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Crites

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[54] **FATIGUE INDICATION**

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[51] **Int. Cl.** **G01l 1/22**, G01b 7/18

[58] **Field of Search** ..... 73/91, 88 R, 88.5 R, 104; 116/114 AH, 114 AC

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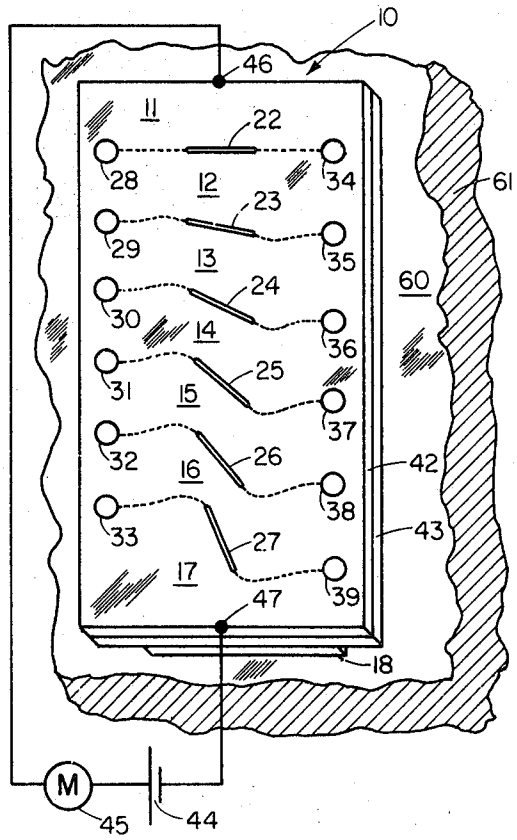
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[57] **ABSTRACT**

A device for indicating accumulated fatigue in a selected portion of a structural member. An elongate electrically conductive foil coupon has crack initiating slots of different sizes or shapes, or oriented at different angles, in regions that crack in response to fatigue and thus increase the electrical resistance between selected points. An adhesive securely bonds the coupon to the selected portion of the structural member, transmitting any strain therein to the coupon, which cracks at a lower level of accumulated fatigue than is enough to crack the structural member in the selected portion. Means responsive to the electrical resistance between the selected points on the coupon provide warning indications in time to avoid rupture of the structural member.

21 Claims, 5 Drawing Figures



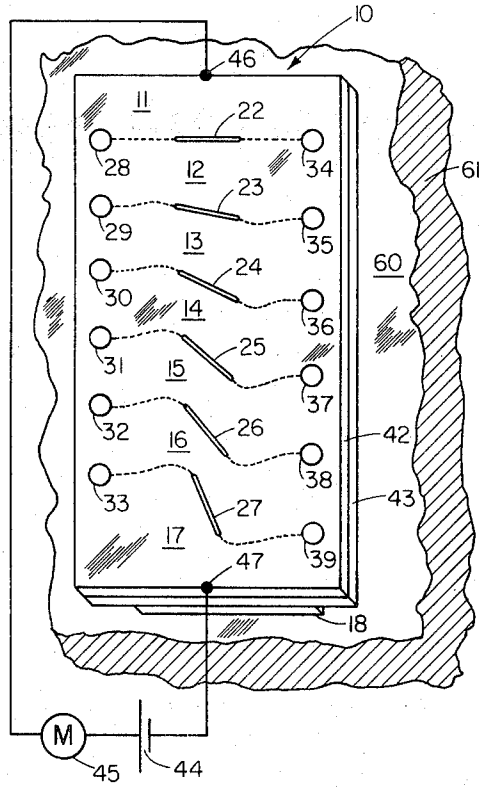


Fig 1

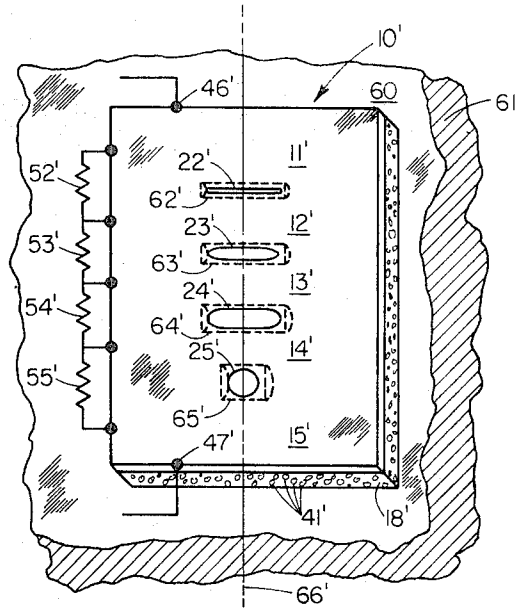


Fig 2

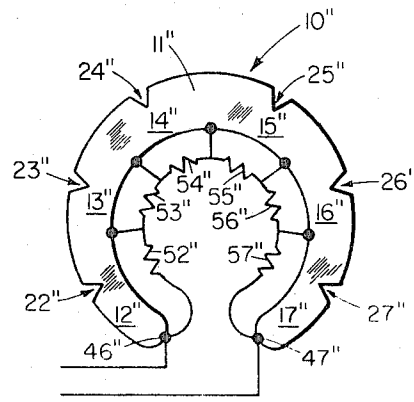


Fig 3

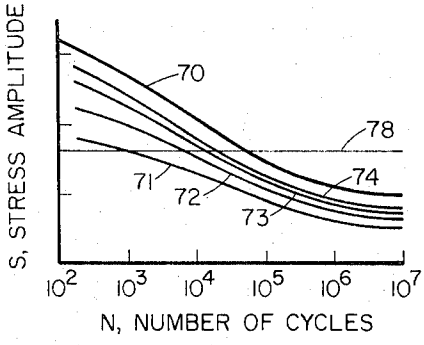


Fig 4

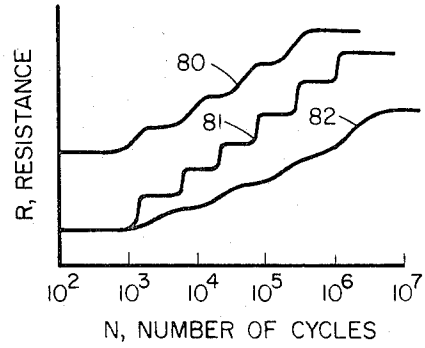


Fig 5

FATIGUE INDICATION

BACKGROUND OF THE INVENTION

A number of devices have been developed in the past to predict incipient fatigue failures in structural members under limited and specific conditions. None of them can be adapted broadly to a variety of structural materials and loading conditions.

One device is based upon the fact that some materials under variable loading accumulate plastic strain and a corresponding change in electrical resistance. This device, sometimes called a fatigue lifetime gage, has a limited range of sensitivity, and in its usual form is generally insensitive to low stress amplitudes which may contribute significantly to structural fatigue damage.

Another device comprises a plurality of relatively large and thick monitoring strips or coupons, each notched to fracture at a different level of fatigue damage and attached mechanically, as by screws at opposite ends, to the structural member. Fracture of each coupon may be noted visually or indicated by failure of electrical continuity in appropriate circuits. Various difficulties are encountered with this type of device, because it produces a stiffening on the structural member, causes stress concentrations at the end attachment points, and requires separate pre-fatigue calibration of each strip to determine its notch sensitivity. Moreover the strips are so large that they cannot fit into the high stress areas of many structural members, and are so thick that they cannot be used satisfactorily on many thin sheet members as they would not be certain to fracture before the member itself would crack.

Still other techniques have utilized various nondestructive inspection methods involving the detection of changes in the structural material itself by sonic, ultrasonic, or electromagnetic means. Experience has shown that these systems require considerable effort in inspection and involve great difficulty in effecting a dependable correlation between the observed changes and the fatigue damage accumulated.

The present invention avoids the above mentioned difficulties and disadvantages of prior fatigue indicating devices and methods.

SUMMARY OF THE INVENTION

A typical device according to the present invention for indicating accumulated fatigue in a selected portion of a structural member comprises an elongate foil coupon having regions that crack in response to fatigue therein, and adhesive means securely bonding the coupon to the structural member in the selected portion to transmit to the coupon any strains therein to which the structural member is subjected.

A plurality of crack initiating means are provided in the coupon. They are responsive to different ranges of accumulated fatigue, and at least one is responsive to a lower range of accumulated fatigue than is enough to crack the structural member in the selected portion. The crack initiating means typically comprise slots, which may be oriented at different angles, or be of different geometries, or both. A plurality of crack terminating means may be provided also in the coupon.

The coupon typically is electrically conductive, and is electrically insulated from the structural member if the latter also is conductive. The adhesive means typically is electrically nonconductive, and may have nonconductive solid particles distributed in it to prevent contact between the coupon and the structural member. Alternatively, the coupon may comprise an electrically conductive outer layer and a nonconductive inner layer to prevent electrical contact with the structural member.

The device may comprise also means responsive to the electrical resistance of the coupon between predetermined locations thereon to provide any convenient type of indication, such as an alarm signal at a remote location, to warn of approaching a range of accumulated fatigue at which the structural member would rupture. The crack initiating means typically are provided in the coupon in selected regions such that cracking therein substantially and progressively increases the electrical resistance between the predetermined locations. Where crack terminators are not provided, rupture of regions between the predetermined locations may separate one portion of the coupon from another, and electrical resistance means should be connected between separable portions of the coupon.

In a typical convenient form, the coupon has substantially the composition of the selected portion of the structural member. It preferably is about 0.1 to 30 mils thick. Suitable adhesive means typically comprise an epoxy, a polyester, or a cyanoacrylate. The adhesive means typically comprises a substantially uniform layer between the regions that crack and the structural member, providing a substantially continuous bond between the structural member and the regions that crack. In some devices, however, a narrow unbonded area is provided at each crack initiating means, and the width of each unbonded area preferably is less than about 3 times the thickness of the coupon there.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an enlarged perspective view of a typical device according to this invention.

FIG. 2 is an enlarged perspective view of another similar device.

FIG. 3 is an enlarged front view of still another similar device.

FIG. 4 is a graph of stress amplitude against number of loading cycles to cracking of a structural member and of regions in a typical device as in FIG. 1, 2, or 3.

FIG. 5 is a graph of electrical resistance against number of cycles for devices as in FIGS. 1, 2, and 3 under loading such as that represented in FIG. 4.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to FIGS. 1, 2, and 3, a typical device 10, 10', or 10'' according to the present invention for indicating accumulated fatigue in a selected portion 60 of a structural member 61 comprises an elongate foil coupon 11, 11', or 11'' having regions 12–17, 12'–15', or 12''–17'' that crack successively in response to accumulated fatigue therein, and adhesive means 18 or 18' securely bonding the coupon 11 or 11' to the structural member 61 in the selected portion 60 to transmit to the coupon 11 or 11' any strains in the portion 60 to which the structural member 61 is subjected.

A plurality of crack initiating means 22–27, 22'–25', or 22''–27'' are provided in the coupon 11, 11', or 11''. They are responsive to different ranges of accumulated fatigue, and at least one is responsive to a lower range of accumulated fatigue than is enough to crack the structural member 61 in the selected portion

60. The crack initiating means typically comprise slots or notches (slots extending in from an edge) 22–27, 22'–25', or 22''–27'' which may be oriented at different angles, as in FIGS. 1 and 3, or be of different geometries (sizes and shapes), as in FIG. 2, or both. A plurality of crack terminating means 28–39 may be provided also in the coupon, as in FIG. 1.

To avoid any risk of initiating cracks where they are intended only to terminate, the adhesive 18 preferably does not extend to the left and right side regions of the coupon 10 where the crack terminating holes 28–33 (left side) and 34–39 (right side) are located, but is applied only to the center regions 12–17, as in FIG. 1, where the crack initiating slots 22–27 are located. Thus, the strains on the structural member 61 are not transmitted to the regions containing the crack terminating holes 28–29.

The coupon 11, 11', 11'' typically is electrically conductive, and is electrically insulated from the structural member 61 if the latter also is conductive. The adhesive means 18,18' typically is electrically nonconductive, and may have nonconductive solid particles 41' distributed in it, as in FIG. 2, to prevent contact between the coupon 11' and the structural member 61. Alternatively, the coupon 11 may comprise an electrically conductive outer layer 42 and a nonconductive inner layer 43 to prevent electrical contact with the structural member 61.

The coupon 11, 11', or 11'' typically comprises a thin metallic foil of essentially the same composition as the structural member upon which it is to be used. However, it may, for some applications, be of a different material than the structural element. Moreover it may be formed in various ways, including stamping, electric discharge machining, etching or otherwise shaping a metallic foil, or by chemical or electrical deposition of a conducting material upon an insulating base or by any means which can provide the geometrical configuration, electrical properties, and mechanical properties necessary to the desired performance. The coupon is preferably thin relative to the selected portion of the structional member and is generally in the range of 0.1 to 30 mils thick.

The device 11, 11', 11'' may comprise also means 44,45 responsive to the electrical resistance of the coupon between predetermined locations 46,47; 46',47'; or 46'',47'' thereon to provide any convenient type of indication or other response, such as an alarm signal at a remote location to warn of approaching a range of accumulated fatigue at which the structural member 61 would crack, or means for automatically terminating the loading thereof. Such means are shown schematically in FIG. 1 as comprising a direct voltage source 44 and a milliameter or other current responsive device 45, but any resistance responsive means providing a visible, audible, or otherwise noticeable signal or other response may be used. Where resistance responsive means are omitted, the coupon need not be electrically conductive and need not be insulated from the structural member. However, the coupon should then be inspected regularly and frequently to determine the range of accumulated fatigue to which it and the structural member have been subjected. The crack initiating means 22, 22', 22'', etc., typically are provided in the coupon 11, 11', 11'' in selected regions such that cracking therein substantially and progressively increases the electrical resistance between the predetermined locations. Where crack terminators are not provided, as in FIGS. 2 and 3, rupture of regions between the predetermined locations may separate one portion of the coupon 11' or 11'' from another, and electrical resistance means 52'–55' or 55''–57'' should be connected between separable portions 12'–15'' or 12''–17'' of the coupon 11' or 11''.

The shunt resistances may be connected at any convenient locations on the separable portions. For example, in FIG. 3 they can be connected around the outside of the annular strip 10'', if preferred, rather than on the inside. Also the resistances 52'–55' or 52''–57'' may be formed conveniently as extensions of the coupon, if desired; and the extensions preferably are not bonded to the structural member. In effect, the left and right side regions adjacent the holes 28–39 in FIG. 1 provide the equivalent of the shunt resistances 52'–55' and 52''–57'' in FIGS. 2 and 3. To provide greater resistance in these regions, they can be made narrower and longer, as by making them sinuous in shape.

In a typical convenient form, the coupon 11, 11', 11'' has substantially the composition of the selected portion 60 of the structural member 61. It preferably is about 0.1 to 30 mils thick. Suitable adhesive means 18, 18' typically comprise an epoxy, a polyester, or a cyanoacrylate. The adhesive means 18,18' typically comprises a substantially uniform layer between the regions that crack 12, 12', etc., and the structural member 61, providing a substantially continuous bond between the structural member 61 and the regions that crack 12,12', etc. In some devices 11', however, a narrow unbonded area 62'–65' is provided at each crack initiating means 22'–25', and the width of each unbonded area 62'–65' preferably is less than about three times the thickness of the coupon 11' there to avoid any likelihood of buckling. Wax, grease, or other suitable separating material may be placed on the coupon at the unbonded areas 62'–65', if desired, to prevent contact between the coupon 11' and the adhesive 18'.

The coupon 11' may comprise only the portion to the left of the line 66', if it is desired that the crack initiating slots 22'–25' be located at an edge of the coupon 11'.

The coupon may have any convenient shape. Illustrative of typical useful shapes are the rectangular coupons 11,11' of FIGS. 1 and 2, and the substantially circular or horseshoe shaped coupon 11'' of FIG. 3 wherein the crack initiating slots 22''–27'' are all perpendicular to the outer edge, yet are oriented in a wide range of different angles relative to each other. The coupon 11, 11', 11'' may be very small, typically about ¼ to ½ inch wide and about ½ to 1 inch long.

The crack initiating slots are made responsive to different ranges of accumulated fatigue by any convenient variations therein, as in size, shape, or both, as in FIG. 2; or in orientation, as in FIGS. 1 and 3. Thus, the coupon can progressively sample the strain field in the selected region of the structural member to which it is attached. The action is illustrated in FIG. 4 wherein the S-N curves show the failure producing combinations of stress amplitude and number of cycles during which the stress is applied. The curve 70 represents the S-N failure characteristics of the structural member 61 in the selected portion 60, while the curves 71–74 represent the S-N failure characteristics in the individual regions that rupture where the crack initiating slots are responsive to different ranges of accumulated fatigue. If the

selected region 60 of the structural member 61 is subjected to many cycles of stress at an amplitude indicated by the horizontal line 78, a crack will form in one of the regions after about 1,000 cycles as is indicated by the intersection of the curve 71 with the horizontal line 78. Similarly a crack will form in another region after about 7,000 cycles as is indicated by the intersection of the curve 72 with the horizontal line 78, a crack will form after about 20,000 cycles as is indicated by the intersection of the curve 73 with the horizontal line 78, and still another crack will form in another region after about 40,000 cycles as is indicated by the intersection of the curve 74 with the horizontal line 78. Thus, ample warning is provided to enable an operator to remove the cyclic strain before the structural member 61 would crack, as it would if the strain were to be continued through about 60,000 cycles as indicated by the intersection of the curve 70 with the horizontal line 78. The response is similar, of course, at other stress amplitude levels and under variable amplitude stressing, whether the strains produced are compressive, tensile, shear, biaxial, or a combination of types.

FIG. 5 illustrates the changes in resistance of the coupon 11, 11', or 11'', the resistance between the points 46, 47; 46',47'; or 46'',47''; being plotted against the number of cycles of fluctuating stress to which the structural member 61 is subjected in the selected portion 60. The curve 80 is a typical resistance characteristic for a device wherein the coupon is provided with crack stoppers such as the holes 28–39 in the coupon 11 in FIG. 1. The curve 81 shows a typical resistance characteristic for coupons such as those in FIGS. 2 and 3 having no crack stoppers wherein adjacent portions of the coupon may separate and wherein electrical resistors 52'–55' or 52''–57'' are connected between adjacent separable portions. Where the resistances are high relative to the resistance of the coupon, the resistance between the predetermined locations 46', 47' or 46'', 47'' increases abruptly upon rupture as shown in the step-like curve 81. Where the shunt resistances are small relatively to the resistance of the coupon, the steps are less pronounced and the resistance characteristic curve is somewhat smoother having a shape of the type shown in the curve 82. The characteristic curve for a particular device can of course be made to have any desired combination of starting level, shape, and other parameters to meet the requirements of the specific use for which it is to be designed.

From the disclosure herein it is clear that a device according to this invention can anticipate and indicate the approaching fatigue lifetime of the structure to which it is attached. Where the device is made of foil similar to the material of the structure itself, it can substantially duplicate the fatigue characteristics of the structure. Also, the device has the effect of having graded stress concentrations which also duplicate the effects of the usual notches and stress concentrations normal to commercial design and fabrications. Since the fatigue life of the structure can be affected considerably by the amount and sequence of the loading, the present devices are very accurate while other fatigue lifetime gages not having this feature do not provide reliable anticipation of the fatigue life. A few large overloads on a structure in its fatigue history can under certain conditions increase the fatigue lifetime of the structure, while without these loads the structure would fail prematurely. Thus other fatigue life gages not having this feature of responding to loads similarly to the structure itself cannot reliably anticipate the fatigue lifetime of the structure.

While the forms of the invention herein disclosed constitute presently preferred embodiments, many others are possible. It is not intended herein to mention all of the possible equivalent forms or ramifications of the invention. It is to be understood that the terms used herein are merely descriptive rather than limiting, and that various changes may be made without departing from the spirit or scope of the invention.

I claim:

1. A device for indicating accumulated fatigue in a selected portion of a structural member, comprising
an elongate foil coupon having regions that crack in response to fatigue therein, and
adhesive means securely bonding the coupon to the structural member in the selected portion to transmit to the coupon any strains therein to which the structural member is subjected;
a plurality of crack initiating means being provided in the coupon, and
the adhesive means providing a substantially continuous bond between the structural member and the regions that crack except in a narrow unbonded area that is provided at each crack initiating means.

2. A device as in claim 1, wherein the crack initiating means are responsive to different ranges of accumulated fatigue.

3. A device as in claim 2, wherein the crack initiating means comprise slots.

4. A device as in claim 1, wherein at least one crack initiating means is responsive to a lower range of accumulated fatigue than is enough to crack the structural member in the selected portion.

5. A device as in claim 1, wherein the coupon is electrically conductive.

6. A device as in claim 5, wherein the coupon is electrically insulated from the structural member.

7. A device as in claim 5, wherein the adhesive means is electrically nonconductive.

8. A device as in claim 5, wherein the coupon comprises an electrically conductive outer layer and a nonconductive inner layer.

9. A device as in claim 5, comprising also means responsive to the electrical resistance of the coupon between predetermined locations thereon.

10. A device as in claim 9, wherein a plurality of crack initiating means are provided in the coupon in selected regions such that cracking therein substantially and progressively increases the electrical resistance between the predetermined locations.

11. A device as in claim 9, wherein rupture of regions between the predetermined locations may separate one portion of the coupon from another, and comprising also electrical resistance means connected between separable portions of the coupon.

12. A device as in claim 1, wherein the coupon has substantially the composition of the selected portion of the structural member.

13. A device as in claim 1, wherein the coupon is about 0.1 to 30 mils thick.

14. A device as in claim 1, wherein the adhesive means comprises an epoxy, a polyester, or a cyanoacrylate.

15. A device as in claim 1, wherein the width of each unbonded area is less than about 3 times the thickness of the coupon there.

16. A device for indicating accumulated fatigue in a selected portion of a structural member, comprising

an elongate foil coupon having regions that crack in response to fatigue therein, and

adhesive means securely bonding the coupon to the structural member in the selected portion to transmit to the coupon any strains therein to which the structural member is subjected;

a plurality of cracks initiating slots responsive to different ranges of accumulated fatigue being provided in the coupon, and the slots being oriented at different angles.

17. A device as in claim 16, wherein a plurality of crack terminating means are provided in the coupon.

18. A device as in claim 16, wherein the adhesive means comprises a substantially uniform layer between the regions that crack and the structural member.

19. A device as in claim 16, wherein the adhesive means provides a substantially continuous bond between the structural member and the regions that crack.

20. A device for indicating accumulated fatigue in a selected portion of a structural member, comprising

an elongate foil coupon having regions that crack in response to fatigue therein, and

adhesive means securely bonding the coupon to the structural member in the selected portion to transmit to the coupon any strains therein to which the structural member is subjected;

a plurality of crack initiating slots responsive to different ranges of accumulated fatigue being provided in the coupon, and the slots having different geometries.

21. A device for indicating accumulated fatigue in a selected portion of a structural member, comprising

an elongate electrically conductive foil coupon having regions that crack in response to fatigue therein, and

adhesive means securely bonding the coupon to the structural member in the selected portion to transmit to the coupon any strains therein to which the structural member is subjected,

the adhesive means being electrically nonconductive and having nonconductive solid particles distributed in it to prevent contact between the coupon and the structural member.

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