Title: AN ELECTRICAL CONNECTOR HAVING A SEPARABLE CONNECTION AND METHOD THEREFOR

Abstract: An electrical connector having a housing and at least one current carrying element is provided. The current carrying element has a first portion and a second portion. A first biasing member is mounted within the housing for urging the first portion and the second portion outwardly. A second biasing member having a shape memory element is in proximity to the current carrying element. The shape memory element is fixed at an end thereof to the first portion and fixed at an opposite end thereof to the second portion. The shape memory element biases the first and second portions inwardly. The shape memory element has a stress riser formed therein. The shape memory element moves from a first configuration to a second configuration when heated at or above a phase transformation temperature and severs at the stress riser.
AN ELECTRICAL CONNECTOR HAVING A SEPARABLE CONNECTION AND METHOD THEREFOR

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to United States Provisional Patent Application No. 60/413,500 filed on September 25, 2002.

FIELD OF THE INVENTION

The present invention relates to an electrical connector having a separable connection and more particularly where the separable connection comprises a shape memory alloy.

BACKGROUND OF THE INVENTION

Interruptible circuit devices have been known in the art for some time. A common form of interrupting a circuit includes using a thermal fuse. Thermal fuses typically consist of a copper core stainless steel pin with a groove formed near its center. As current flows through the pin, electrical resistance heating in the groove is greater than the heating in the rest of the pin. The groove is designed such that during an electrical overload, fusion of the grooved part of the pin assures that the electrical connection will be interrupted. While successful, the thermal fuse does have some limitations. It can be difficult to predict with satisfying precision the triggering current and the associated temperature that will assure fusion. Moreover, molten metal or hot remnants of the fuse can damage the surrounding structure and provoke electrical arcing.

Another common electrical circuit separation device is disclosed in the U.S. Patent No 4,700,259 which uses a mechanical fracture mechanism to break an electrical connection. The breaking device comprises an elongated conductive element which will yield and fracture mechanically under the influence of the permanent tensile load applied to it. Fracture occurs when the conductive element is subjected to a current-induced heat greater than a predetermined level. Yet there remain some limitations with these devices. While such a mechanism produces a relatively smaller amount of molten metal as compared with conventional fuses, the material fusion cannot be completely avoided.
Additionally, the precise prediction of the triggering temperature is difficult for such a device because the material softening and subsequent failure require a larger temperature excursion.

[0005] Accordingly, it is an object of the present invention to provide an electrical connector having a separable connection that is precise, has no shrapnel or remnants after separating, and can be activated quickly and at low temperatures, if desired.

SUMMARY OF THE INVENTION

[0006] The invention provides an electrical connector having a separable connection that retains an electrical connection and which then severs the connection under certain conditions. The electrical connection is held together by a shape memory element in which a stress riser is locally created. The electrical connector has a housing and at least one current carrying element. The current carrying element has a first portion and a second portion at least partially enclosed within the housing. A first biasing member is mounted within the housing for urging the first portion and the second portion outwardly relative to the housing. A second biasing member having a shape memory element is in proximity to the current carrying element. The shape memory element is fixed at an end thereof to the first portion and fixed at an opposite end thereof to the second portion. The shape memory element biases the first and second portions inwardly relative to the body. The shape memory element has a stress riser formed therein. The shape memory element moves from a first configuration to a second configuration when heated at or above a phase transformation temperature. The shape memory element then severs at the stress riser and allows the first biasing member to separate the first portion from the second portion.

[0007] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the invention.
BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0009] Figure 1 is a front view of a refrigeration compressor having an electrical connector constructed according to the invention;

[0010] Figure 2 is an enlarged, partial cross-sectional top view of the refrigeration compressor and the electrical connector of Figure 1 taken along line 2-2;

[0011] Figure 3 is an enlarged cross-sectional top view of the electrical connector of Figure 1 taken along the line 3-3;

[0012] Figure 4 is a perspective view of the electrical connector together with a terminal block and fuse also constructed according to the invention;

[0013] Figure 5 is an enlarged schematic cross-sectional side view of the fuse of Figure 2;

[0014] Figure 6 is a schematic view of the steps used to create and install a shape memory element within the electrical connector and fuse of Figures 1-5;

[0015] Figure 7 is a schematic view of the steps used to create and install a second shape memory element within the electrical connector and fuse of Figures 1-5;

[0016] Figure 8 is a schematic view of the steps used to create and install a third shape memory element within the electrical connector and fuse of Figures 1-5;

[0017] Figure 9 is a schematic view of various stress risers formed on the shape memory elements of Figures 6-8;

[0018] Figure 10 is an exemplary stress-strain curve for a material used in calculating a reduced cross-sectional area for the shape memory element of Figures 6-8;
[0019] Figure 11 is an exemplary recovery stress and support rigidity curve used in calculating a reduced cross-sectional area for the shape memory element of Figures 6-8;

[0020] Figure 12 is a stress-strain curve for NiTi used in calculating a reduced cross-sectional area for an exemplary shape memory element;

[0021] Figure 13 is an exemplary shape memory element and support structure used in calculating a reduced cross-sectional area;

[0022] Figure 14 is an exemplary recovery strain and recovery force curve for the shape memory element of Figure 13;

[0023] Figure 15 is an exemplary stress concentration factor curve for the shape memory element of Figure 13; and

[0024] Figure 16 is a schematic view of the exemplary shape memory element of Figure 13 having a portion of reduced cross-sectional area.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

[0026] With reference to Figure 1, there is illustrated an electrical connector 10 having a shape memory element constructed according to the principles of the present invention shown in operative association with an exemplary compressor 12. The compressor 12 is known in the refrigerant art and includes a wall 14 that encloses a motor (not shown). Power is provided to the motor of the compressor 12 through suitable electrical wires 16 leading from an electrical power source (not shown). The electrical wires 16 are coupled to a terminal block 18 that is mounted to the electrical connector 10. The electrical connector 10 is in electrical communication with the electrical wires 16 and passes current through the wall 14 onto the interior of the compressor 12. The electrical connector 10 interrupts the current in the event of any number of adverse conditions, for example, power surges or overheating.

[0027] Turning to Figure 2, the electrical connector 10 generally includes a body 20 mounted within the wall 14 of the compressor 12 such that the
body 20 extends on each side of the wall 14. It should be noted that he body 20 may have any practical shape. A set of three current conducting pins 22 (all three shown in Figure 4) extend through the body 20. In this regard, the current conducting pins 22 extend from one side of the wall 14 of the compressor 12 to the other side thereof. It should be noted that while in the particular example provided three current conducting pins are shown, any number of pins may be employed with the invention.

[0028] With reference to Figure 3, each current conducting pin 22 includes a first portion 24 and a second portion 26. The first portions 24 extend out from the body 20 on a side thereof and are sealed to the body 20 by hermetic seals 28. The second portions 26 extend out from the body 20 from a side opposite that of the first portions 24. The second portions 26 each have a connector 30 mounted on an end thereof to receive one of the lead wire ends of the electrical wires 4 (Figure 1). The second portions 26 are also sealed to the body 20 by hermetic seals 28. The seals 28 are preferably made of glass, although other materials may be employed. An insulating silicone rubber coating 32 is formed and covers a portion of the pins 22 and the outside of the body 20 to prevent electrical arcing between the current conducting pins 22.

[0029] For each of the current conducting pins 22, each first portion 24 is in separable contact with a corresponding second portion 26 within the body 20, thereby allowing electrical current to flow therebetween.

[0030] Within the body 20, a first retainer 34 is coupled at an end thereof to at least one of the first portions 24. Similarly, a second retainer 36 is coupled at an end thereof to at least one of the second portions 26.

[0031] A biasing member 38, a spring in the example provided, is disposed between the first and second retainers 34, 36 within the body 20. The biasing member 38 produces an axial force outwardly relative to the body 20 against the first and second retainers 34, 36.

[0032] The electrical connector 10 further includes a shape memory element 40 mounted within the body 20. The shape memory element 40 is mounted between the first retainer 34 and the second retainer 36. Specifically, the shape memory element 40 is fixed at an end thereof to the first retainer 34
and fixed at an opposite end thereof to the second retainer 36. Moreover, as will be described in greater detail below, the shape memory element 40 is held in a deformed shape between the first retainer 34 and the second retainer 36. The shape memory element 40 acts as a biasing member opposed to the biasing member 38 to hold the first portions 24 in contact with the second portions 26 inwardly relative to the body 20. Accordingly, in the configuration illustrated in Figure 3, electrical current is uninterrupted between the first portions 24 and the second portions 26.

[0033] The shape memory element 40 is made of a shape memory alloy such as, for example, a NiTi alloy. Shape memory alloys "memorize" a pre-deformed state or configuration. After deformation (e.g. after mechanical tension, compression, torsion, etc. applied to the shape memory alloy) the shape memory alloy will revert to its memorized configuration (e.g. pre-deformation configuration) when subjected to a temperature at or above its phase transformation temperature. The phase transformation temperature will vary from alloy to alloy and is a factor in material selection.

[0034] The shape memory element 40 is preferably cylindrical, although any number of various shapes may be employed. The shape memory element 40 includes a stress riser 42. Generally, the stress riser 42 is a portion of the shape memory element 40 having a reduced cross-sectional area relative to the rest of the shape memory element 40. The shape memory element is intended to sever at the stress riser 42 under certain conditions.

[0035] With general reference to Figures 1-3, during use of the electrical connector 10 in the compressor 12, resistance heating of the current conducting pins 22 in turn heats the shape memory element 40 within the body 20. If the temperature of the shape memory element 40 increases to approximately the phase transformation temperature associated with the material of the shape memory element 40, the shape memory element 40 will attempt to return to its original "memorized" shape. However, because the shape memory element 40 is fixed at both ends to the first and second retainers 34, 36, the shape memory element 40 will be unable to achieve its recovered shape. This in turn will lead to stress building within the shape memory element 40. When the
stress within the shape memory element 40 reaches the ultimate stress associated with its material, the shape memory element 40 will sever at the stress riser 42. The biasing member 38 will then be unopposed and urge the first portions 24 away from the second portions 26 such that they are no longer in electrical contact with one another. This then interrupts the electrical current flowing through the current conducting pins 22 and therefore disconnects the compressor 12 from its power source (not shown).

[0036] Turning to Figure 4, the electrical connector 10 is illustrated in relation to the terminal block 18. The terminal block 18, as mentioned above, attaches to the electrical connector 10. The terminal block 18 serves to protect the current conducting pins 22 from ready access, diffuses any possible leakage from the compressor 12, and provides at least one fuse 46 at a location remote from the current conducting pins 22 in the event of arcing. A plurality of fuses 46 (only one of which is shown) fit within ports 48 formed on the terminal block 18 and are coupled to the electrical connector 10. Such an arrangement is generally discussed in U.S. Pat. No. 5,055,653, the disclosure of which is incorporated herein by reference.

[0037] The fuse 46 generally includes a first lead 50 and a second lead 52 that extend out from a housing 54 (partially removed in Figure 4 for clarity). A shape memory element 56, similar in design to the shape memory element 40, acts as a circuit interrupter and is surrounded by an insulator 58 (shown cut away in Figure 4).

[0038] Turning briefly to Figure 5, the shape memory element 56 is fixed at one end to the first lead 50 and fixed at an opposite end thereof to the second lead 52. The shape memory element 56 is in its deformed configuration and includes a stress concentration riser 60 formed therein. Electrical current passes directly through the shape memory element 56 between the first lead 50 and the second lead 52. When resistance heating of the shape memory element 56 rises to or above the phase transformation temperature of the material of the shape memory element 40, the shape memory element 56 will attempt to return to its original “memorized” shape. However, because the shape memory element 56 is fixed at opposite ends to the first and second leads 50, 52, the shape
memory element 56 will be unable to achieve its recovered shape. This in turn will lead to stress building within the shape memory element 56. When the stress within the shape memory element 56 reaches the ultimate stress associated with its material, the shape memory element 56 will sever at the stress concentration riser 60. This then interrupts the electrical current flowing between the first lead 50 and the second lead 52.

[0039] Returning to Figure 1, in the particular example provided, the compressor 12 has been described to include both the electrical connector 10 and the terminal block 18 with the fuse 46 (Figure 4) as both having shape memory elements. However, either the fuse 46 or the electrical connector 10 alone can include a shape memory element without departing from the scope of the invention.

[0040] With reference to Figure 6, the installation of the shape memory element 40 within the electrical connector 10 will now be described. Initially, as shown at Step I, the shape memory element 40 has a uniform cross section and a first configuration, or “memorized” configuration. At Step II, the shape memory element 40 is deformed to a second configuration, or “deformed” configuration. Preferably, deformation of the shape memory element 40 is accomplished at room temperature and placed under tension until the shape memory element elongates. At Step III, the shape memory element is fixed at one end to the first retainer 34 and the opposite end to the second retainer 36. Also, the stress riser 42 is machined into a portion of the shape memory element 40. The determination of the cross sectional area required will be described in greater detail below. Finally, at Step IV, the shape memory element 40 will attempt to recover its memorized shape upon heating at or beyond the phase transformation temperature. Stress within the shape memory element 40 will sever the shape memory element at the stress riser 42, thereby allowing the biasing member 38 (Figure 3) to interrupt the current flowing through the electrical connector 10.

[0041] With reference to Figure 7, a first embodiment of the shape memory element 40 is illustrated and indicated by reference numeral 40’. The shape memory element 40’ is generally hollow. Deformation of the shape memory element 40’ to a deformed configuration is achieved by applying a
torsional force to the shape memory element 40', as indicated by the arrows in Step I. The stress riser 42 is machined into the shape memory element 40' at Step II and the shape memory element 40' is fixed between the first and second retainers 34, 36 at Step III. As with the previous embodiment, heating of the shape memory element 40' at or above the phase transformation temperature will lead to severing of the shape memory element 40' at the stress riser 42.

[0042] With reference to Figure 8, a second embodiment of shape memory element 40 is illustrated and indicated by reference numeral 40". The shape memory element 40" is generally hollow and has an inner diameter D₁. Deformation of the shape memory element 40" to a deformed configuration is achieved by applying a radial force to the shape memory element 40", as indicated by the arrow in Step I. This creates a deformed configuration in Step II having an inner diameter D₂ that is greater than D₁. An alternate stress riser 42" is machined into the shape memory element 40" at Step II. The alternate stress riser 42" reduces the thickness of the shape memory element 40" along its entire length. The shape memory element 40" is fixed along its entire length at Step III within the electrical connector 10 with a rod 68 fitted within the shape memory element 40". As with the previous embodiments, heating of the shape memory element 40" at or above the phase transformation temperature will lead to severing of the shape memory element 40" along the stress riser 42".

[0043] Turning now to Figure 9, various stress concentration risers are illustrated in conjunction with the shape memory element 40. These stress concentration risers all serve to reduce the cross-sectional area of the shape memory element 40 and include a single large circular hole, a circumferential v-groove, a circumferential square groove, a circumferential semi-circular groove, a plurality of small circular holes, a plurality of v-shaped notches, a plurality of square notches, and a plurality of semi-circular notches.

[0044] With reference to Figures 10-16, the calculation of the required reduction in cross-sectional area of the shape memory element 40 will now be described in greater detail. First, a maximum recovery stress and the associated induced strain for a given shape memory material is determined from known literature or experimentation. As shown in Figure 10, a stress-strain curve for a
given material may be used to determine the maximum stress and associated
strain. At this point it is assumed the rigidity of the supports for the shape
memory element 40 (e.g. the first and second retainers 34, 36) is very great.

[0045] Next, the ultimate stress of the shape memory material is
determined either from experimentation or through known literature. The ultimate
stress corresponds to the amount of stress the shape memory material may
endure before fracturing.

[0046] An effective recovery stress is then calculated taking into
account the rigidity of the support members (e.g. the first and second retainers 34,
36). As illustrated in Figure 11, this may be determined experimentally or through
known literature.

[0047] Finally, a reduced cross-sectional area is calculated that will
assure fracture of the shape memory element 40 when attempting to recover its
memorized shape. The effective recovery stress is compared to the ultimate
stress to determine by what factor the recovery stress in the shape memory
element 40 must be multiplied to induce fracture. This calculated factor may then
be compared to known stress concentration factors associated with various
cross-sectional areas, and a cross-sectional area may be selected.

[0048] By way of example, a cross-sectional area will be calculated for
a shape memory element made of a NiTi shape memory alloy. Figure 12
illustrates a known stress-strain curve for NiTi. A maximum recovery stress
associated with an induced strain can be determined from the graph. The
maximum recovery stress ($\sigma_{\text{rec}}$) is approximately 475MPa and the induced strain
($\varepsilon_{\text{ind}}$) is approximately 8%. The ultimate stress ($\sigma_{\text{ult}}$) of NiTi is known in the
literature and is approximately 800MPa.

[0049] Turning to Figure 13, the rigidity of the support beams is next
taken into account. For purposes of the example, a pair of support beams of
steel 100 and a shape memory element ribbon of NiTi 102 with the dimensions
listed in the chart is assumed. As is noted in Figure 13, as the shape memory
element 102 attempts to recover its memorized shape, the support beams 100
will deflect, thereby reducing the maximum recovery stress in the shape memory
element 102 to the effective recovery stress.
[0050] The effective recovery stress is calculated for the above example by first determining a force-deflection curve for the support beams 100. Assuming the ends of the support beams 100 are fixed and maximum deflection occurs in the center, the deflection can be calculating using the equation: \( y = \frac{F(l^3/48EJ_z)}{}, \) where \( y \) is the deflection, \( F \) is the applied load, \( l \) is the span of the support beams 100, \( E \) is Young’s modulus of elasticity for the support beam 100 material (200GPa for steel), and \( J_z \) is the moment of inertia of the cross section of the support beams 100. For a rectangular cross section, \( J_z = (bh^3)/12, \) where \( b \) is the width of the support beams 100, and \( h \) is the thickness of the support beams 100. The maximum applied force (\( F_{max} \)) is calculated as follows: \( F_{max} = \sigma_{rec}(bh). \) In the example provided, \( F_{max} = 475MPa \times 5mm \times .25mm = 600N. \)

[0051] The maximum deflection (\( d_{max} \)) is then calculated, where \( d_{max} = (1/2) \epsilon_{ind}L, \) and where \( L \) is the length of the shape memory element. In the example provided, \( d_{max} = (1/2)\times.08\times50mm = 2mm. \)

[0052] The recovery force decreases linearly with the strain recovered during heating as the deflection of the support beams 100 increases linearly with the recovery force. Accordingly, as shown in Figure 14, these may be plotted on a graph and an equilibrium force (\( F_{eq} \)) determined. The equilibrium force is approximately 480N in the example provided. The effective recovery stress (\( \sigma_{eff} \)) can then be calculated as follows: \( \sigma_{eff} = F_{eq}/S, \) where \( S \) is the cross-sectional area of the shape memory element 102. In the particular example, \( \sigma_{eff} = 480N/(5mm\times.25mm) = 384 \text{ MPa}. \)

[0053] Accordingly, in order to assure that the shape memory element 102 fractures when attempting to recover its memorized shape, the stress in the shape memory element 102 must be increased by a factor (\( f \)). The factor is determined as follows: \( f = \sigma_{ult}/\sigma_{eff}. \) In the particular example provided, \( f = 800MPa/384MPa = 2.08. \) As shown in Figure 15, a stress concentration factor that is greater than the calculated factor of 2.08 may be determined from the known literature for a given cross section (a rectangular shape memory element and a circular hole in the particular example provided). From the graph in Figure 15, it can be determined that a hole of .5mm diameter can be punched through the shape memory element 102, as illustrated in Figure 16 and indicated by
reference numeral 104. Accordingly, the shape memory element 102 will sever at the hole 104 after heating of the shape memory element 102 at or above the phase transformation temperature associated with NiTi.

[0054] While various preferred embodiments have been described, those skilled in the art will recognize modifications or variations which might be made without departing from the inventive concept. The examples illustrate the invention and are not intended to limit it. Therefore, the description and claims should be interpreted liberally with only such limitation as is necessary in view of the pertinent prior art.
CLAIMS

What is claimed is:

1. An electrical connector comprising:
   a current conducting pin comprising a first portion and a second portion;
   a shape memory element fixed at an end thereof to said first portion and fixed at an opposite end thereof to said second portion, said shape memory element comprising a stress riser;
   wherein when said shape memory element is heated at or above a phase transformation temperature it severs at said stress riser, thereby separating said first portion from said second portion.

2. In a hermetic refrigeration compressor of the type comprising a wall housing a motor and having an electrical connector mounted in said wall for providing electrical power to said motor from a power source, said electrical connector comprising:
   a body;
   at least one current conducting pin, said current conducting pin having and having a first portion and a second portion, said first portion being separable from said second portion;
   a biasing member biasing said first portion and said second portion away from one another; and
   a shape memory element fixed at an end thereof to said first portion and fixed at an opposite end thereof to said second portion, said shape memory element biasing said first portion and said second portion toward each other, said shape memory element having an area of reduced cross-section;
   wherein when said shape memory element is heated at or above a phase transformation temperature it severs at said area of reduced cross-section such that said biasing member separates said first portion of said at least one current conducting pin from said second portion of said at least one current conducting pin and disconnects said electrical power source from said motor.
3. A circuit breaker comprising:
   a first lead;
   a second lead; and
   a shape memory element fixed at an end thereof to said first lead
   and fixed at an opposite end thereof to said second lead, said shape memory
   element having a stress riser formed therein, said shape memory element
   operable to carry current from said first lead to said second lead;
   wherein when said shape memory element is heated at or above a
   phase transformation temperature it severs at said stress riser, thereby
   separating said first lead from said second lead.

4. An electrical connector comprising:
   a body;
   at least one current carrying element having a first portion and a
   second portion, said current carrying element at least partially enclosed within
   said housing;
   a first biasing member mounted within said housing for urging said
   first portion and said second portion away from one another; and
   a second biasing member for urging said first portion and said
   second portion toward one another, said second biasing member comprising a
   shape memory element located in proximity to said at least one current carrying
   element and first and second retainers;
   said first retainer fixed to said first portion of said current carrying
   element and said second retainer fixed to said second portion of said current
   carrying element, said shape memory element being fixed between said first and
   second retainers,
   wherein when said shape memory element is heated at or above a
   phase transformation temperature it severs such that said first biasing member
   drives said first portion of said current carrying element away from said second
   portion of said current carrying element and separates said first portion from said
   second portion.
5. A method for making an electrical connector having a separable connection, said method comprising:

providing a shape memory element having a memorized configuration;

dehorning the shape memory element to a deformed configuration;
forming a stress riser having a reduced cross-sectional area in said shape memory element;
fixing said shape memory element within said electrical connector.

6. A method for making an electrical connector having a separable connection, said method comprising:

providing a shape memory element having a memorized configuration;

dehorning the shape memory element to a deformed configuration;
forming a stress riser having a reduced cross-sectional area in said shape memory element;
fixing said shape memory element with current conducting element of said electrical conductor, said current conducting element having a first portion and a second portion.
Fig. 12

Maximum recovery stress

Associated induced strain