact event.

The holes of the crushable tubes promote longitudinal and progressive collapse of the crushable tubes, thus mitigating buckling and bending of the crushable tubes during an impact event. The holes of the crushable tubes also reduce the energy spike associated with the forces required to initiate crushing of the crushable tubes. The increasing number of crushable tubes per collapsible bay in some embodiments allows the crash cushion apparatus to safely arrest vehicles of different sizes.

The dividers have improved moveability relative to the rails during an impact event due to the gaps between the tabs of the dividers and the ledge of the rails. The beveled surfaces of the dividers also improve moveability of the dividers during an impact event. Specifically, the gaps and the beveled surfaces prevent binding between the dividers and the rails as the dividers are driven rearward. These features also facilitate restoration of the crash cushion apparatus.

The side panels redirect side impacts while not inhibiting the collapsing of the collapsible bays during head-on impact events. To that end, the side panels overlap each other while being slideably linked to the dividers via the biased fasteners and the slots and grooves of the side panels. This also reduces the amount of damage to various components of the crash cushion apparatus during an impact event, which allows the crash cushion apparatus to be refurbished more easily and placed back in service more quickly.

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the

claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Other aspects and advantages of the current invention will be apparent from the following detailed description of the embodiments and the accompanying drawing figures.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

Embodiments of the current invention are described in detail below with reference to the attached drawing figures, wherein:

FIG. **1** is a perspective view of a crash cushion apparatus constructed in accordance with an embodiment of the invention;

FIG. **2** is a side elevation view of the crash cushion apparatus of FIG. **1**;

FIG. **3** is a top plan view of the crash cushion apparatus of FIG. **1**;

FIG. **4** is an enlarged perspective view of the crash cushion apparatus of FIG. **1**;

FIG. **5** is an enlarged perspective view of certain components of the crash cushion apparatus of FIG. **1**;

FIG. **6** is an enlarged front elevation view of certain components of the crash cushion apparatus of FIG. **1**; and

FIG. **7** is a top plan view of the crash cushion apparatus of FIG. **1** during an impact event.

The drawing figures do not limit the current invention to the specific embodiments disclosed and described herein. The drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The following detailed description of the invention references the accompanying drawings that illustrate specific embodiments in which the invention can be practiced. The embodiments are intended to describe aspects of the invention in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments can be utilized and changes can be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense. The scope of the present invention is defined only by the appended claims, along with the full scope of equivalents to which such claims are entitled.

In this description, references to "one embodiment", "an embodiment", or "embodiments" mean that the feature or features being referred to are included in at least one embodiment of the technology. Separate references to "one embodiment", "an embodiment", or "embodiments" in this description do not necessarily refer to the same embodiment and are also not mutually exclusive unless so stated and/or except as will be readily apparent to those skilled in the art from the description. For example, a feature, structure, act, etc. described in one embodiment may also be included in other embodiments, but is not necessarily included. As used in the specification and in the claims, ordering words such as "first" and "second" are used to distinguish between similar components and do not imply specific components. Thus, the current technology can include a variety of combinations and/or integrations of the embodiments described herein.

Turning to the drawing figures, a crash cushion apparatus **100** constructed in accordance with an embodiment of the invention is illustrated. The crash cushion apparatus **100** is configured to be positioned in a road median or shoulder to mitigate head-on vehicle impacts and deflect side impacts. The crash cushion apparatus **100** broadly comprises a rail assembly **102**; a plurality of dividers **104** and a plurality of side panels **106** that together form a plurality of collapsible bays **142** entrained on the rail assembly **102**; a nose component **108** configured to be impacted by a vehicle during a head-on impact event and remain substantially intact as it is driven rearward toward the collapsible bays **142**; and a plurality of crushable tubes **110** that are entrained but not affixed in the collapsible bays **142** and that have improved crushing characteristics. To that end, the crushable tubes **110** crush longitudinally during a head-on impact event, thereby eliminating the need for tube crushing guidance structure.

The rail assembly **102** supports the plurality of dividers **104** and the nose component **108** and acts as a fixed base for the crash cushion apparatus **100** during an impact event. The rail assembly **102** may include a plurality of anchor plates **112**, opposing rails **116**A,B, and a plurality of crossmembers **118**. The rail assembly **102** may be attached to a backstop **114**.

The plurality of anchor plates **112** may be rigidly affixed to a substrate or ground surface so that the rail assembly **102** does not move during an impact event. Each anchor plate **112** may be a flat plate spaced apart from sequentially adjacent anchor plates. The anchor plates **112** may be affixed to the road or a ground surface via threaded anchor bolts or other similar components.

The backstop **114** is positioned near the rearward end **122** of the crash cushion apparatus **100** and includes an anchor plate **128** affixed to the ground or a road surface via threaded anchor bolts or other similar components. The backstop **114** helps prevent an impacting vehicle from advancing further. To that end, the backstop is a fixed point at which tubes in the aft-most collapsible bay crush against in the longitudinal direction.

The opposing rails **116**A,B extend longitudinally from the forward end **120** to the rearward end **122** (and more specifically, to the backstop **114**) and are fixed in place via the plurality of anchor plates **112**. Each of the opposing rails **116**A,B includes a riser **124** and a ledge **126**, with the ledge **126** extending horizontally from an upper end of the riser **124**.

Each of the plurality of crossmembers **118** extends laterally between the opposing rails **116**A,B on one of the plurality of anchor plates **112**. This increases rigidity of the rail assembly **102**.

The plurality of dividers **104** are longitudinally spaced apart from each other and slidably entrained on the rails **116**A,B. Each of the plurality of dividers **104** includes vertical members **130** and horizontal members **132** thereby forming a rectangular structure. Each of the plurality of dividers **104** further includes opposing tabs **134**A,B, one or more cradle members **136**, and one or more entrainment members **138**. Each of the plurality of dividers **104** may also include beveled (filleted, chamfered, or tapered) surfaces **140**A,B.

The plurality of dividers **104** together with the plurality of side panels **106** form a plurality of collapsible bays **142**. The collapsible bays **142** entrain the crushable tubes **110** in spaces formed by the plurality of dividers **104** and plurality of side panels **106** as described below. The dividers **104** have improved sliding characteristics, which ensure more effective and predictable impact behavior.

The horizontal members **132** extend between the vertical members **130** and abut ends of the crushable tubes **110**. This

entrains the crushable tubes **110** in the corresponding collapsible bays **142** and allows impact forces to be transferred between the crushable tubes **110** and the dividers **104**. The horizontal members **132** and crushable tubes **110** are not fixed together.

The opposing tabs **134**A,B are spaced below the ledges **126** of the rails **116**A,B by a gap **144** and extend inwardly toward the risers **124** of the rails **116**A,B to prevent the plurality of dividers **104** from becoming derailed from the rails **116**A,B. The gap **144** may be a predetermined amount that optimally facilitates movement between the plurality of dividers **104** and the rails **116**A,B. A gap size too small, a non-existent gap, or a gap size too large results in binding between the plurality of dividers **104** and the rails **116**A,B, derailment, or poor energy transfer during an impact event. The gap **144** also facilitates restoration of the crash cushion apparatus **100**. In one embodiment, the gap is between approximately $\frac{3}{8}^{th}$ inch and approximately $\frac{1}{8}^{th}$ inch.

As best seen in FIG. **5**, each cradle member **136** extends laterally and adjacent to one of the horizontal members **132** of a corresponding divider **104** and includes one or more recesses **146** corresponding to a number of crushable tubes **110** disposed in the corresponding collapsible bay **142**. The cradle member **136** supports an end of one or more of the crushable tubes **110** and prevents lateral movement thereof.

Each entrainment member **138** extends laterally and adjacent to one of the horizontal members **132** of a corresponding divider **104** and over ends of corresponding crushable tubes **110**. The entrainment member **138**, together with a corresponding cradle member **136** entrain the crushable tube **110** in a longitudinal orientation in the corresponding collapsible bay **142** without the crushable tube **110** being fixed to the corresponding divider **104**. The entrainment members **138** also prevent theft of the crushable tubes **110**.

As best seen in FIGS. **4** and **6**, the beveled surfaces **140**A,B are disposed near the rails **116**A,B and are configured to engage the rails **116**A,B during an impact event. The beveled surfaces **140**A,B improve movement of the plurality of dividers **104** relative to the rails **116**A,B. In other words, the beveled surfaces **140**A,B reduce binding between the plurality of dividers **104** and the rails **116**A,B.

As best seen in FIGS. **2** and **4**, the plurality of side panels **106** extend between and are attached to sides of sequential dividers **104** and may include horizontal slots **150** and horizontal grooves **152** for receiving biased fasteners **154**. Each side panel **106** may be corrugated or have similar geometries thereby increasing rigidity and impact reactivity for deflecting side impacts and redirecting side impact forces. The side panels **106** may overlap adjacent side panels **106** so that the side panels **106** slide next to (i.e., nest with) each other in an impact event. Additional side panels may extend aft of the backstop **114**.

As best seen in FIGS. **4** and **5**, the biased fasteners **154** attach the side panels **106** to the dividers **104** via the slots **150** and corresponding holes of adjacent panels **106**. The biased fasteners **154** include a bolt **156**, a sliding guide **158**, a nut **160**, and a biasing element **162**. The biased fasteners **154** facilitate the aforementioned sliding action and minimize damage that must be fixed before the crash cushion apparatus **100** can be reused after an impact event.

The bolt **156** extends through the slot **150**, through a hole of an adjacent panel **106**, and through a fastener hole of a vertical member **130** of one of the dividers **104**. In this way, adjacent panels **106** are connected to one of the dividers **104** with one of the adjacent panels **106** being slideable relative to the divider **104** and the other one of the adjacent panels **106** being fixed relative to the divider **104**. In some embodiments, the bolt **156** also extends through the biasing element **162** (particularly in the case of a helical spring). A head end of the bolt **156** is attached to or in inter-engagement with the sliding guide **158**.

The sliding guide **158** is positioned on an outer side of the corresponding panel **106** in the horizontal groove **152** in inter-engagement with a head of the bolt **156**. The sliding guide **158** may be elongated for guiding the corresponding panel **106** via the horizontal groove **152** as the panel **106** slides relative to the biased fastener **154**.

The nut **160** retains the biasing element in engagement with the corresponding divider **104**. In the case of a helical spring, the nut **160** entrains the biasing element on the bolt **156**. To that end, the nut **160** may be welded to the bolt **156** or may be an integral part of the bolt **156**. Alternatively, a bolt head, a flange, or the like may be used.

The biasing element **162** adds tension to the corresponding panel **106** to keep the panel **106** in place while allowing it to slide more freely during an impact event. The biasing element **162** may be a coil spring, a Belleville washer, a urethane spring, a leaf spring, or the like. In another embodiment, no biasing element is used.

As best seen in FIGS. **2-4**, some of the dividers **104** and/or the nose component **108** include shock absorption elements **148** for reducing spikes in energy transfer (e.g., minimize shock) between some of the dividers **104** and other components. The shock absorption elements **148** may be rubber or similar material.

As best seen in FIG. **4**, the nose component **108** includes a plurality of rigidly connected members **164**, a delineation plate **166**, side panels, a set of tabs similar to tabs **134**, and a set of beveled surfaces similar to beveled surfaces **140**. The nose component **108** is configured to be impacted by a vehicle during a head-on impact event and remain substantially intact as it is driven rearward toward the dividers **104**.

The plurality of rigidly connected members **164** form a box frame near the forward end **120** of the crash cushion apparatus **100**. The plurality of rigidly connected members **164** are sufficiently strong to transfer loads into the dividers **104** and the crushable tubes **110** without absorbing much energy themselves (except the energy that initiates movement of the nose component **108**).

The delineation plate **166** extends between some of the plurality of rigidly connected members **164** thereby at least partially enclosing the box frame. The delineation plate **166** may include curved edges complementary to the corrugated shape of forwardmost side panels **106**.

The tabs are spaced below the ledges **126** of the rails **116**A,B by a gap and extend inwardly toward the risers **124** of the rails **116**A,B to prevent the nose component **108** from becoming derailed from the rails **116**A,B. As discussed above, the gap may be a predetermined amount that optimally facilitates movement between the nose component **108** and the rails **116**A,B. A gap size too small, a non-existent gap, or a gap size too large results in binding between the nose component **108** and the rails **116**A,B, derailment, or poor energy transfer during an impact event. The gap also facilitates restoration of the crash cushion apparatus **100** after an impact event. In one embodiment, the gap is between approximately $\frac{3}{8}^{th}$ inch and approximately $\frac{1}{8}^{th}$ inch.

The beveled surfaces are disposed near the rails **116**A,B and are configured to engage the rails **116**A,B during an impact event. The beveled surfaces improve movement of the nose component **108** relative to the rails **116**A,B. In other words, the beveled surfaces reduce binding between the nose component **108** and the rails **116**A,B.

As best seen in FIGS. **3** and **5**, the plurality of crushable tubes **110** are oriented longitudinally in spaces formed by the plurality of collapsible bays **142** and extend between sequentially adjacent ones of the plurality of dividers **104** such that the plurality of dividers **104** (and more specifically, the cradle members and entrainment members **138**) entrain the plurality of crushable tubes **110** in the longitudinal orientation without the plurality of crushable tubes **110** being fixed to the plurality of dividers **104**.

Each crushable tube **110** may include one or more holes **168** near one of its ends (e.g., a forward end) for promoting longitudinal and progressive collapse of the crushable tube **110**. Edges of the hole(s) **168** may be between approximately 0.5 inches to approximately 3 inches from the end of the crushable tube **110**. In one embodiment, each crushable tube **110** includes four holes **168**, one on each side.

The plurality of crushable tubes **110** may be distributed unevenly between the plurality of collapsible bays **142** so that at least one of the plurality of collapsible bays **142** has more crushable tubes than at least one other of the plurality of collapsible bays **142**. In one embodiment, the plurality of crushable tubes **110** increase in number per collapsible bay from the forward end **120** to the rearward end **122** of the crash cushion apparatus **100**. In another embodiment, one of the forward-most collapsible bays **142** of the plurality of collapsible bays **142** has zero crushable tubes. In another embodiment, the foremost collapsible bay (nearest to the nose component **108** includes zero crushable tubes, the next two collapsible bays include three crushable tubes each, the next collapsible bay includes four crushable tubes, the next collapsible bay includes six crushable tubes, and the aftmost collapsible bay includes eight crushable tubes. The crushable tubes **110** may include upper crushable tubes positioned near tops of the dividers **104** and lower crushable tubes positioned near bottoms of the dividers **104**.

Turning to FIG. **7**, the crash cushion apparatus **100** arrests a vehicle impacting the nose component **108**. Specifically, the nose component **108** is driven rearward on the rails **116**A,B toward the foremost divider **104**, thus collapsing the first collapsible bay **142**. Similarly, the side panels **106** corresponding to the first collapsible bay **142** are overlapped by side panels of the nose component **108** and begin to slide rearward via the biased fasteners **154**. The shock absorption elements **148** reduce spikes in energy transfer (e.g., minimize shock) between some of the dividers **104** (and particularly the foremost dividers **104**) and other components.

The nose component **108** continues to be driven rearward, thus sequentially collapsing corresponding collapsible bays **142** until the vehicle is stopped. The dividers **104** crush the crushable tubes **110** in the collapsible bays **142** as the dividers **104** are driven rearward.

The above-described crash cushion apparatus **100** provides several advantages. For example, the dividers **104** entrain the crushable tubes **110** in their longitudinal orientation in spaces formed by the collapsible bays **142** without the crushable tubes **110** being fixed to the dividers **104**. This helps ensure that energy transfer between the dividers **104** and the crushable tubes **110** is primarily due to longitudinal rearward movement of the dividers **104** and not from a wider array of forces transferable between fixed joints (e.g., lateral stress, bending, twisting, stretching, recoil, or the like). The crushable tubes **110** being entrained only (and not fixed to the dividers **104**) also ensures the crushable tubes **110** are properly installed—it is not necessary to inspect welds or fasteners between the dividers **104** and the crushable tubes **110**. The entrainment members **138** also prevent theft of the crushable tubes **110**. Furthermore, this also facilitates safely inspecting, restoring, re-building and/or re-using elements of the crash cushion apparatus **100** after an impact event.

The holes **168** of the crushable tubes **110** promote longitudinal and progressive collapse of the crushable tube **110**, thus mitigating buckling and bending of the crushable tubes **110** during an impact event. This also eliminates the need for tube crushing guidance structure. The holes **168** of the crushable tubes **110** also reduce the energy spike associated with the forces required to initiate crushing of the crushable tubes **110**. The increasing number of crushable tubes per collapsible bay in some embodiments facilitates a gradual arrest of the vehicle and maximum safety for its occupants.

The dividers **104** have improved moveability relative to the rails **116**A,B during an impact event due to the gaps **144** between the tabs **134** of the dividers **104** and the ledge **126** of the rails **116**A,B. The beveled surfaces **140** of the dividers **104** also improve moveability of the dividers **104** during an impact event. Specifically, the gaps **144** and the beveled surfaces **140** prevent binding between the dividers **104** and the rails **116**A,B as the dividers **104** are driven rearward and during system restoration.

The side panels **106** redirect side impacts while not inhibiting the collapsing of the collapsible bays **142** during head-on impact events. These side panels **106** may be doubled up to increase side impact resistance. To that end, the side panels **106** overlap each other while being slideably linked to the dividers **104** via the biased fasteners **154** and the slots **150** and grooves **152** of the side panels **106**. This also reduces the amount of damage to various components of the crash cushion apparatus **100** during an impact event, which allows the crash cushion apparatus **100** to be refurbished more easily and placed back in service more quickly.

Although the invention has been described with reference to the embodiments illustrated in the attached drawing figures, it is noted that equivalents may be employed and substitutions made herein without departing from the scope of the invention as recited in the claims.

Having thus described various embodiments of the invention, what is claimed as new and desired to be protected by Letters Patent includes the following:

1. A crash cushion apparatus comprising:

a rail assembly including:

a plurality of anchor plates longitudinally spaced apart from each other; and

a rail extending longitudinally between the plurality of anchor plates;

a plurality of collapsible bays supported on the rail, each of the plurality of collapsible bays including:

a divider slidably entrained on the rail and longitudinally spaced from a divider of an adjacent one of the plurality of collapsible bays; and

a plurality of side panels linking the dividers of the plurality of collapsible bays together, each of the plurality of collapsible bays forming a space; and

a plurality of crushable tubes oriented longitudinally in the spaces formed by the plurality of collapsible bays and extending between sequentially adjacent ones of the plurality of dividers, the plurality of dividers entraining the plurality of crushable tubes in the longitudinal orientation without the plurality of crushable tubes being fixed to the plurality of dividers,

the plurality of dividers being configured to be driven rearward along the rail and crush the plurality of crushable tubes to sequentially collapse the collapsible bays;

each divider comprising one or more cradle members configured to receive a longitudinal end of a respective

one of the plurality of crushable tubes so as to prevent displacement of the crushable tubes relative to the dividers without affixing the crushable tubes to the divider.

2. The crash cushion apparatus of claim **1**, the plurality of crushable tubes being distributed unevenly between the plurality of collapsible bays so that at least one of the plurality of collapsible bays has more of the plurality of crushable tubes than at least one other of the plurality of collapsible bays.

3. The crash cushion apparatus of claim **2**, the crash cushion apparatus having opposing forward and rearward ends, the plurality of crushable tubes increasing in number per collapsible bay from the forward end to the rearward end.

4. The crash cushion apparatus of claim **3**, one of the forward-most collapsible bays of the plurality of collapsible bays having zero crushable tubes.

5. The crash cushion apparatus of claim **2**, some of the plurality of collapsible bays having one more crushable tube than the sequentially adjacent collapsible bay forward therefrom.

6. The crash cushion apparatus of claim **1**, each of the plurality of dividers including an entrainment member extending over the ends of the crushable tubes disposed in the corresponding collapsible bay.

7. The crash cushion apparatus of claim **1**, each of the plurality of crushable tubes including opposing ends and a plurality of holes near one of the opposing ends for promoting consistent longitudinal and progressive collapse of the plurality of crushable tubes.

8. The crash cushion apparatus of claim **1**, the rail assembly including an additional rail laterally spaced from the rail, the rail assembly further including crossmembers extending laterally between the rail and the additional rail.

9. The crash cushion apparatus of claim **1**, each of the plurality of dividers including a tab slidably entraining the divider on the rail and spaced from the rail via a gap to prevent binding between the divider and the rail when the divider moves relative to the rail.

10. The crash cushion apparatus of claim **9**, each of the plurality of dividers including a beveled or tapered surface configured to engage the rail.

11. The crash cushion apparatus of claim **1**, some of the plurality of dividers including a rubber shock absorption element to minimize shock between the plurality of dividers.

12. The crash cushion apparatus of claim **1**, the plurality of side panels overlapping each other and being connected the plurality of dividers via biased fasteners.

13. A crash cushion apparatus including opposing forward and rearward ends, the crash cushion apparatus comprising:

a rail assembly including:

a plurality of anchor plates longitudinally spaced apart from each other; and a rail extending longitudinally between the plurality of anchor plates;

a backstop positioned near an aft end of the rail:

a plurality of collapsible bays supported on the rail, each of the plurality of collapsible bays including:

a divider slidably entrained on the rail and longitudinally spaced from a divider of an adjacent one of the plurality of collapsible bays; and

a plurality of side panels linking the dividers of the plurality of collapsible bays together, each of the plurality of collapsible bays forming a space;

a nose component near the forward end and slidably entrained on the rail in longitudinal alignment with the plurality of collapsible bays, the nose component including:

a plurality of rigidly-connected members forming a box frame; and

a delineation plate extending between some of the plurality of rigidly-connected members thereby at least partially enclosing the box frame; and

a plurality of crushable tubes oriented longitudinally in the spaces formed by the plurality of collapsible bays and extending between sequentially adjacent ones of the plurality of dividers, the plurality of dividers entraining the plurality of crushable tubes in the longitudinal orientation without the plurality of crushable tubes being fixed to the plurality of dividers,

the plurality of dividers being configured to be driven rearward along the rail via the nose component and crush the plurality of crushable tubes to sequentially collapse the collapsible bays;

each divider comprising one or more cradle members configured to receive a longitudinal end of a respective one of the plurality of crushable tubes so as to prevent displacement of the crushable tubes relative to the dividers without affixing the crushable tubes to the divider.

14. The crash cushion apparatus of claim **13**, the plurality of crushable tubes being distributed unevenly between the plurality of collapsible bays so that at least one of the plurality of collapsible bays has more of the plurality of crushable tubes than at least one other of the plurality of collapsible bays.

15. The crash cushion apparatus of claim **14**, the plurality of crushable tubes increasing in number per collapsible bay from the forward end to the rearward end.

16. The crash cushion apparatus of claim **15**, one of the forward-most collapsible bays of the plurality of collapsible bays has zero crushable tubes.

17. The crash cushion apparatus of claim **14**, some of the plurality of collapsible bays having one more crushable tube than the sequentially adjacent collapsible bay forward therefrom.

18. The crash cushion apparatus of claim **13**, each of the plurality of dividers including an entrainment member extending over the ends of the crushable tubes disposed in the corresponding collapsible bay.

19. The crash cushion apparatus of claim **13**, each of the plurality of crushable tubes including opposing ends and a plurality of holes near one of the opposing ends for promoting consistent longitudinal and progressive collapse of the plurality of crushable tubes.

20. A crash cushion apparatus including opposing forward and rearward ends, the crash cushion apparatus comprising:

a rail assembly including:

a plurality of anchor plates longitudinally spaced apart from each other;

a backstop fixed to one of the plurality of anchor plates;

opposing rails extending longitudinally between the plurality of anchor plates and including aft ends; and

a plurality of crossmembers extending laterally between the opposing rails;

a backstop positioned near the aft ends of the opposing rails;

a plurality of collapsible bays supported on the opposing rails, each of the plurality of collapsible bays including:

a divider slideably entrained on the opposing rails and longitudinally spaced apart from a divider of an adjacent one of the plurality of collapsible bays; and

a plurality of corrugated side panels linking the dividers of the plurality of collapsible bays together, the plurality of side panels and dividers of the plurality of collapsible bays being connected via biased fasteners,

each of the plurality of collapsible bays forming a space;

a nose component near the forward end and slidably entrained on the opposing rails in longitudinal alignment with the plurality of dividers, the nose component including:

a plurality of rigidly-connected members forming a box frame; and

a delineation plate extending between some of the plurality of rigidly-connected members thereby at least partially enclosing the box frame; and

a plurality of crushable tubes oriented longitudinally in the spaces formed by the plurality of collapsible bays and extending between sequentially adjacent ones of the plurality of dividers, the plurality of crushable tubes including opposing ends and a plurality of holes near some of the opposing ends for promoting longitudinal and progressive collapse of the plurality of crushable tubes, the plurality of dividers entraining the plurality of crushable tubes in the longitudinal orientation without the plurality of crushable tubes being fixed to the plurality of dividers,

the plurality of dividers being configured to be driven rearward along the rail via the nose component and crush the plurality of crushable tubes to sequentially collapse the collapsible bays;

each divider comprising one or more cradle members configured to receive a longitudinal end of a respective one of the plurality of crushable tubes so as to prevent displacement of the crushable tubes relative to the dividers without affixing the crushable tubes to the divider.

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