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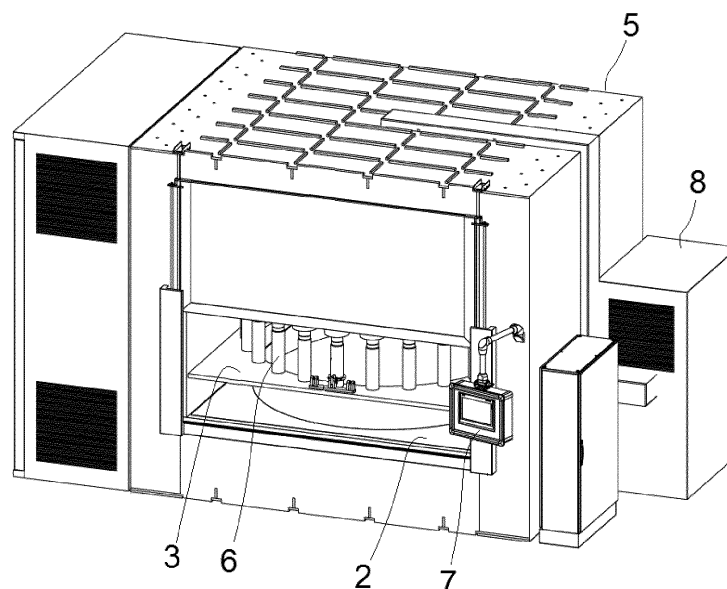
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(54) **HYDROFORMING PRESS WITH OPEN DIE AND INTEGRATED DEEP-DRAWING**

(57) A hydroforming press with open die and integrated deep-drawing, based on the principle of applying hydrostatic pressure for creating a permanent deformation on a sheet metal, which employs an open die that defines, in a plan view, the outer perimeter of the final part, and allows for a permanent bulging to be formed in the same, while making it possible to incorporate a deep-drawing process prior to the hydroforming process in order to integrate the tab parallel to the hydroforming direction. The open die is located on a horizontal plane

inside the press and a plurality of hydraulic cylinders (6) operate on it, of which at least two of them also operate as actuator cylinders, in charge of lowering the die onto the part (1) to be shaped, while all of them come into operation, moving and pressing the female portion (3) of the die against the sheet metal (1) placed on the male portion (2) of the die, before applying the hydroforming hydraulic pressure, operating in the opposite direction, thereon.

Fig. 4



Description

Object of the invention

[0001] The hydraulic machine described herein, is based on the principle of applying hydrostatic pressure for creating a permanent deformation on a sheet or sheet metal. The hydroforming process for the described application is based on an open die that defines, in a plan view, the outer perimeter of the final part. Thus obtaining a permanent bulging of the workpiece, the profile of which will be determined by the contour of the open die used. In addition, it enables the incorporation of specific tools that make the deep-drawing of a tab, prior to the hydroforming process, possible.

[0002] The contour of the part obtained varies by changing the die. In order to carry out this change, the machine of the invention has its own fastening system that enables one profile type to be quickly replaced with another.

[0003] This hydroforming process with an open die is indicated for any type of cover or bottom for tanks with a circular, elliptical or panoramic plan or any other profile. The most relevant feature of the process is the high deformation capacity, plus the level of finish of the part, since there is a uniform distribution of tensile forces in the work process.

[0004] The main innovations of the machine being described herein are:

- The possibility of incorporating a deep-drawing process prior to the hydroforming process in order to integrate the tab parallel to the hydroforming direction.
- The high hydraulic capacity, which enables the deformation of large thicknesses at great deformation heights (even in steels having a high elastic limit).
- Its modular design, which makes it possible to enlarge certain work dimensions with a low redesign load, as well as the increase in the hydraulic load.

Technical field

[0005] The invention falls within the field of machines tools for metal deformation; specifically those employed for sheet metal works using mechanical deformation means. The equipment allows bottoms with a circular, elliptical or panoramic plan or any other profile made of different metals (aluminium, carbon steel, alloy steel, stainless steel, among others) to be obtained. Said bottoms may be assembled in self-supported road cisterns, tank containers for intermodal transport, as well as the rest of mobile or stationary containers or deposits for which covers or bottoms with different profiles are required.

[0006] The described equipment makes it possible to combine a deep-drawing process with an open-die hydroforming process, for which there is a specific tool available that defines the plan profile of the bottom to be man-

ufactured, along with other obvious dimensional features: radius of curvature, material and thickness of the sheet metal; it is therefore important to know the elongation itself since it can limit the deep-drawing depth and load. The high hydraulic load of the described equipment, along with a high stiffness and dimensional accuracy of the work area enable these two processes to be combined in the same work cycle.

Background of the invention

[0007] The hydroforming process consists of shaping a material through the action of a liquid under pressure (water or water and oil emulsions). The process itself is usually divided into three basic steps:

- Loading the part (tubular or sheet metal) into the press.
- Filling the tube or the die with liquid.
- Shaping the part through the simultaneous action of the axial force (in the case of tubes) and internal pressure, which may reach up to 10,000 bars.

[0008] The fluid mainly employed is water, to which some type of lubricant is usually added. Steel is the material on which this process is nowadays employed, although all the metals that can be cold shaped are eligible for the hydroforming process.

[0009] Among the hydroforming processes, one of the most employed is known as simple sheet metal, which is based on the use of a pressurised fluid to force the sheet metal to adopt the shape of the punch or mould. The pressure increase is obtained by means of hydraulic systems (pumps or pressure boosters). The hydroforming of a simple sheet metal may be carried out with an intermediate membrane between the work fluid and the part to be shaped, or directly without the membrane, whereby the fluid and the part are in contact.

[0010] The die hydroforming system uses a die, which acts as a negative of the final shape of the part on one of the faces, and a hydraulic mechanism that provides the pressurised fluid (it may be included in both the upper and lower die) for pushing the sheet metal against the die. The material expands due to the pressure of the fluid inside a die shaped as a closed cavity. The material is deformed by the internal pressure. In general, this process involves the following steps:

- The non-deformed sheet metal is placed into the die.
- The press is closed and a starting pre-shaping pressure is applied to correctly place the sheet metal.
- The upper die (understanding this to be the membrane) is moved by the pressure in order to deform the sheet metal during the first shaping stage.
- After depressurising the fluid, the press is opened and the sheet metal is removed applying thereto, if necessary, a subsequent thermal treatment to eliminate mechanical stresses from the material.

[0011] The hydroforming process, as described in document DE1240801 of 1967, is a process in which the sheet metal is positioned on a die, which only seals the perimeter thereof. Next, the material is deformed with a conventional hydraulic press and liquid under pressure is introduced. Sometimes the starting material has a pre-form (pretensioning) in the direction opposite to the press impact by applying pressure prior to the punch activation. In this way, the material endures a hardening work, which is very difficult to achieve with other traditional deep-drawing methods. It is also possible to leave the die, which acts as a negative, fixed so that the work fluid operates as a punch.

[0012] The hydroforming technology enables large deformations in materials with an elongation ranging from moderate to high, since the stress distribution is clearly more perfect than that produced by a standard deep-drawing process. In order to correctly carry out the hydroforming process a great hydraulic load is necessary, as the machine has a high work section and therefore the lifting force of the piece is high as well.

Description of the invention

[0013] In the manufacturing of metal tanks and containers a serious problem arises with regards to the strength of the bottoms, covers or partitions; the standard manufacturing processes with reasonably high thicknesses (more than 2.5 mm) imply large-tonnage equipment that use a male and a female for, after successive work cycles, creating the curvature of circular or square cross-section.

[0014] For bottoms or covers with a thickness below 2.5 mm, the open-die simple hydroforming process is used; for larger thicknesses, the lifting load generated by the hydroforming fluid is so high that the hydraulic structure and pipeline have a complex and critical sizing. However, the described process provides a slow and progressive deformation, with a homogeneous distribution of the deformation force, the hydrostatic pressure being continuous since the gravitational effects are negligible due to the short deformation height, max. 500 mm. The temper hardening experienced by the sheet metal is also homogeneous, continuous and without areas of stress concentration, unlike most deep-drawing processes.

[0015] The equipment of the present invention enables the hydroforming process to be carried out with great thicknesses (up to 8 mm), with materials having a high elastic limit (such as AISI 316L stainless steel), and with a great deformation height, of up to 500 mm, thus enabling the process to directly compete with the preceding deep-drawing processes conventionally used to manufacture bottoms with these thicknesses.

[0016] The two big technical problems to be solved are, on the one hand the high hydraulic capacity required to hold a sheet metal and, on the other hand, the integration of a tab providing a perpendicular wing to the manufactured bottom or cover. The hydraulic load is closely re-

lated to the work pressure and the cross-section of the sheet metal; as well as the friction thereof with the base of the press and the open die (on the lower and upper portions of the sheet metal, respectively). The relation implies the calculation of the lifting force of the work area together with an empirical value of the metal-rubber friction coefficient for the press base and metal-metal friction coefficient for the open die. Said relation links the work pressure, deformation height, thickness, elastic limit of the material and the effective cross-section to the hydraulic force (provided by a series of hydraulic cylinders). Likewise, it is necessary to generate a hydraulic load of approximately 15-30 MN in order to obtain the deformations described above, which means that a highly resistant mechanical structure is required.

[0017] The other significant technical problem takes place when it comes to manufacturing bottoms that have a non-circular cross-section, which means there is no symmetry axis of revolution. In these cases, the rear seam for finishing the bottom by adding thereto the aforementioned tab cannot be produced with an acceptable level of quality, due to the differences in the centres and radii making up the profile, whether it is panoramic, rectangular or elliptical. Moreover, the usual process generates an irregular base on the bottom due to the significant stress differences in the transit from one radius relative to the other in the same continuous profile of deformation. Thus, the final result is a low-quality bottom with visible marks, a striction of the material at the tab level and a base that does not fit properly with the ferrule assembly, due to the irregular distribution of the seaming stresses.

[0018] The combination of a high hydraulic capacity with a rigid and planned structure along with the design of a tool specific for the described equipment solves both problems. Thus, the invention consists of the configuration of the subsystems making up the hydroforming press with an open die and integrated deep-drawing.

Description of the figures

[0019] In order to complement the description presented herein, and with the aim of gaining a better understanding of the characteristics of the invention, a set of drawings is attached to this specification, wherein, by way of non-limiting examples, the following has been represented:

Figure 1 shows a schematic view of the different stages of the open-die hydroforming process.

Figure 2 shows a schematic view of the different stages of the hydroforming process, with a prior deep-drawing of the sheet metal.

Figure 3 is an exploded perspective view of the press structure subject matter of the invention.

Figure 4 is a perspective view of the hydroforming press assembly.

Figure 5 is a view of the die employed when the deep-

drawing process is carried out prior to the hydroforming process.

Preferred embodiment of the invention

[0020] The work strategy used in a simple hydroforming process, with an open die, is the one shown in figure 1:

a) A thin rubber sheet is arranged on the male portion (2) of the die of the press (2) and the sheet metal (1) to be deformed is placed thereon. (Diagram 1a).

b) Next, the automatic cycle starts, for which the operator places him/herself outside the equipment's work area, and starts the process in the user panel. The hydraulic cylinders (6) bearing the female portion (3) of the die come down, until resting the lower face thereof against the work sheet metal (1). The rest of the cylinders (6) come down and when the hydraulic pressure is reached in the pipeline (determined through a control algorithm including the thickness, the diameter of the die, the material, and the deformation height, as well as the slippage degree sought), the hydroforming starts. (Diagram 1b). Ultrasound sensors arranged on the upper inner portion of the press continuously measure the deformation, an algorithm offsets the elastic recovery of the material. This control method enables the desired final height to be obtained.

c) Once the precise height is reached - and offset by the height control algorithm - the decompression is gently carried out, enabling the pressure to be relieved from the cavity, which was built up by the open die hydroforming process. Said decompression is carried out through a fixed flow reducer, which lengthens the pressure reduction time between 10 and 30 seconds. The water draining is carried out by introducing compressed air at a low pressure using for this purpose the same water pipeline that was previously used for introducing the hydroforming pressure. The tank where the water is recovered is the same as the one employed to feed the pump that performs the hydroforming. Once the water has been recovered, the already finished bottom is decompressed to take out the compressed air contained inside. To this end, there is a valve equipment, which allows for the fast evacuation of the air. When the pressure sensors of the water/air supply pipeline detect a pressure that is very close to the room pressure, the pistons are lifted - first those that do not support the die, and lastly those that do - and the operator removes the finished part with a specific tool, arranged so it can cut it, and as the case may be, subsequently form a tab that provides a wing in the same direction as the axis of the ferrule where said finished bottom is installed. (Diagram 1c).

[0021] The work strategy in the open-die hydroforming process with a prior deep-drawing process has been represented in figure 2 and has the following stages:

resented in figure 2 and has the following stages:

a) As in the process detailed above, the sheet metal or metal sheet (1) is placed on the deep-drawing male (4) located above the male portion (2) of the die, protruding from the central hollow space (22) thereof, which previously was impregnated with lubricant, applied by several sprayers located on the male (2) and female (3) portions of the die, which create a lubricant film that prevents the work material from cracking or tearing due to a seizure thereof. (Diagram 2a)

b) The operator leaves the work area of the machine and starts the combined cycle through the user interface, in which the cylinders (6) bearing the female portion (3) of the die come down enabling the exact alignment with the deep-drawing male (4), for which the pneumatic cylinders are pressurised and carry out a vertical effort downwards, towards the male portion. When the system detects that the female portion is in contact with the work sheet metal (1), the rest of the hydraulic cylinders (6) start coming down until they all reach a minimum pressure that forces them into a vertical alignment, avoiding flexural stresses in the female portion (3) of the die. The deep-drawing cycle starts by raising the pressure in all the cylinders, thereby enabling them to come down and the sheet deformation. Said pressure may be regulated as a function of the die position, the deformation speed sought and other parameters by means of a proportional pressure control valve electronically actuated through a control system. (Diagram 2b).

c) When the deep-drawing process has finished, the hydroforming process starts, which is completely analogous to the process described previously as "open-die simple hydroforming". (Diagram 2c).

d) When the hydroforming process has completely finished, the frontal centring devices of the female portion (3) of the die are lifted creating a large area for extracting the finished bottom, as shown in diagrams 2c and 2d.

[0022] The structure of the press (5) is made up of a series of equidistant rings (51) that provide a modular structure, which may be expanded and reinforced, and which allow a simple assembly given that all the parts are previously cut and are provided with notches (52, 53) that force the welder to place them in a unequivocal position, while the design of the upper and lower beds (54) is optimised so the construction can be realised step by step, without it being necessary to resort to large-tonnage lifting cranes for this purpose.

[0023] The expandable feature enables the bottom of the press to be elongated by simply adding the aforementioned rings (51) along one direction of the press and the other, which enables the creation of sizes according to the specifications of the final user of the machine. The

structure enables the flexural stresses to be distributed, ring by ring (51), in an independent manner, given that an elongation does not change the stress distribution and therefore neither the thicknesses nor the geometry of the remaining rings is modified.

[0024] The feature of being reinforced is achieved by varying the thickness of the rings (51) for example from 10 mm downwards and upwards, thus enabling the manufacture of one single machine - with regards to external dimensions - that may operate, for example, with pressures ranging from 15 MN to 30 MN, without significantly changing any portion of the press. This feature, along with that of being expandable, provides great design flexibility, saving time in the development of new models within the range.

[0025] The press comprises a hydraulic subsystem that, since the machine requires a high hydraulic load, is composed by a large number of hydraulic cylinders (6) (24 in this embodiment) with approximately a 500 mm stroke, employing a work pressure comprised between 20 MPa and 40 MPa, for which the wall and the material of the cylinders must be conveniently calculated. Thus, the hydraulic load varies, according to versions, between 15 MN and 30 MN and with it the work capacity of the machine.

[0026] The hydraulic unit (8) provides the power and control of the cylinder network that makes the manufacture of bottoms possible; this operates sequentially with a redundant response system when faced with failures such as electric shortages, conduit breakages, or mechanical breakdowns:

[0027] The die (3) lowering/lifting is realised with the same hydraulic actuators that generate the hydraulic load, which is controlled through an electrovalve system that blocks the passage of hydraulic fluid to the remaining cylinders; for this process only two cylinders are employed, a front and a rear cylinder.

[0028] The control of the hydraulic pressure is carried out through proportional valves, which enables the relative slippage of the work sheet metal (1) relative to the open die (3) to be adjusted. This "on the fly" pressure adjustment enables certain slippage of the metal sheet and thereby the calibration of the striction (thickness reduction) in the central portion thereof, which is the highest portion of the dome.

[0029] During the hydroforming process, the lifting load generated by the work gradually increases until the end of the cycle. The danger that a loss of hydraulic workholding may be generated is therefore high, for which reason there are dual pilot operated valves arranged in each one of the cylinders, joining both inlets/outlets thereof with the valve body through a rigid conduit. If there is a breakage at that point of the cycle, the cylinders are blocked with the full effective hydraulic load holding the work sheet.

[0030] During the deep-drawing cycle a precise control of the deformation speed is required, for which reason the high pressure pump of the hydraulic unit uses a fre-

quency variator that provides the possibility of calibrating the deformation along a wide range of mm/s.

[0031] The hydraulic cylinders may be adjusted to the work profile by means of guides integrated in the structural design of the machine itself. The movement thereof is manual, performed through the operator.

[0032] The hydroforming process is carried out with drinkable water extracted from the standard water system of the factory where the equipment is installed. The prior deep-drawing process followed by the hydroforming process makes the employment of a lubricant emulsion necessary. At the beginning of the process the emulsion is sprayed - a water soluble dissolution of the lubricant - over the male and female portions of the die, after the deep-drawing, the hydroforming process starts using the same dissolved lubricant fluid. The pump that pressurises the fluid and therefore, the one that enables the hydroforming is the same that finely sprays the fluid over the die to ensure the lubrication of the dies along with the work sheet metal. When the hydroforming cycle ends, a high amount of the fluid used both for the deep-drawing and for the hydroforming - it is the same - is recovered, the recovery percentage of which ranges between 97 and 98 %.

[0033] The die for the prior deep-drawing, as can be seen in figure 5, is made up of the following elements:

- Holder for the male (2) and female (3) portions of the die so as to enable an inexpensive design at the manufacturing level. The die holders manufacturing process is based on an assembly of laser-cut, thin sheets made of low alloy carbon steel (21, 31), that are assembled by means of bolts, the bores of which having already been cut in the sheet metal itself.
- Rear fixed centring devices (23, 33), ensuring a variation of no more than 0.1 mm in the relative position of the female (3) and the male (2) portions during the successive work cycles of the equipment. To this end, a series of centring devices are needed, which at the same time enable the male/female assembly to be rigidified in the deep-drawing process. In the rear position of the press - i.e. that which is not used to load and unload the same - fixed centring devices (23, 33) are used.
- Retractable fixed front centring devices. On the front portion of the press, where the loading and unloading of the finished parts is carried out, it is imperative to maximise the space left free between the male and the female portions of the deep-drawing die once the deep-drawing cycle has finished followed by the hydroforming cycle. That is why there is a set of elements arranged that firstly enable to centre the male with the female in this front portion of the die, and secondly, to create a wide hollow space through which the finished part can be extracted and the work sheet metal be loaded. The front centring assembly is made up of an equal number of bushings, a lower (24) and an upper (34) bushing, through which the

male of the centring device (35) passes driven by a pneumatic cylinder (36). This device enables the centring male (35) to extend and retract according to the work process.

- Given that the assembly of the male/female portions of the die is adjustable as their perimeter may be modified, there is the possibility to realise adjustments in the gap between both of them and consequently change the thickness of the workpiece (which as it has to pass therebetween it depends on the existing clearance between both of them) without thereby generating tears or cracks on the same. The adjustment motion of the perimeter is always in the radial direction taking as the centre the middle point between the symmetric faces of the die.
- Integrated lubrication system. The combination of a deep-drawing process with a hydroforming process makes it necessary to redesign the water pipeline of the simple hydroforming system. To this end, a network of integrated conduits is arranged on the die itself, which spray the lubricant fluid, - the same fluid that is later used for the hydroforming process, and is pressurised with the same pump -, thus avoiding cracking and tearing due to defects in the lubrication and at the same time a second pipeline and oil/water separators is no longer necessary.
- Centring devices of hydraulic cylinders. The large number of hydraulic cylinders as well as their elastic support on their upper portion may generate slight misalignments of the lower portion of the piston - the one resting against the die - with the female itself thereof. To avoid this drawback, 24 conical centring devices (37) are arranged, which force each of the cylinders to keep their position during the lowering, one cycle after the other.

[0034] The control equipment (7) is based on an assembly of programmable automatons, which regulate the entire process, avoiding overlapping processes, optimising the cycle timing and providing the process with a high safety by taking the responsibility for the equipment work away from the operator, whose function is just that of supervising and not acting on the same.

Claims

1. A hydroforming press with open die and integrated deep-drawing **comprising**:

- a modular structure, formed by a series of rings (51), vertically and equidistantly arranged, provided with notches (52, 53) wherein sheets (55) are coupled which join them together from above and from below thus determining a fixed and unequivocal position, before welding them together, whose inner hollow space, inside which the die and the actuating cylinders are positioned,

is delimited by both upper and lower beds (54), said structure only being open frontwards and rearwards;

- an open die (2, 3), located on a horizontal plane in an operating position inside the press, the female portion (3) of which has a central hollow space (32) in alignment with the contour that is intended to be created in the sheet metal (1), upon the die of which a plurality of hydraulic cylinders (6) operate, of which at least two of them also operate as actuator cylinders, in charge of lowering the die onto the part to be shaped, while all of them come into operation, moving and pressing the female portion (3) of said die against the sheet metal (1) placed on the male portion (2) of the die, before applying thereon the hydroforming hydraulic pressure, operating in the opposite direction;

- a series of hydraulic cylinders (6), with a stroke determined by the height of the deformation to be carried out, in charge of moving and pressing the sheet metal (1) against the male portion (2), or against the deep-drawing male (4) located on the male portion (2) of the die, applying against the sheet metal sufficient pressure for the prior hydroforming and/or deep-drawing of a peripheral area thereof;

- a deep-drawing male (4), on which the sheet metal (1) to be deformed is arranged, on which the female portion (3) of the open die falls and the pressure exerted against it by a series of peripheral hydraulic cylinders (6), which establish a fluid-tight seal on the periphery of the male portion (2) of the die, which is provided with a plurality of outlets for water under high pressure that cause an upwards bulging on the sheet metal (1), whose outer profile is determined by the inner hollow space (32) of the female portion (3) of the die and whose height is determined by the hydroforming time and pressure, which is controlled by means of proportional valves that facilitate the sheet metal (1) slippage through the central hollow space of the open die.

2. The hydroforming press with open die and integrated deep-drawing, according to claim 1, **characterised in that** the male (2) and female (3) portions of the die are adjustable, having a variable perimeter realising a movement of their portions in a radial direction, which enables the thickness of the workpiece to be changed without thereby generating tears or cracks thereon.

3. The hydroforming press with open die and integrated deep-drawing, according to the previous claims, **characterised in that** the die has a series of fixed rear centring devices (23, 33), which ensure a minimum variation in the relative position of the female

(3) and the male (2) portions during the successive work cycles of the equipment, and front retractable centring devices, which enable the creation of a wide hollow space through which the finished part can be extracted and the work sheet metal be loaded.

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4. The hydroforming press with open die and integrated deep-drawing, according to the previous claim, **characterised in that** the front centring devices are made up of an equal number of lower (24) and upper (34) bushings, through which a male (35) of the centring device passes driven by a pneumatic cylinder (36). 10
5. The hydroforming press with open die and integrated deep-drawing, according to the previous claims, **characterised in that** the female portion (3) of the die has on its top as many conical centring devices (37) as hydraulic cylinders (6) that are in alignment with them, which force each one of the cylinders to keep their position on their way down as they rest against the upper portion of the die. 15 20
6. The hydroforming press with open die and integrated deep-drawing, according to the previous claims, **characterised in that** the male/female portions of the die have a structure formed by an assembly of superimposed sheets that are assembled with bolts. 25

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Fig. 1

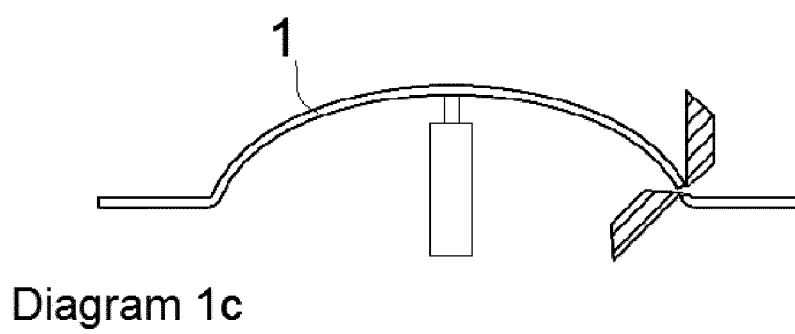
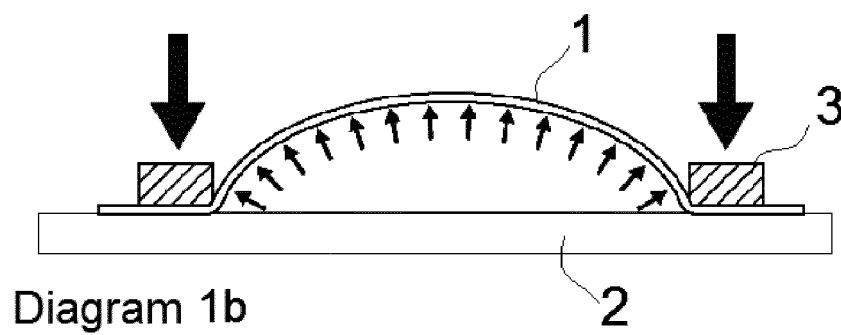
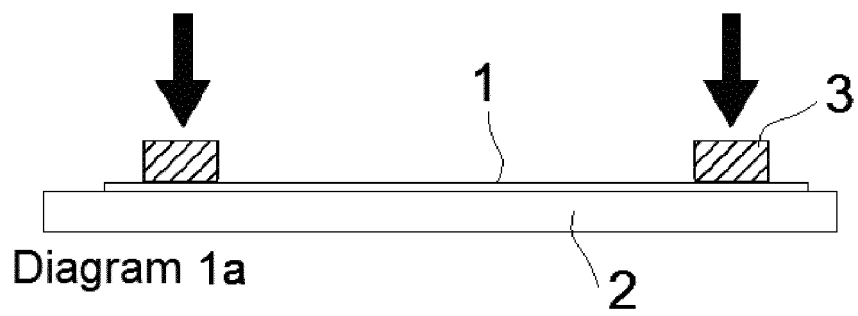


Fig. 2

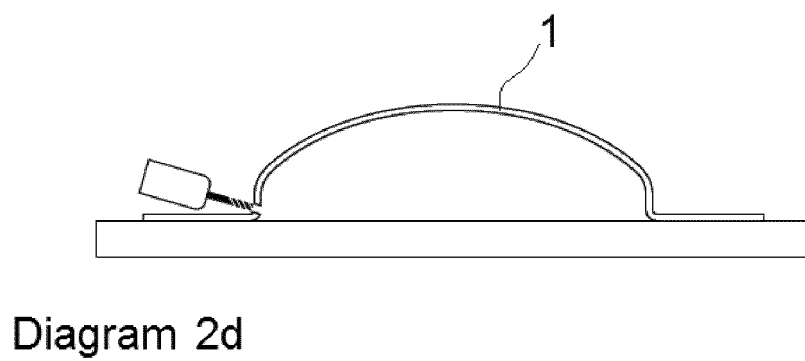
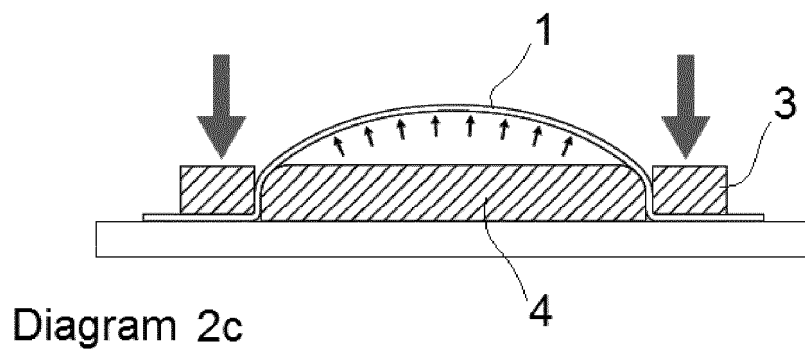
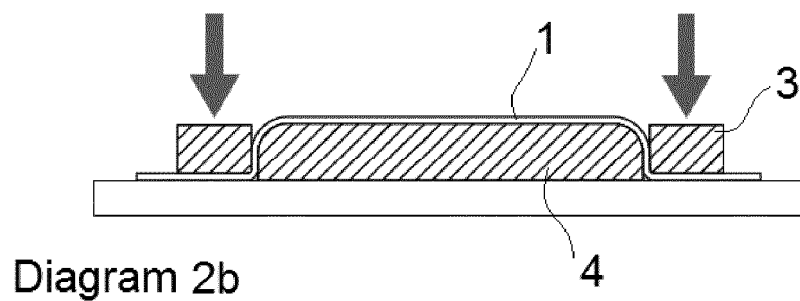
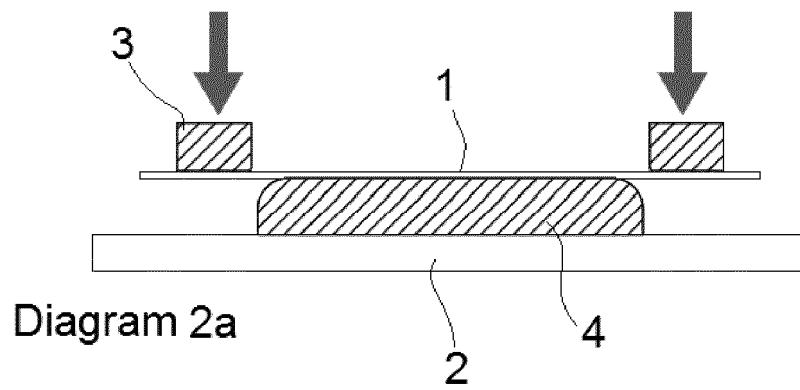


Fig. 3

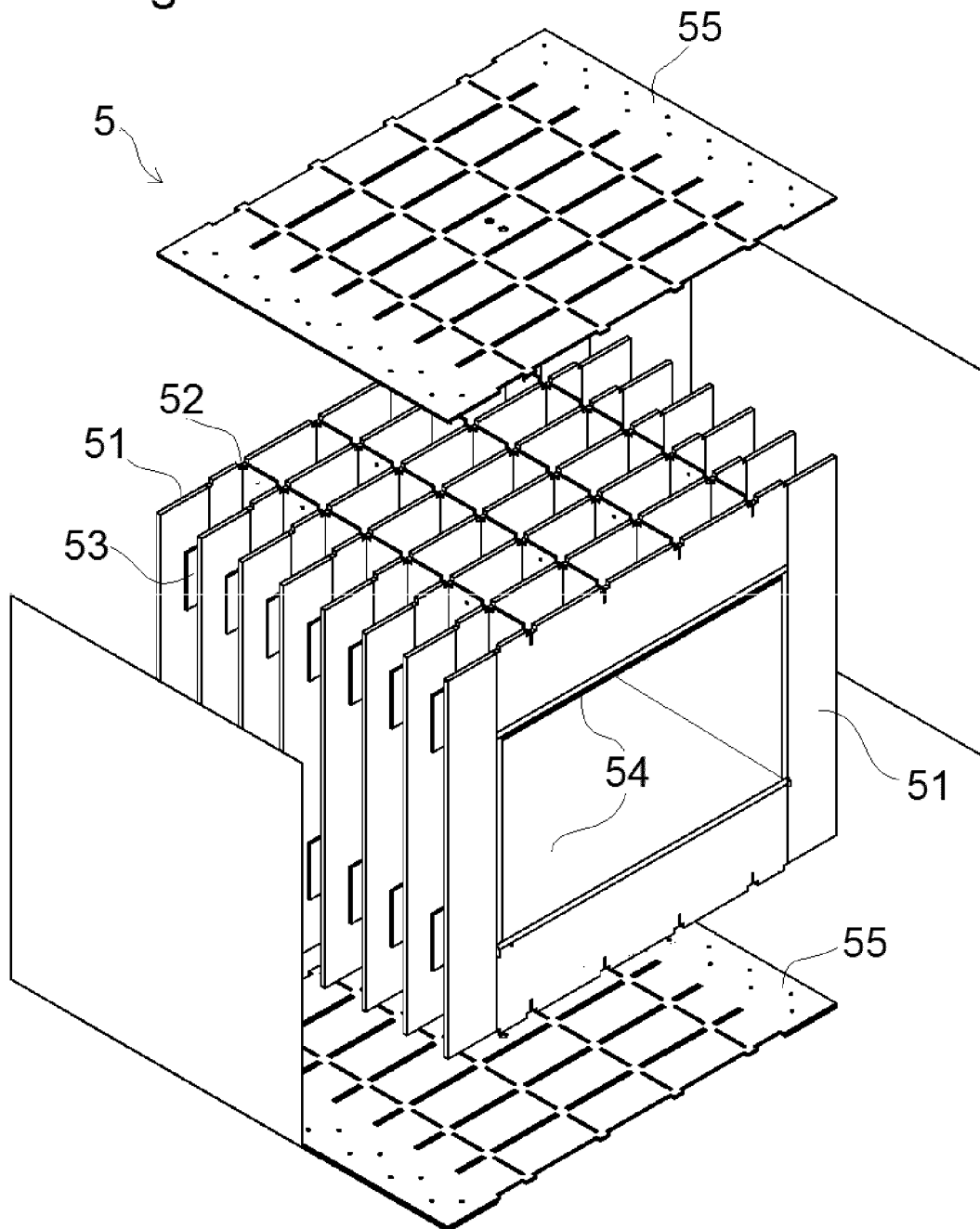


Fig. 4

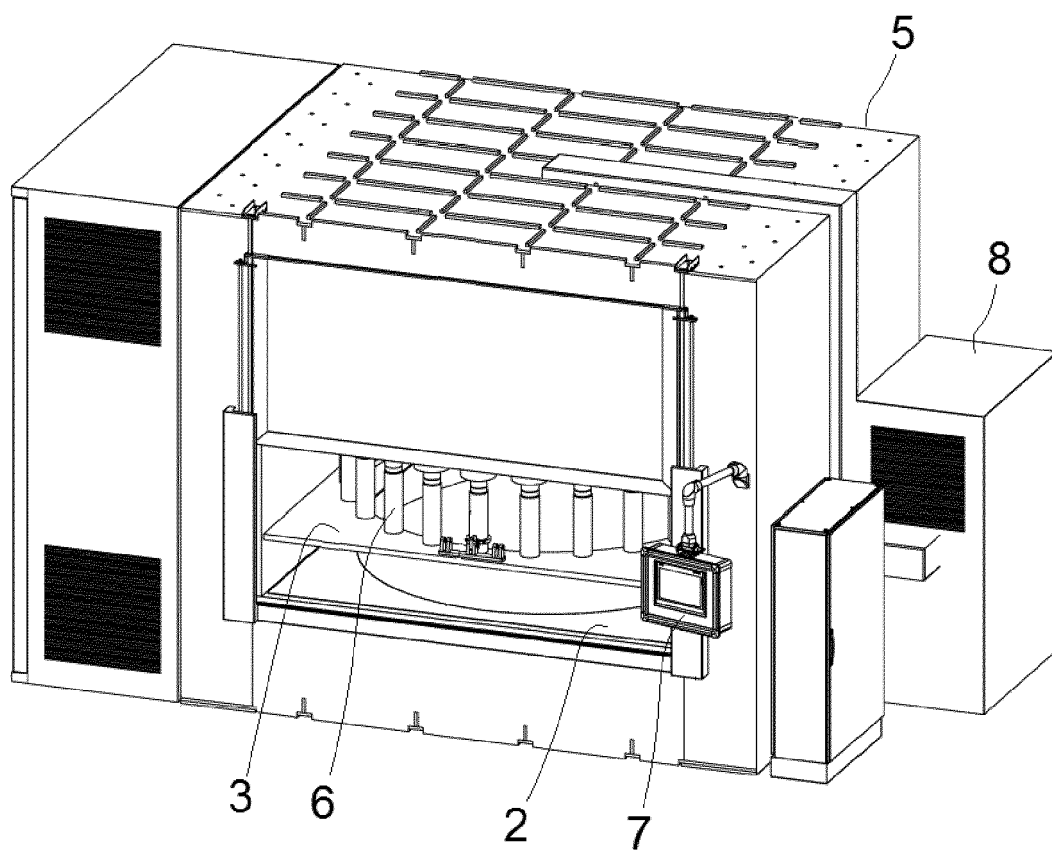
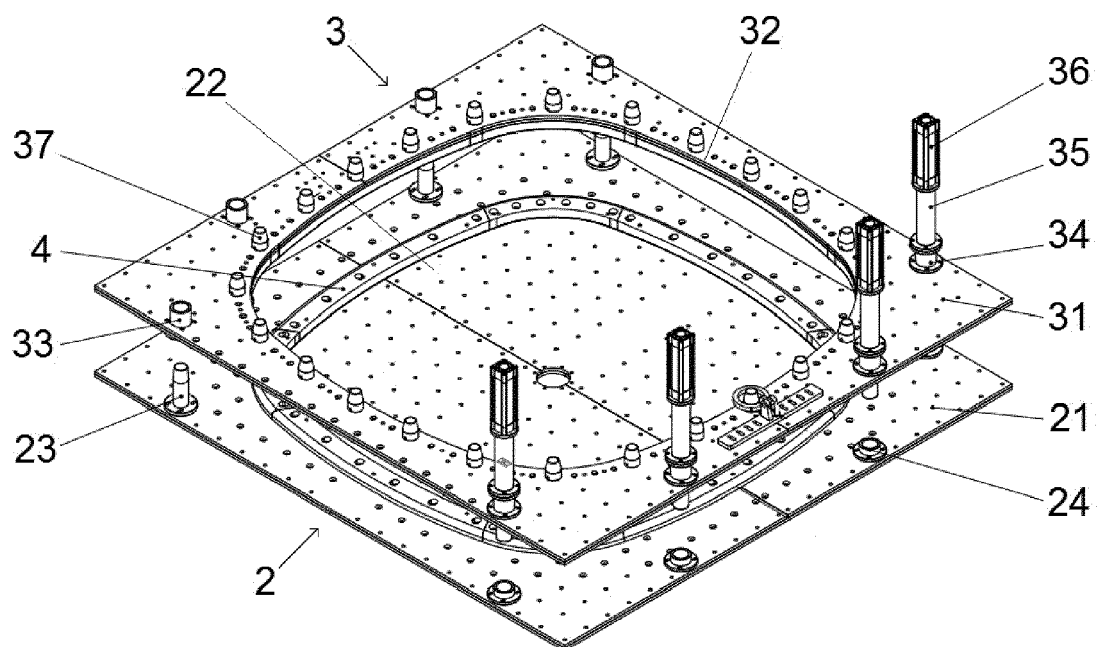


Fig. 5





EUROPEAN SEARCH REPORT

Application Number
EP 16 38 2134

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			B21D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 14 September 2016	Examiner Cano Palmero, A
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