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(71) Applicant *(for all designated States except US)*: UNISEARCH LIMITED [AU/AU]; 221-227 Anzac Parade, Kensington, NSW 2033 (AU).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)* : BAIRD, John, Patrick [AU/AU]; Fox Hill, Kaveney's Road, Via Hall, ACT 2618 (AU). CLARK, Robert, Keith [AU/AU]; 8 Yalgan Place, Giraland, ACT 2617 (AU).

(74) Agents: DUNCAN, Alan, David et al.; Davies Collison Cave, 1 Little Collins Street, Melbourne, VIC 3000 (AU).


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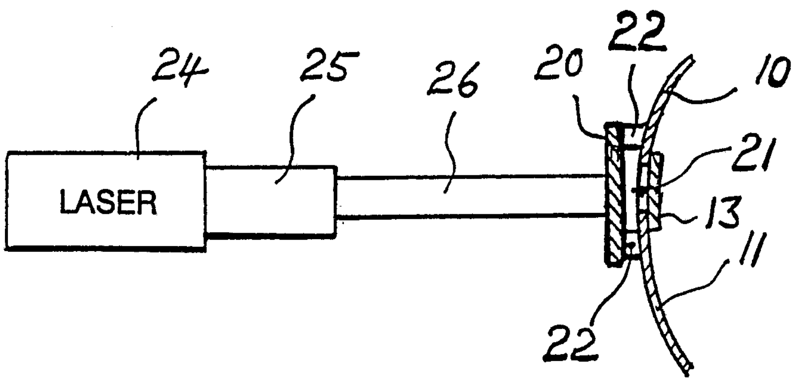
(54) Title: STRUCTURAL EXAMINATION USING HOLOGRAPHIC INTERFEROMETRY




**(57) Abstract**

In-situ, nondestructive examination to test the efficacy of a rivetted, bolted or bonded join of metal sheets (10, 11), or to test whether a composite material is faulted, or to test whether a multi-layer patch is bonded properly, involves the creation of an interferometric hologram. A photographic film or plate (20) is mounted closely above, and isolated vibrationally from a region (21) of a structure containing the join, composite material or patch. The film or plate is illuminated by the expanded beam (26) from a laser (24) firstly when the structure is in a first state of stress, and secondly when the structure is in a second state of stress (the change in stress being sufficient to deform the region over which the film or plate is mounted). At each illumination, a diffraction pattern is produced in the emulsion of the plate or film by interference between the illuminating beam and that part of it which is reflected from the region. The two diffraction patterns combine to produce a fringe pattern in the emulsion. That fringe pattern, when compared with the fringe pattern produced by a good join or a non-faulted composite body or patch, provides information about the region under investigation. The technique is especially useful for testing the joins in the skin of an aircraft fuselage, or potentially damaged composite structures.

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TITLE: "STRUCTURAL EXAMINATION USING HOLOGRAPHIC INTERFEROMETRY"

**Technical Field**

This invention concerns the examination of structures using holographic interferometry. It is particularly suitable for the in-situ analysis of rivetted, bolted and bonded structures to determine (a) the efficacy of the rivetted or bolted joining or the bonding of components and (b) whether fatigue cracks are present in the region of the rivets or bolts. In this application, the invention is especially useful in the examination of the rivetted, bolted and bonded connections in the fuselage of an aircraft which can be pressurised or otherwise loaded. Another particularly useful application of the present invention is the in-situ examination of objects constructed from composite materials, to ascertain the presence of damage to the object or the existence of faults as a result of poor construction. A further use of the present invention is the in-situ checking of the efficacy of the application of a composite patch to a damaged composite or aluminium structure or the like. In these last two applications, the present invention is particularly useful for (but is not limited to) the examination of objects made from a composite comprising a resin and fibres of boron, carbon, glass or the like.

**Background to the Invention**

Structures which use high strength, light weight materials, and which are subject to considerable stress in their normal use, are susceptible to the development of fatigue cracks, particularly in the regions where the sheets of such materials are joined. One example of such a structure is a modern large aircraft, and as the development of the present invention was in part stimulated by the problem of crack detection in the fuselage of a large aircraft, the application of the present invention to this problem will be given some prominence in this specification.

The cause of a significant number of aircraft accidents has been identified as structural failure resulting from the development of fatigue cracks and faulted bonds in the aircraft fuselage, in the vicinity of the rivetted connection of the metal sheets forming the fuselage. Thus it is now recognised that the detection of fatigue cracks in aircraft structures, as soon as possible after their formation, is a matter of critical importance, and there has been a considerable commitment of resources to the establishment of a reliable in-situ crack detection technique.

Several commercial crack detection systems are now available. Those systems include eddy current detection techniques, ultrasonic examination techniques and magnetic rubber applications. Unfortunately, each of those techniques is suitable for only a certain limited range of applications, since the sensitivity of each method depends on the geometry of the component being investigated and other factors. Optical techniques for crack analysis using phenomena such as photoelasticity, caustics, moire pattern observations and shearography have also been developed, but those optical techniques (apart from shearography) are laboratory analysis tools and are not readily able to be adapted to in-situ testing of rivetted, bolted or bonded structures. Thus there remains a need for a reliable in-situ crack detection system for use in the testing of joins in aircraft fuselage structures.

The present invention, as noted above, is also useful in the examination of composite materials, known generally as "composites". Composites comprising resin with fibres of boron, carbon, glass or the like are now being used regularly to construct objects and structures for which the combination of mechanical strength and light weight is desirable. An example of such an object is the rotor blade of a helicopter.

One problem with such objects is that faults in the manufacture of the composite, which may affect the structural strength of the object, are often not visible. Another problem, arising out of the use of such objects, is that, if they receive a substantial blow during their normal use (for example, a bird strike on a helicopter rotor), the structural integrity of the composite material can be affected (that is, the object can be damaged) with no visible indication of the fact that the object has received a blow.

A particular problem experienced with such composite materials is that when they have been visibly damaged and have been patched (sometimes using as many as 30 layers of the patching composite material), there is no means of knowing whether the patch has been applied properly. A weak bond obtained during the patching process can result in the catastrophic failure of an object made from the composite material, without any warning. Similarly, there is currently no satisfactory technique available to test whether a boron composite patch, applied to an aluminium structure (for example, in the repair of an aircraft fuselage), has bonded properly to the substrate material.

One technique that has been used to test the structural integrity of objects made from such composite materials is the technique known as "shearography". This technique is described in some detail in the paper by Y Y Hung entitled "Shearography: A Novel and Practical Approach for Nondestructive Inspection", which was published in the **Journal for Nondestructive Evaluation**, Volume 8, 1989, pages 55 to 67. It is also described in the paper by S L Toh, H M Shang, F S Chau and C J Tay entitled "Flaw Detection in Composites using Time-average Shearography", which was published in **Optics & Laser Technology**, Volume 23, 1991, pages 25 to 30.

Briefly, shearography involves the imaging of a small region of the surface of an object being tested on a photographic film or plate which is positioned at an image plane that is remote from that region. The region is illuminated by the expanded beam from a laser. The image is produced from the reflection of the laser light using an "image-shearing camera", which produces a pair of laterally sheared images in the image plane. These images overlap and produce a speckled random interference pattern over the image. When the object is deformed (for example, by vibration), the displacement of the reflected, interfering beams modifies the speckle pattern. Toh et al, in their aforementioned paper, show that if the object is continuously vibrated, a time averaged "shearogram" is produced in the photographic emulsion. The shearogram can be reconstructed using a white light source. If there is a flaw in the region of the object under investigation (for example, a crack), the image of the shearogram is noticeably different over the region of the flaw, provided the object has been vibrated at approximately the resonance frequency of the flaw (which is invariably a much higher frequency than the natural resonance frequency of the object).

While the technique described by Toh et al is no doubt capable of showing the presence of a flaw which is suspected, it is a cumbersome and time-consuming technique, requiring the production of shearograms for a range of frequencies. As Toh et al point out in their paper:

> "As in holographic interferometry, the time-average technique in shearography is only applicable to steady state vibration studies".

In addition, if a region of a composite object which may be damaged is being investigated, the failure to detect a flaw does not necessarily mean that no flaw is present, unless observations of that region have been carried out over a wide range of closely-spaced vibration frequencies.

The holographic interferometry technique referred to by Toh et al is described in some detail in the paper by D B Neumann and R G Penn entitled "Off-table Holography", which was published in **Experimental Mechanics**, June 1975, pages 241 to 244. That technique utilises a laser with a spatial filter to illuminate a photographic plate which is attached to, but is spaced a short distance from, the surface of a solid structure. A diffraction pattern is recorded in the emulsion of the photographic plate. The diffraction pattern is produced by the interference of the illuminating laser beam and that portion of the illuminating beam which has passed through the plate and has been reflected from the region of the surface over which the plate has been positioned. If a second exposure is taken on the same photographic plate at a different stress level of the object, the two diffraction patterns combine to give a fringe pattern when the developed emulsion is observed in appropriate lighting.

The paper by Neumann and Penn illustrates the use of the holographic interference technique to show structural deformations in thick vibrating structures. It draws attention to the relatively low cost of such an analysis technique. However, it stresses the need for the surface that is being examined to be coated with a retro-reflective paint or tape, which restricts the uses to which the technique can be put. Indeed, Neumann and Penn effectively limit the application of their technique to an analysis of the deformations observable in large objects which have vibratable surface areas.

**Disclosure of the Present Invention**

It is an object of the present invention to provide a reliable, easy to use, in-situ method for examining the structural integrity of rivetted, bolted or bonded joins in sheet metal structures, composite materials that may have suffered damage or be faulty, and patches applied to a damaged composite material or metal sheet.

This objective is achieved using a modified form of the holographic interferometry technique described in the aforementioned 1975 paper by Neumann and Penn.

The present inventors have found that if a rivetted or bolted join is subjected to two stress states and a holographic interferogram is made of that join, the interference patterns which are observed

(i) for an effectively rivetted or bolted join,

(ii) for a join in which a rivet or bolt is present but serves as a pin rather than as a clamp, and

(iii) for a join which has been stressed to the point where a crack has formed in the material lying under the domed head of a rivet or the head of the bolt,

are different from each other, but are consistent in their differences so that the quality of the join can be assessed from the features of the interference pattern.

The present inventors have also discovered that, contrary to the findings of Neumann and Penn, it is not necessary to apply a retro-reflective medium to the surface of the region being analysed, for interference patterns can be detected using the reflected laser light from a metallic surface, provided the surface roughness is not sufficient to introduce excessive background "noise" to the reflected light (in which case, a simple polishing of the surface will usually reduce the background noise, although experience has shown that in most cases the existing surface finish is adequate). In fact, the use of a retro-reflective surface can randomise the polarisation of the reflected light, which is not preferred (it is necessary, for good quality fringes, to have the reflected light with the same polarisation as the incident light).

Furthermore, the present inventors have also discovered that the holographic interferometry technique can be used for sub-surface crack detection in thin structures such as rivetted, bolted or bonded sheets, in composite bodies, and for detection of non-bonded areas in multi-layer patches applied to the surface of a metal sheet or composite body.

Additionally, the present inventors have ascertained that their use of a modified holographic interferometric technique can reveal cracks and non-bonded regions or zones which are not detected by the known techniques, noted above, which use eddy currents, ultrasound or magnetic rubber.

Thus according to the present invention, a method of examining a region of a rivetted, bolted or bonded join, composite material, multi-layer patch, or the like, comprises the sequential steps of:

(a) mounting a photographic plate or film over, but spaced a small distance from and vibrationally isolated from the region;

(b) illuminating the region and the photographic plate or film with an expanded beam of a laser for a predetermined period;

(c) applying stress to, or changing the stress applied to, the region so that there is a slight distortion of the region caused by the change in the stress thereof;

(d) illuminating the region and the photographic plate or film with the same expanded laser beam for a second predetermined period, whereby a holographic interferogram is created within the emulsion of the photographic plate or film; and

(e) comparing the fringes of the holographic interferogram thus obtained with the fringes of a holographic interferogram from a correctly rivetted, bolted or bonded join, undamaged or non-faulted composite material, properly bonded multi-layer patch, or normal state of the region, as the case may be, to determine the presence of any structural defect in the region.

Normally the first and second periods of illumination of the region will be the same length of time.

The comparison of the holographic interferograms may be effected by digitising the fringe patterns and performing the comparison using appropriate computer software.

This examination method is especially suitable for the examination of thin structures, where there is significant deformation of the structure when its stress level is changed.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings.

**Brief Description of the Drawings**

Figures 1a and 1b are sectional views, showing the two conventional ways in which sheets of aluminium may be joined, using rivets, in an aircraft fuselage.

Figure 2 is a partly schematic illustration of the adoption of the present invention to the analysis of a rivetted join in the fuselage of an aircraft.

Figure 3 is a holographic interferogram of a correctly rivetted join.

Figure 4 is a holographic interferogram obtained from a rivetted join with a crack present under the domed head of the rivet.

Figure 5 is a partly schematic illustration of an arrangement used for examining a region of an object made from a composite material, using the present invention.

Figures 6 and 7 are partly schematic plan and elevation views of an arrangement for examining a large region of an aircraft fuselage without repositioning the laser mount.

Figure 8 illustrates (partly schematically) equipment which may be used to examine the structural adequacy of a long join in an aircraft fuselage.

Figure 9 illustrates another embodiment of equipment that may be used in the examination of joins in an aircraft fuselage.

**Detailed Description of the Illustrated Embodiments**

A modern aircraft is essentially a thin-walled pressure vessel made from sheet aluminium which has a thickness of from 1 mm to 2 mm. The aluminium sheets are joined by rivets as shown in Figure 1a or Figure 1b. In the Figure 1a type of join, the abutting metal sheets 10 and 11 have their seam 12 covered by an aluminium strip 13 which is connected to the sheets 10 and 11 by a series of rivets 14. In the illustrated arrangement, the rivets have domed heads which are proud of the surfaces being connected by the rivets, but in practice the rivets will often be countersunk.

In the Figure 1b arrangement, there is a simple lapped join of the aluminium sheets 10 and 11, with rivets 14 at regular spacing to secure the sheets 10 and 11 to each other. Again, the rivets are shown as domed head rivets but they may be countersunk. In the Figure 1b arrangement, there is a tendency for the lapped join to tip about an axis, which is approximately at the centre of the line of rivets, when a load is applied to the structure.

When the joins shown in Figures 1a and 1b are first effected, the act of rivetting creates a solid join. When loads are applied to the join, it is found that one or two rivets in each of the series of rivets take the load initially, but after the load has been removed and re-applied several times, it becomes more evenly distributed between the rivets. Nevertheless, it is not uncommon for loose rivets to be found in a join, which take little or none of the applied load. Such loose rivets can be detected using the present invention.

A similar situation exists when bolts are used instead of rivets (which is sometimes the case in aircraft construction, particularly when metal sheets are being attached to a more substantial sub-surface member).

In an aircraft, the load on the joins in the fuselage is applied when the aircraft fuselage is pressurised. If cracks develop adjacent to a rivet or bolt as a consequence of fatigue resulting from many cycles of pressurisation and decompression, the crack may be potentially dangerous if it reaches the edge of a domed head of a rivet or bolt. Unfortunately, as noted above, hitherto there has been no reliable in-situ nondestructive technique for observing the presence of a crack before it grows to its potentially dangerous size. Such a technique is needed because of the possibility of the occurrence of what structural engineers call "multi-site damage". Multi-site damage exists when a number of small cracks are present in a structure. Individually, each small crack is unlikely to have a significant effect upon the structure. Collectively, however, the cracks can constitute a substantial weakening of the structure and create a very dangerous situation.

Figure 2 shows the way in which the present invention is used to investigate the reliability of a rivetted join in the fuselage of an aircraft or a similar sheet metal structure. A photographic film or plate 20 is mounted over the region of a rivetted join 21 of the metal sheets 10 and 11 of the fuselage (or other structure). This mounting can conveniently be effected using double-sided adhesive tape 22 (shown much thicker than is the case in reality, due to the schematic nature of Figure 2) near the edge of the film or plate 20. The important features of the mounting arrangement are (i) that there is a small space between the emulsion of the film or plate and the closest surface of the join 21, and (ii) the spacers must isolate the film or plate 20 vibrationally (and therefore structurally) from the region being investigated, so that the film or plate is not distorted when the stressing of the underlying region is changed. Double-sided adhesive tape has been found to be ideal for such mounting.

If the surface over which the plate or film 20 is mounted is very rough, it may be necessary to polish that surface before mounting the photographic film or plate 20 as shown in Figure 2. In most instances, however, and almost always when the join is in the skin of a large aircraft, the metallic or painted surface as manufactured will be adequate to enable a good holographic interferogram to be obtained without the need for polishing. The limiting factor for the resolution of small fringes (see below) is the background noise caused by surface roughness. The scale of any roughness of the region 21 should be smaller than the fringe spacing. Using the present invention, fringes as close as 50 micrometres can be routinely detected.

A laser 24, equipped with a spatial filter and beam expander 25, is mounted a distance from the photographic film or plate 20, so that a laser beam 26 is incident upon the plate 20. The distance between the laser 24 and the plate 20 is not critical. Normally, the laser 24 and its associated spatial filter and beam expander will be mounted on a tripod (not shown in Figure 2). However, use of a tripod is not essential. Indeed, good quality interferograms have been obtained by the present inventors using a hand held laser.

The plate or film 20 is first exposed to the laser beam 26 with the fuselage in a pre-determined state of stress. The stressing of the fuselage is then changed (usually, it is pressurised, having been unpressurised previously) and the film or plate is exposed to the laser beam 26 again. Usually the time of each exposure is the same. Subsequent development of the film or plate reveals the presence of fringes covering the image in the emulsion. Examples of such fringes are shown in Figures 3 and 4. The fringes are caused by the interference between the two diffraction pattern images in the emulsion, due to variations (when the stressing of the structure was changed) in the path lengths of the beams travelling between the photographic emulsion and the surface of the fuselage, and reflected back to the emulsion. The differences in the path lengths are caused by the relative distortions between the two stress levels in the aircraft skin. Abnormalities in the skin caused by a less than effective join 21, or by the presence of a crack under the head of a rivet or bolt, or under the strip 13 covering the join (if the Figure 1a arrangement is used) give rise to abnormal fringe patterns.

A holographic interferogram, obtained using the present invention, of a good rivetted join is shown in Figure 3.

The arrow A in Figure 3 indicates the direction of the load applied to the rivet. It will be noted that circular fringes appear above and below the rivet in Figure 3.

Figure 4 is a holographic interferogram, also obtained using the present invention, of a second rivetted join. The direction of the applied load is again indicated by an arrow A. In this instance, a crack was present under the head of the rivet. It will be noted that the fringes above the rivet (in the Figure) are nearly circular, whereas the fringes below the rivet have a totally different pattern.

Although any abnormal fringe pattern shows the presence of a faulty join in the vicinity of the rivet or bolt, it is possible to categorise the nature of the fault in the join from the nature of the fringe pattern that is observed using the present invention. In a development of the present invention, the standard fringe pattern is digitised and stored in a computer memory, and the observed fringe pattern is also digitised. A comparison between the observed and standard fringe patterns can then be effected, using appropriate computer software, to detect imperfect joins.

In the arrangement for investigating the structural integrity of a composite body which is illustrated schematically in Figure 5, a photographic film or plate 20 is mounted over a region 21 on the surface of an object 50 (such as the rotor blade of a helicopter) constructed using a fibre composite material (typically a carbon fibre composite). The photographic film or plate is mounted so that there is a small spacing between the emulsion of the film or plate and the adjacent surface of the region 20 and the plate or film is vibrationally isolated from the object

50. As noted above, such a mounting arrangement is conveniently effected using strips of double-sided adhesive tape 22 near to the edge of the film or plate 20.

When supporting the object 50 for the investigation of the region 21 using the present invention, it may be necessary - or convenient - to stress the object.

A laser 24, provided with a spatial filter and beam expander 25, is mounted a distance from the photographic film or plate 20, so that the expanded laser beam 26 is incident upon the film or plate. As noted in the description of Figure 2, the distance between the laser 24 and the film or plate 20 is not critical, and normally the laser with its spatial filter and beam expander will be supported by a tripod, or other suitable means for holding the laser in a required position.

The plate or film 20 is first exposed to the laser beam 26 when the object 50 is unstressed or in its initial stressed state. The object 50 is then stressed (or the stressing of the object is varied) and the film or plate is exposed to the laser beam 26 a second time. When the photographic film or plate is developed, fringes are present over the image in the emulsion. The fringes are caused by interference between the two images due to variations in the path lengths of the beams travelling between the photographic emulsion and the adjacent surface of the object 50, and reflected back to the emulsion. The differences in the path lengths are caused by the distortion (usually about 10 micrometres) of the surface of the object 10 when the stressing of the object is effected or changed. Abnormalities or flaws in the region 21 which is under the photographic film or plate 20, caused by fractured fibres in, or delaminations of, or weak bonding in, the composite material, give rise to abnormal fringe patterns.

It has been found that no treatment of the surface of the object 50 is necessary to ensure the production of good quality fringes in the holographic interferogram. The present invention has been used effectively with a composite body having a matt black surface, as well as with materials having (optically) highly reflective surfaces.

The arrangement shown in Figure 5 is also used to investigate the bonding in a multi-layer patch applied to a damaged region of a composite material or metallic (for example, aluminium) structure. The testing of the bonding may be effected after each layer of the patch has been applied, or it may be used after the patching has been completed, to detect the presence of regions or zones of the patch layers which have not bonded properly.

Although any abnormal fringe pattern shows the presence of a fault in the composite material in the vicinity of the region 21, it is possible, with experience, to interpret the extent of the damage to the fibres of the composite material, or the extent of the non-bonding of a patch layer (as the case may be), from the nature of the distortion of the fringes.

As in the analysis of rivetted, bolted or bonded joins, the standard fringe patterns for composites and patches may be digitised and stored in a computer memory, and the observed fringe pattern also be digitised. The observed and standard fringe patterns can then be compared, using appropriate computer software, to detect damaged regions of the composite material, or imperfect patching.

When using the present invention to examine the structural integrity of rivetted, bolted or bonded joins in the fuselage (or in other parts) of an aircraft, the aircraft should be placed in a darkened hangar and illuminated only by light having a wavelength to which the emulsion of the photographic film or plate is insensitive. If a dark hangar is not available, a shroud to darken one section of the aircraft may be used. The choice of laser will also depend upon the wavelength range to which the emulsion of the photographic plate is sensitive. For example, red light illumination of the aircraft will be used when the emulsion is sensitive to ultra-violet wavelengths.

Similarly, when using the present invention to examine the structural integrity of an object made with a fibre composite material, the object will normally be placed in a darkened room (or covered with a shroud) and illuminated only by light having a wavelength to which the emulsion of the photographic film or plate is insensitive.

In a further development of the present invention, in its application to aircraft fuselage testing, holographic interferograms may be taken of large regions of an aircraft fuselage, using the arrangement shown in Figures 6 and 7. In this arrangement, a film strip or a series of photographic plates 60 is positioned a short distance above the joins in a section of an aircraft fuselage 61. A laser 64 with an associated spatial filter and beam expander is mounted on a two-axes positioning device 65 of known construction. The laser 64 generates an expanded laser beam 66 which is scanned over the entire length of the film strip or plates 60 by the oscillation of the laser about the axes of the device 65. In a preferred embodiment of the arrangement shown in Figures 6 and 7, the movement of the laser 64 is controlled by a computer (using known technology). Fringes in the emulsion of the strip or plates 60 are created in each region of the section of the fuselage over which the laser beam is scanned (firstly when the fuselage is unpressurised, then again when the fuselage is pressurised). Thus examination of the fringe patterns created in the emulsion provides information about the efficacy of each rivet, bolt or bond in the section being investigated. The maximum extent of the region of fuselage that can be covered by the arrangement shown in Figures 6 and 7 depends upon the contours of the fuselage. Typically, the system is effective until the plane of the photographic film or plates is at about 30° to the laser beam.

It is to be expected that it will not always be convenient to darken a hangar and perform the pressurising and depressurising of an aircraft while examining rivetted, bolted or bonded joins using the present invention as described above. In many instances, it will be desirable to have other work carried out on the aircraft while the integrity of the sheet metal joins is assessed. Accordingly, the present inventors have devised the equipments featured in Figures 8 and 9.

The equipment featured in Figure 8 uses a laser 84 mounted on a travelling support (not shown in Figure 8) which runs along tracks (also not shown in Figure 8) which are laid on the surface of the fuselage so that the laser 84 runs over the joins in the skin of the fuselage. An array of double glass plates 83 is mounted (using vibration isolating mounts 82) a short distance above the lines of a long join.

As the laser moves slowly over the linear array of glass plates, a rectangular portion of a strip of photographic film 85 is laid between each pair of glass plates, and a first exposure is made of each rectangular portion. A flexible cover or shroud 87 covers the entire assembly of tracks, glass plates, travelling supports, photographic strip and laser (with its associated mirrors 86) and has its edges sealed against the fuselage to prevent the ingress of unwanted light.

The laser 84 moves over the entire length of the photographic strip 85 when the fuselage is in a first stressed state. Then the stress applied to the fuselage is changed and the laser is moved back to its starting position. A second exposure of each rectangular portion of the strip is made while the laser returns to its starting position, to obtain interference fringes in the image in the emulsion of the strip. Subsequently, analysis of the fringes (after developing the film strip) is carried out to assess the integrity of each join covered by the film strip.

It is not necessary to pressurise the entire aircraft to apply a stress to a region of the fuselage. Stressing or loading of a region of fuselage can be effected by applying two vacuum pads, each with a lever extending away from the fuselage but rigidly attached to the pad, to the fuselage surface near each end of the region being investigated. To change the load on the region of fuselage, the outer end of each lever is moved towards, or away from, the other lever. Such a load-applying arrangement is particularly useful when it would be inconvenient to pressurise the entire aircraft.

Another embodiment of the join inspection equipment for an aircraft fuselage, that can conveniently be used with a vacuum pad loading arrangement of this type, is shown in Figure 9. This inspection equipment can be used, in effect, to take snapshots of joins. It comprises a light-tight box 90 (like a large camera body) which is provided with a seal 91 around its edge which is positioned close to the surface of the fuselage 98. The box 90 is connected via outlet 92 to a source of low vacuum, which reduces the pressure in the box 90 to enable it to be held in any required position on the fuselage, or to apply a load to the zone of the fuselage structure surrounded by the seal 91.

Within the box 90 there is a length of film 95 which is wound around two spools 97. A pair of glass plates 93 is mounted between the spools 97, so as the film 95 is wound from one spool 97 and onto the other spool 97, it passes between the glass plates. The glass plate which is nearest to the fuselage has evacuable feet 88, connected via a length of hose 89 to a higher vacuum system, which is used to "clamp" the feet 88 against the fuselage.

Light from a laser is conducted to a lens system 99 within the box 90 by an optical fibre 94. The lens system expands the output from the optical fibre 94, so that the region of fuselage under the glass plates is illuminated.

To investigate a join of the fuselage, the glass plates, and thus the box 90 also, are positioned over the join and both the low vacuum and higher vacuum systems are activated to effectively clamp the glass plates and the box 90 in position. A fresh length of the film strip 95 is positioned between the glass plates by winding it off one of the spools 97 (the other spool 97 taking up unwanted film). The film is then illuminated with the vacuum pad arrangement creating a first stress over the join being checked. The vacuum pad levers are then moved to change the load applied to the fuselage and the film strip between the glass plates is illuminated again, to form fringes in the image in the emulsion of the film, as described above. Alternatively, a change in the low vacuum in the box 90, or other means, may be used to load the structure.

One possible disadvantage with the use of a vacuum pad arrangement to stress, or modify the stress applied to, a region of the fuselage of an aircraft is that the loading able to be created by the use of vacuum pads is not the same as the loading actually experienced in flight, when the aircraft fuselage is pressurised. However, the present invention is not limited to aircraft fuselage examination, but is suitable for use with any thin metal structure, and when a rivetted, bolted or bonded join is being examined using the present invention, and the join is not in the fuselage of an aircraft, any suitable means of applying a load to the join may be used.

A particularly important feature of the present invention, in its application to the testing of composites and multi-layer patches, as well as bolted, bonded and rivetted structures, is its ability to detect almost any abnormality in the region being investigated which is sufficient to change the way in which the structure takes a load. Thus it is not only surface defects that are detected by the present invention.

It should be appreciated that specific embodiments of the present invention have been illustrated and described above, but variations to or modifications of the illustrated and described embodiments can be made without departing from the present inventive concept. One example of such a modification is shown in Figure 9, where light from a laser is supplied to the region of the test via an optical fibre, and an expanded laser beam is created using a lens system.

CLAIMS

1. A method of examining a region of a rivetted, bolted or bonded join, a composite material, a multi-layer patch, or the like, said method comprising the sequential steps of:
   (a) mounting a photographic plate or film over, but spaced a small distance from and vibrationally isolated from the region;
   (b) illuminating the region and the photographic plate or film with an expanded beam of a laser for a predetermined period;
   (c) applying stress to, or changing the stress applied to, the region so that there is a slight distortion of the region caused by the change in the stress thereof;
   (d) illuminating the region and the photographic plate or film with the same expanded laser beam for a second predetermined period, whereby a holographic interferogram is created within the emulsion of the photographic plate or film; and
   (e) comparing the fringes of the holographic interferogram thus obtained with the fringes of a holographic interferogram from a correctly rivetted, bolted or bonded join, undamaged or non-faulted composite material, properly bonded multi-layer patch, or normal state of the region, as the case may be, to determine the presence of any structural defect in the region.

2. A method as defined in claim 1, in which said first and second periods of illumination are substantially equal periods of time.

3. A method as defined in claim 1 or claim 2, including the steps of digitising the pattern of the fringes obtained by step (d) and effecting the comparison of step (e) by comparing said digitised fringe pattern with the digitised fringe pattern of a correctly rivetted, bolted or bonded join, or non-faulted composite material or patch, using a computer.

4. A method as defined in any preceding claim, in which said mounting of a photographic plate or film is effected using pads of double-sided adhesive tape.

5. A method as defined in any preceding claim, in which said region is a region of a rivetted, bolted or bonded join of a sheet metal structure.

6. A method as defined in claim 5, in which said region is an extensive region, a strip of photographic film or a series of photographic plates being mounted over said region, and each illumination of said region and photographic film or plates is effected by scanning said laser beam over said region.

7. A method as defined in claim 6, in which said scanning of said laser beam is effected by rotational movement of the laser about a mounting position.

8. A method as defined in claim 6, in which said scanning of said laser beam is effected by mounting said laser on a carriage and moving said carriage so that the expanded laser beam passes over the photographic film.

9. A method as defined in claim 6, claim 7 or claim 8,

in which the photographic film is sandwiched between the glass plates of an array of pairs of thin glass plates, each pair of thin glass plates in said array being mounted (i) a small distance from and vibrationally isolated from a segment of said jcin, and (ii) closely adjacent to the next pair of glass plates of said array.

10. A method as defined in claim 5, in which

(a) said expanded laser beam is created within a light-tight housing by a lens system to which light from a laser is supplied via an optical fibre;

(b) said housing is open at an end thereof which is remote from said lens system, said open end being provided with a flexible seal, whereby a low vacuum system may be used to mount said housing in sealing arrangement against the surface of said sheet metal structure;

(c) the interferogram is obtained in the emulsion of a strip of photographic film which is wound on a first spool but is transferable to a second spool, a portion of said film strip being sandwiched between a pair of thin glass plates located between said first and second spools;

(d) said spools and said thin glass plates are mounted within said housing adjacent to the open end thereof; and

(e) one of said thin glass plates is mounted on hollow pads which are adapted to be secured against the surface of the sheet metal structure by suction applied by a second vacuum system.

11. A method as defined in any one of claims 5 to 10, in which said sheet metal structure is the skin of an aircraft.

12. A method as defined in claim 1, substantially as hereinbefore described with reference to the accompanying drawings.

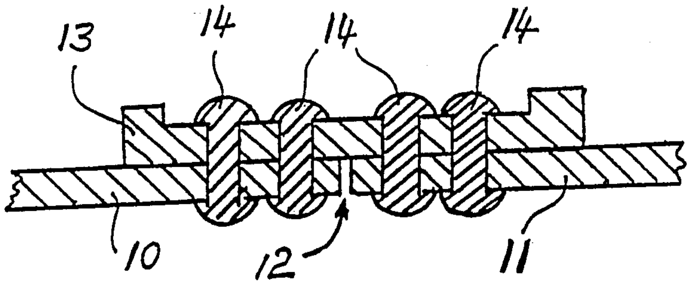


FIG.1a.

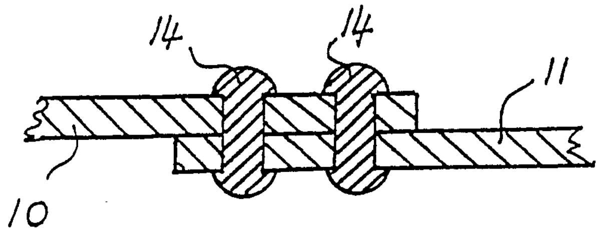


FIG.1b.

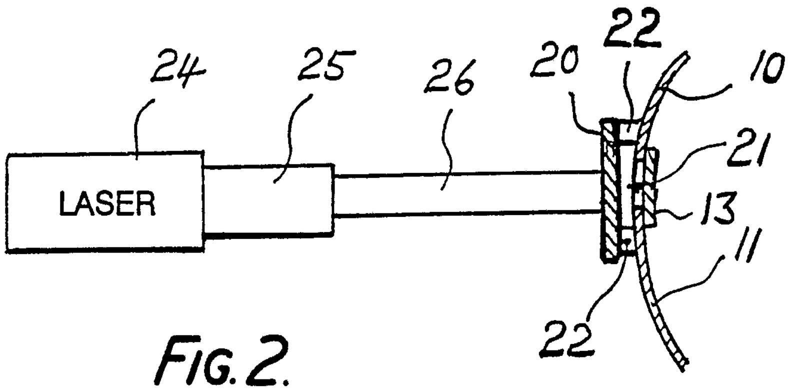


FIG.2.

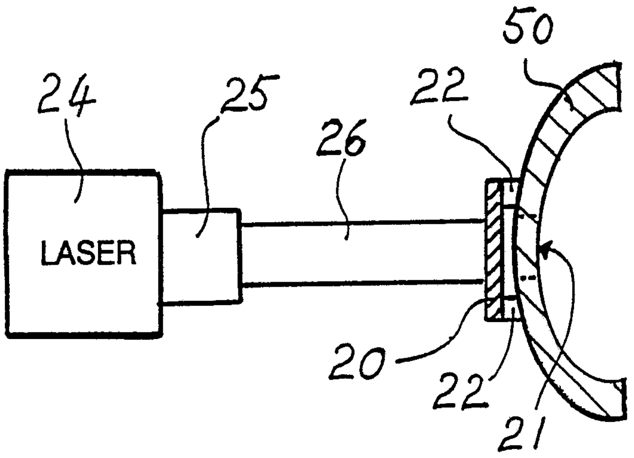


FIG.5.

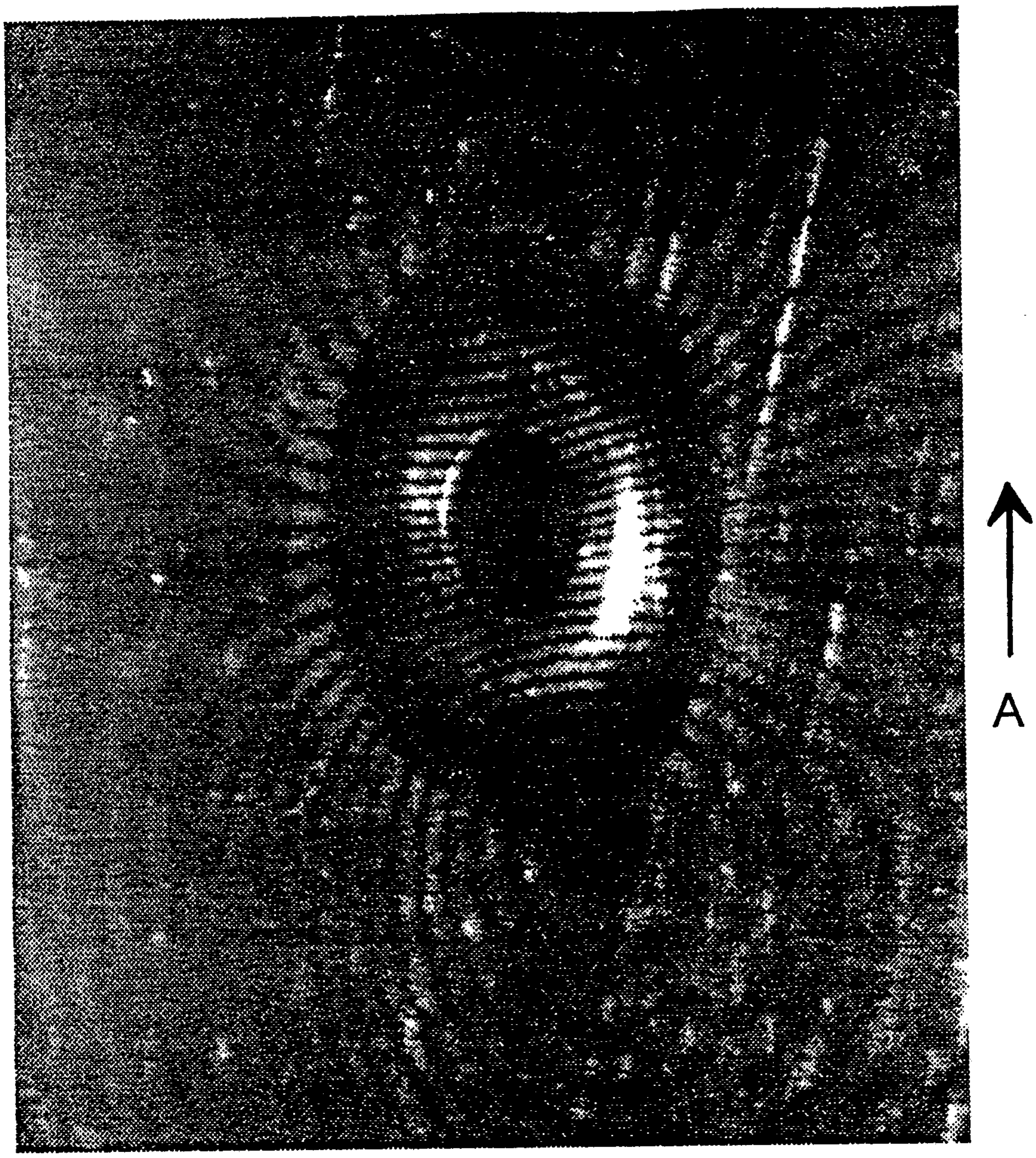


*Fig. 3.*

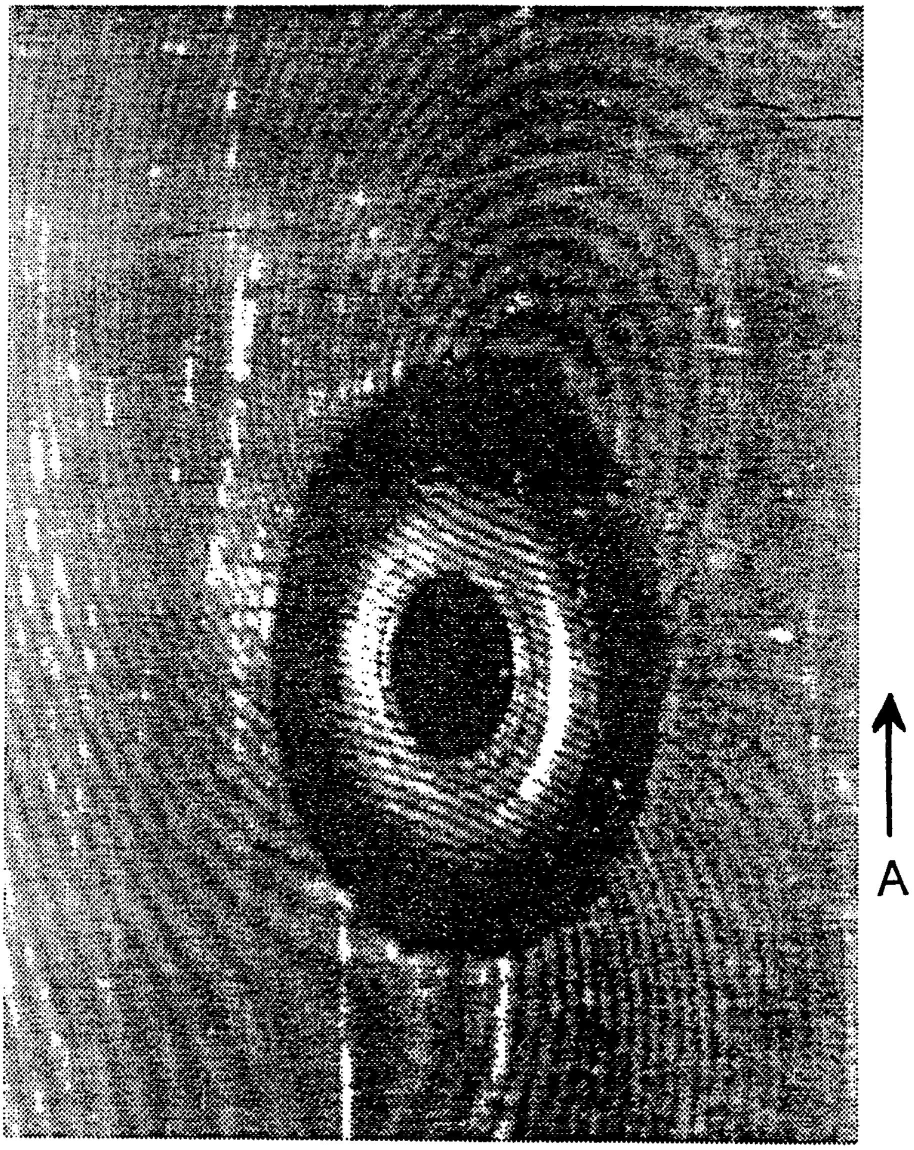


*FIG. 4.*

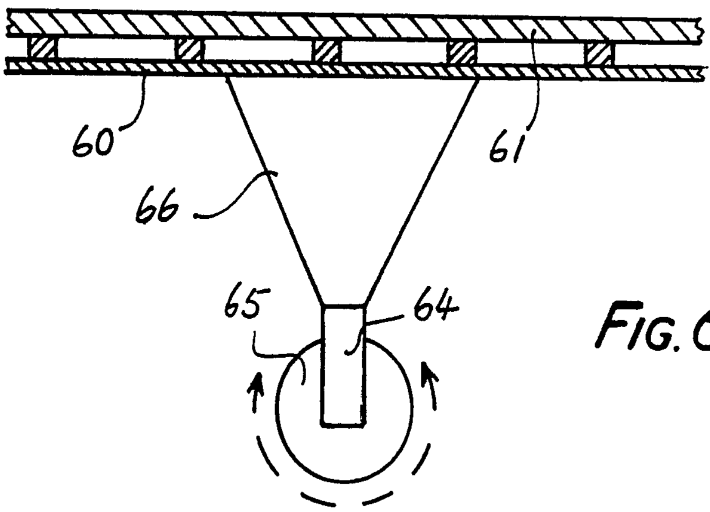


FIG. 6.

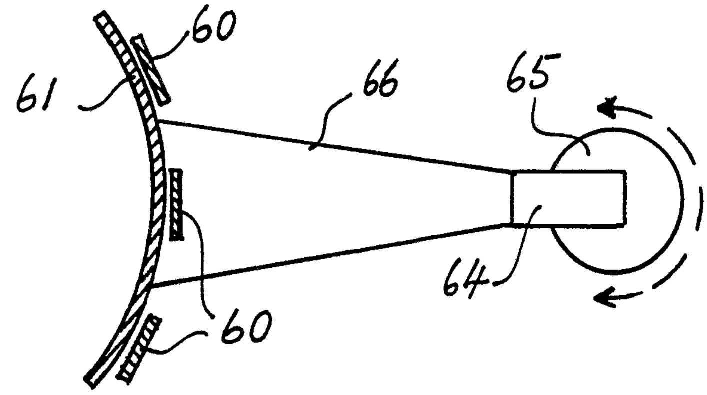


FIG. 7.

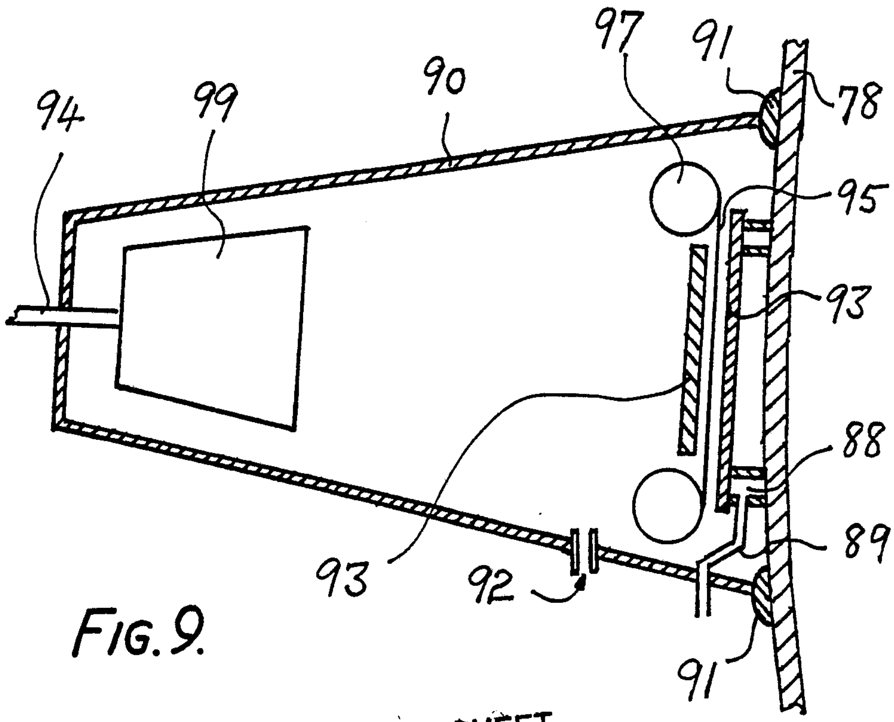


FIG. 9.

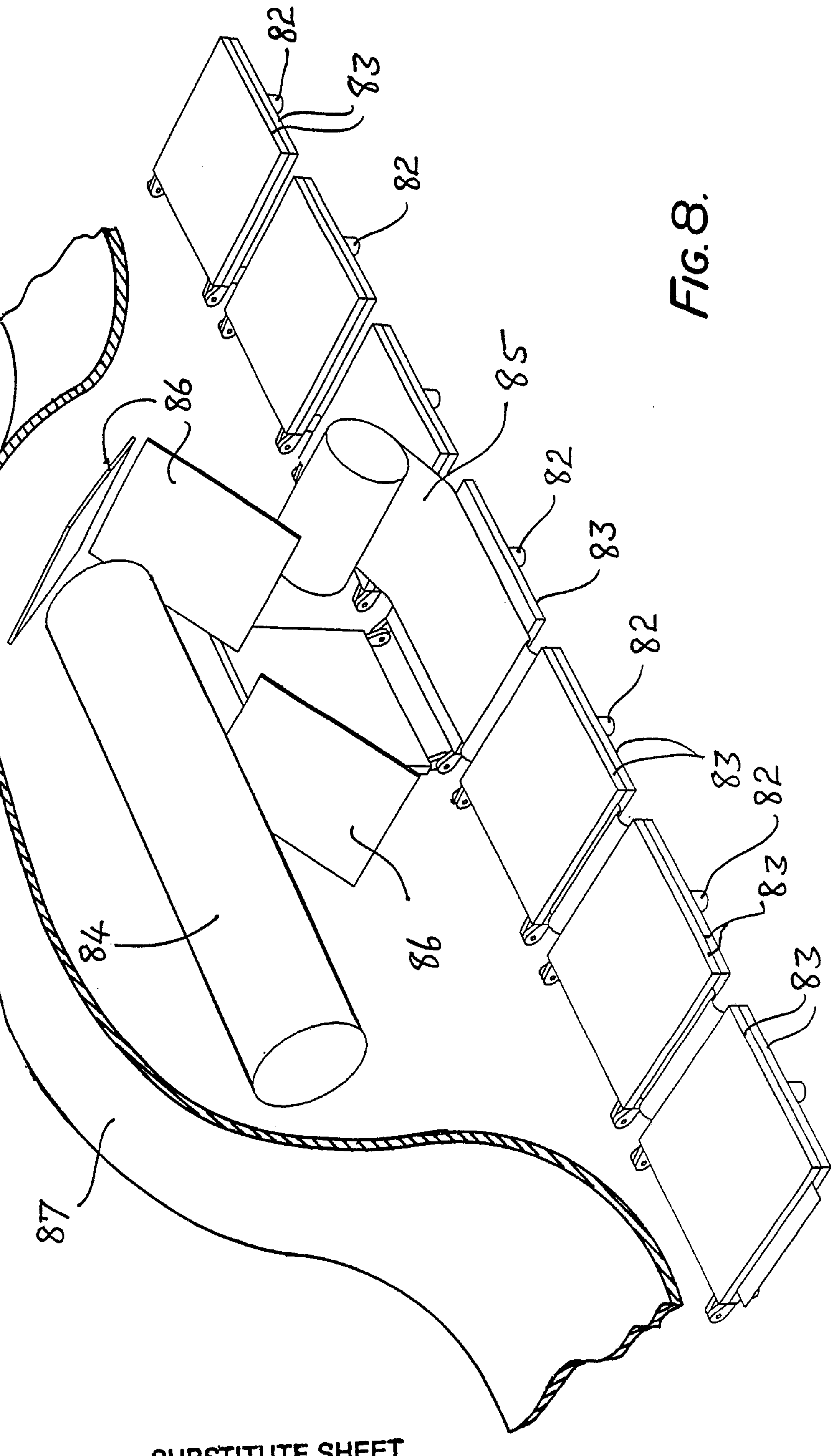


FIG. 8.

# INTERNATIONAL SEARCH REPORT

## I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent classification (IPC) or to both National Classification and IPC
Int. Cl.[5] G01B 9/021, 11/16

## II. FIELDS SEARCHED

Minimum Documentation Searched [7]

| Classification System | Classification Symbols |
|---|---|
| IPC | G01B 9/02, 9/021, 11/16 |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

AU : IPC as above

## III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

| Category* | Citation of Document, [11] with indication, where appropriate of the relevant passages [12] | Relevant to Claim No [13] |
|---|---|---|
| A | US,A,3911733 (BHUTA et al.) 14 October 1975 (14.10.75). See figure 1 and column 2 lines 9-59. | |
| A | US,A,3828126 (RAMSEY JR) 6 August 1974 (06.08.74) See figure 1 and column 3 lines 37 - column 4 line 14. | |
| A | US,A,3587301 (HEARY) 28 June 1971 (28.06.71). See figures 1 and 2 and abstract. | |
| A | US,A,3860346 (KERSCH et al.). See figure 1 and column 1 lines 21-54. | |
| | (continued) | |

* Special categories of cited documents : [10]

"A" Document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior t the international filing date but later than the priority date claimed

"T" Later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

## IV. CERTIFICATION

| Date of the Actual Completion of the International Search | Date of Mailing of this International Search Report |
|---|---|
| 13 March 1992 (13.03.92) | 23 March 1992 (23.03.92) |
| International Searching Authority | Signature of Authorized Officer |
| AUSTRALIAN PATENT OFFICE | R. HALLETT |

**FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET**

| | | |
|---|---|---|
| A | US,A,4139302 (HUNG et al.) 13 February 1979 (13.02.79). See figure 1 and column 2 line 50 - column 3 line 25. | |
| A | US,A,4464052 (NEUMANN) 7 August 1984 (07.08.84). See figure 1 and column 1 line 62 - column 2 line 20. | |

**V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim numbers ..., because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim numbers ..., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim numbers ..., because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4a

**VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]**

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.

# ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL APPLICATION NO. PCT/AU 91/00595

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

| Patent Document Cited in Search Report | Patent Family Member | | |
|---|---|---|---|
| US 3911733 | CA 1022784<br>JP 50143552 | DE 2514195 | GB 1453262 |
| US 4139302 | CA 1112921<br>GB 1600955 | DE 2806845<br>IT 1102269 | FR 2381280<br>JP 53102775 |
| US 3860346 | CA 936397<br>NL 7100150 | DE 2107101 | FR 2083033 |