PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : B32B 31/20

A1

(11) International Publication Number: WO 90/13425

(43) International Publication Date: 15 November 1990 (15.11.90)

(21) International Application Number: PCT/US90/02489

(22) International Filing Date: 4 May 1990 (04.05.90)

(30) Priority data:
348,822 8 May 1989 (08.05.89) US

(71) Applicant: AMERICAN COMPOSITE TECHNOLOGY INC. [US/US]; 306 Northern Avenue, Boston, MA 02210 (US).

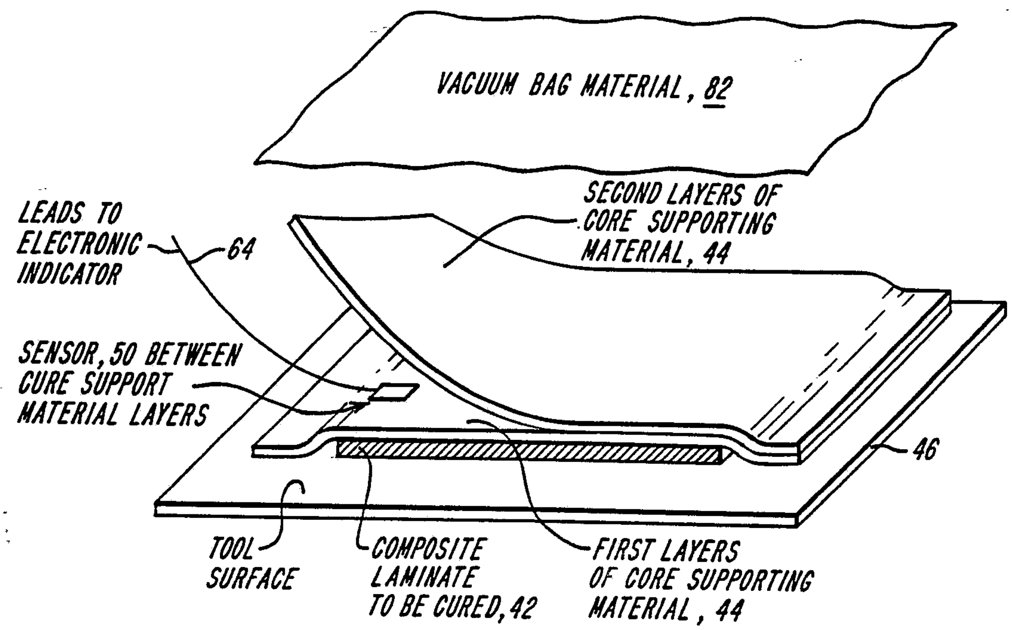
(72) Inventors: FANUCCI, Jerome, Paul ; 43 Elliot Road, Arlington, MA 02174 (US). NOLET, Stephen, C. ; 103 Weathervane Drive, Leominster, MA 01453 (US).

(74) Agents: BEVILACQUA, Michael, J. et al.; Hale and Dorr, 60 State Street, Boston, MA 02109 (US).

(81) Designated States: AT (European patent), BE (European + patent), CA, CH (European patent), DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent).

**Published**
*With international search report.*
*With amended claims and statement.*

(54) Title: SYSTEM AND METHOD FOR MONITORING PRESSURE DURING THE PRODUCTION OF FIBER REINFORCED POLYMERS




(57) Abstract

Disclosed is a system and method of monitoring exerted pressure during the production of composite material laminates that utilizes a thin, low cost, durable, temperature resistant force sensing resistor (50). The sensor (50) can be embedded directly on the surface of the composite laminate (42), or can be positioned between layers of the composite laminate (42). Alternatively, the sensor (50) is built into or mounted on a tool (46) or die used to form or exert pressure on the laminate (42). In all of these cases, the force sensing resistor (50) monitors the pressure experienced by the laminate (42) during processing of the laminate (42).

+ See back of page

*FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | |
|---|---|---|---|---|---|
| AT | Austria | ES | Spain | MC | Monaco |
| AU | Australia | FI | Finland | MG | Madagascar |
| BB | Barbados | FR | France | ML | Mali |
| BE | Belgium | GA | Gabon | MR | Mauritania |
| BF | Burkina Fasso | GB | United Kingdom | MW | Malawi |
| BG | Bulgaria | GR | Greece | NL | Netherlands |
| BJ | Benin | HU | Hungary | NO | Norway |
| BR | Brazil | IT | Italy | RO | Romania |
| CA | Canada | JP | Japan | SD | Sudan |
| CF | Central African Republic | KP | Democratic People's Republic of Korea | SE | Sweden |
| CG | Congo | | | SN | Senegal |
| CH | Switzerland | KR | Republic of Korea | SU | Soviet Union |
| CM | Cameroon | LI | Liechtenstein | TD | Chad |
| DE | Germany, Federal Republic of | LK | Sri Lanka | TG | Togo |
| DK | Denmark | LU | Luxembourg | US | United States of America |

# SYSTEM AND METHOD FOR MONITORING PRESSURE DURING THE PRODUCTION OF FIBER REINFORCED POLYMERS

## BACKGROUND OF THE INVENTION

The present invention relates to a system and method for monitoring pressure exerted on materials during the production of fiber reinforced polymer composites and more particularly to a system and method for monitoring pressure exerted on fiber reinforced polymer composites through the use of a force sensing resistor in either the composite or the tool or die.

Use of fiber reinforced polymer has seen a dramatic increase in recent years as the demand for high performance plastics in commercial, industrial and military applications has risen. The benefits of composite materials, such as high strength and stiffness, low weight, resistance to fatigue and corrosion, make these materials extremely attractive in applications ranging from aircraft to bridges. New fabrication technologies have opened the door to low cost processing, allowing hundreds of new companies to enter production. Composites manufacturing, however, requires a careful monitoring control of the many complex processes common to every composite molding operation.

Most composite production processes start with the assembly of individual layers of fiber and matrix material. The basic materials used to construct the laminate can be in any number of forms including dry fiber and liquid resin, sheets of fiber impregnated with matrix material, sprayed mixtures of resin and matrix, as well as other combinations. The matrix materials can include thermosetting types, which undergo irreversible chemical reactions as they cure to form a rigid laminate, or thermoplastics, which can be repeatedly heated, melted and reconsolidated.

The manufacturing of a composite laminate, regardless of the fiber type and polymer matrix, requires the application of heat and pressure. Heat is required to either polymerize a thermosetting resin system (cure) or melt a thermoplastic system (such as Ultem). Application of pressure is required to consolidate the laminate to eliminate voids in the form of trapped air or volatiles that are generated during the cure. Without careful consideration of both the temperature history or pressure profile of the composite part during processing, the ability to produce high quality parts is severely crippled. For this reason, the reinforced plastics industry has spent a large portion of its research funds developing sophisticated hardware to monitor the state of a composite laminate during fabrication. Instruments for monitoring cure state of thermosetting and thermoplastic resins abound. Differential scanning calorimetry (DSC), thermograimetric analysis (TGA), thermemechanical analysis (TMA), parallel plate rheometers, dielectric-electrics, ultrasonics, and fiberoptics are only a few of the sensing and measurement technologies that have been applied to research and production of composite materials. None of these monitoring instruments have proven, however, to be useful in monitoring the pressure exerted on or between the layers of the composite material.

Composite structures, unlike their metallic counterparts, are built up rather than "machined down". This difference permits the integration of embedded sensors for use in such diverse applications as adaptive structures which actively damp vibrations or maintain precise geometry over a broad temperature and loading spectrum to structures which monitor the health of the structure in order to warn when damage is present.

Embedded sensors have also recently been used in process technology as well. Thin dielectric cure sensors and thermocouples are routinely laminated between plies in the composite to provide feedback for control of autoclaves and hot presses during processing. Fiber optic cables provide similar information in the autoclave and may also serve a second purpose in the structure as a health monitoring device, communications link or strain indicator.

A missing link in composites processing is a pressure monitoring device that can be embedded in the laminate. In-situ pressure monitoring during process development and during production is extremely important for a number of reasons. Referring to Fig. 1, in a typical laminate consolidation and cure process used in autoclave molding, in resin transfer molding and in filament winding operations, several layers of disposable materials are used to provide high surface quality, absorb excess resin and provide even vacuum distribution. The materials are sealed beneath the nylon film. The area between the caul sheet 14 (or mold surface) and the vacuum bag 16 is evacuated with a vacuum pump (not shown) to approximately 20 inches Hg or less. The vacuum draws volatiles out of the laminate 12 and provides the necessary pressure gradient between the autoclave and the laminate 12. In autoclave processing, if a vacuum bag 16 breaks or loses its seal, the net force consolidating the part becomes zero and the laminate will not be of acceptable quality after the cure. The part, which may require several weeks to prepare for cure, is then scrapped.

A record of the pressure versus time history of each component is often required to verify the quality of every high performance composite part made. A sensor capable of indicating loss of vacuum pressure would obviously be a valuable quality control and process monitoring tool. It is possible that early warning of vacuum loss could allow the problem to be repaired or laminate damage minimized. A knowledge of the pressure history during cure is also an important consideration. Pressure may be varied at different times during a normal autoclave cure cycle.

In complex tool situations, thermal expansion of metal tooling is used to provide laminate pressurization. Shrink wrap films are often applied to filament wound vessels, radomes and cylinders to apply pressure when heated. Matched dies are used for consolidation in compression molding of composite materials. In all these applications, the actual applied pressure on the laminate is virtually unknown and is unmeasurable by previous existing techniques. Lamination pressure will typically vary from point to point in large complex dies. A reliable pressure sensing system would be a valuable asset in measuring such applied pressure.

Pultrusion technology has also emerged as one of the most rapidly growing (by volume) manufacturing processes for reinforced polymer materials. Referring to Fig. 2, in pultrusion manufacturing, fibers 22 and resins 24 are pulled through a heated die 26 and cured. Fibers are impregnated with resin by either pulling them through a resin bath or by direct injection at the entrance of the die. The part undergoes an extremely complex series of chemical reactions and thermal expansion, leading to wild excursions in volumetric dimension. Changes in material volume lead to pressure variation within the die which affects consolidation of the laminate. A variety of factors including temperature, formulation of resin, volume of fibers, pulling speed and die design influence the pressure profile of the part during cure. The complex interaction of the parameters and their effect on laminate pressure cannot be readily analyzed nor can the results be verified until a continuous pressure measurement can be determined. Currently, temperature profiles are obtained by passing a thin thermocouple through the die. An example of a temperature profile of an epoxy resin system is shown in Fig. 3. A cross-section of the die is shown on the plot to illustrate the relative position of the thermocouple in the die. The die temperature is approximately 150° C. The exothermic reaction produces higher resin temperatures. The combination of both a thermal profile and pressure profile would unlock the answers to many important questions regarding the process conditions within a pultrusion die.

It is therefore a principal object of the present invention to provide a system and method of monitoring exerted pressure during the production of composite material laminate.

Another object of the present invention is to provide a system and method of monitoring exerted pressure on a manufactured laminate utilizing a force sensing device either in the laminate or on a tool or die used to manufacture the laminate.

It is another object of the present invention is to provide a composite material laminate or a laminate forming tool including a pressure sensing device for providing a record of pressure versus time history of the composite material laminate.

Yet another object of the present invention is to produce a composite material laminate with a low cost, durable, low profile, temperature resistant pressure sensor embedded therein.

Still another object of the present invention is to provide tools or dies for creating a composite material laminate that include a device for measuring pressure exerted on the composite material laminate created by the tool or die during production.

## SUMMARY OF THE INVENTION

Accordingly, a system and method of monitoring exerted pressure during the production of composite material laminates utilizes a thin, low cost, durable, temperature resistant force sensing resistor. The sensor can be embedded directly on the surface of the composite laminate, or can be positioned between layers of the composite laminate. In this way, the force sensing resistor monitors the pressure experienced by the laminate during processing of the laminate. Alternatively, the sensor is built into or mounted on a tool or die used to form or exert pressure on the laminate.

These and other features and objects of the present invention will become more fully understood from following the detailed description which should be read in light of the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is layup of a prior art preimpregnated composite material laminate constructed out of a variety of auxiliary materials;

Fig. 2 is a diagrammatic view of a prior art pultrusion processing system;

Fig. 3 is a graph of a thermal profile of a graphite/epoxy part generated using a prior art thermocouple passed through the die with the materials used for creating a composite;

Figs. 4(a)-4(d) are perspective views of alternate embodiments of the positioning of a sensor in the system of the present invention;

Fig. 5 is a schematic view of a device for use in calibrating the force sensing resistor utilized in the composite material laminate of the present invention;

Fig. 6 is a perspective view of a force sensing resistor placed between layers of a composite material laminate of the present invention;

Fig. 7 is diagrammatic view of pultrusion die through which a force sensing resistor will be pulled with the materials for creating a composite material laminate according to the present invention;

Fig. 8 shows use of a force sensing resistor mounted on a tool of the present invention used in an autoclave.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In a preferred embodiment, in order to measure the pressure exerted on a composite laminate manufactured through the use of autoclave molding, compression molding, resin injection molding, pultrusion, reaction injection molding, press molding and other procedures, a thin force sensing resistor is embedded between laminate layers of the product during assembly of its layers or is placed between the surface of the composite laminate and the tool against which the composite is cured. In some cases, layers of disposable materials are positioned between the composite product and the tool, and the sensor can be placed in these layers as well. A suitable resistor is described in U.S. Patent No. 4,301,337, the teachings of which are incorporated herein by reference. In preferred embodiments, the resistor, however, includes one pressure switch rather than the two described in this patent.

The force sensing resistor, which was developed to generate tones in an electronic musical device, is a dual switch that is actuated in response to a single touch force. In its commercial form, this force sensing resistor, which is sold by Interlink Electronics of Santa Barbara, California under the designation Forcing Sensing Resistor or FSR, has a thickness of less than 0.5 mm, has good dynamic and pressure ranges and has minimum temperature sensitivity. In particular, the force sensing resistor is available in thicknesses ranging from 0.005 to 0.050 inches. As will be more fully described below, this thin profile allows the force sensing resistor to be implanted inside a laminate, placed on the surface of a laminate, placed within supporting cure materials of a laminate, placed on a laminate forming tool, or built permanently below the surface of the tool.

This force sensing resistor is also available in a variety of surface areas. Sensors with surface areas from less than 0.5 to more than 5,000 square cm are currently available with other sizes possible for special applications. This range of surface areas allows the device to be used for many different types of pressure monitoring applications. The use of a sensor with a small surface area in the present invention allows pressure at a point to be measured, and the use of a sensor with a large surface area allows the measurement of average pressures or the determination of the distribution of pressure over a large area. The sensor in its commerical form can be used in temperatures up to 300°F and it is possible to special order the sensor so that it can operate at temperatures approaching 800°. Such temperature ranges are appropriate for many plastics, composites and chemical manufacturing, testing and service conditions. Another advantage of the sensor is that it can be tailored to be sensitive to a variety of pressure ranges of interest to the material processing industry. The sensitivity of the sensor to changes in operating temperatures is small. For many applications such as monitoring the loss of vacuum pressure, temperature sensitivity can be ignored. For more percise measurements, temperature effects can be accounted for by simple calibration and curve fittings. The resistor (or sensor) can remain a permanent part of the composite after the consolidation and cure of the material has been completed (and therefore lost during the production process) or, if properly positioned, it can be removed during a trimming operation.

The creation of the composite laminate with an embedded sensor will now be described in detail. During the layup of uncured laminate, a force sensing resistor 50 is placed between material layers 42 at locations in the laminate (Fig. 6) and/or the surrounding trim, scrape or follower materials, where measurement of the processing pressure is desired. Alternatively, the force sensing resistor can be placed between layers of supporting material 44 (Fig. 4a), placed directly between the laminate 42 and the tool 46 (Fig. 4b), placed on the tool 46 away from the composite laminate 42 (Fig. 4c) or permanently built into the processing tool 46 slightly below the tool surface (Fig. 4d). Because of the very thin profile of the sensors and leads, the surface imperfection at the sensor location from the build-up of additional thickness is minimized. The thinness of the force sensing resistor also improves its ability to accurately measure the pressure in the laminate, especially when manufacturing techniques such as press molding, matched die molding and pultrusion, which apply load to the surface by closing or otherwise controlling the thickness of the laminate as it cures, are employed. Thick points, caused by thick sensors, in a laminate would locally contact the surfaces with more force. Therefore, the thinness of the force sensing resistor becomes an important feature of the present invention that allows this force sensing resistor to be used as part of a composite laminate.

Prior to positioning the sensor in the system of the present invention (e.g. between layers of unprocessed laminate), the sensor may need to be calibrated. The calibration can be obtained from non-specific data supplied by the sensor manufacturer, or each sensor can be individually calibrated. The force sensing resistor operates by changing its electrical resistance in a way that is directly and repeatedly related to applied surface pressure. Calibration of the sensor, for those applications requiring more detailed and accurate pressure readings, can be accomplished by applying a series of known pressures to the surface of the force sensor resistor and measuring its resistance at each of these pressures.

Fig. 5 shows one possible method for obtaining a pressure versus sensor output curve for individual sensors when detailed calibration is required. The force sensing resistor 50 is placed on a base plate 52, and a thin plastic film 54 with its edges sealed against air leaks covers the force sensing resistor 50. A top plate 56 is placed over the force sensing resistor 50 and base plate 52. Air lines 58 connected to the top plate 56 apply a variable air pressure from a variable air pressure source 60 under control of gauge 62 to the force sensing resistor 50. An ohm meter 64 measures the resistance.

Referring to Fig. 6, after the force sensing resistor 50 has been calibrated, lead wires 64 must be connected to the sensor. These lead wires may be connected by soldering, bonding, crimping or mechanical fastening. Leads must be long enough to reach the laminate, following a possibly convoluted path to reach the outside of the tooling used to form the laminate, exit the machinery used to apply pressure and temperature to the laminate as it cures and finally connect to the device 66 used to monitor the signal from the force sensing resistor. Care should be taken to select leads that can withstand the temperature and pressure conditions to which the leads are exposed during the laminate processing. In particular, the melting temperature of the insulation on the leads should be higher than the maximum processing temperature.

After the sensor has been positioned between layers of unprocessed laminate, wires from the sensor should be strung to the exterior of the mold and loading machine. It is often desirable to run the leads through the laminate in a direction parallel to the principal fiber direction of the adjacent layers of the material so the leads can nest in the most unobtrusive manner possible between the reinforcing fibers when pressure is applied. In addition, if the sensor and leads are not located in a position that will be trimmed from the finished laminate prior to its use, care should be taken to insure that the sensors and leads do not compromise the structural performance of the laminate. The leads from the force sensing resistor are attached to a device for measuring the resistance of the force sensing resistor.

The force sensing resistor responds to pressure applied to its surface by changing its resistance in relation to applied loads. The simplest device for measuring the resistance of the sensor, and thus inferring the pressure by correlating the resistance reading to pressure using the calibration curves determined for the force sensing resistor, is a simple ohm meter. By measuring the resistance of the sensor, the pressure at that point in the laminate can be determined.

Once the force sensing resistor has been positioned in the unprocessed laminate, pressure and temperature are applied to the laminate. Process pressure can be applied using any of a variety of standard methods used by the composite material processing industry including, autoclave methods, hydraulic presses, matched tooling, expanding tooling, compression molding machines, etc. As pressure is applied to the laminate, the applied pressure is monitored by reading resistance and correlating the readings with applied pressure. This pressure in the laminate can be read directly from analog meters as a resistance; it can be converted electronically to pressure by applying the proper calibration equations relating pressure to resistance; it can be converted by the use of look-up tables; or it can be read in digital form using a computer to both display and record the data. In some cases it may be necessary to monitor temperature changes and account for its effect on the sensor.

In an alternate embodiment of the present invention shown in Fig. 4(d), the force sensing resistor can be permanently embedded for monitoring pressure at a surface of material forming tools or other tools and equipment used for the production or testing of composite material laminates or other plastic, chemical or metal products. In this embodiment, the sensor is built permanently into the tool 46 or equipment, either on or slightly below the surface, rather than into the part being manufactured. The tool can be constructed from a number of materials including composite material, metal, plastic, ceramic and other materials or combination of materials. Protective surfaces such as sprayed metal, plastics and other materials could be used to coat the sensor and provide a smooth tool surface. When employed in this fashion, the sensor will become a permanent part of the tool. It could be used to measure pressure during the production of multiple parts from the same tool, rather than being expendable. Multiple sensors can be built into the surface of each tool to measure the pressure distribution at a variety of points in the product.

In this embodiment, the calibration and the connection of the sensors would be accomplished as described above in connection with the embodiment of Figs. 5-6, except that the sensor need not necessarily be implanted between layers of composite material, but could instead be positioned directly on the solid surface of the tool. In this embodiment, unlike the embodiment described above and shown in Figs. 5-6, the force sensing resistors would be reusable.

Referring now to another alternate embodiment shown in Fig. 7, the force sensing resistor is utilized in a special composite material processing method known as pultrusion. Pultrusion is currently used mostly for production of parts having a constant cross section. Fiber and resin materials 70 are pulled through a pultrusion die 72 at a continuous and steady speed by a variety of mechanical systems. The resin is cured inside the die as it moves through.

When employing the thin force sensing resistor 50, that has been described above, to measure to pultrusion process pressures, the resistor is calibrated as described above in connection with Fig. 5, and the leads are attached to the sensor in the manner described above. Care should be taken to assure that the leads are long enough to reach the electronic device that will be used to monitor the sensor output to the die entrance and through the die, possibly a distance of 10 feet or more. The leads from the force sensing resistor 50 to the device that measures the resistance of the force sensing resistor 50 are also attached in the same way as described above in connection with the embodiment of Fig. 5.

The force sensing resistor 50 is placed between layers of material prior to the entrance of the material 70 to the pultrusion die. Leads 64 applied to the force sensing resistor are positioned in a way that they will not bind as they are pulled into and through the pultrusion die 72, but instead will feed smoothly without knots, kinks or folds. In Fig. 7, material 70 is fed into the pultrusion die 72, and the finished product 74 exits to the right of the pultrusion die as shown in Fig. 7. The force sensing resistor 50 is initially positioned near the entrance to the die 72 with the leads 64 spooled at the side ready to feed in as the material pulls the force sensing resistor through the system. While Fig. 7 illustrates a pultrusion die using a resin injection method to wet out the materials, an almost identical approach could be used if a wet bath or through bath wet out method is used.

Applied pressure is monitored by reading resistance and correlating the reading with applied pressure as described above in connection with the embodiments of Figs. 5-6. As the force sensing resistor is pulled through the pultrusion die, a continuous read out of resistance (pressure) can be measured and recorded. By noting the time that each reading is taken, it is possible to calculate the position in the die with which the pressure reading corresponds. When the sensor exits the pultrusion die with the now consolidated and cured laminate the leads should be cut from the entrance end of the die.

In the alternate embodiment of the present invention shown in Fig. 8, a heated and pressurized vessel known as an autoclave is used to apply pressure to a laminate 80 through a vacuum bag 82 and an exterior pressurized atmosphere. The successful manufacture of composite parts in an autoclave requires that the integrity of the vacuum bag be maintained throughout the process. Loss of the vacuum can result in destruction of the part if the failure is not rapidly attended. The force sensing resistor 50 is used as a simple vacuum integrity sensor. When used as a vacuum integrity sensor, the sensor end leads 64 are calibrated and prepared as described above in connection with other embodiments. The sensor is then placed on the surface of the production tool 84, or within layers of auxiliary cure materials in a position where it will be contained inside the vacuum bag 82. The force sensor resistor 50 is sealed inside the vacuum bag 82 using standard bag preparation techniques with the leads 64 extending outside the bag 82 through a vacuum tight seal. The lead wires are lead to a device 66 that can monitor the resistance of the force sensing resistor 50. The reading of the force sensing resistor 50 prior to applying the vacuum to the vacuum bag is noted and this reading represents the zero pressure value. The vacuum is then applied to the bag and a new reading from the sensor is noted. This reading represents the value that should be maintained throughout the process if vacuum integrity in the bag is maintained. The reading from the sensor is monitored during autoclave processing. If the value drops below a previously selected limit, indicating an unacceptable leak in the vacuum integrity of the bag, corrective action should be taken in time to save a part that would otherwise be improperly cured.

The foregoing invention has been described with reference to its preferred embodiments. Various alterations and modifications will occur to those skilled in the art. All such variations and modifications are intended to fall within the scope of the appended claims.

What is claimed is:

1. A system for monitoring pressure exerted during the production of a composite material laminate, said system comprising:

fiber material and polymer matrix material mixed together to form a composite material through the application of heat and pressure;

a force sensing resistor positioned within the system for monitoring process pressure experienced by said composite material while the composite material is being produced.

means for measuring resistances sensed by said force sensing resistor.

2. The system for monitoring pressure of claim 1 wherein said force sensing resistor is embedded in a surface of said composite material laminate for monitoring the process pressure applied to a surface of said composite material.

3. The system for monitoring pressure of claim 1 further comprising layers of composite material laminate and wherein said force sensing resistor is positioned between two of said layers of said composite material laminate.

4. The system for monitoring pressure of claim 1 wherein said system further comprises a forming tool for exerting pressure on said composite material and wherein said force sensing resistor is embedded in said forming tool below a surface of the forming tool.

5. The system for monitoring pressure of claim 1 wherein said system further comprises:

a forming tool for exerting pressure on said composite material, and

at least two layers of cure supporting materials; and wherein said force sensing resistor is positioned between said two layers of cure supporting materials.

6. The system for monitoring the pressure the claim 1 wherein said system further comprises a forming tool for exerting pressure on said composite material, and wherein said force sensing resistor is placed on a surface of said forming tool between said forming tool and said composite material.

7. The system for monitoring pressure of claim 1 wherein said system further comprises:

a forming tool for exerting pressure on said composite material;

a vacuum bag that encloses said composite material; and wherein said force sensing resistor is positioned within said vacuum bag out of contact with said laminate.

8. A method for monitoring pressure exerted during the production of a composite material laminate, said method comprising the steps of:

mixing fiber material and polymer material together to form a composite material through the application of heat and pressure;

positioning a force sensing resistor relative to said mixed materials so as to enable said force sensing resistor to monitor a pressure experienced by said mixed materials while the composite material is being produced;

measuring the resistance sensed by said force sensing resistor;

converting said resistance into a corresponding pressure reading indicating the pressure experienced by said mixed materials while the composite material is being produced.

AMENDED CLAIMS
[received by the International Bureau
on 16 October 1990 (16.10.90);
original claims 1-8 replaced by amended claims 1-8; new claims 9-15 added (4 pages)]

1. (Amended) A system for measuring pressure exerted during the production of a composite material laminate, said system comprising:

fiber material and polymer matrix material mixed together to form a composite material through the application of heat and pressure;

a force sensing resistor positioned within the system for measuring process pressure applied to said composite material while the composite material is being produced;

means for measuring resistances sensed by said force sensing resistor.

2. (Amended) The system for measuring pressure of claim 1 wherein said force sensing resistor is embedded in a surface of said composite material laminate for meausring the process pressure applied to a surface of said composite material.

3. (Amended) The system for measuring pressure of claim 1 further comprising layers of composite material laminate and wherein said force sensing resistor is positioned between two of said layers of said composite material laminate.

4. (Amended) The system for measuring pressure of claim 1 wherein said system further comprises a forming tool for exerting pressure on said composite material and wherein said force sensing resistor is embedded in said forming tool below a protective layer on a surface of the forming tool.

5. (Amended) The system for measuring pressure of claim 1 wherein said system further comprises:

a forming tool for exerting pressure on said composite material, and

at least two layers of cure supporting materials; and wherein said force sensing resistor is positioned between said two layers of cure supporting materials.

6. (Amended) The system for measuring the pressure the claim 1 wherein said system further comprises a forming tool for exerting pressure on said composite material, and wherein said force sensing resistor is placed on a surface of said forming tool between said forming tool and said composite material.

7. (Amended) The system for measuring pressure of claim 1 wherein said system further comprises:

a forming tool for exerting pressure on said composite material;

a vacuum bag that encloses said composite material; and wherein said force sensing resistor is positioned within said vacuum bag out of contact with said laminate.

8. (Amended) A method for measuring pressure exerted during the production of a composite material laminate, said method comprising the steps of:

mixing fiber material and polymer material together to form a composite material through the application of heat and pressure;

positioning a force sensing resistor relative to said mixed materials so as to enable said force sensing resistor to measure a pressure experienced by said mixed materials while the composite material is being produced;

measuring the resistance sensed by said force sensing resistor;

converting said resistance into a corresponding pressure reading indicating the pressure experienced by said mixed materials while the composite material is being produced.

9. (New) The system for measuring pressure of claim 1 wherein said force sensing resister has a thickness between 0.005 inches and 0.50 inches.

10. (New) The system for measuring pressure of claim 1 wherein said sensor has an appropriate surface area and is positioned within said system at a location appropriate to allow the measurement of pressure applied to a single small area of said composite material.

11. (New) The system for measuring pressure of claim 1 wherein said sensor has an appropriate surface area and is positioned within said system at a location appropriate to allow the measurement of average pressures.

12. (New) The system for measuring pressure of claim 1 wherein said sensor has an appropriate surface area and is positioned within said system at a location appropriate to allow the determination of the distribution of pressure over an entire area.

13. (New) The system for measuring pressure of claim 1 wherein said force sensing resistor changes its electrical resistance in direct relationshp to pressure applied to a surface of said resistor.

14. (New) The system for measuring pressure of claim 1 wherein said composite material is produced in a pultrussion die and said force sensing resistor is positioned between layers of composite material laminate before said layers are pulled through said die.

15. (New) A system for measuring pressure exerted during the production of a composite material laminate, said system comprising:

fiber material and polymer matrix material mixed together to form a composite material through the application of heat and pressure;

a force sensing means, positioned within the system for measuring process pressure experienced by said composite material while the composite material is being produced; said force sensing means having a thickness between 0.005 and 0.050 inches and a surface area greater than 0.5 cm

means for measuring resistances sensed by said force sensing resistor.--

## STATEMENT UNDER ARTICLE 19

The below listed claims have been amended to more clearly describe the subject of the invention.

Claims 1-8 replace claims 1-8 as originally filed.

Claims 9-15 are new.

The amendments to claims 1-8 were made to make it clear that applicant's system is measuring rather than simply monitoring pressure. The amendment to claim 4 was made to clarify what was meant by "below a surface."

Support for new claim 9 can be found at page 8, line 11; support for claim 10 can be found at page 8, lines 24-26; support for claims 11 and 12 can be found at page 8, lines 26-29; support for claim 13 can be found at page 11, lines 33-35; support for claim 14 can be found at page 13, lines 23-31; and support for claim 15 can be found in the original claims and at page 8, line 11.

Replacement sheets containing the amended claims are enclosed in accordance with PCT Article 19(1).

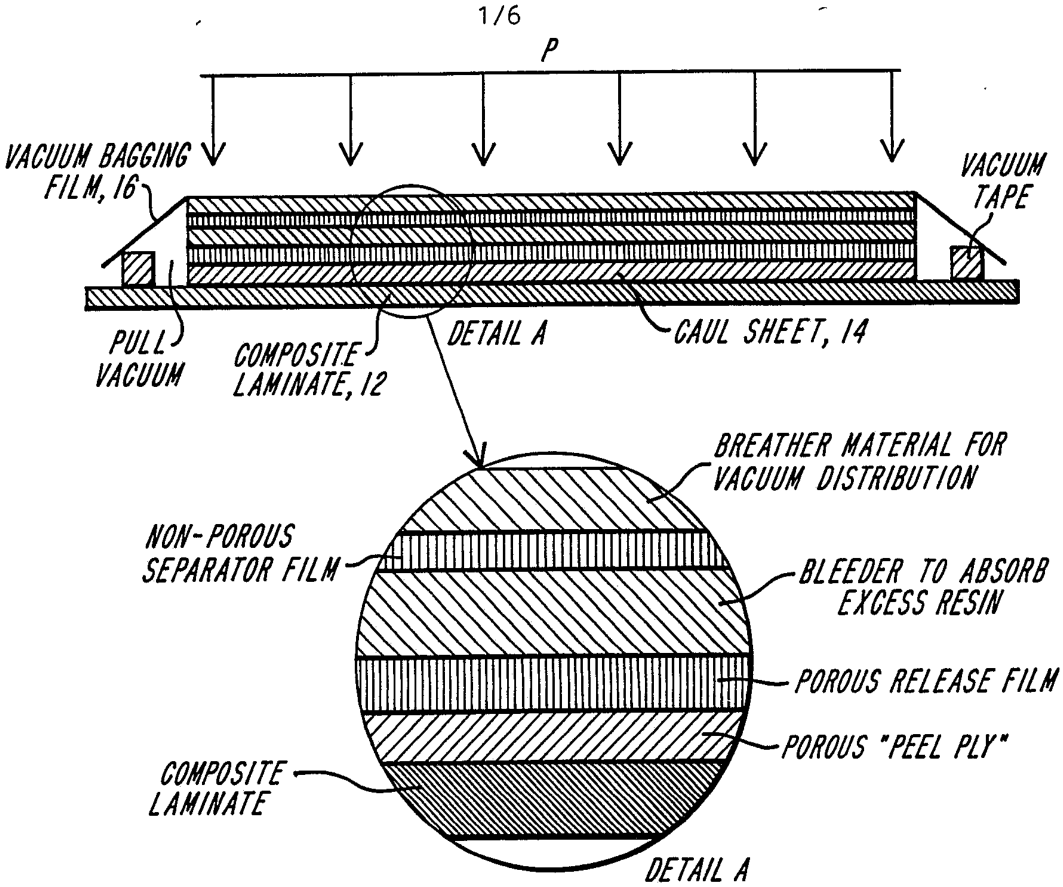

P
VACUUM BAGGING FILM, 16
VACUUM TAPE
PULL VACUUM
COMPOSITE LAMINATE, 12
DETAIL A
CAUL SHEET, 14
BREATHER MATERIAL FOR VACUUM DISTRIBUTION
NON-POROUS SEPARATOR FILM
BLEEDER TO ABSORB EXCESS RESIN
POROUS RELEASE FILM
POROUS "PEEL PLY"
COMPOSITE LAMINATE
DETAIL A

*FIG. 1*

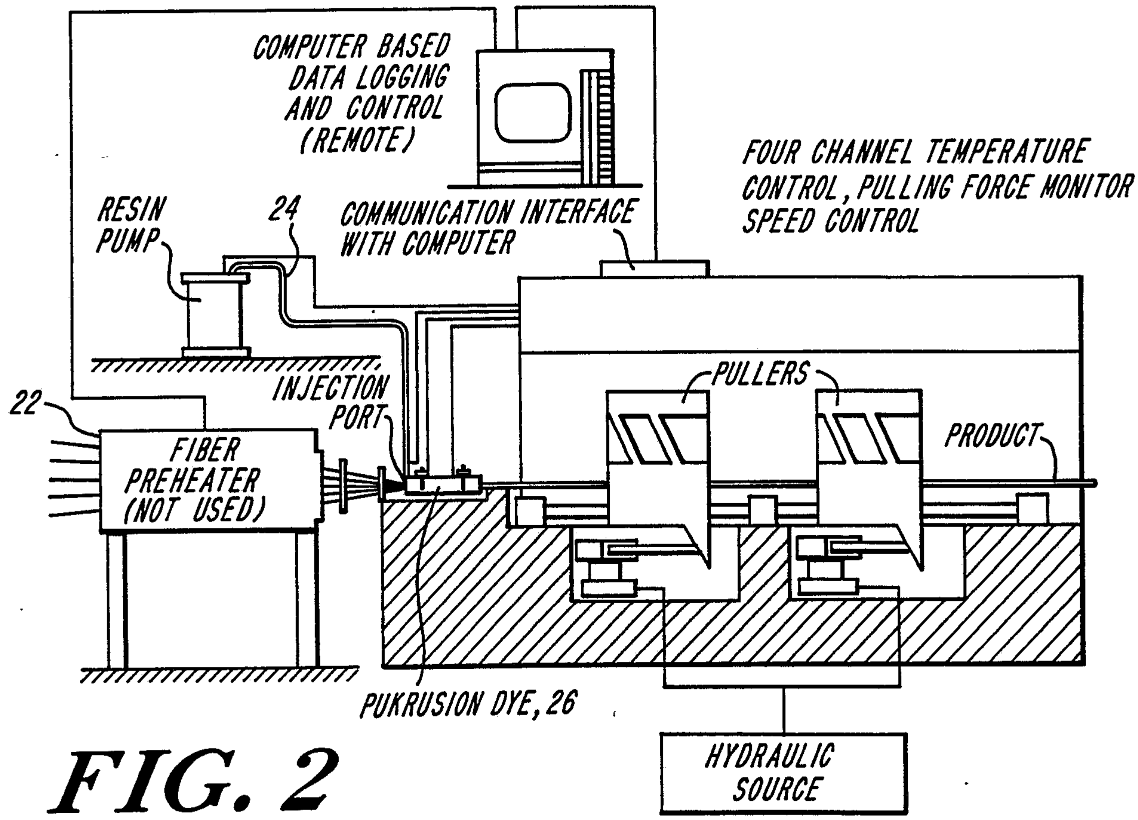

COMPUTER BASED DATA LOGGING AND CONTROL (REMOTE)
FOUR CHANNEL TEMPERATURE CONTROL, PULLING FORCE MONITOR SPEED CONTROL
RESIN PUMP
24
COMMUNICATION INTERFACE WITH COMPUTER
PULLERS
INJECTION PORT
22
FIBER PREHEATER (NOT USED)
PRODUCT
PUKRUSION DYE, 26
HYDRAULIC SOURCE

*FIG. 2*

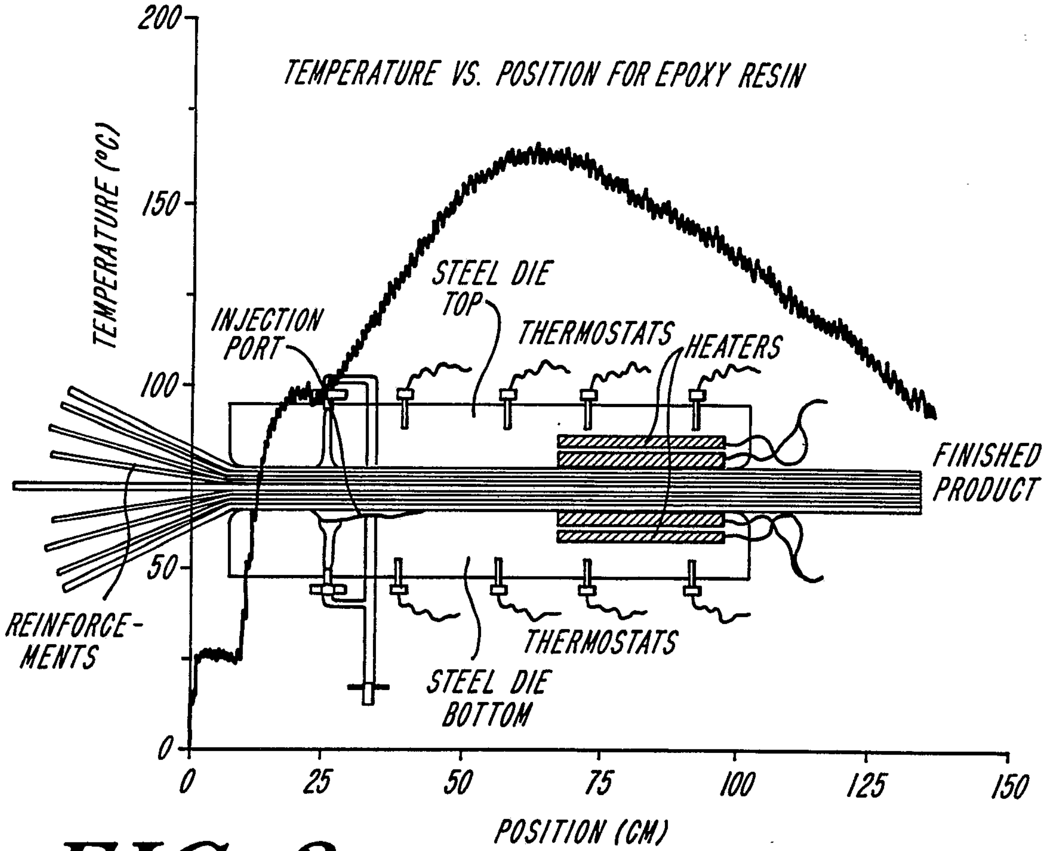

TEMPERATURE VS. POSITION FOR EPOXY RESIN
TEMPERATURE (°C)
200
150
100
50
0
POSITION (CM)
0
25
50
75
100
125
150
INJECTION PORT
STEEL DIE TOP
THERMOSTATS
HEATERS
FINISHED PRODUCT
REINFORCE-MENTS
THERMOSTATS
STEEL DIE BOTTOM

FIG. 3

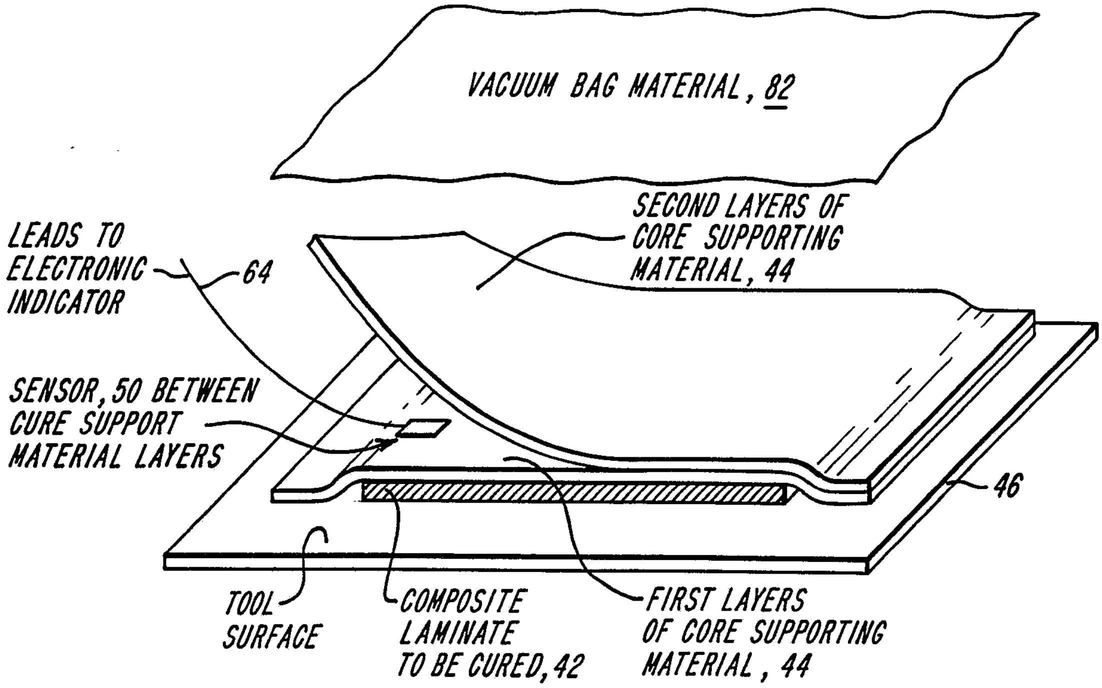

VACUUM BAG MATERIAL, 82
SECOND LAYERS OF CORE SUPPORTING MATERIAL, 44
LEADS TO ELECTRONIC INDICATOR
64
SENSOR, 50 BETWEEN CURE SUPPORT MATERIAL LAYERS
46
TOOL SURFACE
COMPOSITE LAMINATE TO BE CURED, 42
FIRST LAYERS OF CORE SUPPORTING MATERIAL, 44

FIG. 4A

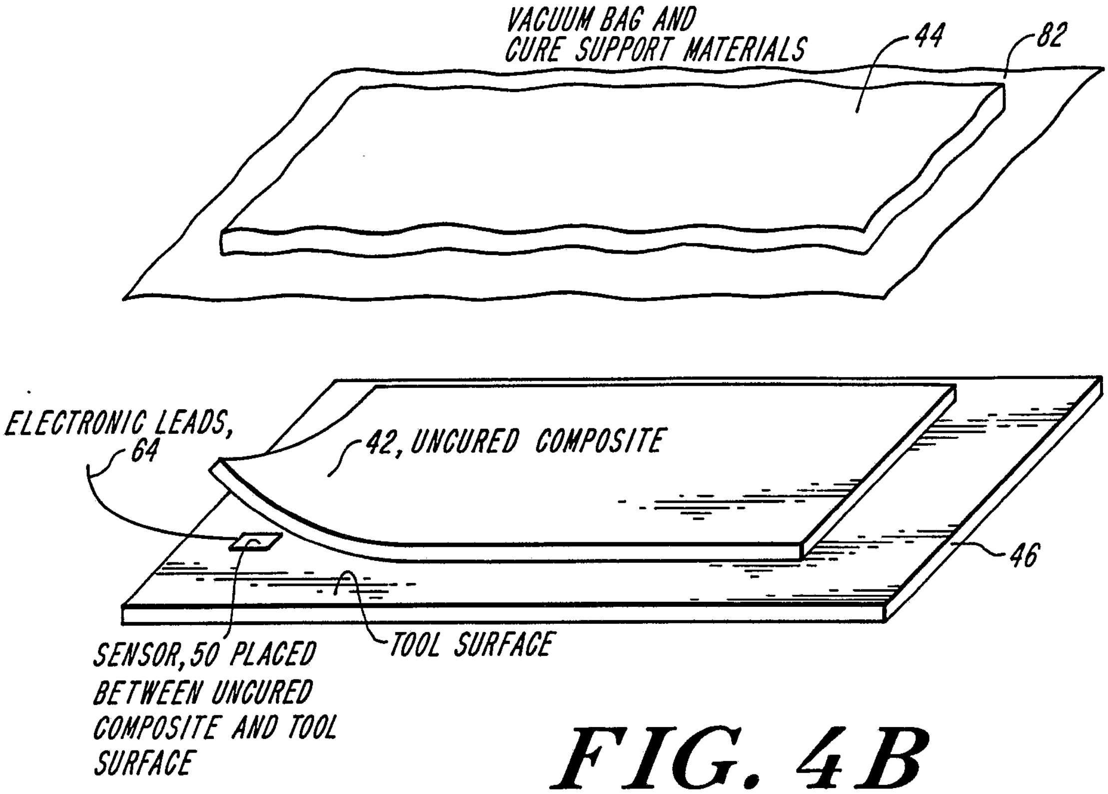

VACUUM BAG AND
CURE SUPPORT MATERIALS
44
82
ELECTRONIC LEADS,
64
42, UNCURED COMPOSITE
46
SENSOR, 50 PLACED
BETWEEN UNCURED
COMPOSITE AND TOOL
SURFACE
TOOL SURFACE

FIG. 4B

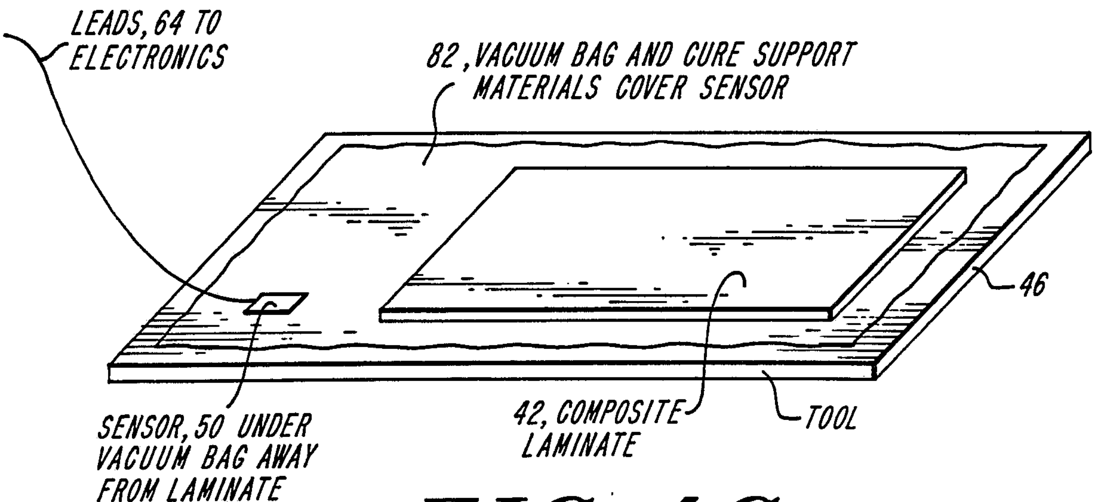

LEADS, 64 TO
ELECTRONICS
82, VACUUM BAG AND CURE SUPPORT
MATERIALS COVER SENSOR
46
SENSOR, 50 UNDER
VACUUM BAG AWAY
FROM LAMINATE
42, COMPOSITE
LAMINATE
TOOL

FIG. 4C

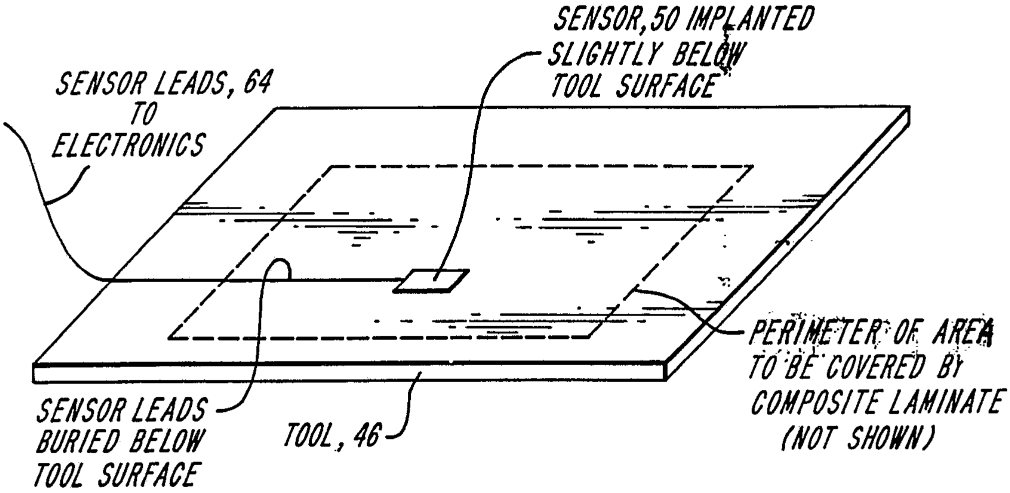

SENSOR,50 IMPLANTED
SLIGHTLY BELOW
TOOL SURFACE
SENSOR LEADS, 64
TO
ELECTRONICS
PERIMETER OF AREA
TO BE COVERED BY
COMPOSITE LAMINATE
(NOT SHOWN)
SENSOR LEADS
BURIED BELOW
TOOL SURFACE
TOOL, 46

FIG. 4D

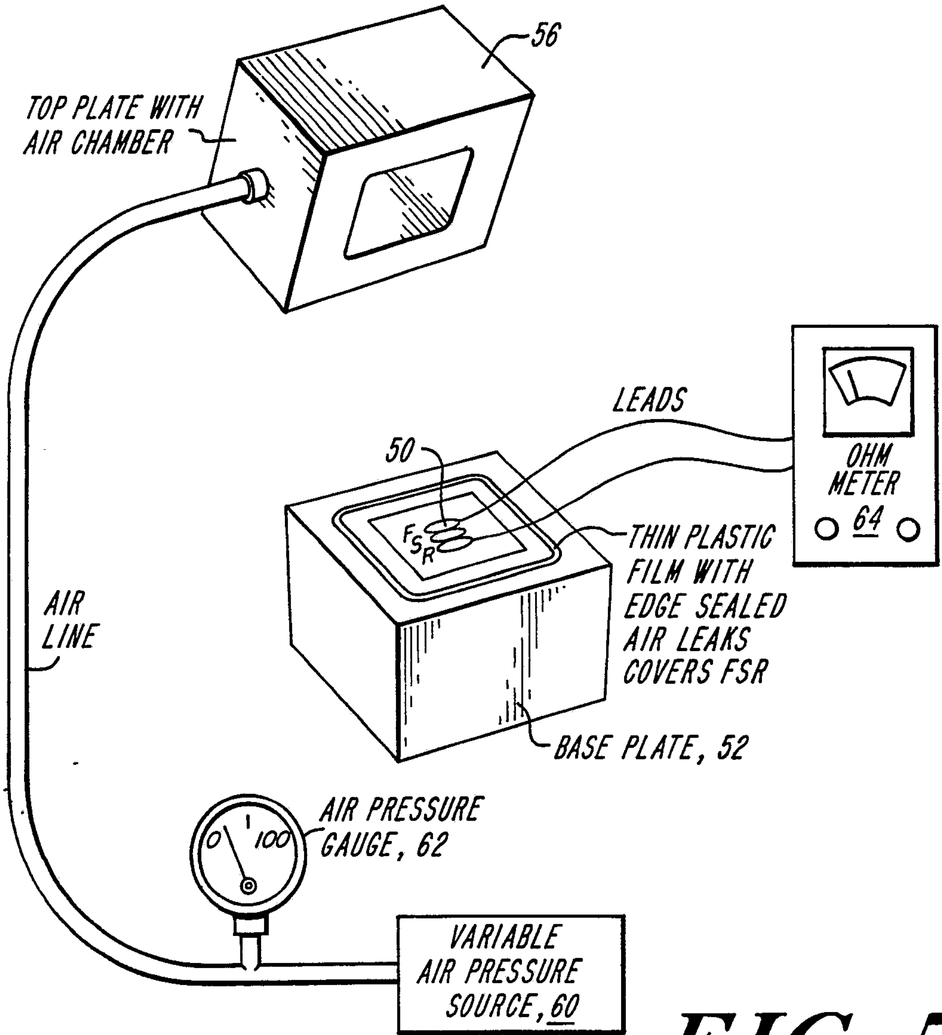

56
TOP PLATE WITH
AIR CHAMBER
LEADS
50
OHM
METER
64
FSR
THIN PLASTIC
FILM WITH
EDGE SEALED
AIR LEAKS
COVERS FSR
AIR
LINE
BASE PLATE, 52
AIR PRESSURE
GAUGE, 62
0
100
VARIABLE
AIR PRESSURE
SOURCE, 60

FIG. 5

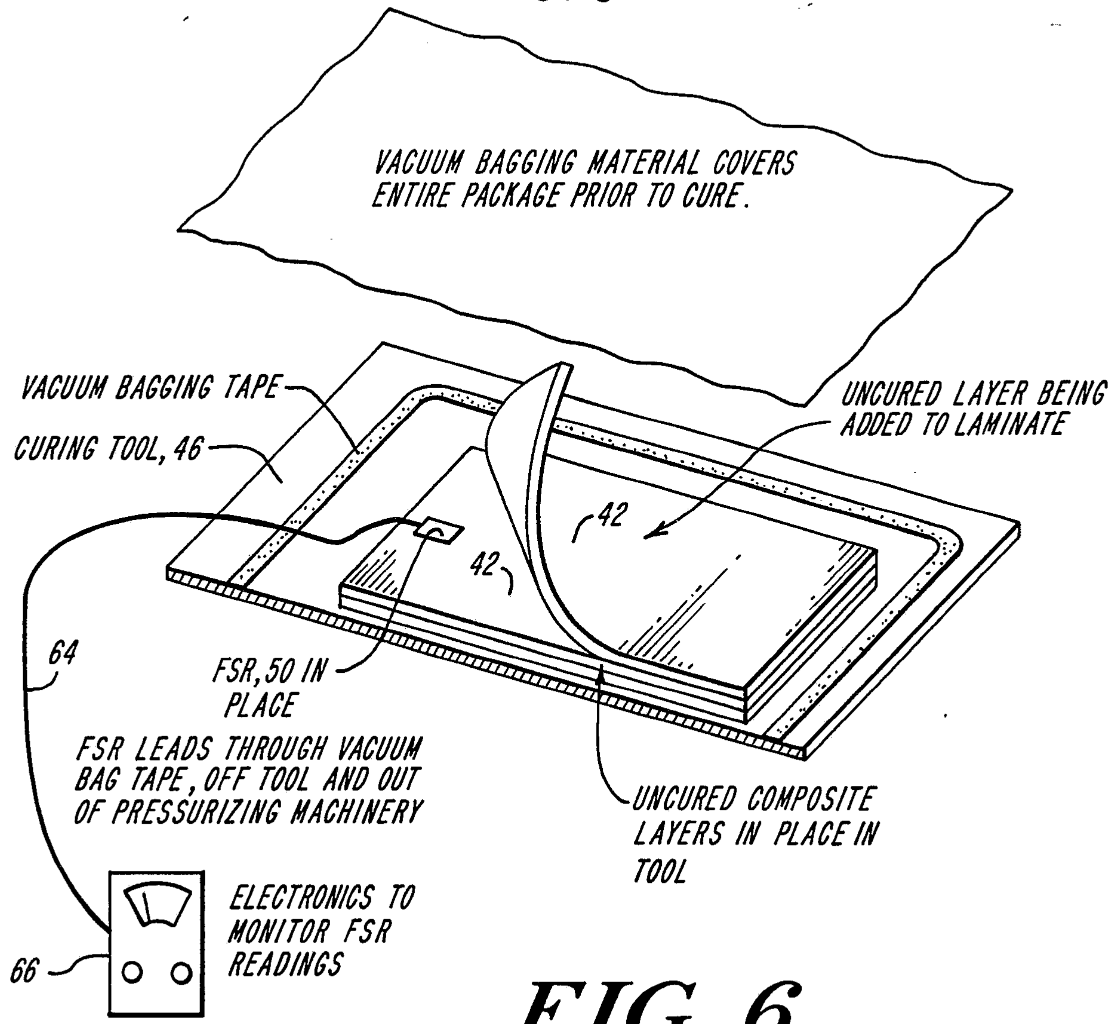

VACUUM BAGGING MATERIAL COVERS ENTIRE PACKAGE PRIOR TO CURE.
VACUUM BAGGING TAPE
CURING TOOL, 46
UNCURED LAYER BEING ADDED TO LAMINATE
42
42
64
FSR, 50 IN PLACE
FSR LEADS THROUGH VACUUM BAG TAPE, OFF TOOL AND OUT OF PRESSURIZING MACHINERY
UNCURED COMPOSITE LAYERS IN PLACE IN TOOL
66
ELECTRONICS TO MONITOR FSR READINGS

FIG. 6

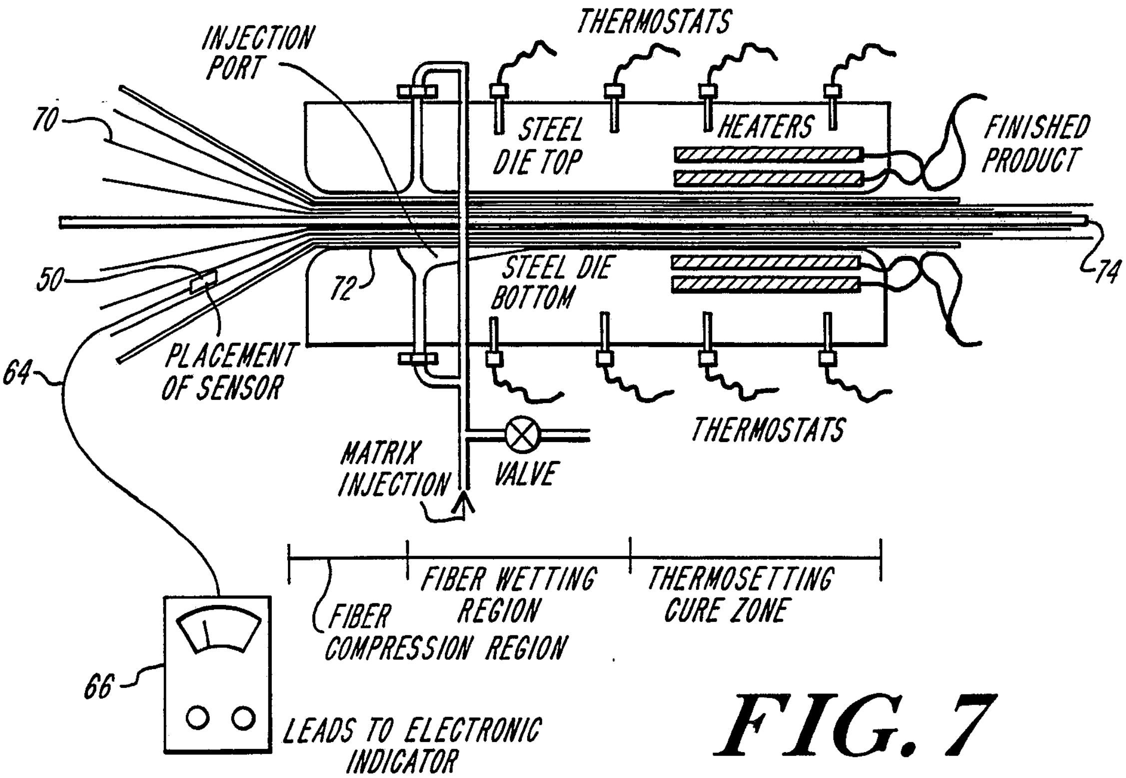

INJECTION PORT
THERMOSTATS
70
STEEL DIE TOP
HEATERS
FINISHED PRODUCT
50
72
STEEL DIE BOTTOM
74
64
PLACEMENT OF SENSOR
THERMOSTATS
MATRIX INJECTION
VALVE
FIBER WETTING REGION
THERMOSETTING CURE ZONE
FIBER COMPRESSION REGION
66
LEADS TO ELECTRONIC INDICATOR

FIG. 7

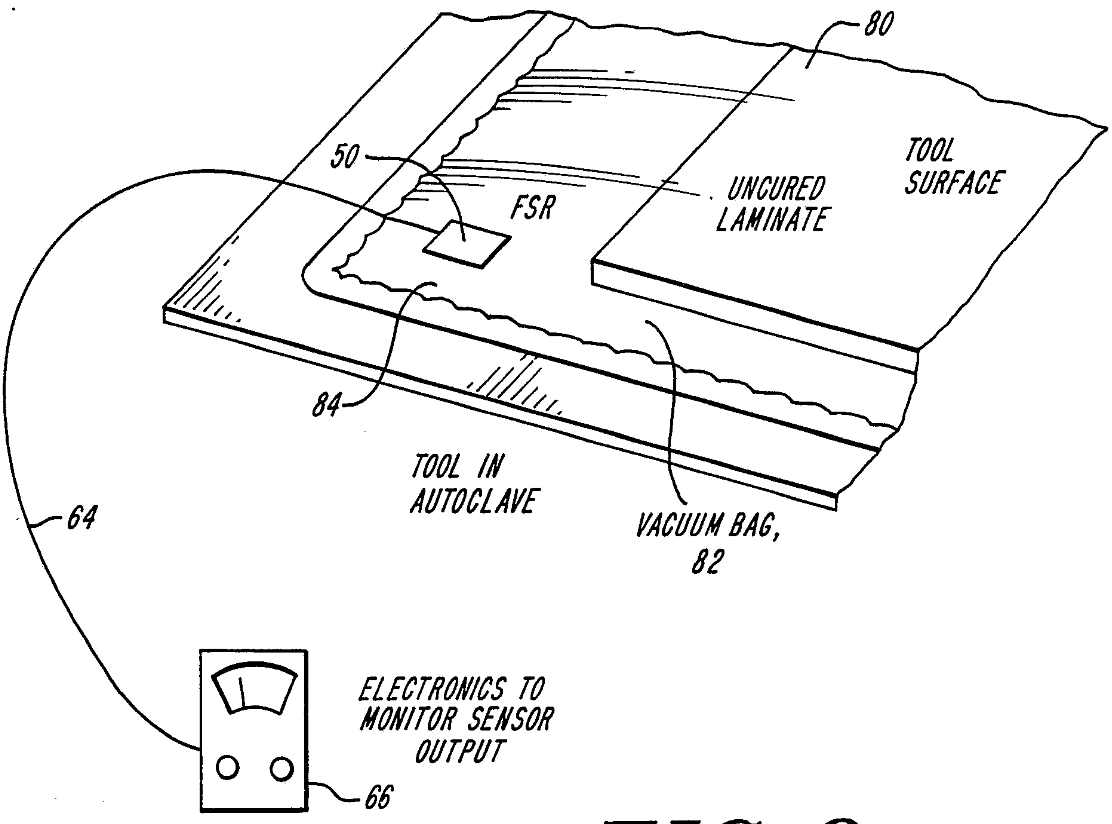

80
TOOL
SURFACE
50
FSR
UNCURED
LAMINATE
84
TOOL IN
AUTOCLAVE
VACUUM BAG,
82
64
ELECTRONICS TO
MONITOR SENSOR
OUTPUT
66

FIG. 8

# INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/02489

**I. CLASSIFICATION OF SUBJECT MATTER** (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (5): B32B 31/20

U.S. CL.: 156/358

**II. FIELDS SEARCHED**

Minimum Documentation Searched [4]

| Classification System | Classification Symbols |
|---|---|
| U.S. | 73/862.62, 862.63, 862.65; 425/149; 156/64, 358, 359 |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

**III. DOCUMENTS CONSIDERED TO BE RELEVANT** [14]

| Category * | Citation of Document, [16] with indication, where appropriate, of the relevant passages [17] | Relevant to Claim No. [18] |
|---|---|---|
| Y | US, A, 4,773,021, (HARRIS ET AL) 20 September 1988, See entire document. | 1,2,6,8 |
| Y | US, A, 4,502,857, (HINKS) 05 March 1985, See entire document. | 1,2,6,8 |
| Y | US, A, 4,140,050, (GIDDINGS) 20 February 1979, See entire document. | 3,5 |
| Y | US, A, 4,486,996, (ALEJOS) 11 December 1984, See entire document. | 3,5 |
| Y | US, A, 3,893,792, (LACZKO) 08 July 1975, See entire document. | 4 |
| Y | US, A, 3,925,139,(SIMMONS) 09 December 1975, See entire document. | 7 |
| A | US, A, 4,515,545,(HINRICHS ET AL) 07 May 1985, See entire document. | 1-8 |
| A | US, A, 4,367,115 (BOHN ET AL) 04 January 1983 Seeentire document. | 1-8 |

* Special categories of cited documents: [15]

"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 to 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 [2] | Date of Mailing of this International Search Report [2] |
|---|---|
| 25 JULY 1990 | 16 AUG 1990 |
| **International Searching Authority** [1] | **Signature of Authorized Officer** [20] |
| ISA/US | Nguyen Ngoc Ho for JAMES J. ENGEL NGUYEN NGOC-HO INTERNATIONAL DIVISION |

Form PCT/ISA/210 (second sheet) (May 1986)