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(54) **A DEPLOYABLE TENSEGRITY STRUCTURE, ESPECIALLY FOR SPACE APPLICATIONS**

EINSETZBARE TENSEGRITY-STRUKTUR, INSBESONDERE FÜR WELTRAUMANWENDUNGEN

STRUCTURE DE TENSÉGRITÉ DÉPLOYABLE, SPÉCIALEMENT DESTINÉE AUX APPLICATIONS SPATIALES

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## Description

**[0001]** The invention relates to a structure which is deployable from a folded state to a deployed state.

**[0002]** The invention more particularly relates to a deployable tensegrity structure.

**[0003]** Tensegrity is a structural principle based on the use of isolated components, such as rigid bars or struts (in compression), linked together by a continuous net of cables or tendons (in tension), in such a way that the rigid bars or struts do not touch each other.

**[0004]** The distribution of compression and tension forces within the structure is such that a tensegrity structure takes and maintains its shape without any direct contact or joint between the different rigid bars or struts.

**[0005]** Tensegrity structures may be deployable or not according to the technical field to which they pertain.

**[0006]** In the space industry, a deployable reflector with a tensegrity support has already been proposed in US 6,542,132.

**[0007]** An advantage to use a tensegrity structure for such a deployable reflector is to diminish the risk of failure of the deployment. Indeed, in non-tensegrity structures, the joints between two rigid bars or struts raise the failure risks.

**[0008]** However, the quoted document proposes a prismatic structure wherein rigid bars extend from the periphery towards the centre.

**[0009]** Consequently, the rigid bars are quite long and, in practice, can hardly be stowed within the envelope of typical space launchers, even in the case of small scale structures.

**[0010]** Moreover, since the proposed prismatic structure is not symmetric with respect to any plane, perpendicular to the longitudinal axis of the structure, the stability of the structure in orbit is not optimal.

**[0011]** To the applicant's knowledge, this structure has not been used to date.

**[0012]** Former deployable structures do not present the drawbacks of the tensegrity structure proposed in US 6,542,132.

**[0013]** In facts, these former deployable structures can be stowed within the envelope of typical space launchers and are also stable in orbit.

**[0014]** Such a deployable structure is proposed in US 5,680,145. It is well-known to the experts in the field under the name *"Astromesh"*.

**[0015]** The *"Astromesh"* is composed of a ring-shaped support structure around a longitudinal axis which includes a series of upper rigid contour elements and lower contour elements which, when connected end-to-end, form an upper contour and a lower contour, kept separated by a number of vertical rigid struts.

**[0016]** This support structure allows obtaining a deployable structure which is substantially symmetric with respect to a transversal plane, perpendicular to the longitudinal axis (axis of symmetry) of the support structure itself. A good stability in orbit may thus be obtained.

**[0017]** However, the *"Astromesh"* structure is not a tensegrity structure, as the contour elements in the upper and lower rigid contour sequences are mounted with each other through joints without which the structure could not be stowed in the space launcher. Moreover, the vertical rigid struts are also mounted through rigid connecting members to said contour elements.

**[0018]** Consequently, the risk of failure of deployment is non-negligible.

**[0019]** Moreover, the number of rigid parts (contour elements and struts) increases the weight of the support structure, whereas it is preferable to have a low mass structure for a space launcher.

**[0020]** Another tensegrity structure is disclosed in US 2004/0261351.

**[0021]** An aim of the invention is to propose an improved tensegrity structure which is deployable from a folded state to a deployed state.

**[0022]** To reach this aim, the invention proposes a deployable tensegrity structure comprising, in the deployed state, a support structure having a ring shape around a longitudinal axis and comprising :

- a first flexible tension member defining a first contour of said ring and a second flexible tension member defining a second contour of said ring ;
- a first plurality of rigid compression members extending between said first and second contours, one end of each rigid compression member of the first plurality being mounted on the first contour whereas the other end is not mounted on a contour and; a second plurality of rigid compression members extending between said first and second contours, one end of each rigid compression member of the second plurality being mounted on the second contour whereas the other end is not mounted on a contour; said first and second plurality of rigid compression members being arranged with a repetitive crossing pattern around the ring;
- a first plurality of flexible tension members linking each end of a compression member mounted on one of said contours to an end of another compression member which is not mounted on one of said contours and, a second plurality of flexible tension members linking each end of a compression member which is not mounted on a contour to an end of another compression member which is also not mounted on a contour.

**[0023]** The structure may also have the following technical features, alone or in combination:

- the first plurality of flexible tensions members comprises first flexible tension members which link rigid compression members belonging to the same first or second plurality of rigid compression members;
- the first plurality of flexible tension members comprises second flexible tension members which link

rigid compression members of the first plurality to rigid compression members of the second plurality;
- the second plurality of flexible tension members link rigid compression members of the first plurality to compression members of the second plurality;
- several rigid compression members comprise a means, such as a spring, for varying the length of at least one flexible tension member;
- several rigid compression members comprise a device for locking at least one flexible tension member;
- two flexible nets are mounted all around a respective contour of the support structure, said nets being linked together by a plurality of linking members so that the nets have both a concave shape and are disposed symmetrically with respect to a transversal symmetric plane of the support structure;
- the rigid compression members are bars or struts;
- the flexible tension members are cables or tendons;
- it is provided a plurality of active actuators for pre-tensioning the support structure to a required value;
- it is provided three active actuators for pre-tensioning the support structure, said actuators being distributed at regular intervals around the longitudinal axis of said support structure.

**[0024]** The invention also proposes a combination of a deployable tensegrity structure according to one the invention with a device comprising a plate intended to be mounted on a boom of a spacecraft and a plurality of bars which first ends are hinged on the plate and which second ends comprise revolute joints mounted on respective ends of rigid compression members of the support structure.

**[0025]** This combination may also be such that two bars of said plurality of bars are mounted on ends of rigid compression members which are themselves mounted on a contour, a third bar of said plurality of bars being mounted on an end of another rigid compression member itself mounted on the other contour.

**[0026]** Alternatively, the invention proposes another combination of a deployable tensegrity structure according to one the invention with a boom of a spacecraft, said boom comprising a central trunk and three branches which are fixed on the central trunk and arranged at regular intervals around the longitudinal axis of the trunk, said branches being intended to be hinged on ends of rigid compression members of the support structure.

**[0027]** The structure according to the invention is particularly convenient for space applications. However, some of these features make it also well adapted for non-space applications, as it will be described hereinafter.

**[0028]** The invention shall be better understood, and other aims, advantages and features will appear by reading the following description, written with reference to the accompanying drawings, on which:

- figure 1 is a perspective view of a support structure of a deployable tensegrity structure according to the invention, showing said support structure both in the folded state and in the deployed state;
- figure 2 is a close-up view of figure 1 only showing the support structure in the deployed state;
- figure 3 is a schematic view of a generic embodiment of a tensegrity deployable structure according to the invention, further comprising two opposite flexible tension member nets, one of which intended to support an electromagnetic wave reflector (not shown in the picture);
- figure 4 is a close-up view of two opposite flexible nets, such as that one shown in figure 3, at the level of the centre of the flexible cable nets;
- figure 5 is a cut-off vertical view of a compression member, used in the support structure shown in figures 1 and 2;
- figure 6 shows a spacecraft, a boom attached to said spacecraft and an attachment means of said boom to the support structure shown in figures 1 and 2, said attachment means comprising a plurality of hinged bars attached to said support structure;
- figure 7 is a perspective view of the plate comprising the plurality of hinged bars shown on figure 6;
- figure 8 shows an alternative embodiment to attach the spacecraft to the structure according to the invention

**[0029]** The support structure 100 is shown in figure 1, both in a folded state and in a deployed state and in a close-up view in figure 2 in its deployed state.

**[0030]** The folded state corresponds to the state of the structure when it is stowed in the launch vehicle. The deployed state corresponds to the state of the structure when it is in operation.

**[0031]** The deployed support structure 100 has a ring shape which longitudinal axis Z passes through its geometric centre C.

**[0032]** The support structure 100 comprises a first flexible tension member 101 defining a first (upper) contour of said ring shape.

**[0033]** It also comprises a second flexible tension member 102 defining a second (lower) contour of said ring.

**[0034]** As the support structure 100 has the shape of a ring, it is understood that the contours 101, 102 have similar diameters when the structure 100 is in the deployed state.

**[0035]** The flexible tension members 101, 102 may be cables or tendons. Moreover, each tension member 101, 102 may be composed of one single cable/tendon or of a plurality of cables/tendons disposed in series in order to form said contour.

**[0036]** The flexible tension members 101, 102 are inextensible, that is to say that they do not vary in length.

**[0037]** Tension members 101, 102 can be coiled at one side of the ring to achieve the stowed configuration 100 shown in figure 1.

**[0038]** Coiling can be simply achieved by motorized pulley system.

**[0039]** In the stowed configuration of figure 1, adequate amount of elastic energy is stored into compression springs housed in rigid compression members. It will be further discussed hereinafter with figure 5.

**[0040]** By un-coiling tensions members 101, 102 in a controlled way, the elastic energy stored in said compression members can be released gradually, as such obtaining a progressive and controlled deployment of the tensegrity structure as shown in figure 1.

**[0041]** Moreover, the support structure 100 comprises a plurality of rigid compression members 103, 103', 104, 104' extending between said first and second contours 101, 102.

**[0042]** These rigid compression members may be bars or struts.

**[0043]** One end 1030, 1030', 1040' of each rigid compression member 103, 103', 104' is mounted on one of said two contours 101, 102, whereas the other end 1031, 1041, 1041' is not mounted on a contour.

**[0044]** Additionally, the support structure 100 comprises a plurality of flexible tension members 105, 106, 107, 110, 111, 108, 109, 112 which link the rigid compression member with each other.

**[0045]** These flexible tensions members 105, 106, 107, 110, 111, 108, 109, 112 may be separated in two types.

**[0046]** The first type of flexible tensions members 105, 106, 107, 110, 111 links each end 1030, 1030', 1040' of a compression member mounted on one of said contours 101, 102 to an end of another compression member which is not mounted on one of said contours.

**[0047]** The second type of flexible tension members 108, 109, 112 links each end 1031, 1031", 1041, 1041' of a compression member which is not mounted on a contour to an end of another compression member which is also not mounted on a contour.

**[0048]** These flexible tension members may be cables or tendons.

**[0049]** The compression members 103, 104, 103', 104' may also be separated in two types, whether they are mounted on the first contour 101 or on the second contour 102.

**[0050]** The compression members of the same type are preferably identical. Additionally, all the compression members of the support structure 100 are advantageously identical.

**[0051]** The first type of compression members 103, 103' is mounted on the first (upper) contour 101 by one respective end 1030, 1030'. The distance between two successive compression members 1030, 1030' of the first type is the same so that said these compression members 103, 103' form a repetitive pattern.

**[0052]** This is possible because a compression member 103' is mounted on the first (upper) contour 101 by a first end 1030' and the preceding compression member 103 is maintained in position with respect to the following compression member 103' by its second end 1031 to, on the one hand, the first end 1030' of the following compression member 103' and to, on the other hand, the first end 1040' of another compression member 104 (of the second type) by means of a respective flexible tension member 105, 111.

**[0053]** Accordingly, two flexible tension members 105, 111 are necessary to maintain the end 1031 of the rigid compression member 103, which is not mounted on a contour 101, 102, in position with respect to the ends 1030', 1040' of the rigid compression members 103', 104', which ends 1030', 1040' are both mounted on a contour 101, 102.

**[0054]** It should be noted that the flexible tension members 105, 111 are both of the first type.

**[0055]** Moreover, the flexible tension member 105, shown in figure 2, is in the present case a substantially vertical cable and the flexible tension member 111, also shown in figure 2, is a cable, named diagonal cable.

**[0056]** The vertical cable 105 links two successive compression members 103, 103' of the same type whereas the diagonal cable 111 links two compression members 103, 104' of different types.

**[0057]** The second type of rigid compression members 104, 104' is mounted on the second (lower) contour 102 by one respective end 1040'. The distance between two successive rigid compression members 104, 104' of the second type is the same so that these compression members 104, 104 also form a repetitive pattern.

**[0058]** This is possible because a compression member 104' is mounted on the second (lower) contour 102 by a first end 1040' and the preceding compression member 104 is maintained in position with respect to the following compression member 104' by its second end 1041 to the first end 1040' of the following compression member 104' and to the first end 1030 of the compression member 103 by means of a respective flexible tension member 106, 107.

**[0059]** Once again, two flexible tension members 106, 107 are necessary to maintain the end 1041 of the rigid compression member 104, which is not mounted on a contour 101, 102, in position with respect to the ends, of the rigid compression members, which ends 1030, 1040' are both mounted on a contour 101, 102.

**[0060]** It should be noted that the flexible tension members 106, 107 are both of the first type.

**[0061]** The flexible tension member 106, shown in figure 2, is in the present case a substantially vertical cable and the flexible tension member 107, also shown in figure 2, is a diagonal cable.

**[0062]** The flexible tension members 107, 106, 111, 105 form a repetitive pattern around the ring.

**[0063]** To guarantee the stability of the support structure 100 when it is deployed, other flexible members 108, 112 are added between the second end 1041, 1041' of compression members 104, 104' of the second type and the second end 1031 of a compression member 103 of the first type. These additional flexible tension members link two ends which are not mounted on the contours

101, 102.

**[0064]** It should be noted that these additional flexible tension members 108, 112 are of the second type, so that they link ends of compression members which are not mounted on a contour 101, 102.

**[0065]** These additional flexible members may be cables, named saddle cables, or tendons.

**[0066]** Similarly, the flexible members 108, 109 link the second end 1041 of a compression member 104 of the second type and the respective second ends 1031, 1031" of two compression members 103, 103" of the first type.

**[0067]** Once again, the additional flexible member 109 may be a cable, named saddle cable, or a tendon.

**[0068]** The links between the different compression members 103, 103', 104, 104' are advantageously made between the closest compression members, as shown in figure 2.

**[0069]** The flexible tension members 108, 109, 112 of the second type also define a repetitive pattern around the ring.

**[0070]** Moreover, rigid compression members of both types are arranged with a repetitive crossing pattern all around the ring. As the support structure 100 is a tensegrity structure, there is no mechanical connection between any two compression members: they are disposed in a crossing pattern but they maintain a non-null clearance between them.

**[0071]** The support structure 100 described here above is fully compatible with the installation of two flexible nets 201, 202 which are each mounted all around one of contours 101, 102 of the support structure 100.

**[0072]** Figure 3 shows the two opposite flexible nets 201, 202, together with a plurality of linking members 203 in an embodiment representative of a possible flight hardware configuration.

**[0073]** In this figure, the rigid compression bars 103, 104, 103', 104', 103" and their flexible links are not represented.

**[0074]** Thanks to the linking members 203, each net 201, 202 has a concave shape. In that way, one of the nets 201, 202 may support an electromagnetic wave reflector (not shown in the figure).

**[0075]** As shown in this figure, the nets 201, 202 are mounted in such a way that they are disposed symmetrically with respect to a transversal symmetric plane P of the support structure 100.

**[0076]** Figure 4 more specifically shows a close-up view of the centre of the nets 201, 202. Actually, it has to be noticed that figure 4 represents an embodiment related to a particular realisation of a tensegrity structure prototype, for which only the mechanical characteristics of the said flexible nets and linking members had to be represented.

**[0077]** However, the design shown in figure 3 is consistent with figure 4.

**[0078]** The centre $C_1$, $C_2$ of each net 201, 202 belongs to the longitudinal axis Z of the ring (axis of symmetry). These centres are preferably linked by an attachment means 204.

**[0079]** The deployment of the structure from its folded state to its deployed state is advantageously realised with the two following phases.

**[0080]** In the first phase, the full deployment of the support structure is achieved by means of a spring 113 based actuation, housed in a compression member 103. By releasing its energy, the spring 113 allows deploying the support structure 100 from its folded state to its deployed state.

**[0081]** It assumes that the spring 113 is initially compressed to store energy when the support structure 100 is in a folded state.

**[0082]** During deployment, a flexible tension member 110 partially housed in the rigid compression member 103 gets in the rigid compression member 103. Accordingly, the length of the flexible tension member 110 outside the rigid compression member 103 decreases.

**[0083]** Once the support structure 100 is deployed, a latching device 112 also housed in said rigid compression member 103 locks the flexible tension member 110 in its final position.

**[0084]** It avoids loosening of tension after deployment.

**[0085]** The means employed for the first deployment phase are more specifically shown in figure 5. Figure 5 is a cut-off vertical view of one compression member, in that case the compression member 103 shown in figure 2.

**[0086]** The flexible tension member which is chosen to this end is a vertical cable 110. However, it may be carried out with another flexible tension member, such as a diagonal cable of the support structure 100.

**[0087]** The compression member 103 houses the spring 113, which one end 1130 is mated to the casing of the compression member 103 and which other end 1131 is mated to the upper part 1120 of the locking device 112.

**[0088]** The lower part 1121 of the locking device 112 locks the vertical cable 110. The device 112 is in an unlocked position when the support structure is in a folded state. When full deployment is achieved it is locked to avoid loosening of tension.

**[0089]** Figure 5 also shows the other vertical cable 105 which is linked to the compression member 103'. The length of the visible part of the vertical cable 105 may also vary in length by a corresponding device (spring, locking device) housed in the compression member 103', pursuant to the design shown in figure 5.

**[0090]** Moreover, figure 5 also shows the diagonal cables 107, 111 which respectively link said compression member 103 to the compression members 104, 104'.

**[0091]** Advantageously, all the compression members of the support structure 100 will include an internal design described with figure 5 as, in that case, the risk of failure of deployment is limited.

**[0092]** However, we may also select some rigid compression members among all the rigid compression members contained in the support structure.

**[0093]** In the second phase of deployment of the support structure 100, an active actuation is applied to one or several flexible tension members of the support structure 100 to reach a required pre-tensioned state.

**[0094]** This second phase guarantees stiffness and stability of the deployed support structure 100. It also ensures proper tensioning of the two flexible nets 201, 202 which have to support the electromagnetic reflector. Indeed, the stability of the shape of the reflector has to be maintained during the operational life of the reflector.

**[0095]** Active actuation is carried out by actuators which will be powered by the spacecraft.

**[0096]** Due to the specific features of tensegrity structures, a limited number of actuators is sufficient to ensure an efficient tensioning of the contours 101, 102, of the different flexible tension members from 105 to 111 and of the flexible nets 201, 202.

**[0097]** For example, a number of three actuators has proved to be sufficient.

**[0098]** Indeed, the applicant has designed and tested a small scale structure according to the invention, in which three actuators distributed at regular intervals around the longitudinal axis of the structure have proved to be efficient enough. It means that the actuators were separated from each other from a peripheral angle of 120°.

**[0099]** In the tests performed, the actuation was carried out on diagonal cables but, other cables may have been chosen.

**[0100]** Moreover, it should be noted that more than three actuators may be employed to improve safety.

**[0101]** The two phases of deployment of the support structure 100 described here above is preferential.

**[0102]** However, we may envisage a simpler design for the deployment sequence, so that the second phase is not carried out. To that extent, suitable sizing of compression springs 113 within compression members of figure 5 would provide enough energy to achieve required pre-tensioning at the end of deployment of the first phase.

**[0103]** Another important aspect in the deployment of electromagnetic reflectors is related to the interface between its support structure 100 and the spacecraft.

**[0104]** Generally, a long deployable boom is foreseen to bring the structure comprising the reflector at a given distance from the spacecraft to avoid any issue during the deployment of said structure. In the particular case where the support structure has the shape of a ring, the boom of the spacecraft is generally attached to at least one contour of the support structure.

**[0105]** However, the invention proposes a specific attachment means between the boom 400 of the spacecraft 500 and the support structure 100 according to the invention.

**[0106]** Figures 6 and 7 shows such an attachment means, in operation in figure 6 and remote in figure 7.

**[0107]** This attachment means is more specifically directed to electromagnetic wave reflectors when used in an "off-set" type of antenna optical configuration, namely when the reflector ring is attached to the spacecraft boom by one side only.

**[0108]** The attachment means is a device 300 comprising a plate 301 intended to be fixed on the boom 400 of the spacecraft 500 and, a plurality of rigid bars 302, 303, 304 intended to be connected to respective ends of compression members of the support structure 100.

**[0109]** The rigid bars are hinged on the plate 301 by first ends, so that a rotation movement of said rigid bars 302, 303, 304 is possible with respect to the plate 301.

**[0110]** The other ends of the rigid bars 301, 302, 303 comprise revolute joints to be mounted on the ends of the compression members, so that a rotation movement in three directions is possible with respect to these compression members.

**[0111]** As shown in figure 7, three hinged bars 301, 302, 303 may be sufficient to ensure a proper deployment of the support structure 100. It is particularly interesting when the plate 301 has a triangular shape, as each rigid bar 302, 303, 304 may be hinged at the level of a corner of the plate 301.

**[0112]** However, the plate 301 may have another shape, provided that three attachment points are provided.

**[0113]** Indeed, a plate with three hinged bars mounted with revolute joints on three respective ends of compression members provides an iso-static structure which is particularly suitable for obtaining a support structure/reflector with a transversal symmetry plane.

**[0114]** In practice, two 303, 304 hinged bars will be mounted on a first contour 101 and the last one 302 on the other contour 102.

**[0115]** In an alternative embodiment, it is possible to have a boom 400' comprising a central trunk 401' connected to the spacecraft 500 and a plurality of branches 402', 403', 404' all fixed, on the one hand, to the central trunk 401', and each hinged with a revolute joint to a corresponding end of a compression member belonging to the support structure 100.

**[0116]** Figure 8 shows such an alternative.

**[0117]** This alternative is more specifically directed to sunshields or solar sailing applications.

**[0118]** As can be seen in this figure, the spacecraft 500 is located above the support structure 100 so that the boom 400' extends downwards with respect to the spacecraft 500.

**[0119]** The different branches, in that case three branches 402', 403', 404', are distributed at regular intervals around the longitudinal axis of the central trunk 401'. It means that the branches 402', 403', 404' are separated from each other from a peripheral angle of 120°.

**[0120]** In that case, the deployment of the support structure 100 is carried out in a radial direction, in plane located below the spacecraft 500 and the boom 400'.

**[0121]** A convenient deployment is thus obtained.

**[0122]** The tensegrity deployable structure according to the invention may be used in connection with many types of reflectors, among which an antenna.

**[0123]** It may also be used in connection with a sunshield, a solar sail or any large surface useful for collection of radiofrequency.

**[0124]** Other applications such as generating air-drag for re-entry of the spacecraft in the atmosphere may also be considered.

**[0125]** In addition, terrestrial applications are possible.

**[0126]** For example, the invention may find application for temporary or portable shelters or tents.

**[0127]** According to another example, the invention may find an application for aquaculture.

**[0128]** For terrestrial applications, it should be noted that the deployment phase may be limited to the first phase, as the pre-tensioning of the support structure to a required value is not generally as much important as for space applications, in which the shape of the reflector has to be precisely controlled. Moreover, the nets 201, 202 will not generally be envisaged.

**[0129]** Whatever the application, the invention proposes a tensegrity deployable structure which is light, stable and reliable, especially when its deployment is considered.

**[0130]** Moreover, in space applications, the structure according to the invention can be stowed in the envelope of a space launcher.

## Claims

1. A deployable tensegrity structure comprising, in the deployed state, a support structure (100) having a ring shape around a longitudinal axis and comprising :

   - a first flexible tension member (101) defining a first contour of said ring and a second flexible tension member (102) defining a second contour of said ring ;
   - a first plurality of rigid compression members (103, 103', 103") extending between said first and second contours (101, 102), one end (1030, 1030') of each rigid compression member of the first plurality being mounted on the first contour (101) whereas the other end (1031, 1031") is not mounted on a contour and; a second plurality of rigid compression members (104, 104') extending between said first and second contours (101, 102), one end (1040') of each rigid compression member of the second plurality being mounted on the second contour (102) whereas the other end (1041, 1041') is not mounted on a contour; said first and second plurality of rigid compression members (103, 103', 103" 104, 104') being arranged with a repetitive crossing pattern around the ring;
   - a first plurality of flexible tension members (105, 106, 107, 110, 111) linking each end (1030, 1030', 1040') of a compression member mounted on one of said contours (101, 102) to an end of another compression member which is not mounted on one of said contours and, a second plurality of flexible tension members (108, 109, 112) linking each end (1031, 1031", 1041, 1041') of a compression member which is not mounted on a contour to an end of another compression member which is also not mounted on a contour.

2. A deployable tensegrity structure according to claim 1, wherein the first plurality of flexible tensions members (105, 106, 107, 110, 111) comprises first flexible tension members (105, 106, 110) which link rigid compression members belonging to the same first or second plurality of rigid compression members.

3. A deployable tensegrity structure according to one of the preceding claims, wherein the first plurality of flexible tension members (105, 106, 107, 110, 111) comprises second flexible tension members (107, 111) which link rigid compression members of the first plurality (103, 103', 103") to rigid compression members of the second plurality (104, 104').

4. A deployable tensegrity structure according to one of the preceding claims, wherein the second plurality of flexible tension members (108, 109, 112) link rigid compression members of the first plurality (103, 103', 103") to compression members of the second plurality (104, 104').

5. A deployable tensegrity structure according to one of the preceding claims, wherein several rigid compression members (103, 103', 103", 104, 104') comprise a means (113), such as a spring (113), for varying the length of at least one flexible tension member (110).

6. A deployable tensegrity structure according to one of the preceding claims, wherein several rigid compression members (103, 103', 103", 104, 104') comprise a device (112) for locking at least one flexible tension member (110).

7. A deployable tensegrity structure according to one of the preceding claims, wherein two flexible nets (201, 202) are mounted all around a respective contour (101, 102) of the support structure (100), said nets being linked together by a plurality of linking members (203) so that the nets have both a concave shape and are disposed symmetrically with respect to a transversal symmetric plane of the support structure (100).

8. A deployable tensegrity structure according to one of the preceding claims, wherein the rigid compression members (103, 103', 103", 104, 104') are bars

or struts.

**9.** A deployable tensegrity structure according to one of the preceding claims, wherein the flexible tension members (105 to 112) are cables or tendons.

**10.** A deployable tensegrity structure according to one of the preceding claims, wherein it is provided a plurality of active actuators for pre-tensioning the support structure (100) to a required value.

**11.** A deployable structure according to the preceding claim, wherein it is provided three active actuators for pre-tensioning the support structure (100), said actuators being distributed at regular intervals around the longitudinal axis of said support structure.

**12.** A combination of a deployable tensegrity structure according to one of the preceding claims with a device (300) comprising:

- a plate (301) intended to be mounted on a boom (400) of a spacecraft (500);
- a plurality of bars (302, 303, 304) which first ends are hinged on the plate (301) and which second ends comprise revolute joints mounted on respective ends of rigid compression members of the support structure (100).

**13.** A combination according to the preceding claim, wherein two bars of said plurality of bars (303, 304) are mounted on ends of rigid compression members which are themselves mounted on a contour (101), a third bar (302) of said plurality of bars (302, 303, 304) being mounted on an end of another rigid compression member itself mounted on the other contour (102).

**14.** A combination of a deployable tensegrity structure according to one of claims 1 to 11 with a boom (400') of a spacecraft, said boom (400) comprising a central trunk (401') and three branches (402', 403', 404') which are fixed on the central trunk (401') and arranged at regular intervals around the longitudinal axis of the trunk (401'), said branches being intended to be hinged on ends of rigid compression members of the support structure (100).

**Patentansprüche**

**1.** Einsetzbare Tensegrity-Struktur, aufweisend, im entfalteten Zustand, eine Stützstruktur (100), die eine Ringform um eine Längsachse hat und Folgendes aufweist:

- ein erstes flexibles Zugelement (101), das eine erste Kontur des Rings definiert, und ein zweites flexibles Zugelement (102), das eine zweite Kontur des Rings definiert;
- eine erste Vielzahl starrer Kompressionselemente (103, 103', 103''), die sich zwischen den ersten und zweiten Konturen (101, 102) erstrecken, wobei ein Ende (1030, 1030') jedes starren Kompressionselements der ersten Vielzahl an der ersten Kontur (101) montiert ist, während das andere Ende (1031, 1031") nicht an einer Kontur montiert ist, und; eine zweite Vielzahl starrer Kompressionselemente (104, 104'), die sich zwischen den ersten und zweiten Konturen (101, 102) erstrecken, wobei ein Ende (1040') jedes starren Kompressionselements der zweiten Vielzahl an der zweiten Kontur (102) montiert ist, während das andere Ende (1041, 1041') nicht an einer Kontur montiert ist; wobei die erste und zweite Vielzahl starrer Kompressionselemente (103, 103', 103'', 104, 104') mit einem sich wiederholenden Kreuzmuster um den Ring herum angeordnet sind;
- eine erste Vielzahl flexibler Zugelemente (105, 106, 107, 110, 111), die jedes Ende (1030, 1030', 1040') eines Kompressionselements, das auf einer der Konturen (101, 102) an einem Ende eines anderen, nicht an einer der Konturen montierten Kompressionselements montiert ist, und eine zweite Vielzahl flexibler Zugelemente (108, 109, 112), die jedes Ende (1031, 1031'', 1041, 1041') eines nicht auf einer Kontur montierten Kompressionselements mit einem Ende eines anderen Kompressionselements, das ebenfalls nicht auf einer Kontur montiert ist, verknüpft.

**2.** Einsetzbare Tensegrity-Struktur nach Anspruch 1, wobei die erste Vielzahl flexibler Zugelemente (105, 106, 107, 110, 111) erste flexible Zugelemente (105, 106, 110) umfasst, die starre, zur gleichen ersten oder zweiten Vielzahl starrer Kompressionselemente gehörende Kompressionselemente miteinander verknüpfen.

**3.** Einsetzbare Tensegrity-Struktur nach einem der vorhergehenden Ansprüche, wobei die erste Vielzahl flexibler Zugelemente (105, 106, 107, 110, 111) zweite flexible Zugelemente (107, 111) umfasst, die starre Kompressionselemente der ersten Vielzahl (103, 103', 103'') mit starren Kompressionselementen der zweiten Vielzahl (104, 104') verknüpfen.

**4.** Einsetzbare Tensegrity-Struktur nach einem der vorhergehenden Ansprüche, wobei die zweite Vielzahl flexibler Zugelemente (108, 109, 112) starre Kompressionselemente der ersten Vielzahl (103, 103', 103'') mit Kompressionselementen der zweiten Vielzahl (104, 104') verknüpft.

5. Einsetzbare Tensegrity-Struktur nach einem der vorhergehenden Ansprüche, wobei mehrere starre Kompressionselemente (103, 103', 103'', 104, 104') ein Mittel (113), wie eine Feder (113), zum Variieren der Länge mindestens eines flexiblen Zugelements (110) aufweisen.

6. Einsetzbare Tensegrity-Struktur nach einem der vorhergehenden Ansprüche, wobei mehrere starre Kompressionselemente (103, 103', 103'', 104, 104') eine Vorrichtung (112) zum Sperren mindestens eines flexiblen Zugelements (110) aufweisen.

7. Einsetzbare Tensegrity-Struktur nach einem der vorhergehenden Ansprüche, wobei zwei flexible Netze (201, 202) vollständig um eine jeweilige Kontur (101, 102) der Stützstruktur (100) montiert sind, wobei die Netze durch eine Vielzahl von Verknüpfungselemente (203) so miteinander verknüpft sind, dass die Netze sowohl eine konkave Form aufweisen als auch in Bezug auf eine quersymmetrische Ebene der Stützstruktur (100) symmetrisch angeordnet sind.

8. Einsetzbare Tensegrity-Struktur nach einem der vorhergehenden Ansprüche, wobei die starren Kompressionselemente (103, 103', 103'', 104, 104') Stäbe oder Streben sind.

9. Einsetzbare Tensegrity-Struktur nach einem der vorhergehenden Ansprüche, wobei die flexiblen Zugelemente (105 bis 112) Kabel oder Spannglieder sind.

10. Einsetzbare Tensegrity-Struktur nach einem der vorhergehenden Ansprüche, wobei eine Vielzahl von aktiven Aktuatoren zum Vorspannen der Stützstruktur (100) auf einen erforderlichen Wert bereitgestellt ist.

11. Einsetzbare Tensegrity-Struktur nach dem vorhergehenden Anspruch, wobei drei Aktuatoren zum Vorspannen der der Stützstruktur (100) bereitgestellt sind, wobei die Aktuatoren in regelmäßigen Abständen um die Längsachse der Stützstruktur bereitgestellt sind.

12. Kombination einer einsetzbaren Tensegrity-Struktur nach einem der vorhergehenden Ansprüche mit einer Vorrichtung (300), aufweisend:

- eine Platte (301), die für eine Montage an einem Ausleger (400) eines Raumfahrzeugs (500) vorgesehen ist;
- eine Vielzahl von Stäben (302, 303, 304), deren erste Enden an der Platte (301) angelenkt sind und deren zweite Enden an den jeweiligen Enden der starren Kompressionselemente der Stützstruktur (100) befestigte Drehgelenke aufweisen.

13. Kombination nach dem vorhergehenden Anspruch, wobei zwei Stäbe der Vielzahl von Stäben (303, 304) an Enden von starren Kompressionselementen montiert sind, die ihrerseits auf einer Kontur (101) montiert sind, wobei ein dritter Stab (302) der Vielzahl von Stäben (302, 303, 304) an einem Ende eines anderen starren Kompressionselements montiert ist, das selbst an der anderen Kontur (102) montiert ist.

14. Kombination einer einsetzbaren Tensegrity-Struktur nach einem der Ansprüche 1 bis 11 mit einem Ausleger (400') eines Raumfahrzeugs, wobei der Ausleger (400) einen zentralen Stamm (401') und drei Zweige (402', 403', 404') aufweist, die am zentralen Stamm (401') befestigt und in regelmäßigen Intervallen um die Längsachse des zentralen Stamms (401') herum angeordnet sind, wobei die Zweige vorgesehen sind, an Enden von starren Kompressionselementen der Stützstruktur (100) angelenkt zu werden.

## Revendications

1. Structure déployable en tenségrité comprenant, dans l'état déployé, une structure de support (100) ayant une forme d'anneau autour d'un axe longitudinal et comprenant :

- un premier organe flexible de tension (101) définissant un premier contour dudit anneau et un second organe flexible de tension (102) définissant second contour dudit anneau ;
- une première pluralité d'organes rigides de compression (103, 103', 103" ) s'étendant entre lesdits premier et second contours (101, 102), une extrémité (1030, 1030') de chaque organe rigide de compression de la première pluralité étant montée sur le premier contour (101) tandis que l'autre extrémité (1031, 1031'') n'est pas montée sur un contour et ; une seconde pluralité d'organes rigides de compression (104, 104') s'étendant entre lesdits premier et second contours (101, 102), une extrémité (1040') de chaque organe rigide de compression de la seconde pluralité étant montée sur le second contour (102) tandis que l'autre extrémité (1041, 1041') n'est pas montée sur un contour ; lesdites première et seconde pluralités d'organes rigides de compression (103, 103', 103'', 104, 104') étant agencées selon un motif de croisement répétitif autour de l'anneau ;
- une première pluralité d'organes flexibles de tension (105, 106, 107, 110, 111) reliant chaque extrémité (1030, 1030', 1040') d'un organe de

compression monté sur l'un desdits contours (101, 102) à une extrémité d'un autre organe de compression qui n'est pas monté sur l'un desdits contours et, une seconde pluralité d'organes flexibles de tension (108, 109, 112) reliant chaque extrémité (1031, 1031'', 1041, 1041') d'un organe de compression qui n'est pas monté sur un contour à une extrémité d'un autre organe de compression qui n'est également pas monté sur un contour.

2. Structure déployable en tenségrité selon la revendication 1, dans laquelle la première pluralité d'organes flexibles de tension (105, 106, 107, 110, 111) comprend des premiers organes flexibles de tension (105, 106, 110) qui relient des organes rigides de compression appartenant à la même première ou seconde pluralité d'organes rigides de compression.

3. Structure déployable en tenségrité selon l'une quelconque des revendications précédentes, dans laquelle la première pluralité d'organes flexibles de tension (105, 106, 107, 110, 111) comprend des seconds organes flexibles de tension (107, 111) qui relient des organes rigides de compression de la première pluralité (103, 103', 103'') à des organes rigides de compression de la seconde pluralité (104, 104').

4. Structure déployable en tenségrité selon l'une quelconque des revendications précédentes, dans laquelle la seconde pluralité d'organes flexibles de tension (108, 109, 112) relie des organes rigides de compression de la première pluralité (103, 103', 103'') à des organes de compression de la seconde pluralité (104, 104').

5. Structure déployable en tenségrité selon l'une quelconque des revendications précédentes, dans laquelle plusieurs organes rigides de compression (103, 103', 103'', 104, 104') comprennent un moyen (113), tel qu'un ressort (113), servant à faire varier la longueur d'au moins un organe flexible de tension (110).

6. Structure déployable en tenségrité selon l'une quelconque des revendications précédentes, dans laquelle plusieurs organes rigides de compression (103, 103', 103'', 104, 104') comprennent un dispositif (112) servant à bloquer au moins un organe flexible de tension (110).

7. Structure déployable en tenségrité selon l'une quelconque des revendications précédentes, dans laquelle deux filets flexibles (201, 202) sont montés tout autour d'un contour respectif (101, 102) de la structure de support (100), lesdits filets étant liés ensemble par une pluralité d'organes de liaison (203) de façon que les filets aient tous les deux une forme concave et soient disposés symétriquement par rapport à un plan de symétrie transversale de la structure de support (100).

8. Structure déployable en tenségrité selon l'une quelconque des revendications précédentes, dans laquelle les organes rigides de compression (103, 103', 103'', 104, 104') sont des barres ou mâts.

9. Structure déployable en tenségrité selon l'une quelconque des revendications précédentes, dans laquelle les organes flexibles de tension (105 à 112) sont des câbles ou des tendons.

10. Structure déployable en tenségrité selon l'une quelconque des revendications précédentes, dans laquelle il est fourni une pluralité d'actionneurs actifs servant à la mise en tension préalable de la structure de support (100) jusqu'à une valeur requise.

11. Structure déployable selon la revendication précédente, dans laquelle il est fourni trois actionneurs actifs servant à la mise en tension préalable de la structure de support (100), lesdits actionneurs étant répartis à des intervalles réguliers autour de l'axe longitudinal de ladite structure de support.

12. Combinaison d'une structure déployable en tenségrité selon l'une quelconque des revendications précédentes avec un dispositif (300) comprenant :

- une plaque (301) destinée à être montée sur un bras (400) d'un véhicule spatial (500) ;
- une pluralité de barres (302, 303, 304) dont les premières extrémités sont articulées sur la plaque (301) et dont les secondes extrémités comprennent des articulations rotoïdes montées sur des extrémités respectives d'organes rigides de compression de la structure de support (100).

13. Combinaison selon la revendication précédente, dans laquelle deux barres de ladite pluralité de barres (303, 304) sont montées sur les extrémités d'organes rigides de compression qui sont eux-mêmes montés sur un contour (101), une troisième barre (302) de ladite pluralité de barres (302, 303, 304) étant montée sur une extrémité d'un autre organe rigide de compression lui-même monté sur l'autre contour (102).

14. Combinaison d'une structure déployable en tenségrité selon l'une quelconque des revendications 1 à 11 avec un bras (400') d'un véhicule spatial, ledit bras (400) comprenant un tronc central (401') et trois branches (402', 403', 404') qui sont fixées sur le tronc central (401') et agencées à des intervalles réguliers autour de l'axe longitudinal du tronc (401'), lesdites

branches étant destinées à être articulées sur des extrémités d’organes rigides de compression de la structure de support (100).

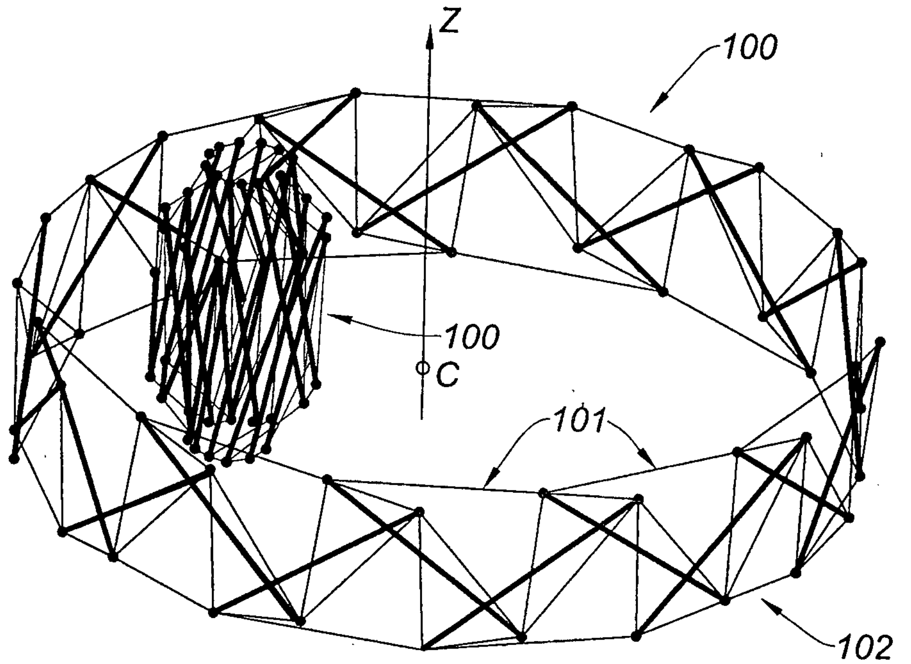
Z
100
100
C
101
102

Fig. 1

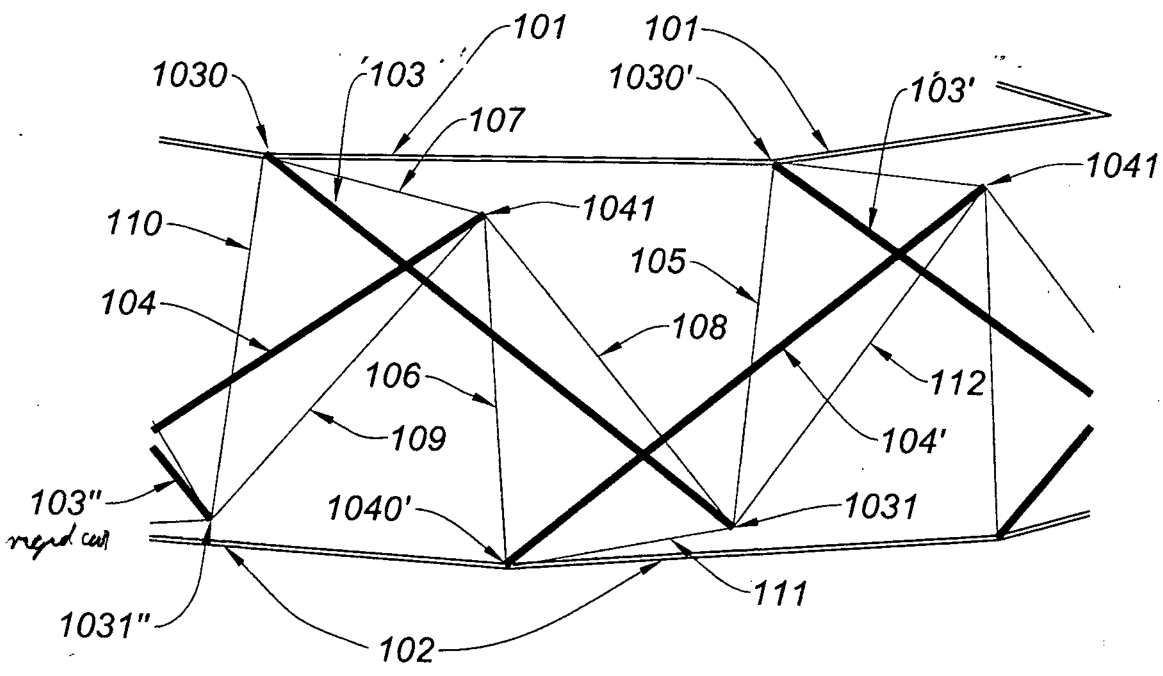
1030
103
101
101
1030'
103'
107
1041'
110
1041
105
104
108
106
112
109
104'
103"
1040'
1031
1031"
111
102

Fig. 2

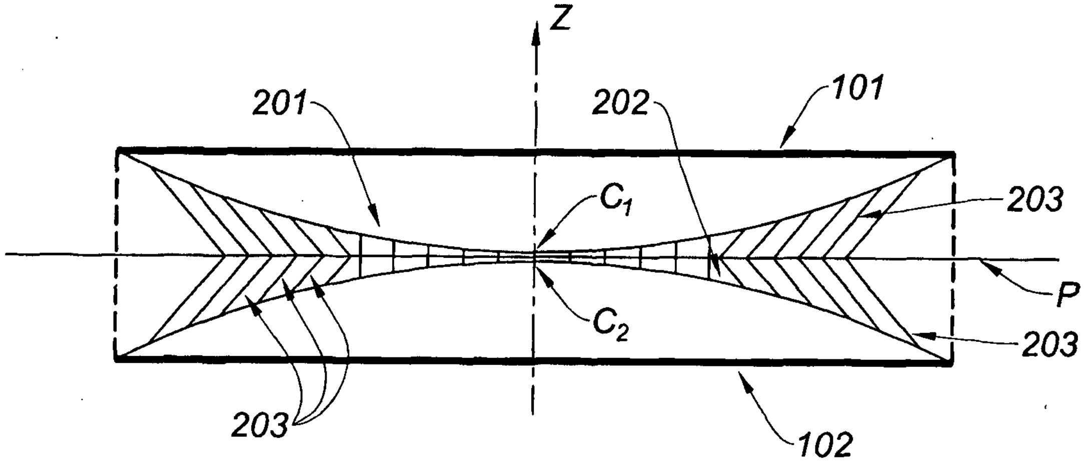


Fig. 3

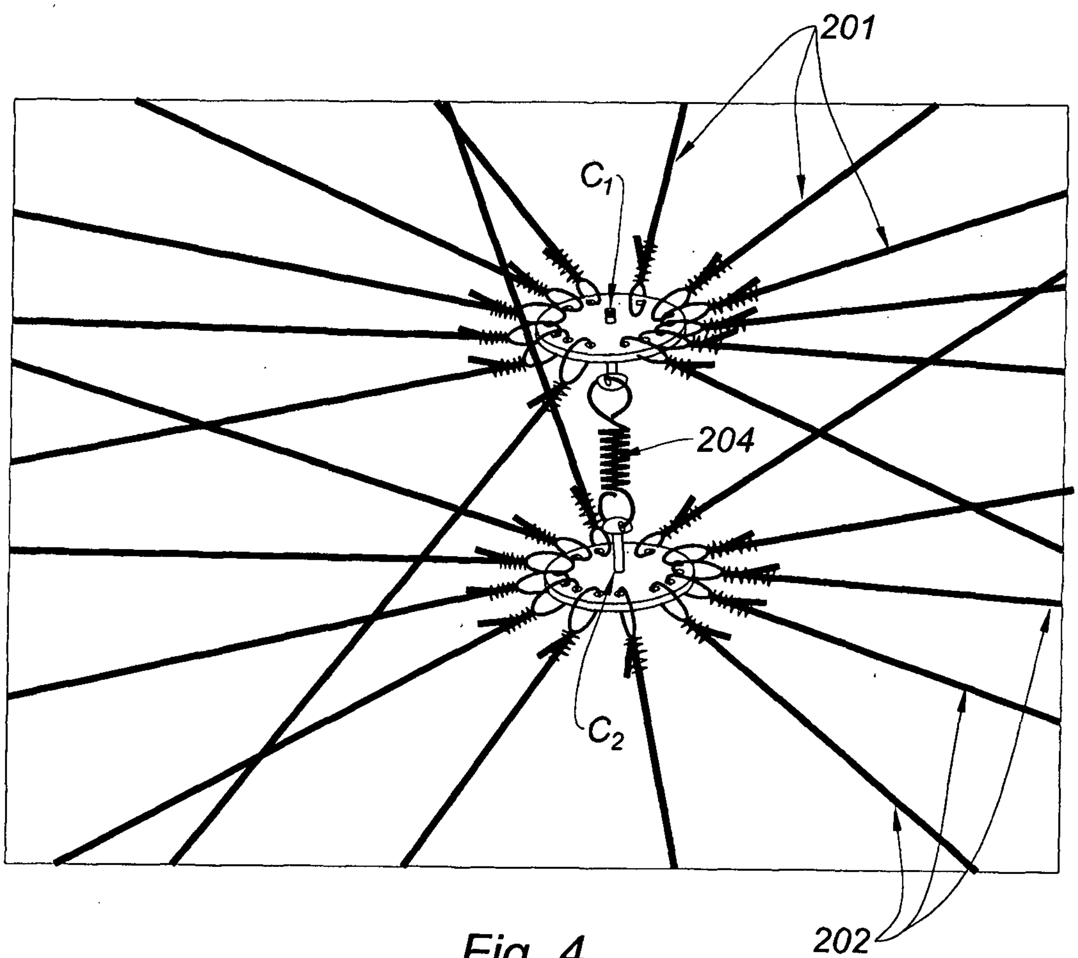


Fig. 4

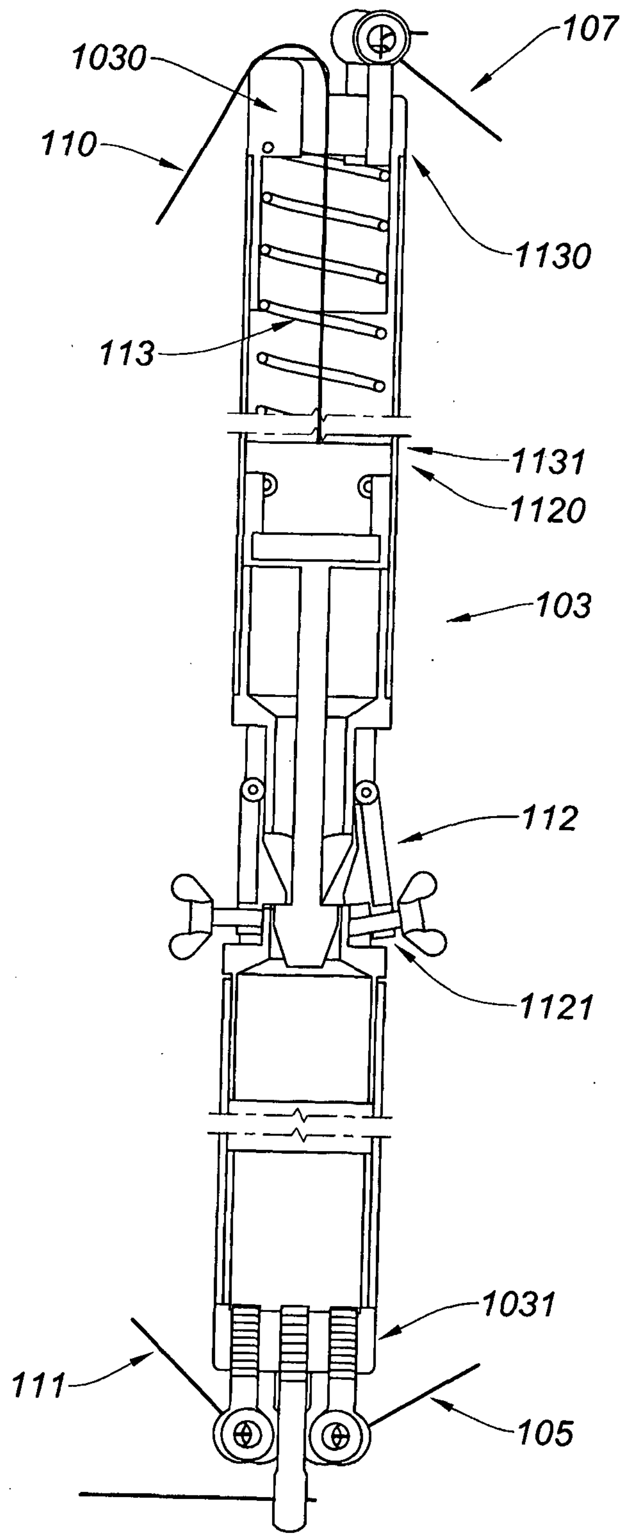


Fig. 5

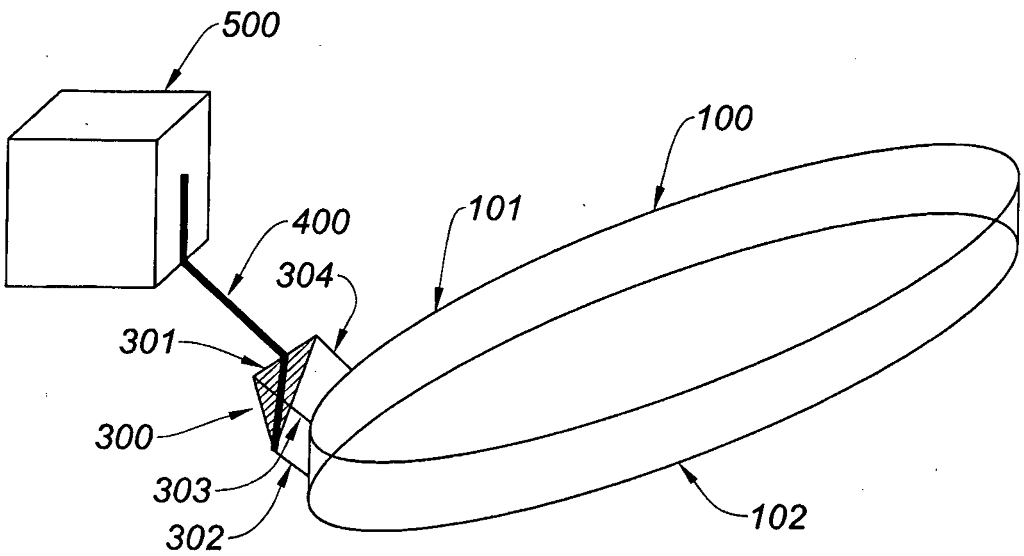


Fig. 6

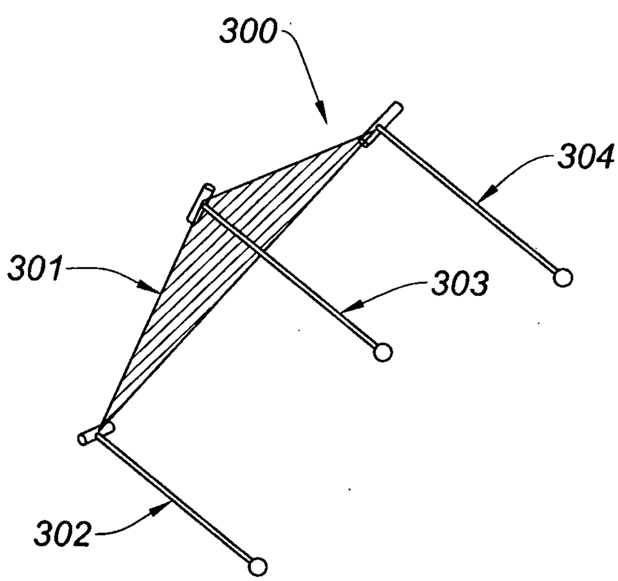


Fig. 7

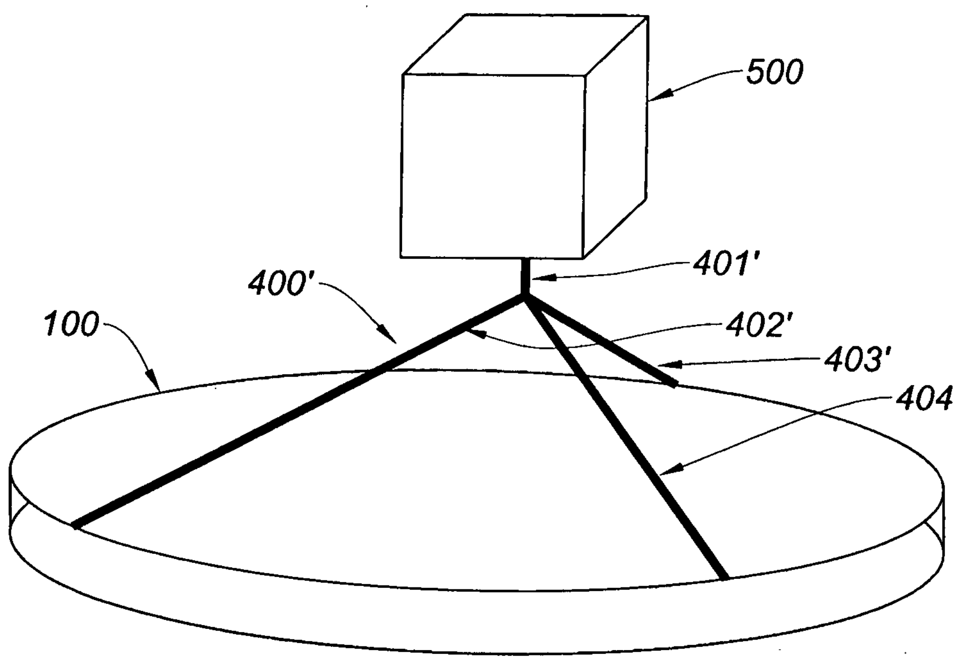


Fig. 8

## REFERENCES CITED IN THE DESCRIPTION

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