There is scope for improvements in existing technology for monitoring or indicating high-energy blunt impacts on structures such as aircraft.

SUMMARY

The subject matter disclosed herein is directed to systems and methods using fluid-filled hollow microspheres to assist in monitoring or indicating high-energy blunt impacts on structures such as aircraft. A multiplicity of microspheres may be adhered to or embedded in a coating applied on a surface of a substrate (e.g., a tape or an appliqué), which substrate in turn can be adhered to a surface of a structure to be monitored. The microspheres are designed to rupture at one or more specified pressure thresholds. In some embodiments, the microspheres are filled with electrically conductive fluid which, if released from ruptured microsphere, changes the electromagnetic state of the substrate. In response to the detection of a sufficiently large change in the electromagnetic state of the substrate, a blunt impact indication is generated. The impact site may then undergo non-destructive inspection.

One aspect of the disclosure is a blunt impact indicator device comprising:

a substrate comprising first and second surfaces;

a multiplicity of rupturable shells disposed in proximity to said first surface of said substrate, the shells having an electrically conductive fluid disposed in an internal volume of the shells;

an antenna comprising first and second electrical conductors which are not electrically coupled to each other in the absence of electrically conductive fluid; and

a radio-frequency identification circuit comprising a transceiver connected to said first and second electrical conductors,

wherein said first and second electrical conductors are disposed on one side of said first surface of said substrate and configured and spaced so that said first and second electrical conductors can be electrically coupled to each other

in the presence of electrically conductive fluid released from said multiplicity of shells, and

wherein any response transmitted by the transceiver will have a frequency which is a function of an impedance of the antenna when the first and second serpentine electrical conductors are electrically coupled to each other by electrically conductive fluid escaped from the multiplicity of shells.

Another aspect of the disclosure is a blunt impact indicator device comprising:

a substrate;

a breakable electrical conductor disposed on or embedded in said substrate and having first and second terminals;

a voltage supply connected to said first and second terminals of said breakable electrical conductor;

a continuity indicator electrically connected to said breakable electrical conductor;

a multiplicity of rupturable shells disposed in proximity to a surface of said substrate, said shells being distributed over an area encompassing said breakable electrical conductor, each shell having an internal volume; and

an electrically conductive fluid disposed in the internal volumes of respective shells of said multiplicity of shells.

Another aspect of the disclosure is a method for monitoring a structure for damage due to blunt impact, comprising:

attaching a substrate to a surface of the structure, the substrate comprising a multiplicity of rupturable shells adhered thereto or embedded therein, each shell having an internal volume, and an electrically conductive fluid disposed in the internal volumes of respective shells of said multiplicity of shells; and

detecting a change in electrical conductivity of the substrate,

wherein said detecting a change in electrical conductivity of the substrate comprises:

placing a coil in proximity to the substrate;

causing alternating current to flow through the coil during first and second time intervals, a magnitude of said alternating current and a distance separating the coil from the substrate being selected for inducing eddy currents in the substrate; and

measuring any difference between a first impedance of the coil during said first time interval and a second impedance of the coil during said second time interval.

Another aspect of the disclosure is a method for monitoring a structure for damage due to blunt impact, comprising:

attaching a substrate to a surface of a structure, the substrate comprising a multiplicity of rupturable shells disposed in proximity to a surface of the substrate, each shell having an internal volume, and an electrically conductive fluid disposed in the internal volumes of respective shells of said multiplicity of shells; and

detecting a change in thermal state of the substrate.

Another aspect of the disclosure is a method for monitoring a structure for damage due to blunt impact, comprising:

placing a radio-frequency identification circuit and first and second serpentine electrical conductors on a substrate, the first and second serpentine electrical conductors having respective first terminals electrically connected to respective terminals of the radio-frequency identification circuit and respective second terminals which are not electrically connected to each other;

placing a multiplicity of rupturable shells over the first and second serpentine electrical conductors, each shell having an internal volume at least partially filled with electrically conductive fluid; and

interrogating the radio-frequency identification circuit by transmitting a radio-frequency signal through a volume of space intersected by radio-frequency identification circuit,

wherein any response to the interrogation by the radio-frequency identification circuit will have a frequency which is a function of an impedance of an antenna formed if the first and second serpentine electrical conductors are electrically coupled to each other by electrically conductive fluid escaped from the multiplicity of shells.

Another aspect of the disclosure is a system for monitoring a structure for damage due to blunt impacts, comprising:

a substrate comprising first and second surfaces;

a multiplicity of radio-frequency identification circuits adhered to said first surface of said substrate;

a multiplicity of rupturable shells comprising respective sets of rupturable shells overlying respective radio-frequency identification circuits, each shell having electrically conductive fluid disposed in an internal volume thereof; and

a multiplicity of antennas respectively connected to said multiplicity of radio-frequency identification circuits,

wherein each of said antennas comprises first and second electrical conductors which are configured and spaced so that said first and second electrical conductors can be electrically coupled to each other in the presence of electrically conductive fluid released from said multiplicity of shells;

wherein each radio-frequency identification circuit comprises a respective transceiver connected to said first and second electrical conductors of a respective antenna; and

wherein any response transmitted by a transceiver will have a frequency which is a function of an impedance of the respective antenna when said

first and second electrical conductors are electrically coupled to each other by electrically conductive fluid escaped from the multiplicity of shells.

Aspects of the subject matter disclosed further include:

A1. A blunt impact indicator device, comprising:

a substrate comprising first and second surfaces; and

a multiplicity of rupturable shells disposed in proximity to said first surface of said substrate, the shells having an electrically conductive fluid disposed in an internal volume of the shells.

A2. The blunt impact indicator device as recited in A1, wherein said shells are hollow microspheres made of dielectric material.

A3. The blunt impact indicator device as recited in any of A1-A2,

CLAIMS

1. A blunt impact indicator device comprising:

a substrate comprising first and second surfaces;

a multiplicity of rupturable shells disposed in proximity to said first surface of said substrate, the shells having an electrically conductive fluid disposed in an internal volume of the shells;

an antenna comprising first and second electrical conductors which are not electrically coupled to each other in the absence of electrically conductive fluid; and

a radio-frequency identification circuit comprising a transceiver connected to said first and second electrical conductors,

wherein said first and second electrical conductors are disposed on one side of said first surface of said substrate and configured and spaced so that said first and second electrical conductors can be electrically coupled to each other in the presence of electrically conductive fluid released from said multiplicity of shells, and

wherein any response transmitted by the transceiver will have a frequency which is a function of an impedance of the antenna when the first and second serpentine electrical conductors are electrically coupled to each other by electrically conductive fluid escaped from the multiplicity of shells.

2. The blunt impact indicator device as recited in claim 1, wherein said shells are hollow microspheres made of dielectric material.

3. The blunt impact indicator device as recited in claim 1, further comprising a layer of adhesive on said second surface of said substrate.

4. The blunt impact indicator device as recited in claim 1, wherein said substrate is in the form of a tape or an applique.

5. The blunt impact indicator device as recited in claim 1, wherein said first and second electrical conductors are serpentine.

6. The blunt impact indicator device as recited in claim 1, wherein said radio-frequency identification circuit further comprises non-volatile memory storing information which uniquely identifies said radio-frequency identification circuit.

7. A blunt impact indicator device comprising:

a substrate;

a breakable electrical conductor disposed on or embedded in said substrate and having first and second terminals;

a voltage supply connected to said first and second terminals of said breakable electrical conductor;

a continuity indicator electrically connected to said breakable electrical conductor;

a multiplicity of rupturable shells disposed in proximity to a surface of said substrate, said shells being distributed over an area encompassing said breakable electrical conductor, each shell having an internal volume; and

an electrically conductive fluid disposed in the internal volumes of respective shells of said multiplicity of shells.

8. The blunt impact indicator device as recited in claim 7, wherein said breakable electrical conductor has a serpentine or spiral configuration.

9. A method for monitoring a structure for damage due to blunt impact, comprising:

attaching a substrate to a surface of the structure, the substrate comprising a multiplicity of rupturable shells adhered thereto or embedded therein, each shell having an internal volume, and an electrically conductive fluid disposed in the internal volumes of respective shells of said multiplicity of shells; and

detecting a change in electrical conductivity of the substrate,

wherein said detecting a change in electrical conductivity of the substrate comprises:

placing a coil in proximity to the substrate;

causing alternating current to flow through the coil during first and second time intervals, a magnitude of said alternating current and a distance separating the coil from the substrate being selected for inducing eddy currents in the substrate; and

measuring any difference between a first impedance of the coil during said first time interval and a second impedance of the coil during said second time interval.

10. The method as recited in claim 9, wherein said detecting a change in electrical conductivity of the substrate further comprises:

determining whether a difference between said first and second impedances is greater than a specified threshold; and

performing non-destructive inspection in the area of the structure which the coil is in proximity to if said difference between said first and second impedances is greater than said specified threshold.

11. A method for monitoring a structure for damage due to blunt impact, comprising:

attaching a substrate to a surface of a structure, the substrate comprising a multiplicity of rupturable shells disposed in proximity to a surface of the substrate, each shell having an internal volume, and an electrically conductive fluid disposed in the internal volumes of respective shells of said multiplicity of shells; and

detecting a change in thermal state of the substrate.

12. The method as recited in claim 11, wherein said detecting a change in thermal state of the substrate comprises performing the following steps during first and second intervals of time which do not overlap:

(a) placing a coil in proximity to the substrate;

(b) causing alternating current to flow through the coil while the coil is in proximity to the substrate;

(c) after the substrate has been heated in an area during step (b) due to eddy currents induced in the electrically conductive fluid by the alternating current in the coil, removing the coil; and

(d) after the coil has been removed, acquiring a thermal image of the area of the heated substrate using a thermal imaging camera.

13. The method as recited in claim 12, wherein said detecting a change in thermal state of the substrate further comprises:

comparing a first thermal image acquired during said first interval of time with a second thermal image acquired during said second interval of time.

14. The method as recited in claim 13, further comprising displaying an image representing differences between said first and second thermal images.

15. A method for monitoring a structure for damage due to blunt impact, comprising:

placing a radio-frequency identification circuit and first and second serpentine electrical conductors on a substrate, the first and second serpentine electrical conductors having respective first terminals electrically connected to respective terminals of the radio-frequency identification circuit and respective second terminals which are not electrically connected to each other;

placing a multiplicity of rupturable shells over the first and second serpentine electrical conductors, each shell having an internal volume at least partially filled with electrically conductive fluid; and

interrogating the radio-frequency identification circuit by transmitting a radio-frequency signal through a volume of space intersected by radio-frequency identification circuit,

wherein any response to the interrogation by the radio-frequency identification circuit will have a frequency which is a function of an impedance of an antenna formed if the first and second serpentine electrical conductors are electrically coupled to each other by electrically conductive fluid escaped from the multiplicity of

shells.

16. A system for monitoring a structure for damage due to blunt impacts, comprising:

a substrate comprising first and second surfaces;

a multiplicity of radio-frequency identification circuits adhered to said first surface of said substrate;

a multiplicity of rupturable shells comprising respective sets of rupturable shells overlying respective radio-frequency identification circuits, each shell having electrically conductive fluid disposed in an internal volume thereof; and

a multiplicity of antennas respectively connected to said multiplicity of radio-frequency identification circuits,

wherein each of said antennas comprises first and second electrical conductors which are configured and spaced so that said first and second electrical conductors can be electrically coupled to each other in the presence of electrically conductive fluid released from said multiplicity of shells;

wherein each radio-frequency identification circuit comprises a respective transceiver connected to said first and second electrical conductors of a respective antenna; and

wherein any response transmitted by a transceiver will have a frequency which is a function of an impedance of the respective antenna when said first and second electrical conductors are electrically coupled to each other by electrically conductive fluid escaped from the multiplicity of shells.

17. The system as recited in claim 16, further comprising:

a radio-frequency reader capable of acquiring data representing changes in frequency response of said radio-frequency identification circuit; and

a host computer configured for processing acquired data received from said radio-frequency reader to determine a location and an extent of a blunt impact based on identities of any radio-frequency identification circuits having a changed frequency response.