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Tirmizi

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(54) **PYROTECHNIC CIRCUIT BREAKER**

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H01H 39/00 (2006.01)

(52) **U.S. Cl.** **337/30; 337/157; 337/401; 337/405**

(58) **Field of Classification Search** **337/30; 337/157, 401, 405; 361/115; 200/61.08**
See application file for complete search history.

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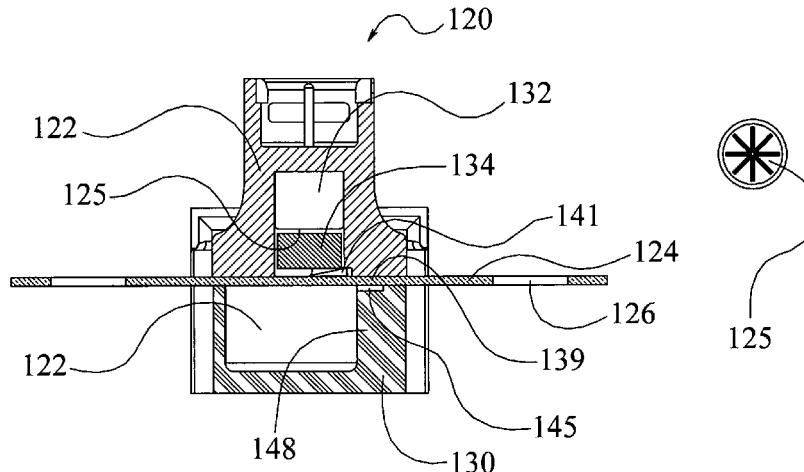
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(57) **ABSTRACT**

A circuit breaker including a pyrotechnic element configured to ablate, tear, or cut a portion of the circuit. The portion of the circuit to be broken may be formed to be readily broken and/or may be a current load-based fuse. Also, the circuit breaker may be configured to ensure predictable progressive lateral tearing of the portion of the circuit to be broken; the circuit breaker may optionally be configured so that substantially all of the pyrotechnic element's output is focused on breaking the circuit; and the circuit breaker may optionally include a positive displacement mechanism that, after actuation of the pyrotechnic igniter, prevents the circuit breaker from inadvertently re-closing.

8 Claims, 7 Drawing Sheets



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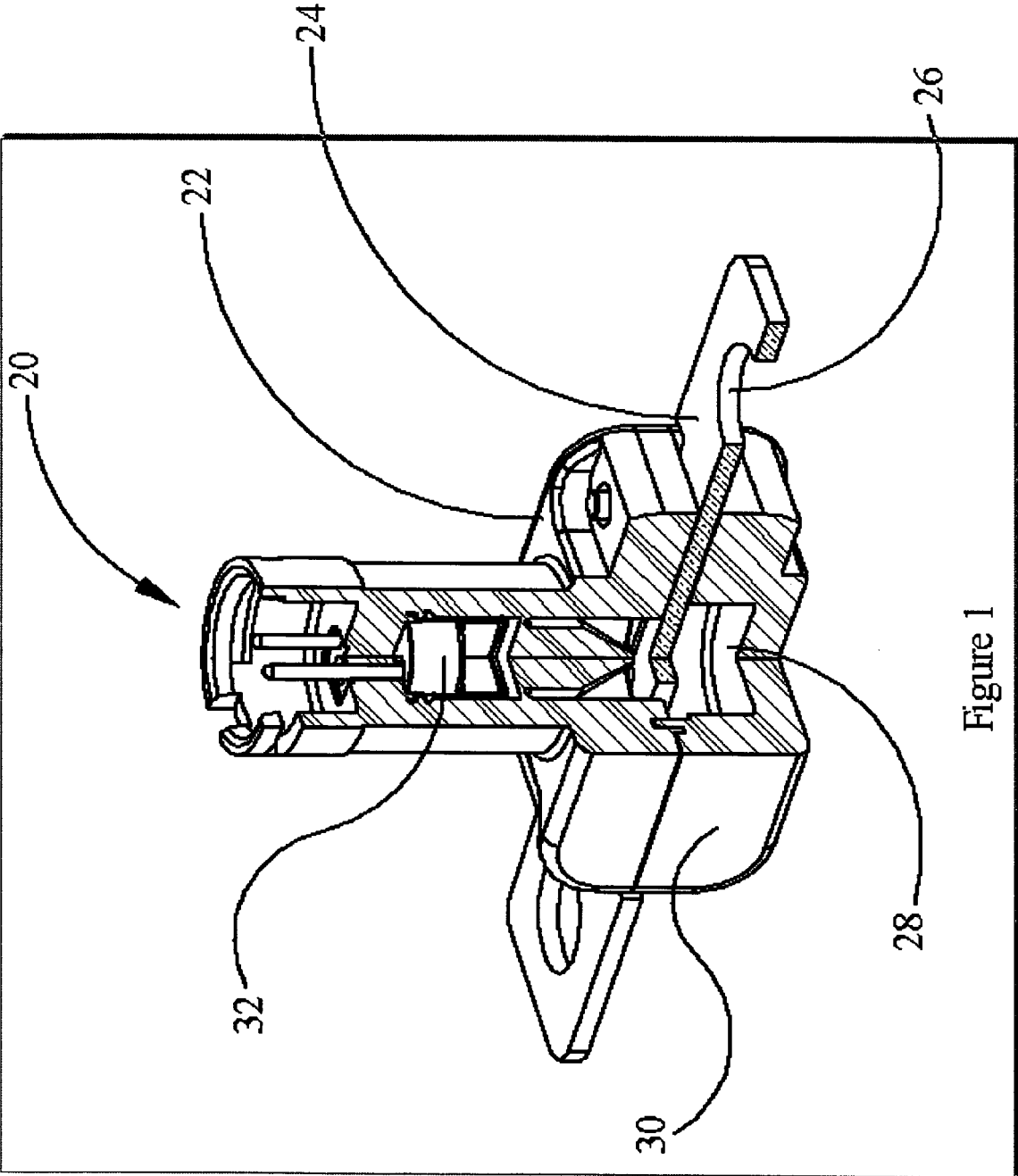


Figure 1

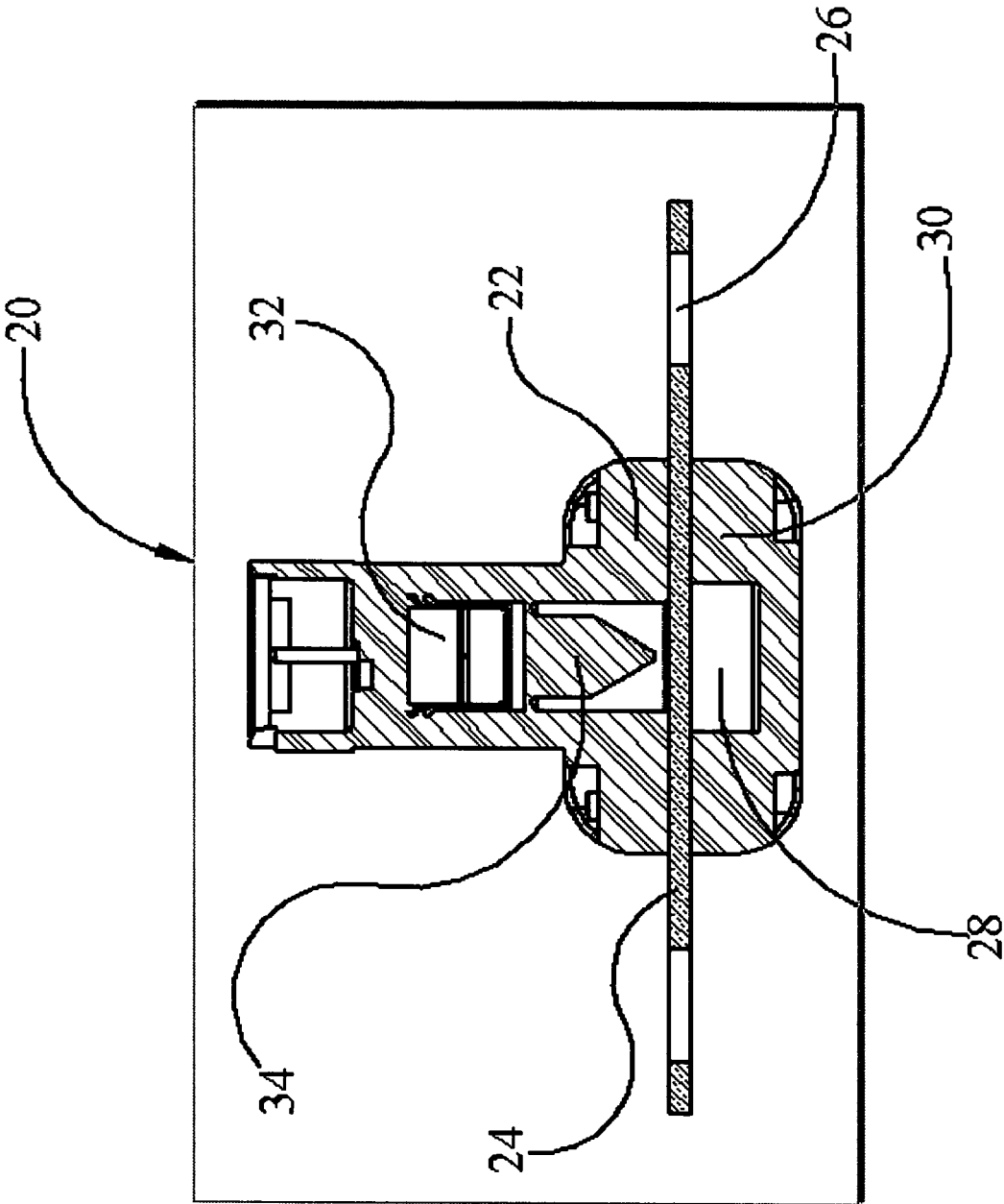


Figure 2

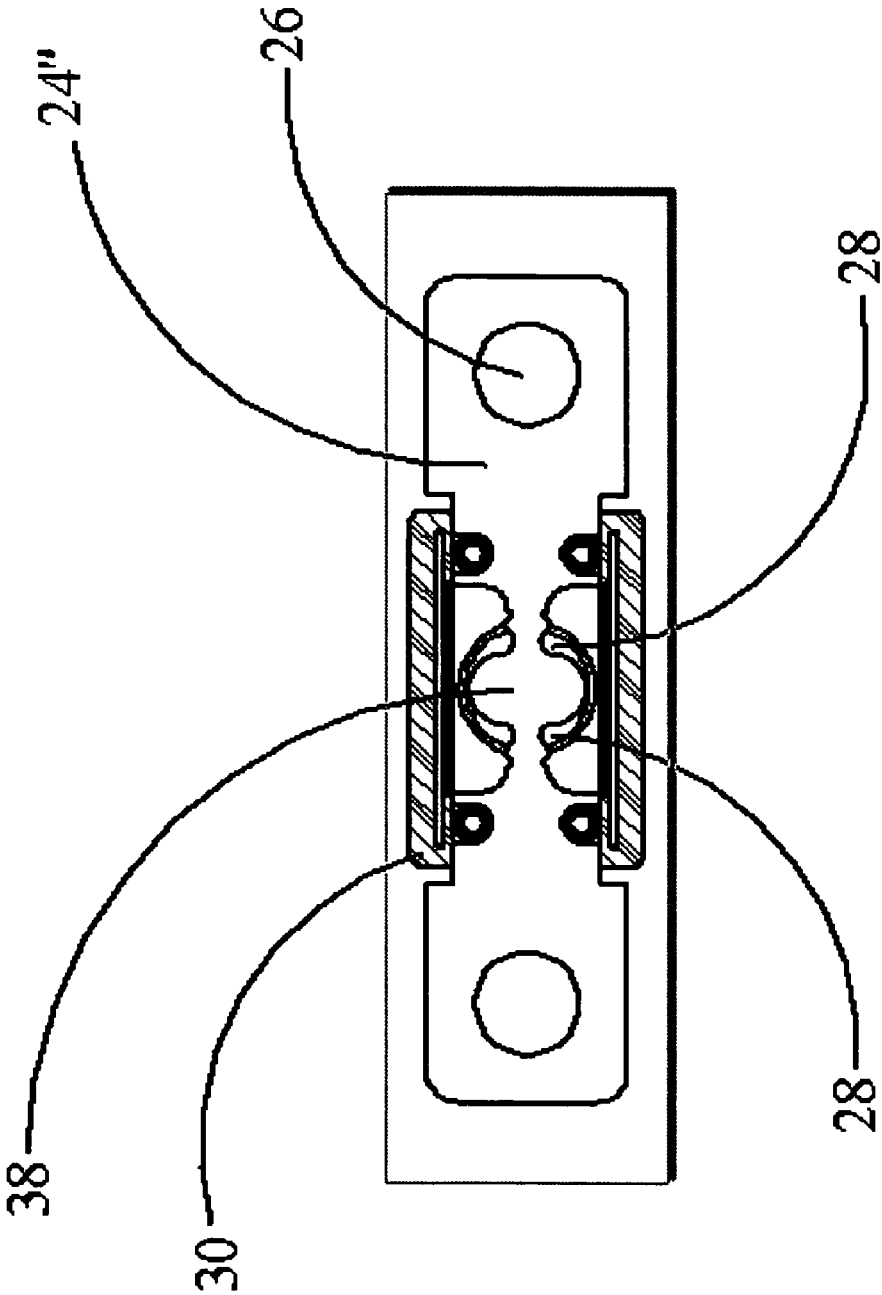


Figure 4

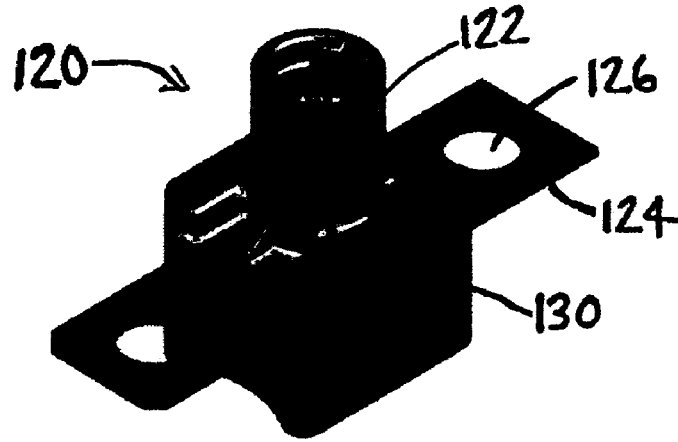


FIG. 5

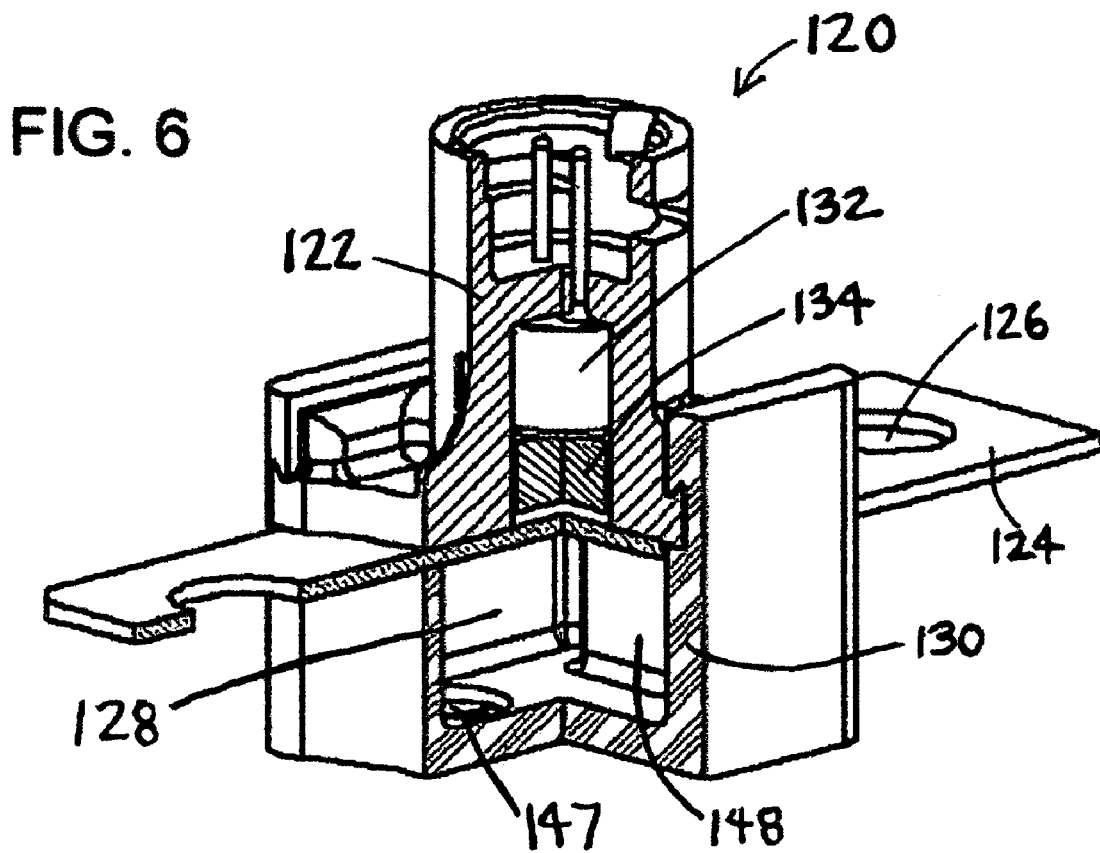


FIG. 6

FIG. 7a

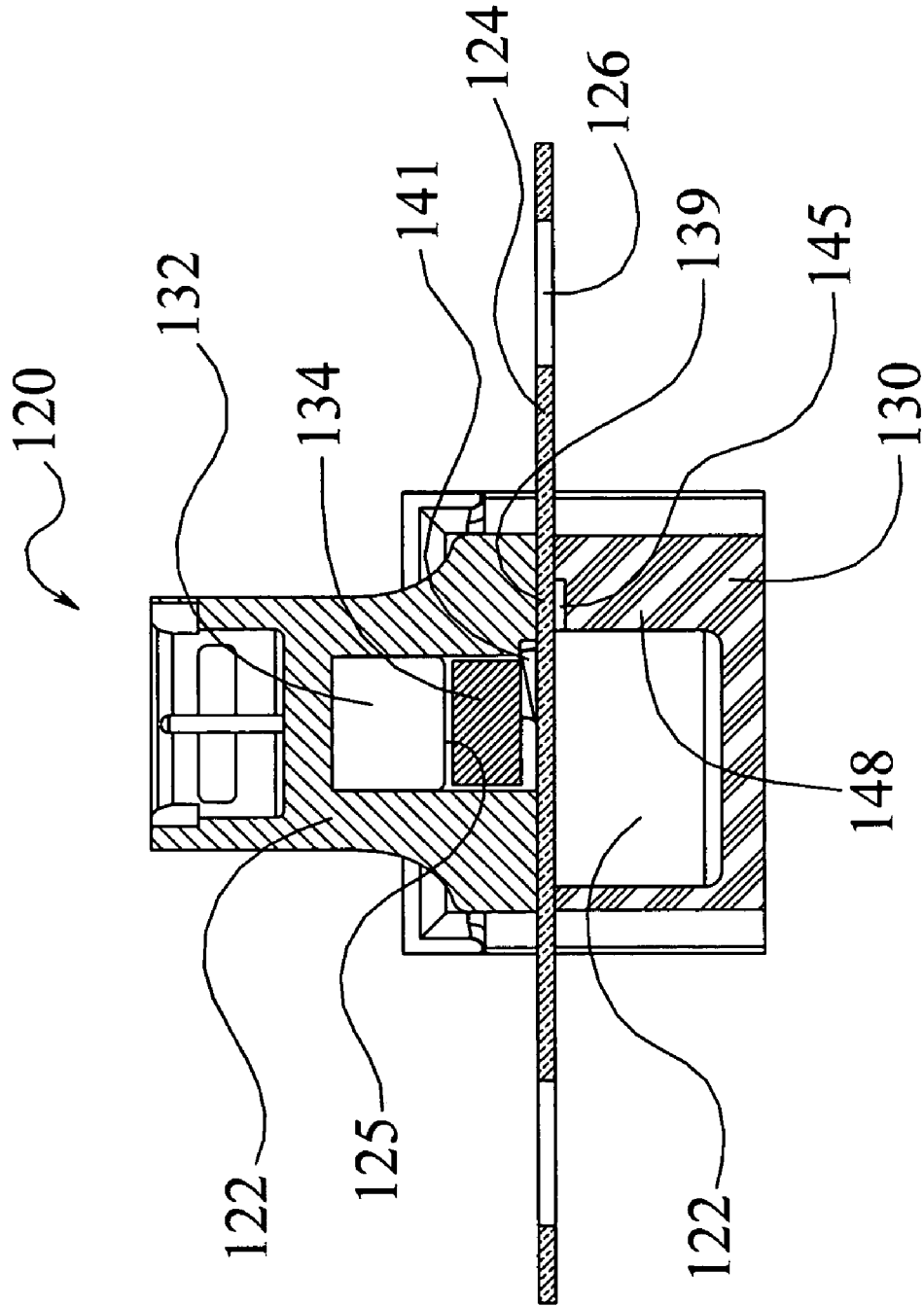
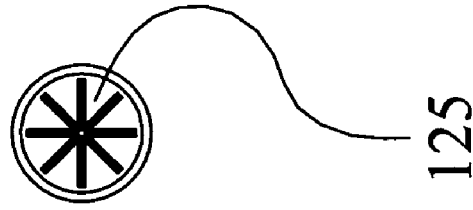


FIG. 7b



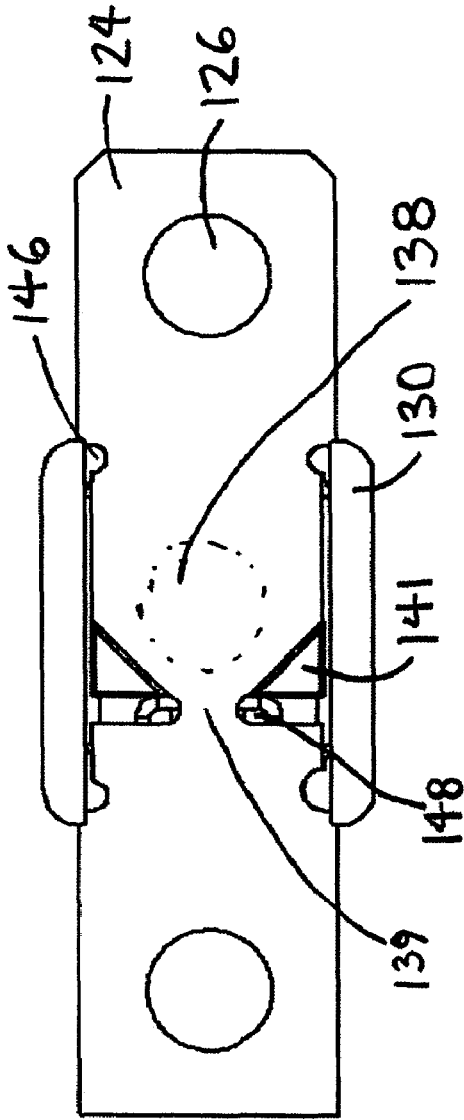


FIG. 8

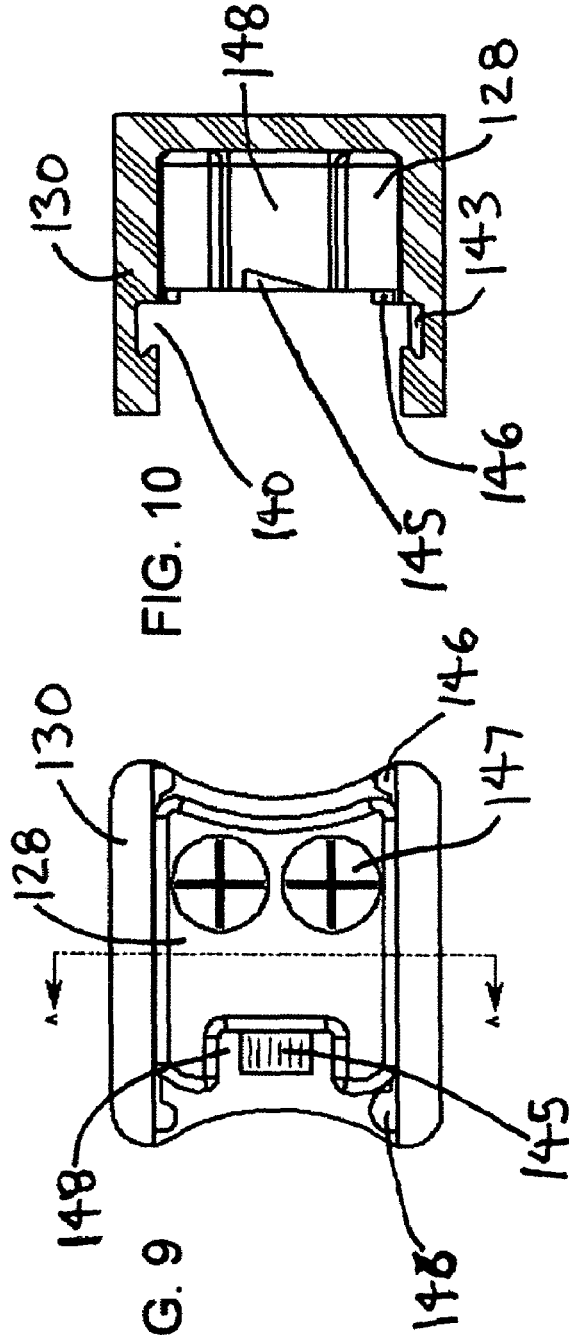


FIG. 9

FIG. 10

PYROTECHNIC CIRCUIT BREAKER

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of U.S. patent application Ser. No. 10/688,020 entitled "Pyrotechnic Circuit Breaker," filed Oct. 17, 2003.

The present invention is directed generally to the field of circuit breakers, and more particularly, to a circuit breaker including a pyrotechnic element for breaking the circuit.

The circuit breakers used in various electrical systems in motor vehicles such as automobiles, trucks, buses, fixed wing aircraft, helicopters, marine vessels and the like, have conventionally employed fuse-type resistor elements that burn out when an excessive level of current passes through the element, causing a break in the circuit.

Various substitutes for such conventional fuses have also been devised, such as to permit breaking of a circuit in response to abnormal conditions (such as the collision of a vehicle) that would not necessarily create an immediate excessive current load in a fuse. For example, U.S. Pat. No. 6,194,988 to Yamaguchi et al. teaches the use of a sort of "hot plate" that is spring-biased against a relatively low melting point fuse section, with the hot plate being heated by an attached igniting device that contains a solid combustion agent; the igniting device is rapidly activated such as in the case of a collision, heating the hot plate which then melts the adjacent fuse section and (due to the spring bias) drives through the molten fuse section, cutting it out and thereby breaking the circuit. Devices such as that of the '988 patent based on melting that is induced by conducted heat, however, cannot exploit the rapidity of a pyrotechnic ignition because the process of heat conduction is quite slow in comparison to the speed of a pyrotechnic ignition. Such devices can also be relatively complex and costly.

There are also a number of recent battery cable clamp breaker devices that include a pyrotechnic device (configured to ignite in response to an abnormal condition such as a collision of the vehicle containing the device) that physically drives apart two parts of the clamp or terminal so that they are no longer electrically connected, such as in U.S. Pat. No. 5,725,399 to Albiez et al. and U.S. Pat. Nos. 5,818,121, 6,144,111, and 6,171,121 to Krappel et al. This type of device is generally capable of deploying quickly, e.g., in the case of a collision so as to reduce the chance of an electrical fire in the damaged vehicle irrespective of whether the conditions would rapidly cause a conventional fuse to blow. Yet such devices are in general a relatively complex, costly, and/or bulky way to provide the function of pyrotechnically-induced circuit breaking. Moreover, such devices do not intrinsically involve a conventional (i.e., current load-based) fuse, so if it were desired to also retain the conventional function of current load-based breaking in such a circuit breaker, a conventional fuse would need to be added as a distinct additional component, thus rendering the resulting device yet more complicated and costly.

Finally, U.S. Pat. No. 3,991,649 to Patrichi and U.S. Pat. No. 5,877,563 to Krappel et al. teach circuit breaker devices in which a pyrotechnic device is used to propel a cutter through a wire or to unplug a connector. Neither patent, however, teaches the pyrotechnically-driven breaking of a current load-based fuse in a circuit.

SUMMARY OF THE INVENTION

A circuit breaker according to the present invention includes a pyrotechnic igniter and a portion of the circuit that

breaks as a result of the ignition of the pyrotechnic igniter. The portion of the circuit to be broken may also be a current load-based fuse.

In a separate and independent aspect of the invention, the circuit breaker may be configured to ensure predictable progressive lateral tearing of the portion of the circuit to be broken.

Optionally, the circuit breaker may be configured so that substantially all of the pyrotechnic igniter's output is focused on breaking the circuit. Also optionally, the circuit breaker may include a positive displacement mechanism to ensure that the circuit, once broken by actuation of the pyrotechnic igniter, cannot be re-closed inadvertently.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective, partly cut-away view of an embodiment of a pyrotechnic circuit breaker according to the present invention, utilizing a cutting projectile.

FIG. 2 is a transverse sectional view of the embodiment of FIG. 1.

FIG. 3 is a lateral sectional view of another embodiment of a pyrotechnic circuit breaker according to the present invention, not utilizing a cutting projectile, but a focused ignition output.

FIG. 4 is a lateral sectional view similar to that of FIG. 3, but depicting an alternative embodiment in which the portion of the circuit to be broken has an enlarged impact area, which may optionally be used with a cutting projectile.

FIGS. 5-10 depict another embodiment of a pyrotechnic circuit breaker according to the present invention, utilizing a slug that tears a portion of the circuit. FIG. 5 is a perspective view, FIG. 6 is a partly cutaway perspective view, and FIG. 7a is a transverse sectional view, of the circuit breaker. FIG. 7b is a bottom view of the igniter of the circuit breaker, showing its cruciform petals. FIGS. 8 and 9 are top-down views of the circuit breaker's lower housing respectively with and without the bolt-on fuse strip, and FIG. 10 is a sectional view of the lower housing through the line A-A shown in FIG. 9.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to FIGS. 1 to 3, a preferred embodiment of a pyrotechnic circuit breaker 20 in accordance with the present invention may include an upper housing 22 and a lower housing 30, which may be made of metal, ceramic, or polymer, preferably a suitable high-strength, high-temperature polymer thermoplastic or thermoset such as Rytan®, Amodel®, Ultem®, Phenolic®, Zytel® and the like. The housing may preferably be constructed as an integral, one-piece, injection molded-in-place housing, preferably created by joining together two or more components. Optionally, a polymer overmolding (preferably selected for beneficial cost, formability, and electrical insulation characteristics) or a superstructure or skeleton of metal may be utilized for added strength. A pyrotechnic igniter assembly 32 is held securely within the upper housing 22, and the portion of the electrical circuit to be broken by the output of the pyrotechnic igniter assembly 32 is situated between the upper housing 22 and the lower housing 30 and may preferably take the form of a bolt-on fuse strip 24 (which includes bolt holes 26 for securing the device to a terminal or the like) (or 24' in FIG. 3). The pyrotechnic igniter assembly 32 may preferably be any suitable reliable, low-cost pyrotechnic device such as an automotive airbag initiator. The pyrotechnic igniter

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assembly 32 is thus initiated by the issuance of an appropriate electrical signal through its connector leads, which, for example in the case of an automobile, are preferably connected to the electronic control unit of the automobile's occupant restraint system, either as an integral part of the device or at the end of a two-wire cable assembly.

As can be seen, the pyrotechnic igniter assembly 32 is oriented so that its output is directed through a passage to the bolt-on fuse strip 24, generally perpendicularly to the axis of the bolt-on fuse strip 24. Vents (not shown) through either or both halves of the housing may also optionally be provided to safely release the hot gases created by ignition of the pyrotechnic igniter assembly 32. Increasing the diameter of the passage between the pyrotechnic igniter assembly 32 and the bolt-on fuse strip 24 tends to increase the required output of the pyrotechnic igniter assembly 32 and thus may necessitate a stronger housing (both of which tend to increase manufacturing cost); however, the passage's diameter cannot be decreased arbitrarily as that may undesirably reduce the ability of the housing to withstand the flow of high or excessive current through the bolt-on fuse strip 24. The heat tolerance of the housing may be improved so as to permit further reduction of the diameter of the passage, however, such as by forming the housing of a thermoset type polymer, or by adding heat stabilizers or anti-aging additives to a suitable thermoplastic, or by using a cast metal such as zinc or aluminum (although in that case, electrical insulation must be provided between the housing and the fuse).

Optionally (as depicted), a projectile 34 may be provided between the pyrotechnic igniter assembly 32 and the bolt-on fuse strip 24 or other such portion of the electrical circuit that is to be broken, and if so, the projectile 34 can preferably be integrally molded into the upper housing 22 as is shown. Upon ignition of the pyrotechnic igniter assembly 32, the projectile 34 breaks free and is propelled into the bolt-on fuse strip 24, with its pointed front portion facilitating cutting of the bolt-on fuse strip 24. It is noted that the projectile 34 does not necessarily need a point or sharp edge, because the action may primarily be that of shearing the 24 fuse strip. Also, the projectile 34 can made be of the same material as the housing, even if it is polymer, because the action may primarily be a function of the velocity of the projectile 34 rather than its strength. Thus, the projectile 34 may be monolithically molded as part of the housing, eliminating a separate part and the associated cost and scrap, and increasing reliability. In that case, the material connecting the projectile 34 to the rest of the housing preferably may have a cross-section and material strength selected so as to break upon output with enough energy to accelerate the projectile 34 to the velocity required to break the fuse strip 24, and is preferably configured so that an edge is formed upon separation of the projectile 34 from the housing that may provide a seal to the projectile 34 as it travels through the fuse strip 24. When the projectile 34 (which is non-conductive) breaks the fuse strip 24, it pushes the fuse strip 24 into the rupture area 28 (see FIG. 2), preferably locking the broken fuse strip 24 section in place so that it cannot inadvertently re-make the circuit.

Referring to FIG. 2 in particular, it can be seen that a rupture area 28, which is an empty cavity, is provided below the bolt-on fuse strip 24 between the standoff in the sides of the lower housing 30. As noted, the rupture area 28 accommodates the resulting projection of the adjacent portion of the bolt-on fuse strip 24 when impacted by the output of the pyrotechnic igniter assembly 32 or the optional projectile 34. The rupture area 28 can also help reduce the heat

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conducted into the upper housing 22 and lower housing 30 when the bolt-on fuse strip 24 experiences an excessive current load.

Referring to FIG. 3 in particular, this embodiment reduces ignition charge size for a given sized fuse by focusing ignition gases around the fuse portion to be severed. This increases the local temperature and severs the fuse by applying drag forces across the thickness of the fuse generated by high-speed ignition gases and focused force of the ignition exhaust. The housing is preferably designed to follow the contours of the fuse such that the ignition gases can only pass through a narrow aperture (clearance) around the fuse exerting pressure to break it. The bolt-on fuse strip 24' has a thickness and minimum fuse width that correspond to the rated amperage of the particular fuse, as is known in the art. Bolt-on fuse strips are well-known for use in breaking a circuit under high current override conditions. The output of the pyrotechnic igniter assembly 32, and the configuration of the upper housing 22, lower housing 30, projectile 34 (if any) and rupture area 28, should be designed to accommodate the thickness of whatever fuse may be chosen for use in the circuit breaker, and to ensure reliable breaking of the fuse upon activation of the pyrotechnic igniter assembly 32. Where projectile 34 is not used, the clearance between the periphery of the fuse strip and the adjacent perimeter of the rupture area has a significant effect on the rupturing impact of the pyrotechnic output on the fuse (with less clearance increasing the rupture force exerted). (Although the depicted preferred embodiments utilize a fuse as the portion of a circuit that is formed to be readily broken, which is preferable, it does not necessarily have to be a fuse).

As shown in FIG. 4, an alternate bolt-on fuse strip 24" can be provided with an enlarged impact area 38 that reduces the amount of energy that must be produced by the pyrotechnic igniter assembly 32 in order to ablate or otherwise break the bolt-on fuse strip 24", thus permitting (depending on the embodiment) the use of a lower cost pyrotechnic igniter assembly than the one depicted in FIG. 3. This acts like a "force accumulator" and absorbs force generated from the ignition exhaust, allowing for a smaller ignition charge to sever a given sized fuse. Alternately, if the optional projectile 34 is omitted, the enlarged impact area 38 can be employed to receive more of the output energy of the pyrotechnic igniter assembly 32 so that a larger igniter is not needed.

It has been determined that the embodiment of the invention described here can be configured to result in breakage of the circuit in about 0.1 to 5 ms, e.g., 1 ms, after issuance of a signal to pyrotechnic igniter assembly 32. Such a fast response time can help reduce the potential for buildup of heat in wiring and circuitry such as in a vehicle that has experienced a collision, prevent electrocutions, and stop fast-moving machinery or cutting apparatus or other abnormal condition such as in industrial safety systems.

Turning to FIGS. 5-10, another embodiment of a pyrotechnic circuit breaker according to the present invention is shown that utilizes a slug to tear a portion of the circuit.

This embodiment of circuit breaker 120 includes an upper housing 122 containing an insert-molded pyrotechnic igniter 132 and a lower housing 130 containing an empty rupture area 128. Between the upper and lower housing is a bolt-on fuse strip 124 with bolt holes 126 at which the circuit breaker 120 may be attached to the circuit to be protected (e.g., at cables from a power device such as a car battery), such as with nuts and bolts, preferably mounting the circuit breaker 120 in close proximity to either the power supply or

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the circuit to be protected. The upper and lower housing may be made from the same or different materials, preferably a durable thermoplastic such as Ticona's PA66 (60% glass filled nylon) with an impact modifier at 10%-20%, preferably 10%-15%, by weight of base material. A suitable impact modifier mix is 10%-20% Pellathane 2012-65D polyurethane. The upper housing may be formed of a somewhat lower performance material such as glass-filled nylon, Zytel, or Valox.

Just below the output end of the igniter 132 is a generally cylindrical passage extending to the top of the strip 124, with a slug 134 located in the passage directly between the output end of the igniter 132 and an impact area 138 of the strip 124. The slug 134 is made out of an electrically non-conductive material and shaped like a puck, preferably of a diameter about the same as the igniter 132 and just slightly less than the passage within which it is located. The slug 134 is either molded in place as part of the upper housing 122, or alternately it can be installed separately. The slug 134 may also serve to partly insulate the igniter 132 from the high operating temperatures of the fuse.

Adjacent to its impact area 138, the strip 124 includes a necked area 139 that tears upon actuation of the igniter 132. As can be seen in FIGS. 7 and 8, the necked area 139 is directly above a laterally inclined ramp 145 at the top of a base 148 that extends into the otherwise empty rupture area 128. The ramp 145 extends laterally approximately the same distance as the narrowed width of the necked area 139 of the strip 124, and is preferably molded with a sharp ninety-degree angle edge along its length at the front face of the base 148. At the bottom of the rupture area 128, the lower housing 130 may include through-holes for venting. More preferably, it may include blind vents 147 closed by a thin layer designed to burst under exhaust pressure, so that the circuit breaker 120 is sealed from the environment during normal operation yet able to vent adequately after firing.

To assemble the circuit breaker 120, the strip 124 is snapped into place in the lower housing 130 as shown in FIG. 8, with bosses 146 (which may be non-uniform to ensure correct orientation of the strip 124) inserting into corresponding notches defined in the strip 124. The upper housing 122 is then slid into the lower housing 130 along the top surface of the strip 124, with slots 140 in the lower housing 130 and corresponding protrusions of the upper housing 122 sliding together until the stop 143 is reached. Upwardly bent tabs 141 on the strip 124 inhibit the upper housing 122 from sliding back out, and the upper and lower housing may also be provided with mating snap-lock features.

In use, preferably an external, independent source (e.g., sensors, a computer, and/or a person) determines a condition that warrants discontinuing current flow through the circuit to be protected, and actuates the pyrotechnic igniter 132. The output end of the igniter 132 then discharges directly into the slug 134, forcing it into the impact area 138 of strip 124, and pushing the strip 124 toward rupture area 128 and ramp 145 of the lower housing 130. Since the slug 134 substantially fills the passage, the slug must completely escape the passage (and thus the strip 124 must be broken as described below) before exhaust gas from the igniter 132 can be released into rupture area 128 and then vented. Consequently, substantially all output energy from the igniter is directed onto the strip 124, maximizing the force applied to tearing the strip 124 as described below.

While the slug 134 causes the impact area of the strip 124 to move freely down into the rupture area 128 without any direct obstruction below, the necked area 139 of the strip 124

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strikes the aforementioned sharp ninety degree angle edge of the ramp 145 at the front face of the base 148. The sharp edge acts somewhat like a guillotine, causing the strip 124 to tear at its necked area 139, progressively along its lateral extent from its side directly above the higher end of the ramp 145, to the other side directly above the lower end of the ramp 145. The angle of incline of the ramp 145 is preferably optimized (according to principles well known in the metal stamping art) for the particular configuration and materials so that the sharp edge most efficiently tears the strip 124 progressively from end to end rather than essentially shearing the whole width at once. Since the output energy directed to tearing the strip 124 is maximized as noted above, neither a metal cutting edge for the ramp nor a metal slug is needed, which reduces possible short circuits after the circuit is broken. After the necked area 139 of the strip 124 is torn, the non-conductive slug 134 is securely driven between the broken sides of the necked area 139 of the strip 124, with blown-out cruciform petals 125 on the output end of the igniter 132 preventing the slug 134 from moving back toward its original location, eliminating possible re-connections due to spring-back, jarring of the circuit breaker 120, etc.

Testing of a circuit breaker according to the embodiment of FIGS. 5-10 with no metal parts other than the igniter and fuse strip and using only a 35 mg ZPP charge showed it to reliably break copper fuse strip thick, over a temperature range of -40 C. to +125 C. Such a decreased charge size results in less exhaust gases, and reduces the size and cost of the assembly needed to adequately absorb pyrotechnic shock and contain exhaust gases, thus also expanding the range of potential applications for such a circuit breaker.

If desired, electronic circuitry (not shown) may also be incorporated into the pyrotechnic circuit breaker 20 or 120, for example in applications where actuation of the igniter may require a secure digital signal for security or safety reasons, e.g., in the case of actuation by law enforcement or military personnel in the event of theft, pursuit, et cetera. If included, such circuitry could also be configured to monitor (based on, e.g., inductive field, temperature, or other desired means) the condition of the fuse itself to determine if a condition is present that warrants breaking the circuit. In such case, if suitable current-sensing means are employed, the portion of the circuit broken by the pyrotechnic igniter assembly need not be a fuse but instead can simply be an ordinary low resistance portion that is formed (e.g., by flattening, widening, necking, and/or scoring) to be readily ablated, torn, or cut.

Although the foregoing description has described the action of the pyrotechnic igniter assembly as sufficient to fully ablate, tear, or cut the bolt-on fuse strip, other embodiments can readily be conceived in which the combination of heat, shock loading, and output gas pressure from the igniter breaks, weakens, or damages the fuse so as to decrease the amount of current required to sever the fuse (or cause it to break more rapidly at its rated current). It is also possible that the pyrotechnic igniter assembly can be used as the main actuator of the fuse in response to a command signal as well as in response to an excessive current load, such as by choosing a configuration and composition of the pyrotechnic igniter assembly whereby the igniter auto-ignites in response to heat generated by the fuse during excessive current load.

As will be readily apparent to one in the art, there are a number of applications in which suitable embodiments of a pyrotechnic circuit breaker according to the present invention may be employed. Considering just automotive applications by way of example, suitable embodiments may be

used in an automobile to rapidly cut power in the case of a collision and thus reduce the risk of electrical fire or damage to electrical components. Circuitry generally similar to that used in safety system controllers could also be incorporated to monitor one or more conditions and when appropriate provide a command to the initiator to break the circuit, for example, a predetermined amount of time after the initial sensing of a collision. As another example, suitable embodiments of the present invention may be employed to disable an automobile (such as in response to a command transmitted by the owner, security service vendor, or government personnel) in the case of theft or unlawful operation of the vehicle. In such case, other measures known in the art may also be employed in conjunction so as to reduce the likelihood of immediate loss of control of the vehicle in response to such a command, et cetera. Another application is industrial equipment and personnel safety systems, such as safety curtains, emergency brakes for fast-moving rotary or linear machinery, cutting blades/apparatus, electrocution prevention, quick disconnects, etc.

Thus, although the present invention has been described in the context of one particular preferred embodiment, one skilled in the art will appreciate that numerous variations, modifications, and other applications are also within the scope of the present invention. For example, the present invention can be used in any suitable application in which there is a need for remote or automatic cutting of power in a rapid manner, such as in military or commercial vessels or aircraft (e.g., in case of enemy attack), commercial building power control panels and oil pipeline pumping stations (e.g., in an emergency such as an earthquake or terrorist attack), munitions or explosive devices (e.g., to disarm associated electronic circuitry), industrial safety curtains and high speed equipment (e.g., as a rapid power disconnect), and a number of other applications. Thus, the foregoing detailed description of preferred embodiments is not intended to in any way limit the invention, which is limited only by the following claims and their legal equivalents.

What is claimed is:

1. A pyrotechnic circuit breaker for use in an electrical circuit comprising:

- a) a housing;
- b) an electrically conductive portion secured to said housing and including means for secure incorporation into the electrical circuit;
- c) a pyrotechnic igniter secured to said housing and including an output end having cruciform petals oriented toward said electrically conductive portion;
- d) a passage defined in said housing between said electrically conductive portion and said output end of said pyrotechnic igniter;
- e) a rupture area defined in said housing adjacent said electrically conductive portion and on the side of said electrically conductive portion opposite said output end of said pyrotechnic igniter; and
- f) an electrically non-conductive mass within said passage between said pyrotechnic igniter and said electrically conductive portion;

wherein said pyrotechnic igniter, cruciform petals, passage, electrically non-conductive mass, and electrically conductive portion are positioned and configured such that after actuation of said pyrotechnic igniter and breaking of the circuit, said cruciform petals are blown out into a position that prevents said electrically non-conductive mass from moving to a position in which said electrically conductive portion could reconnect.

2. The circuit breaker of claim 1, wherein said electrically conductive portion includes a portion that is formed to be readily cut and/or torn.

3. The circuit breaker of claim 1, further including vents in said rupture area.

4. The circuit breaker of claim 1, wherein said electrically conductive portion includes a current load-based fuse.

5. A pyrotechnic circuit breaker for use in an electrical circuit comprising:

- a) a housing;
- b) an electrically conductive portion secured to said housing and including means for secure incorporation into the electrical circuit, wherein said electrically conductive portion is formed to be readily cut or torn;
- c) a pyrotechnic igniter secured to said housing and including an output end oriented toward said electrically conductive portion;
- d) a passage defined in said housing between said electrically conductive portion and said output end of said pyrotechnic igniter;
- e) a laterally ramped portion defined in said housing immediately below said electrically conductive portion;
- f) a rupture area defined in said housing adjacent said electrically conductive portion and on the side of said electrically conductive portion opposite said output end of said pyrotechnic igniter; and,
- g) an electrically non-conductive mass within said passage between said pyrotechnic igniter and said electrically conductive portion;

wherein said circuit breaker is configured so that upon actuation of said pyrotechnic igniter, said electrically non-conductive mass predictably progressively laterally cuts and/or tears said electrically conductive portion against said laterally ramped portion.

6. The circuit breaker of claim 5, wherein said electrically conductive portion includes a current load-based fuse.

7. The circuit breaker of claim 6, wherein said fuse is a bolt-on fuse strip.

8. The circuit breaker of claim 7, wherein said bolt-on fuse strip is an integral single piece having a uniform thickness.