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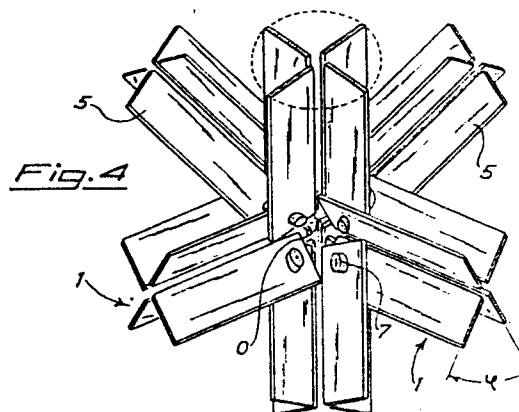
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54 **Improved bar for plane lattice spatial structures without junction knots.**

57 Some embodiments are described of an improved bar or rod (1, 1') adapted to form planar three-dimensional single or multiple layered lattice structures, without the need for connecting knots. The coupling among the various rods is simply performed by fastening together the X-shaped, substantially radially oriented flanges (5) of said bars. The relative angle (φ) between couples of rod flanges (5), which defines the geometrical coupling planes, and therefore the contact surfaces between two bars converging with their axes into the center of a virtual node (0), has to satisfy a predetermined relationship among the direction cosines (a, b, c) of said axes, each of which is coincident with the axis of a sheaf of planes corresponding to said flanges whose angular orientation has to be determined. An improved fastening means (7, 11) is also described, particularly adapted to fasten converging bar flanges (5) to each other, in view of the narrow room available.



"IMPROVED BAR FOR PLANAR LATTICE STRUCTURES WITHOUT
JUNCTION KNOTS"

This invention relates to an improved type bar, for
junction planar three-dimensional lattice or truss
5 structures without junction knots, the structures formed
in this way and a fastening device particularly adapted
to join said bars together in such a structure.

Three-dimensional lattice structures are known,
particularly for covering more or less extended areas,
10 which are assembled by connecting together metal rods
or bars in various ways, being required in any case
some kind of connecting knot elements at the joints,
even in the instance of single or multi-layered planar
truss structures. In fact, the rods whose geometrical
15 axes effectively converge in a single point are never
directly joined to each other, but it was always been
preferred to provide the mutual connections by means
of an auxiliary element that materializes, so to speak,
the geometrical knot. A number of embodiments are known
20 for said connecting knot elements, of more or less
complex construction depending upon the type of structure
to be obtained, and in particular upon the number
of rods converging towards each knot, but, in any case,
it is necessary that in addition to the rods, provision
25 is also made for these usually expensive elements which
require skilled labour for the assembly thereof. While
this can all be justified, from a financial point of
view, for important structures, designed to cover very

large size areas, it is not so for less extended ceilings, where it would be desirable to use, as the only structural members, extruded material rods made for instance from aluminum alloy, and the related fastening means.

It is therefore an object of this invention to provide a rod or bar of the kind mentioned above, characterized by substantially radial flanges, where the rod can be obtained through a simple extrusion process, and is adapted to be connected to other identical rods all converging, at the longitudinal axes thereof, towards a single geometrical center of a virtual knot, without interposition of connecting means at the joint, but only by means of the mechanical fastening of the conjugate rod flanges, overlapping each other. Said mechanical fastening obtained by means of ordinary bolts, rivets, pins and so on, or preferably, where justified, by means of an improved bolt particularly adapted to be inserted in the narrow areas between said rod flanges, provides the necessary stiffness to the three-dimensional structure thus assembled.

The bar or rod of the invention is characterized by comprising at least three substantially radially extended flanges, each flange having a first surface which defines a plane belonging to a sheaf of planes having its axis coincident with the longitudinal axis of said bar, the other surface of each rod flange being offset from the associated plane of the sheaf, always directed to the same direction of rotation around said longitudinal axis or else, only in those cases where the flanges are an even number, being symmetrically arranged relative

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ve to a plane bisecting a pair of opposite angles defined by said planes, where these angles in any case, at least at the bar ends, are such as to allow for the coupling of rods having at least the same number of flanges with the same angles, by means of overlapping in a position of planar coincidence relationship of the flanges corresponding to conjugate connecting planes.

According to a preferred embodiment thereof, the bar of the invention is provided with four X-shaped flanges, the radial planes associated therewith defining each other an angle φ and the supplemental thereof, respectively, where the angle value is given by $\text{tg } \varphi = -c:b$, with b and c being two of the three direction cosines of the longitudinal axis of each bar designed to converge into the same center of the joint or nodal point.

Still according to this invention when each bar has at least four flanges, the obvious difficulty being experienced in tightening the fastening device between the flanges of two converging rods, due to the narrow room available, is solved by using an expansion head bolt which is tightened at the nut side, characterized by an expansion head having a helical spring housed within a suitable seat around the bolt shank and held into position by a washer which can slide around the shank to a position where it contacts a tightening nut threadable onto said shank.

Other objects, advantages and features of the bar according to this invention, of the bolt particularly adapted for the assembly thereof, and of the corresponding structure provided thereby, will be apparent to

those skilled in the art, from the following description of some embodiments, given as non-limiting examples with reference to the attached drawings, in which:

5 FIGURES 1 and 1a show a perspective view of a square looped pattern, single-layered truss structure in a general schematic view, and of a section of the same structure hatched in Fig. 1 and shown in a larger scale, respectively;

10 FIGURES 2 and 2a are geometrical representations of a pyramidal lattice section forming a square loop of Fig. 1, and of the diagonal rods converging towards a point taken as the origin of three coordinate axes, respectively;

15 FIGURES 3a and 3b are two schematic views of a bar according to this invention, to show two different construction approaches thereof;

20 FIGURES 4 and 4a show a perspective view and an exploded section in polar coordinates, respectively, for the connection formed by the bars according to this invention and visible in the foreground for a structure according to Fig. 1 and 1a;

25 FIGURE 5 shows a schematic view of a bolted joint of bars according to this invention, particularly of the kind shown in the following Fig. 8, to emphasize the design and operation of the expansion head bolt according to the invention;

FIGURES 6 to 13 show end views of several embodiments of four-flanged bars, all of which can be inscribed in a circle;

30 FIGURES 14 and 15 show end views of two further embodiments of the bar according to the invention,

three- and six-flanged; respectively; and

FIGURES 16 and 17 show two further embodiments of four-flanged bars of the invention, having peripheral square shaped profiles, closed and open, respectively.

5 Referring now to the drawings, Figs. 1 and 1a show a planar three-dimensional lattice structure, in particular a single-layered structure, that can be advantageously built by fastening the bars of the invention to each other without nodal connecting elements in the
10 areas where several bars meet, which are shown here simply by the longitudinal axes thereof. This kind of a structure, which could of course comprise two or more layers, one over the other, includes a certain number of square loop elements 10 adjacent to each
15 other, and forming the base of pyramidal elements 3 whose apex is located in a geometrical knot point 0. Rods or bars 1 form the sides and the diagonals of loop elements 10 and of pyramidal elements 3. In the case shown here, a maximum of eight rods 1 can converge
20 towards an apex 0, while in the instance where more layers are provided the rods can be twelve in number.

An essential requirement that has to be met by bars 1 according to this invention is that they must have substantially radial members, or suitably oriented
25 "flanges" 5, in order to define, about the bar longitudinal axis, such angles as to allow for an overlapping in a position of geometrical planar coincidence of the conjugate flanges belonging to bars whose axes converge in the same joint point 0 which is the virtual center
30 of the knot or, as it could be better defined, a "no-knot node" since the same point is not materialized in the

space as an actual structure element. The angular arrangement of flanges 5 of a certain bar 1 is then related according to the invention, to the angles mutually formed by the same bars to each other, or better by
5 the longitudinal axes thereof.

Referring now to Figs. 2 and 2a said concept is better described making reference to a purely geometrical representation, respectively of a single pyramidal element 3, taken out of a square looped lattice structure, as shown in Figs. 1 and 1a, and of a node 0' taken
10 as the origin of a set of three coordinate axes in order to determine the angle orientation of a diagonal rod having its origin in said node. The subject diagonal rod is that designated 1' in Fig. 2 wherein there is
15 also shown the three coordinate axes x, y, and z, then reproduced in Fig. 2a. In the latter figure there has been indicated with p a unitary length of rod 1', whose components along the three coordinate axes are a, b, and c, respectively, while the angles that said unitary
20 length form with the three coordinate axes in the planes marked by shading respectively with horizontal lines, sloping lines and dots have been shown as α , β , γ . The following equations can be obtained:

$$\begin{aligned} a &= p \cos \alpha \\ b &= p \cos \beta \\ c &= p \cos \gamma \end{aligned}$$

25

therefore a, b and c are those quantities usually defined as the diagonal rod 1' direction cosines referred to the three coordinate axes, two of which coincide
30 with two bars of square looped element 10, or base of the pyramidal element 3.

It has been found that the angular orientation of flanges 5 of each bar 1 has to be a function of said direction cosines in order to obtain a mutual planar direct flange connection in a point where the bars meet. In the far preferred instance, i.e. that of four-flanged bars having X-arranged flanges to form square loop elements of a pyramidal configuration, angle φ between these flanges, as shown in Figs. 3a and 3b, is simply given by the following equation:

10
$$\operatorname{tg} \varphi = -\frac{c}{b}$$

as can be verified starting from the equations given above. In fact, once the angle φ has been calculated, the same and the supplement $180^\circ - \varphi$ thereof, identify two X-oriented planes intersecting along the bar longitudinal axis and providing the conjugate planes which must be mutually coincident at the node geometrical virtual center (or "no-knot node"). In other words, the longitudinal geometrical axis of the bars is considered as the axis of a sheaf of planes whose direction cosines coincide with those of the bars; among the planes belonging to said sheaf just those conjugate planes are determined, as shown in Figs. 3a and 3b, which provide the geometrical coupling planes, in particular by means of the above equation. The contact surfaces between two matching flanges are determined in this way, as indicated on the drawing by a thicker dash-and-dot line, but of course the flanges have a thickness, limited only by the size of mechanical junction elements in addition to cost evaluations related to the weight of the overall structure. Due to said thickness the flanges cannot be defined as actually

radial with respect to the bar geometrical axis as, if a surface thereof coincides with one of said planes, this is not true for the second one which will be offset from said plane, for all the flanges of a same bar, in
5 the same direction, clockwise or counterclockwise, when rotating around the bar geometrical axis as it is shown in Fig. 3a (counterclockwise rotation). This is the most general way of arranging the flanges, but for four-flanged bars a mirror-image arrangement is
10 also feasible, as it is shown in Fig. 3b, where the flange arrangement is symmetrical to the axis S-S bisecting two opposite angles, in this case the ϕ amplitude angles.

Based on the foregoing, the values of the angles
15 defined between the flange planes depend upon the geometrical properties of the modular lattice structure, and therefore they depend for instance, upon the different height that is desired for the structural layer of Fig. 1, since the diagonal rod angles, and consequently
20 the direction cosines thereof, are in fact a function of said height. In particular, based upon the aforementioned equation $\text{tg}\phi = -c:b$ and for a structure composed of pyramidal lattice elements where all the bars have the same length (i.e. diagonal rods of same length as
25 those forming the sides of each loop) the calculations show that the bar flanges form alternate angles whose values are approximately $70^{\circ}31'44''$ and the supplement value thereof i.e. $109^{\circ}28'16''$.

In Figs. 4 and 4a there is shown the meeting area,
30 about a nodal point O, of only the rods visible in the foreground among the twelve that can converge with

their geometrical axes in the point 0, of a two-layered
pyramidal lattice structure. Rods 5 have been shown
here as X-shaped rods and bars, and in Fig. 4 without
the central intersection area, whereby they are caused
5 to be lightened while of course an outer tubular element
(not shown) is provided, which encircles and rigidly
restrains the flanges. In this way the connection surface
and its efficiency are increased, but obviously
other different embodiments are possible (as shown for
10 instance in Fig. 4a) among those hereinafter disclosed
taking into account in particular that the bar can
have any desired shape, with any desired flange orientation,
provided that, at least at the ends thereof designed
for connection to other bars, its flanges have the
15 orientation necessary to ensure that the flanges can
overlap at conjugate connection planes. As it is apparent
from Fig. 4a, the diagonal rods provide the connecting
element between the stringers.

In Fig. 4 and 4a there is also schematically shown
20 the fastening means 7 for mechanical connection of the
overlapping flanges of bars converging towards the
centre point 0, having only the function of withstanding
shear stresses. As a consequence, in order to solve
the problem of the limited room available to insert
25 and to tighten means 7, in particular where the angle
between the flanges is less than 90° , this invention
provides for use of an expansion head type bolt which
is described in the following referring to Fig. 5.
Bolt 11 is shown in a side view outside a rod 1 having
30 flanges 5 shaped as shown in Fig. 4 or, more completely,
in Fig. 9, in addition to a sectional view where

it is shown tightened with expanded head for the fasten-
ing of two flanges of two separate associated bars. In
fact it is apparent that insertion of a normal screw
having a head integral with the shank, and tightening
5 thereof by means of a nut, would prove to be very diffi-
cult, if not impossible, also because screwing operations
on a structure made up of bars according to the invention
have necessarily to be performed sideways of the screw.

Referring now to Fig. 5, an expansion head bolt 11
10 which advantageously embodies a fastening device 7,
according to the invention comprises a partially thread-
ed shank 21 provided with a central through bore, a
cylindrical pin 23 being housed in said through bore
and having an end thereof shaped as a square tang 23a,
15 while the other end is shaped as a conical disc 25.
Both ends 23a and 25 project from shank 21 and pin 23
is made integral therewith by means of a suitable bond-
ing adhesive. The size of the maximum diameter section
of pin conical head 25 is equal, and in any case no
20 larger than the outer diameter of shank 21, in order
to define, together with the associate end of shank
21, a cavity adapted to provide a seat for helical
spring 20 whose inner end is attached to pin 23, said
spring being normally held into position by a washer
25 27 whose inner diameter corresponds, irrespective of
a small clearance, to the outer diameter of shank 21.
At the opposite, outerly threaded end of the shank, in
the proximity of tang 23a a tightening nut 29 is screwed.

Thereby the bolt 11 can be inserted and tightened
30 in any case operating from the same side, i.e. the
side of tang 23a, no operation being necessary on the

other side of the bolted connection, that side having been chosen that affords more room available, i.e. a larger angular opening, as it is apparent from Fig. 5. First, shank 21 carrying the pin integral therewith is inserted in the aperture provided on the flanges to be joined, starting with end 25. Once washer 27, obviously larger than the through bore, has come into contact with the flanges to be joined, tang 23a is caused to back up by hitting it with a suitable tool, and in meantime the seat of helical spring 20 is released whereas the spring is still compressed when passing through aperture of flanges 5, and eventually expands coming out of the opposite side, until it takes the form of open head as shown in cross-section in Fig. 5. To make the disengagement of spring 20 from washer 27 easier, the inner opening of the latter is chamfered. Thereafter tightening is performed by keeping the shank stationary through pin tang 23a and screwing at the same time hexagonal nut 29 up until the two flanges to be joined are tightly clamped between the expanded head formed of spring 20, and washer 27.

It is possible to disassemble the flanges and therefore the structure, either partially or completely, by holding with a suitable hooked tool the helical spring head whereby it is made to coil up on itself while the pin is rotated through tang 23a. The shank is then taken out by hitting it at end 25, for instance by means of the same hooked tool which can be inserted in a narrow space, or removing the same by means of the tang as well.

Referring now to Figs. 6 to 13, some examples of

four flanged rod cross-sections are shown, all of which can be circumscribed in a circle, among them those of Figs. 6, 7 and 8 having a continuous open X-shape, which in Figs. 7 and 8 is provided with dependent peripheral elements. Figs. 9 and 10 show two additional examples of bars formed of enclosed tubular elements having inner or outer flanges; i.e. converging from the periphery towards the center or diverging towards the periphery, respectively. While the exemplary embodiment of Fig. 6 has already been shown in Fig. 4a, the one of Fig. 9 has already been shown in Figs. 4 and 5, and in particular in Fig. 4 without the tubular peripheral part, also because in this case, as usual when dealing with closed profiles, or with open cross-section with peripheral elements, the crossing near the joint nodes is obtained by removing the peripheral portions. All of these different available shapes of the bar cross-sections are advantageously obtained simply by extrusion for instance from aluminium alloys, as well as the embodiments of Fig. 12 showing a variation of Fig. 6, where two opposite closed peripheral elements are provided, and of Fig. 13 which can be considered in turn a variation of Fig. 12, where two flanges on the same radial plane are cut in the central area.

25 The embodiment of Fig. 11 is rather different, but always in accordance with the requirements of the invention, as it comprises a simple tubular element having local flanges, only at each rod end, wherein the flanges are formed for instance by plastic deformation of the tube, or by addition of material. On the other hand, as already mentioned, no matter how the bars are obtain-

ed, the only essential and sufficient condition is that the flanges have the required angular orientation to allow for coupling with conjugate flanges of converging rods, even though at the ends only, for instance by means of material added. It is understood that where the necessary shape is provided at the ends only, the advantage of obtaining a constant cross-section bar by means of a simple extrusion process is lost.

According to this invention it is also possible to use bars having a different number of flanges depending upon the three-dimensional geometry adopted. For instance with three-flanged bars, as shown in Fig. 14, it is possible to build structures whose elementary module is the tetrahedron, and with six-flanged rods of Fig. 15, hexagonal loop planar structures, instead of square based-pyramidal trusses are obtained. In the case of the tetrahedron, the geometrical stiffness is increased since the structure made of these modules is typically hyperstatic. In this case an additional advantage comes from the angle φ between the flanges being larger, which makes junctions easier, possibly making unnecessary the use of the abovementioned expansion head bolt.

It is finally possible to use rods whose flanges are circumscribed inside a peripheral square enclosure completely or partially closed, as it is shown in Figs. 16 and 17 respectively.

It should be noted that the outer upper and lower planes can be completed by using stub sections of the missing diagonals, or by means of wings made as lengths of the missing diagonal rod flanges.

In such a way, with no need for structural elements

other than the abovementioned rods which are available through extrusion, subjected to the only cutting (at size or in order to take away the peripheral enclosures at the node areas), and drilling operations to allow
5 for bolt insertion, as well as bolt tightening, also by hiring unskilled labour it is possible to assemble roof covering of a fairly large size. The peripheral complementary members mentioned above, besides fulfilling a structural function, can also be utilized as a
10 connecting means for vertical panels, or horizontal panelling for covering or ceiling.

Possible additions and/or modifications can be made by those skilled in the art to the embodiments described above of the structural bar according to the invention,
15 as well as to the abovementioned expansion head bolt, without exceeding the scope of this invention. In particular different cross-sectional shapes from those shown can be adopted, provided that they meet the requirements concerning mutual orientation of the flanges.

CLAIMS

1. An improved bar for planar three-dimensional lattice structures, characterized by comprising at least three substantially radial flanges (5), each having a first surface defining a plane in a sheaf of
5 planes having its axis coincident with the geometrical longitudinal axis of said bar, the other surfaces of all the flanges of a bar (1) being offset from the associated plane, always directed to the same direction of rotation around the said longitudinal axis or, only
10 in the case of an even number of flanges, said other surfaces being symmetrically arranged relative to a plane (S-S) bisecting a pair of opposite angles defined by said planes, the said angles in any case, at least at bar ends, being such as to allow for the coupling
15 of rods (1) having at least the same number of flanges (5) with the same angular orientation, by overlapping in a position of planar coincidence relationship of the flanges relating to conjugate coupling planes.

2. The structural bar of claim 1, characterized in
20 that the angles (φ) between said first surfaces of two adjacent flanges (5) are dependent upon the angles (α , β , γ) formed by the geometrical axes of the bars converging into the same nodal point, relative to a system of three coordinate axes having its origin in the center
25 of said node (0), and in particular upon the direction cosines (a, b, c) thereof.

3. The structural bar according to claim 2, characterized in that it has four X-shaped flanges (5), whose radial planes relative to said first surface define
30 therebetween an angle (φ) and its supplement angle,

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respectively, the value of which resulting from the equation: $\operatorname{tg} \varphi = - c:b$.

4. The structural bar according to claim 3, characterized in that said four X-shaped flanges have associated therewith peripheral elements that can be inscribed in a circle whose center lies on said longitudinal axis.

5. The structural bar according to claim 4, wherein said peripheral elements provide an enclosed tubular profile from which said flanges extend, in a substantially radial direction, to a position close to said geometrical axis, without reaching the same, there being also provided that said outer tubular enclosure is missing at the joint nodes, where the bars connect to each other.

6. The structural bar according to claim 3, characterized in that said flanges extend from a central tubular element, co-axial with said geometrical longitudinal axis of said bar.

7. The structural bar according to claim 3, comprising a longitudinal tubular element adapted to form said four X-shaped flanges, with the angular orientations required, only in a region close to the bar ends by squashing of said tubular element.

8. The structural bar according to any of preceding claims 1 to 6, made of continuously extruded material, in particular of aluminum alloy, and cut to the desired size.

9. A planar three-dimensional structure formed by at least a single layer of pyramidal trusses (3) having a square loop base (10) formed of bars (1) according to claim 3 and one of claims 4 to 7, with fastening elements (7) to join to each other the flanges (5) of

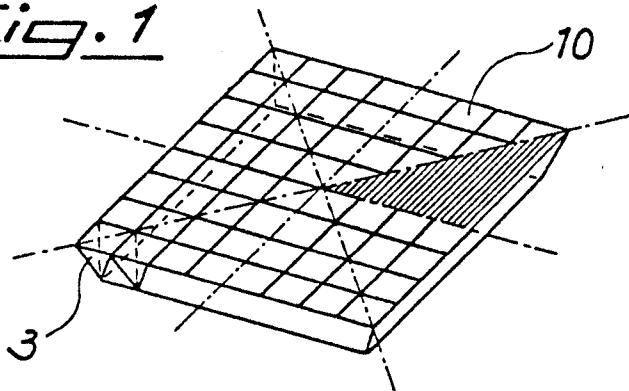
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bars converging in the same virtual geometric node (0), and overlapping at said first surface associated with said conjugate coupling planes.

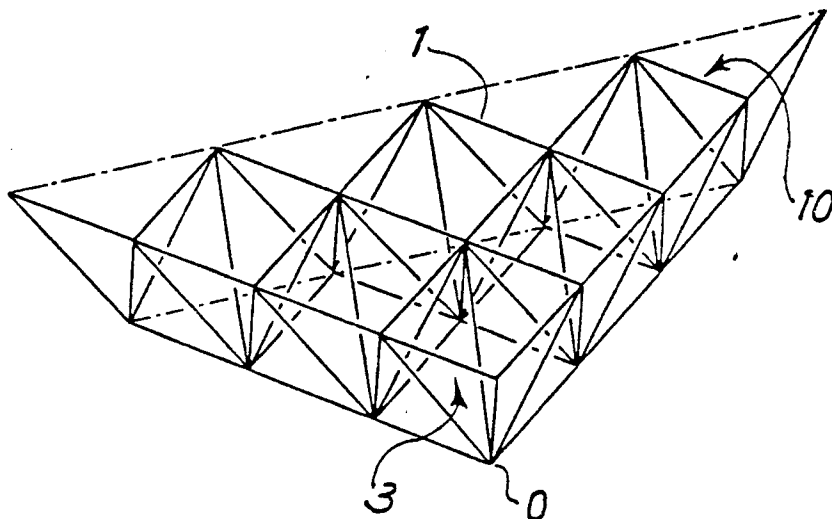
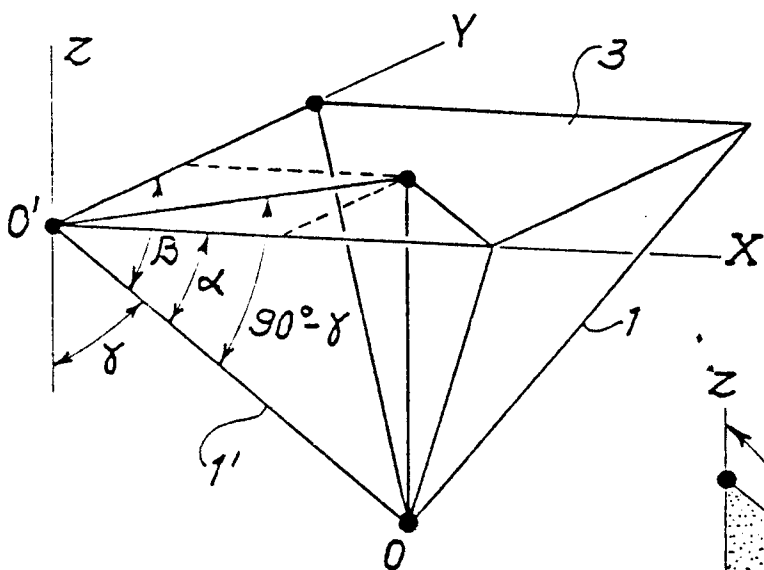
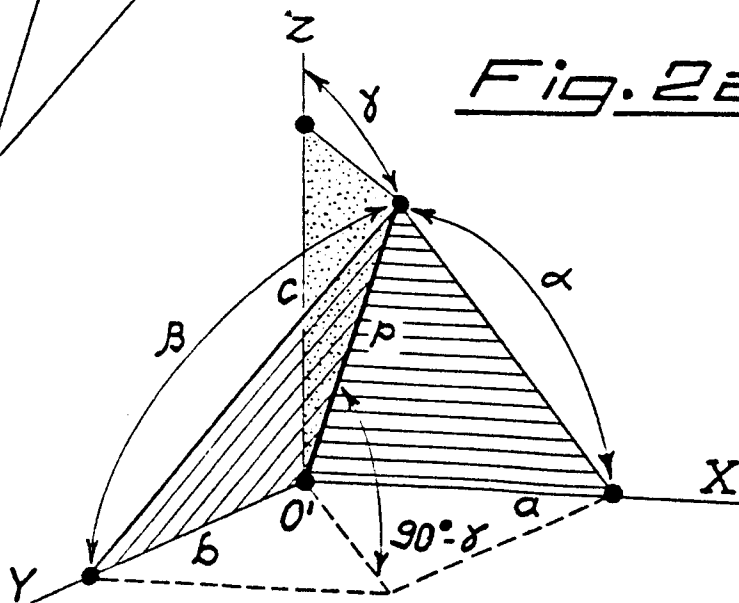
5 10. A three-dimensional planar lattice structure formed by tetrahedron elements connected to each other, each comprising bars according to claim 1 or 2, having three flanges.

10 11. A fastening device to be used to fasten to each other homologous bars according to one of claims 1 to 7, characterized in that it comprises an expansion head bolt (11), a helical spring (20) housed in a suitable seat around bolt shank (21) and kept in position by a washer (27) slidable on said shank until it abuts a tightening nut (29) to be screwed up on said shank
15 (21).

12. The fastening device according to claim 11, characterized in that said shank (21) has a partial external thread along an end length thereof, for screwing of said nut (29) thereon, and said helical spring (20)
20 is housed in a cavity defined between the opposite end of shank (21) and a conical head (25) whose diameter is not larger than said shank diameter, integral with a pin (23) mounted within, and made integral with shank (21), the opposite end of which projects from said
25 shank and is shaped as a square tang (23a), said spring (20) having one end thereof fastened to said pin (23).

Fig. 1

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Fig. 1aFig. 2Fig. 2a

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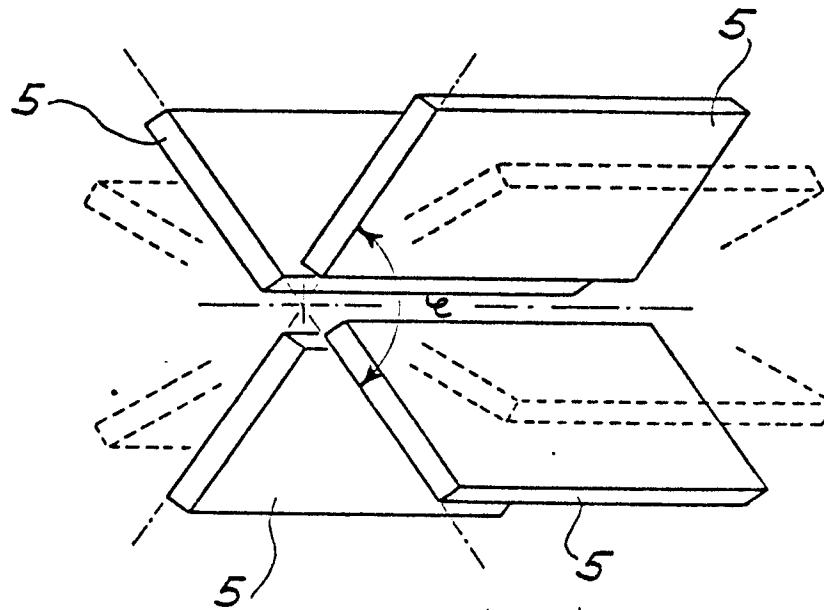
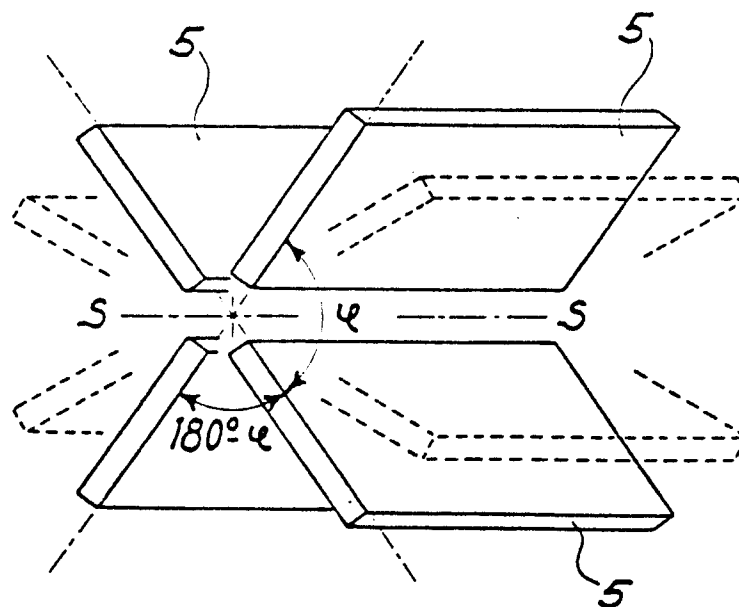
Fig. 3aFig. 3b

Fig. 4

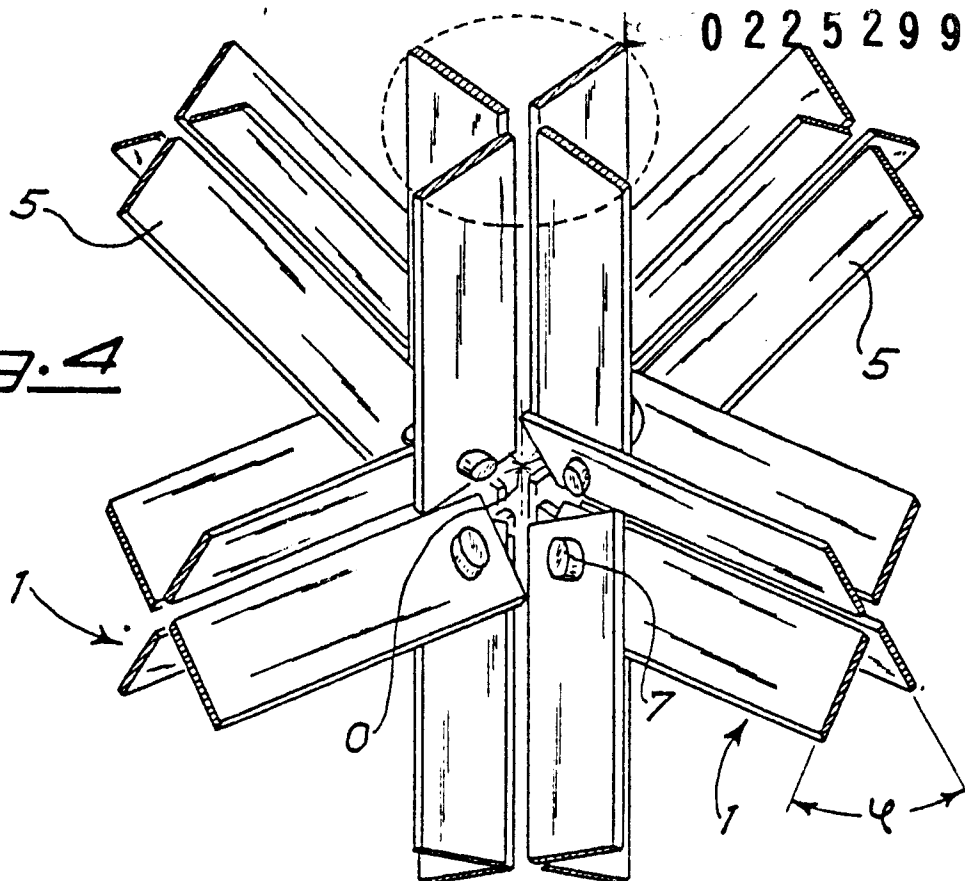


Fig. 4a

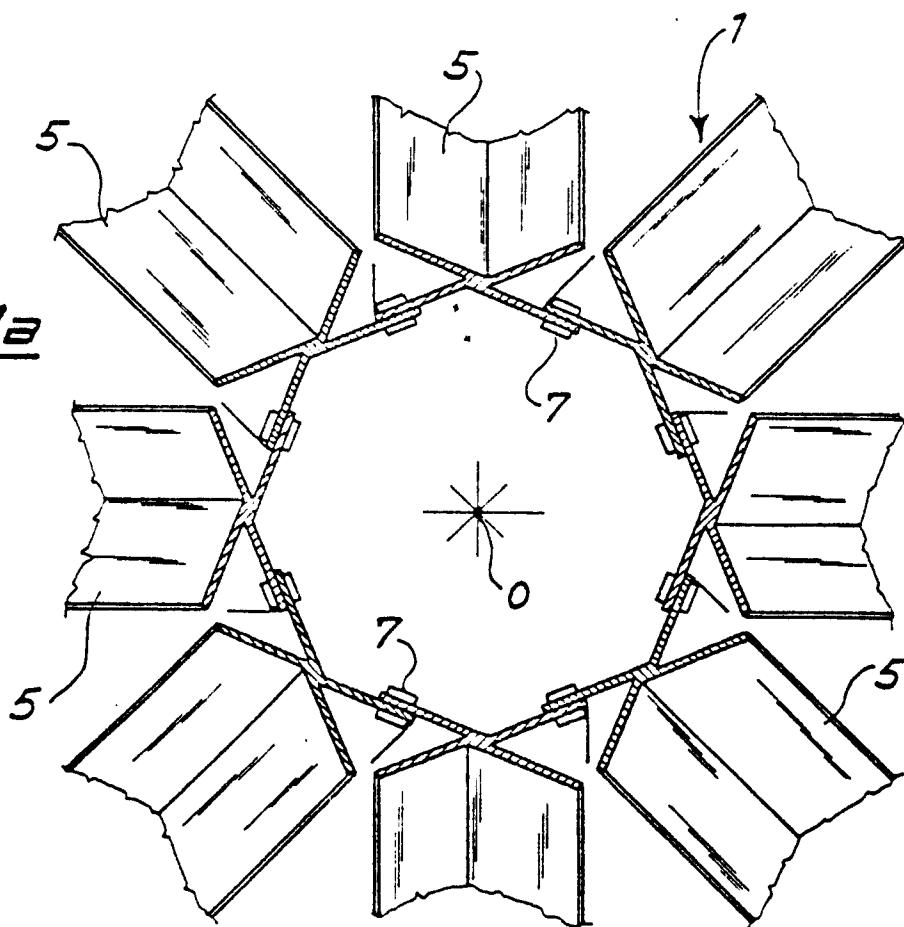


Fig. 5

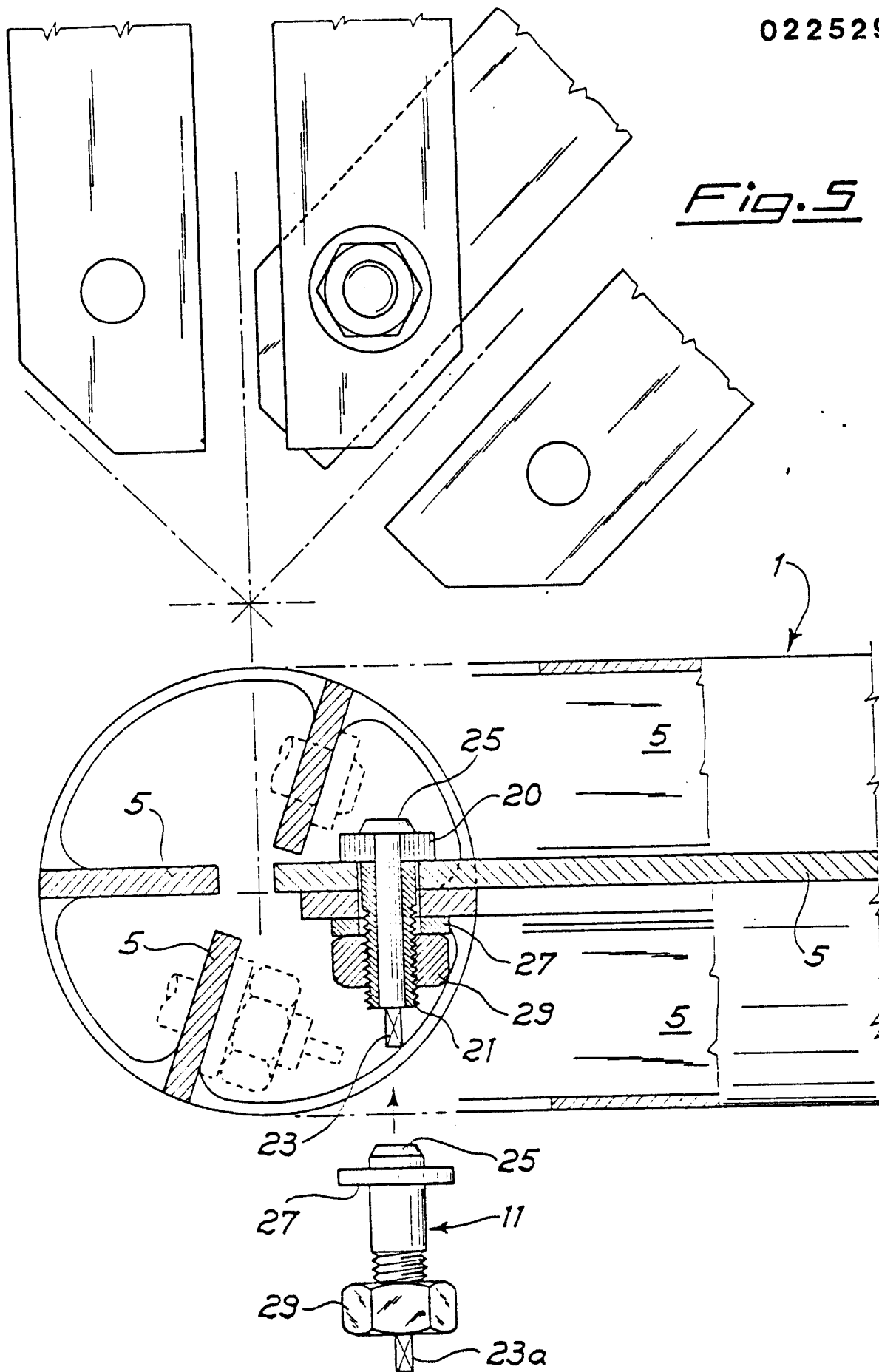
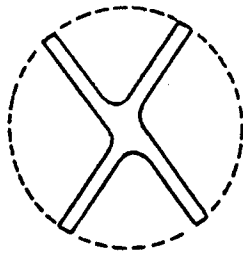
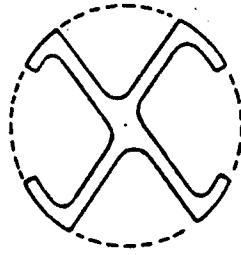
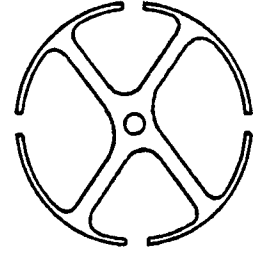
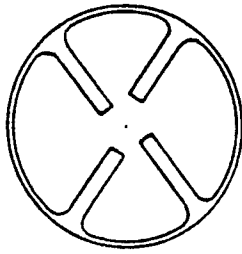
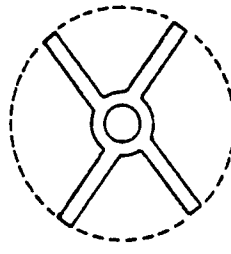
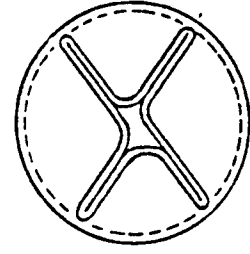
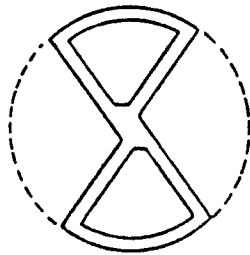
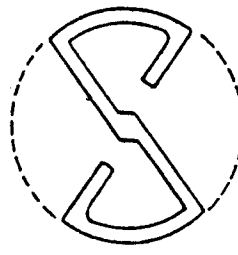
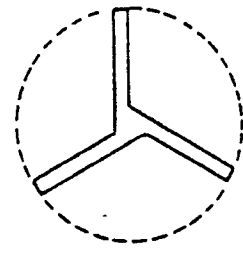
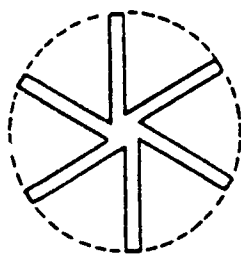
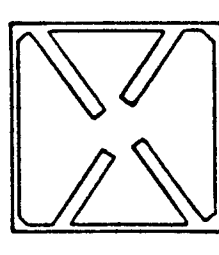


Fig. 6Fig. 7Fig. 8Fig. 9Fig. 10Fig. 11Fig. 12Fig. 13Fig. 14Fig. 15Fig. 16Fig. 17