(12) UK Patent Application (19) GB (11) 2550605 (13) A

(43) Date of A Publication 29.11.2017

(21) Application No: 1609163.9

(22) Date of Filing: 23.05.2016

(71) Applicant(s):
David Chambers
10 Lady Bay Road, Nottingham, NG2 5BJ, United Kingdom

(72) Inventor(s):
David Chambers

(74) Agent and/or Address for Service:
David Chambers
10 Lady Bay Road, Nottingham, NG2 5BJ, United Kingdom

(51) INT CL:
B29C 70/84 (2006.01) ***E04B 1/18*** (2006.01)
F16L 41/02 (2006.01)

(56) Documents Cited:
CN 201043512 Y
US 20130309435 A1
US 20120040169 A1
JP H07243573

(58) Field of Search:
INT CL **B29C, E04C, F03D, F16B**
Other: **EPODOC, WPI**

(54) Title of the Invention: **A joint comprising an interface enabling structural continuity between joining intersecting**
Abstract Title: **A joint comprising intersecting members**

(57) A joint comprising an interface between first and second intersecting members using composite materials forming the perimeter wall, the interface being the common space shared by the intersecting members, and a method of manufacturing the joint. The composite material extends into and around the interface. An interface between hollow members the joint may be constructed in situ by interweaving the tensile component of the material forming the intersecting walls. Internal forms and shell moulds may also be used to form the inner surface shape of the joint, with a second set to form the outer surface. Tensile material is laid around the forms or injected into the space between the forms. One embodiment of the interface forms the central hub of a wind turbine rotor.

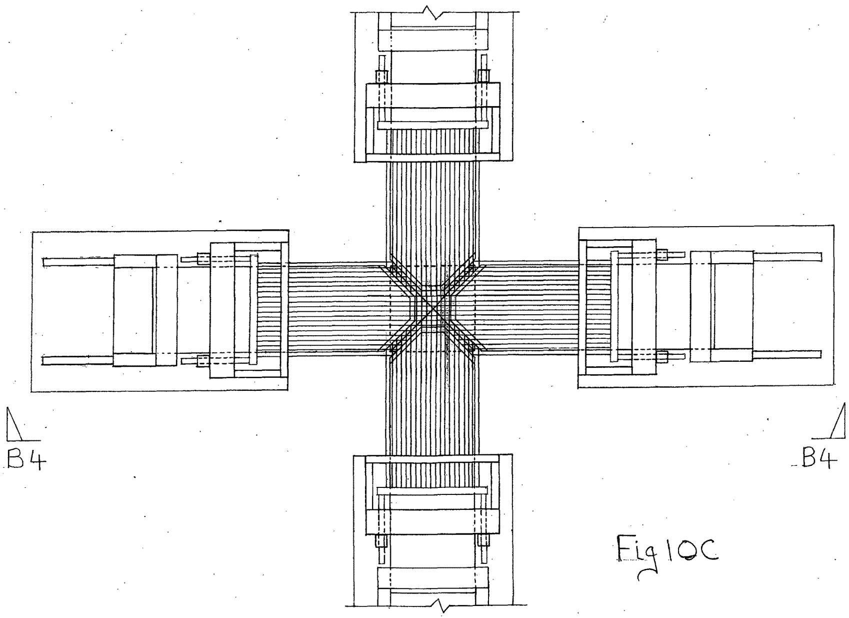


Fig 10C

GB 2550605 A

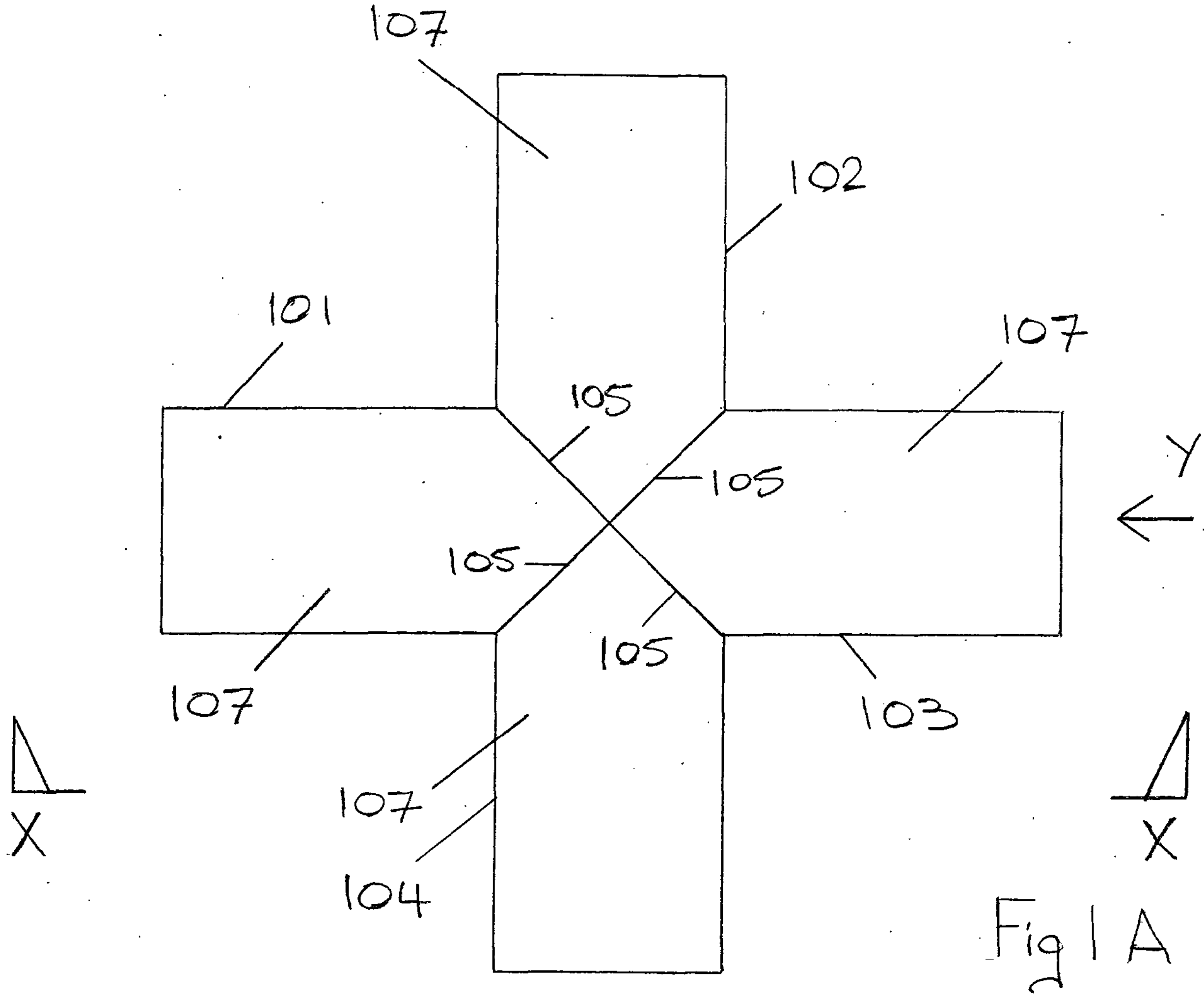

107
102
101
107
105
105
105
105
Y
107
107
103
107
104
X
X

Fig 1A

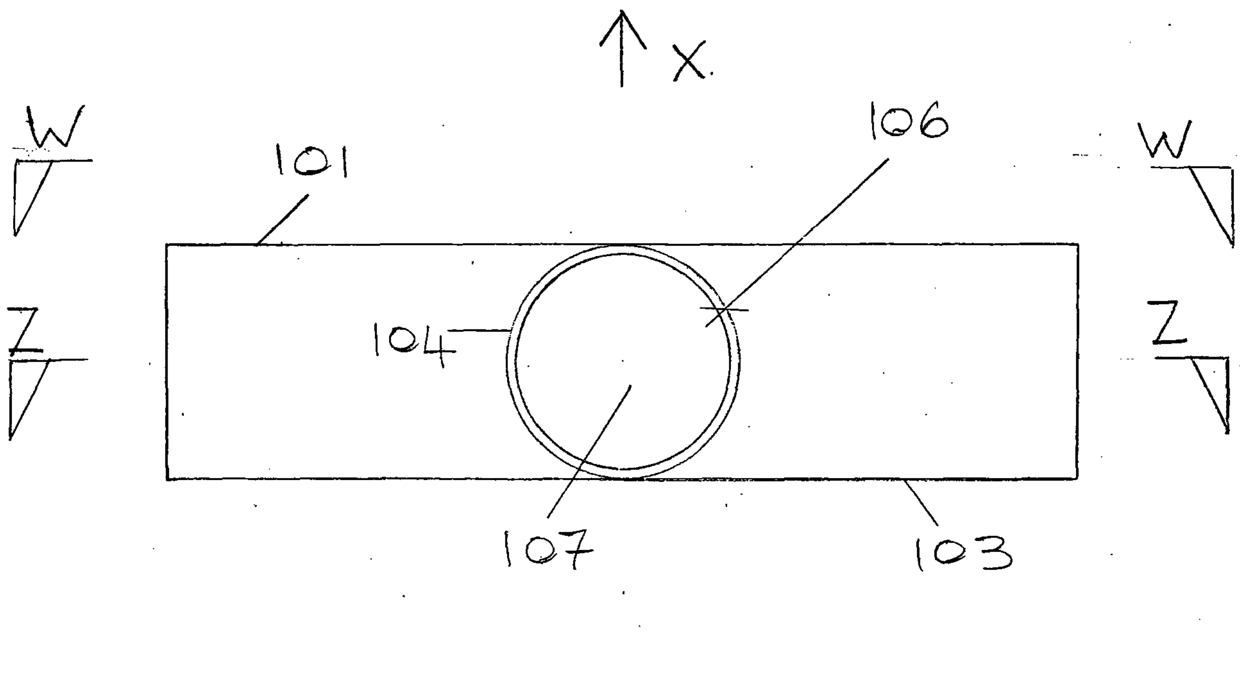

X
W
W
101
106
Z
Z
104
107
103

Fig 1B

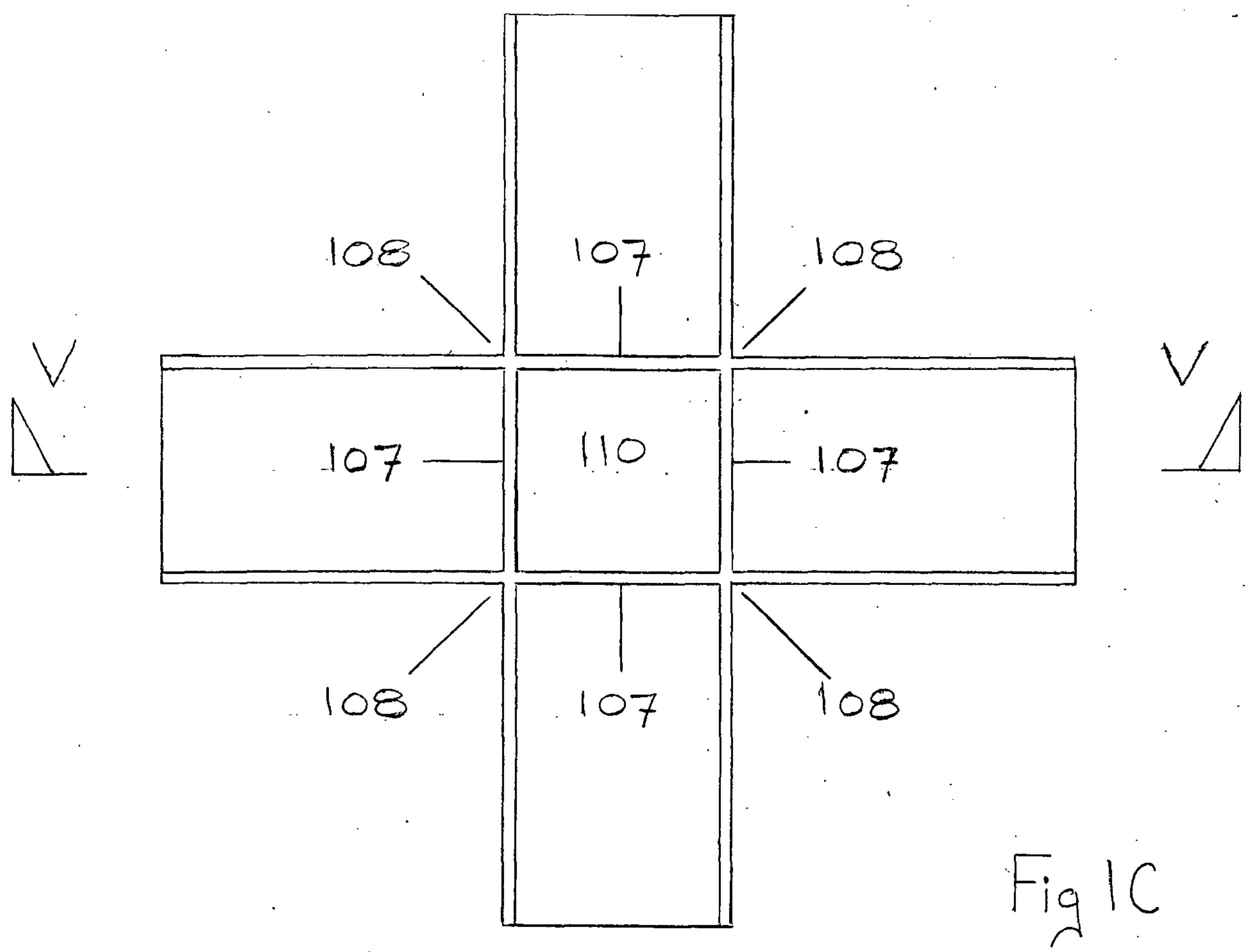


Fig 1C

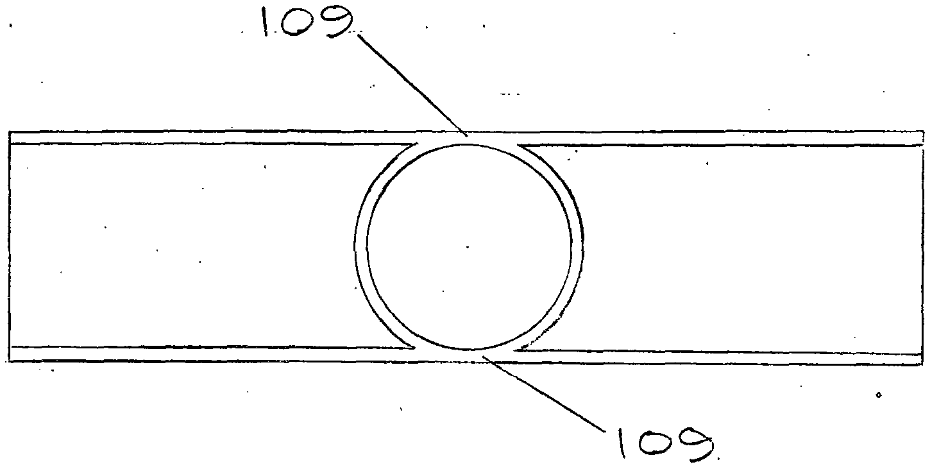


Fig 1D

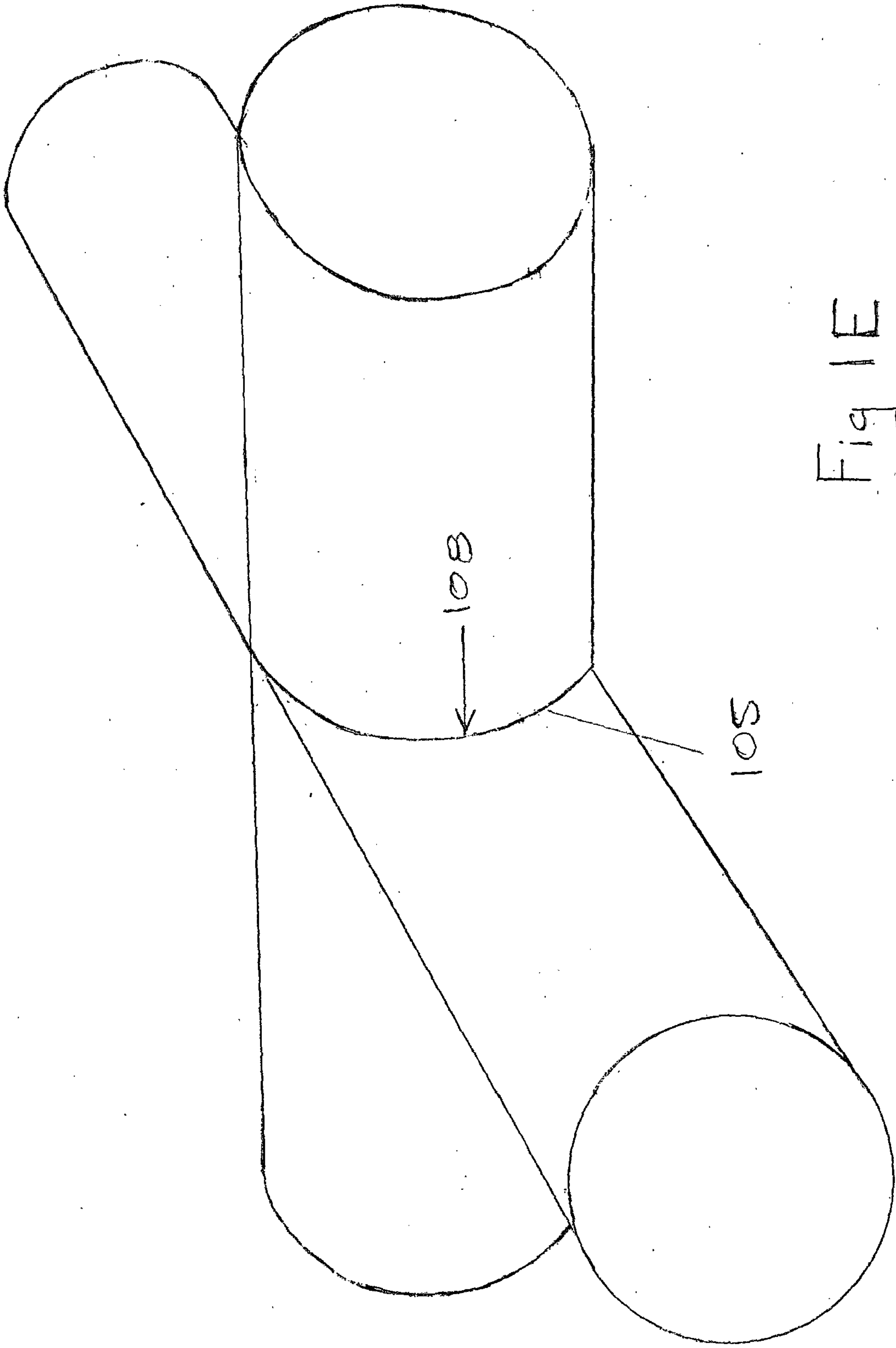


Fig 1E

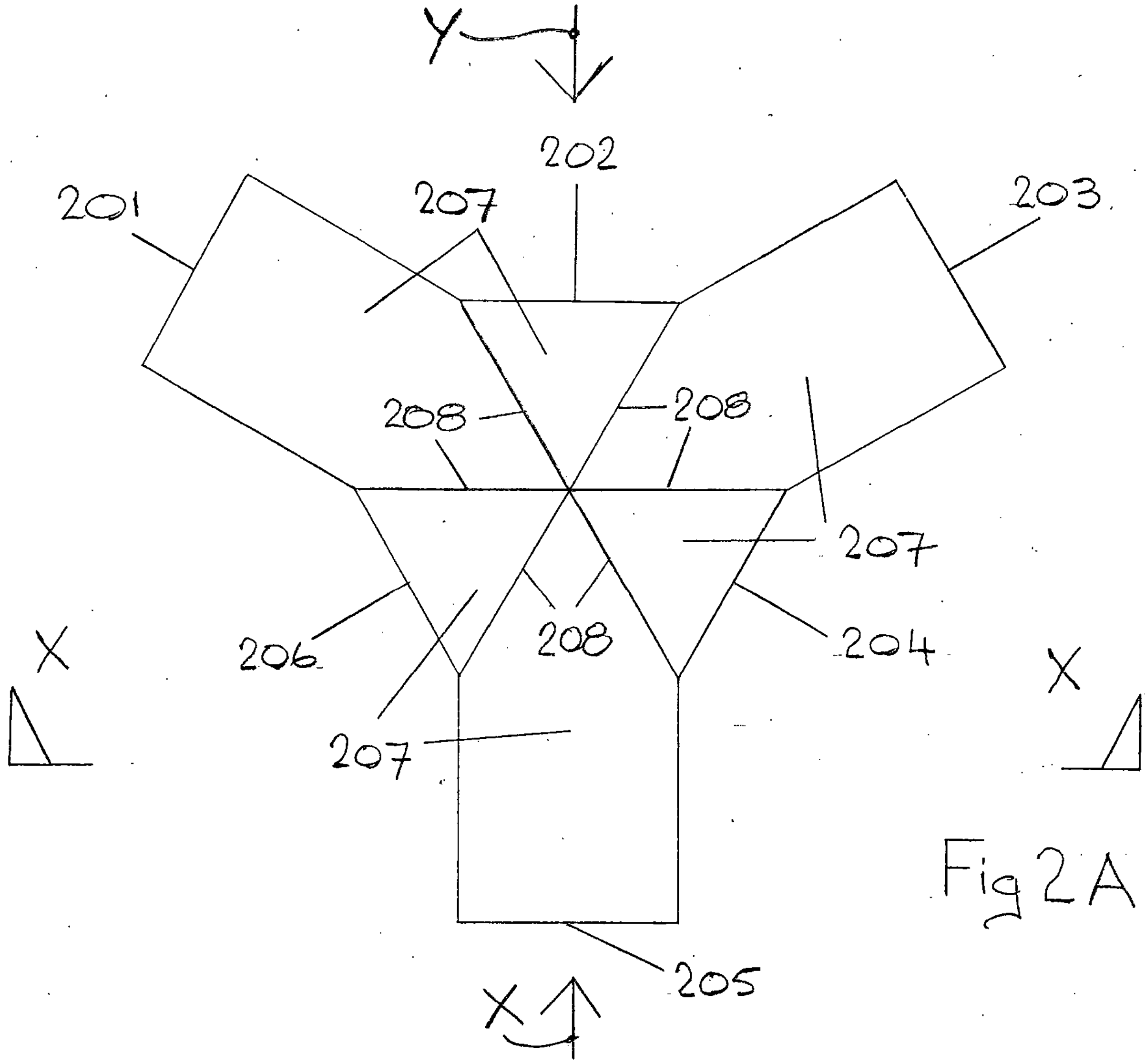

Y
202
201
207
203
208
208
207
206
208
204
X
X
207
205
X

Fig 2A

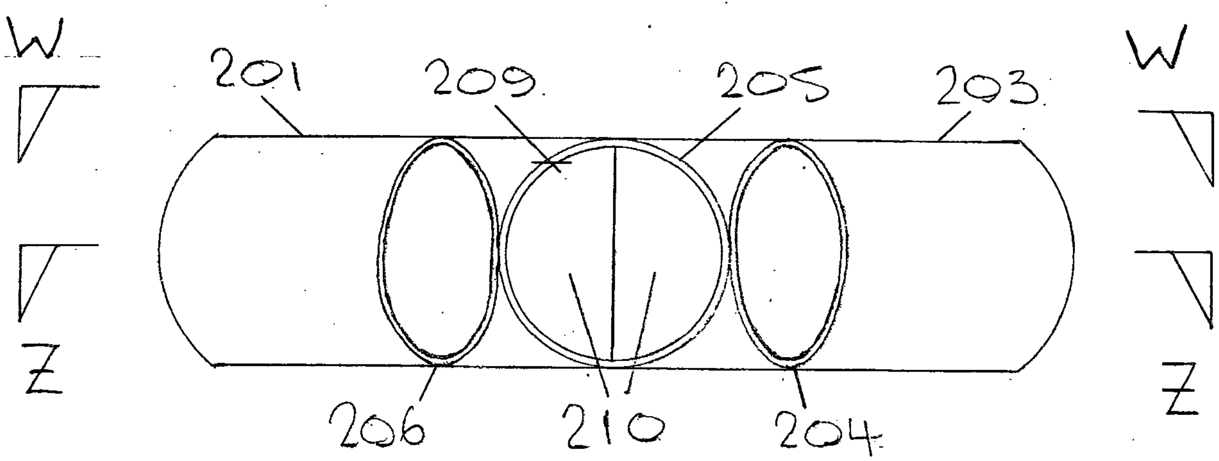

W
201
209
205
203
W
Z
206
210
204
Z

Fig 2B

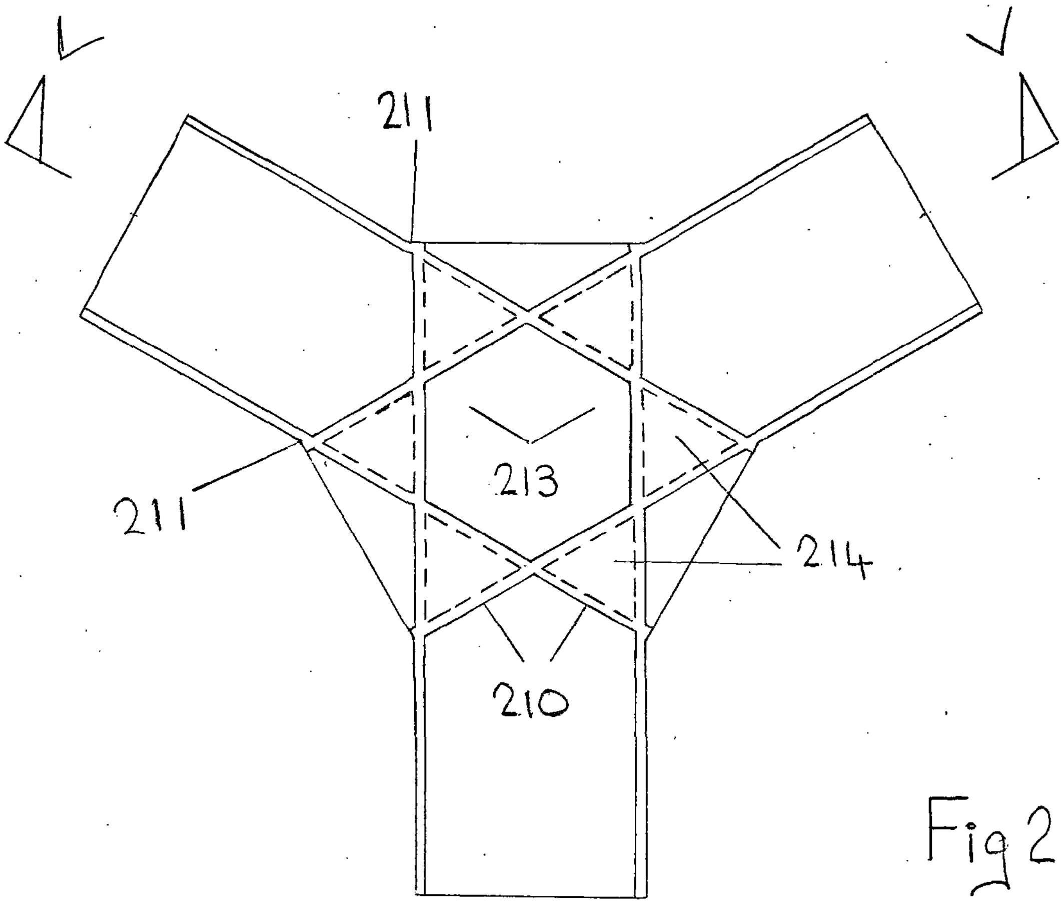


Fig 2C

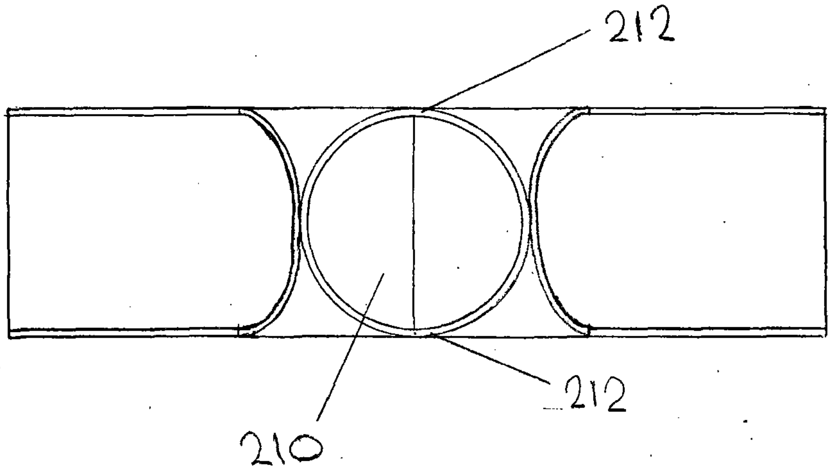


Fig 2D

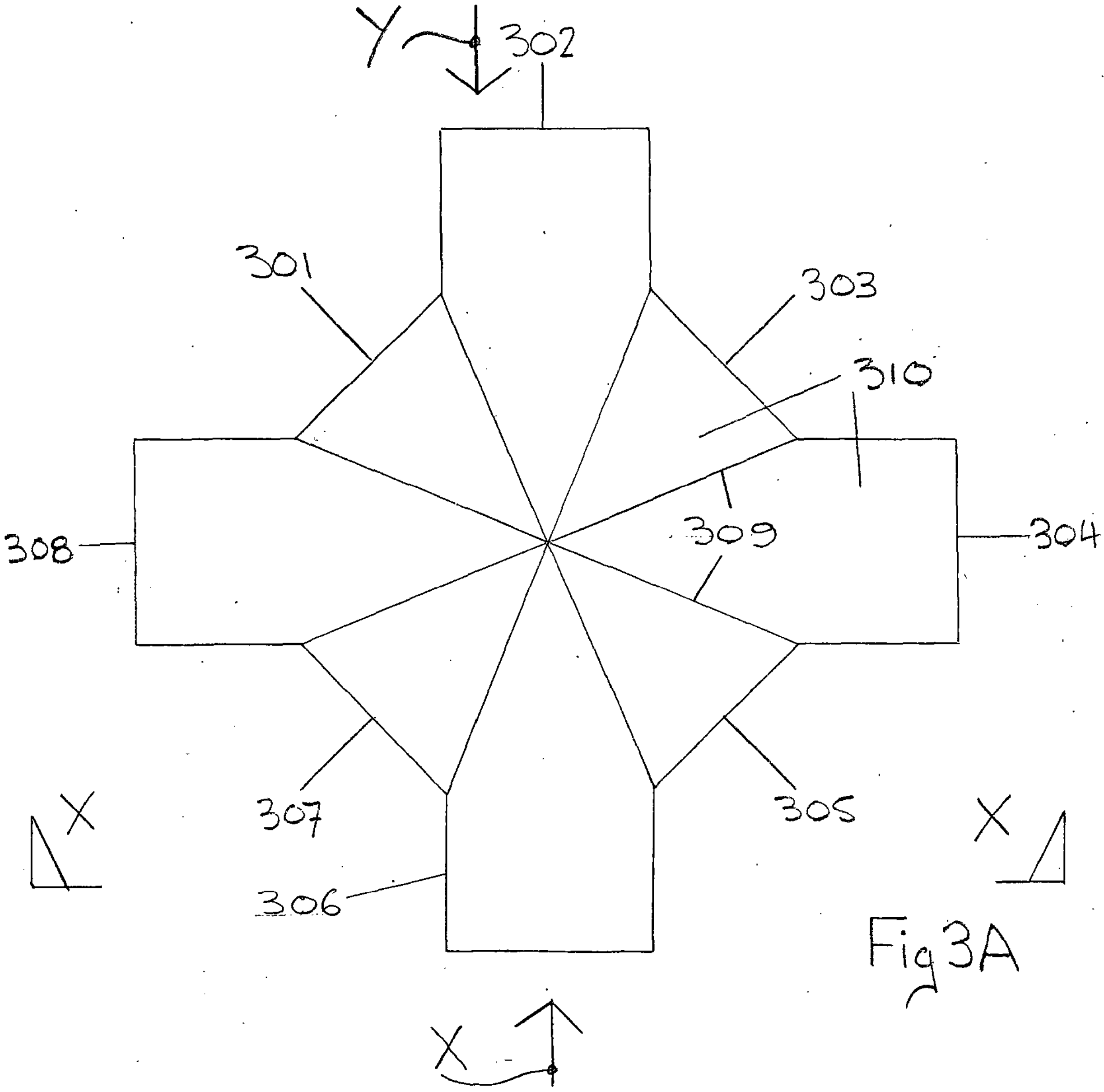


Fig 3A

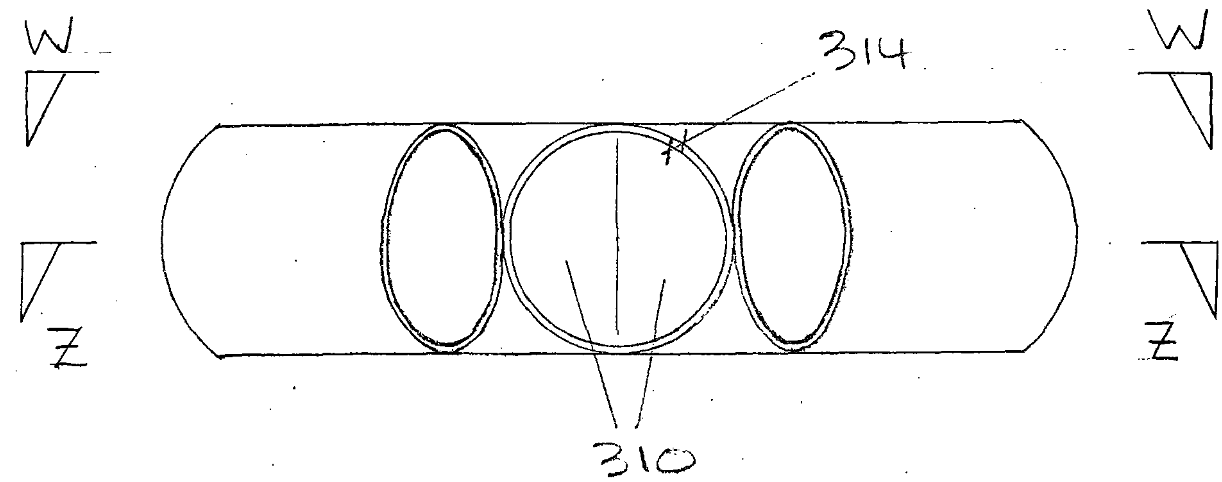


Fig 3B

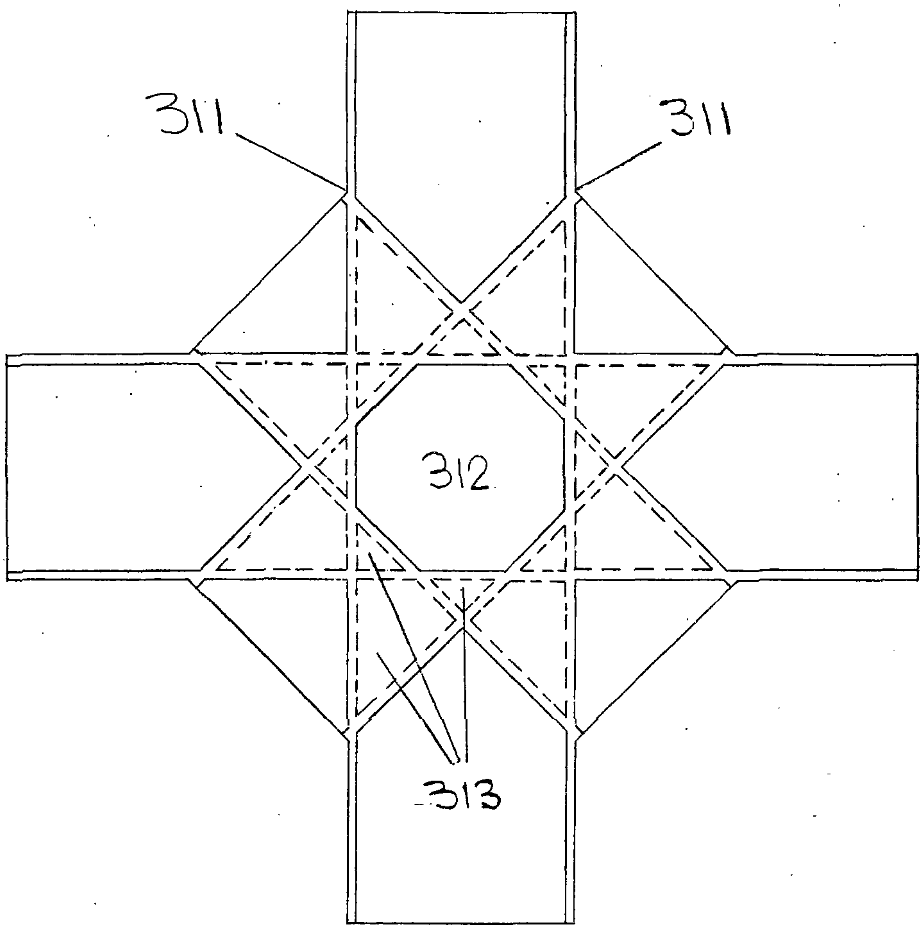


Fig 3C

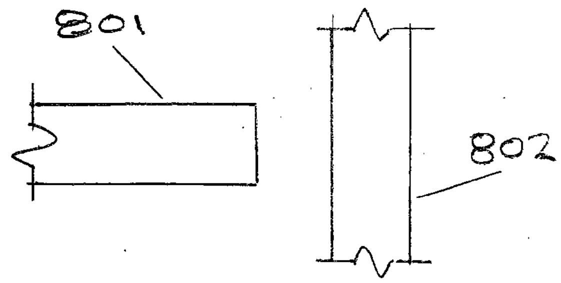


Fig 4A-1

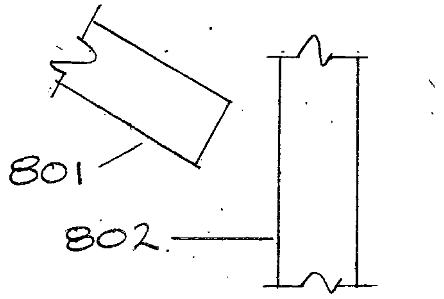


Fig 4A-2

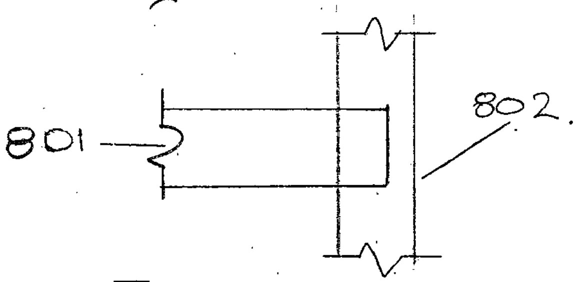


Fig 4B-1

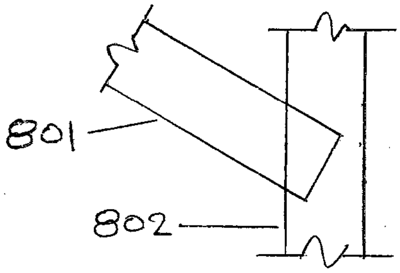


Fig 4B-2

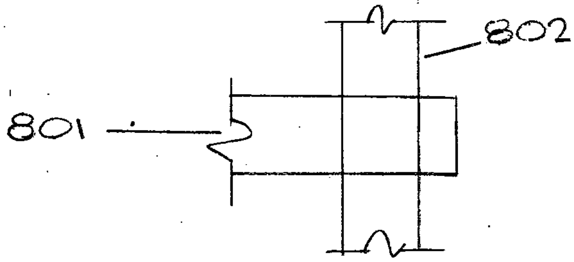


Fig 4C-1

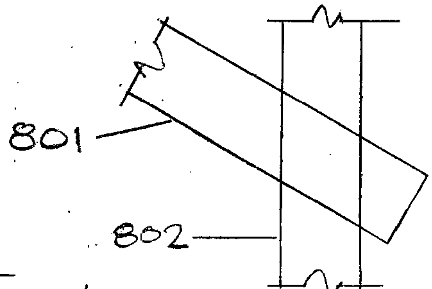


Fig 4C-2

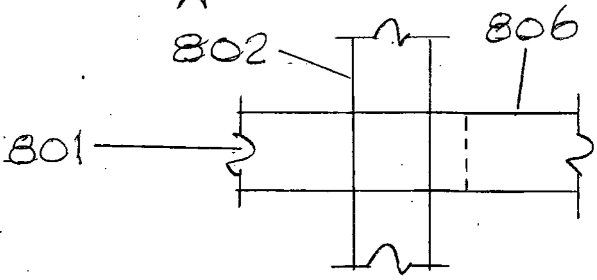


Fig 4D-1

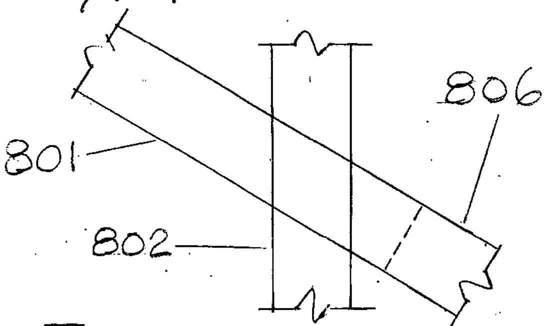


Fig 4D-2

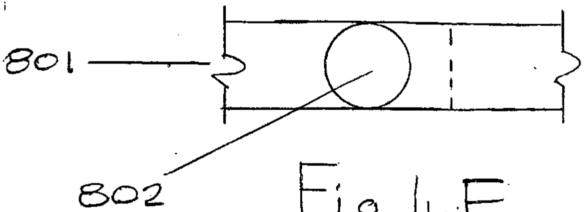


Fig 4E

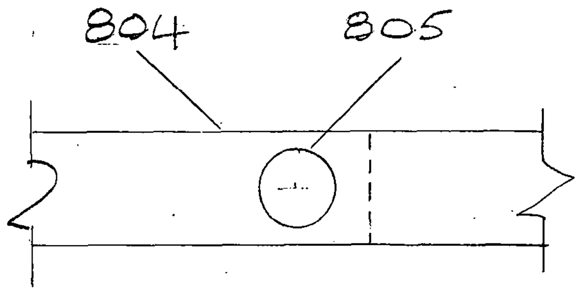


Fig 4F-1

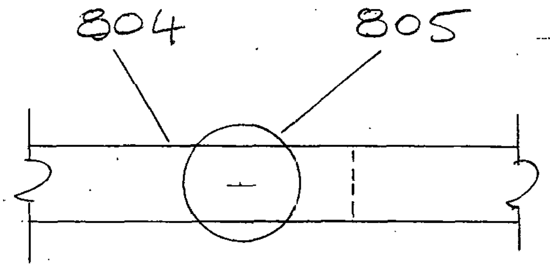


Fig 4F-2

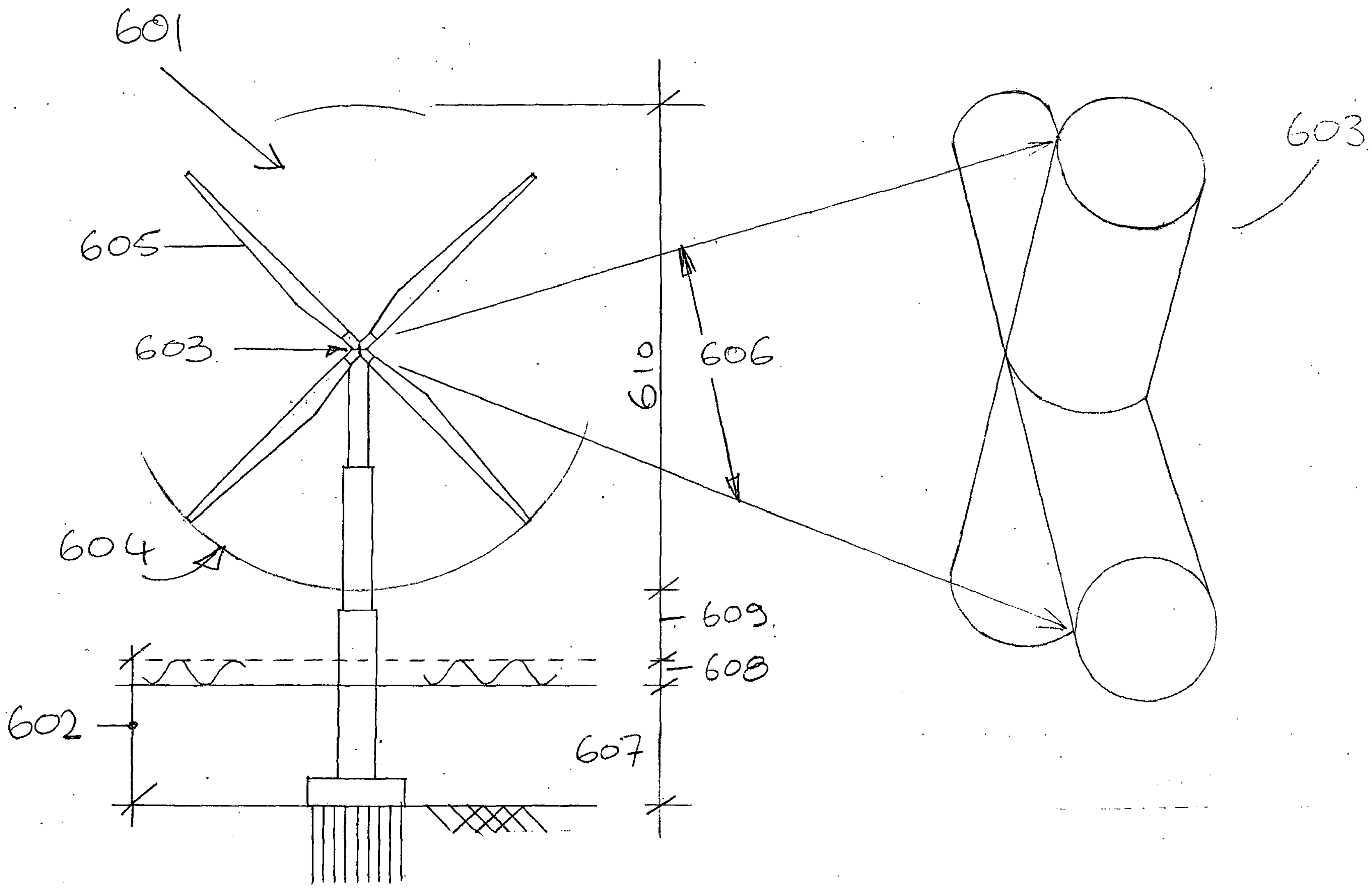
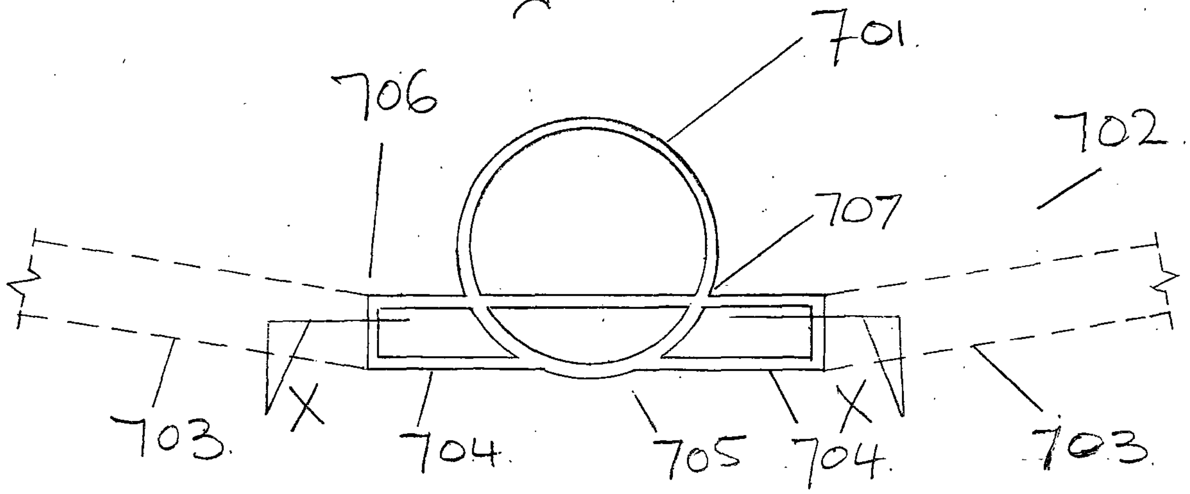


Fig 5A

Fig 5B

Fig 6A


701
706
702
707
703
X
704
705
704
X
703

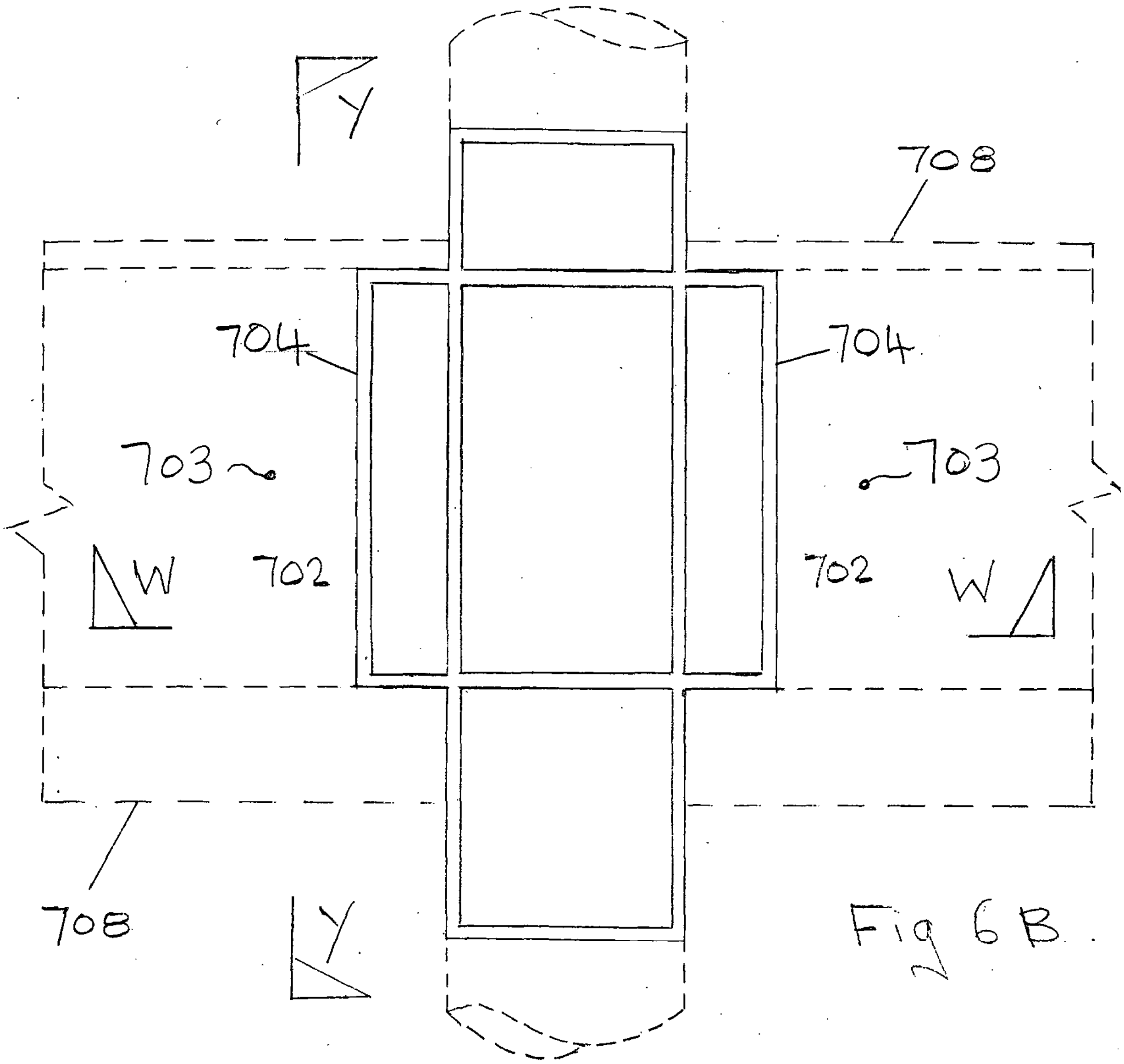

Y
708
704
704
703
703
W
702
702
W
708
Y

Fig 6B

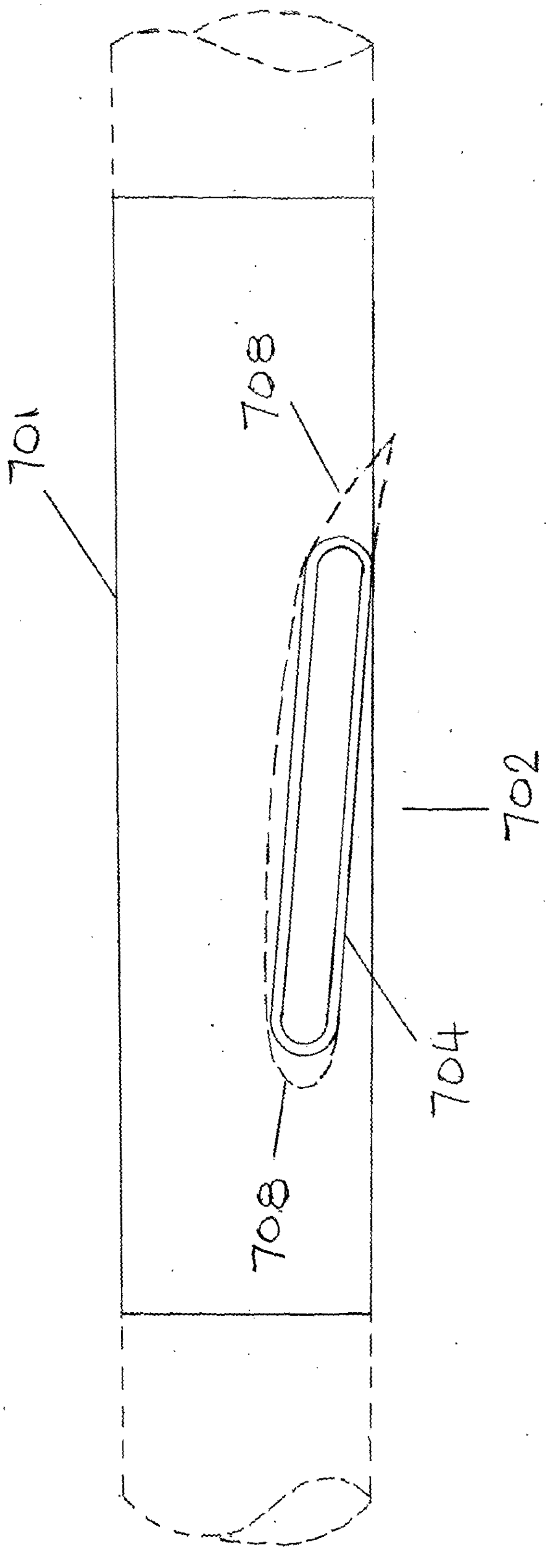


Fig 6C

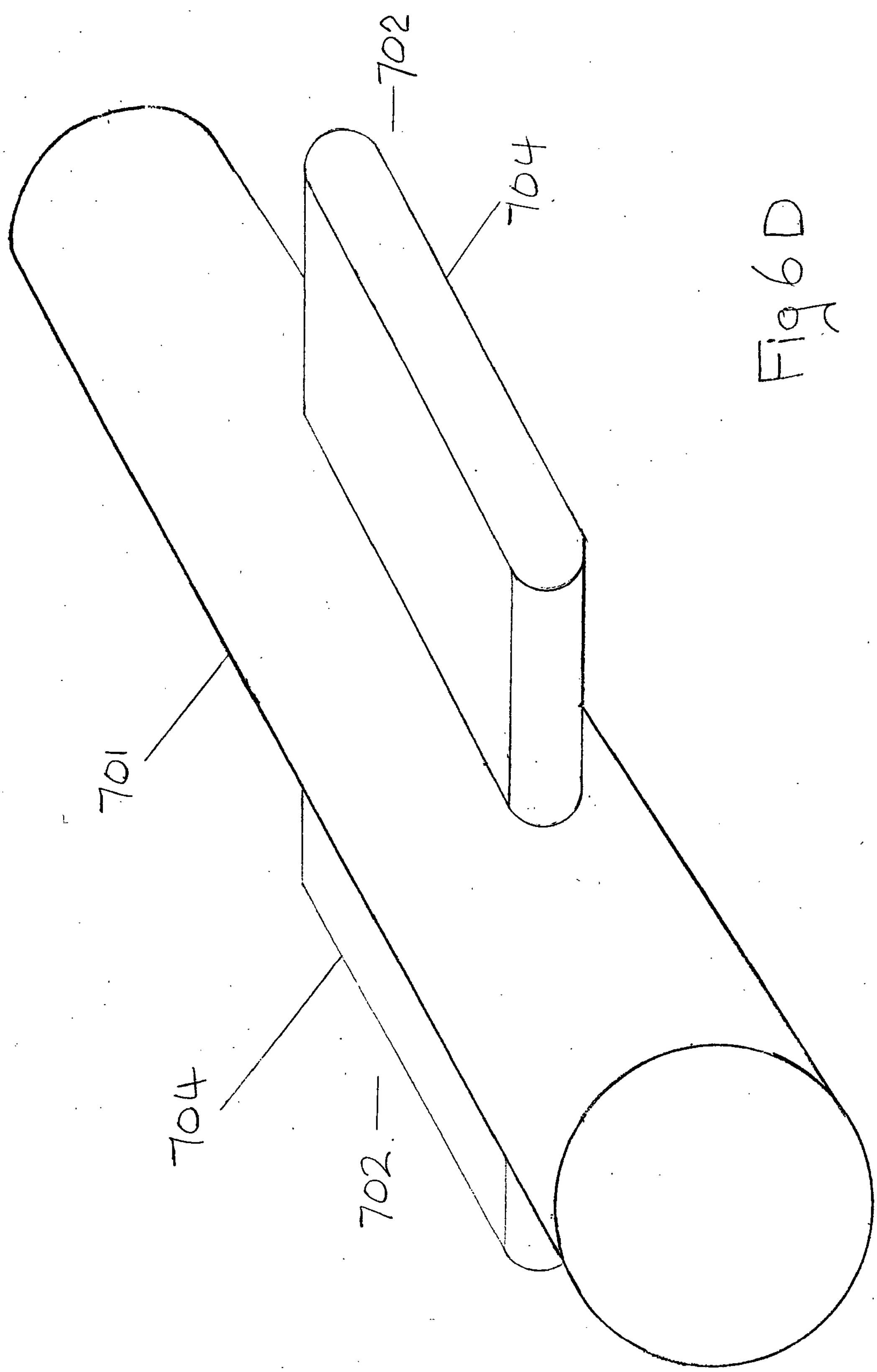


Fig 6D

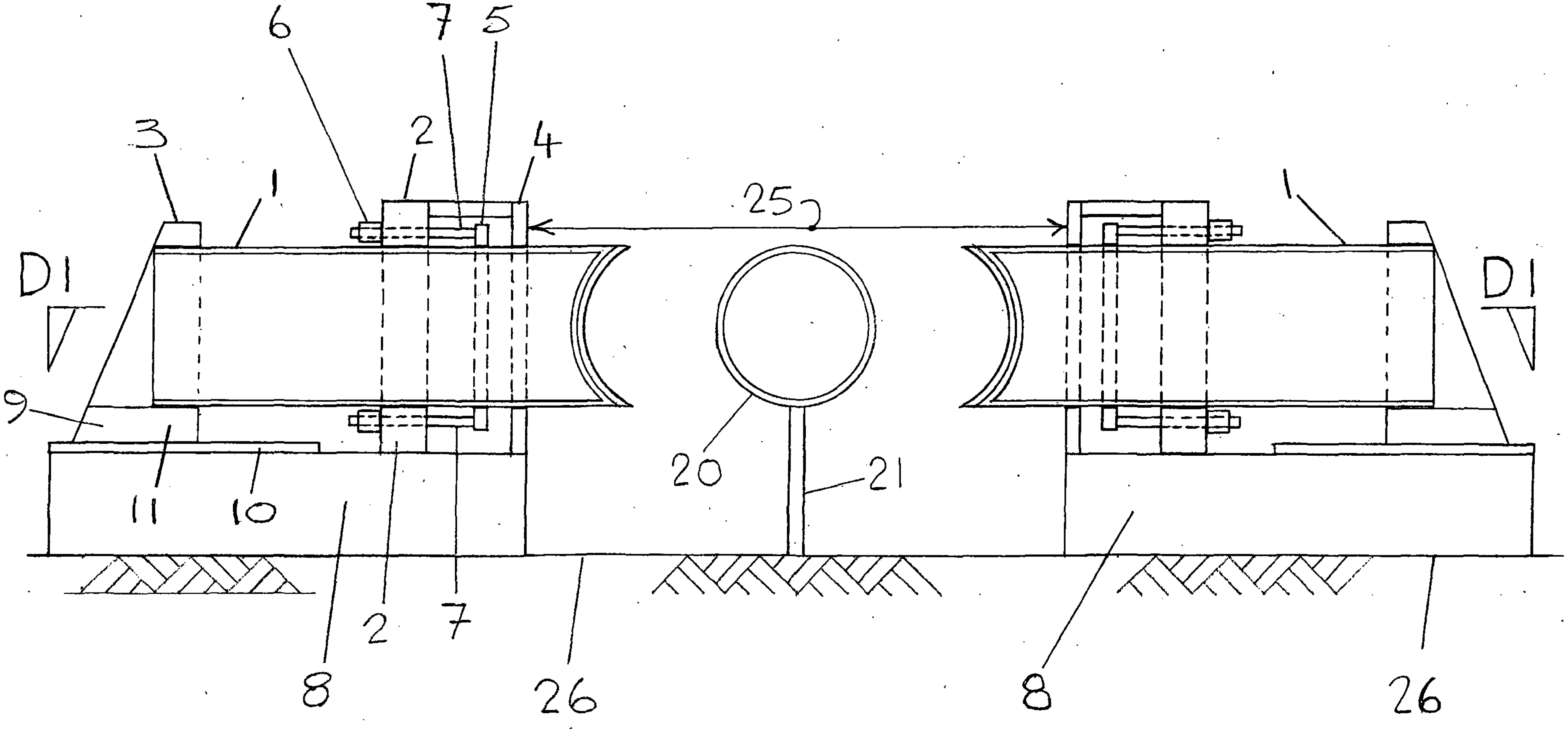


Fig 7A

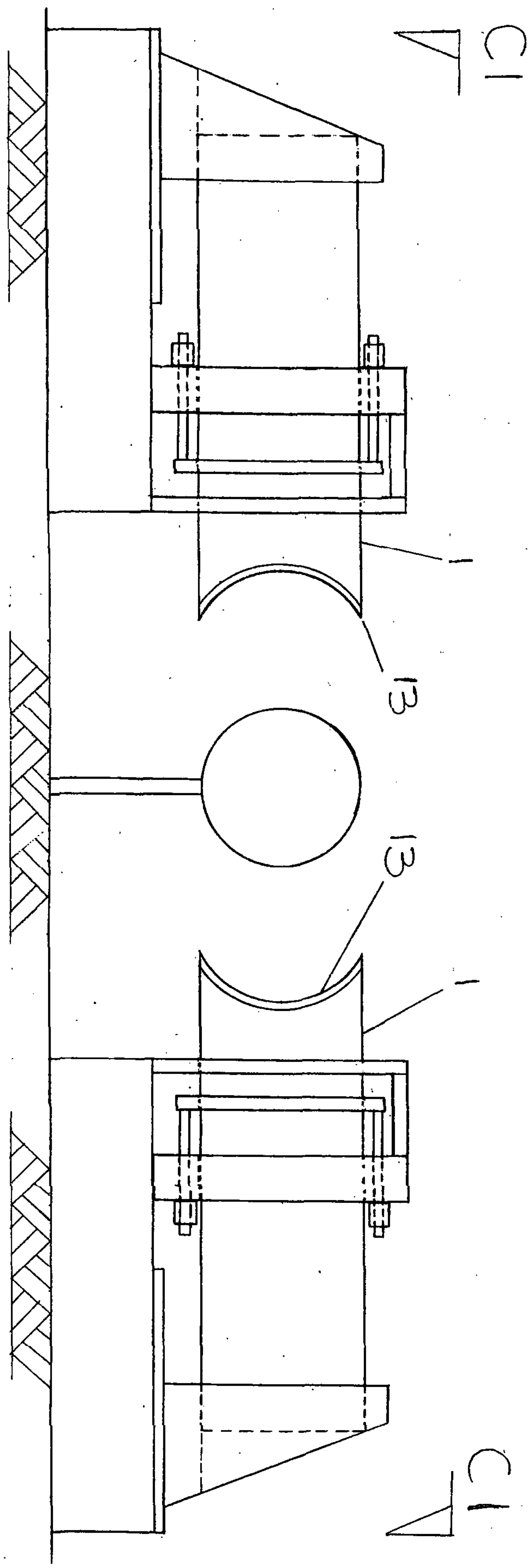


Fig 7B

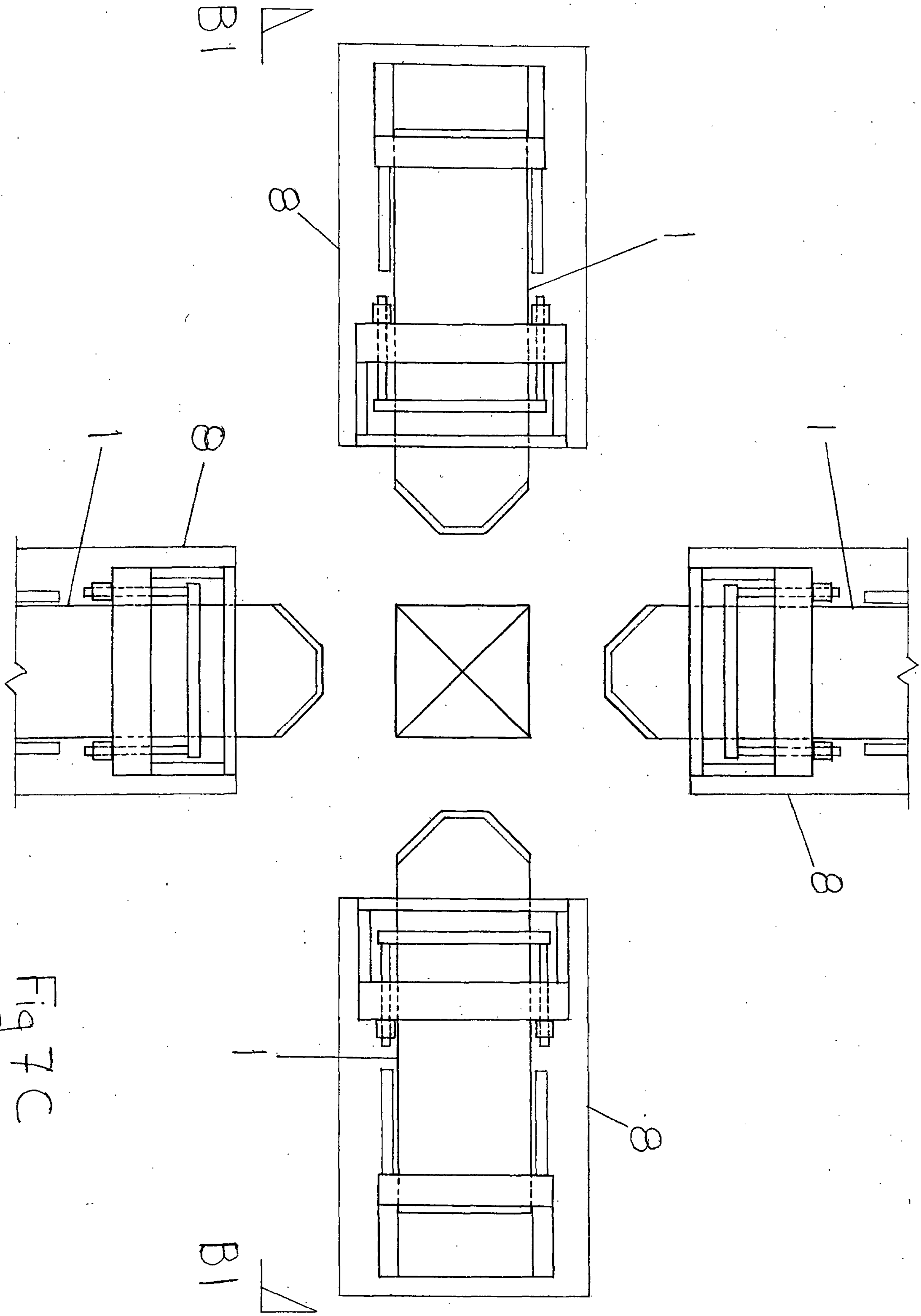


Fig 7C

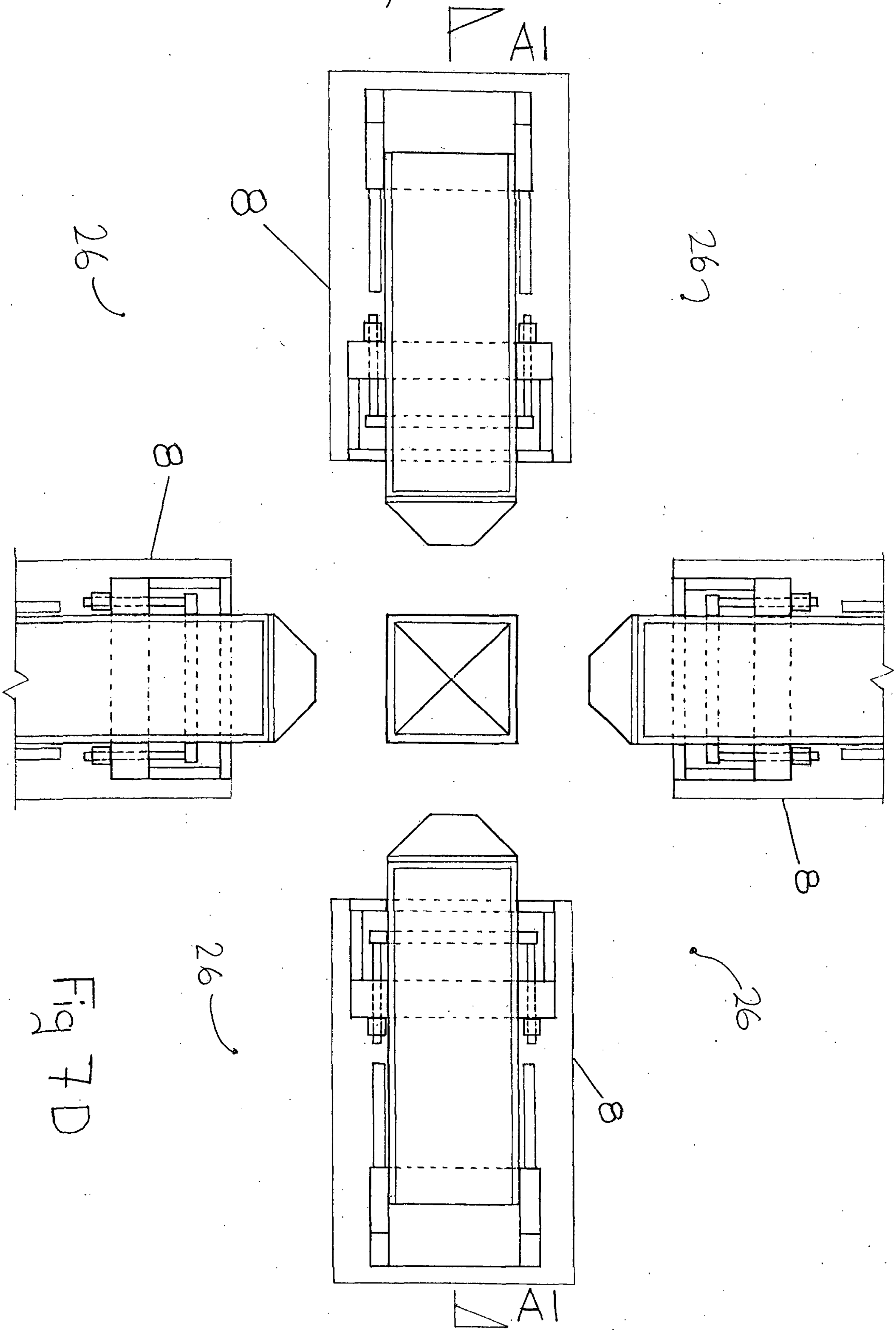


Fig 7D

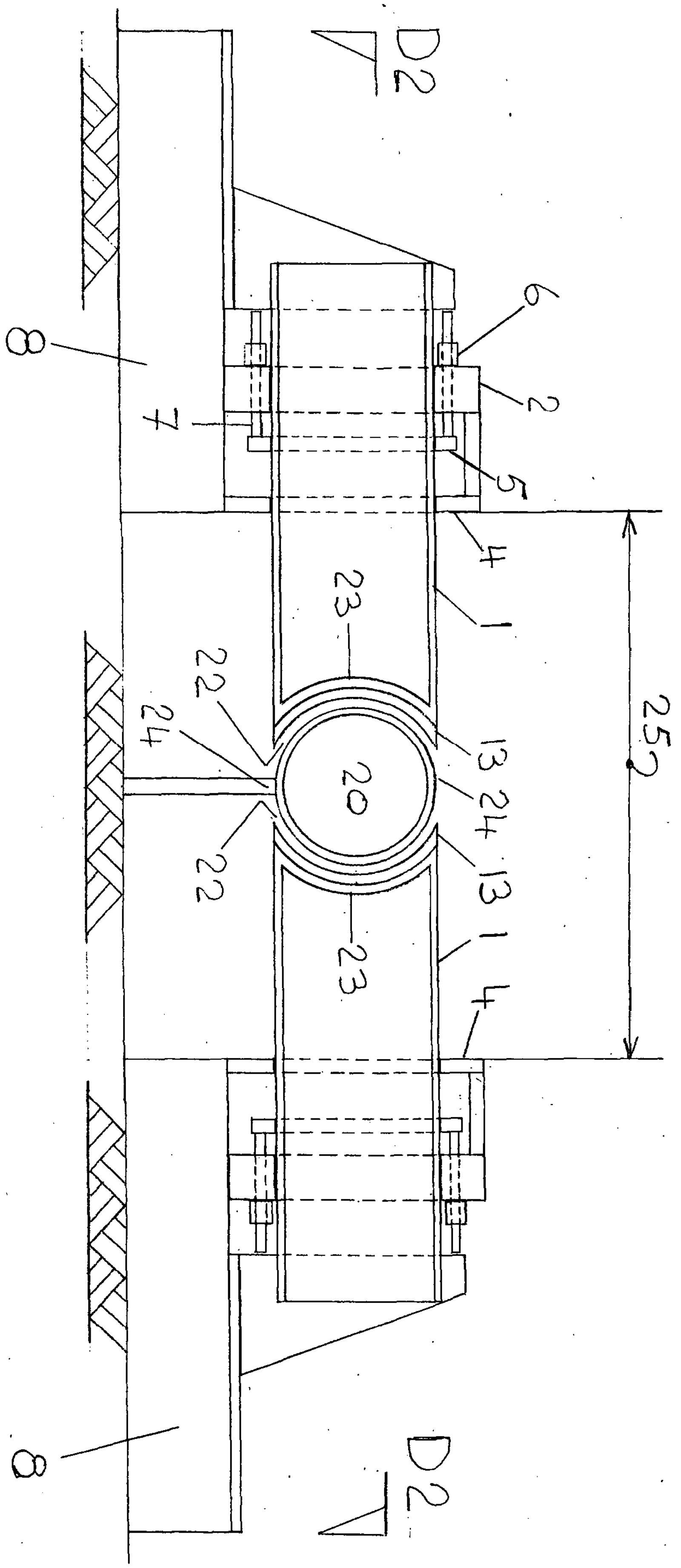


Fig 8A

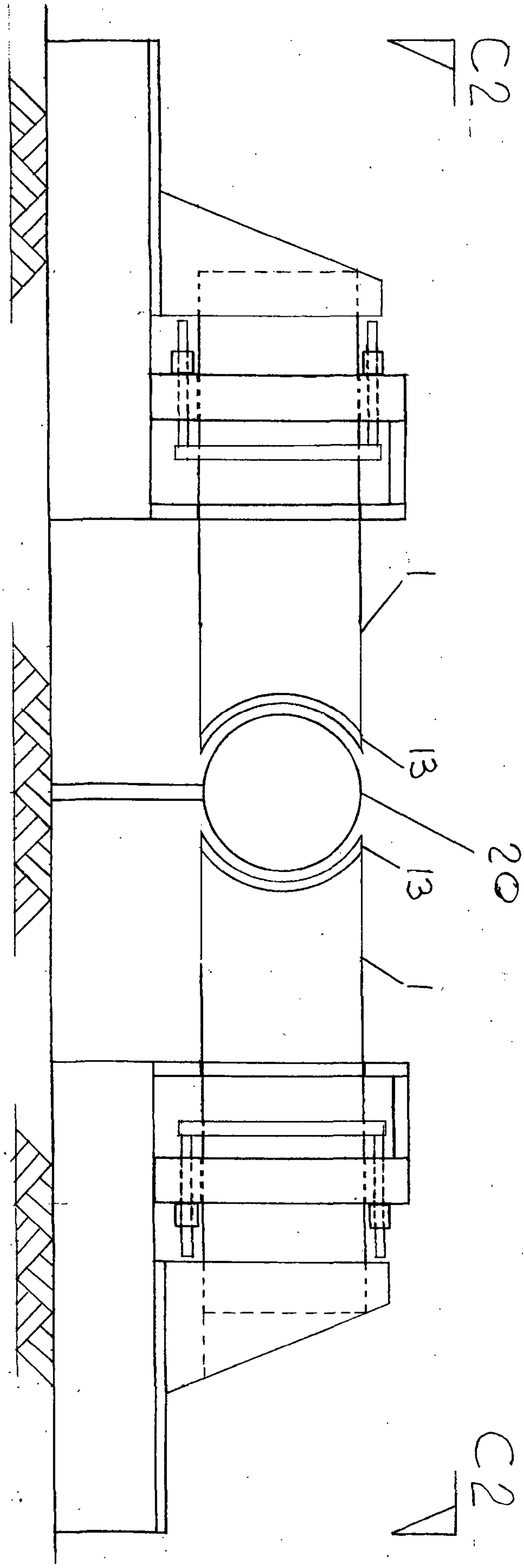


Fig 8B

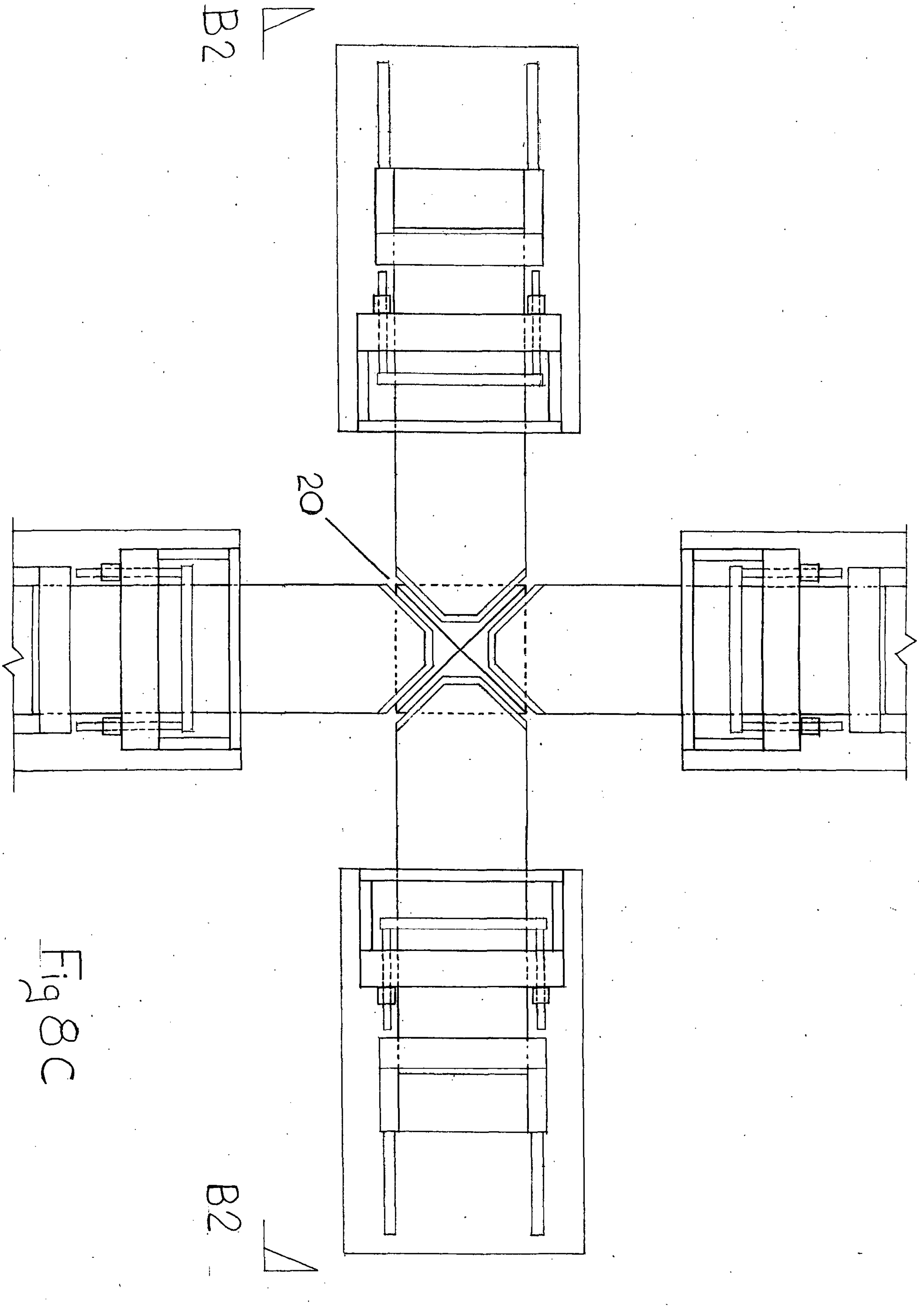


Fig 8C

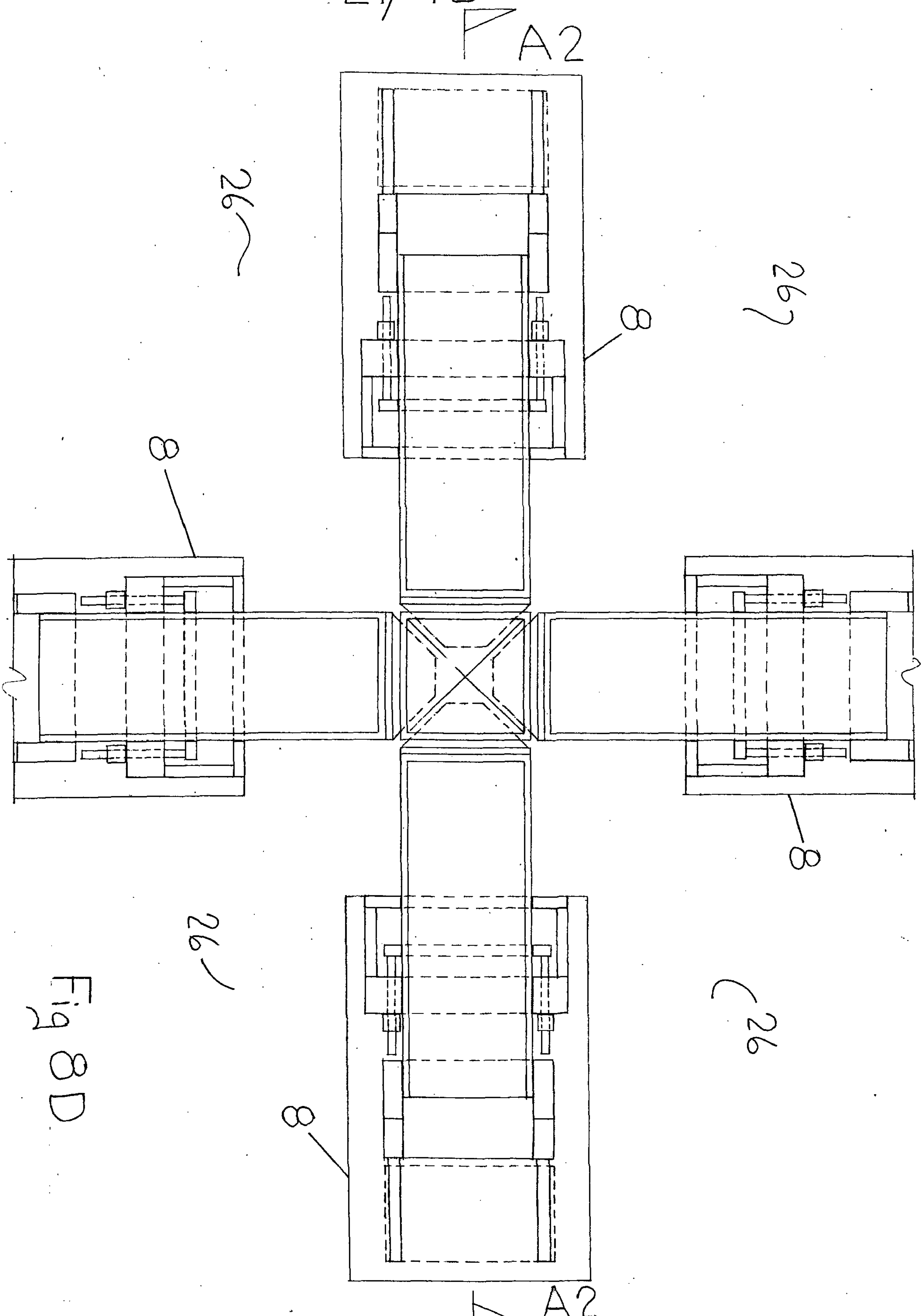


Fig 8D

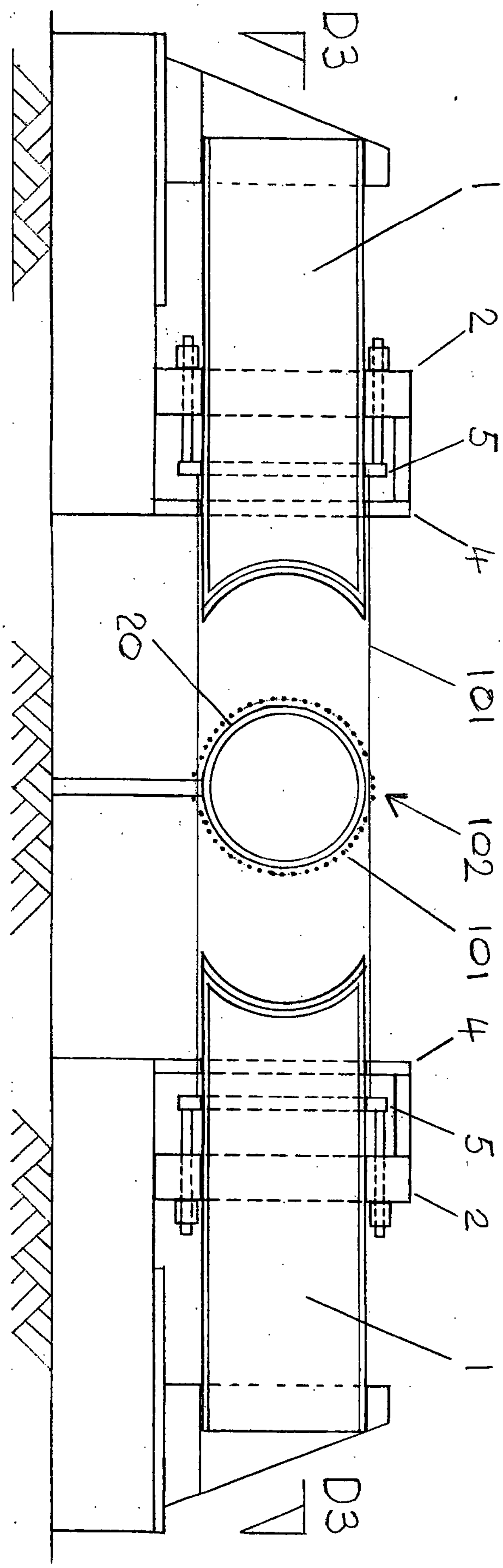


Fig 9A

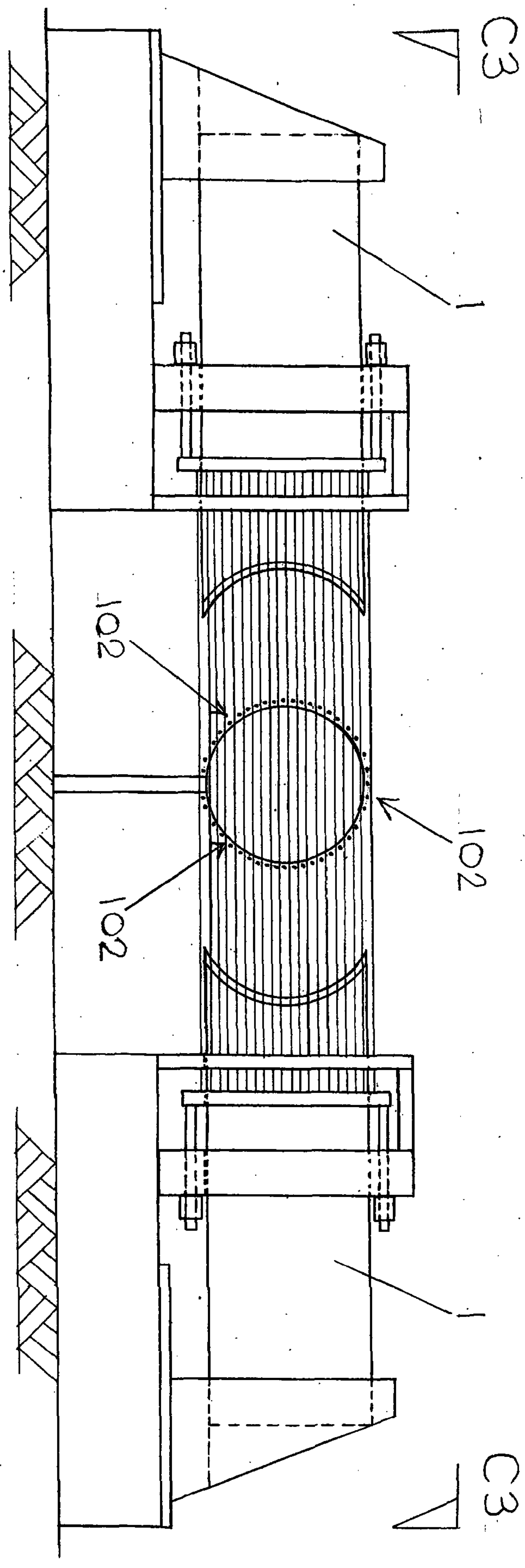


Fig 9B

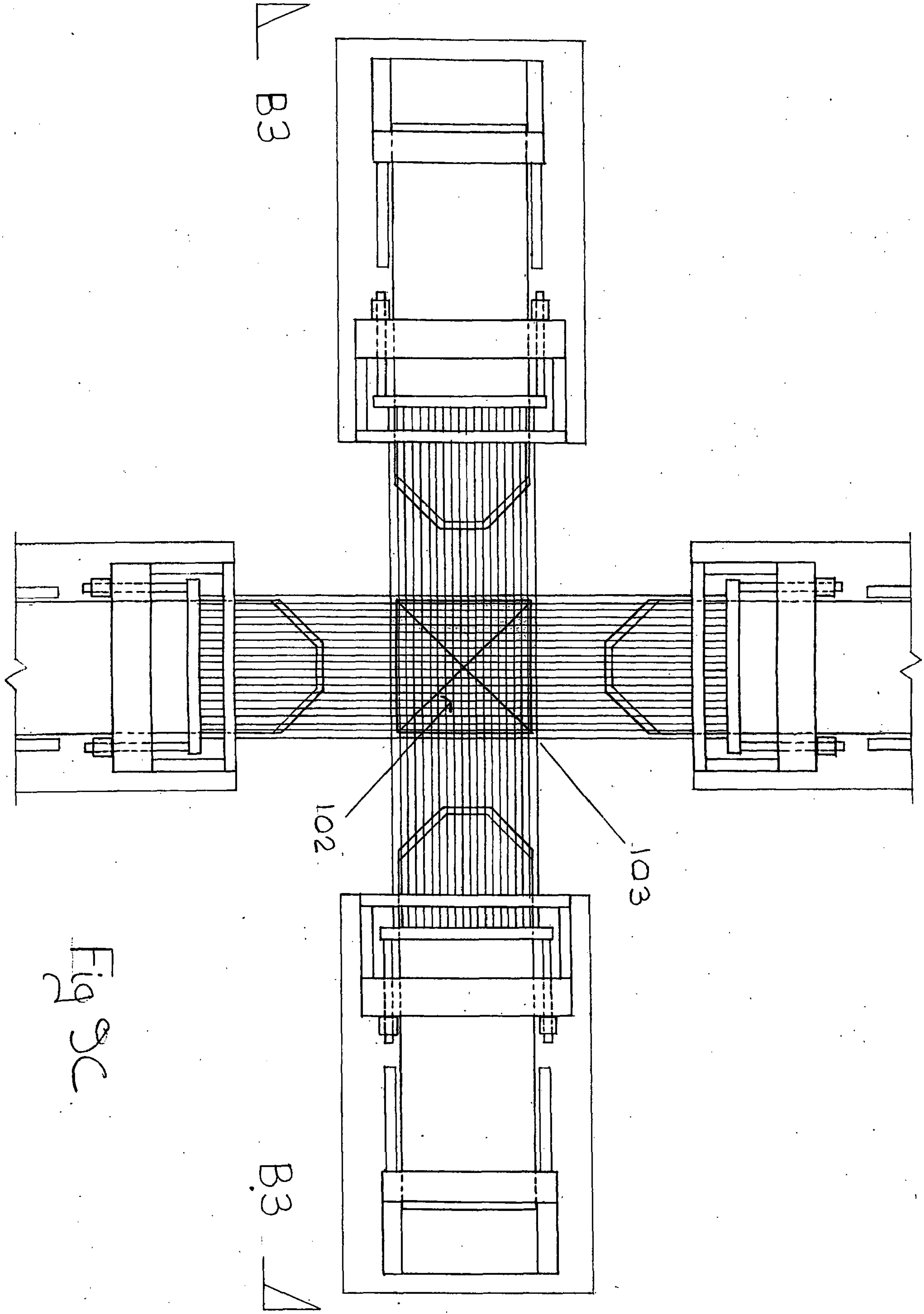


Fig 9C

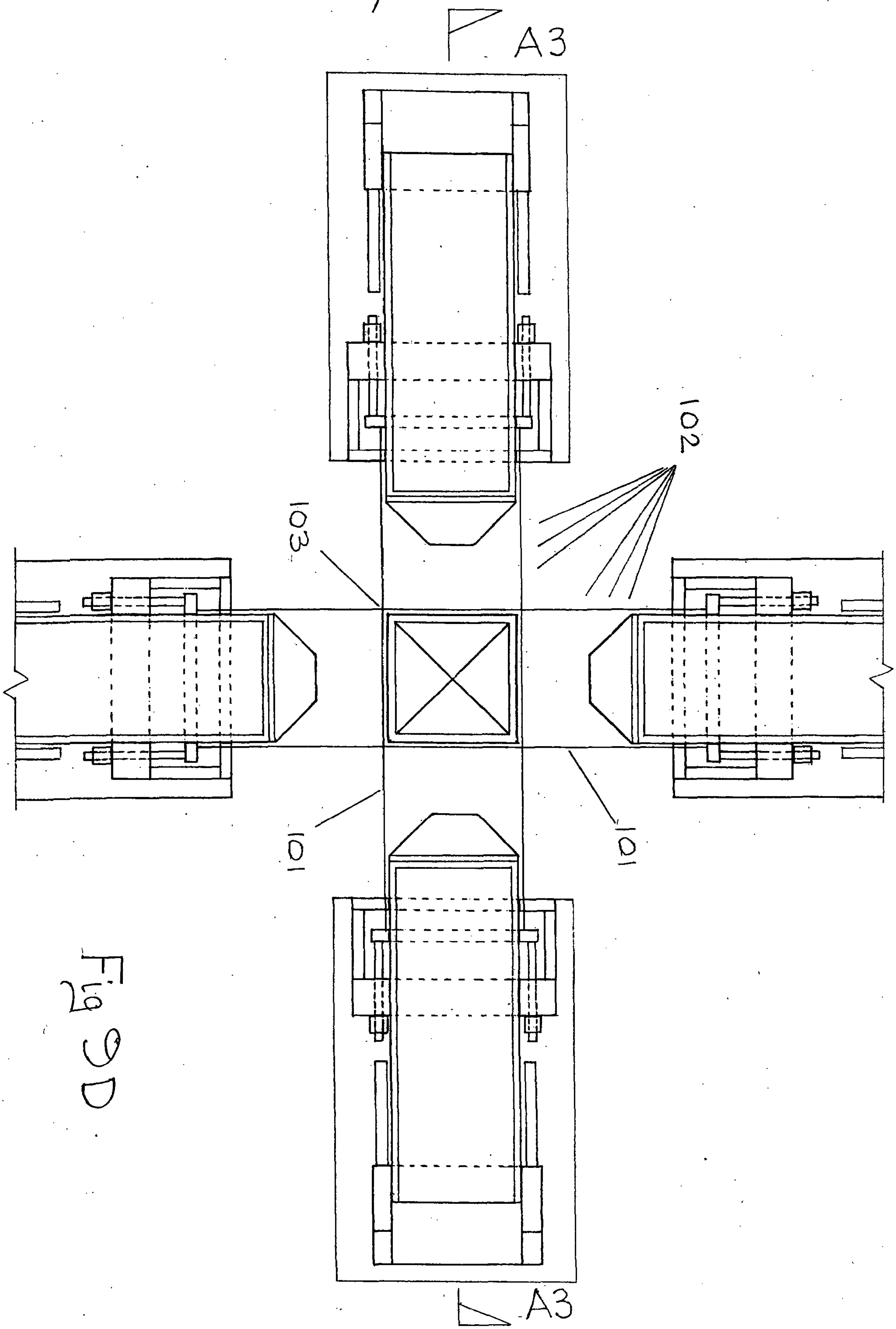


Fig 9D

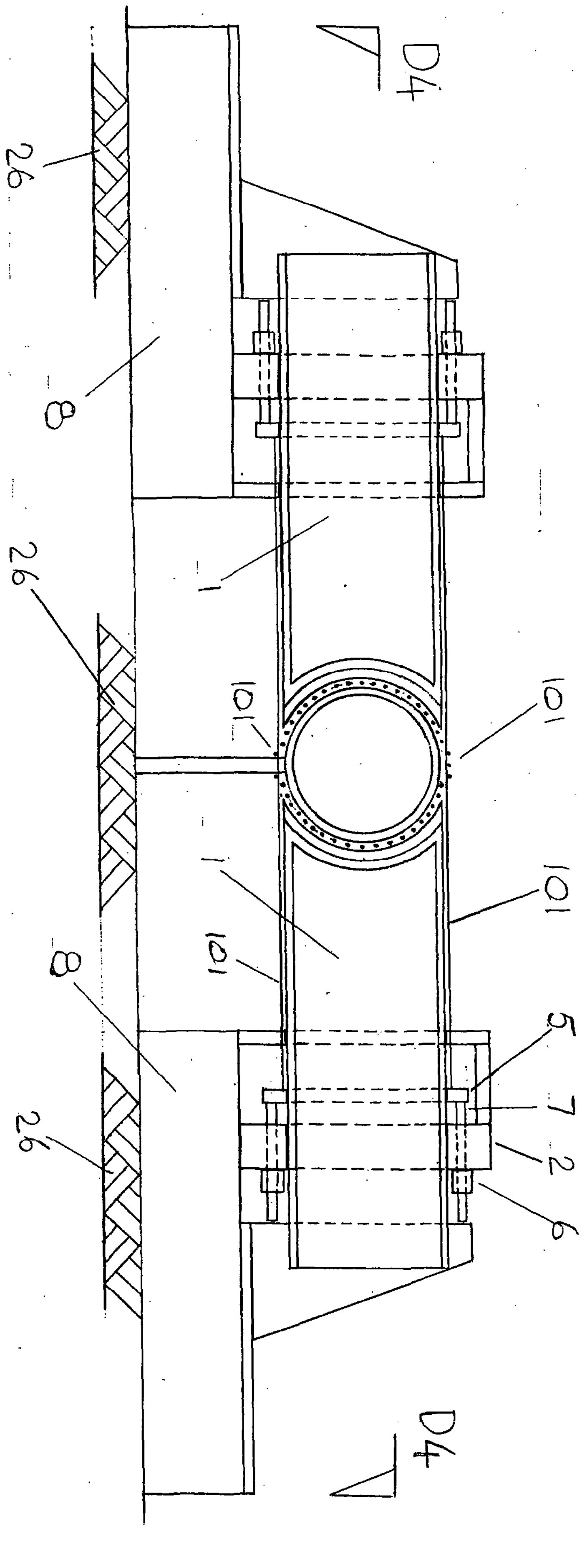


Fig 10A

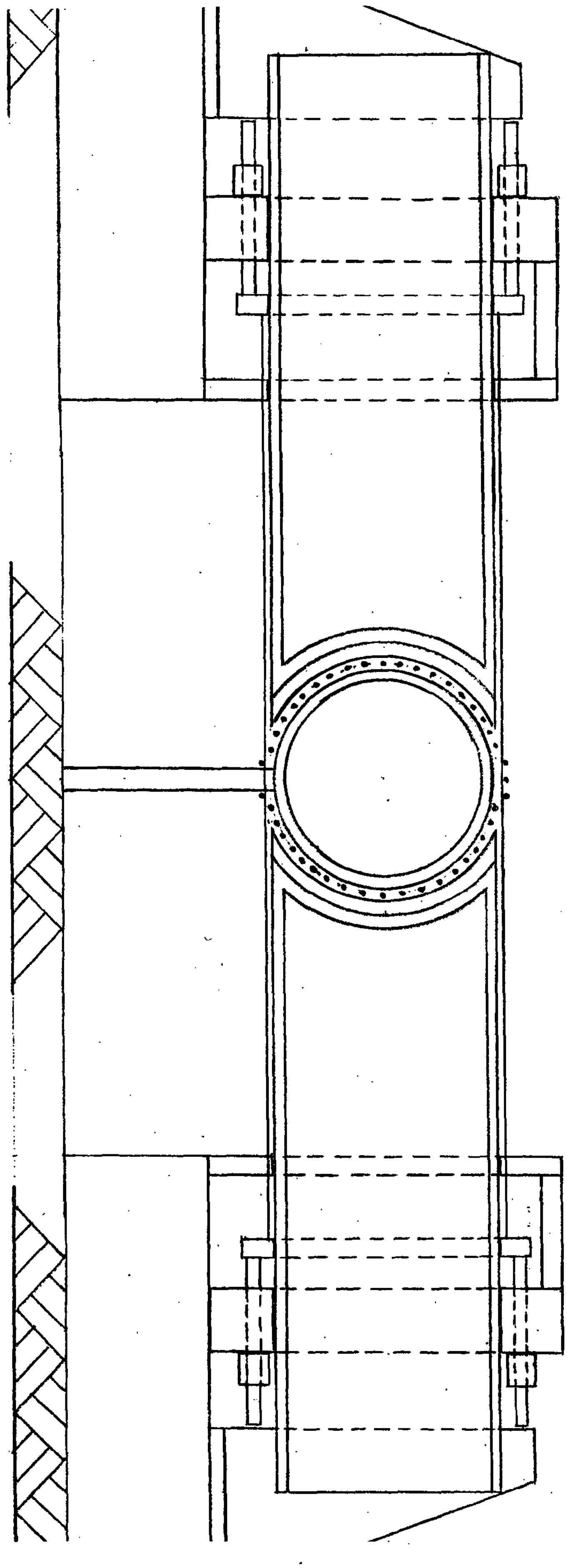


Fig 10A/1

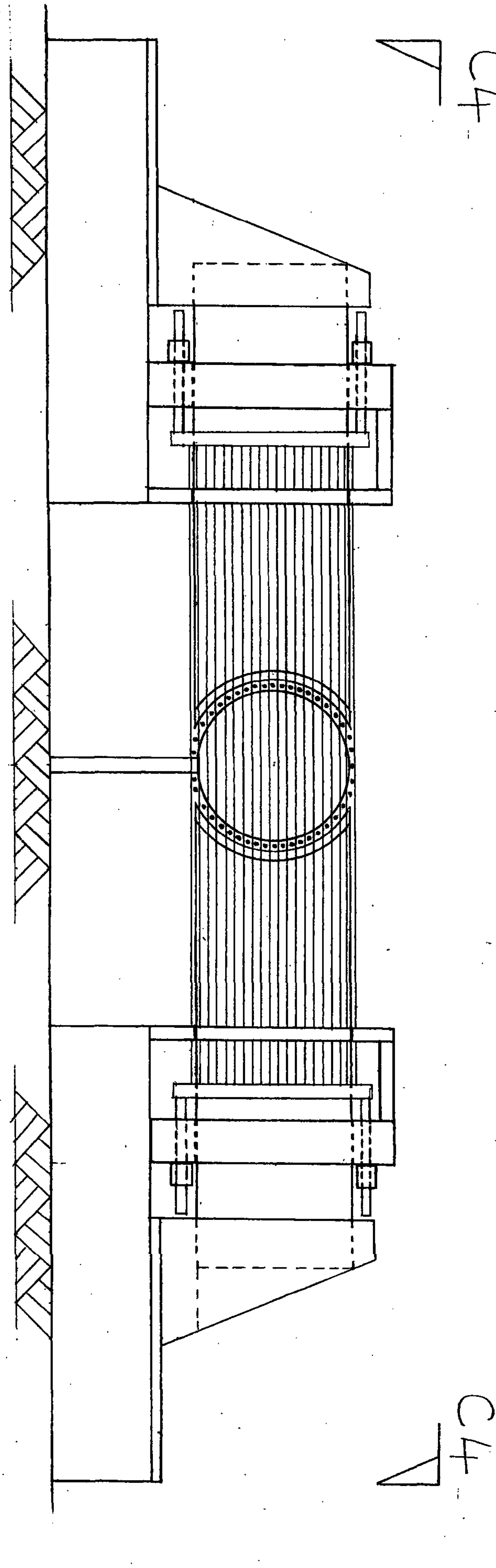


Fig 10B

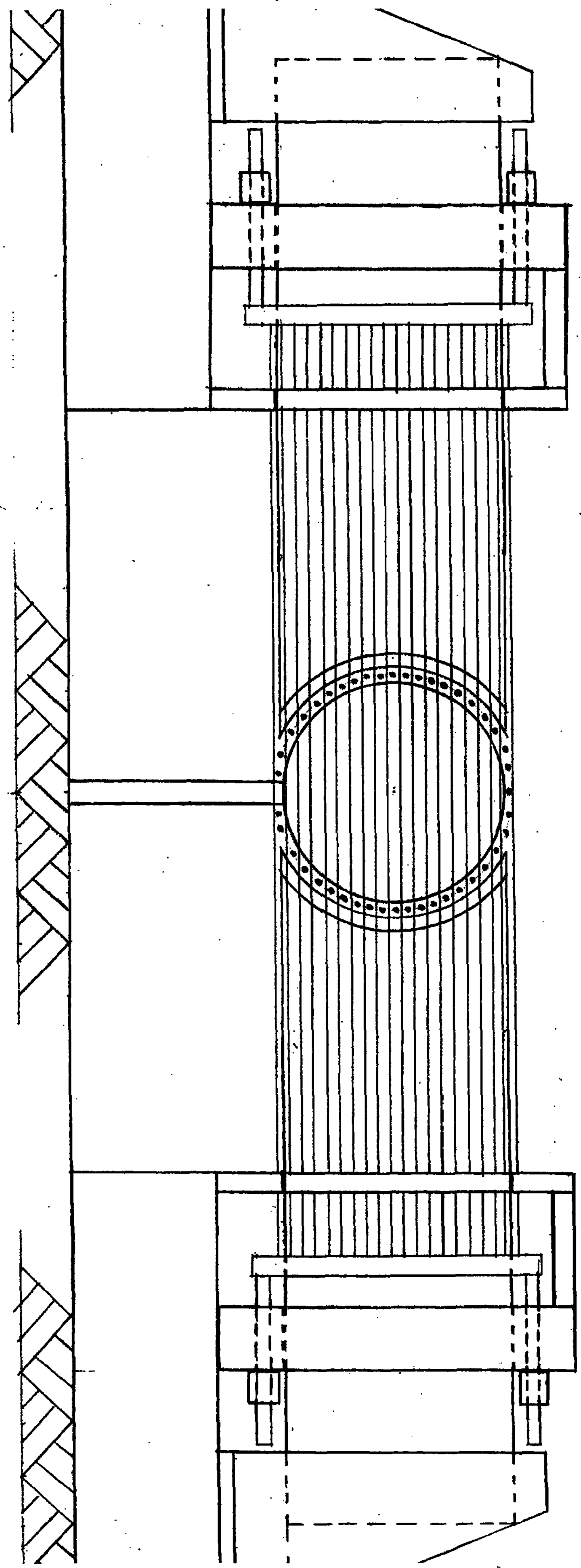
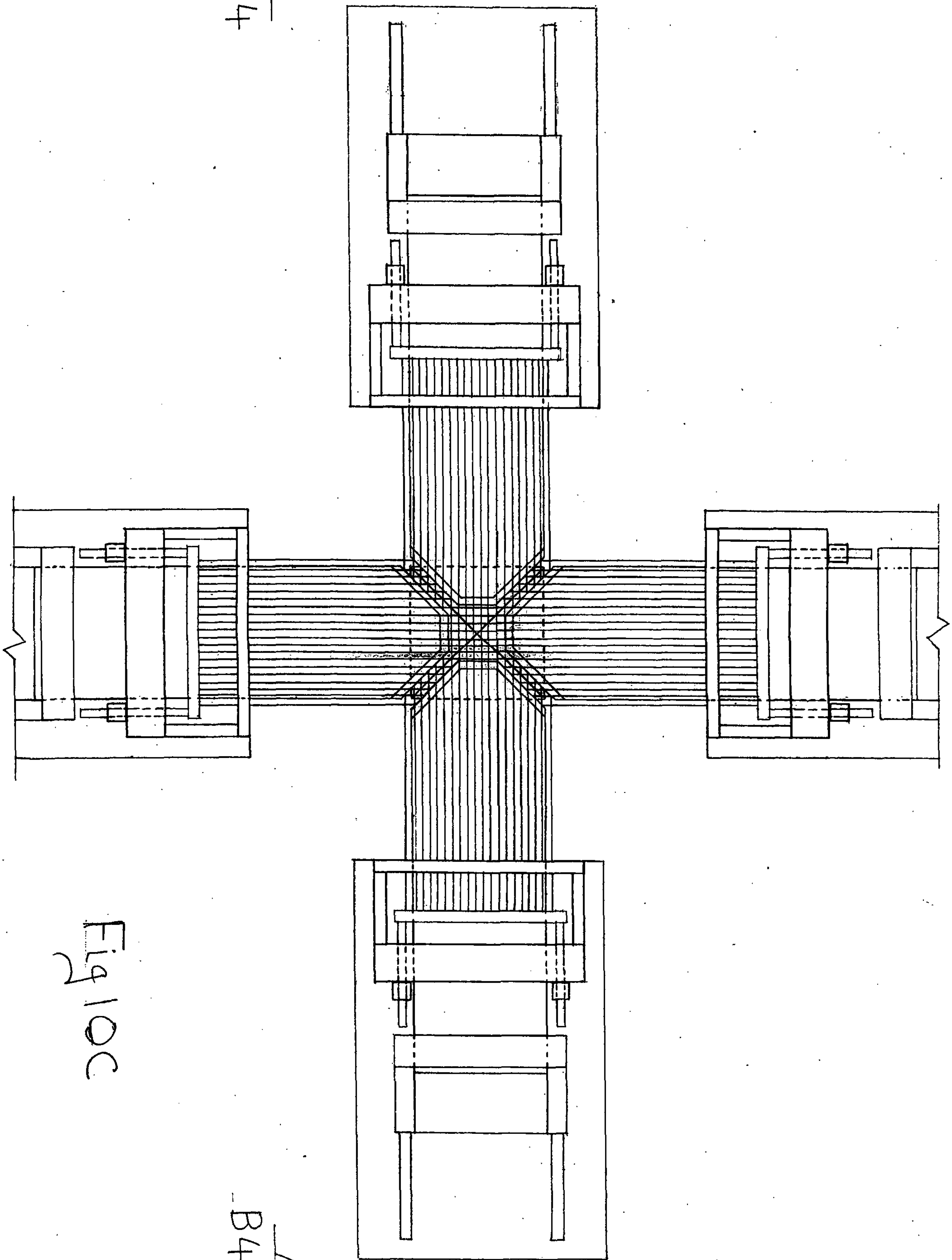


Fig 10B/1

B4



B4

Fig 10C

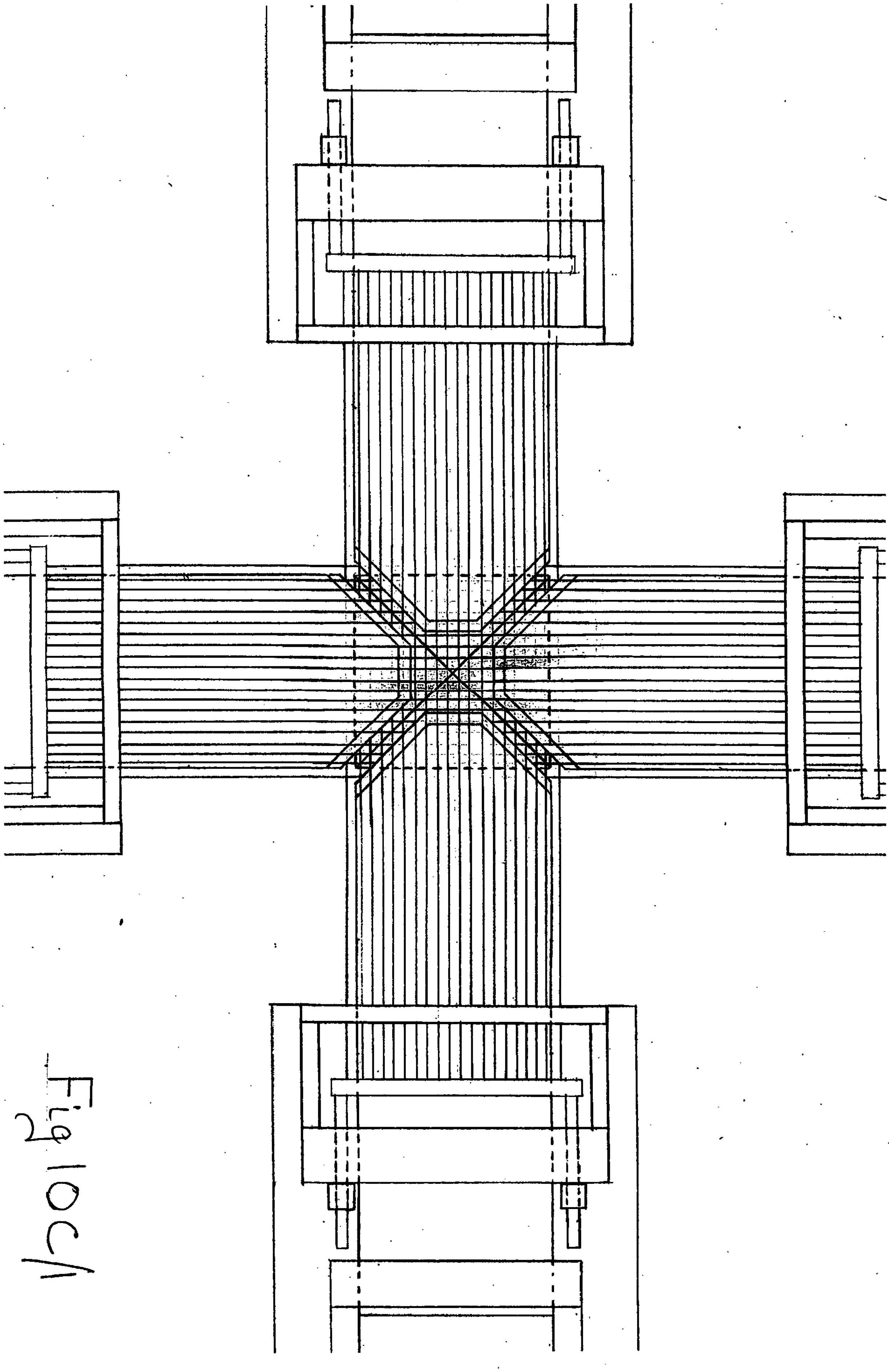


Fig 10C/1

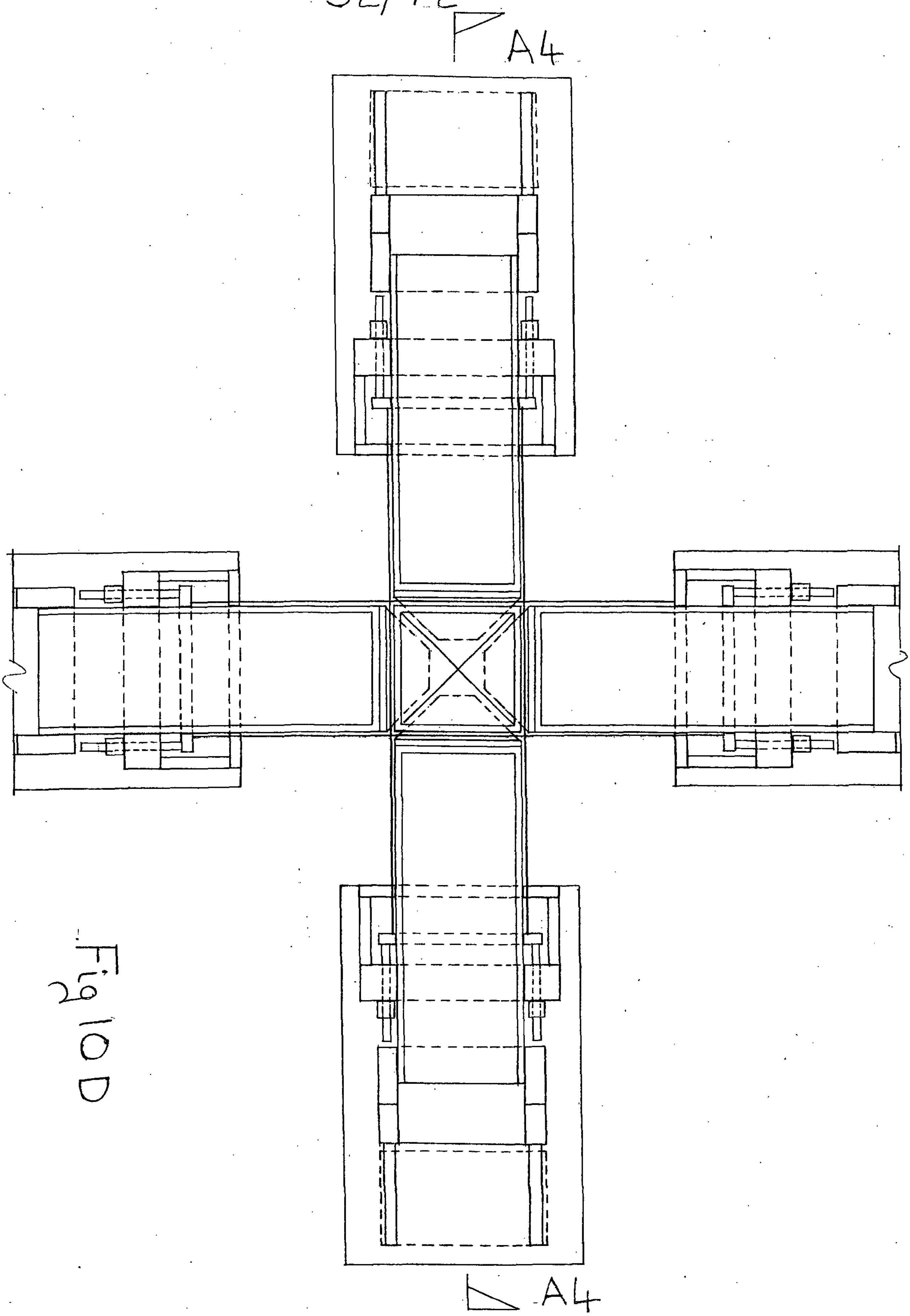


Fig 10D

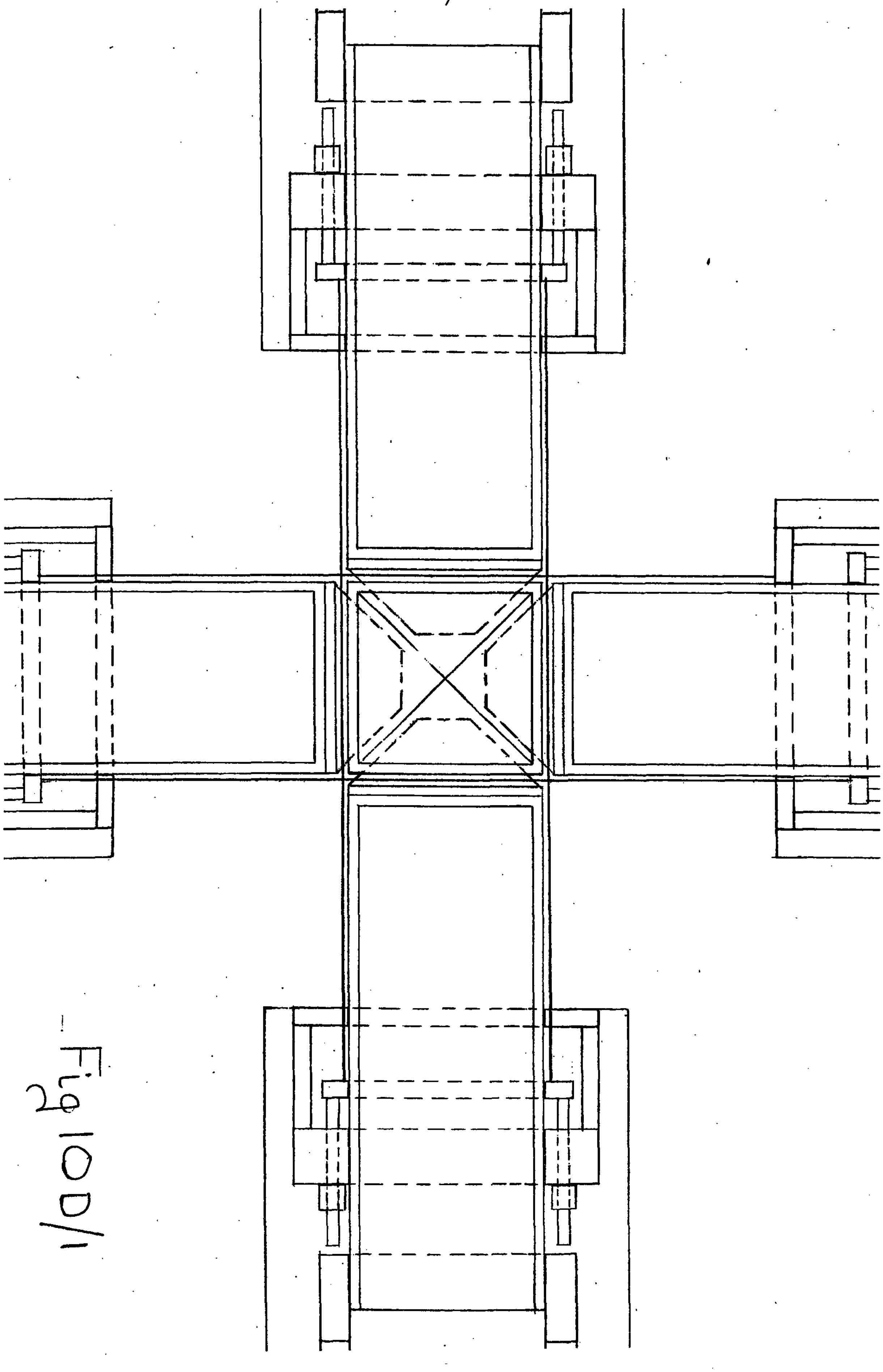


Fig 10D/1

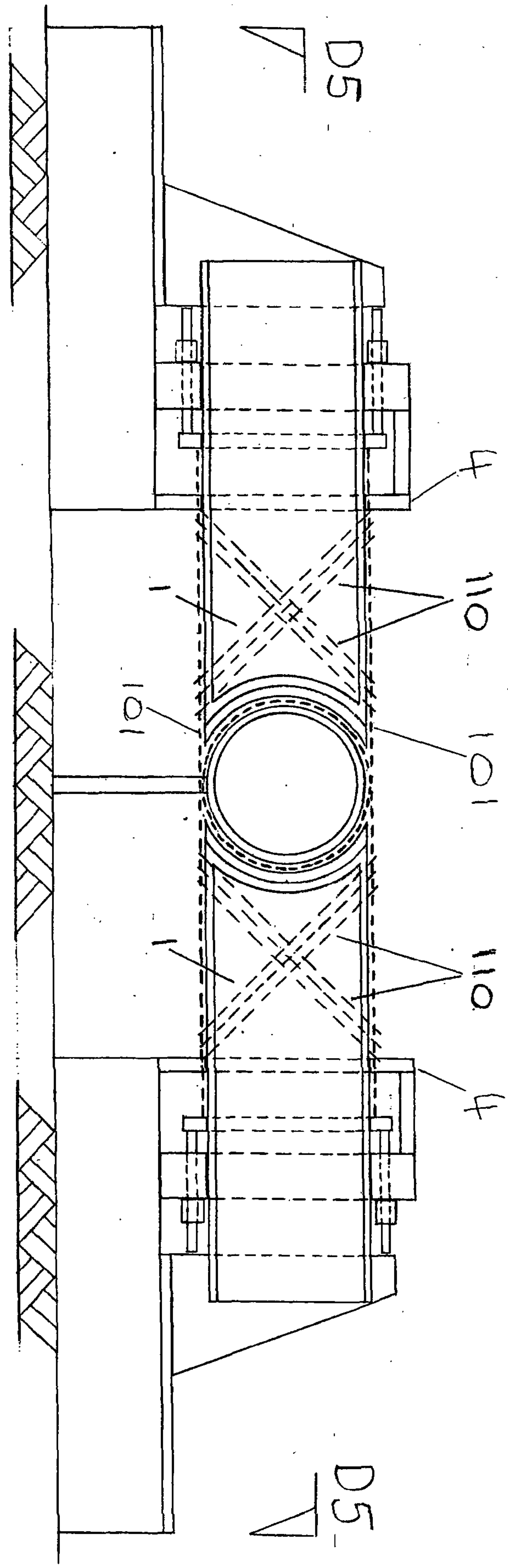


Fig 11A

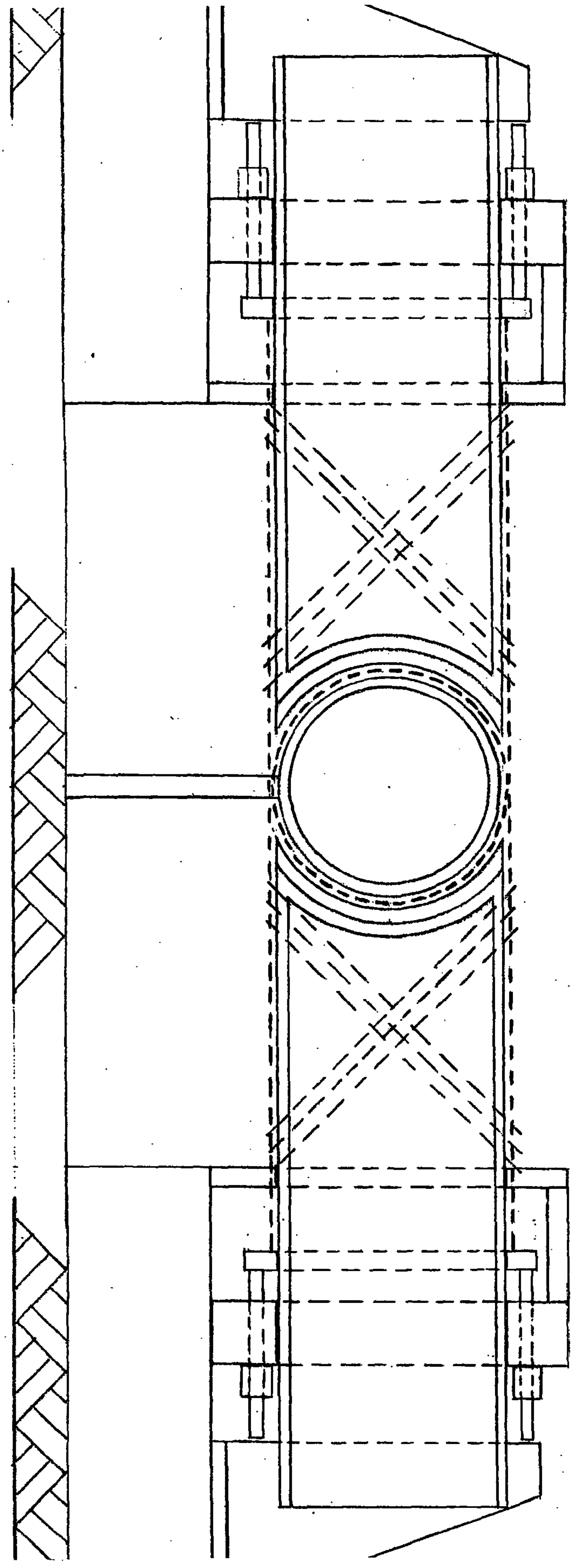


Fig 11A/1

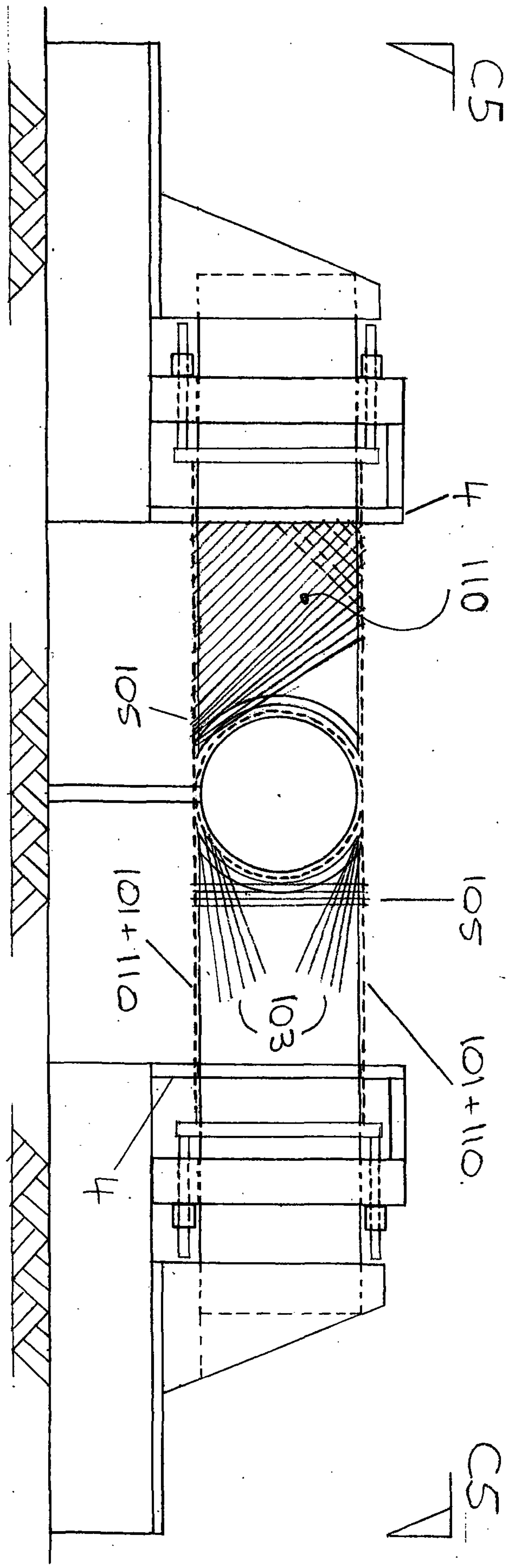


Fig 11B

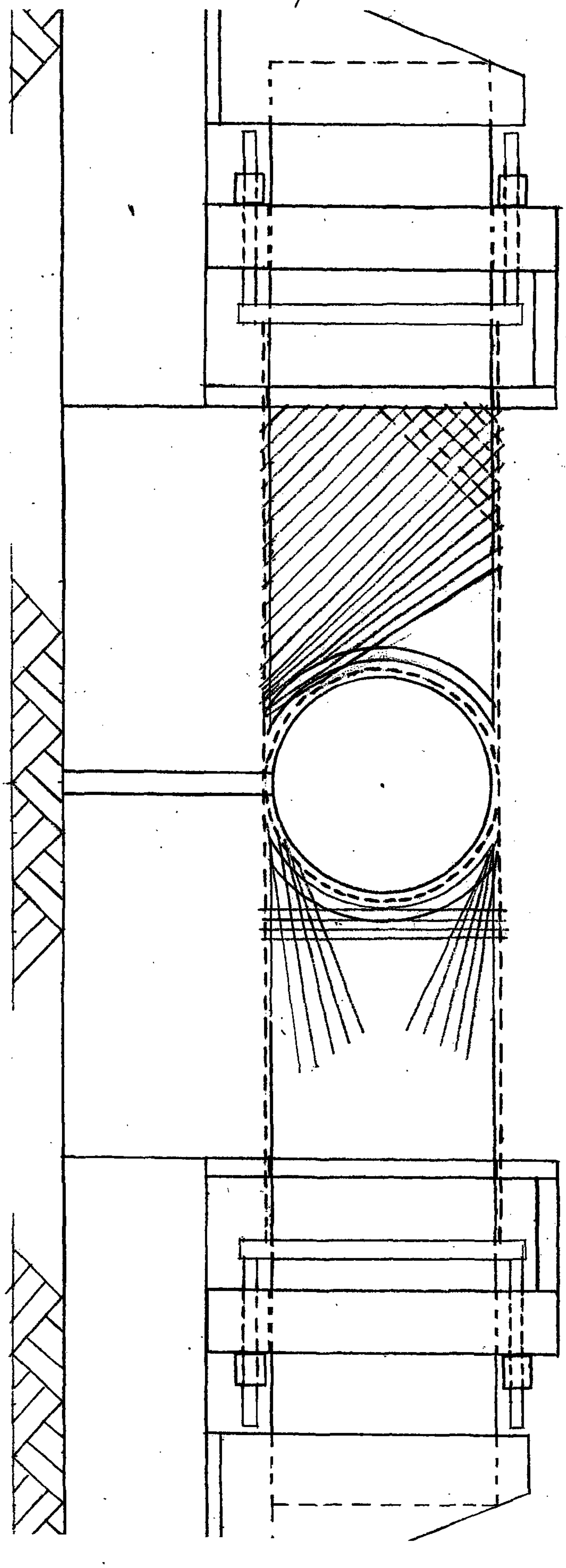


Fig 11B/1

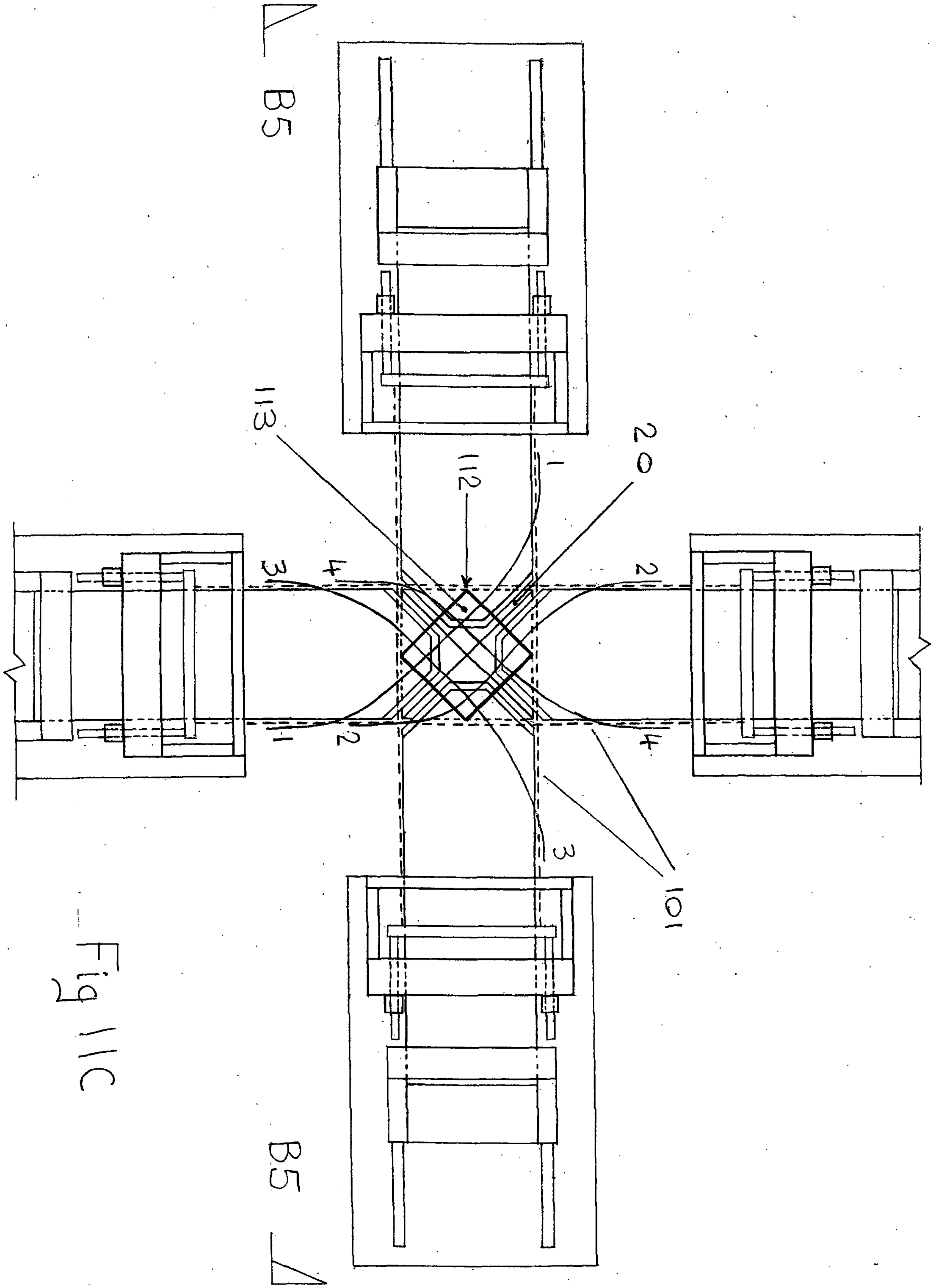


Fig 11C

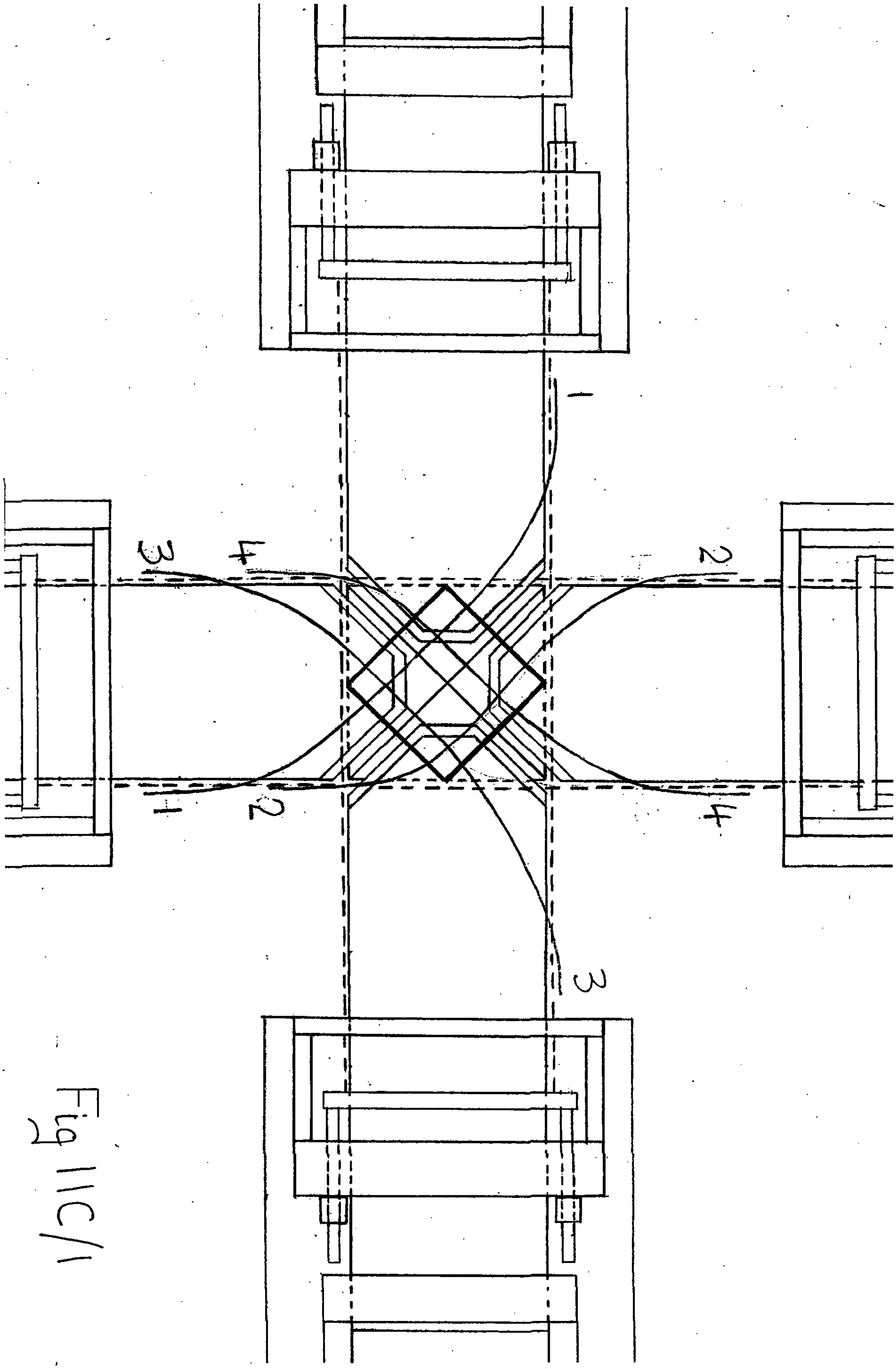


Fig 11C/1

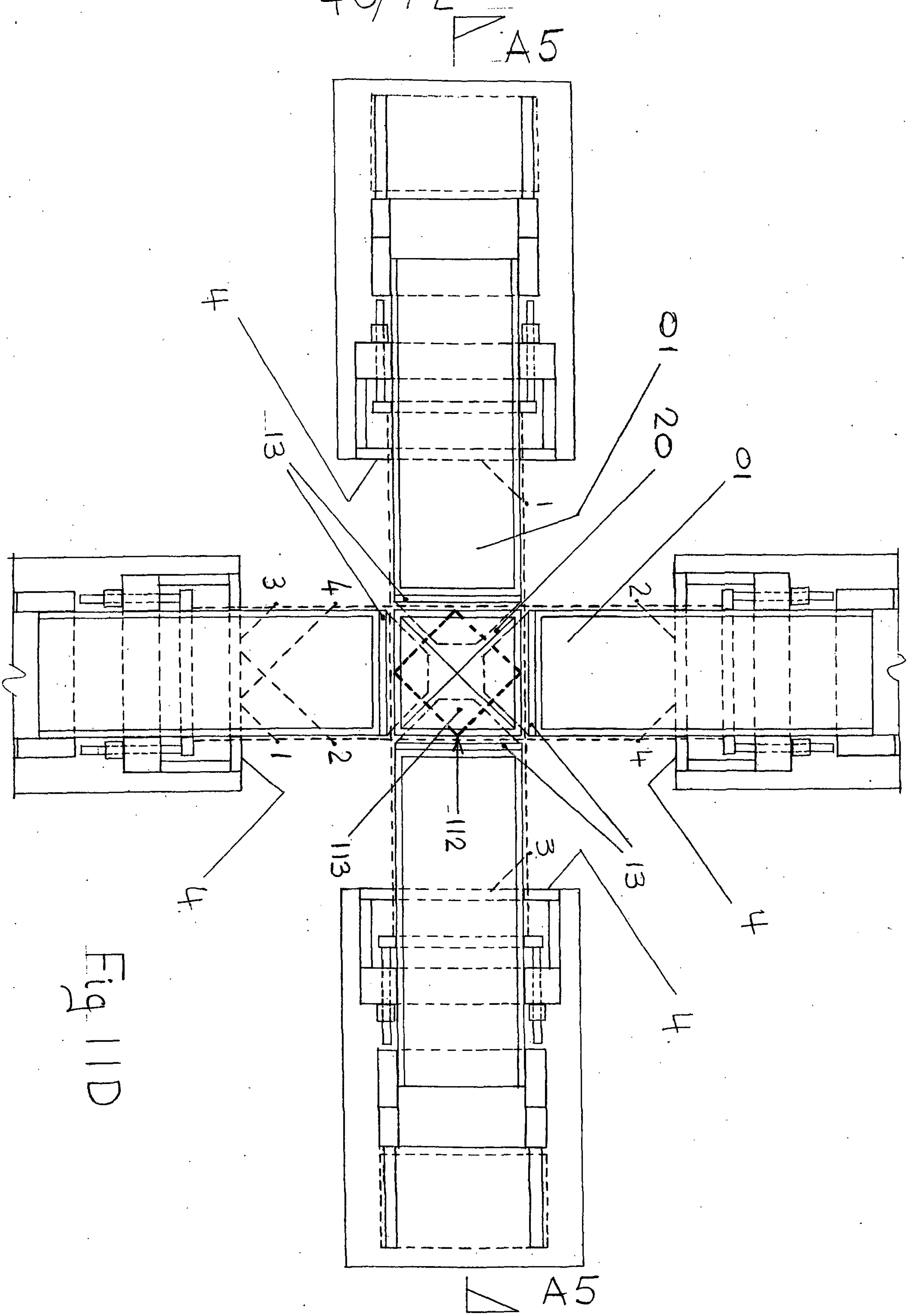


Fig 11D

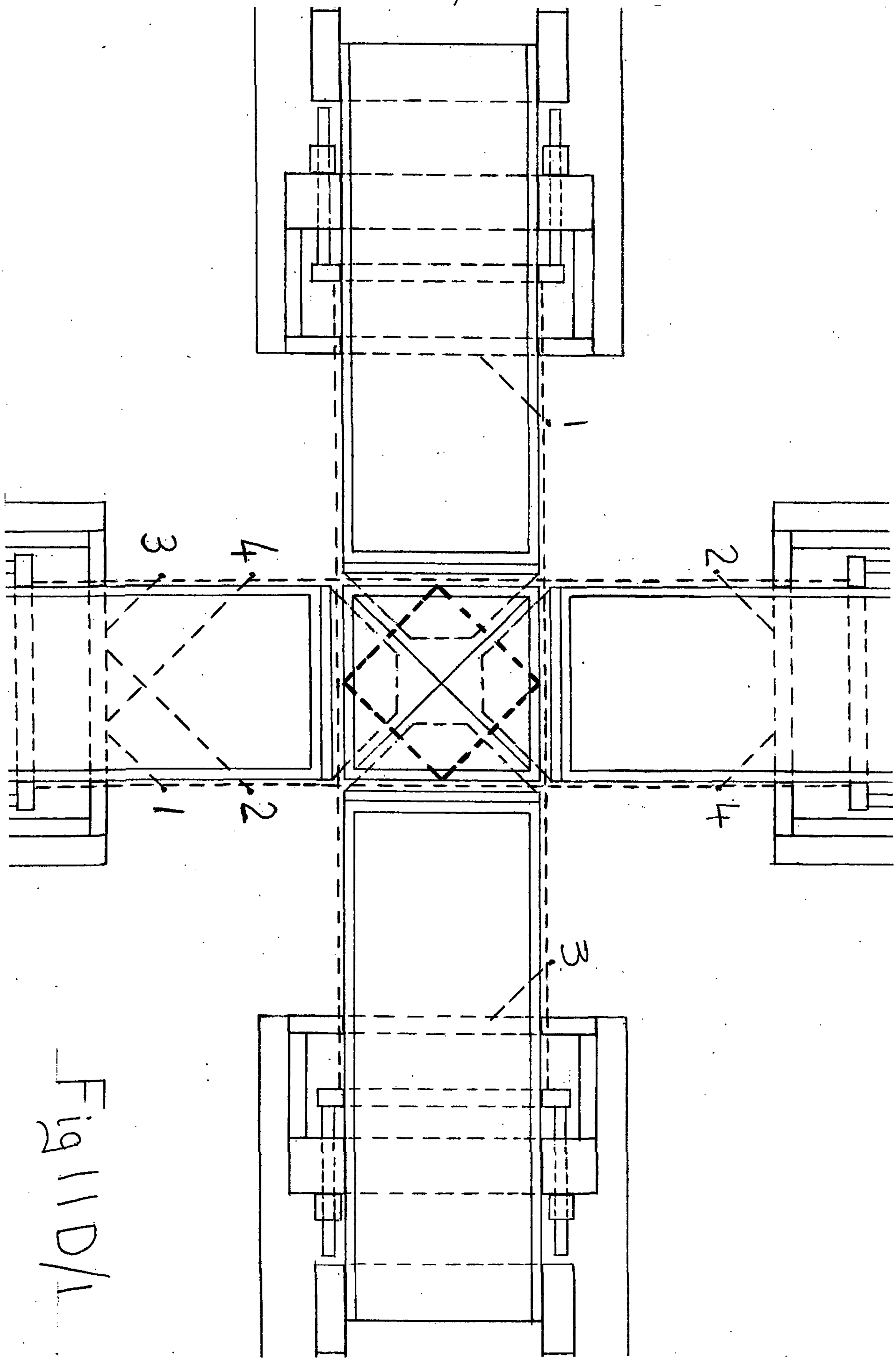


Fig 11D/1

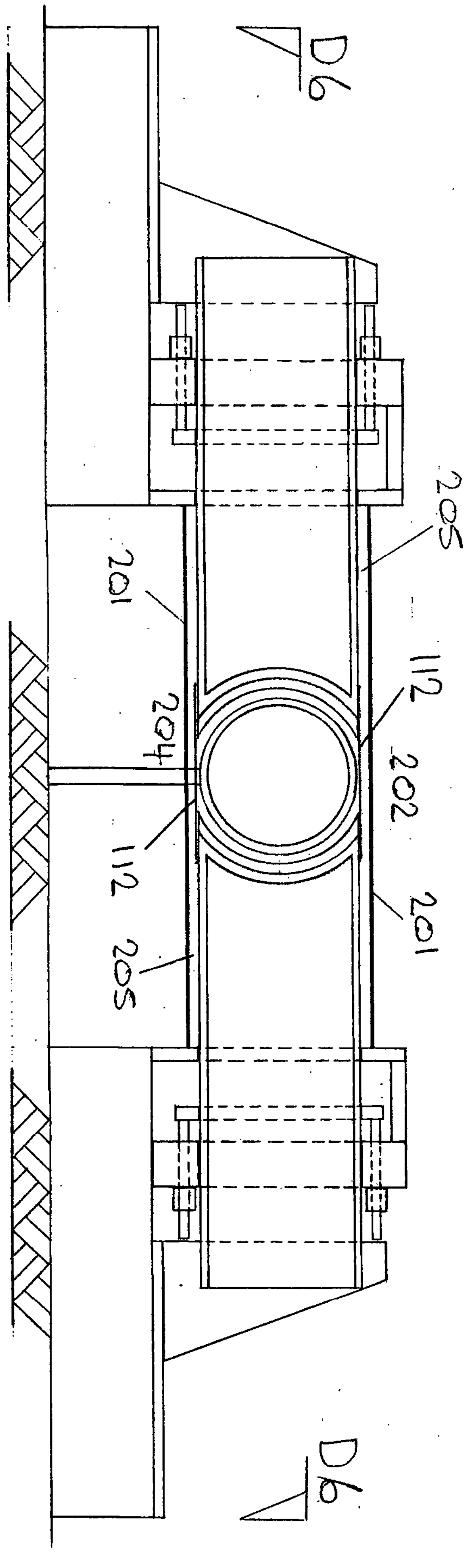


Fig 12A

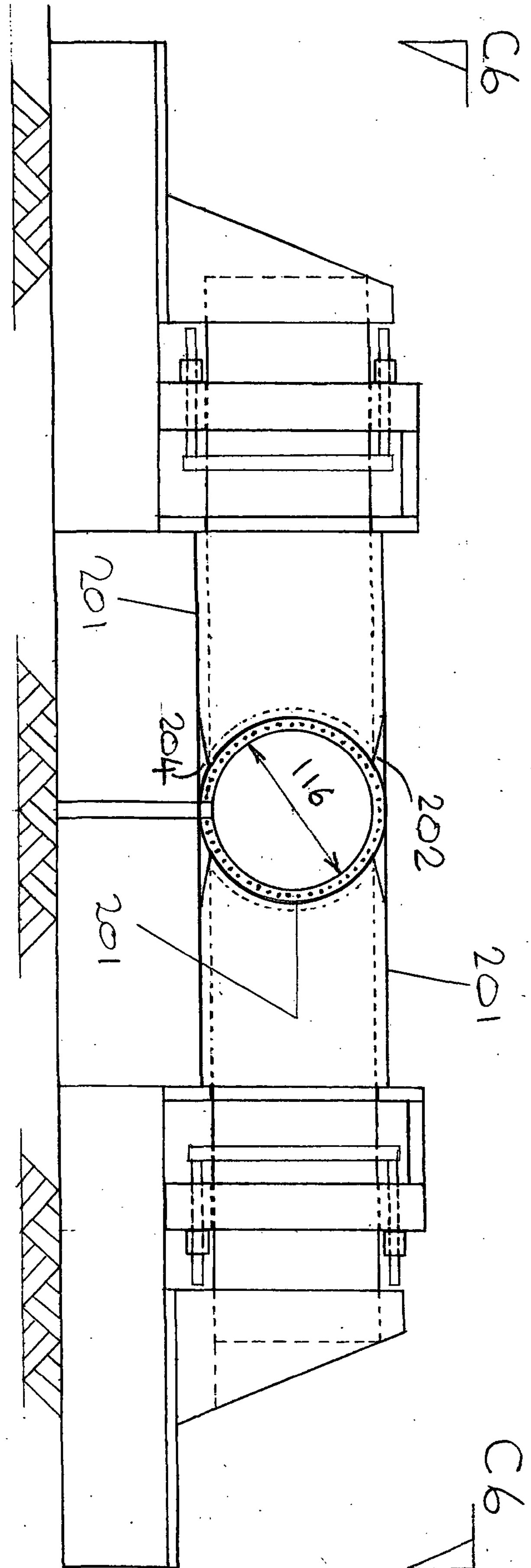


Fig 12B

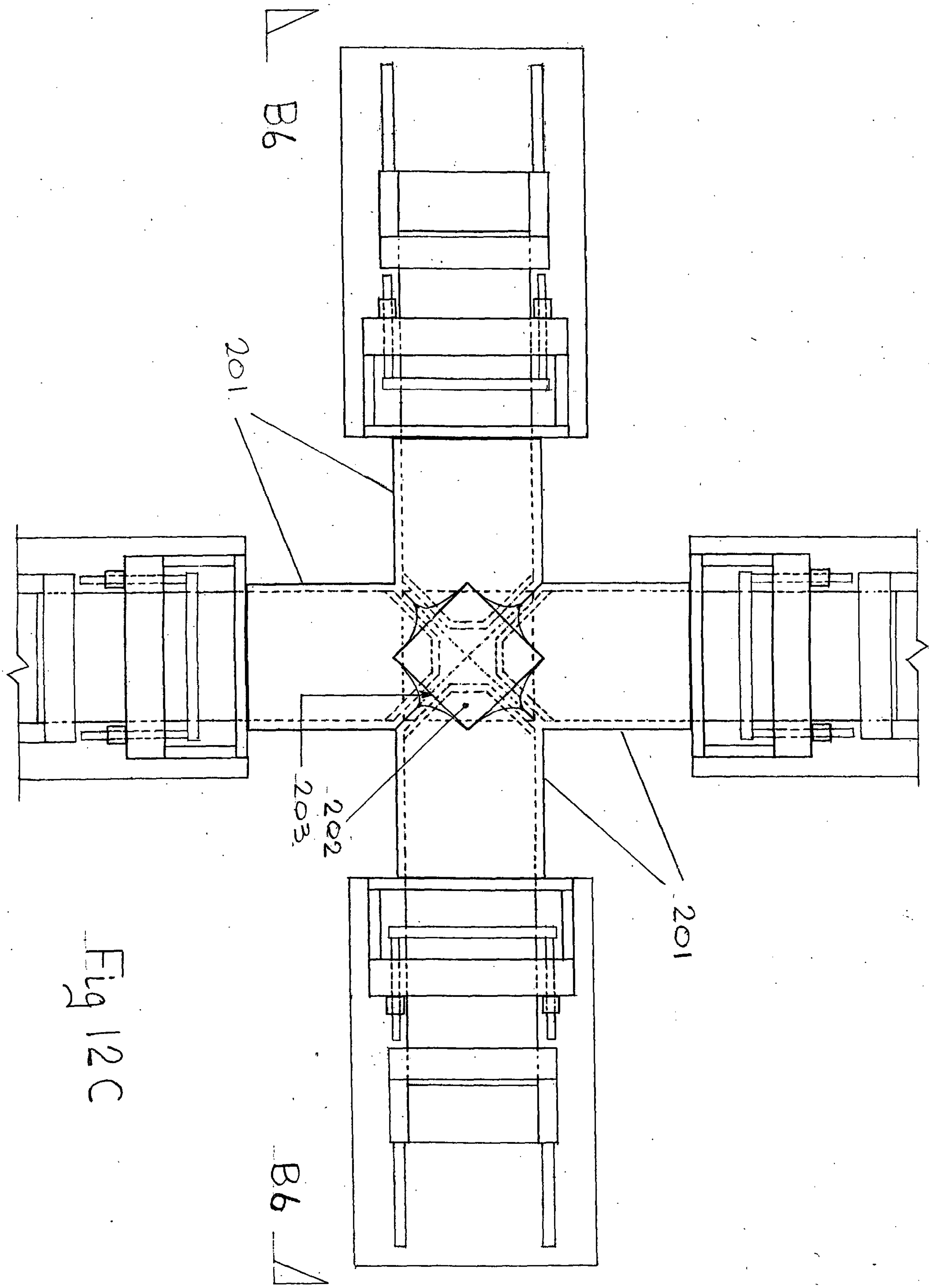


Fig 12C

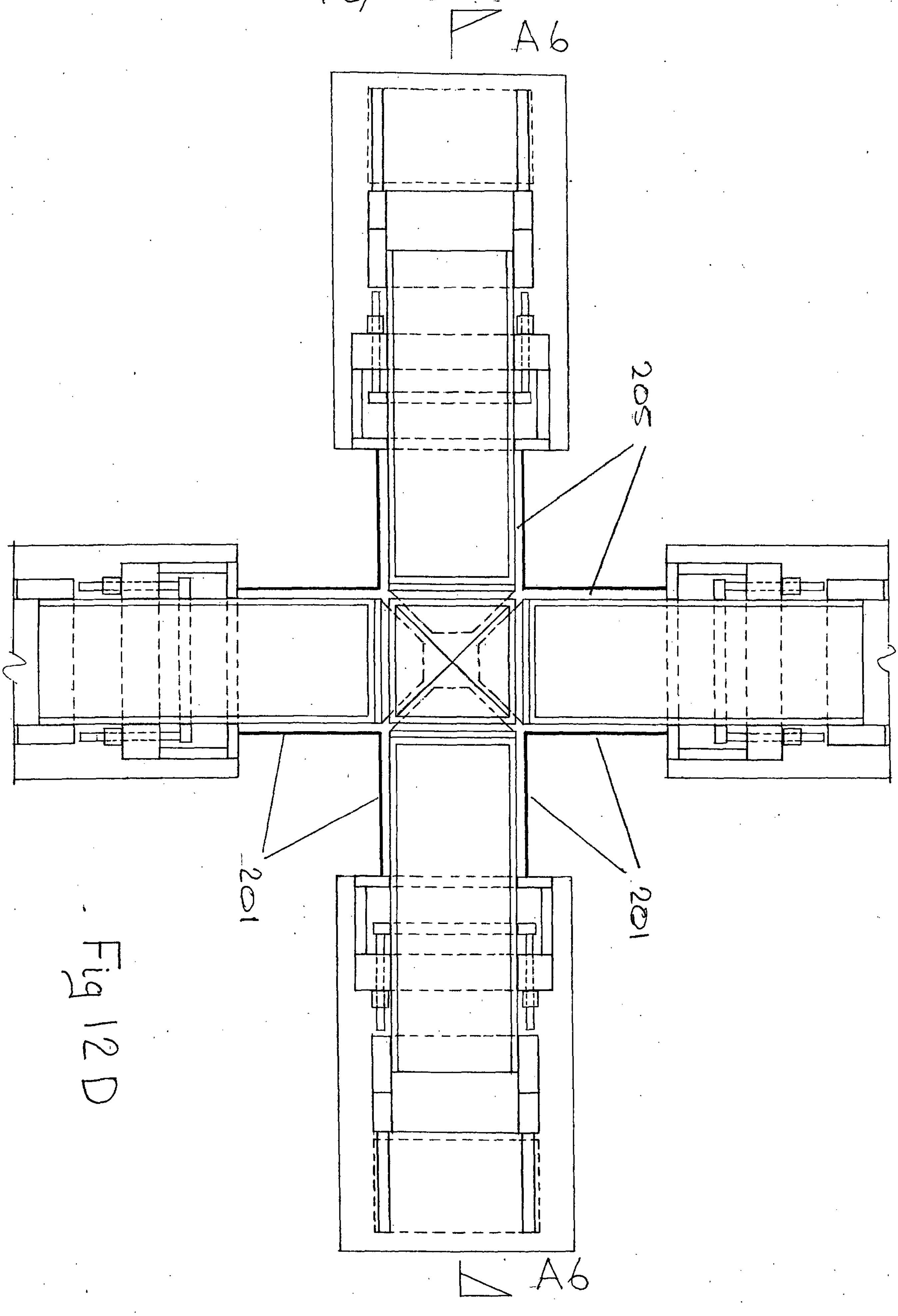


Fig 12D

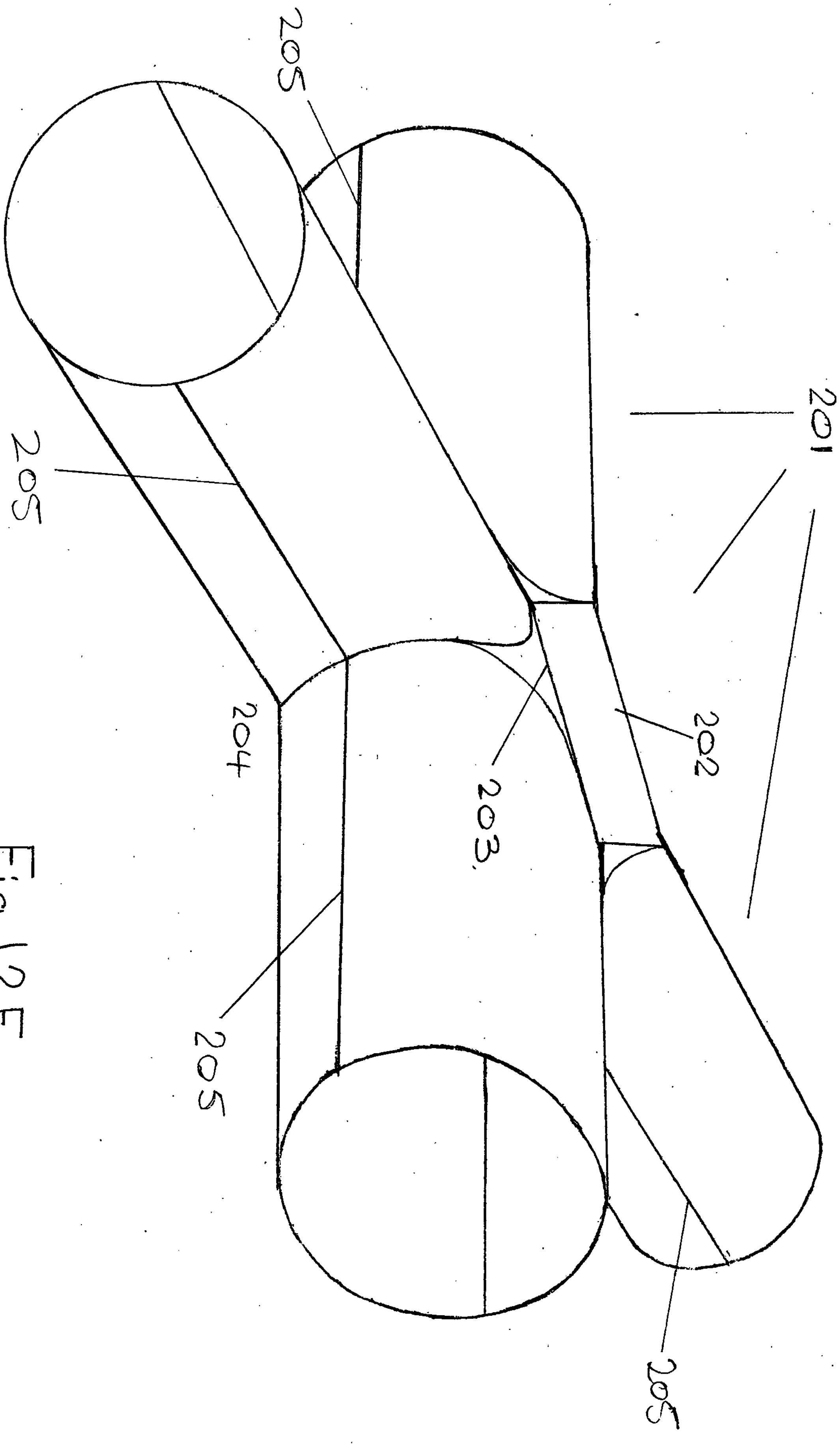


Fig 12E

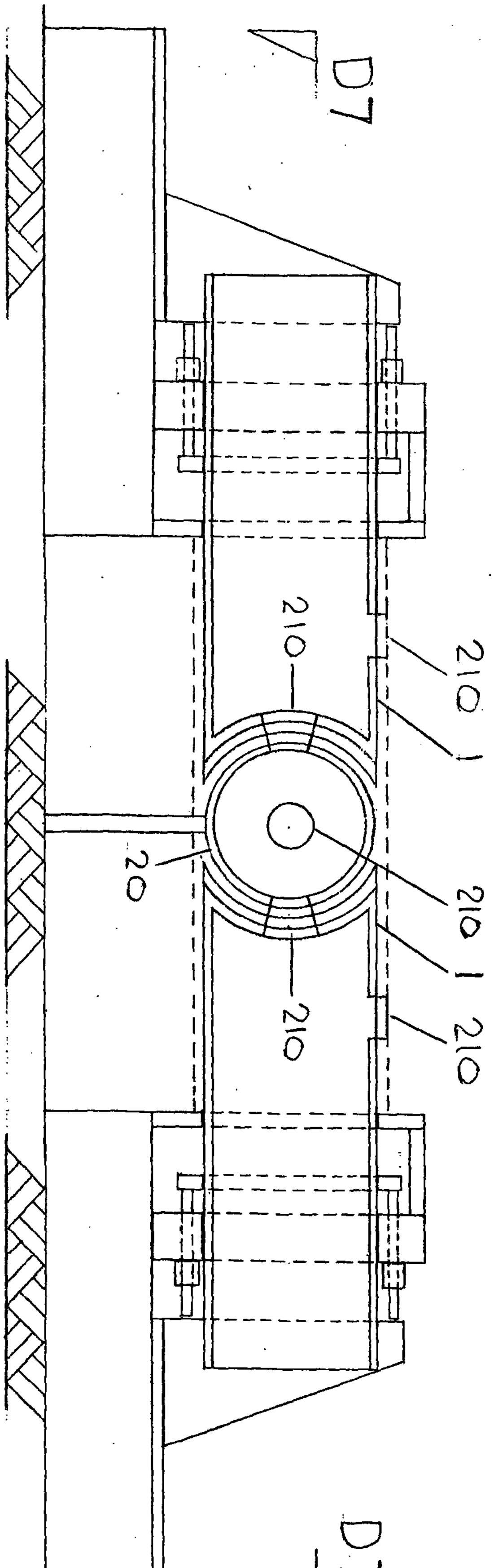


Fig 13A

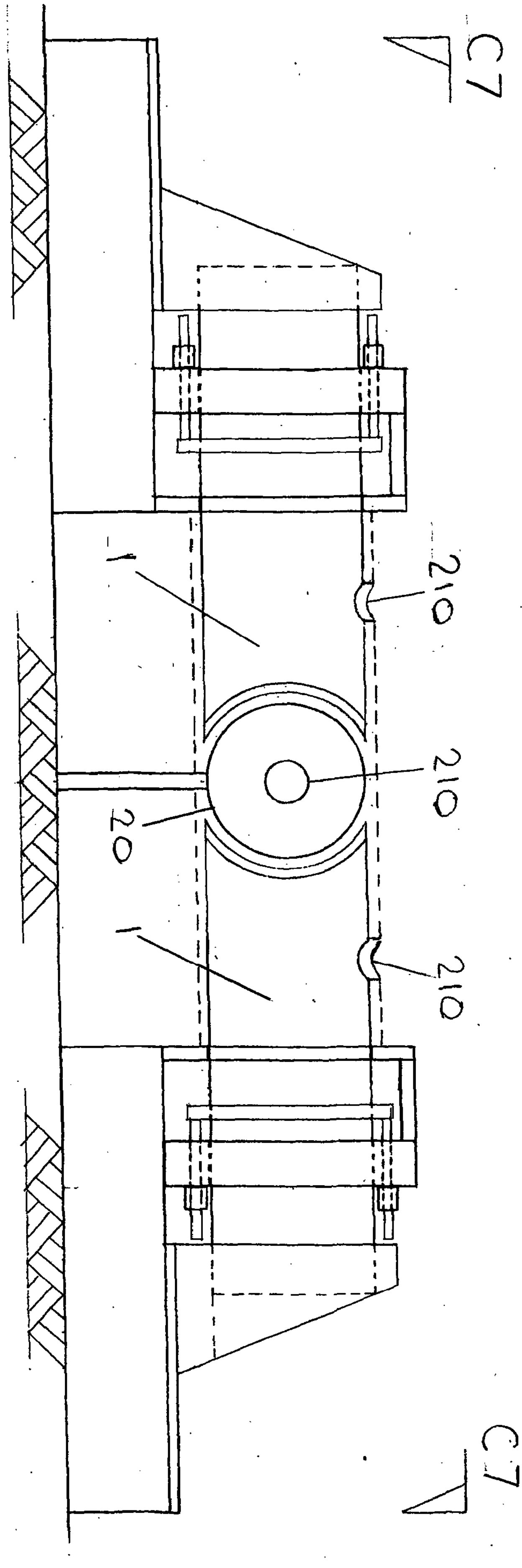


Fig 13B

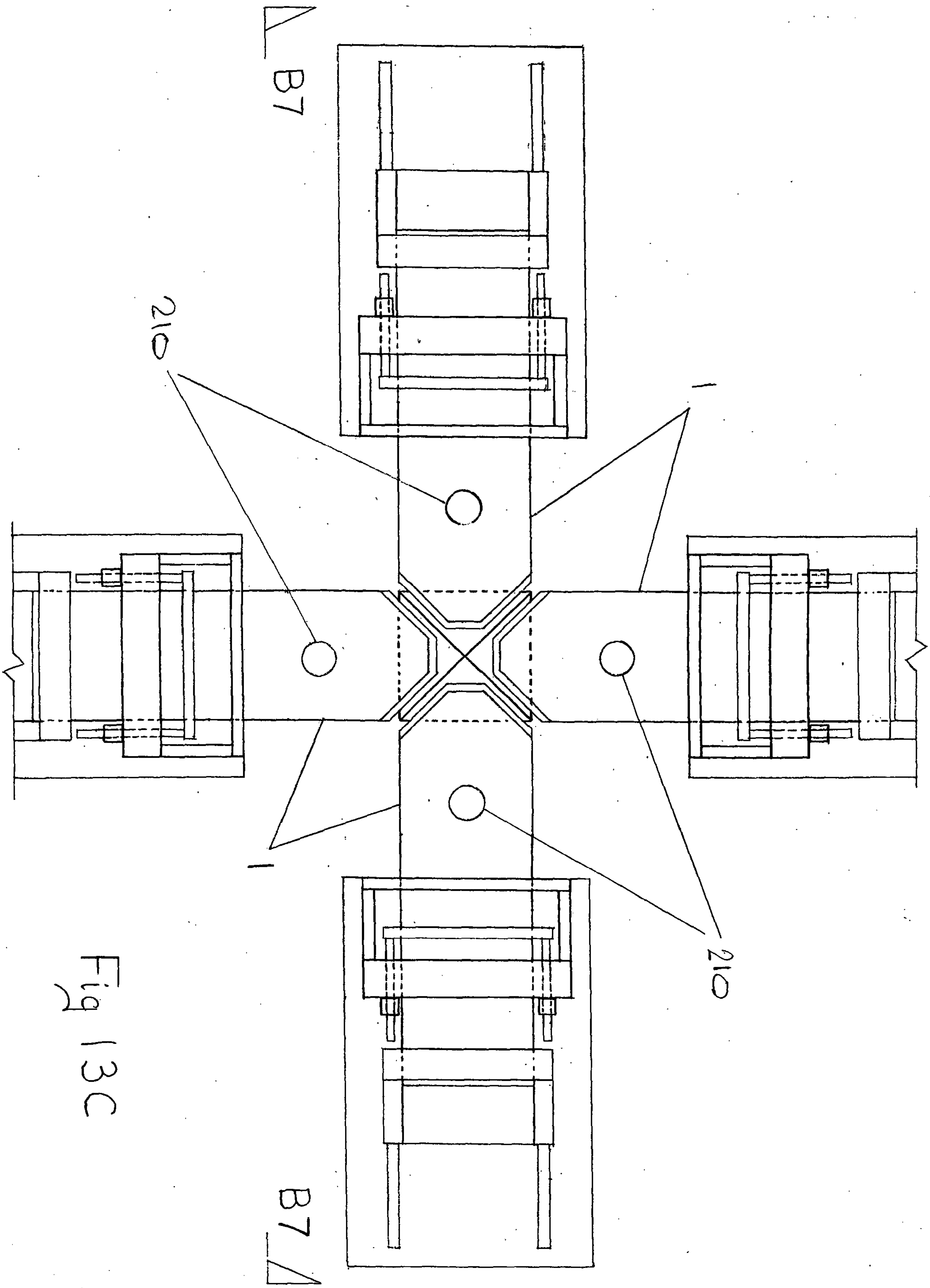


Fig 13C

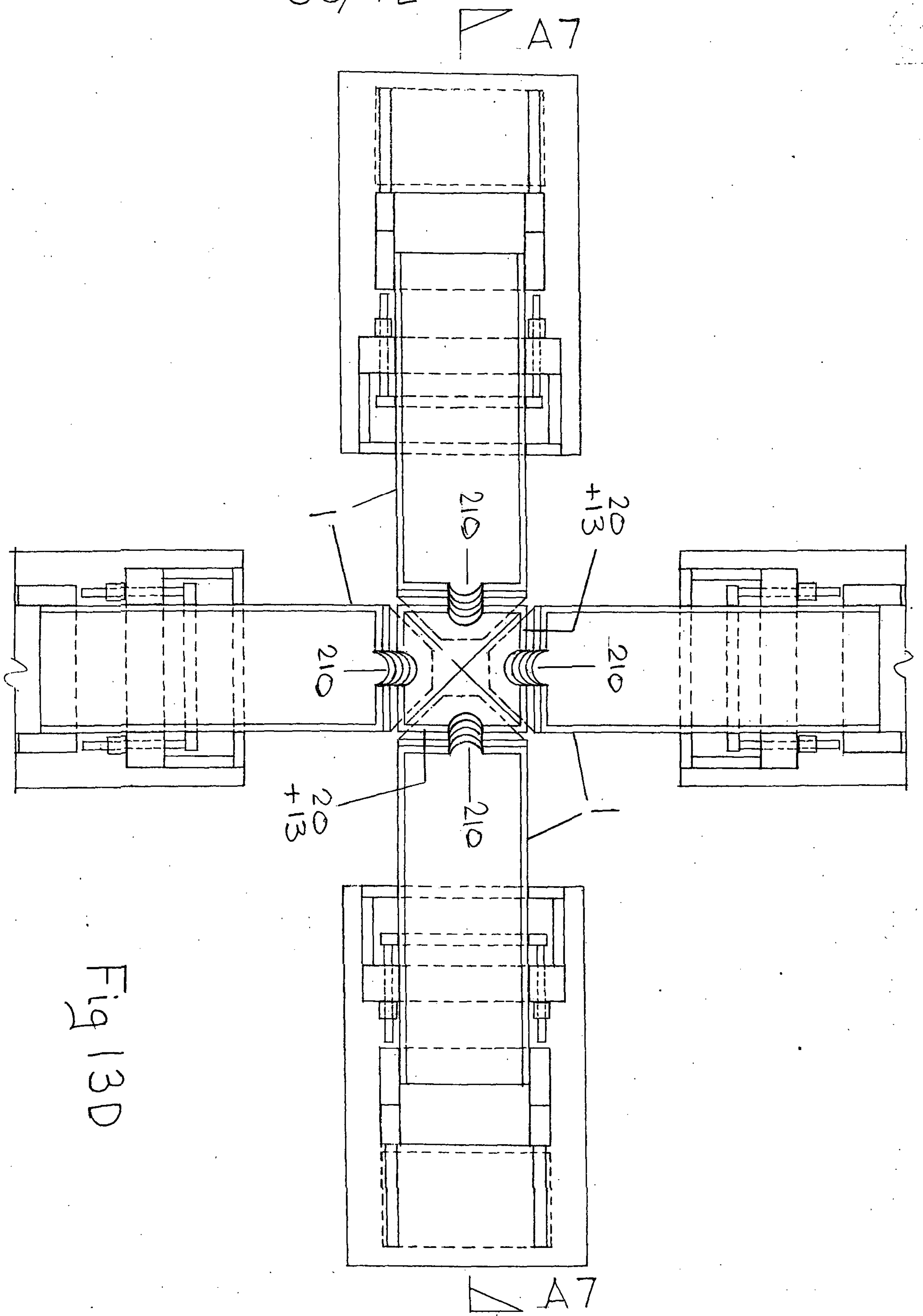


Fig 13D

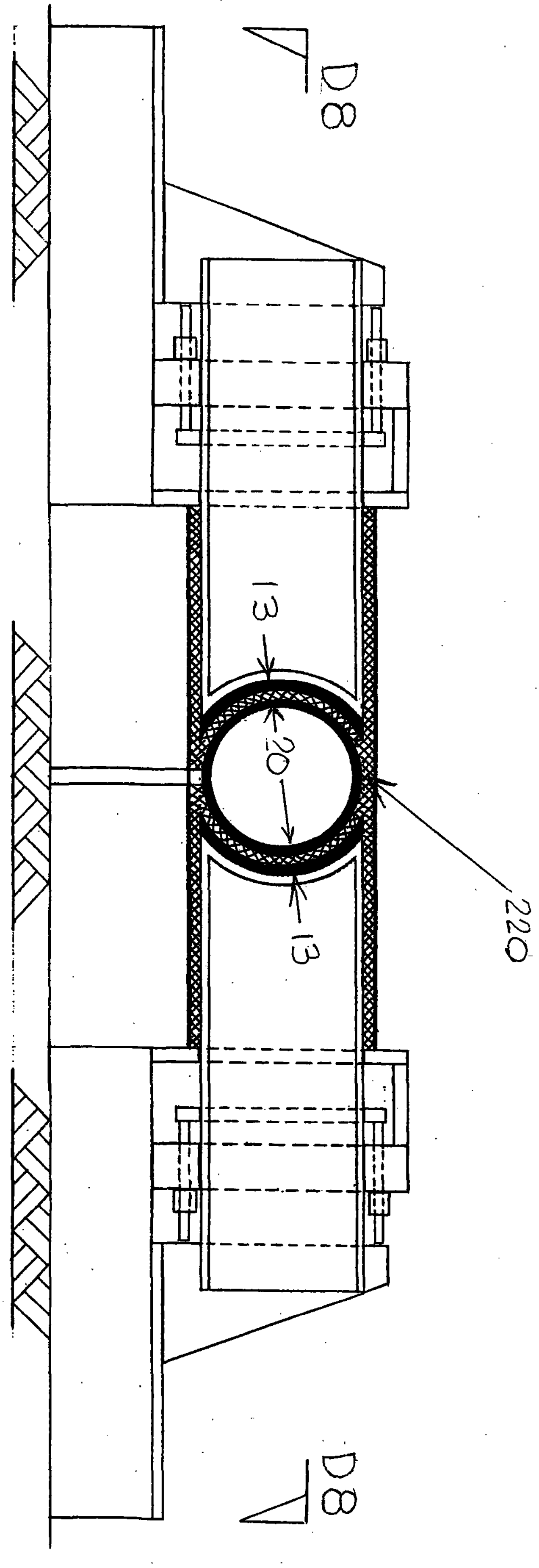


Fig 14A

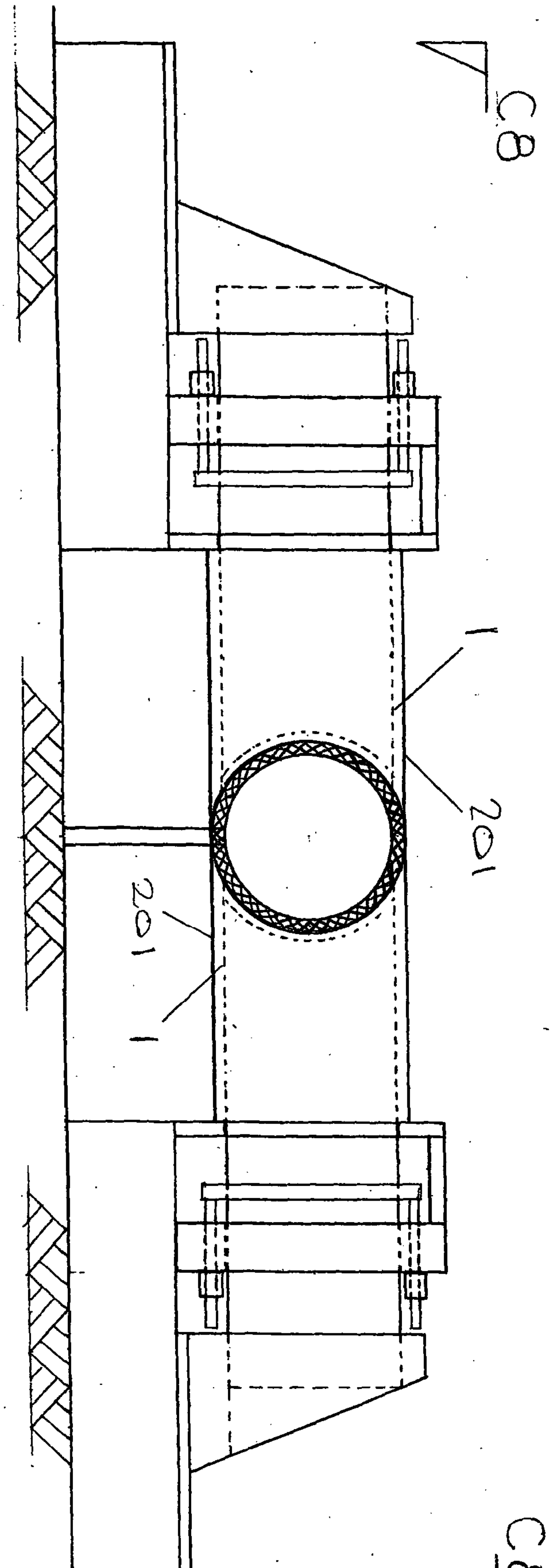


Fig 14B

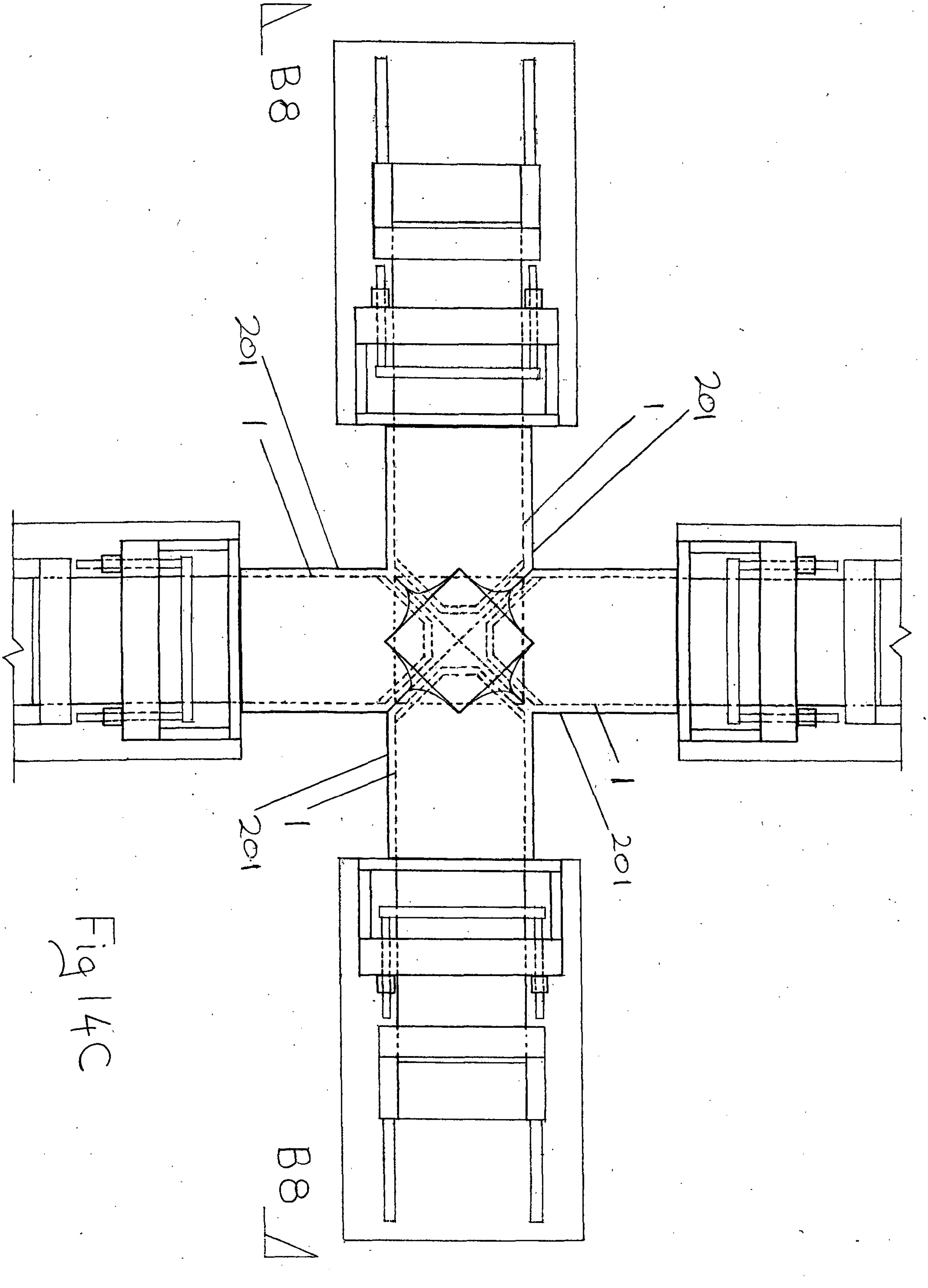


Fig 14C

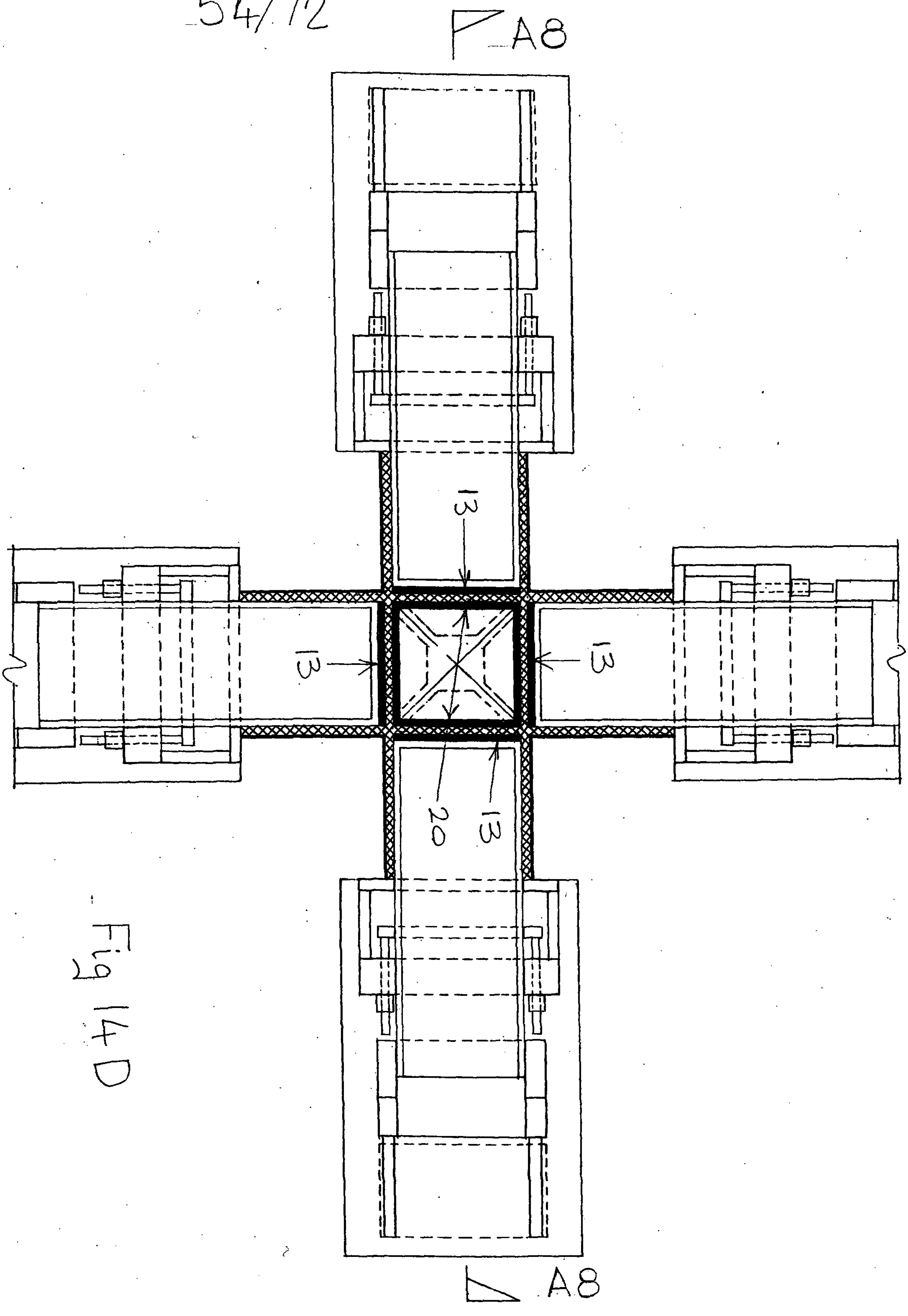


Fig 14D

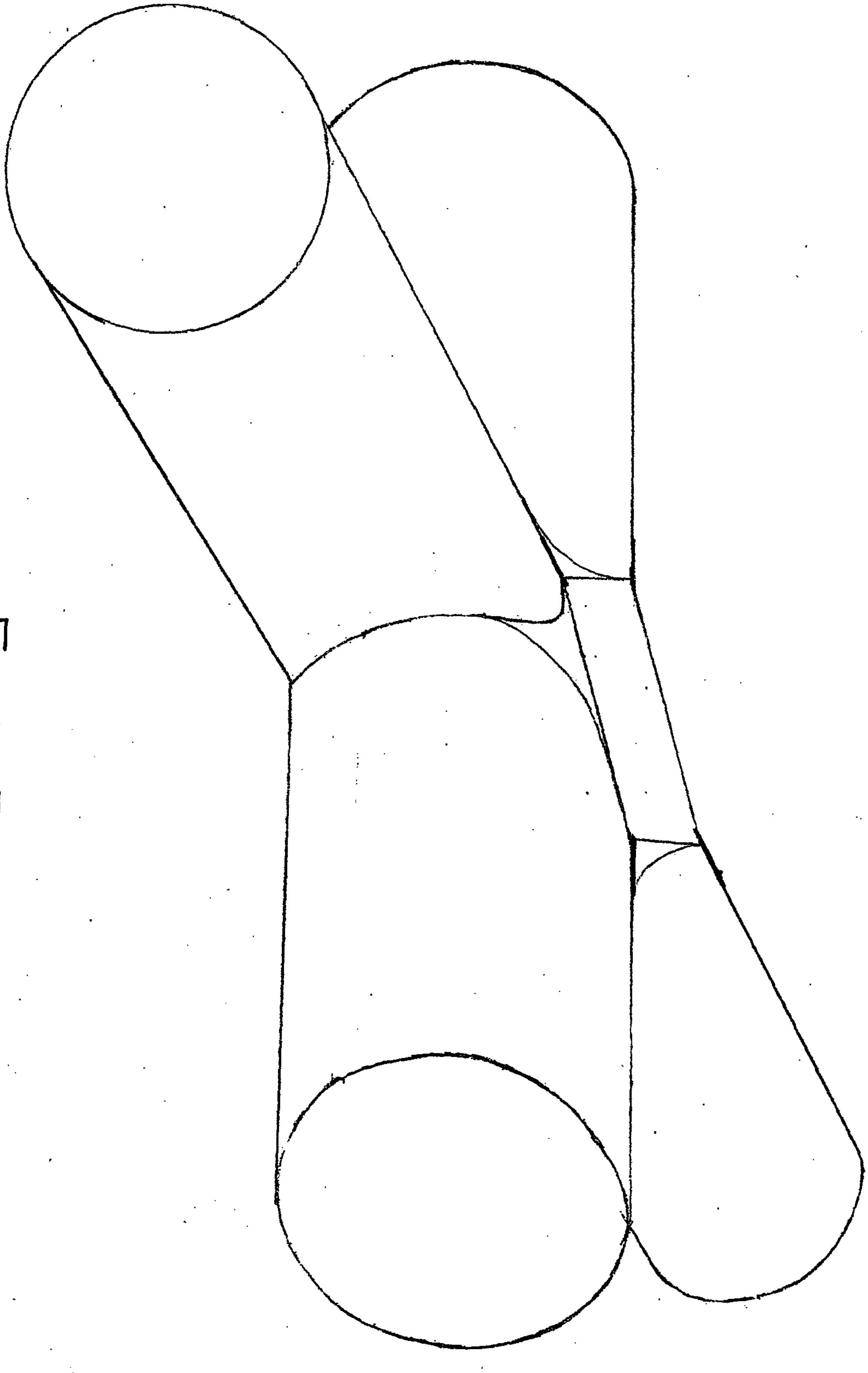


Fig 14E

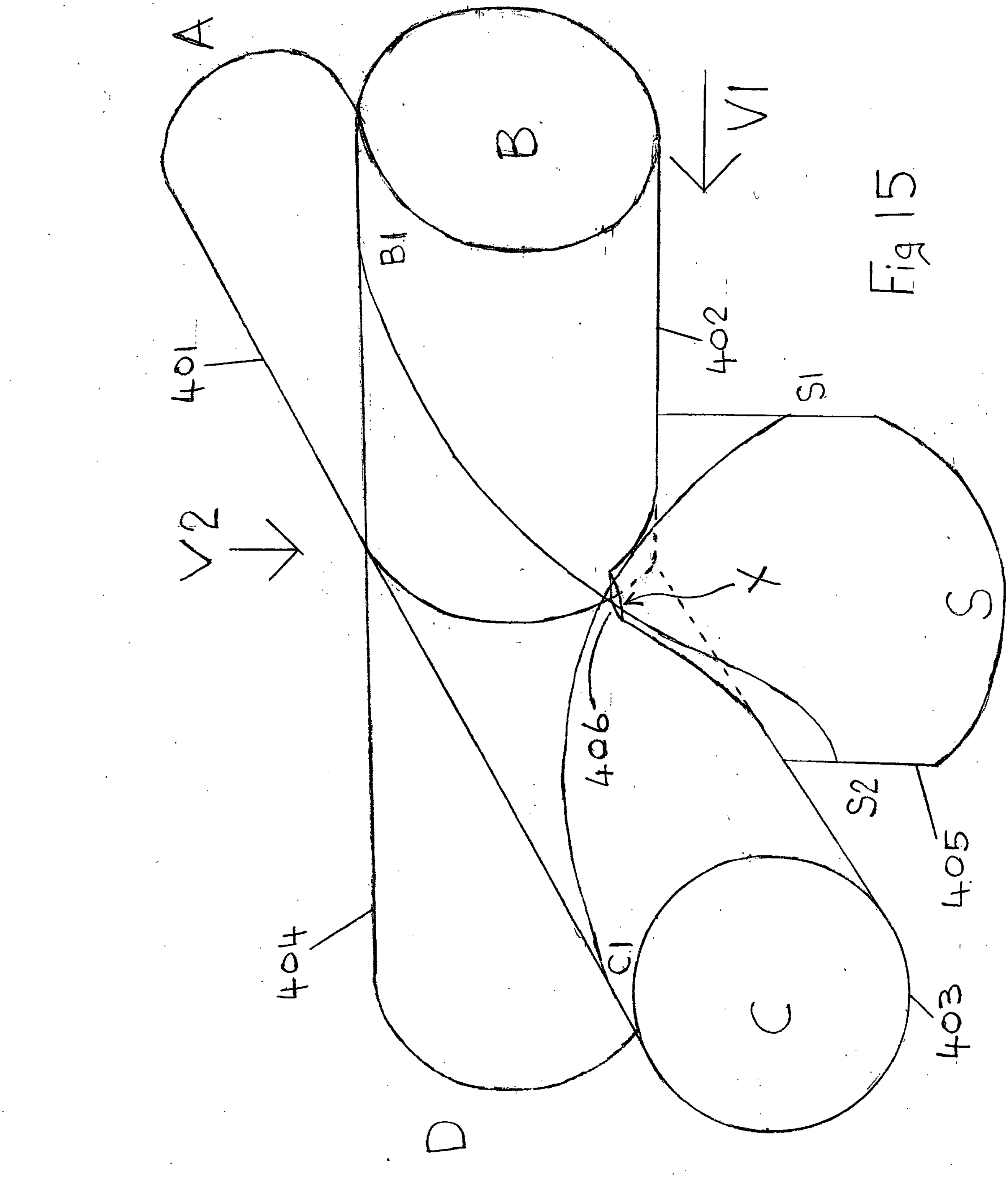


Fig 15

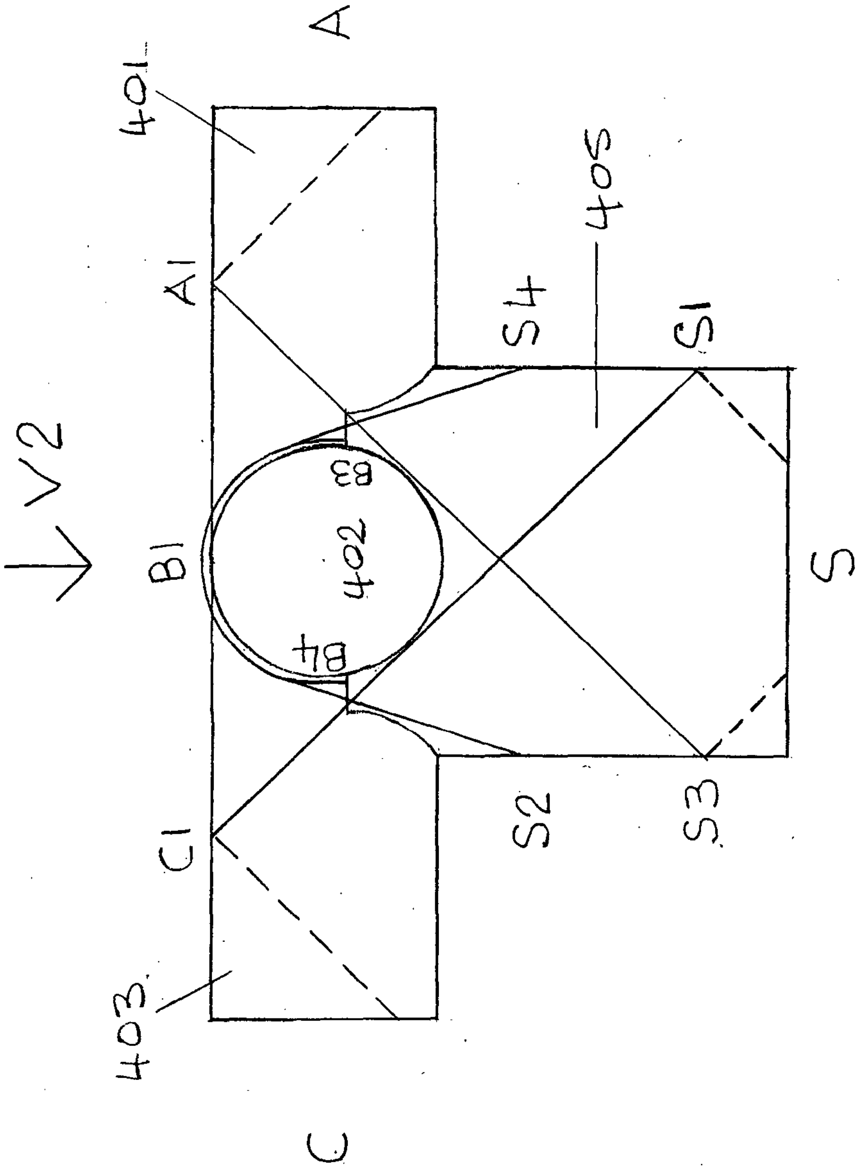


Fig 16

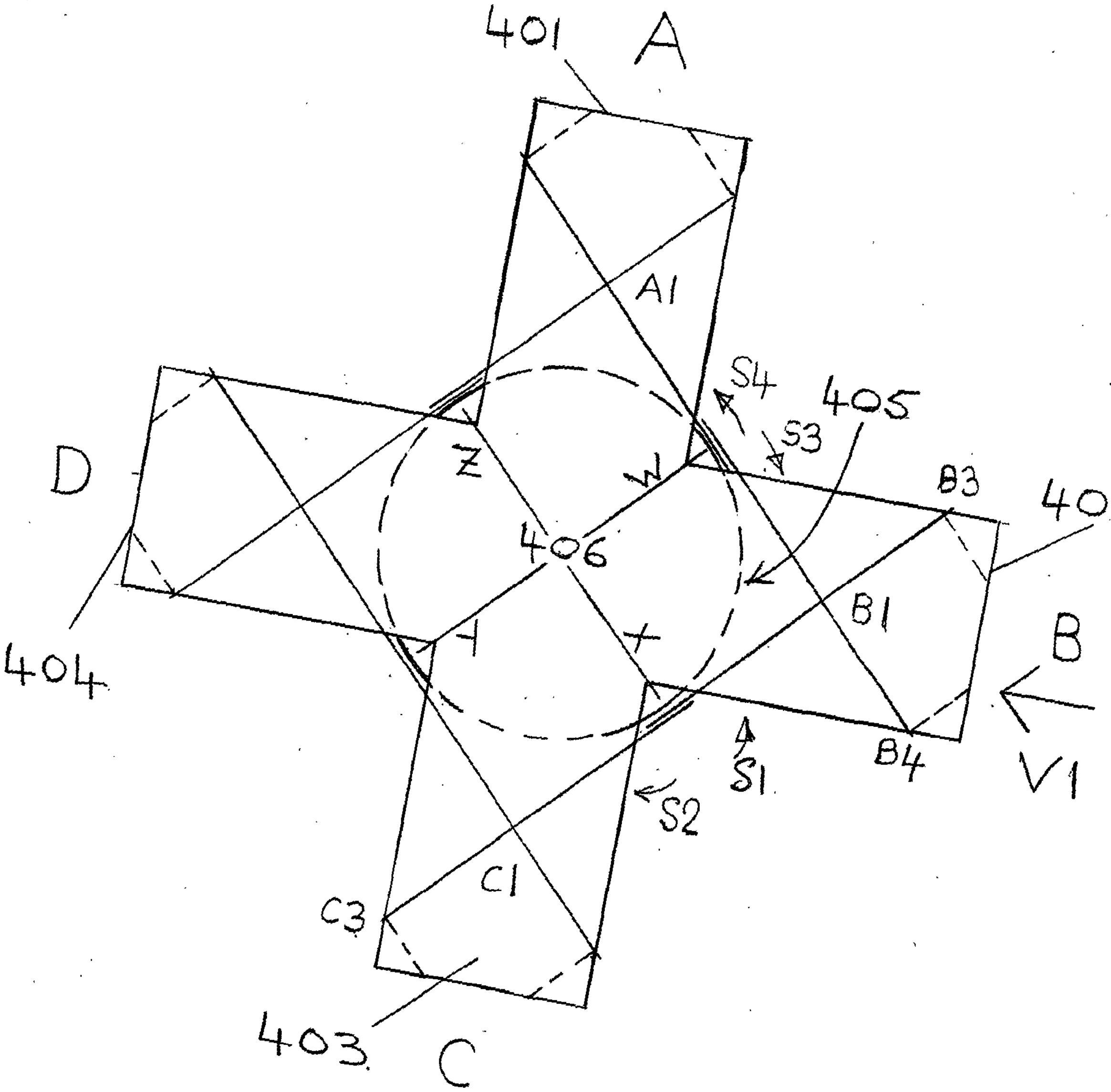


Fig 17

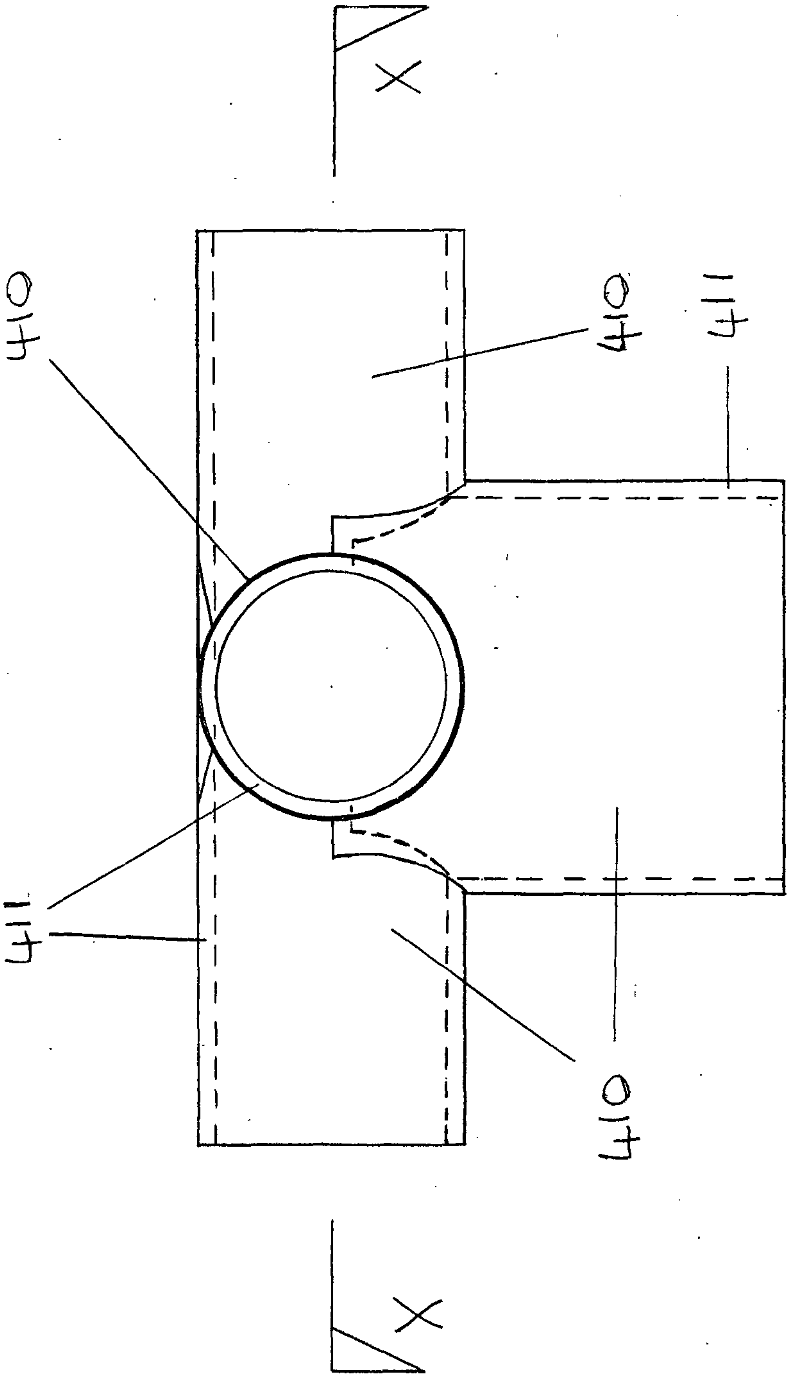


Fig 18

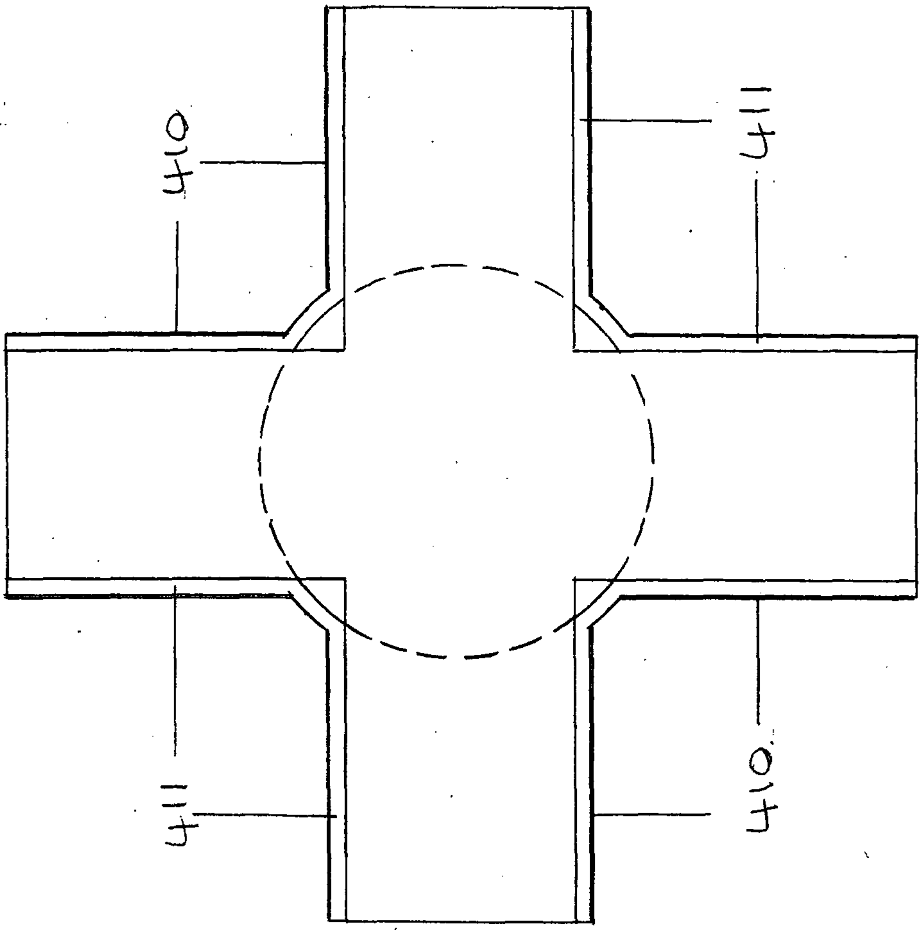


Fig 19

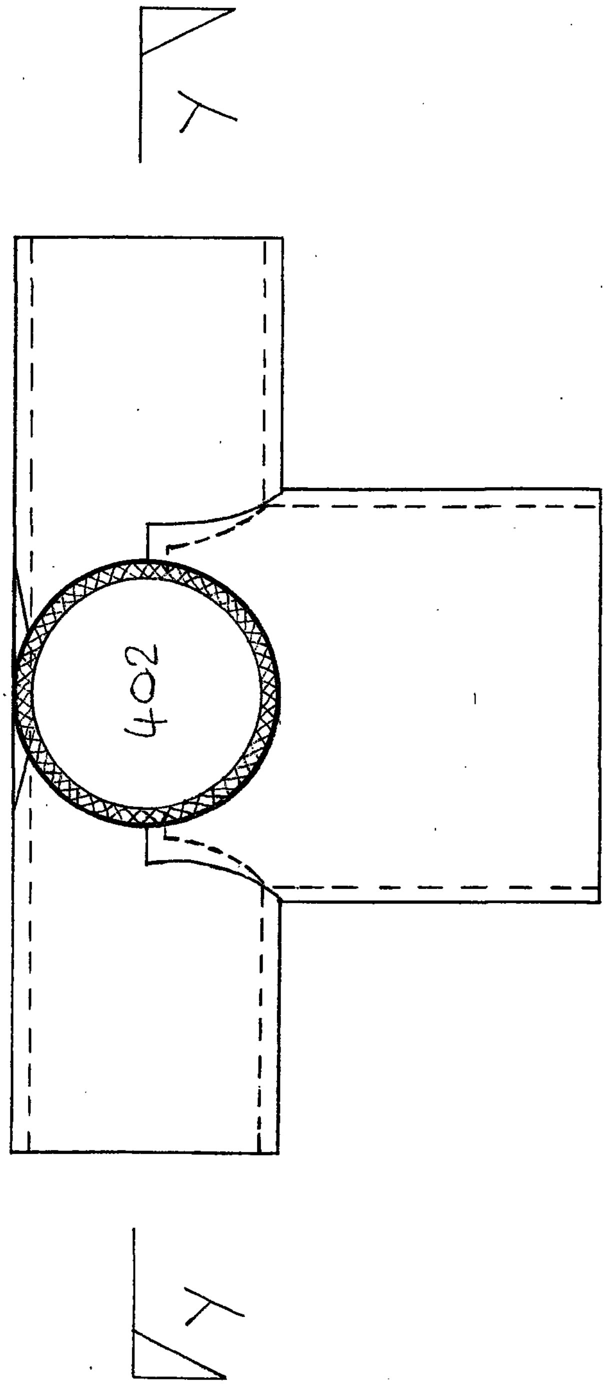


Fig 20

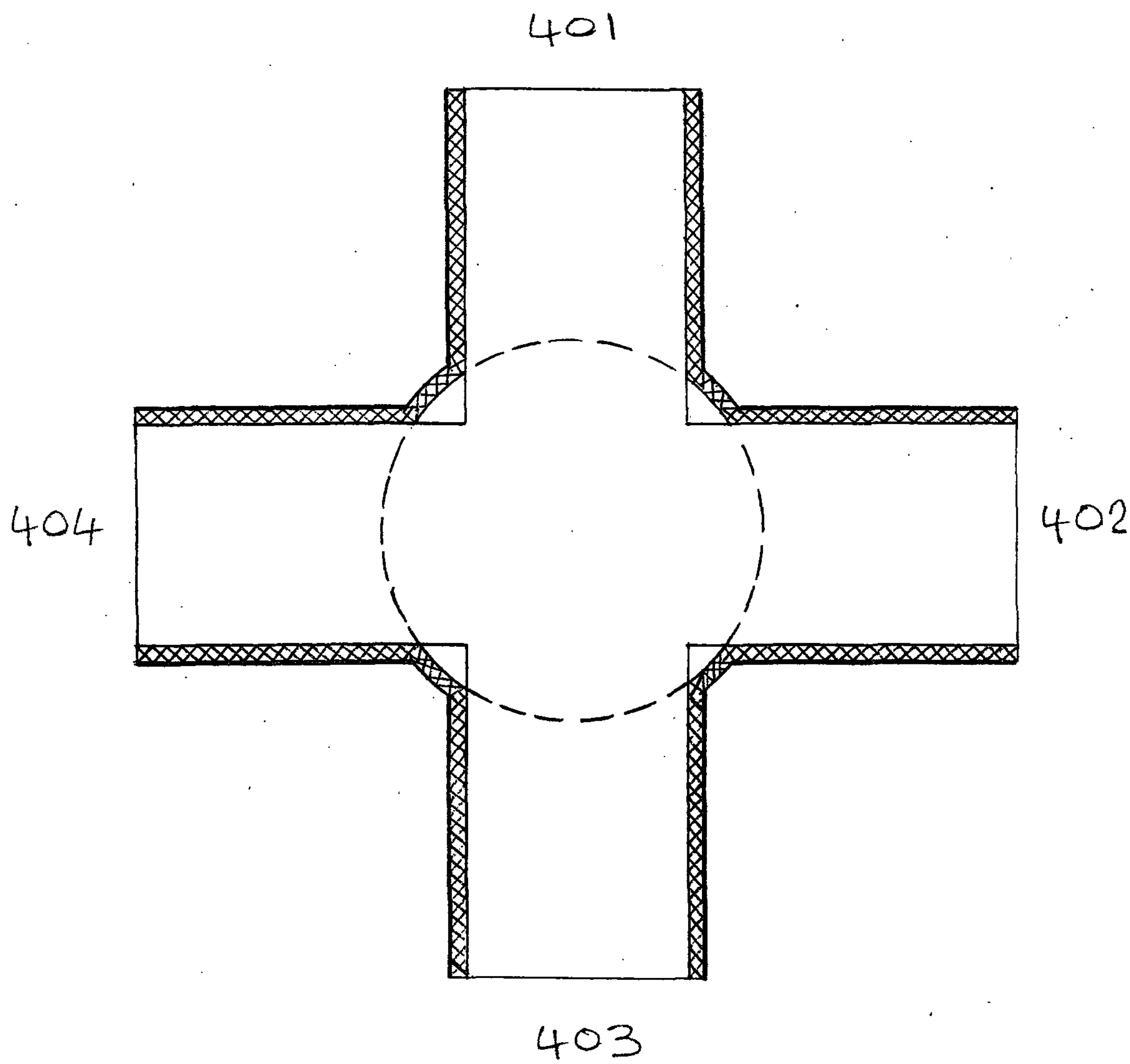


Fig 21

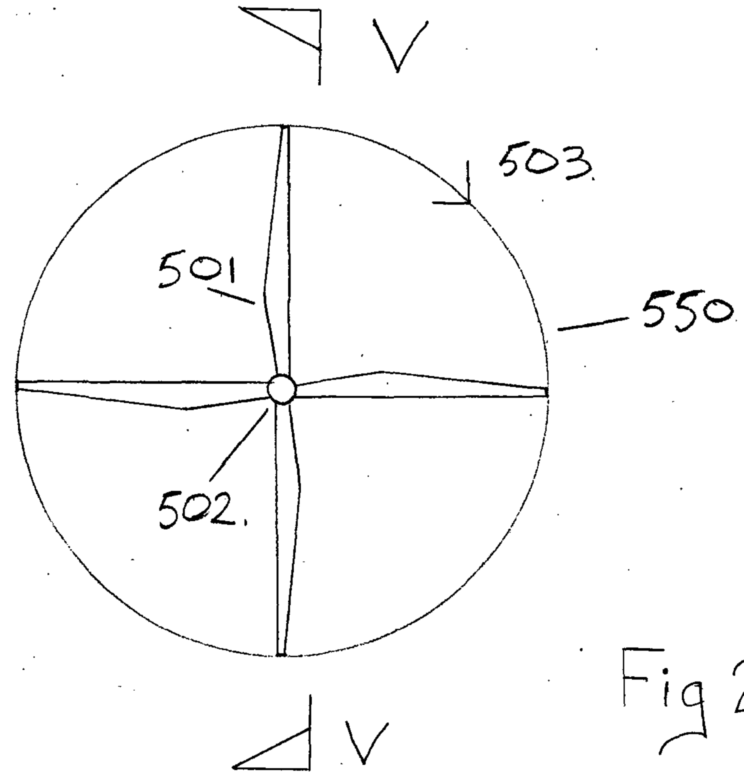


Fig 22A

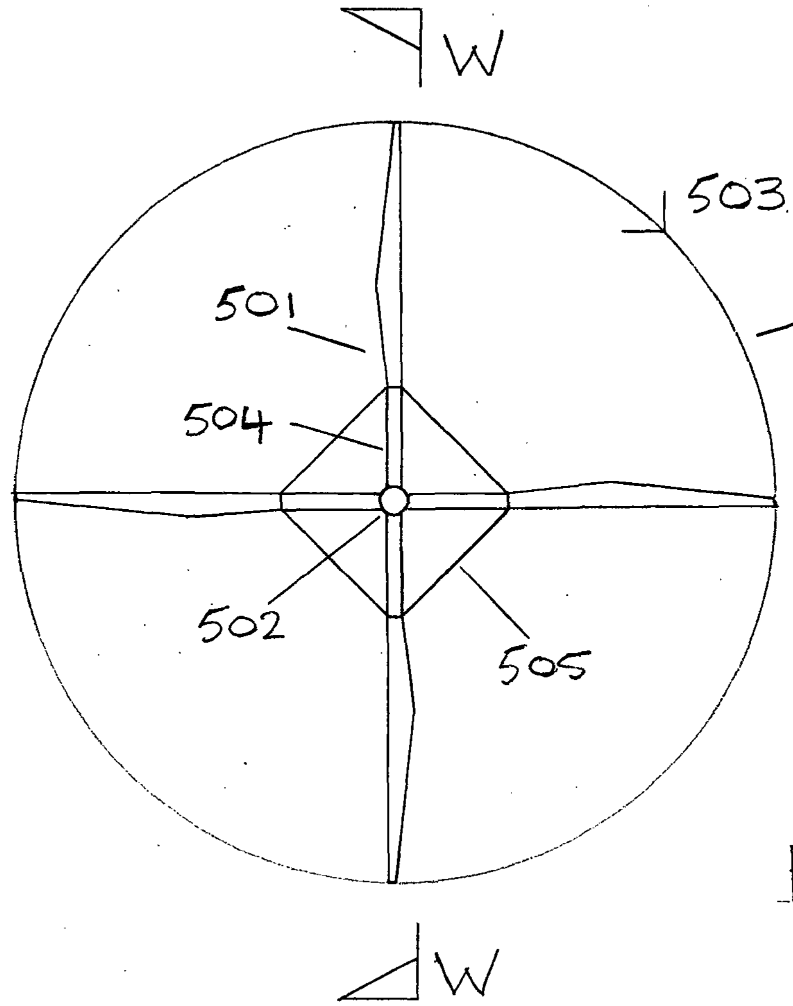


Fig 22B

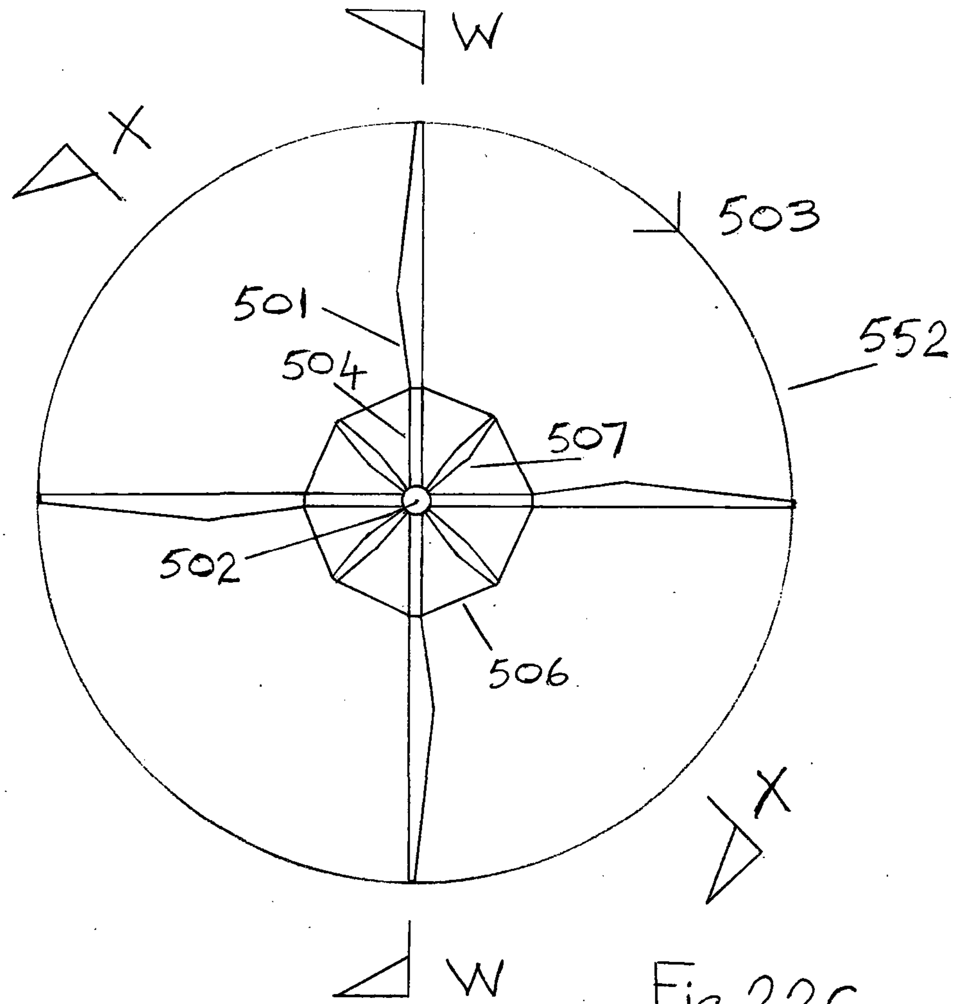


Fig 22C

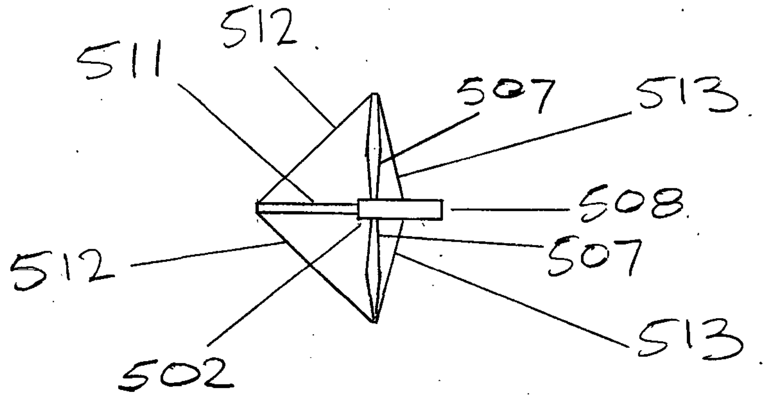


Fig 22D

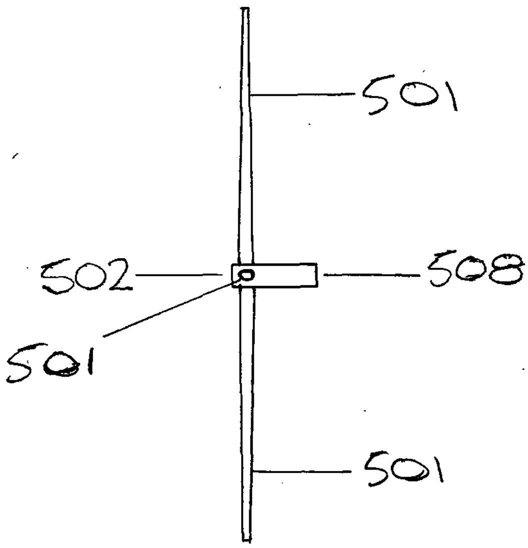


Fig 22E

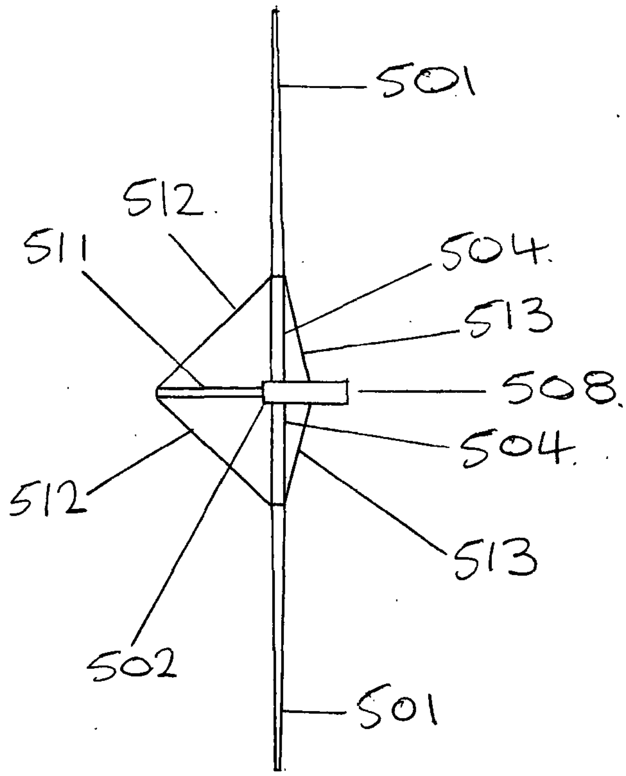


Fig 22F

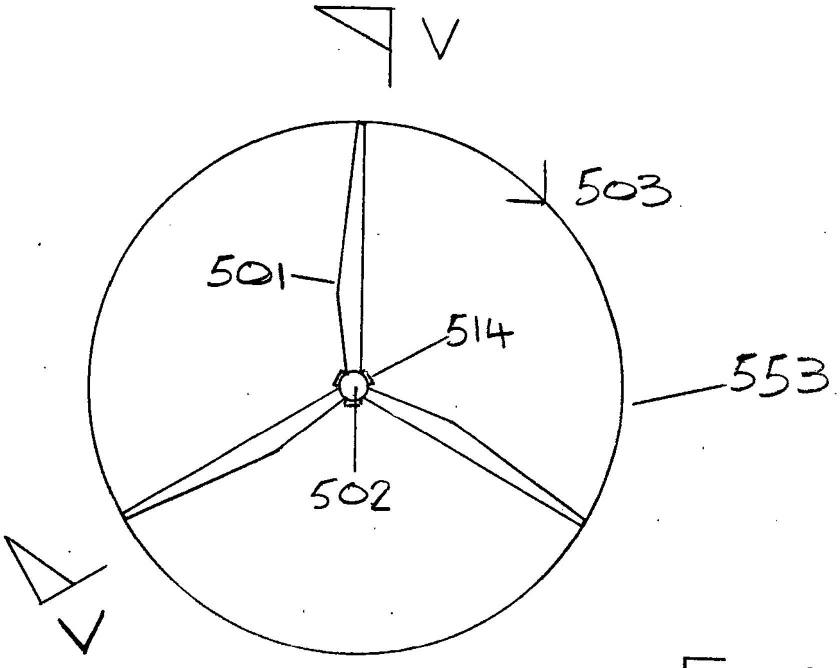


Fig 23A

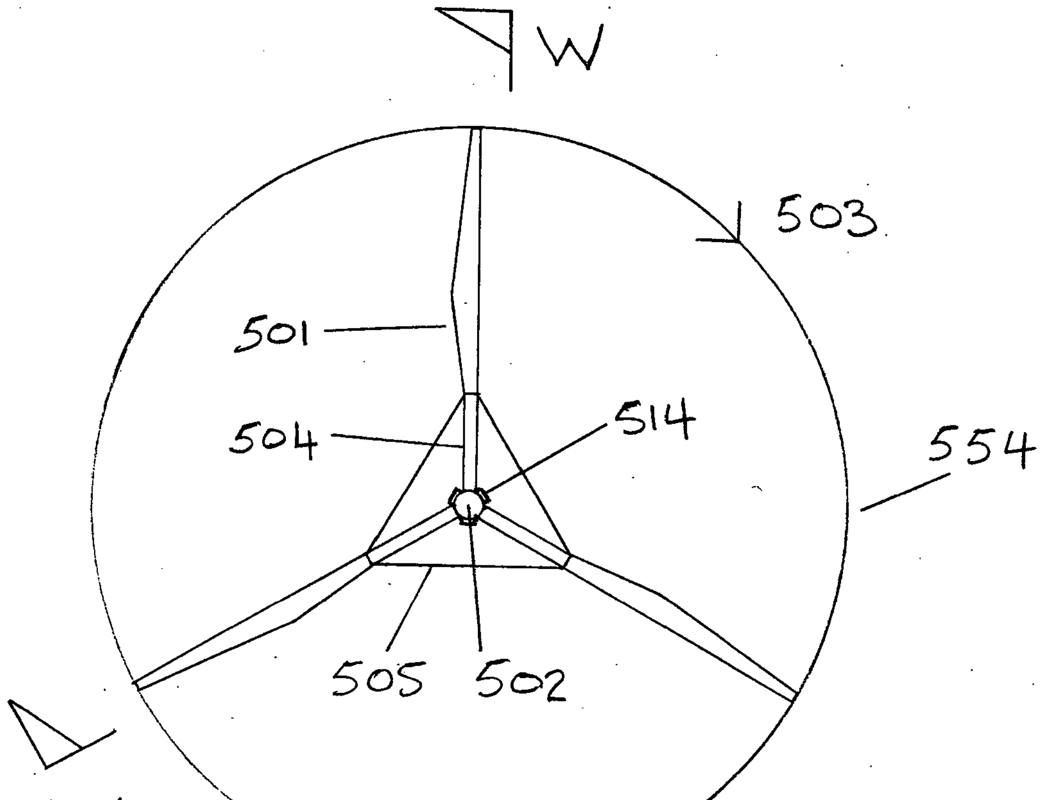


Fig 23B

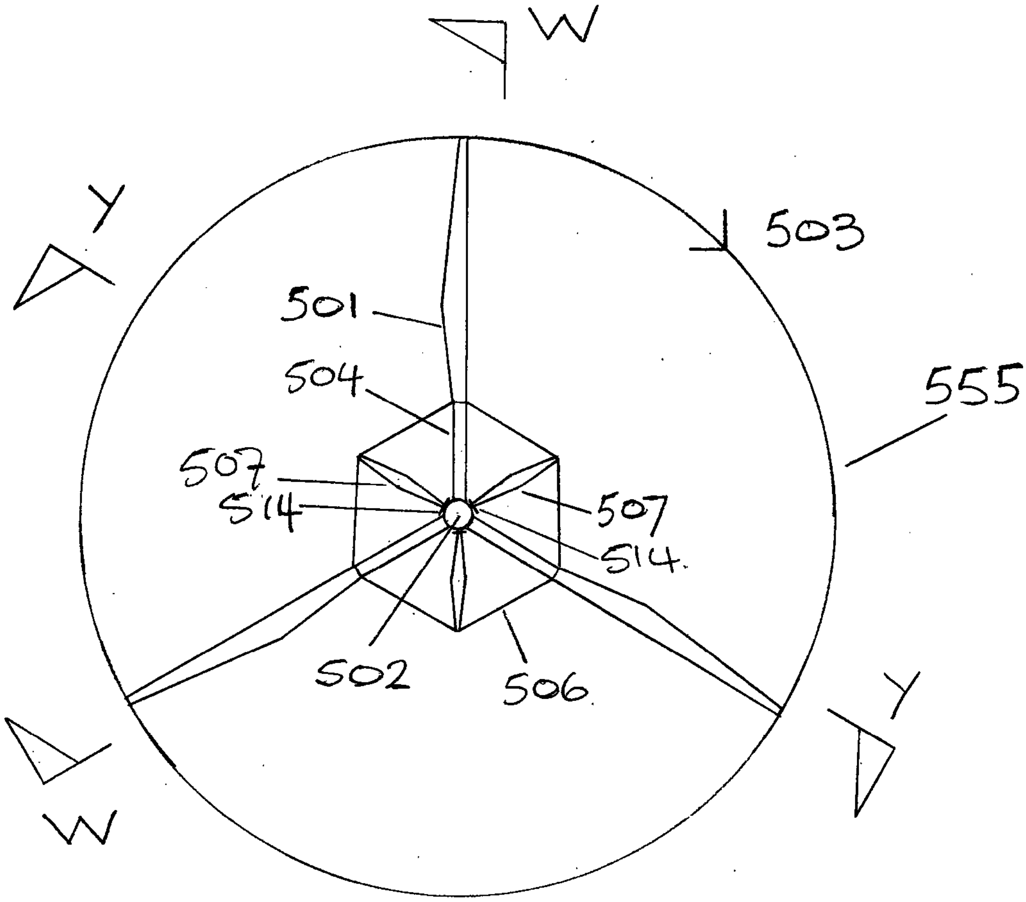


Fig 23C

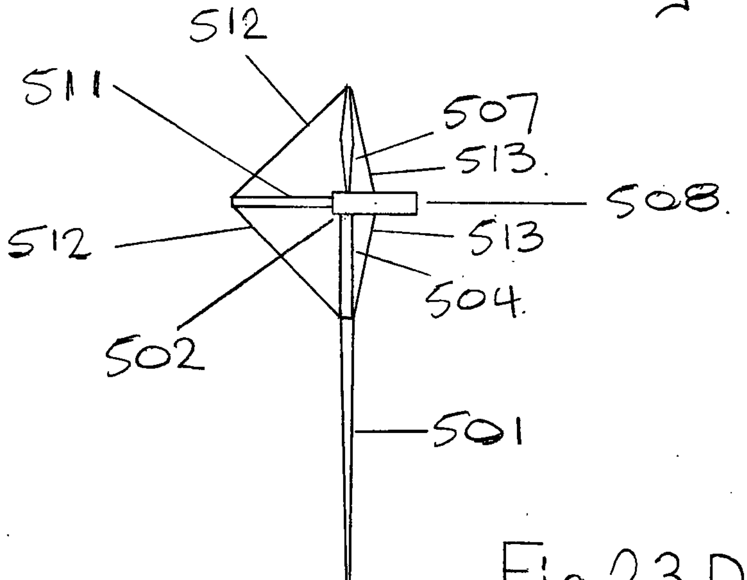


Fig 23D

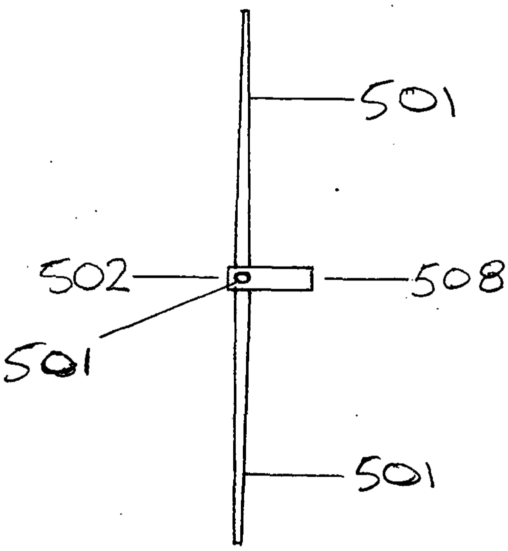


Fig 23E

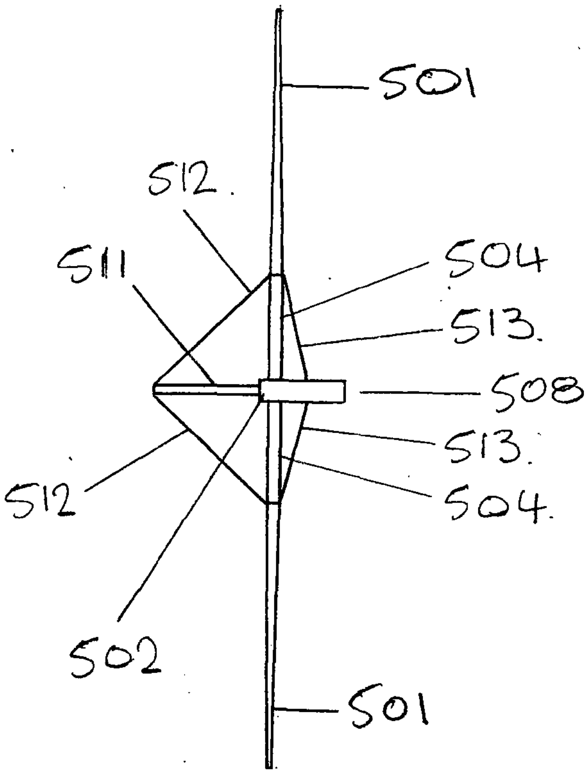


Fig 23F

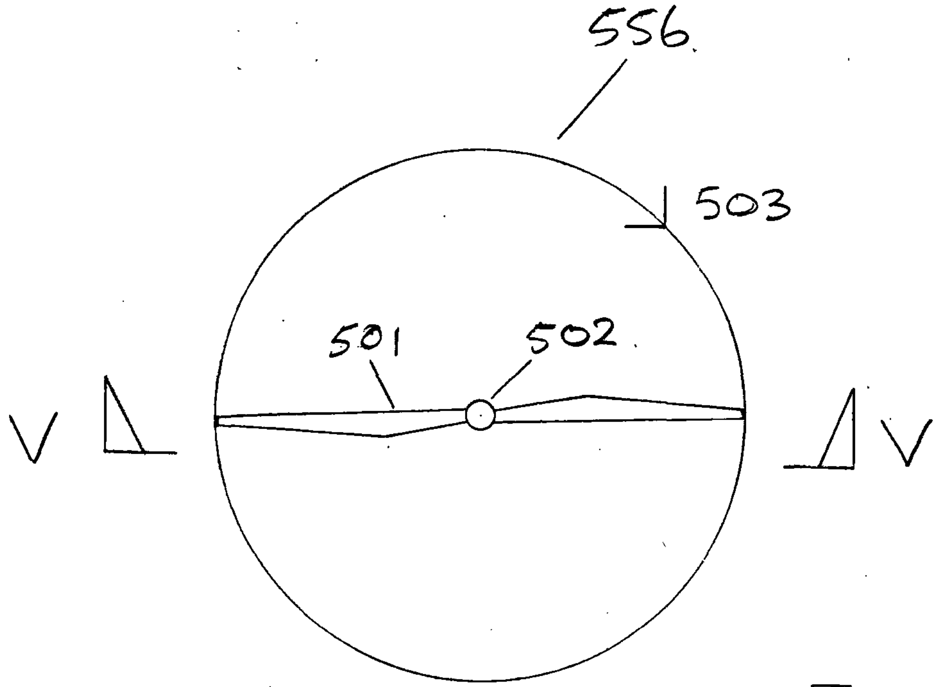


Fig 24A

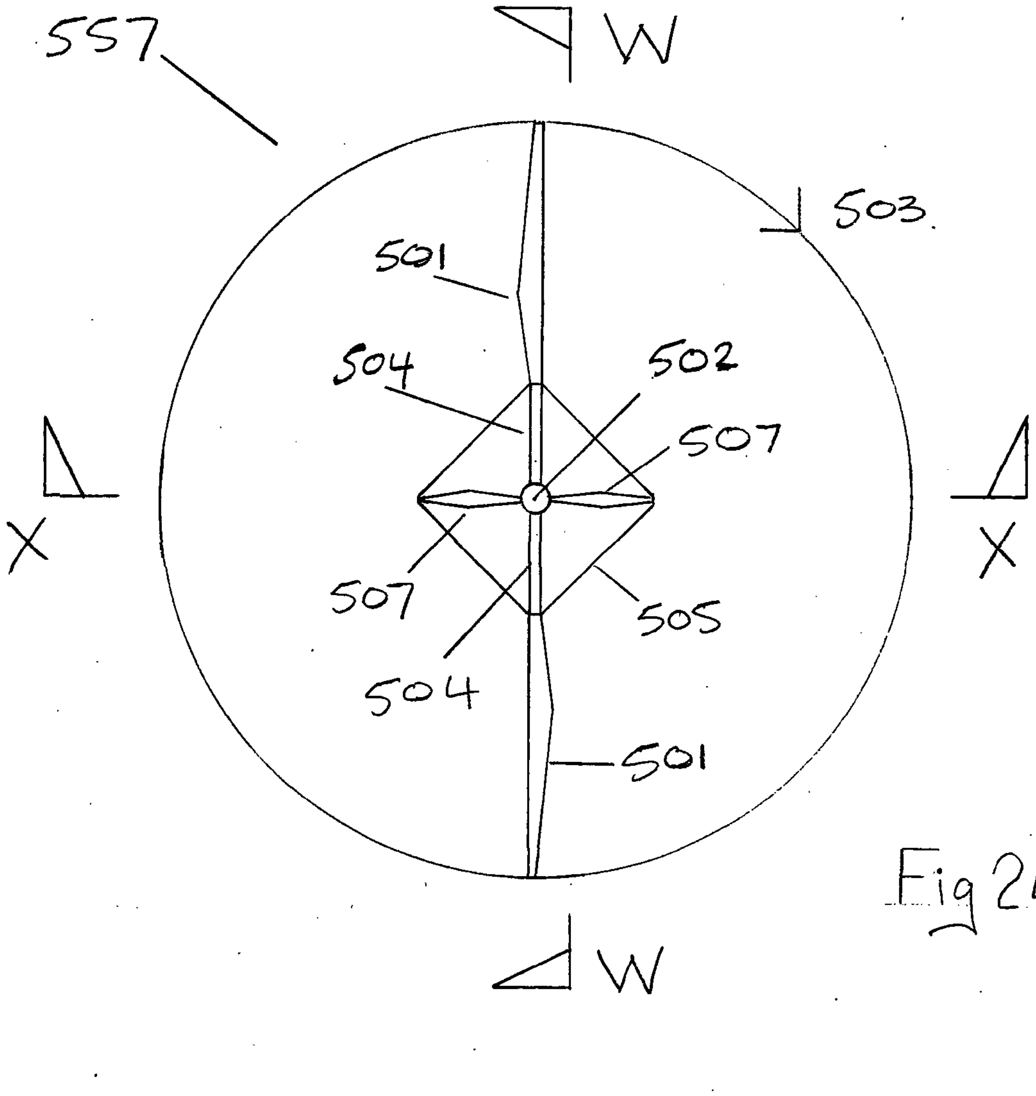


Fig 24C

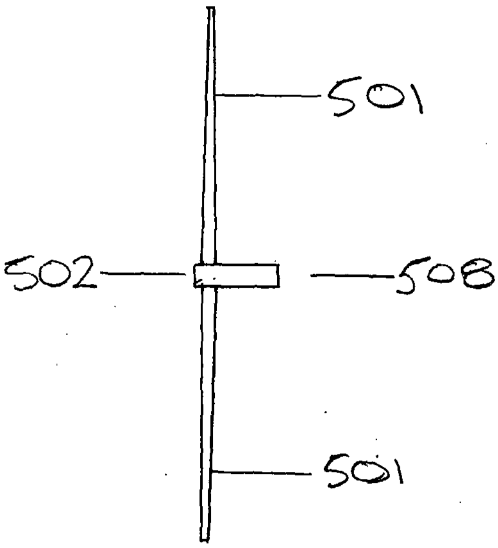


Fig 24D

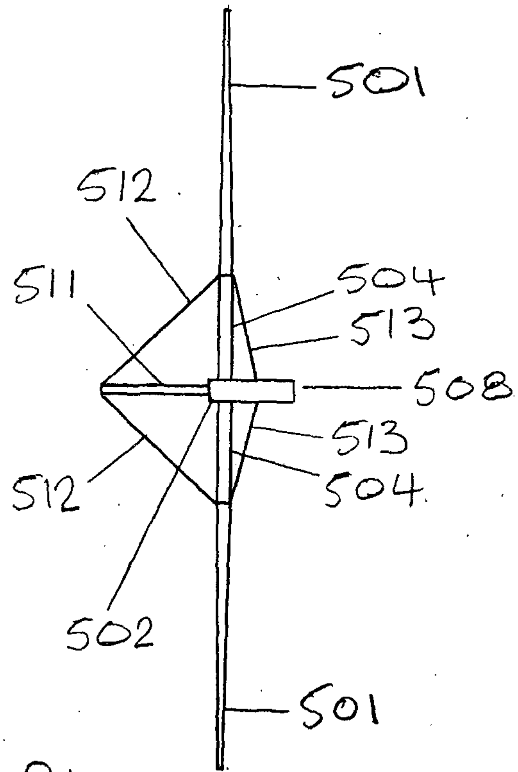


Fig 24E

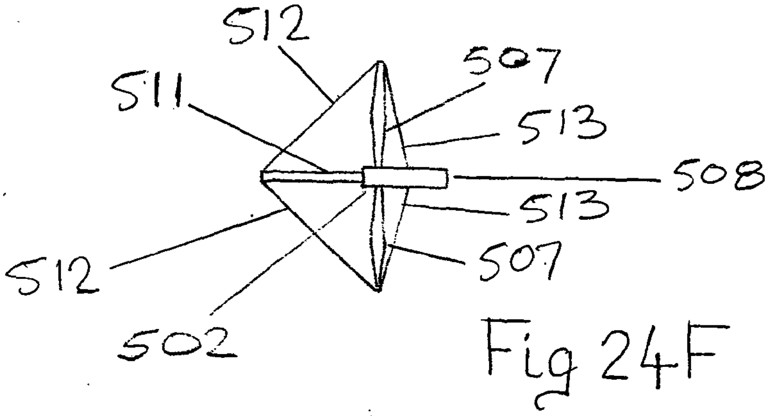


Fig 24F

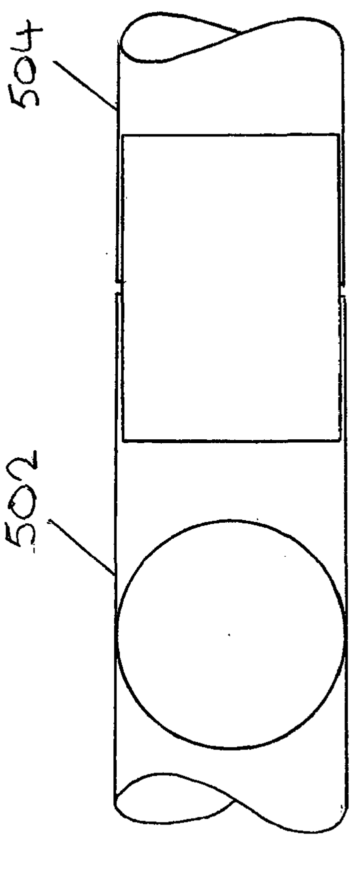


Fig 25A

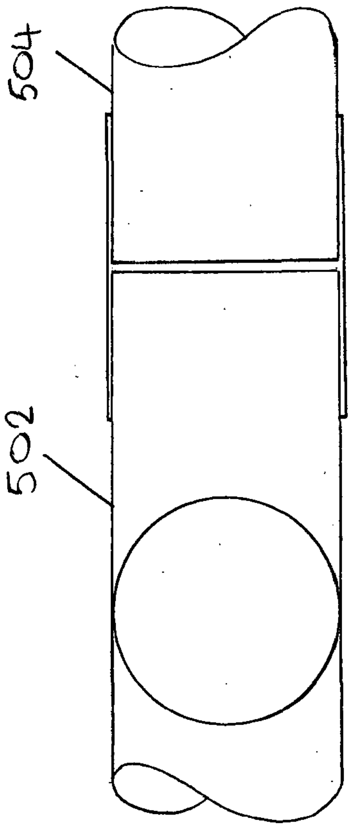


Fig 25 B

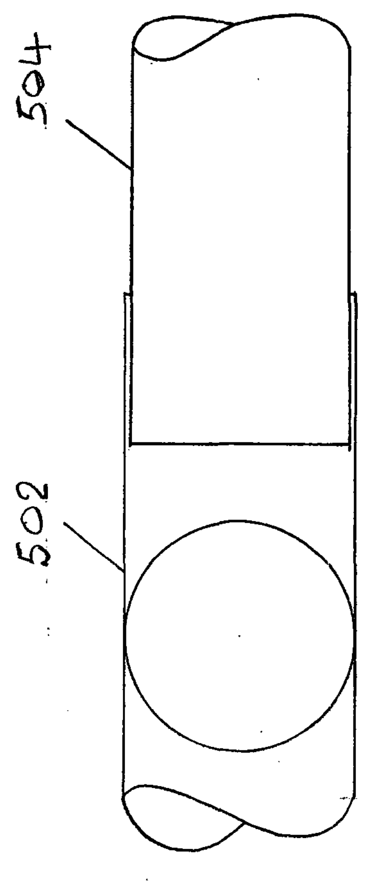


Fig 25C

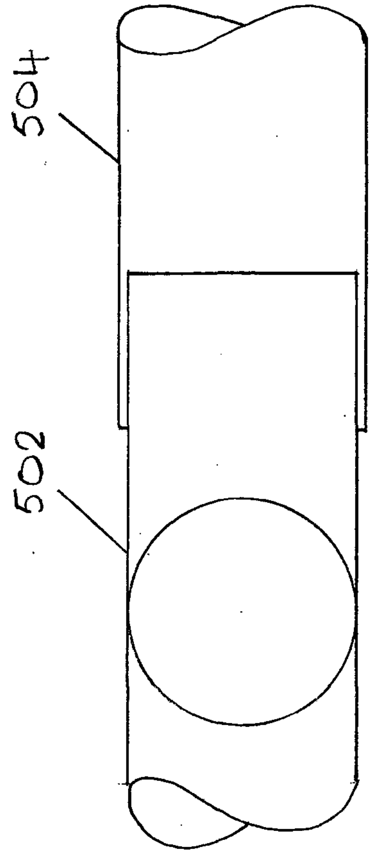


Fig 25D

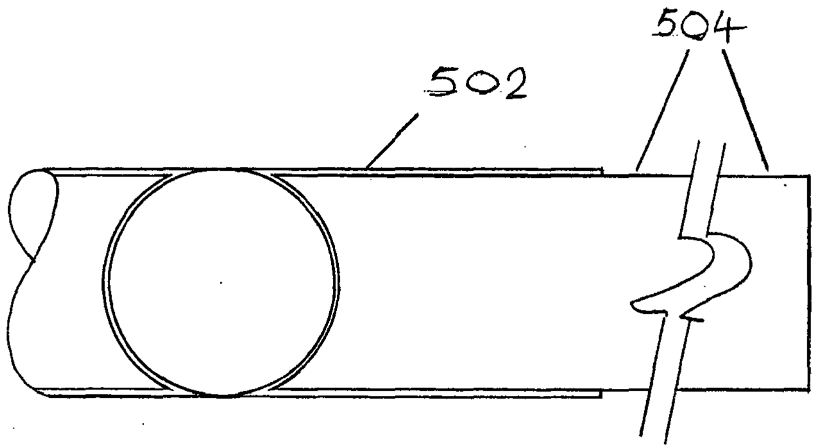


Fig 25E

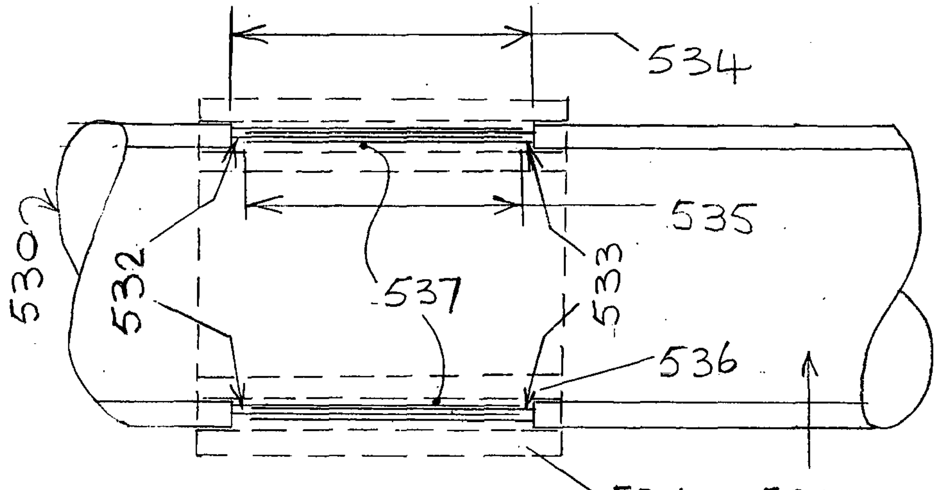


Fig 25H

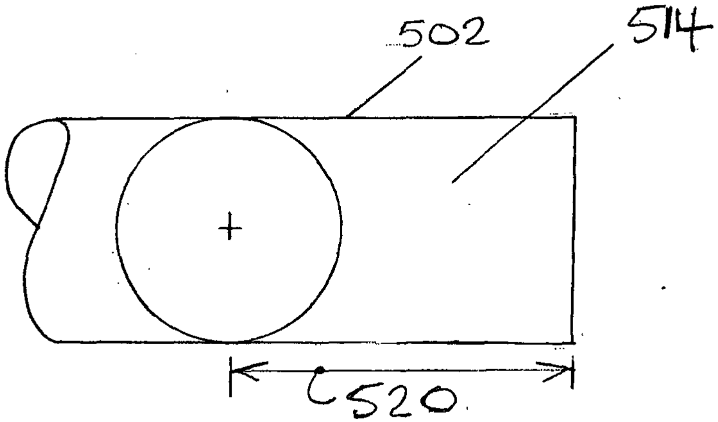


Fig 25F

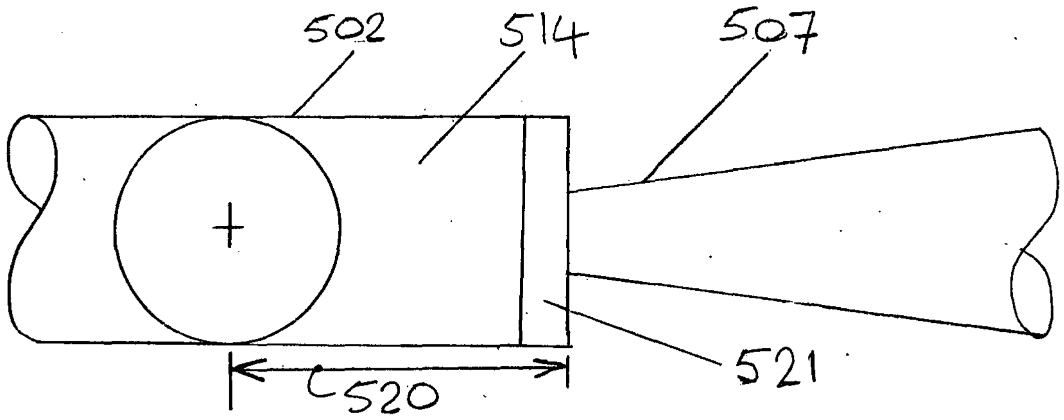


Fig 25G

A joint comprising an interface enabling structural continuity between joining intersecting members manufactured using composite materials.

Joint interfaces enabling structural continuity between two or more intersecting members forming a joint are required in the construction of many types of structures and machines. Such joints that provide a common point of connection between 2 or more members could commonly be referred to as 'lugs' or 'hubs'. These interfaces between two or more joining intersecting members can be categorised into three types depending on how far a first member joining a second member at an interface extends relative to the second member.

The interface within the joint is the common space occupied by the intersecting members.

The word joint describes the assembly comprising the intersecting members and the interface.

In all three types of interface the orientation between a first and a second member may be orthogonal or not orthogonal.

In a Type 1 interface a first member extending towards a second member terminates before contacting the second member or terminates at the surface of the second member without penetrating that surface. This type of interface requires an additional component or additional components or adhesive to form the interface between the two members. Examples of the additional component(s) required for Type 1 interfaces are: bolted angle brackets and welded end plates for structural steelwork or shelf support wall brackets or bolted fish plates at the joints in railway lines. The present invention does not apply to Type 1 interfaces.

In a Type 2 interface a first member meeting a second member in the interface passes through the first surface of the second member and terminates within the second member or in the case of a hollow member, within the walls of the second member which may be increased in thickness to accommodate the interface. The interface is formed within the dimensions of the members.

In a Type 3 interface a first member passes through a second member and extends beyond the second member a distance equal to or exceeding the distance required to enable the interface to provide the structural continuity required between the joining intersecting members.

Type 3 interfaces can be sub-divided into two variants. A first variant is an interface where there is at least one first member which maybe supports a component mounted to a first end and the second end passes through a second member but there is not a component mounted to the second end of the first member.

A second variant is an interface where there is at least one first member which maybe supports a component mounted to a first end and the second end passes through a second member and there is a component mounted to the second end of the first member.

These two variants of Type 3 interfaces are illustrated by the first embodiment of the present invention comprising the central hub of a wind turbine rotor with either three or four blades described in detail later in this specification. The component referred to in this case is a wind turbine blade or part of a blade support system mounted to the central hub. In a three bladed wind turbine rotor hub joint the first member does not support a component at the second end. In a four bladed wind turbine rotor hub joint the first member does support a component at the second end. The first and second members are the radial members of the hub.

A second illustration of the Type 3 interfaces is the second embodiment of the present invention described below comprising the joining of aircraft wings to an aircraft fuselage. In this embodiment the component referred to is the cantilever wing attached to the first and second ends of the stub wing which is the first member. The fuselage is the second member.

The present invention enables the forming of Types 2 and 3 interfaces manufactured using composite materials.

The 3 different types of joints comprising an interface between two or more intersecting members are illustrated in the following Figures 4A to 4E and the two embodiments of the present invention already referred to are illustrated in Figures 5 and 6. These embodiments comprise the central hub of a wind turbine rotor and the joint between the wings and fuselage of an aircraft.

Composite materials are materials comprising two or more constituent materials. The constituent materials are combined to form a composite material that has different tensile and compressive characteristics. Engineered composites are usually made up of fibrous reinforcement, such as glass fibre or carbon fibre, which provide the tensile and compressive strength and a polymer matrix which transfers shear.

In all type two and three interfaces comprising two or more intersecting members formed using composite materials there is a requirement for a crossover of forces within the materials of the composite material, which forces are carried by intersecting tensile and compressive components of the composite material forming the joint. The difficulty of forming such joints is the structural requirement to pass the materials of the intersecting members continuously through or into each other so that one member passes through or into the other and so that the structural properties of the different components of the composite material forming the members are continuous into, across and, in some cases, around the joint, according to the requirements of the geometry of the joint.

The present invention is of a joint comprising an interface enabling structural continuity between intersecting members with axes in one or more planes manufactured using composite materials.

If the walls or sections of adjacent intersecting members comprising an interface between the intersecting members can be made structurally continuous, by which means the members are structurally continuous into and or across and or around the interface, while also intersecting each other, then a two or three dimensional interface can be created that is structurally more effective than an interface in which the intersecting members are not structurally continuous into and / or across and / or around the interface.
For an interface between hollow members constructed using composite materials the configuration of the intersecting walls or sections of adjacent members can be constructed in situ by interweaving the tensile component of the composite material forming the intersecting walls or sections of adjacent members. This is the basis of the present invention.

Furthermore, for composite material to be as strong as possible the tensile component of the composite material has to be straight and parallel to and coincident with the direction of the applied forces. The present invention enables intersecting members with straight and parallel tensile components to be assembled.

As explained above there are two components in a composite material; a fibrous element often called reinforcement and a polymer matrix often referred to as resin. One of the key features of composite materials selected for strength is the tensile strength of the reinforcement and so the reinforcement is usually categorized by its tensile strength. But the same reinforcement also provides compressive strength when required but this is usually less than the tensile strength and is governed by buckling issues which are exacerbated if the strands of reinforcement material are not straight.

When it is stated that the tensile reinforcement has to be straight to provide composite material as strong as possible the issue is that straight reinforcement cannot elongate by straightening if it is already straight. Elongation has the effect of reducing available strength.

A similar situation applies to the corresponding compressive strength of the reinforcement which is subject to the influence of in-line buckling in that straight reinforcement will perform better in compression than reinforcement that is not straight because the effects of buckling are reduced. Therefore it can be seen that for the best structural performance the reinforcement needs to be straight and this aspect forms a primary feature of the present invention which provides for the strands of reinforcement material to be straightened during the manufacturing process.

The present invention includes a method for straightening by tightening and / or tensioning the reinforcement component of the composite material forming the interface by adjusting the interwoven reinforcement material to be straight and tight.

The in-situ manufacture, using composite materials, of the intersecting members can then be completed by the provision of internal and external shell moulds and formers. These are operated and removed to enable the injection and curing of the resin component of the composite material around the tensile component of the composite material forming the intersecting members of the interface to complete the formation of the interface and the joint as a whole.

There now follows an introduction to one embodiment of the present invention comprising the central hub of the rotor of a wind turbine assembly.

All of the large multi-megawatt wind turbines being manufactured today are horizontal axis wind turbines with three blades. The blades are arranged symmetrically around a central hub formed from a steel casting of a three sided semi-pyramidal shape.

For this almost universal three bladed design of wind turbine rotor the individual blades do not align opposite each other, they are arranged at 120 degrees radial spacing between each blade around the perimeter of the hub. As blade length increases with increasing size of wind turbines the disadvantages of this arrangement, with blades not opposite each other around the hub, becomes a more significant problem. This is because the cantilever fixity moments required to support each blade in operation cannot be balanced against each other as would be the case if the blades were arranged to be opposite each other on opposite sides of the rotor hub. To enable a balanced arrangement requires an even number of blades and hub radial members, two, four or six or more, rather than the currently popular arrangement consisting of three blades.

The current monolithic cast steel hub design of a three bladed wind turbine rotor hub provides a rigid mounting for a cantilever-moment-resisting connection between each turbine blade and the traditional monolithic cast steel hub. As turbines get bigger it is becoming more difficult to manufacture the monolithic cast steel hub and to provide a large enough rigid cantilever-moment – resisting connection to support the turbine blades. This is because as the turbine blades get bigger and more powerful and heavier the required cantilever-fixing-moment increases. The connection of the turbine blades to the hub also has to accommodate a rotational bearing to allow for the pitch rotation of the turbine blades relative to the hub, to enable a pitch control mechanism to change the pitch of the blades.

Within the wind turbine industry today a three bladed rotor arrangement is generally regarded to be the best compromise between the cost of and the generating power of wind turbine rotors and this arrangement is by far the most common. However, for turbine size and power to be able to increase further, beyond 10MW by way of example only, then four bladed rotors should become the preferred option to provide the ideal structural arrangement of blades being mounted to the central hub opposite each other on the same shared axis for each pair of blades.

In a traditional horizontal axis wind turbine rotor the turbine blades come together at the hub at the centre of the rotor. The blades are mounted to the hub and the hub is supported by a horizontal drive shaft or by a cantilever bearing extending within the hub. The function of the hub is to support the rotor blades and to transform the forces in the blades that are generated by the action of the wind on the blades into a torque and to transfer that torque to the electricity generator either directly or via a shaft with or without a gearbox.

Furthermore, the traditional design arrangement for the most common three bladed wind turbine is currently to form the hub steel casting with three large openings to accommodate an integral pitch control bearing for each of the three blades, one in each opening. The necessary three holes required in the hub limit the strength of the hub casting and there will eventually be a point reached with increasing blade length, power and weight, when a hub casting with three holes cannot economically be made strong enough to support the blades. This would be even more of a problem if the hub were to include openings for the preferred four or more bladed arrangement as there would have to be more openings in the cast steel hub resulting in less structural material remaining to carry larger loads.

The present invention overcomes this dilemma by accommodating three or four bladed rotors and avoiding the strength problems of the conventional cast steel hub if applied to larger four bladed rotors. The present invention will enable stronger and larger hubs and blade to hub cantilever- fixity-moment connections and will enable larger diameter four bladed rotors to be constructed comprising more powerful blades than is the case today.

This will enable much more powerful high-specific-power wind turbines to be constructed than is the case today when low-specific-power wind turbines are becoming the norm. The specific power of a wind turbine is the power rating divided by the swept area of the rotor. By way of example only, the current largest commercially available wind turbine rotors based on current low specific power designs today are of the order of 7 to 8 MW power rating in 10 m / sec. average wind speed conditions, whereas the power available from high specific power similar sized rotors comprising a central hub in accordance with the present invention would be of the order of 15MW or more in the same wind conditions.

Another existing example of this aspect are the 3.5 MW power rating high specific power wind turbines installed in the London Array wind farm in the Thames Estuary, where average wind speeds are 8 m / sec. If these wind turbine rotors were strengthened in accordance with the present invention and were installed in the middle section of the North Sea, where average wind speeds are 10 m / sec., then they would generate 7 MW power whereas the current offshore wind industry policy is to use turbines with significantly larger rotors with low specific power to achieve a 7 MW rating, as already described.

This policy appears to be due to the limited capacity of current tower and foundation designs adopted by the offshore wind industry which can only accommodate lower specific power rotors that generate less drag forces per unit of power in 10m / sec wind conditions, which forces the tower and foundation have to resist. However there are alternative tower and foundation designs complimentary to the present invention. See UK patents numbers: GB2451191 for an offshore wind turbine support tower and foundation and GB2481321 for a method of assembly, transfer and installation of an offshore wind turbine support tower and foundation. Both of these patents relate to higher specific power wind turbines in the 20MW plus range power rating.

If stronger towers were deployed then by using existing blade technology in conjunction with a hub embodying the present invention would enable wind turbines of 20 MW power in 10m / sec. wind to be supplied. This would lead to the electricity generated by these larger turbines becoming cheaper which is the essential aim of current UK Government offshore wind policy.

The present invention will be made from composite materials rather than a steel casting and this overcomes another major problem with a cast steel hub used for a wind turbine rotor hub. As wind turbines become larger the hub casting becomes increasingly difficult to cast reliably without structural defects, also the hub casting becomes significantly heavier and difficult to handle and transport. Transporting steel hubs larger than those cast today would be very expensive or impractical by rail or road on account of their size/width and weight.

Although the present embodiment would also have some transportation issues, the composite material rotor hubs could easily be manufactured at the coast to therefore minimize most transportation problems, whereas the steel casting facilities required to manufacture a cast steel hub, i.e. furnaces able to make 100 tons plus of liquid steel at any one time, do not exist by the coast and will never be available away from established inland steel making facilities. The materials required to manufacture a rotor hub in accordance with the present invention can easily be delivered by lorry and the electrical energy required for manufacture can be drawn from the local supply grid.

According to a first aspect of the present invention there are intersecting members constructed using composite materials forming an interface within which the intersecting members are structurally and materially continuous into and / or across and / or around the interface and so forces in the intersecting members can be transferred into and / or across and / or around the interface.

According to a second aspect of the present invention there is a method whereby during manufacture the tensile component of the composite material forming the walls or sections of adjacent intersecting members is in the form of layers of ribbons. These layers of ribbons are laid so as to pass over and between each other in alternate layers or groups of layers to form an intersecting arrangement of tensile components parallel to one or another of the intersecting adjacent intersecting members.

According to a third aspect of the present invention the ends of the ribbons of the tensile component of the composite material forming the walls or sections of adjacent intersecting members are during the formation of the walls or sections of the intersecting members temporarily anchored to a movable support at the location of the respective ends of the intersecting members. This movable support is adjusted to straighten and / or tension the tensile components so as to align them to be straight and parallel to the longitudinal axes of the respective members. This movable support in conjunction with the attachment device connecting the ribbons to the support adjusts all and each individual ribbon independently to ensure that each ribbon is straight and has the same tightness and profile without catenary sagging.

According to a fourth aspect of the present invention there is a set of internal forms, shell moulds and reinforcements shaped to form the inner surface shape of the intersecting members comprising the joint and also a set of outer shell moulds shaped to form the outer surface shape of the intersecting members comprising the joint. These forms, shells, reinforcements and moulds are assembled and arranged inside and outside of the laid out arrangement of the ribbons forming the tensile component of the composite material forming the walls or sections of adjacent intersecting members. This creates a defined and confined space around the tensile components that can be filled with resin filler material to complete the formation of the composite material forming the walls or sections of the adjacent intersecting members.

According to a fifth aspect of the present invention, when the interface between the intersecting first members and the first members themselves have been completely manufactured then a perpendicular second member orientated with the longitudinal axis of the second member in a plane effectively perpendicular to the plane of the first members is connected to the joint comprising an interface using the same methods whereby tensile components of composite material are woven and wrapped around the second member and around the joint comprising an interface and are pulled tight. Shell formwork is then positioned around the perpendicular second member and the intersecting first members of the joint comprising an interface and resin filler material is injected to fill the formwork and encapsulate the woven tensile composite material around the second member and the joint comprising an interface to form the completed assembly. This fifth aspect of the present invention applies for the embodiment of the present invention comprising the hub of a wind turbine rotor mounted on a horizontal shaft, by way of example only.

List of figures

Throughout the following text listing Figures 1 to 25 inclusive the word 'joint' is to be read as including the words 'joint comprising an interface'

Figures 1 describe a joint between four intersecting radial members, all in the same plane.

Fig. 1A is a plan view of the joint located by arrows W – W in Fig. 1B.
Fig. 1B is a cross sectional elevation located by arrows X – X in Fig. 1A.
Fig. 1C is a plan in section parallel to the plane of the joint and coincident with the centre line of the joint and located by arrows Z – Z in Fig. 1B.
Fig. 1D is a sectional elevation located by arrows V – V on Fig. 1C.
Fig. 1E is a three dimensional projection view of the whole joint described here in Figures 1.

Figures 2 describe a joint between three or six intersecting radial members, all in the same plane.

Fig. 2A is a plan view of the joint located by arrows W – W in Fig. 2B.
Fig. 2B is a cross sectional elevation located by arrows X – X in fi Fig. 2A.
Fig. 2C is a plan in section parallel to the plane of the joint and coincident with the centre line of the joint and located by arrows Z – Z in Fig. 2B.
Fig. 2D is a sectional elevation located by arrows V – V on Fig. 2C.

Figures 3 describe a joint between eight intersecting radial members, all in the same plane.

Fig. 3A is a plan view of the joint located by arrows W – W in Fig. 3B.
Fig. 3B is a cross sectional elevation located by arrows X – X in Fig. 3A.
Fig. 3C is a plan in section parallel to the plane of the joint and coincident with the centre line of the joint and located by arrows Z – Z in Fig. 3B.
Fig. 3D – not used.

Figures 4 - Shows the fundamental arrangement of Types 1, 2 and 3 joints between two or more intersecting members.

The figures illustrate joints between orthogonal members and between members that are not orthogonal.

Figs. 4A-1 and 4A-2 are type 1 joints.

Figs. 4B-1 and 4B-2 are type 2 joints.

Figs. 4C-1 and 4C-2, and Figs. 4D-1 and 4D-2 are type 3 joints.

Fig. 4E is a typical plan for joints between members of the same size cross sections.

Figs. 4F-1 and 4F-2 are typical plans for joints between members of different size cross sections.

Figures 5 and 6 show two embodiments of the present invention.

Fig. 5A - An elevation of a four bladed offshore wind turbine.

Fig. 5B - Shows an embodiment of the present invention comprising the central hub of the rotor illustrated in Fig 5A.

Figs. 6 A, 6B, 6C and 6D - plan, cross sections and 3D projection illustration showing an embodiment of the present invention enabling the connection of the wings of an aircraft to the fuselage of an aircraft.

Figures 7 and 8 provide a detailed description of the apparatus for manufacturing a joint providing structural continuity between intersecting members with axes in one or more planes manufactured using composite materials.

In the four Figures 7A, B, C and D the apparatus is shown in the initial 'open' position at the start of the joint manufacturing process.

Fig. 7A is a vertical longitudinal section A1 – A1 as indicated on the plan section Fig.7D.

Fig. 7B is an elevation view B1-B1 as indicated in the plan view Fig. 7C.

Fig. 7C is a plan view C1 – C1 of the apparatus in the open position as indicated in the elevation view Fig. 7B.

Fig. 7D is a horizontal section plan D1 – D1 of the apparatus in the open position as indicated in the vertical longitudinal section Fig. 7A.

In the four Figures 8A, B, C and D the apparatus is shown in the closed position. The transition from the open to the closed position occurs at an intermediate stage of the manufacturing process as explained in Figures 10.
Fig. 8A is a vertical longitudinal section A2 – A2 as indicated in the plan section Fig. 8D.
Fig. 8B is an elevation view B2-B2 as indicated in the plan view Fig. 8C.
Fig. 8C is a plan view C2 – C2 of the apparatus in the closed position as indicated in the elevation view Fig. 8B.
Fig. 8D is a section plan D2 – D2 of the apparatus in the closed position as indicated in the vertical longitudinal section Fig. 8A of the apparatus.

Figures 9 to 14 describe the process for constructing a joint using the apparatus as already described in Figures 7 and 8.

The four figures 9 show the apparatus in the open position with longitudinal tensile ribbons being installed.
Fig. 9A is a vertical longitudinal section A3 – A3 as indicated on the plan section Fig. 9D.
Fig. 9B is an elevation view B3-B3 as indicated in the plan view Fig. 9C of the apparatus.
Fig. 9C is plan view C3 – C3 as indicated in the elevation view Fig. 9B of the apparatus in the open position.
Fig. 9D is a section plan view D3 – D3 as indicated in the vertical longitudinal section Fig.9A of the apparatus in the open position.

Figs 10 shows the apparatus moved to the closed position with tensile ribbons installed and being tightened by moving the tensioning rings.

Fig. 10A is a vertical longitudinal section A4 - A4 as indicated in the plan section Fig 10D.
Fig. 10A/1 is a repeat of the central part of Fig.10A to a larger scale.
Fig. 10B is an elevation view B4 – B4 as indicated in the plan view Fig. 10C.
Fig. 10B/1 is a repeat of the central part of Fig.10B to a larger scale.
Fig. 10C is plan view C4 – C4 of the apparatus in the closed position as indicated in elevation view Fig. 10B.

Fig. 10C/1 is a repeat of the central part of Fig.10C to a larger scale.
Fig. 10D is a section plan D4 – D4 of the apparatus in the closed position as indicated in vertical longitudinal section 10A.
Fig. 10D/1 is a repeat of the central part of Fig.10D to a larger scale.

Figure 11 shows apparatus in the closed position with tensile ribbons installed and tightened and the addition of the circumferential tensile ribbons, diagonally inclined and perpendicular to the longitudinal axis.

Fig. 11A is a vertical longitudinal section A5 – A5 as indicated in the plan section Fig.11D.
Fig. 11A/1 is a repeat of the central part of Fig.11A to a larger scale.
Fig. 11B is an elevation view B5 – B5 as indicated in the plan section Fig.11C.
Fig. 11B/1 is a repeat of the central part of Fig.11B to a larger scale.
Fig. 11C is plan view C5 – C5 of the apparatus in the closed position as indicated in elevation view Fig.11B.
Fig. 11C/1 is a repeat of the central part of Fig.11C to a larger scale.
Fig. 11D is a section plan D5 – D5 of the apparatus in the closed position as indicated in the vertical longitudinal section Fig. 11A.
Fig. 11D/1 is a repeat of the central part of Fig.11D to a larger scale.

Figure 12 shows the apparatus in the closed position with longitudinal and circumferential tensile ribbons installed and tightened and the addition of the outer shell forms shown in place.

Fig. 12A is a vertical longitudinal section A6 - A6 as indicated in the plan section Fig 12D.
Fig. 12B is an elevation view B6 – B6 as indicated in plan view Fig. 12C.
Fig. 12C is a plan view C6 – C6 of the apparatus in the closed position as indicated in elevation view Fig.12B.
Fig. 12D is a section plan D6 – D6 of the apparatus in the closed position as indicated in the vertical longitudinal section Fig. 12A.
Fig. 12E shows a three dimensional view of the external shell forms for a joint between four intersecting radial members.

Figure 13 shows the apparatus in the closed position with the provision of man access holes incorporated in the embodiment of the present invention as a central hub for a wind turbine rotor.

Fig. 13A is a vertical longitudinal section A7-A7 as indicated in the plan section Fig. 13D.

Fig. 13B is an elevation view B7 – B7 as indicated in the plan section Fig.13C

Fig. 13C is a plan view C7 – C7 of the apparatus in the closed position as indicated in plan section Fig. 13B.

Fig. 13D is a section plan D7 – D7 of the apparatus in the closed position as indicated in plan section Fig. 13A.

Figure 14 shows the apparatus in the closed position with tensile ribbons installed and tightened, circumferential ribbons installed and outer shell formwork in place and resin / filler injected – shown shaded hatched. The composite material reinforcement shells are shown with solid shading.

Fig. 14A is a vertical longitudinal section A8 - A8 as indicated in the plan section Fig 14D.

Fig. 14B is an elevation view B8 – B8 as indicated in plan view Fig. 14C.

Fig. 14C is a plan view C8 – C8 of the apparatus in the closed position as indicated in elevation view Fig. 14B.

Fig. 14D is a section plan D8 – D8 of the apparatus in the closed position as indicated in the vertical longitudinal section Fig. 14A.

Fig. 14E shows a three dimensional view showing a finished joint comprising four intersecting radial members after the removal of formwork.

Figure 15, 16, 17, 18, 19, 20 and 21 describe the details of how a joint between four intersecting radial members can be extended to include the connection of a radial member that is perpendicular to the plane of the joint.

Figure 15 is a three dimensional projection view showing four intersecting radial members in one plane connected to a fifth radial member lying in a plane orientated to be perpendicular to the plane of the four intersecting radial members.

Fig. 16 is an elevational view V1 indicated by the view arrow V1 in Fig.15 and Fig. 17.

Fig. 17 is an elevational view V2 indicated by the view arrow V2 in Fig. 15 and Fig. 16.

Fig. 18 is an elevational view V1 indicated by the view arrow V1 in Fig. 15, and Fig. 17 showing formwork for the shaft / joint connection, similar to Fig.16.

Fig. 19 is an elevational view V2 indicated by the view arrow V2 in Fig. 15 and Fig. 16 showing formwork for the shaft / joint connection.

Fig. 20 is an elevational view V1 indicated by the view arrow V1 in Fig.15 and Fig. 17 showing formwork for the shaft / joint connection and the resin filler having been injected.

Fig. 21 is an elevational view V2 indicated by the view arrow V2 in Fig.15 and Fig. 16 showing formwork for the shaft / joint connection and the resin filler having been injected.

The following 3 figures 22, 23 and 24 illustrate various embodiments of the present invention comprising the central hub in wind turbine rotors.

Fig. 22A Elevation of a rotor with four blades mounted on a traditional hub.

Fig. 22B Elevation of a rotor with four blades mounted to an offset rotor hub.

Fig. 22C Elevation of a rotor with four blades mounted to an offset rotor hub including a circumferential tie support system.

Fig. 22D Section view X – X – on Fig. 22C.

Fig. 22E Section view V – V – on Fig. 22A.

Fig. 22F Section view W – W – on Fig. 22B and Fig. 22C.

Fig. 23A Elevation of a rotor with three blades mounted on a traditional hub

Fig. 23B Elevation of a rotor with three blades mounted to an offset rotor hub

Fig. 23C Elevation of a rotor with three blades mounted to an offset rotor hub including a circumferential tie support system.

Fig. 23D Section view Y – Y on Fig. 23C.

Fig. 23E Section view V – V on Fig. 23A.

Fig. 23F Section view W – W on Fig. 23B and Fig. 23C.

Fig. 24A Elevation of a rotor with two blades mounted on a traditional hub

Fig. 24B not used.

Fig. 24C Elevation of a rotor with two blades mounted to an offset rotor hub including a circumferential tie support system.

Fig. 24D Section view V-V – on Fig. 24A.

Fig. 24E Section view W-W – on Fig. 24C.

Fig. 24F Section view X-X – on Fig. 24C.

The integration of a structurally continuous intersecting member comprising a joint in accordance with the present invention at the centre of a wind turbine rotor requires that a radial member be connected to extensions of that radial member. Figures 25 show configurations that can be used to connect extensions to a radial member, by way of example only.

Fig. 25A Connection to a radial member of an extension of the same diameter using an inner sleeve joint.

Fig. 25B Connection to a radial member of an extension of the same diameter using an outer sleeve joint.

Fig. 25C Connection to a radial member directly of an extension with a smaller diameter section requiring no sleeve.

Fig. 25D Connection to a radial member directly of an extension with a larger diameter section requiring no sleeve.

Fig. 25E Connection to a radial member of a carrier member.

Fig. 25F A radial member forming a radial anchorage member.

Fig. 25G Connection to a radial member of a circumferential tie support system radial member.

Fig 25H. A method of joining two tubes made of composite material of similar diameter using composite material by layering tensile reinforcement and resin injection.

Detailed description of Figures 1 to 25

Throughout the following text describing Figures 1 to 25 inclusive the word 'joint' is to be read as including the words 'joint comprising an interface'

The following figures 1 to 14 now explain in detail the geometry of joints in general, two embodiments of the present invention and the form and manufacture of a joint between four radial hollow members of circular cross section constructed in composite materials lying in one plane.

Figures 1A, 1B, 1C, 1D and 1E illustrate in plan, elevation, sections and three dimensional view, a joint between four intersecting orthogonal radial members, all in the same plane.

This four radial members joint illustrates the main feature of the present invention, which is the creation of a joint whereby hollow members fully intersect each other. Each member section passes continuously through the section of the other member and vice versa. It is not a joint formed by one member joining onto another member. All the members have equal status within the joint and so gain maximum strength and effectiveness from the joint.

Fig. 1A is a plan view of the joint shown by location arrows W – W in Fig. 1B and shows the four intersecting members 101, 102, 103 and 104. The curved outer surfaces 107 of each of the members intersect at four intersecting lines 105.

Fig. 1B is a cross sectional elevation shown by location arrows X –X on Fig.1A. The members are hollow and of circular cross section as shown in the section 106. Within the circular cross section 106 of the member 104 in view X on Fig. 1A the curved outer surface 107 of the members 101 and 103 is visible. Similarly in view Y on Fig. 1A the curved outer surface 107 of the members 102 and 104 would be visible.

Fig. 1C is a plan section parallel to the plane of the joint and coincident with the centre line of the joint. The location of this plan section is indicated by the location arrows reference Z - Z in Fig. 1B. This plan section again shows how the walls of the sections of the intersecting members pass through each other. Typical intersection point 108 applies around the whole perimeters of intersection lines 105 shown in Fig.1A. The internal surfaces 107 shown in Fig. 1B are also indicated.

Fig. 1D shows a sectional elevation indicated by location arrows reference V – V on Fig. 1C perpendicular to the plane of the joint and coincident with the centre line of one of the intersecting members. This section shows how the intersecting walls of the sections of the intersecting members are homogenous, one wall coincident with and passing through the other 109.

Fig. 1E is a three-dimensional projection view illustrating the whole configuration of the joint and how the walls of each member pass through the walls of an adjacent member intersecting on lines 105 (see Fig.1A) and at points 108 (see Fig.1C).

It can be deduced from the figures that there is a closed space 110, see Fig. 1C, in the middle of the joint bound by the surfaces 107 in figures 1B and 1C. To form the joint there is a void former in the shape of this space. This hollow void former is a permanent component of the joint and forms part of the internal formwork used to mould the resin filler material used in forming the joint as will be explained in Figs. 7 to 15 inclusive.

The shape of this void former is specific to the number of members meeting at the joint and the former for an orthogonal joint between four intersecting circular members of the same diameter is the simplest shape 110 and consists of four semi-circular facets forming a truncated sphere as will be seen in figures 7 to 15.

Figures 2A, 2B, 2C and 2D illustrate in plan, elevation and sections a joint between three or six intersecting radial members, all in the same plane.

Fig. 2A is a plan view of the joint shown by arrows W – W in Fig. 2B and shows the intersecting members 201, 202, 203, 204, 205 and 206. The curved outer surfaces 207 of each of the members intersect at six intersecting lines 208.

Fig. 2B is a cross sectional elevation shown by arrows X –X on Fig. 2A. The members are hollow and of circular cross section as shown in the section 209. Within the circular cross section 209 of the member 205 in view X (Fig. 2A) the curved outer surfaces 207 of the members 204 and 206 are visible. Similarly in view Y (Fig. 2A) the curved outer surfaces 207 of the members 202 and 204 would be visible.

Fig. 2C is a plan in section parallel to the plane of the joint and coincident with the centre line of the joint. The location of this plan section is shown by arrows reference Z - Z in Fig. 2B. This plan section again shows how the walls of the sections of the intersecting members pass through each other. Typical intersection point 211 applies around the whole perimeters of intersection lines 208 shown in Fig. 2A. The internal surfaces 207 shown in Fig. 2B are also indicated.

Fig. 2D shows a sectional elevation indicated by arrows V – V on Fig. 2C perpendicular to the plane of the joint and coincident with the centre line of two of the intersecting members. This section shows how the intersecting walls of the sections of the intersecting members are homogenous, one wall coincident with and passing through the other 212.
It can be deduced from the figures that there is a closed space 213 in the middle of the joint bound by the surfaces 207 in Figs. 2B and 2C. To form the joint there is a void former in the shape of this space. This hollow void former is a permanent component of the joint and forms part of the internal formwork used to mould the composite resin filler material used in forming the joint as will be explained in figures 7 to 15 inclusive.

The shape of this void former is specific to the number of members meeting at the joint and the former for a joint between three or six intersecting members of the same diameter is a more complicated version of the void former 110 in Fig. 1C and consists of six semi-circular facets forming a truncated sphere.

There is a further complication in that there are six additional common spaces 214 between the intersecting members. These spaces are created automatically by the weaving of the composite material forming the members, see Figs. 9 and 10 and become filled with resin filler material. If required, additional permanent formwork / filler blocks, made of balsa wood for example, can be introduced into these spaces during weaving to displace the resin filler material. This may be desirable to reduce the build-up of excessive heat associated with large volumes of resin filler material during curing or on the grounds of economy as resin filler material is expensive.

Figures 3A, 3B and 3C illustrate in plan, elevation and section a joint between eight intersecting radial members, all in the same plane.

Fig. 3A is a plan view of the eight intersecting member joint shown by arrows W – W in Fig. 3B, and shows the eight intersecting members 301, 302, 303, 304, 305, 306, 307 and 308. The curved outer surfaces 310 of each of the members intersect at eight intersecting lines 309.

Fig. 3B is a cross sectional elevation shown by arrows X –X on Fig. 3A. The members are hollow and of circular cross section as shown in the section.
Within the circular cross section 314 of the member 306 in view X (Fig. 3A) the curved outer surfaces 310 of the members 305 and 307 are visible. Similarly in view Y (Fig. 3A) the curved outer surfaces 310 of the members 303 and 305 would be visible.

Fig. 3C is a plan in section parallel to the plane of the joint indicated by arrows Z - Z on Fig. 3B and coincident with the centre line of the joint. This plan section again shows how the walls of the sections of the intersecting members passing through each other. Typical intersection point 311 applies around the whole perimeters of intersection lines 309 shown in Fig. 3A.

It can be deduced from plan Fig. 3C that there is a closed space 312 in the middle of the joint. To form the joint there is a void former in the shape of this space. This hollow void former is a permanent component of the joint and forms part of the internal formwork used to mould the composite resin used in forming the joint as will be explained in Figs. 7 to 15 inclusive.

The shape of this void former is specific to the number of members of the same diameter meeting at the joint and the former for a joint between eight intersecting members consists of eight semi-circular facets forming a truncated sphere.

There is a further complication in that there are sixteen additional common spaces between the intersecting members 313. These spaces are created automatically by the weaving of the composite material forming the members, see later Figs. 9 and 10 and become filled with resin filler material. If required additional formwork / filler blocks, made of balsa wood for example, can be introduced into these spaces during weaving to displace the resin filler material. This may be desirable to reduce the build-up of excessive heat associated with large volumes of resin filler material during curing or on the grounds of economy as resin filler material is expensive.

It can be seen that the same principles can be applied to the detail of a joint between any number of intersecting members although the joint between two or four intersecting members remains the simplest with a joint between three or six members being the next simplest. The typical joint between two intersecting members will be the joint that is most used for practical constructions such as, by way of example only, the central hub of a wind turbine rotor and for connecting the wings to the fuselage of an aircraft.

The following Figs. 4A to 4F inclusive illustrate the fundamental arrangement of Types 1, 2 and 3 joints between two or more intersecting members.

The two or more intersecting members meeting at the joint can be perpendicular to each other or inclined to each other, as shown in the two examples drawn in each of Figs. 4A to 4D for each type of joint.

Figures 4A-1 and 4A-2 show a Type 1 joint. The member 801 does not extend upto the face of member 802.

Figures 4B-1 and 4B-2 show a Type 2 joint. The member 801 extends into the member 802. In this type of joint the length of the penetration of member 801 into member 802 is sufficient to effectively join members 801 and 802.

Figures 4C-1 and 4C-2 show a first variant of a Type 3 joint in which the second end of the first member 801 extends through and beyond the member 802 by a sufficient distance required to effectively join members 801 and 802 but there is no component attached to the second end of the first member 801 extending beyond the second member 802.

Figures 4D-1 and 4D-2 show a second variant of a Type 3 joint. The second end of the first member 801 extends through and beyond the second member 802 by a distance similar to the extension shown in Figs. 4C-1 and 4C-2 indicated by the dotted line and there is a component 806 mounted to the second end of the member 801 at the dotted line extending beyond the second member 802.

Figure 4E is a plan showing the layout of two circular members 801 and 802 of the same diameter forming a joint as described in Figs. 4A to 4D

Figures 4F-1 and 4F-2 show in plan the layout of two circular members 804 and 805 of differing diameters forming a joint as described in Figs. 4A to 4D

The present invention enables the manufacture of joints Type 2 and both variants of joints Type 3.

Type 1 joints require an additional jointing component or the use of an adhesive to form the interface comprising the joint.

The basic principles described here for two members meeting at a joint also apply for joints with more than two members meeting and these joints are also enabled by the present invention in the same way as described in this specification.

Figures 5 and 6 describe by way of example only, two possible embodiments of the present invention within wind turbines and aircraft where the application of the present invention will solve current structural problems enabling increased value for money from these applications.

Figure 5A shows an elevation of a four bladed wind turbine 601standing in the sea 602 offshore. One embodiment of the present invention comprises the central hub 603 to which the four blades 605 are mounted comprising the wind turbine rotor 604.

By way of example only. A 20MW power wind turbine operating offshore in the North Sea would have a rotor diameter 610 of 200m and would be located in sea water depth 607 of 50m with tide, surge and wave addition 608 of 10m and blade tip clearance 609 of 30m giving a height to the centre of the rotor above seabed level of 190m.

The rotor hub 603 is made using composite materials and is in the form of four intersecting radial members with each radial member supporting one turbine blade 605. This embodiment of the present invention is described in detail in this specification.

Fig. 5B is a larger scale expanded three dimensional illustration of the hub 603 arrangement as indicated by the arrows 606. It will be seen in the following description of Figs. 7 to 25 how the manufacture of this hub is enabled by the present invention.

Figure 6A shows a vertical cross section shown by arrows W-W in Fig. 6B and Fig. 6B shows a plan section, as indicated by the plan section arrows X – X in Fig. 6A, through the fuselage (body) of an aircraft 701 at the location where the wings 702 are connected. The fuselage and wings are constructed using composite materials.

The cantilever wings 703 are connected to stub wings 704 extending each side of the fuselage. The stub wings form a continuous member 705 which passes continuously through the lower section of the fuselage. The members comprising the stub wings and the fuselage are two intersecting members passing through each other to form a very strong monolithic joint at the point of maximum bending moment for the wings. Dotted lines 708 show the outline shape of the outline of the wings.

The bending moment at the point 706 will be less than the bending moment occurring at the face 707 of the fuselage. This facilitates the connection at this point.

Figure 6C shows a vertical cross section indicated by section arrows Y – Y on Fig. 6B and shows the stub wing member in section and in relationship to the fuselage member 701 through which the stub wing member 704 passes.

Figure 6D is a three dimensional illustration of the fuselage / stub wing arrangement enabled by the present invention.

It can be seen that the structural arrangements in Figs. 5B and 6D are fundamentally similar, i.e. two intersecting members passing through each other in full or part section. See also previous Fig. 1E. There will be many other embodiments incorporating this fundamental feature of the present invention.

Figures 7A to 7D and 8A to 8D provide a general description of the apparatus for constructing joints between structurally continuous intersecting radial members made of composite material – in the example described here there are four orthogonal first radial members. There can be different permutations of structurally continuous intersecting radial members that can be joined together using the apparatus described here adapted to accommodate differing numbers and arrangements of intersecting radial members.
A second radial member perpendicular to the plane of the four first radial members can be introduced with all members intersecting within one defined space as described in Figures 15, 16, 17, 18, 19, 20 and 21.

In the four Figs. 7A, B, C and D the apparatus used for the manufacture of the present invention is shown in the initial 'open' position at the start of the joint manufacturing process. It can be seen from plan Figs. 7C and 7D that the apparatus shown in this example is for a joint between four intersecting radial members.
As can be seen in the figures the same details of the apparatus occur in both plan, elevation and sections in all four of the Figs. 7A, B, C and D and therefore the detailed descriptions of components provided for Figure 7A, which is a vertical longitudinal section view A1 – A1 drawn on a centre line of the apparatus as indicated on Fig. 7D, also apply to Figs. 7B, C and D.
The next six paragraphs all refer to Fig. 7A

Fig. 7A is a vertical longitudinal section A1 – A1 as indicated on plan section Fig.7D in which two of the four circular cross section cylindrical internal shell formworks 1 shown in plan Figs. 7C and 7D are shown supported by the fixed annular support 2 and by the sliding annular support 3 and the fixed annular stop end support 4.

The sliding annular tensioning rings 5 fit around the formworks 1 and are adjusted in a horizontal sliding manner along the axis of the internal shell formworks by mechanism 6 operating via pull/push rods 7.

Annular support 2 is rigidly mounted to the main base 8. Sliding support 3 is mounted to sliding base 9 which can slide along tracks 10 rigidly mounted to main base 8. The main bases 8 are fixed to and are supported by a floor slab or other supporting structure 26.

Sliding base 9 is moved horizontally along the tracks 10 by a mechanism 11 mounted to sliding base 9 and engaging with fixed main base 8 via tracks 10.

The whole apparatus described in Figs. 7A, B, C and D comprises four circular cross section cylindrical internal shell formworks 1 and associated supports and equipment arranged orthogonally around centre form 20.

Centre form 20 in the apparatus shown here is formed from four identical circular segments cored from the wall of a circular cylinder, each segment extending over one half of the perimeter of that cylinder wall and the segments are fitted symmetrically together at four opposite corners to form a truncated sphere circular in vertical side elevation as seen in Figs. 7A and 7B and square in plan view as seen in Figs. 7C and D, mounted to a vertical central support post 21. The radius of the four outer circular curved surfaces of the truncated sphere forming centre form 20 is the same as the radius of the outer circular curved surfaces of the circular cross section cylindrical internal shell formworks 1. For an explanation of the dimension indicated by reference 25 refer to Fig. 8A.

The next paragraph refers to Fig. 7B

Fig. 7B is an elevation view B1-B1 as indicated in plan view Fig. 7C and shows a general external view of the apparatus in the open position showing the general arrangement of the components already described in Fig. 7A. Note that the reinforced composite strengthening shells 13, also shown in Figs. 7A, 7C and 7D and fully described in Fig. 8A, extend to the outer surface of the circular cross section cylindrical internal shell formworks 1 and are therefore visible in this elevation. Noting this particular point will help clarify the description of the manufacturing process.

The next paragraph refers to fig 7C.

Fig. 7C is a plan view C1 – C1 as indicated in elevation view Fig. 7B of the apparatus in the open position for the manufacture of a joint between four radial members.

The next paragraph refers to fig 7D

Fig. 7D is a horizontal section plan D1 – D1 as indicated in vertical longitudinal section Fig. 7A of the apparatus in the open position for the manufacture of a joint between four radial members. The four fixed bases 8 are fixed to the support floor / structure 26. The location of bases 8 can be adjusted to suit the manufacture of joints with different lengths of radial members.

In the four Figs. 8A, B, C and D the apparatus used for the manufacture of the present invention is shown in the closed position. The transition from the open to the closed position occurs at a later stage of the joint manufacturing process as explained in Figs. 10. It can be seen that the same details of the apparatus occur in both plan, elevation and sections in all four of the Figs. 8A, B, C and D and also all the components in Figures 8 are the same as the components in Figs. 7 where they have already been referenced and described in the preceding paragraphs.

Fig. 8A is a vertical longitudinal section A2 – A2 as indicated in plan section Fig. 8D in which the circular cross section cylindrical internal shell formworks 1 have been moved into a new converged closed configuration leaving a narrow curved space 22 between the curved end piece 23 of the circular cross section cylindrical internal shell formworks 1 and the curved surfaces of the centre form 20. The width of this space is adjustable and allows space for the reinforced composite strengthening shells 13 (see below) and determines the wall thickness of the present invention at the intersection of the radial members of the joint.

The reinforced composite strengthening shells 13 are temporarily mounted to the ends 23 of the circular cross section cylindrical internal shell formworks 1 adjacent to the curved space 22. These shells 13 will become bonded to the material injected into the space 22 forming the intersecting walls of the joint and will be released from the curved ends 23 of the circular cross section cylindrical internal shell formworks 1 when these formworks are withdrawn after completion of the joint formation. As will become evident from the description of later Figs. 11A, B, C and D, the reinforced composite strengthening shells 13 are installed to provide the circumferential reinforcement of the walls of the intersecting members of the joint within the internal space of the joint where, as will be described, it is not possible to continue the externally applied circumferential tensile reinforcement to the radial members.

It can be seen that the radii of the surfaces of the central form 20 and the circular cross section cylindrical internal shell formworks 1 are the same, giving a level cylindrical surface of the void 22 of the same radius as and parallel to the circular cross section cylindrical internal shell formworks 1 through the central area of the apparatus 24. This facilitates the layering and weaving of the tensile component of the composite material forming the joint, as will be described in Fig. 10 and Fig. 11 below.

In the closed configuration in Fig. 8A it can be seen that the tensioning ring 5 has been pulled closer towards the fixed annular support 2 by the mechanism 6 via the pull/push rods 7, the purpose of this will be explained in Figs. 10 below.

The dimension between stop-ends 4 indicated by the arrow 25 is the same as the dimension 25 shown on Fig. 7A for the open configuration. The stop-ends are fixed in position for each size of joint and determine the overall end to end length of the radial members forming a particular joint. By adjusting the position of the stop ends, by moving the main bases 8, the dimension 25 can be increased or reduced for different lengths of radial members forming the joint.

By way of example only the dimension 25 could be of the order of 6m for an embodiment of the present invention comprising the hub of a wind turbine rotor of 8MW power. In this example the radial members of the hub could be extended using one of the methods described in Figure 25 to add length to accommodate pairs of simple bearings supporting the turbine blades. The extensions tubes would be made from composite material using a mandrel winding method rather than the weaving method described in the present invention. This would be a more practical and economical method of manufacturing the hub radial member lengths required. Nonetheless, the whole hub assembly could be manufactured in one piece using the weaving method described in the present invention throughout.

Fig. 8B is an elevation view B2-B2 as indicated in plan view Fig. 8C of the apparatus in the closed position, the exposed edge of the reinforced composite strengthening shells 13 can be seen around the perimeter of the ends of the circular cross section cylindrical internal shell formworks 1. The truncated sphere forming centre form 20 can be seen to be circular in this elevation whereas in plan Figs. 8C and 8D it will be seen to be square.

Fig. 8C is a plan view C2 – C2 indicated in elevation view Fig. 8B of the apparatus in the closed position. As already mentioned the truncated sphere forming centre form 20 can be seen to be square in this plan view.

Fig. 8D is a section plan D2 – D2 indicated in vertical longitudinal section Fig. 8A of the apparatus in the closed position. This plan shows the whole apparatus generally and how the four limbs of the apparatus for the manufacture of a joint between four radial members relate to each other, including the four fixed bases 8 fixed to the support floor / structure 26.

This concludes the description of the common components occurring in all of the Figs. 7 to 14 of the apparatus and describes the two basic moves for the operation of the apparatus. The two basic moves are the movement of the circular cross section cylindrical internal shell formworks 1 from the open to the closed configurations and the movement of the tensioning rings 5 back towards the fixed annular support 2, the purpose of which is to straighten and tighten the composite material ribbons, see Fig.10A.

As explained already, the detailed descriptions for the components of the apparatus shown in Figs. 7 and 8 apply also for Figs. 9, 10, 11, 12, 13 and 14. These detailed descriptions have not been repeated for each of these subsequent figures.

Figures 9A to 9D show the apparatus open with longitudinal tensile ribbons being installed.

Fig. 9A is a vertical longitudinal section A3 – A3 as indicated on the plan section Fig. 9D of the apparatus in the open position at the start of the manufacturing process showing the installation of longitudinal ribbons of the tensile material 101 comprising the composite material used to form the radial members of the joint. The ribbons extend along and parallel to the circular cross section cylindrical internal shell formworks 1 between the stop ends 4. These ribbons consist of bundles of strands of tensile linear material such as glass fibre and/or carbon fibre. The ribbons pass through openings in the stop ends 4 and are connected to the tensioning rings 5.

The ribbons are installed one at a time alternating between adjacent circular cross section cylindrical internal shell formworks 1 starting at the lowest point on the circumference of the circular cross section. The ribbons are laid by hand or machine passing alongside the centre form 20 and the ribbons cross over each other layer on layer at this location, as indicated by arrow 102 which is typical of the whole circumference, see also arrows 102 on figure 9B. In this way continuous strands of the tensile material forming circular cross section shapes that pass through each other are installed to form the continuous interwoven reinforcement of the present invention manufactured using composite materials.

The longitudinal ribbons are installed by hand or machine and are pulled tight when attached to the tensioning rings 5. When all the longitudinal ribbons have been installed the tensioning rings will be moved towards the fixed supports 2, as will be shown in Figs. 10 below, and in so doing will ensure that the ribbons are tight and in straight lines effectively parallel to the circular cross section cylindrical internal shell formworks 1. The connection devices connecting the ribbons to the tensioning ring 5 adjusts the tension in each ribbon as the ring 5 moves and so all of the ribbons achieve the same tightness.

Fig. 9B is an elevation view B3-B3 as indicated in plan view Fig. 9C of the apparatus in the open position. In Fig. 9B a complete set of ribbons are shown having been installed, one at a time, alternating between adjacent circular cross section cylindrical internal shell formworks 1 starting at the lowest point on the circumference of the circular cross section. The ribbons cross over each other layer by layer as indicated by arrows 102. In this way, continuous strands of tensile material forming circular cross section shapes that pass through each other are installed to form the continuous interwoven reinforcement of the present invention.

Fig. 9C is plan view C3 – C3 as indicated in elevation view Fig. 9B of the apparatus in the open position. This is an external plan view of a complete set of ribbons viewed from above. The arrangement of ribbons forms two intersecting circular curved surfaces. The ribbons cross over each other layer by layer as indicated by arrow 102. Reference 103 indicates a particular crossing location where ribbons on the horizontal centre line of the joint pass over each other. This same crossing point is indicated also 103 in Figure 9D.

Fig. 9D is a section plan view D3 – D3 as indicated in vertical longitudinal section Fig.9A of the apparatus in the open position showing the installation of longitudinal ribbons of tensile material 101.The ribbons cross over each other one at a time layer by layer as indicated by arrows 102 in the previous Fig. 9C. Reference 103 indicates a particular crossing location where longitudinal tensile ribbons on the level of the horizontal centre line of the joint pass over each other.

Figures 10A to 10D show the apparatus with the longitudinal tensile ribbons having been installed and tightened by moving the tensioning rings, the apparatus having been adjusted to the closed position

After the completion of the installation of all the longitudinal ribbons of tensile material 101, comprising the composite material used to form the radial members of the joint, as shown in Figs. 9A, 9B, 9C and 9D, the circular cross section cylindrical internal shell formworks 1 are moved to the closed position as shown in Figs. 10A, 10B, 10C and 10D. The mechanism for this is described in Fig. 7A

Fig. 10A is a vertical longitudinal section A4-A4 as indicated in the plan section Fig. 10D of the apparatus in the closed position. The tensioning rings 5 have been pulled closer towards the fixed annular supports 2 by the mechanisms 6 via the pull/push rods 7. This process straightens and pulls tight the longitudinal ribbons of tensile material 101. The forces generated by this process are resisted by the fixed bases 8 secured to the support floor / structure 26.

The same notes applied to Figs. 9A, 9B, 9C and 9D also apply to Figs. 10A, 10B, 10C and 10D.

Fig.10A/1 is the same as the central part of Fig. 10A to a larger scale

Fig. 10B is an elevation view B4 – B4 as indicated in the plan view Fig.10C of the apparatus in the closed position with the longitudinal tensile ribbons installed and tightened as described for Fig. 10A.

Fig.10B/1 is the same as the central part of Fig. 10/B to a larger scale

Fig.10C is a plan view C4 – C4 as indicated in elevation view Fig.10B of the apparatus in the closed position with the longitudinal tensile ribbons installed and tightened as described for Fig. 10A.

Fig.10C/1 is the same as the central part of Fig. 10C to a larger scale.

Fig. 10D is a section plan D4 – D4 as indicated in the vertical longitudinal section in Fig. 10A of the apparatus in the closed position with the longitudinal tensile ribbons installed and tightened as described for Fig. 10A.

Fig.10D/1 is the same as the central part of Fig. 10D to a larger scale.

Figures 11A to 11D show the apparatus closed with the longitudinal tensile ribbons installed, straightened and tightened and showing the addition of the circumferential tensile ribbons, generally inclined to the longitudinal axis of the radial members.

After the longitudinal tensile ribbons have been straightened and tightened by adjusting the tensioning rings the next stage is to install the circumferential tensile ribbons, which wrap around the outer surface of the cylindrical drum formed by the longitudinal tensile ribbons. The circumferential tensile ribbons are installed by hand or machine and are arranged generally helically around the longitudinal drum of tensile ribbons. Curved spacer bars or other supports are introduced between the surface of the internal shell formworks 1 and the longitudinal ribbons to keep both the longitudinal and the circumferential ribbons at the correct spacing above the internal shell formworks 1. This is required to prevent the circumferential ribbons pressing the longitudinal ribbons into a very shallow catenary shape bearing onto the internal shell formworks 1.

Fig.11A is a vertical longitudinal section A5 – A5 as indicated in the plan section Fig. 11D of the apparatus in the closed position with the longitudinal tensile ribbons installed and tightened and showing the installation of the circumferential tensile ribbons 110, which are shown dotted because in this section the circumferential ribbons are behind the internal cylindrical internal forms 1. Only a few typical circumferential ribbons are shown for clarity. The perimeter of the drum of tight longitudinal tensile ribbons is indicated by dotted lines 101 (see also Figs. 9A and 10A). The circumferential ribbons 110 are connected to the annular support rings 4.

Fig. 11A/1 is the same as the central part of Fig.11A to a larger scale.

Fig.11B is an elevation view B5 – B5 as indicated in plan section Fig.11C of the apparatus in the closed position with the longitudinal tensile ribbons installed and tightened. The perimeter of the drum of tight longitudinal tensile ribbons is indicated by dotted lines 101 (see also Figs. 9A, 10A and 11A)

The circumferential ribbons 110 are connected to the annular support rings 4 at each end of the drum formed by the longitudinal tensile ribbons and are wrapped around the outer surface of the longitudinal tensile ribbons. The circumferential tensile ribbons 110 are laid out generally helically inclined along the length of the drum formed by the tight and straight longitudinal ribbons, as already shown dotted in Fig.11A.

Through the central section of the joint, where the radial members intersect, the spacings of the circumferential tensile ribbons at the top and bottom of the drum 105 are closed up and the helical arrangement becomes inclined closer to the circumferential. This enables the continuous full length circumferential tensile ribbons to pass over the shoulders of the intersection between the radial members forming the joint and to pass through the central area of the joint.

To fill in areas into which the full length helical circumferential ribbons do not extend, additional discontinuous ribbons are started at intermediate points, 103 for example. These shorter length ribbons are woven into the general pattern of helical circumferential ribbons. All the ribbons become bonded together and anchored when they are all surrounded by the resin filler material injected during the later stage of manufacturing as shown in Figs. 14A, B, C and D.

Fig.11B/1 is the same as the central part of Fig.11B to a larger scale.

Fig.11C is a plan view C5 – C5 indicated in elevation view Fig.11B of the apparatus in the closed position with the longitudinal tensile ribbons installed and tightened and showing the installation of the circumferential tensile ribbons.

The top and bottom surfaces of the drum formed by the longitudinal tensile ribbons in the area of the internal form 20 are padded out with pre-formed cushions 112 of composite material to form two flat areas 113 above and below internal form 20 over which the circumferential tensile ribbons can flow without piling up on top of each other. If strictly drawn the hidden apparatus under cushions 112 should be shown dotted but the illustration is considered to be more clear by retaining the solid line work in this instance.

The circumferential tensile ribbons are shown crossing over the top of the central area of the drum formed by the longitudinal tensile ribbons 101, shown dotted. Note how these circumferential ribbons can be spaced out over the cushion pads 112 and therefore the ribbons are not piled up in the corners of the intersection between the radial members. The single digit numbers 1, 2, 3 and 4 identify the two ends of typical circumferential ribbons 1 to 4 to clarify the route pattern that is followed by the circumferential ribbons.

Fig. 11C/1 is the same as the central part of Fig.11C to a larger scale.
Fig.11D is a section plan D5 – D5 as indicated in the vertical longitudinal section Fig. 11A of the apparatus in the closed position with the tensile ribbons installed and tightened showing the typical circumferential tensile ribbons numbered 1 to 4 shown dotted (see Fig.11C) extending to the annular support rings 4 also shown dotted to which they are attached. These circumferential ribbons and support rings 4 are shown dotted because they are below the internal shell formworks 01. Also shown dotted are the lower cushions 112 and the associated flat area 113.

Fig.11D/1 is the same as the central part of Fig.11D to a larger scale

From the descriptions for Figs. 11A, B, C and D it can be seen that the circumferential tensile ribbons cannot pass around the drums of the longitudinal tensile ribbons within the common areas of intersection between the continuous surfaces of the intersecting drums of longitudinal ribbons forming the intersecting surfaces of the intersecting radial members. The longitudinal tensile ribbons in orthogonal directions block the circumferential ribbons, which have to be wound closer together and pass around the area of intersection as already described.

This results in there being no circumferential tensile ribbons reinforcement 110, as so far described, within the areas of intersection which would result in low shear and torsional strength within these areas. To avoid this weakness the present invention provides pre-formed reinforced shells 13 made of the same composite materials as are used to form the members of the joint. The shells 13 are shown and described in Figs. 7 and 8 and 11D. The shells are temporarily mounted to the ends of the circular cross section cylindrical internal shell formworks 01 and are bonded into the walls of the intersecting radial members by the injected resin filler material which when hardened structurally binds the reinforced shells onto the longitudinal tensile ribbons. When the circular cross section cylindrical internal shell formworks 01 are withdrawn they release the reinforced shells13, which are only weakly attached to the circular cross section cylindrical internal formworks 01.

The circumferential reinforcement within the shells provides the shear and torsion reinforcement across the longitudinal tensile ribbons within the central area of the joint. There will be a remaining narrow band within the actual shared volume of material at the intersection between the orthogonal walls of the intersecting radial members that does not have circumferential ribbons but this narrow band is so constrained by all the surrounding circumferential and longitudinal tensile ribbons that it possesses sufficient shear and torsion strength without the circumferential ribbons actually passing through.

The pre-formed reinforced shells 13 are cut from the walls of a circular cylinder made using the same composite materials as used for the manufacture of the members of the joint. The circumferential tensile ribbons in this cylinder are wound diagonally around the perimeter of the longitudinal tensile ribbons of the circular cylinder so that the ribbons are aligned diagonally and orthogonally across each other along the length of the cylinder. Each shell is a truncated circular piece cut from the side of this circular cylinder. The diameter of the cylinder is determined to suit the geometry of the outer surfaces of the intersecting radial members to which the shells are to be mounted and the thickness and material content is adjusted to provide the required strength. The shells 13 could be formed using industry standard pre-formed looms into which resin can permeate. The looms could be open fabric on a solid back former.

Referring to Figs. 11A, B, C and D it can be seen that the internal centre form 20 can provide the same circumferential strengthening of the radial members passing through the central area as does the pre-formed reinforced shells 13 already described above. The construction of the internal centre form 20 comprises four pre-formed reinforced shells forming a truncated sphere as already described in Figs. 7.

When this stage of the manufacture of the joint is complete it can be seen that the longitudinal drums of longitudinal tensile ribbons are sandwiched between the pre-formed reinforced shells 13 and the centre former 20 within the central area of the joint.

Detailed description of Figures 12 to 25 continues on the next page.

Figures 12A to 12E show the apparatus closed with longitudinal and circumferential tensile ribbons installed and tightened and the addition of the outer shell forms.

After completion of installation of the circumferential tensile ribbons the whole assembly of longitudinal and circumferential tensile ribbons is enclosed within an outer formwork shell, which in combination with the inner shell formworks 1 and the centre form 20 creates a continuous three dimensional cruciform shaped set of circular cross section moulds enclosing the assembly of longitudinal and circumferential tensile ribbons.

Fig.12A is a vertical longitudinal section A6-A6 as indicated in the plan section Fig. 12D of the apparatus in the closed position showing the installation of the outer shell forms 201. The cushions 112 are shown and the outer shell formwork 201 is shaped to accommodate these cushions as shown at point 202, see Fig.12E. The space 205, which will be filled with resin filler material, accommodates the longitudinal tensile ribbons and the circumferential tensile ribbons which have not been shown for clarity.

Fig.12B is an elevation view B6 – B6 as indicated in the plan view Fig.12C of the apparatus in the closed position. The longitudinal and circumferential tensile ribbons are not generally visible in this elevation because the outer shell forms are in place. The longitudinal ribbons are visible in the circular section 116. The outer shell formwork 201 is shaped at 202 to accommodate the raised edge of the cushion 112 in Fig.11C, see also 203 in Fig.12C, see also Fig.12A. A similar arrangement is provided at the underside location 204.

Fig.12C is a plan view C6 – C6 as indicated in elevation view Fig.12B of the apparatus in the closed position with the outer shell formwork 201 in place. The longitudinal and circumferential tensile ribbons are not visible because the outer shell formwork is in place. Raised area 202 and edge 203 accommodates cushions 112 in Fig.11C.

Fig.12D is a section plan D6 – D6 as indicated in the vertical longitudinal section Fig.12A of the apparatus in the closed position with the longitudinal and circumferential tensile ribbons installed and tightened and the outer shell formwork 201 in place. The longitudinal and circumferential tensile ribbons have been omitted for clarity so that the required gap 205 between the inner forms and formwork and the outer shell formwork can be clearly seen. This gap, which will be filled with the resin filler material, determines the thickness of the walls of the radial members forming the joint.

Fig.12E shows an axiomatic view of the external shell forms for a joint between four intersecting radial members. In this embodiment of the present invention the shell formwork is assembled around the assembly of longitudinal and circumferential tensile ribbons forming the joint between four intersecting radial members as described above. Other combinations of radial members will require other shapes of external formwork, and different internal and centre forms.

The outer shell forms are in two halves, an upper half and a lower half joined at lines 205. The lower half has to accommodate the central post supporting the inner centre form. To enable the installation of the lower half of the formwork a temporary hanging support is provided connected to the top centre point of the centre form. This enables the centre post to be removed while the lower half form is installed. It may facilitate the installation of the lower and upper external formwork if each is subdivided into smaller sections assembled together to form the whole shape. This would also avoid the requirement for a temporary hanging support

The formwork 201 is accurately manufactured and assembled and provided with seals between each component of the formwork and between the outer edges of the formwork and the stop ends.

The shape of the outer shell formwork is maintained by additional external stiffeners if required to maintain the rigidity of the formwork to provide the required gaps between the inner and outer formwork to accommodate the longitudinal and circumferential ribbons and to provide the required wall thickness. Internal ties between the inner and outer formwork may be required to resist the forces created by internal pressures required to inject the resin filler as described in Figs. 14.

The outer shell formwork extends from one stop end 4 in Figs. 7 and 8 to the opposite stop end and will therefore be the same overall length as the radial members forming the joint. Notice the area of shell formwork 202 and extended raised edges 203 to accommodate the padded platform 112 referred to in Fig.11C. A similar addition to the shell formwork will be located on the underside of 201 at location 204.

Figures 13A to 13D show a special case that only applies for the provision of man access holes incorporated in the embodiment of the present invention as a central hub for a wind turbine rotor.

By way of example only, for the embodiment of the present invention forming the central hub of a wind turbine rotor. For a 20 MW power turbine the diameter of tubular radial members forming the hub will be of the order of 3m. This diameter tube will easily accommodate internal man access for the maintenance of blade control equipment located within the hub. The internal access will also enable blade changes without men working dangerously outside of the hub. The man access holes described here will align with a safe enclosed gantry walkway from a hatch at the front of the nacelle. The present invention therefore enables all maintenance work to be carried out completely within a safe warm internal environment which is not the case with smaller current state of the art wind turbines.

Fig.13A is a vertical longitudinal section A7-A7 as indicated in the plan section Fig. 13D of the apparatus in the closed position showing the installation of formwork 210 positioned between the outer shell forms and the inner shell formworks 1 to create man access holes on the upper surface of the circular cross section cylindrical internal shell formworks 1 and in the vertical faces of the centre form 20 if required. The outer shell forms are shown dotted because they would not have been installed by the stage illustrated by Figs. 13A and 13B. The internal ovoid or circular annular formwork rings forming the spaces for the man access holes are fitted with seals between the upper and lower edges of the ovoid or circular rings and the inner and outer formwork.

Fig.13B is a vertical elevation B7 – B7 as indicated in the plan view Fig.13C of the apparatus in the closed position showing the location of formwork 210 on the internal shell formworks 1 within the outer shell forms to create man access holes on the upper surface of the circular cross section cylindrical internal shell formworks 1 and the vertical faces of the centre form 20 if required.

Fig.13C is a plan view C7 – C7 as indicated in vertical elevation view Fig.13B of the apparatus in the closed position showing the location of man access holes and formwork 210 on the upper surface of the circular cross section cylindrical internal shell formworks 1.

Fig.13D is a plan section view D7 – D7 as indicated in the vertical longitudinal section Fig.13A of the apparatus in the closed position showing the installation of circular formwork 210 within the centre form 20, the reinforced shell forms 13 and the end panel of internal shell formworks 1 to create man access into and through the centre form 20 if required.

Figures 14A to 14E show the apparatus closed with tensile ribbons installed and tightened and outer shell forms in place (and man access formwork as per Figures 13 in place if required, but not shown here) and the resin filler material injected – shown shaded hatched.

When the outer shell formwork is complete as shown in Figs.12 and the ovoid or circular man access holes formwork has been incorporated as shown in Figs. 13, if required, then the internal space between the formwork is filled with the resin filler material component of the composite material to form the joint between the intersecting radial members.

The filler resin material is in liquid form and is injected under pressure and flows within the formwork surrounding and encapsulating all the tensile ribbons. The resin filler material is injected at several points and the injection system is designed to ensure the complete filling of the formwork without leaving any unfilled voids. In addition to external pipework the injection system may comprise internal distribution pipes and injection points to achieve the required consistency and density of the composite material.

After injection of the resin filler material has been completed the completeness of the filling of the formwork can be checked by reconciling the volume of resin filler material installed with the calculated volume of the formwork less the volume of the tensile ribbons. Furthermore, the composite material can be checked for the presence of voids by using, by way of example only, ultrasound tools or other sub-surface survey technologies.

Any voids can be further filled by drilling an inlet hole and an outlet hole through the outer shell formwork at the location of the void. The void can then be filled by further injection of resin filler material.

Fig.14A is a vertical longitudinal section A8 - A8 as indicated in the plan section Fig. 14D of the apparatus in the closed position with the outer shell forms in place and the resin filler material injection having been completed. The spaces filled with the resin filler material are shown using hatched shading 220. The pre-formed reinforced shells 13 and the centre form 20 are shown using solid shading.

In Figs. 14B and 14C the surfaces of the internal circular cross section cylindrical internal shell formworks 1 are shown dotted because they are hidden inside the external shell formworks 201.

Fig.14B is an elevation view B8 – B8 as indicated in the plan view Fig.14C of the apparatus in the closed position with the outer shell forms in place and the resin filler material having been injected, shown by hatched shading where the section cuts through one of the radial members

Fig.14C is a plan view C8 – C8 as indicated in elevation view Fig.14B of the apparatus in the closed position with the outer shell forms in place and the resin filler material having been injected. There is no hatched shading in this view because there is no section passing through the resin filler material.

Fig.14D is a section plan D8 – D8 as indicated in the vertical longitudinal section Fig. 14A of the apparatus in the closed position and the outer shell forms in place and the resin filler material having been injected. The spaces filled with the resin filler material are shown using hatched shading. The pre-formed reinforced shells 13 and the centre form 20 are shown using solid shading.

Strip external and internal forms

When the injected resin filler material has cured then the outer shell formwork can be removed. Each of the inner longitudinal formworks 1 is then folded in on itself along a longitudinal hinge or other enabling arrangement to become detached from the inner surface of the wall of the associated radial member within the completed joint and then each formwork 1 is extracted through the outer end of each limb of the apparatus. The centre form 20 and the reinforced part shells 13 shown solid shaded in Figs. 14A, B, C and D are left in place as part of the finished joint structure. In one embodiment of the present invention the inner longitudinal formworks 1 may not be removed and remain as an integral part of the completed joint

Fig.14E is a three dimensional view showing a finished joint comprising four intersecting radial members after stripping of the outer shell formwork and the inner formwork. The completed joint can be examined for defects that can be repaired using standard procedures for repairing components made from composite materials.

This completes the manufacture of the joint.

The following Figures 15 to 21 inclusive describe a method for adding an orthogonal member to the joint

For the embodiment of the present invention comprising the central hub of a wind turbine rotor the joint described in Figs. 7 to 14 is joined to a shaft member and radial member extensions are added to the radial members of the joint in accordance with the following Figs. 15, 16, 17, 18, 19, 20, 21 and 25, which describe the details of how a joint between four intersecting radial members in a first plane, manufactured in accordance with the current invention as described in Figs. 7 to 14 inclusive above, can be extended, using the same principles and techniques as already described, to include the connection of a radial member with the central axis orientated in a second plane that is perpendicular to the first plane of the joint. This requirement arises when an embodiment of the present invention is used to form a joint between radial members that are arranged in a three dimensional space, by way of example only, in the central hub of a wind turbine rotor that is mounted to the horizontal shaft of a wind turbine.

Fig.15 shows four continuously jointed intersecting first radial members 401, 402, 403 and 404 which lie in one first plane connected to a second radial member 405 with the central axis orientated in a second plane that is perpendicular to the first plane and the central axis passes through or is adjacent to the intersection point of the other first radial members. Second radial member 405 is profile cut to fit around the curved outer surfaces of the other first radial members with a typical flat shoulder area 406 between each of the first radial member circumferential intersection points. This shoulder accommodates the crossing of ribbons of tensile composite material that are woven criss-cross between all the members as shown by typical ribbons S2 to B1 and S1 to C1. The letters A, B, C, D and S are used to indicate the respective end regions of the five radial members 401, 402, 403, 404 and 405.

Typical interwoven ribbons S2 to B1 and S1 to C1 extend from points within the end region S of member 405 where the ribbons are anchored, by way of example only, using a mechanical anchorage mechanism or possibly an adhesive anchorage, to the end regions B and C of members 402 and 403. There will be parallel ribbons extending over the same route and weaving between each other through the nexus region indicated X. The total number of ribbons over each route and the size and strength of the ribbons will be adjusted to enable the ribbons to transfer the forces required to effectively join the member 405 into the other members and so form an extended three dimensional joint comprising the central hub of a wind turbine rotor.

Fig. 16 is an elevational view V1 on the end B of member 402. Members 401, 403 and 405 also occur in this view and the route of ribbons S1 to C1 and S2 to B1 can be followed. Also ribbon S2 to B1 can be seen extending onwards to B3 and ribbon S1 to C1 can be seen extending beyond C1 towards end C of 403 as shown by a dotted line which is behind the elevation of 403 in this view.
Similar ribbon routes are also shown, for example, the route S3 to A1 and then as a dotted line behind member 401 beyond A1 towards end A of 401, this is similar to the route S1 to C1to end C. Ribbon route S4 to B1 to B4 is similar to S2 to B1 to B3. In the final fabrication there will be a the required number of ribbons following similar routes to those described here to provide the required strength of the connection between the members forming the three dimensional joint

Fig. 17 is a view V2 shown in Figs.15 and 16 onto the four members 401, 402, 403 and 404 looking onto the 4 shoulders marked 406W, 406X, 406Y and 406Z of circular member 405 shown dotted below. In this view can be seen the symmetrical layout of ribbons of which S1 to C1 to C3 and S2 to B1 to B3 are typical examples. The ribbons can be identified in Fig.16 by the same line references. The way the ribbons weave past each other in the shoulder areas 406W, 406X, 406Y and 406Z can be seen in this view V2.

As explained in Fig.15 the ribbons are anchored in the end regions of the members and they wrap around the members in the manner shown and pass over and by each other in the shoulder regions 406. The ribbons are installed one at a time and pulled tight one by one until sufficient ribbons have been installed for the required strength in the joint. The ribbons bind the member 405 to the members 401, 402, 403 and 404 after the injection and curing of the resin filler material, see Figs. 18 to 21 below.

The same notes describing the resin filling of the joint in figures 14A, B, C and D also apply to figures 18, 19, 20 and 21.

Fig. 18 is an elevational view V1 indicated by the arrows V1 in Figs.15 and 17 showing formwork and moulds in place prior to resin filling. When the required number of ribbons has been installed then outer shell formwork 410 is installed enveloping the five members in a continuous enclosed space 411 between the outer shell formwork and the outer curved surfaces of the five members. This space is made leak proof and the resin filler material is then injected to fill the space completely and encapsulate the ribbons thus forming the composite material shell joining the five members together.

Fig. 19 is a plan section X – X indicated by the arrows X in Fig.18, showing formwork and moulds in place prior to injecting the resin filler material. The outer shell formwork 410 is installed enveloping the five members in a continuous enclosed space 411

Fig. 20 is an elevational view V1 indicated by the arrows V1 in Figs.15 and 17 showing formwork and moulds in place and also the resin filler material which has been injected as indicated by the hatched shading within the vertical cross section through the radial member 402.

Fig. 21 is a plan section Y – Y indicated by the arrows Y in Fig. 20, showing formwork and moulds in place and also the resin filler material which has been injected as indicated by the hatched shading within the horizontal cross section through radial members 401, 402, 403 and 404.

The following 3 Figs. 22A to F, 23A to F and 24A to F, illustrate embodiments of the present invention comprising the central hub of wind turbine rotors. These figures show wind turbine rotor elevations and sections comprising joints between structurally continuous intersecting radial members in the form of three dimensional central hub configurations supporting the radial components of a wind turbine rotor mounted to a horizontal shaft.

Fig. 22A is a front elevation of a wind turbine rotor 550 with four blades 501 mounted to a central hub 502. Arrow 503 indicates that this rotor is driven by the wind in a clockwise direction. The central hub 502 is manufactured in accordance with the present invention and has four radial members to which the blades 501 are mounted.

Fig. 22B is a front elevation of a wind turbine rotor 551 with four blades 501 mounted to a central hub radial extension 504 which is mounted to the central hub 502. Arrow

503 indicates that this rotor is driven by the wind in a clockwise direction. The central hub 502 is manufactured in accordance with the present invention and has four radial members to which four radial member extensions 504 are mounted. The radial member extensions 504 are connected together and braced by four circumferential ties 505 which are in the same plane as the elevation. The section indicated by the section arrows W – W, which comprises Fig. 22F, shows further radial member extension forward and rear support struts / ties 512 and 513 perpendicular to the plane of the central hub and rotor.

Fig. 22C is a front elevation of a wind turbine rotor 552 with four blades 501 mounted to central hub radial extensions 504 which are mounted to the central hub 502. Arrow 503 indicates that this rotor is driven by the wind in a clockwise direction. The central hub 502 is manufactured in accordance with the present invention and has eight radial members to which four radial member extensions 504 and four struts 507 forming a blade support system are mounted. The radial member extensions 504 are connected together and braced by eight circumferential ties 506 which are in the same plane as the elevation. The circumferential ties 506 are further supported (see section X – X in Fig. 22D) by the four struts 507 plus a further eight forward struts / ties 512 and eight rear struts / ties 513 forming a blade 501 support system connected to the four radial member extensions 504

Fig. 22D is a Section view X – X indicated by arrows X on fig 22C. This section shows a forward facing strut 511 is mounted to hub 502 and supports raking struts / ties 512 which are connected to radial struts 507 forming part of a blade support system. Rear struts / ties 513 are mounted to shaft 508 and connect to radial struts 507 also forming part of a blade 501 support system.

Fig. 22E is a Section view V – V indicated by arrows V on fig. 22A.This section shows blades 501 mounted to hub 502, which is mounted to support shaft 508.
It can be seen that the arrangement shown in figures 22A and 22E is the simplest arrangement of four blades mounted directly to the rotor hub. The following two figures 22B and 22C show more complex four bladed rotor assemblies which enable larger diameter rotors for a given length of blade which enables a given blade to

develop more power and therefore more electricity in a given wind speed. This will produce economies of scale for larger wind turbines.

Fig. 22F is a section view W - W indicated by arrows W shown on figs. 22B and 22C. Forward facing strut 511 is mounted to hub 502 and supports raking struts / ties 512 which are connected to hub radial member extensions 504 forming a blade 501 support system. Rear struts / ties 513 are mounted to shaft 508 and connect to hub radial extensions 504 also forming a blade 501 support system.

Fig. 23A is a front elevation of a wind turbine rotor 553 with three blades 501 mounted to a central hub 502. Arrow 503 indicates that this rotor is driven by the wind in a clockwise direction. The central hub 502 is manufactured in accordance with the present invention and has three radial members to which the blades 501 are mounted and three radial members to which radial anchorages 514 are mounted diametrically opposite the blades 501 to provide fixity for these blades in conjunction with the hub 502.

Fig. 23B is a front elevation of a wind turbine rotor 554 with three blades 501 mounted to a central hub radial extension 504 which is mounted to the central hub 502. Arrow 503 indicates that this rotor is driven by the wind in a clockwise direction. The central hub 502 is manufactured in accordance with the present invention and has three radial members to which the radial member extensions 504 are mounted and three radial members to which radial anchorages 514 are mounted diametrically opposite the radial extensions 504 to provide fixity for these extensions in conjunction with the hub 502.

The three blades 501 are mounted to the three radial member extensions 504. The radial member extensions 504 are connected together and braced by three circumferential ties 505 which are in the same plane as the elevation. The section indicated by section arrows W – W, which comprises Fig. 23F shows further radial member extension forward and rear support struts / ties 512 and 513 perpendicular to the plane of the central hub and rotor.

Fig. 23C is a front elevation of a wind turbine rotor 555 with three blades 501 mounted to a central hub radial extension 504 which is mounted to the central hub 502. Arrow 503 indicates that this rotor is driven by the wind in a clockwise direction. The central hub 502 is manufactured in accordance with the present invention and has three radial members to which the radial member extensions 504 are mounted and three radial members supporting anchorages 514 and to which radial struts 507 are mounted, diametrically opposite the radial member extension 504. The three blades 501 are mounted to the three radial member extensions 504. The radial member extensions 504 are connected together and braced by six circumferential ties 506 which are in the same plane as the elevation. The circumferential ties 506 are further supported (see section Y - Y in Fig. 23D) by the three struts 507 plus a further six forward struts / ties 512 and six rear struts / ties 513 forming a blade 501 support system connected to the three radial member extensions 504

Fig. 23D is a Section view Y – Y indicated by arrows Y on Fig. 23C. This section shows forward facing strut 511 is mounted to hub 502 and supports forward raking struts / ties 512 which are connected to radial struts 507 and radial extensions 504 forming part of a blade 501 support system. Rear struts / ties 513 are mounted to shaft 508 and connect to radial struts 507 and radial extensions 504 also forming part of a blade 501 support system.

Fig. 23E is a Section view V – V indicated by arrows V on Fig. 23A.This section shows blades 501 mounted to hub 502, which is mounted to support shaft 508. It can be seen that the arrangement shown in figures 23A and 23E is the simplest arrangement of three blades mounted directly to the rotor hub. The following two figures 23B and 23C show more complex three bladed rotor assemblies which enable larger diameter rotors for a given length of blade which enables a given blade to develop more power and therefore more electricity in a given wind speed. This will produce economies of scale for larger wind turbines.

Fig. 23F is a Section view W-W indicated by the arrows W on Fig. 23B and 23C. This section shows blades 501 mounted to radial member extensions 504 mounted to hub 502, which is mounted to support shaft 508. Forward facing strut 511 is mounted to hub 502 and supports raking struts / ties 512 which are connected to hub radial member extensions 504 forming a blade 501 support system. Rear struts / ties 513 are mounted to shaft 508 and connect to hub radial extensions 504 also forming a blade 501 support system.

Fig. 24A is a front elevation of a wind turbine rotor 556 with two blades 501 mounted to a central hub 502. Arrow 503 indicates that this rotor is driven by the wind in a clockwise direction. The central hub 502 is manufactured in accordance with the present invention and has two radial members to which the blades 501 are mounted.

Fig. 24B. This figure reference has not been used.

Fig. 24C is a front elevation of a wind turbine rotor 557 with two blades 501 mounted to a central hub radial extension 504 which is mounted to the central hub 502. Arrow 503 indicates that this rotor is driven by the wind in a clockwise direction. The central hub 502 is manufactured in accordance with the present invention and has two radial members to which the radial member extensions 504 are mounted and two radial members to which radial struts 507 are mounted. The two blades 501 are mounted to the two radial member extensions 504. The radial member extensions 504 are connected together and braced by four circumferential ties 505 which are in the same plane as the elevation. The circumferential ties 505 are further supported (see section X – X in Fig. 24F) by the two struts 507 plus forward raking struts / ties 512 which are connected to radial struts 507 and radial extensions 504 forming part of a blade 501 support system. Rear struts / ties 513 are mounted to shaft 508 and connect to radial struts 507 and radial extensions 504 also forming part of a blade 501 support system.

Fig. 24D is a Section view V – V indicated by arrows V on Fig. 24A.This section shows blades 501 mounted to hub 502, which is mounted to support shaft 508. It can be seen that the arrangement shown in Figs. 24A and 24D is the simplest arrangement of two blades mounted directly to the rotor hub. The following Fig. 24C shows a more complex two bladed rotor assembly which enables larger diameter rotors for a given length of blade which enables a given blade to develop more power and therefore more electricity in a given wind speed. This will produce economies of scale for larger wind turbines.

Fig. 24E is a Section view W-W indicated by arrows W on Fig. 24C. This section shows blades 501 mounted to radial member extensions 504 mounted to hub 502, which is mounted to support shaft 508. Forward facing strut 511 is mounted to hub 502 and supports forward raking struts/ties 512 which are connected to hub radial extensions 504 forming a blade 501 support system. Rear struts/ties 513 are mounted to shaft 508 and connect to hub radial extensions 504 also forming a blade 501 support system.

Fig. 24F is a section view X-X indicated by arrows X on Fig. 24C. Forward facing strut 511 is mounted to hub 502 and supports forward raking struts / ties 512 which are connected to radial struts 507 forming part of a blade 501 support system. Rear struts / ties 513 are mounted to shaft 508 and connect to radial struts 507 also forming part of a blade 501 support system.

The integration of a structurally continuous intersecting radial member comprising a joint in accordance with the present invention at the centre of a wind turbine rotor requires that radial member to be connected to extensions of that radial member. Figures 25 show configurations that can be used to connect extensions to a radial member, by way of example only.

Fig. 25A. Connection to a radial member of an extension of the same diameter using an inner sleeve joint. In this connection detail a radial member extension 504 is shown connected to a central hub 502 using an inner sleeve to support the joint. The joint would also include wrapping around the outside to reinforce the joint and adhesive between the sleeve and the other members

Fig. 25B Connection to a radial member of an extension of the same diameter using an outer sleeve joint. In this connection detail a radial member extension 504 is shown connected to a central hub 502 using an outer sleeve to support the joint. The joint would also include wrapping around the outside to reinforce the joint and adhesive between the sleeve and the other members

Fig. 25C Connection to a radial member directly of an extension with a smaller diameter section requiring no sleeve. In this connection detail a radial member extension 504 is shown connected to a central hub 502. The radial member extension 504 fits inside the hub 502. The joint would also include wrapping around the outside to reinforce the joint and adhesive between the extension and the hub. Fig. 25D Connection to a radial member directly of an extension with a larger diameter section requiring no sleeve. In this connection detail a radial member extension 504 is shown connected to a central hub 502. The radial member extension 504 fits around the outside of the hub 502. The joint would also include wrapping around the outside to reinforce the joint and adhesive between the extension and the hub

Fig. 25E Connection to a radial member of an extension forming the inner shell of the hub radial member constructed in accordance with the present invention. This design uses the extension member as the permanent liner form located inside of the longitudinal and circumferential tensile ribbons used in the manufacture of the hub.

Fig. 25F A radial member forming a radial anchorage member. For rotor hubs in which there are not an even number of blades with pairs of blades opposite each other across the hub, in a three bladed rotor by way of example only, there is a requirement for an anchorage opposite each blade to stabilize / balance the forces generated by the blades on opposite sides of the hub. (see the component reference 514 in figure 23B for example) The anchorage is provided by the appropriate length, indicated by arrow 520, of the radial member to accommodate the necessary anchorage length of the tensile component of the composite material forming the hub extending through the hub from the radial member opposite the anchorage.

Fig. 25G. Connection to a radial member of a blade support system radial member. This detail is to illustrate that the blade support system struts 507 taper at each end to give flexibility and the radial member of the joint to which the strut is mounted requires an end cap 521 to accommodate and support the smaller diameter end of the strut and strengthen the end of the radial member. The radial member length indicated by arrow 520 provides anchorage 514 if required.

Fig. 25H. This figure shows the detail of a method whereby a radial member 530 is extended using an extension 531 also manufactured from composite material. The connection is formed by layering together the tensile components of the composite material forming the radial member 532 and the extension 533. In this method the tensile components of the composite materials are exposed and overlap each other over the length of the connection 534. It is necessary to ensure the strands of the tensile component of the composite materials remain straight and parallel to each other. The required length of the overlap 535 of the tensile components is calculated to provide the required strength for the connection. The overlapping length of tensile components is encased within inner and outer formwork 536 to form an enclosed space 537 which is then filled with resin filler to complete the formation of the composite material forming the connection. When the resin filler has cured the formwork is removed leaving the completed connection in place.

The general design of the wind turbine rotors and aircraft shown in the Figures 5 and 6 is and in Figs. 22, 23 and 24 is all prior art and is not included in the claims.

The invention provides any suitable combination of features of the apparatus, method steps and operation of any of the embodiments described.

Claims

.1 A joint comprising an interface between first and second intersecting members constructed using composite materials in which the structural material forming the whole cross section or perimeter wall, or part of the whole cross section or perimeter wall of each of the intersecting members extends continuously as continuous material into the interface and / or across the interface and / or around the interface providing structural continuity of the intersecting members into the interface and / or across the interface and / or around the interface, the interface being the common space shared by the first and second intersecting members.

.2 A method of manufacturing an interface in accordance with claim 1 whereby the structural material forming the whole cross section or perimeter wall, or part of the whole cross section or perimeter wall of each of the intersecting members is enabled to extend continuously as continuous material into the interface and / or across the interface and / or around the interface providing structural continuity of the intersecting members extending continuously into the interface and / or across the interface and / or around the interface.

.3 A step in accordance with claim 2 whereby the tensile component of the composite material forming the intersecting members meeting at a joint comprising an interface is laid in alternate intersecting layers within the cross section profile, or within the whole or part of the cross section profile of the perimeter walls, of each of the intersecting members to form the interface between the intersecting cross section or walls of adjacent members.

.4 A step in accordance with claim 3 whereby the tensile component of the composite material forming the interface between intersecting members of a joint comprising an interface is tightened and / or tensioned after laying to straighten and linearly align the elements of the tensile components.

.5 A step in accordance with claim 4 whereby the tensile components of the composite material forming the interface between the intersecting members of a joint comprising an interface are tightened and / or tensioned and aligned to be mutually parallel after laying by moving the anchorages provided to enable the laying of the tensile components of the composite material forming the interface between the intersecting members.

6. A step in accordance with claim 2 whereby internal and external shell moulds and formers and reinforcements are installed or incorporated in the joint comprising an interface and are operated and removed from the joint to enable the injection of resin filler material within and around the tensile component of the composite material forming the interface between the intersecting members of the joint to complete the formation of the composite material forming the structure of the intersecting members of the joint comprising the interface.

.7 A step in accordance with claim 6 whereby resin filler material is injected within the internal and external shell moulds and formers and reinforcements installed and incorporated and operated and removed from the joint comprising an interface, to complete the formation of the composite material forming the interface between the intersecting members and to complete the formation of the composite material forming the joint comprising an interface.

.8 A step in accordance with the preceding claims whereby a structure forming the drive shaft supporting a wind turbine rotor hub is formed to fit around the members of a joint comprising an interface in accordance with claims 1 and 2 and be made structurally integral with the joint comprising an interface by the wrapping of tensile material around the drive shaft and the joint comprising an interface and the injection of resin filler material within inner and outer mould formwork.

.9 A joint comprising an interface in accordance with claims 1 and 2 and 8 comprising a central hub of a wind turbine rotor comprising a wind turbine assembly.

.10 A joint comprising an interface in accordance with claims 9 comprising a central hub of a wind turbine rotor comprising a wind turbine assembly provided to generate electricity.

AMENDED CLAIMS HAVE BEEN FILED AS FOLLOWS :

Claims

1. A joint comprising an interface between first and second intersecting structural members forming a structure constructed using composite materials in which the continuous filaments of structural reinforcement material forming the whole cross section or perimeter wall, or part of the whole cross section or perimeter wall of each of the intersecting structural members extends continuously as continuous material into the joint comprising an interface or across the joint comprising an interface providing structural continuity of the intersecting structural members into the joint comprising an interface or across the joint comprising an interface , the joint and the interface being the common space shared by the first and second intersecting structural members.

2. A method of manufacturing a joint comprising an interface in accordance with claim 1 whereby the structural material forming the whole cross section or perimeter wall, or part of the whole cross section or perimeter wall of each of the intersecting structural members is enabled to extend continuously as continuous material into the joint comprising an interface or across the joint comprising an interface providing structural continuity of the intersecting structural members extending continuously into the joint comprising an interface or across the joint comprising an interface .

3. A step in accordance with claim 2 whereby the tensile component of the composite material forming the intersecting structural members meeting at a joint comprising an interface is laid in alternate intersecting layers of reinforcement within the whole or part of the cross section profile of each of the intersecting structural members, or within the whole or part of the cross section profile of the perimeter walls of each of the intersecting structural members to form the joint comprising an interface between the intersecting cross section or walls of adjacent members.

4. A step in accordance with claim 3 whereby the tensile component of the composite material forming the joint comprising an interface between

intersecting structural members of a joint comprising an interface is tightened or tensioned after laying, to straighten and linearly align the elements of the tensile components.

5. A step in accordance with claim 4 whereby the tensile components of the composite material forming the joint comprising an interface between the intersecting structural members of a joint comprising an interface are tightened or tensioned and aligned to be mutually parallel after laying by moving the anchorages provided to enable the laying of the tensile components of the composite material forming the joint comprising an interface between the intersecting structural members.

6. A step in accordance with claim 2 whereby internal and external shell moulds and formers and reinforcements are installed or incorporated in the joint comprising an interface and are operated and removed from the joint to enable the insertion of filler material within and around the tensile component of the composite material forming the joint comprising an interface between the intersecting members to complete the formation of the composite material forming the structure of the intersecting members of the joint comprising an interface.

7. A step in accordance with claim 6 whereby resin filler material is introduced within the internal and external shell moulds and formers and reinforcements installed and incorporated and operated and removed from the joint comprising an interface, to complete the formation of the composite material forming the joint comprising an interface between the intersecting structural members.

8. A step whereby a structure forming the drive shaft supporting a wind turbine rotor hub is formed to fit around the members of a joint comprising an interface in accordance with claims 1 and 2 comprising the hub of a wind turbine rotor and be made structurally integral with the joint comprising an interface by the wrapping of tensile material around the drive shaft and the joint

comprising an interface and the addition of compressive filler material within inner and outer mould formwork.

9. A joint comprising an interface in accordance with claims 1 and 2 comprising a central hub comprising a wind turbine rotor comprising a wind turbine assembly provided to generate electricity.

10. A step in accordance with claim 9 to supply electricity to parties acquiring electricity.

Application No:	GB1609163.9	**Examiner:**	Mrs Margaret Phillips
Claims searched:	1-10	**Date of search:**	22 June 2017

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1 at least	JP H07243573 A (MITSUBUSHI) See WPI Abstract Accession Number 1995-369279 and drawings 1, 2 and 9 a & b
X	1 at least	US 2013/309435 A1 (BOURSIER) see paragraph 0021 and fig 6
X	1 at least	US 2012/040169 A1 (BOURSIER) Whole document
X	1 at least	CN 201043512 Y (YONGYUAN) See WPI Abstract Accession Number 2008-F07455and all drawings

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

B29C; E04C; F03D; F16B

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
F16L	0041/02	01/01/2006