MAGNETIC IMPACT ABSORPTION IN
PROTECTIVE BODY GEAR

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ABSTRACT

Magnetic repulsive forces can be exploited for impact absorption in protective body gear such as, e.g., helmets.
MAGNETIC IMPACT ABSORPTION IN PROTECTIVE BODY GEAR

TECHNICAL FIELD

[0001] This invention relates to protective body gear, particularly helmets, and the impact-absorbing structures used therein.

BACKGROUND

[0002] During sports games and other physical activity, individuals are often exposed to impact forces that, if not at least partially absorbed, can cause severe injury. Therefore, they usually wear protective sporting gear, such as helmets, shields, elbow and knee pads, etc. Such protective gear typically includes impact-absorbing structures that deform elastically and/or plastically in response to an impact force, thereby mechanically absorbing the impact. For example, many helmets have a crushable foam layer disposed between a rigid or semi-rigid outer shell and an inner liner that conforms the helmet to the wearer’s head. More recent helmet designs feature, in place of a continuous layer, discrete fluid-filled compression cells, which resistively vent a fluid through an orifice of the cell enclosure to absorb the impact.

[0003] Unfortunately, mechanical absorption mechanisms are inherently subject to wear and tear on the absorbing structures, resulting over time in degraded performance of the protective mechanisms and a frequent need to replace the protective gear. Compression cell designs are likewise prone to failure, as shear stresses of the venting fluid can cause the material around the venting aperture or valve to become brittle and crack, or otherwise lose its mechanical integrity.

[0004] Moreover, mechanical impact-absorption mechanisms tend eventually to “bottom out,” i.e., reach a compression state where they cannot absorb forces any further. As a consequence, they generally need to be designed for a certain range of forces, outside of which their effectiveness is substantially diminished. To accommodate a large range of impact forces, it would be desirable to provide an absorption mechanism whose resistance increases with increasing impact forces.

SUMMARY

[0005] The present invention generally exploits magnetic forces to absorb (or assist absorption of) impacts. In certain embodiments, protective structures in helmets or other wearable protective articles are provided with two or more opposing magnets separated along an axis substantially normal to the outer surface of the protective article, i.e., oriented such that impact forces imparted on the article under the expected directions will push the magnets towards one another. (“Substantially normal” is meant to indicate that the orientation of the axis deviates by less than 30°, preferably less than 10°, more preferably less than 3° from perfect normality to the surface.) Magnets are “opposing” or have “substantially opposite polarity,” as the terms are used herein, if the magnetic forces between them are mutually repulsive. (Preferably, the magnetic field lines are substantially anti-parallel in the space between the magnets, i.e., enclose an angle that deviates from 180° by less than 45°, preferably less than 15°, more preferably less than 5°.) Advantageously, impact absorption with a magnetic field is unlike mechanical impact absorption—not subject to wear and tear on moving parts, and can, thus, result in significantly prolonged lifetimes of the protective structures. In addition, the repulsive forces between the magnets increase as the magnets approach one another, so that resistance increases with increasing impact forces and a large range of impact forces can effectively be absorbed. Furthermore, when the magnets get very close to each other, the repulsive force tends to cause lateral shifting between the magnets (e.g., due to minimal residual or deliberate misalignment); thus, the protective structure shears rather than compressing fully and letting the two magnets touch physically. This, generally, a desired effect, which contributes to the dissipation of impact forces.

[0006] In one aspect, the invention provides, in various embodiments, a shock-absorbing helmet including a protective shell, an interior liner (for contact with the wearer’s head) connected to the inner surface of the shell, and a pair of magnetic elements disposed between the shell and the interior liner. The magnetic elements are spaced-apart (e.g., along an axis passing perpendicularly through the interior liner and the shell) and oriented such that they are mutually repulsive between the interior liner and the shell. Their magnetic strengths may be sufficient to prevent contact between the magnets as long as the shock forces do not exceed an expected maximum force.

[0007] In some embodiments, the helmet further includes mechanical constraints on the shell and liner for laterally aligning the magnetic elements. The mechanical constraints may prevent lateral motion of the magnetic elements at least at distances between them that exceed a specified threshold; alternatively or in addition, the mechanical constraints may simply exhibit sufficient flexibility to permit a limited amount of lateral movement (which is insufficient, at any distance between magnets, to significantly degrade mutual repulsion). In some embodiments, the magnetic elements have substantially opposite polarity and are mounted to opposing interior surfaces of a compression cell disposed between the shell and the interior liner. The compression cell may be substantially tubular (i.e., include top and bottom walls connected along their circumference by a side wall structure), and have the two magnetic elements mounted to its interior floor and ceiling, respectively. The magnetic elements may be disk-shaped. The helmet may contain multiple distributed pairs of opposing magnetic elements.

[0008] In another aspect, the invention is directed to protective body gear including a protective shell, an interior liner connected to an inner surface of the liner, and a pair of magnetic elements in mutually repulsive orientation disposed between the inner liner and the shell. The body gear may include or consist of, for example, a chest shield, a knee pad, an elbow pad, a shin pad, or an arm shield. The features of magnetic impact-absorbing structures described above with respect to helmets may apply to other body gear as well.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The foregoing will be more readily understood from the following detailed description of the invention, in particular, when taken in conjunction with the drawings, in which:

[0010] FIG. 1 is a cross section of a portion of protective gear including multiple pairs of opposing magnets between a liner and a shell in accordance with one embodiment;

[0011] FIG. 2A are a cross-section and perspective view, respectively, of a compression cell with embedded magnets in accordance with one embodiment;

[0012] FIG. 3 is a perspective view of a magnet-alignment scaffold in accordance with one embodiment; and
FIG. 4 is an elevational view of a protective helmet with multiple distributed compression cells in accordance with one embodiment.

DETAILED DESCRIPTION

Protective body gear in accordance herewith generally utilizes permanent magnets of opposite polarity to magnetically absorb impact forces. The magnets may be made of naturally occurring magnetic materials, such as iron, nickel, cobalt, gadolinium (a rare-earth metal that is ferromagnetic at temperatures below 90°C and strongly paramagnetic above this temperature), or of man-made alloys or composites, such as rare-earth metal alloys (e.g., neodymium-iron-boron and samarium-cobalt), iron oxide ceramics (ferrites), alnico (iron alloys with additions of aluminum, nickel, and cobalt), or injection-molded or flexible composites of resin or vinyl and magnetic powders. Magnetic materials for any particular application may be selected, without undue experimentation, based on the required magnetic strength, mechanical properties, commercial availability and price of the various materials. Rare-earth magnets, for example, generally produce the strongest magnetic fields (e.g., in excess of 1.4 Tesla), but are generally brittle and vulnerable to corrosion, requiring protective coatings. Alnico magnets are corrosion-resistant, and can have superior mechanical characteristics if sintered, or have high magnetic fields strengths and intricate shapes if casted. Flexible, injection-molded magnets are generally lower in strength, but allow for low-cost manufacturing of complex and flexible shapes, and may, therefore, be desirable for use in clothing articles that require the magnets to conform to certain anatomic regions of the wearer. In general, the type, size, shape, and strength of the magnets can be readily selected by a person of skill in the art based on the intended application. For example, for helmets used in particular sports, where the expected maximum impact force can reasonably be determined, magnets of sufficient magnetic strength may be chosen to prevent contact between the magnets in response to shock forces at or below the expected maximum force. Permanent magnets adaptable for use in embodiments of the present invention are readily available commercially from various manufacturers.

In some embodiments, the magnets are located within the impact-absorbing gear between an exterior shell subject to impact forces and an inner liner in contact with the wearer. For example, FIG. 1 schematically illustrates a layered protective article 100 that includes a shell 102 and a liner 104 substantially conforming to the wearer’s body B, and several pairs of opposing magnets 106, 108 within respective compression cells 110 disposed between the shell 102 and liner 104. The magnets 106, 108 are aligned and oriented such that they absorb the normal (i.e., perpendicular) components F_n of impact forces F exerted on the outer surface of the shell 102. That means, in general, that the geometric centers of the opposing magnets 106, 108 are separated along a geometric axis 112 locally perpendicular to the shell surface. The normal force components F_n then tend to cause the opposing magnets 106, 108 to move towards one another, and the repulsive magnetic forces resist such motion, thereby absorbing the impact.

The magnets may be retained in a compressible alignment or guiding structure that limits lateral shifting between the magnets, keeping their respective geometric centers on or about their axis of separation 112. In the illustrated embodiment, alignment of magnets 106, 108 is achieved by attaching one magnet 106 of each pair to the bottom and the other magnet 108 to the ceiling of the respective compression cell 110, and affixing the cell 110 to the outer surface of the liner 104 and inner surface of the shell 102. In some embodiments, lateral shifting between the magnets is permitted (at least within specified limits) in order to allow for the dissipation of tangential forces on the shell. Such lateral shifting can be facilitated, e.g., by providing alignment structures that shear in response to tangential forces, thereby allowing the shell to be laterally displaced with respect to the liner. In certain embodiments, lateral shifting is impeded as long as the opposing magnets are at a distance exceeding a predetermined threshold, and enabled when the distance between the magnets falls below the threshold. Such functionality may be achieved with a guiding structure that buckles and/or shears only at sufficiently high impact forces.

FIGS. 2A and 2B illustrate an exemplary shock-absorbing cell 200 (which may be used in place of cell 110) in more detail. The cell 200 includes an enclosure 202 forming substantially parallel top and bottom plates 204, 206 connected by a tubular side wall structure 208. As shown, the top and bottom plates 204, 206 may be circular, and the connecting side wall structure 208 may be rotationally symmetric. However, the shape of the enclosure is not critical; other geometric shapes are also possible. (For example, the top and bottom plates may be rectangular and connected by a side wall structure having four wall segments.) The enclosure 202 may be made of a polymer material, such as a thermoplastic, and may be injection-molded in one piece or more pieces. For example, the top plate 204 and side wall structure 208 may form a single molded unit that is thermally bonded, glued, or otherwise attached to the separately molded base plate 206.

The enclosure 202 may include semi-flexible flanges or lips 210 (protruding from the interior surfaces of the top and bottom plates 204, 206) that conform to and at least partially surround the magnets 106, 108, thereby retaining them against the interior surfaces of plates 204, 206. This configuration facilitates inserting prefabricated magnets in a simple step, e.g., by press-fitting them into the space between the interior surface and the lip. Alternatively, the magnets may be, for example, screwed, glued, or clamped to the top and bottom plates, or affixed in any of a variety of other ways that will be readily apparent to one of skill in the art.

As illustrated in FIGS. 2A and 2B, the magnets may be substantially disk-shaped, i.e., have flat, substantially parallel top and bottom surfaces (which may, but need not be circular) of dimensions larger than the thickness of the disk. This shape results in a high degree of homogeneity of the magnetic field in the space between the magnets, which may be advantageous to provide uniform resistance at least during an initial compression phase. Further, thin, disk-shaped magnets help minimizing the overall thickness of the protective structure, which is desirable, for example, in helmets for reducing the bulkiness of the helmet. However, other magnet shapes may also be used. For example, in some embodiments, the magnets may be spherical, or semi-spherical with their flat surface attached to the compression cell enclosure and their curved surfaces facing each other, resulting in magnetic repulsion that increases steadily as the magnets approach one another. In certain embodiments, the two opposing magnets have different, but complementary shapes; for instance, one magnet may be bowl-shaped and face, with its concave su-
face, a spherical opposing magnet sized to fit within the bowl interior, leaving a uniform gap between the opposing magnet surfaces.

[0020] Magnetic impact absorption may be combined with various mechanical impact-absorption mechanisms. For example, in the embodiment illustrated in FIGS. 2A and 2B, the side walls 208 of the enclosure 202 may itself resist compression of the cell 200, at least during an initial phase, thereby contributing to impact absorption. Moreover, the cell 200 may contain a fluid (e.g., air) that resistively vents through one or more orifices 212 in the enclosure (typically, in the top or bottom walls 204, 206), providing an additional absorption mechanism.

[0021] The magnet alignment structure need not necessarily fully enclose the magnets 106, 108. Rather, in some embodiments, the magnets 106, 108 may be affixed to an open frame or scaffold, an example of which is illustrated in FIG. 3. The alignment scaffold 300 may include several legs connected, e.g., by star- or ring-shaped top and bottom portions, to which the magnets 106, 108 are attached. In the shown example, three legs are connected to the three ends of approximately Y-shaped top and bottom portions. As the magnets 106, 108 are pushed closer to each other, the legs of the alignment scaffold 300 may buckle. The scaffold may allow for some tilting of the legs to one side, resulting in lateral motion between the two magnets. Accordingly, the scaffold is desirably stiff enough to help resist impact forces, but flexible enough to buckle and shift without breakage. Alignment structures such as the scaffold 300 illustrated in FIG. 3 may be manufactured, e.g., of injection-molded plastic at low cost, but may also be made from various other materials, including, e.g., thin sheets of metal. Other structural implementations of alignment and guiding structures are also contemplated. For example, the magnets may be retained in loops of a spring structure at opposite ends thereof.

[0022] Magnetic impact-absorbing structures as described above may employed advantageously in a variety of applications, including, for example, protective body gear, vehicle dash boards, and shock-absorbing seats. FIG. 4 illustrates, as one exemplary application, a protective helmet 400 including multiple compression cells 402 distributed between a shell and a helmet liner. Each compression cell 402 may contain a pair of magnets of opposing polarity, as described above, for example, with reference to FIGS. 2A and 2B. In some applications, such as, e.g., a knee pad, a single pair of magnets may be used. Further, in some embodiments, one magnet may oppose multiple, typically smaller, magnets.

[0023] Certain embodiments of the present invention are described above. It is, however, expressly noted that the present invention is not limited to those embodiments; rather, additions and modifications to what is expressly described herein are also included within the scope of the invention. Moreover, it is to be understood that the features of the various embodiments described herein are not, in general, mutually exclusive and can exist in various combinations and permutations, even if such combinations or permutations are not made express herein, without departing from the spirit and scope of the invention. In fact, variations, modifications, and other implementations of what is described herein will occur to those of ordinary skill in the art without departing from the spirit and the scope of the invention. As such, the invention is not to be defined only by the preceding illustrative description.

What is claimed is:
1. A shock-absorbing helmet comprising:
   a protective shell;
   connected to an inner surface of the shell, an interior liner for contact with a wearer’s head; and
   disposed between the shell and the interior liner, first and second spaced-apart magnetic elements oriented such that they are mutually repulsive between the interior liner and the shell.
2. The helmet of claim 1, further comprising mechanical constraints on the shell and liner for laterally aligning the first and second magnetic elements.
3. The helmet of claim 2, wherein the mechanical constraints prevent lateral motion of the magnetic elements at a distance therebetween that exceeds a specified threshold.
4. The helmet of claim 1, wherein the first and second magnetic elements have substantially opposite polarity and are mounted to opposing interior surfaces of a compression cell disposed between the shell and the interior liner.
5. The helmet of claim 4, wherein the shock-absorbing cell is substantially tubular and the first and second magnetic elements are mounted to an interior floor and an interior ceiling, respectively, of the substantially tubular cell.
6. The helmet of claim 5, wherein the first and second magnetic elements are disk-shaped.
7. The helmet of claim 1, wherein the first and second elements have magnetic strengths sufficient to prevent contact therebetween in response to shock forces not exceeding an expected maximum force.
8. The helmet of claim 1, comprising multiple distributed pairs of first and second magnetic elements.
9. The helmet of claim 1, wherein the magnets are spaced apart along an axis passing perpendicularly through the interior liner and the shell.
10. Protective body gear comprising:
    a protective shell;
    connected to an inner surface of the shell, an interior liner for contact with a wearer’s body; and
    disposed between the shell and the interior liner, first and second spaced-apart magnetic elements oriented such that they are mutually repulsive between the inner liner and the shell.
11. The body gear of claim 10, further comprising mechanical constraints on the shell and liner for laterally aligning the first and second magnetic elements.
12. The body gear of claim 11, wherein the mechanical constraints prevent lateral motion of the magnetic elements at a distance therebetween that exceeds a specified threshold.
13. The body gear of claim 10, wherein the first and second magnetic elements have substantially opposite polarity and are mounted to opposing interior surfaces of a compression cell disposed between the shell and the interior liner.
14. The body gear of claim 13, wherein the shock-absorbing cell is substantially tubular and the first and second magnetic elements are mounted to an interior floor and an interior ceiling, respectively, of the substantially tubular cell.
15. The body gear of claim 14, wherein the first and second magnetic elements are disk-shaped.
16. The body gear of claim 10, wherein the first and second elements have magnetic strengths sufficient to prevent contact therebetween in response to shock forces not exceeding an expected maximum force.
17. The body gear of claim 10, comprising multiple distributed pairs of first and second magnetic elements.
18. The body gear of claim 10, wherein the magnets are spaced apart along an axis passing perpendicularly through the interior liner and the shell.

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