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US 5756179 A **US 5632837 A**
US 4300321 A **US 4289465 A**

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(72) Inventor(s):
Andrew Paul Dixon

(73) Proprietor(s):
Magna Parva
2 Meridian South, Meridian Business Park,
LEICESTER, Leicestershire, LE19 1WY,
United Kingdom

(74) Agent and/or Address for Service:
Magna Parva
2 Meridian South, Meridian Business Park,
LEICESTER, Leicestershire, LE19 1WY,
United Kingdom

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Figures

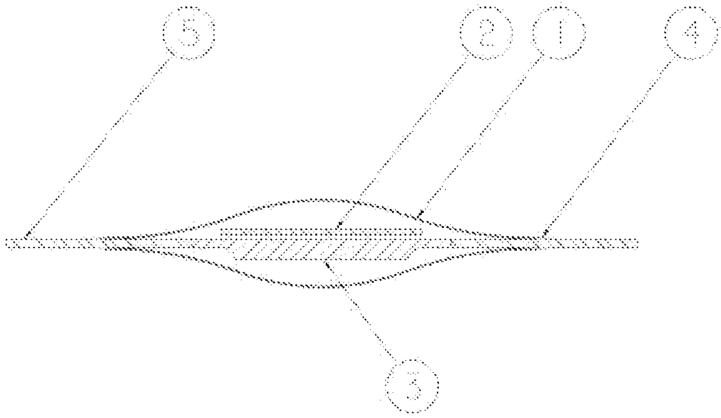

Fig. 1

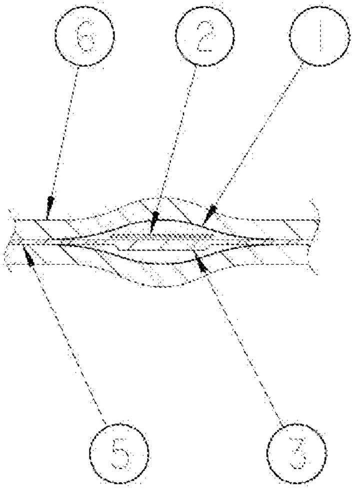

Fig. 2

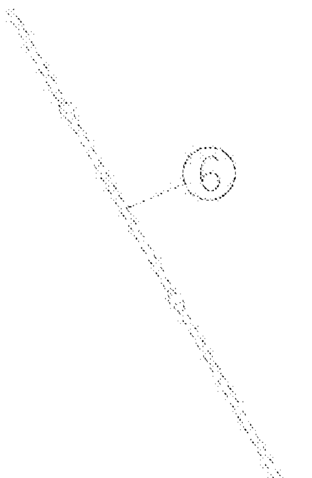

Fig. 3

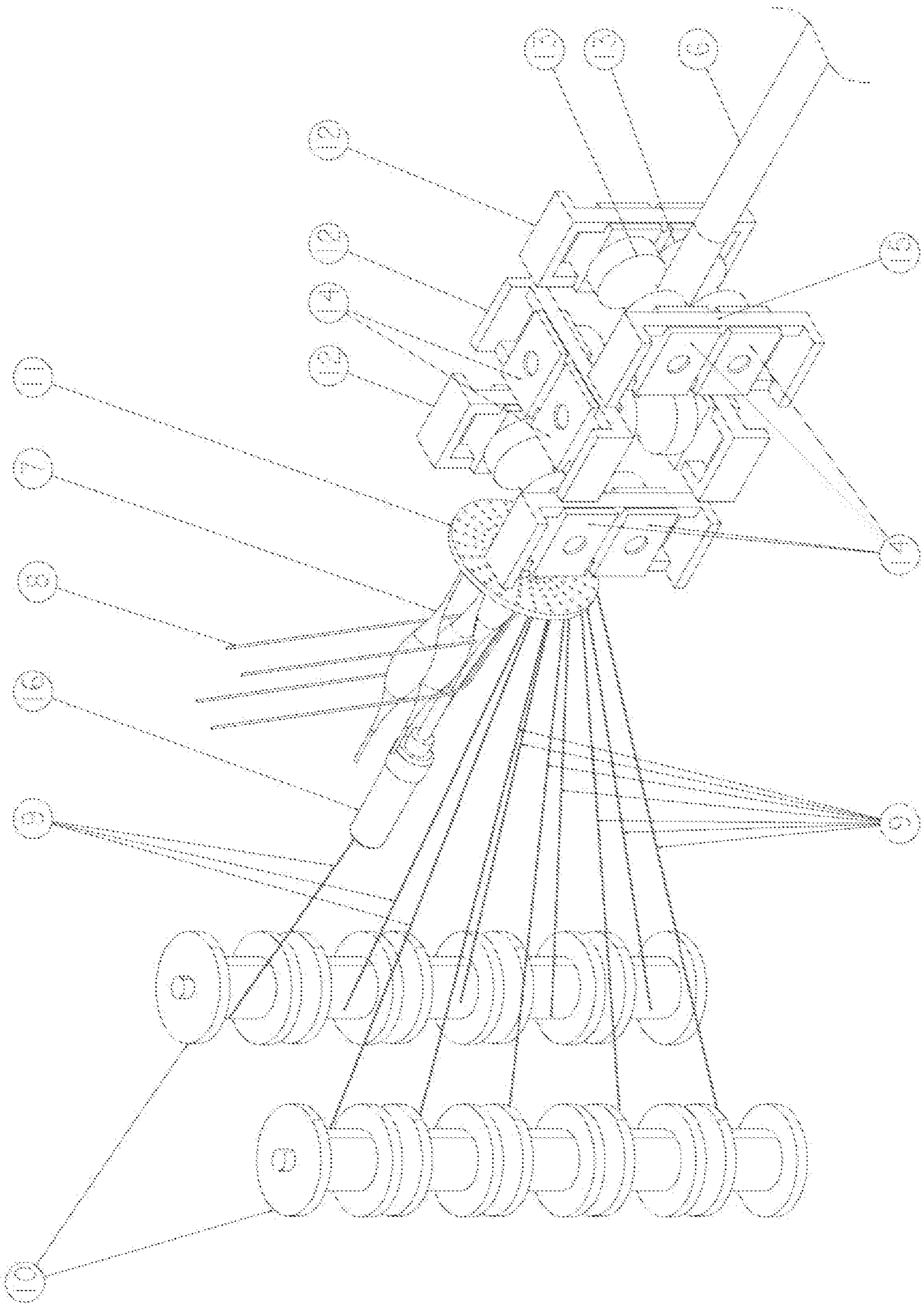

Fig. 4

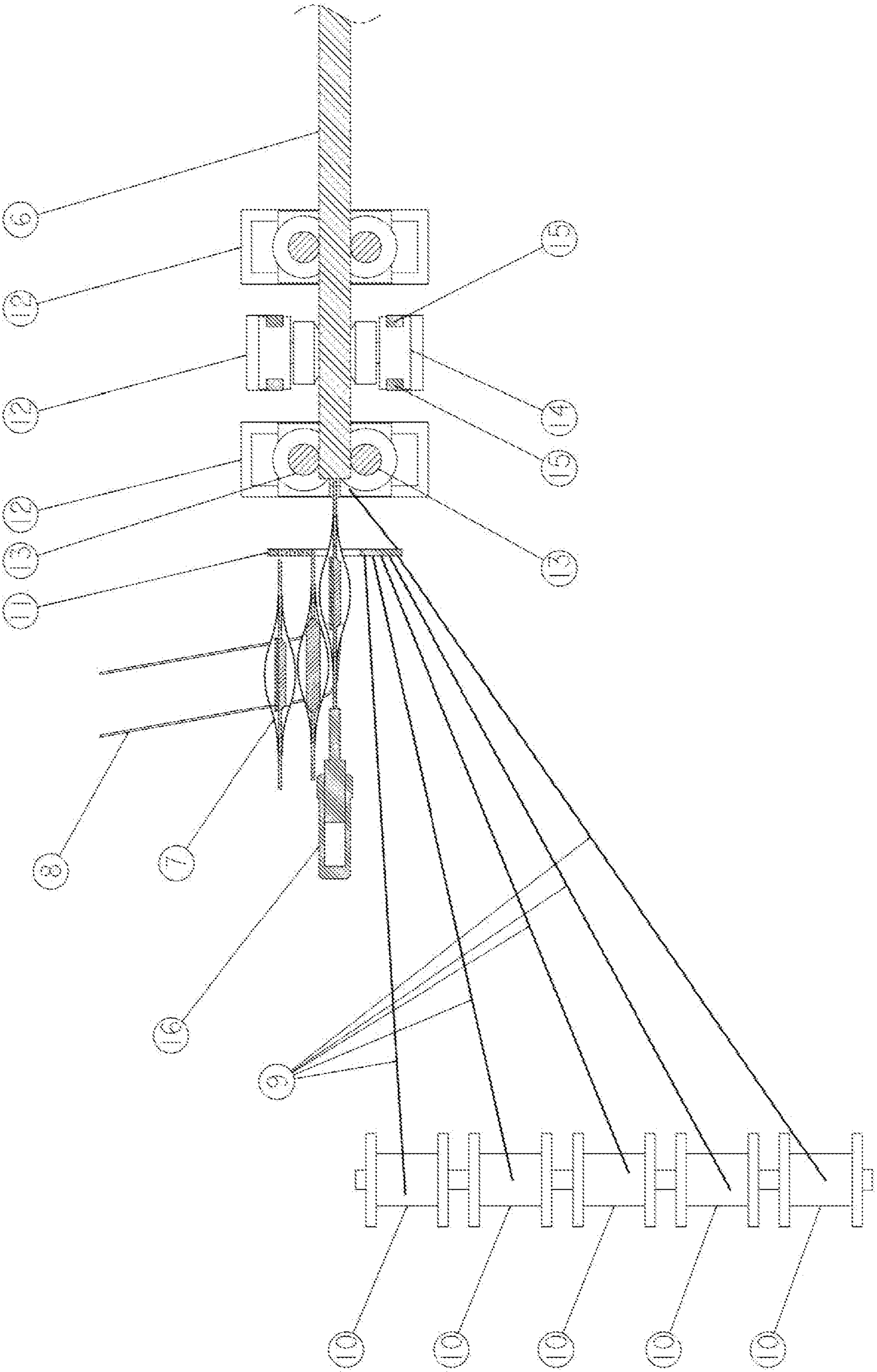

Fig. 5

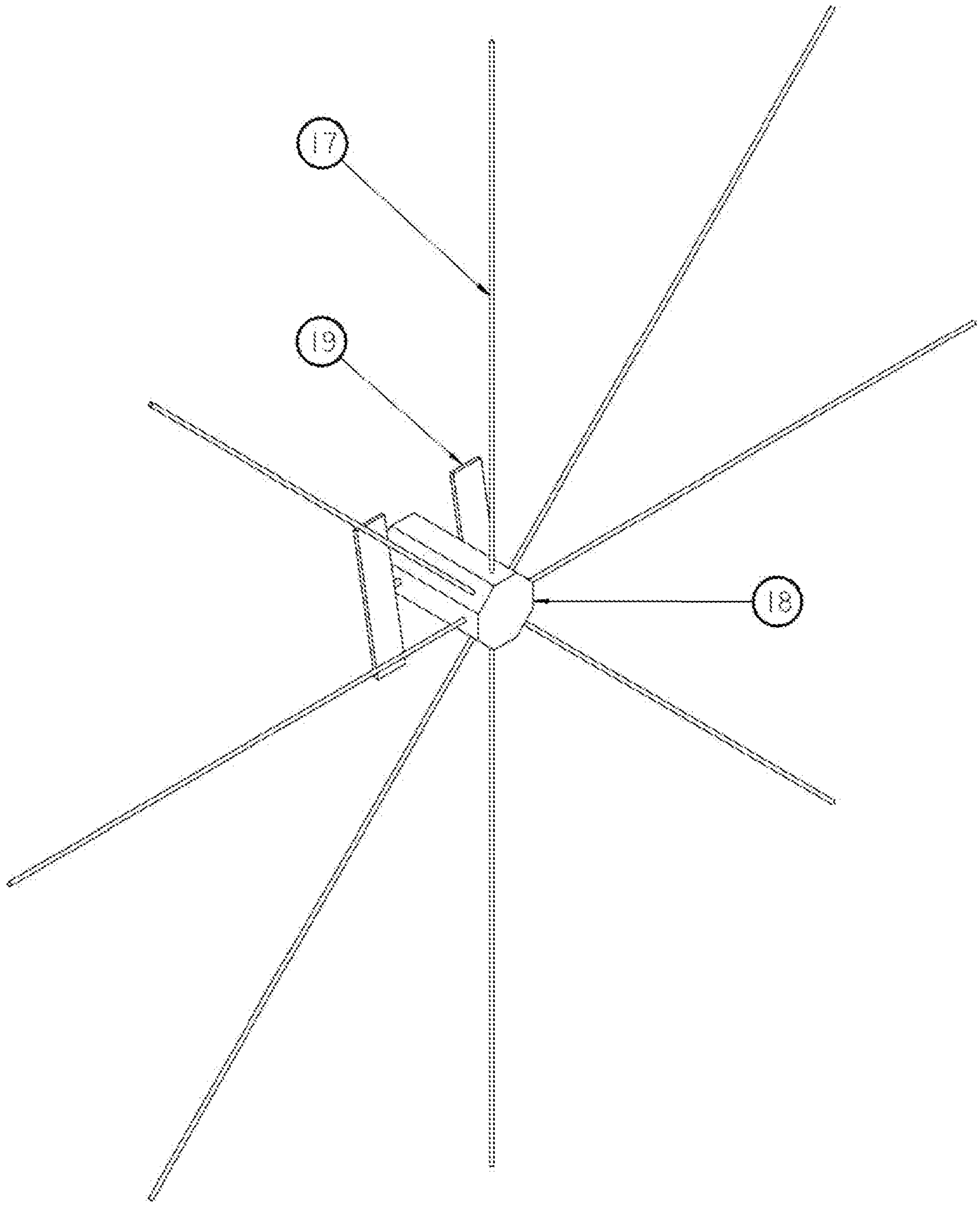

Fig. 6

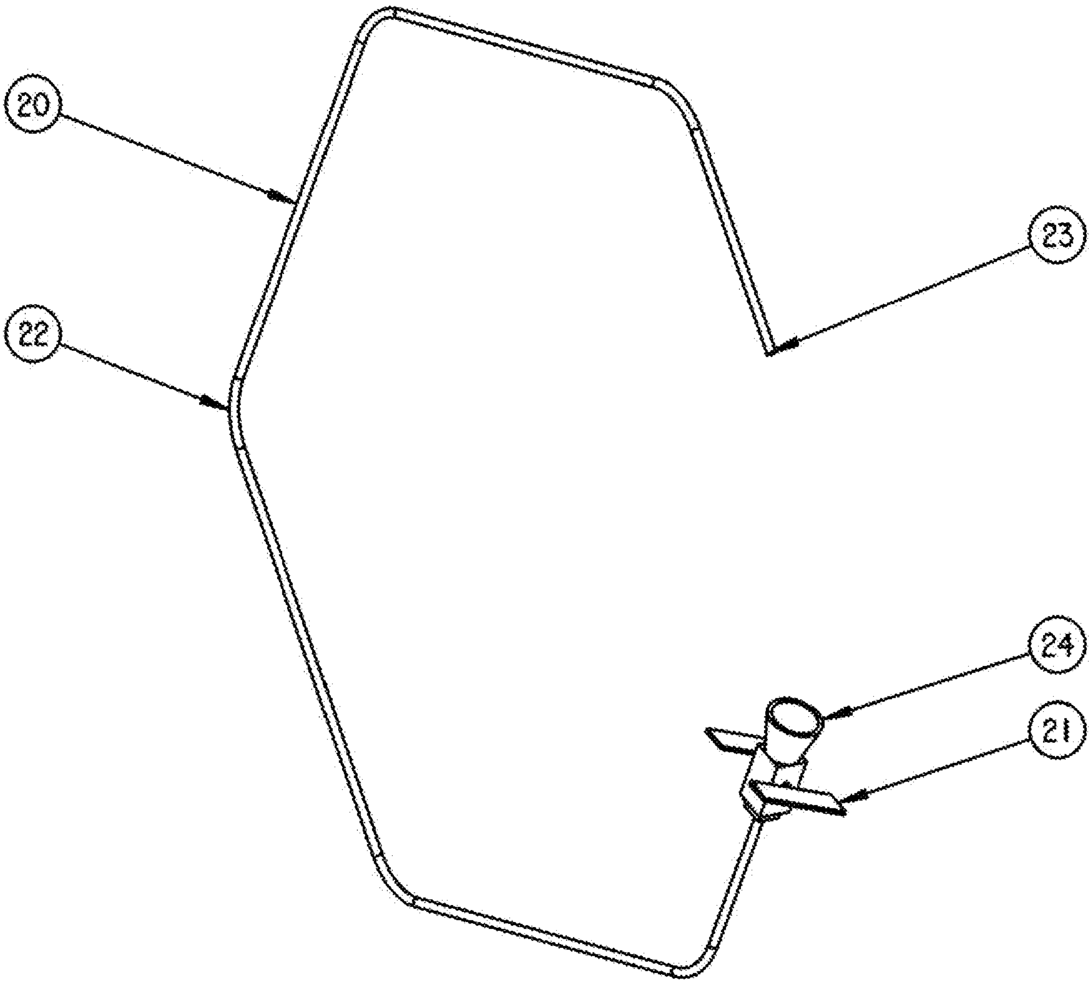

Fig. 7

Title – Roller Pultrusion of Intelligent Composite Structures

Field of Invention

The present invention relates to a method for the co-pultrusion of systems, devices and any other such objects into continuously-manufactured intelligent composite structures. The invention has particular application in the fields of composite manufacturing for aerospace applications, but may find other applications in processes where an object must be incorporated into a composite structure during layup.

Prior Art

Sensors and means of continuous production of composites are described in patent literature. Representative patents include world pat. appl. No WO 2009/069081 and U.S. Pat. 6,420,696.

In current practice, the inclusion of sensing and actuation elements into a composite structural element such as a beam or panel is performed by fastening the actuator by adhesive or mechanical means. Sensing elements may be attached to the exterior of a cured structure by adhesive bonding, or may be included in the layup during manufacture of the structure. Actuation methods currently known to the art include the use of piezoelectric or shape-memory metal actuators which may be bonded to a thin-walled composite structure. Other active components such as patch antennae may be incorporated by co-curing; however all of the aforementioned methods suffer from being reliant on hand-layup techniques and cannot incorporate larger items.

World Pat. No. WO 2009069081 discloses a method for the forming of profiled materials by means of rotating formers or dies. A puller is included in this invention such that the material in question may be guided accurately through the formers. Thus the prior art allows the use of a rotating former in the production of profile sections.

U.S. Pat. 6,420,696 discloses a method for incorporating a fibre-optic sensing element within a unidirectional layup of carbon fibre tows. The method allows for the orientation of the sensor to be predetermined such that the measurement of a given property may be resolved with respect to direction. This is accomplished by bonding a tag onto the sensing element, which allows for the orientation of the sensor with respect to that of the fibres local to it to be assured. Therefore the prior art shows that sensors may be incorporated into composite structures at the time of layup.

U.S. Pat. Appl. 2009/0071593 discloses a method for the pultrusion of composite components whereby the matrix element of the composite is a polyurethane resin. The method employs a pumping means to force the liquid resin into a die, whereupon the matrix and reinforcing fibres are consolidated under the pressure of the die and caused to polymerise by the elevated die temperature. Thus the prior art allows the pultrusion of composite materials that employ die injected matrices.

U.S. Pat. 0126860 discloses a method for forming composite structures by means of a pultrusion method, in which the feed material is a glass or carbon fibre fabric that is pre-impregnated with thermosetting resin. This is accomplished by co-pultruding a liner material possessing a low coefficient of friction, with the composite layup, this overcoming the problem of the composite material sticking in the forming die. Thus the prior art allows the forming of composite structural elements from pre-impregnated material by means of the pultrusion process.

Statement of the Invention

The invention provides a system whereby the aforesaid processes may be enacted in a continuous process without the need for post-cure operations such as adhesive bonding, drilling, bolting or the like. Furthermore it allows for the embedding of subsystems containing active components such as actuators, power supplies, radio transmitters and similar devices. The embedment of such devices is advantageous as it allows for the manufacture of large active structures such as phased and synthetic radar antennae, towed sonar arrays, communications and surveillance systems and optical interferometry systems. However the invention will find application in any situation whereby it is required to manufacture pultruded structures with co-cured or embedded items.

The invention comprises pultrusion means as defined in claims 1-22 and in-situ pultrusion as defined in claim 23.

In a preferred form, the invention may comprise a roller pultrusion system comprising a number of opposed sets of roller dies acting on a pre-impregnated layup of composite materials. The uncured layup is formed by having a number of reels or creels as they are commonly known to the art, upon which the individual tows of fibre are stored. The fibre tows are brought together by means of a series of guide plates, rollers and other means well known to those of moderate skill in the art, and arranged such that the desired configuration of reinforcements are fed into the curing dies. The matrix material which may be a thermosetting polymer, a thermoplastic polymer, a metal, a ceramic or any other such material can be either applied to the fibres prior to their entering the dies, or may be introduced into the die cavities under pressure. If the latter means is employed, then suitable feed methods and means of removing the excess matrix shall be provided such that the excess does not foul the rotating dies.

A magazine or supply of modules is disposed such that the modules, which contain actuators, sensing elements or other devices, may be inserted into the layup at will prior to it entering the die. The roller dies being mounted on a movable structure such that the die opening or aperture may be regulated in order to admit the module, whilst maintaining the correct pressure to achieve a satisfactory state of cure. This method has the advantage that a structure containing all features required in the finished product may be produced continuously, with a minimum of finishing operations required.

Preferably, in order that the system be as reliable as is possible, and to prevent resin-rich inclusions in the cured part, the modules should incorporate tapering features with a surface finish that will promote adhesion of the pre-impregnate matrix. In order to provide a communication between individual modules, they may be linked together with an electrical or fibre-optic cable, optical or radio-frequency waveguides or acoustic waveguides which are introduced into the composite layup in the same way as the reinforcing tows.

According to a further, exemplary formulation of the invention, the modules contain actuating means. Said means may be a piezoelectric element, shape memory alloy, a hydraulic ram or any other type of actuation means. The actuator is disposed within the module such that the length of the module is thereby alterable. The ends of the module are terminated in a tow of the reinforcing fibre, which is consolidated into the composite structure along with the normal reinforcements. This method has the advantage that an actuator is placed within a structure, allowing for the curvature of a beam, for example to be continuously variable. This allows oscillations in a large structure to be damped actively or for a variable preload to be applied to load-bearing members. In order to provide a source of actuator power to individual modules, they may be linked together with an electrical cable, or a pipe to allow the conveyance of fluids such as hydraulic oil or compressed gas which are introduced into the composite layup in the same way as the reinforcing tows.

According to another, exemplary embodiment of the invention, the modules contain hydrophones of the type employed in SONAR equipment. In this way a long array of hydrophones may be manufactured and deployed from a moving vessel to aid in activities such as undersea exploration, geophysical surveying and the detection of submarines. This is advantageous because the towed array can be considered as disposable, allowing the captain of the towing ship to jettison the array in case of an emergency, or to repair a damaged array by merely pultruding further sections. Furthermore, shipping costs will be reduced in comparison to that required for a pre-manufactured array as only the modules need to be delivered; the composite materials may be sourced from a vessels home shipyard.

Brief Description of the Drawings

Exemplary embodiments of the invention will now be described in greater detail with reference to the drawings;

Fig. 1 is a simplified section view of a transmitter module intended for consolidation within a composite boom;

Fig. 2 is a simplified section view of part of a pultruded composite beam showing a transmitter module embedded within the beam;

Fig. 3 is a simplified iso-metric view showing a pultruded composite beam incorporating a number of transmitter modules along its length;

Fig. 4 is a simplified iso-metric view showing a roller die pultrusion mechanism with variable die geometry for consolidating a module into a pultruded composite section. For clarity a number of the rovings are not shown;

Fig. 5 is a simplified section view showing a pultrusion system, including reinforcement rovings and a consolidated member. For clarity a number of the rovings are not shown;

Fig. 6 is a simplified isometric view of a large-aperture phased array antenna constructed from transmitter modules and booms.

Fig. 7 is a simplified isometric view of a structural element constructed from a continuously-pultruded section.

Specific Description

Fig. 1 shows a transmitter module for consolidation into a round section of composite material. The shell **(1)** contains an antenna **(2)** and electronics package **(3)**. A cable **(5)** connects the transmitter module to the preceding and following identical modules in the assembly. Said cable **(5)** is sealed to the body **(1)** of the transmitter by means of cable glands **(4)**. In this embodiment the modules contain all systems required to form an element of a phased antenna array of considerable aperture size that may be deployed from a space vehicle as part of a communications network. By employing a phase-steering method, the pultruded structure may be made to a very low mass as it does not have to mechanically point the antenna array at the intended receiver.

The embedded transmitter module is shown in **Fig. 2**. The pultruded boom **(6)** envelopes the transmitter body **(1)** and cable **(5)**, without voids or resin-rich inclusions, whilst the electronics package **(3)** and antenna **(2)** are protected from resin ingress by the cable glands **(4)** and transmitter body **(1)**.

Fig. 3 shows a composite boom antenna system manufactured according to an exemplary embodiment of the invention. The Boom **(6)** has incorporated into its structure a number of individual transmitters as shown in **Fig. 2**. The distribution of the aforementioned transmitters may be at evenly spaced intervals along the length of the boom, or it may be in any pattern as may be desired. This has the advantage of allowing the radiation pattern of the boom **(6)** as a whole to be tailored for a specific application to, for example, eliminate dead spots or reduce power lost to the antenna side-lobes.

Fig. 4 and **Fig. 5** depict a system for manufacturing structures of the type described in **Figs. 1, 2** and **3**. Transponder modules **(7)** are stored and aligned in a magazine rack **(8).** The beam **(6)** is formed by continuous tows or rovings of reinforcement fibres **(9)**, which are pre-impregnated with a matrix material and stored on creels **(10)**. The rovings **(9)** pass through an aligning plate **(11)**, prior to entry into the presses **(12)**. Said presses employ dies **(13)** which are in the form of rollers shaped in the profile of the required beam. The roller dies **(13)** are mounted in bearings **(14)** which incorporate a rotating means such as electric motors, hydraulic motors or some other source of rotary motion. Said bearings **(14)** are mounted in slide-ways **(15)** such that they may be moved apart to allow passage of the modules through the system. At predefined intervals transponder modules **(7)** are introduced into the layup of rovings **(9)**, by a pushing means **(16)**, which may be a pneumatic ram, or another form of linear actuator. The Module **(7)** is thereby pushed through an aperture in the aligning plate **(13)** into the opening between the first set of roller dies **(13)**. The first set of dies is provided with an actuation means, which provides a constant compressive force between the two dies **(13)**. The body of the transponder module **(7)** forces the dies apart, and the force supplied by the dies causes the reinforcements to bond to the body of the module **(7)**. Alternatively, the slideable bearings **(14)** may be driven by automatic means, such that the rollers follow the profile of the now embedded sensor.

Further sets of roller dies **(13)** serve to consolidate and cure the composite structure and are provided with a heating means to achieve this purpose. The dies **(13)** also provide the tractive force required to pull the rovings **(9)** from their respective creels **(10)** because at least one set of roller dies **(13)** is in contact with the pultruded beam **(6)** at all times, and ensure the straightness of the finished pultrudate beam **(6)**, the respective presses **(12)** being arranged such that their axes of force act in a number of directions, assuring full consolidation of the beam **(6)**. When the structure is completed to the required length, a termination is applied manually, or by some automated means and the structure is either placed into service directly or reeled onto a storage spool.

Fig. 6 depicts a satellite antenna array manufactured according to the invention. Booms **(17)** incorporating a number of transmitter modules **(7)** are pultruded from the spacecraft **(18)** following its insertion into the desired orbit. The spacecraft **(18)** provides power from solar panels **(19)** and control signals to each of the transmitter modules **(7)** via cables consolidated into the booms **(17)**.

Fig. 7 depicts a large structural member manufactured in space according to the invention. A continuous boom **(20)** is pultruded from the manufacturing unit **(21)**. Corners **(22)** are formed without breaking the pultrusion; instead the rotation rates of the press dies and the angles between them are altered by automatic means to generate curved sections. When the manufacturing unit **(21)** comes to join the ends of the structure together, a grapple captures the free end **(23)** of the boom **(20)** and draws it into a socket **(24)** where jointing operations are carried out. In this case the modules implanted into the structure contain sensor packages for monitoring the condition of the structure, actuators for damping vibrations and communications infrastructure.

The above description of the preferred embodiment has been given by way of an example. From the disclosures given, those skilled in the art will understand the invention and its advantages, and will also find apparent changes and modifications to the structures and processes disclosed. It is sought therefore to cover all such changes that lie within the scope of the invention, as defined in the appended claims and equivalents thereof.

Claims

1. Pultrusion means comprising;

    a. A supply of unconsolidated composite material;

    b. A supply of elements or modules which may be co-consolidated with the composite material;

    c. A series of fibre guides;

    d. A number of opposed sets of articulated roller dies;

    e. A means of structure termination.

2. The pultrusion means of claim 1 wherein the unconsolidated material is pre-impregnated with a matrix material.

3. The pultrusion means of claim 1 wherein the unconsolidated material is infused with a matrix material immediately prior to use.

4. The pultrusion means of claims 2 and 3 wherein the co-consolidated elements incorporate adhesion-promoting surface features.

5. The pultrusion means of claims 2 and 3 wherein the co-consolidated elements incorporate composite ligaments which are also consolidated into the composite structure to promote the transfer of forces between the embedded element and the composite structure.

6. The pultrusion means of claims 2 and 3 wherein an electrical cable passes between the co-consolidated elements.

7. The pultrusion means of claims 2 and 3 wherein an optical fibre passes between the co-consolidated elements.

8. The pultrusion means of claims 2 and 3 wherein a pipe for the conveyance of fluids passes between the co-consolidated elements.

9. The pultrusion means of claims 2 and 3 wherein an RF waveguide passes between the co-consolidated elements.

10. The pultrusion means of claims 2 and 3 wherein an acoustic waveguide passes between the co-consolidated elements.

11. The pultrusion means of claims 2 and 3 wherein mechanical control cables, ligaments or rods pass between the co-consolidated elements.

12. The pultrusion means of the above claims wherein the fibre guiding elements are arranged so as to allow the placement of the optional elements within the composite lay-up.

13. The pultrusion means of the above claims wherein the fibre guiding elements are arranged so as to allow the placement of the optional elements at the surface of the composite lay-up.

14. The pultrusion means of the above claims wherein the fibre guiding elements are articulated so as to allow a transient composite lay-up during the pultrusion process.

15. The pultrusion means of the above claims wherein the roller dies may be temperature controlled to effect curing of the matrix.

16. The pultrusion means of the above claims wherein the roller dies are articulated so as to allow non-constant cross section items to be produced.

17. The pultrusion means of the above claims wherein the arrangement of the roller dies may be articulated to produce curved beams.

18. The pultrusion means of the above claims wherein the roller dies incorporate traction-promoting surfaces.

19. The pultrusion means of the above claims wherein the roller die assembly incorporates sensing elements to allow the correct pressure and temperature to be applied to the pultruded composite.

20. The pultrusion means of the above claims wherein the means of structure termination comprises one of the co-consolidated elements, which has features that protrude from the composite layup to allow for example, a bolted joint to be made.

21. The pultrusion means of the above claims wherein the means of structure termination comprises adhesively bonding the pultruded layup to the roller dies, such that the pultruded structure is permanently anchored to the pultrusion means.

22. The pultrusion means of the above claims wherein the means of structure termination comprises automatic manipulation of the layup and roller dies to form, for example, a socket or lug at the end of the pultruded member.

23. Producing a cured composite structure in situ at its point of use by pultruding the structure using pultrusion means as defined in any of the above claims.