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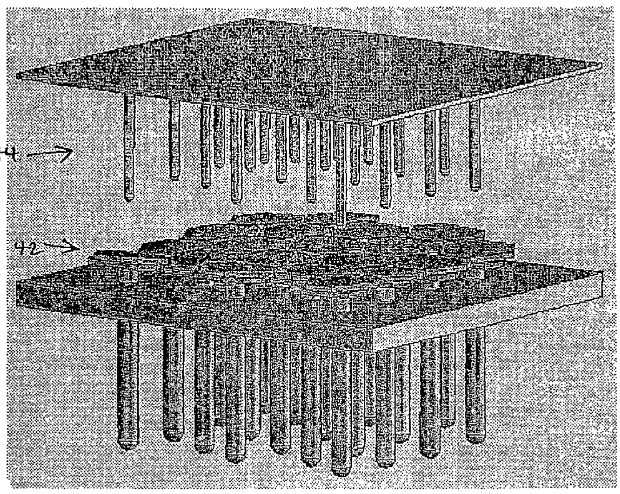
(54) Title: ACTIVE RECONFIGURABLE STRETCH FORMING



(57) Abstract: This invention concerns an active reconfigurable stretch forming tool, and in another aspect the invention is a method of stretch forming. The tool comprises an array of extensible shape forming elements which are driven in extension to produce the same force per unit area across a workpiece during shape forming. An array of limit switches are located in front of the array of shape forming elements, such that each shape forming element is driven in extension towards a respective limit switch during shape forming. In use, each limit switch is activated by the workpiece as it is shaped and each switch, upon activation, prevents further extension of the respective driven element. The tool and method are useful in the forming of three dimensional shapes in solid sheet metal or mesh, to produce panels for reflector antennas.

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Title

Active Reconfigurable Stretch Forming

Technical Field

In a first aspect the invention is an active reconfigurable stretch forming tool, and in another aspect the invention is a method of stretch forming. The tool and method are useful in the forming of three dimensional shapes in solid sheet metal or mesh, to produce panels for reflector antennas.

Background Art

The manufacture of accurate antenna panels remains one of the most difficult and labour intensive aspects of large-scale reflector antenna manufacture, and one that has a significant impact on antenna performance.

A number of methods have been employed in the manufacture of antenna panels. Some of these methods aim for high-accuracy construction at the expense of speed and cost, while others are more suited to mass manufacture of less accurate parts. Some of the more widely used methods are outlined below:

Bed of Bolts

The "bed of bolts" methods involves laying sheetmetal strips over an array of adjustable bolts attached to a large flat table. The bolts are adjusted in height to represent the curvature required.

Strips of sheetmetal sufficiently narrow to take the required curvature with only elastic deformation are laid across the tops of the bolts and are then pulled down by vacuum bagging. Whilst the strips are held in shape by a modest vacuum, a rigid backing structure is bonded to the open side, to hold the strips permanently in the formed shape.

While this method produces highly accurate panels of any desired shape, the presence of elastic deformation stresses in the material requires a closely spaced array of backing members to hold the panel in shape. The vacuum used to hold the panel can lead to shallow regularly spaced dimples between the bolts, and the regular spacing of the backing members has been known to cause periodic ripples. Both of these issues have caused problems with antenna grating lobes. The Bed of Bolts method is described more fully in CSIRO's patent for rapidly setting the heights of the adjustable bolts [1].

Press Forming

Press forming involves compressing a sheet of material between shaped dies. The material is deformed plastically so that it permanently retains the pressed shape. Depending on the shape being produced, the material may be either plastically stretched or compressed, or both, during forming. Some spring back or “recovery” occurs after the pressing forces are removed, so the shape of the forming dies is not necessarily the same as the shape of the completed panel.

Forming an accurate shape free from wrinkles and buckles is complex and may involve a large number of iterations to the shape and details of the forming dies. The dies are typically made from hardened tool steel, are large and expensive, and may only produce one shape each. Large presses up to many hundreds of tonnes in capacity are required to operate the dies. However, once the dies have been proven, production of repetition parts is extremely fast.

Hydroforming

Hydroforming involves stretching a flat panel into a shaped die under hydraulic pressure. The material then retains the shape of the die. Like press forming, the material will recover to some degree after forming. The hydroforming process for manufacture of antenna dishes has been put to commercial use by Anderson Manufacturing Inc. in the United States.

Hydroforming dies are large, but simple in comparison to press form dies, and may be made from soft materials or backed with polymer filling compounds to simplify shaping. No large press is required. Extremely large panels may be produced, but the die, once corrected and proven, will only produce parts of one shape, and variations in the properties of the workpiece material may affect the repeatability of the recovery after forming.

Recent efforts in the United States aimed at developing antenna solutions for radioastronomy have resulted in the successful hydroforming of numerous 6 metre dishes for the Allan Telescope Array, and investigations into hydroforming reflectors with a diameter of 12 metres are continuing.

Stretch Forming

The term Stretch Forming covers a number of areas of metal forming, from the shaping of curved beams to the shaping of panels for aircraft and automotive bodies. Like press forming and hydroforming, a shaped die or stretch form tool is required.

In the case of stretch forming of sheet material, the sheet is strongly gripped along two opposing edges and supported above a shaped form block. The form block is then driven up underneath the tightly stretched sheet (or the grippers move downwards), until the shape of the form tool is reproduced in the material, in a manner similar to stretching a sheet of thin rubber over, say, a football. This is illustrated in Fig. 1. In Fig. 1(a) a sheet of material is shown gripped above a form block for stretching. In Fig. 1(b) stretching load is applied by the grippers and the form block is moved relative to the sheet to the point of contact. In Fig. 1(c) forming is complete.

The simultaneous application of stretching and forming forces significantly reduces, and can almost eliminate, the shape recovery of the material after forming. The mechanism through which this is achieved is illustrated in Fig. 2.

In Fig. 2(a), a piece of material has been deformed by application of a bending load. Tensile and compressive stresses are generated within the material as it is bent. These stresses increase in magnitude towards the outside faces of the material and there is a neutral axis in the centre where no tensile or compressive stresses exist.

All materials will recover elastically to some degree after plastic deformation, in a direction opposing that of the applied deformation stresses. In this case the uneven distribution of stresses will cause the material to straighten slightly after the bending load is removed, and the final curvature will be noticeably less than intended.

In Fig. 2b, the material has been both bent and stretched along its own axis. If the stretching load is sufficient to cause yielding or slight plastic deformation in this direction, the stresses within the material will change to an even distribution of tensile stress. Later, when the stretching load is removed, the elastic recovery occurs along the centreline of the material, with little or no change in overall shape.

An hydraulically powered machine, called a stretch former, is used to carry out this process. It consists of a base or table on which the stretch form tool is mounted, and an array of grippers on two sides that hold the edges of the workpiece while it is being stretched over the form block. The grippers simultaneously apply a sufficiently large stretching load to cause the workpiece material to yield across its full width. Stretch formers are relatively common in industrial use.

Stretch forming has traditionally been performed over solid form blocks, made from metal, hard plastics and occasionally wood where shapes are modest and accuracy is not critical.

Stretch forming is a fairly fast process, but the need for manufactured form tools and the limitations imposed by form blocks with fixed shapes, have prompted development of reconfigurable tools consisting of an array of adjustable elements that can be set to form an approximation to a continuous curved surface, in a manner similar to the Bed of Bolts described above.

A representation of a reconfigurable stretch form tool with a 6 x 6 array of adjustable elements is shown in Fig. 3. In practice the elements are typically domed on their working faces, rather than flat-ended as shown.

As the surface of the reconfigurable form block is composed of individual facets rather than a continuous surface, a layer of conformable material such as a sheet of polymer rubber is laid over the top of the form tool to prevent dimpling of the workpiece. This layer is known as an interpolator.

A number of papers have been published detailing the development and application of this technique to the manufacture of repair parts for aircraft, from both sheet metal and composite materials. [2], [3], [4].

Of these papers, [2] and [3] discuss aspects of the actuation and control of the elements of a reconfigurable stretch form tool, using 2688 individual moveable elements with servo motor and lead screw control, to set the positions of the adjustable elements before locking them into place and using the tool as a conventional fixed form tool. A number of patents exist covering aspects of construction and control of this type of system. [5], [6], [7], [8].

In [4], Walczyk notes that where composite materials are concerned, automatic lay-up machines can be used to prepare composite parts over the top of reconfigurable tools in the flat state, with subsequent active driving of the reconfigurable tool from below the part to form the required curvature.

A number of drawbacks are apparent in these methods:

Where large tools with many elements are concerned, the task of controlling thousands of individual elements is difficult. Each element is subject to a proportion of the total force applied by the stretch forming machine, so the elements must be robust or they are likely to be unreliable in positioning or repeatability.

Where panels of non-uniform curvature are involved, the effective pressure between the interpolator and the workpiece material can vary, resulting in differing degrees of compression of the interpolator over the top of the form tool elements. This results in a departure of the shape of the formed part from the nominal surface defined by the tool elements.

And lastly, as the entire forming load is supported by the structure of the form tool and its elements, any deformation of the tool structure under load will be replicated in the shape of the workpiece.

Disclosure of the Invention

A first aspect of the invention is an active reconfigurable stretch forming tool for forming a three dimensional shape in a solid sheet metal or mesh workpiece, to produce a panel for a reflector antenna. The tool comprises:

An array of extensible shape forming elements which are driven in extension to produce the same force per unit area across a workpiece during shape forming.

And an array of limit switches located in front of the array of shape forming elements, such that each shape forming element is driven in extension towards a respective limit switch during shape forming.

Wherein, in use, each limit switch is activated by the workpiece as it is shaped and each switch, upon activation, prevents further extension of the respective driven element.

The array of limit switches defines the shape to be imparted to the workpiece. The active reconfigurable tool achieves shape control of the workpiece by directly measuring the workpiece during shaping. The tool also permits variation of the shape produced, and facilitates correction of systematic shape-forming errors, such as deformation of the tool structure or compression of an interpolator. Further, the tool may incorporate shape-control feedback or error correction as shaping proceeds.

The tool may be used in a conventional industrial stretch forming machine, with no significant modifications to the machine's usual set-up or operation. For instance, the conventional opposing sets of workpiece grippers may be used.

The shape forming elements may comprise hydraulic cylinders and rams each of which is powered from a single hydraulic power supply. Since the hydraulically powered elements are connected via hydraulic lines to a single power supply, the hydraulic pressure in the cylinders will be equalised. This prevents any one cylinder causing localised excessive deformation of the workpiece.

Each ram may be surmounted by a tilting pad and each tilting pad may be interlocked with its adjacent pads to form a continuous articulated surface. As a result of using the tilted pads the array of elements may be sparse compared to a conventional reconfigurable stretch forming tool. The tilting pads may be provided with a spherical seat to fit spherical ends on the hydraulic cylinder rams.

An interpolator may be located on the articulated surface to receive the workpiece.

The rams will generally be arranged below the workpiece to produce concave workpieces. An extension of the invention is to place an array of rams both above and below the workpiece. This will allow the production of panels with both concave and convex curvature.

The limit switches may be aligned vertically over respective tilting pads. Other locations for the limit switches may be used, provided they can be actuated by the movement of the workpiece, interpolator, or ram, as the formation of the workpiece shape proceeds. Each switch may be connected to a simple solenoid valve in the hydraulic line leading to its respective cylinder. As the workpiece is shaped it will contact one or more of the limit switches, and as soon as this occurs the switch operates to close the solenoid valve and prevent further movement of the respective tilting pad.

The switches themselves may be simple On-Off mechanical switches. Alternatively, the switches may be constant-contact analogue devices, and they may be programmed or set to trigger at the appropriate height. As a result it may be possible to implement multi-staged forming, where a panel is formed to initial,-intermediate-final, or roughing-finishing stages. This graduated approach may be beneficial where deep shapes or high accuracy, or both, are required, by avoiding excessive stretching or the possibility of buckling in any one stage.

To further approximate a continuously curved surface the shaping surfaces of the tilting pads may be formed with a spherical radius approximating the curvature of the required panel.

A number of sets of tilting pads with a range of spherical radii may be provided for the tool. Alternatively, the top of each tilting pad could be made flat, with provision for clipping inserts of varying spherical radius into place.

Where an individual panel has areas of high and low curvature, a set of pads with appropriate incrementally different radii could be clipped to the stretch form tool to accommodate such variations.

Another aspect of the invention is a method for forming three dimensional shapes in a solid sheet metal or mesh workpiece, to produce a panel for a large reflector antenna. The method comprises:

Stretching a metal workpiece in a flat state in front of an array of extensible shape forming elements.

Driving each shape forming element of the array in extension to produce the same force per unit area across the workpiece, to form a shape in the workpiece.

Extending each shape forming element towards a respective limit switch during shape forming until the workpiece activates the limit switch.

Preventing further extension of a shape forming element upon activation of the respective limit switch.

Unlike other implementations of reconfigurable stretch forming tools, simultaneous position control of very large numbers of driven elements is not required. In this invention the shape forming elements are driven to produce the same force per unit area across the workpiece, and the distribution of power and the element positions during stretching is controlled by the natural behaviour of the workpiece material.

The shape forming elements may comprise hydraulic rams, and the method may produce panels of any curvature within the travel available in the hydraulic rams.

The final position of the shape forming elements, and therefore the panel shape, though accurately controlled by the array of limit switches, is "dumb" and requires no active intervention by a control system. It is anticipated that the setting of the limit switch array will be performed according to the method described in [1].

Variations between measured and theoretical panel shapes may be accommodated in the settings of the limit switch array. If the limit switch array is also used for shape measurement, it may be possible to implement an automatic process with closed-loop shape control.

Using the invention, large sections of panel may be formed from one piece of material, eliminating the time and labour involved in laying up the numerous individual strips required by the bed of bolts method.

The use of one-piece panels rigidly formed to an accurate shape eliminates the need for multiple pre-formed backing ribs to hold the panel's shape, and the need for the ribs to be aligned with the joints between individual strips. This will allow the backing structure to be designed for stiffness and economy without constraints imposed by the layout or curvature of the panel.

The method makes use of existing metal forming machinery and techniques, off the shelf parts, and a simple control system.

The method proposed offers significant improvements in terms of cost and versatility while maintaining equivalent surface accuracy to the best methods currently available.

Brief Description of the Drawings

The prior art has been described above with reference the following drawings in which:

Fig. 1 is a series of schematic diagram illustrating stretch forming. In Fig. 1(a) a sheet of material is shown gripped above a form block for stretching. In Fig. 1(b) stretching load is applied by the grippers and the form block is moved relative to the sheet, to the point of contact. In Fig. 1(c) forming is complete.

Fig. 2(a) is a diagram showing the distribution of tensile and compressive stresses during bending of a piece of material.

Fig. 2(b) is a diagram showing the distribution of tensile-only stresses during stretch forming.

Fig. 3 is a diagram showing a reconfigurable stretch-form tool with a 6 x 6 array of adjustable elements.

An example of the invention will now be described with reference to the following drawings, in which:

Fig. 4 is a series of diagrams illustrating the principle of operation of an active stretch forming tool. Fig. 4(a) shows a reconfigurable stretch tool in an industrial stretch forming machine before stretching commences Fig. 4(b) shows the reconfigurable stretch tool at an intermediate point of stretching. Fig. 4(c) shows the tool when stretching is completed.

Fig. 5(a) is a diagram showing a tilting pad for the tool of Fig. 4. Fig. 5(b) is the pad of Fig. 5(a) inverted.

Fig. 6 is a diagram showing three interlocking pads forming an articulated surface.

Fig. 7(a) illustrates a model of an array of rams and tilting pads below an array of stops. Fig. 7(b) shows how the array of pads tilt and orient to form the curve defined by the stops when they are brought into contact with each other.

Best Modes of the Invention

Referring now to Fig. 4(a) reconfigurable stretch forming tool 10 involves a sparsely populated array of elements 12. Each element 12 comprises an hydraulic cylinder 14 all of which are powered from a single hydraulic power supply 16. An hydraulic ram 18 may be driven upwards by each cylinder 14. The tool may be used in a conventional industrial stretch forming machine, with no significant modifications to the machine's usual set-up or operation.

The span between elements 12 is much larger than that in the reconfigurable tools previously described, and each ram 18 is surmounted by a tilting pad 20. Each tilting pad 20 is interlocked with its adjacent pads to form a continuous articulated surface indicated generally at 22. A polymer interpolator 24 is placed between the pads 20 and the workpiece 26 which is held by grippers 28 and 30.

Rather than providing a fixed, pre-set surface over which a sheet or workpiece material is stretched, as in a stretch forming machine, the material 26 is held stretched in the flat state while the rams 18 of the reconfigurable tool are driven upwards, so forming a three dimensional shape in the panel.

The hydraulically powered elements 12 are not individually controlled. As they are connected via hydraulic lines to a single power supply 16, the hydraulic pressure in the cylinders will be equalised. This prevents any one cylinder causing localised excessive deformation of the workpiece 26.

Above the workpiece 26 is suspended an array of limit switches 32, aligned vertically over each active element 12. Each switch 32 is connected to a simple solenoid valve 34 in the hydraulic line leading to its relevant cylinder 14. The switches 32 themselves may be simple On-Off mechanical limit switches of the types often used in industrial machinery, where switching occurs on contact. Alternatively, the switches may be constant-contact analogue devices like linear voltage differential transducers (LVDTs), programmed or set to trigger at the appropriate height.

If such a programmable device is used in place of an On-Off switch, it may be possible to implement multi-staged forming, where a panel is formed to initial,-intermediate-final, or roughing-finishing stages. This graduated approach may be beneficial where deep shapes or high accuracy, or both, are required, by avoiding excessive stretching or the possibility of buckling in any one stage.

As the workpiece 26 rises, areas of the workpiece will make contact with some of the limit switches 32, as shown in Fig. 4(b), closing off the solenoid valve for the cylinder at that point and preventing further movement. When all the solenoid valves have been closed in this way, as shown in Fig. 4(c), the forming process is complete.

Final stretching of the workpiece after all active elements have contacted their respective limit switches, will equalise internal stresses within the workpiece material, and ensure that its formed shape is retained after relaxation of all forming forces, and removal of the workpiece from the stretch forming machine.

The positions of the array of limit switches defines the shape of the workpiece that will be produced. It is anticipated that the setting of the limit switch array will be performed according to the method described in [1].

Tooling Details.

The array of tilting pads 20 used on the ends of the hydraulic cylinder rams 18, interlock with each other. In this way a continuous articulated forming surface 22 is created. The interpolator sits on the relatively continuous surface 22, and the combined effect is to prevent localised high-spots that could dimple the workpiece 26 between points measured by the limit switch array.

The tilting pads 20 are provided with a spherical seat 36 on one side to fit spherical ends 38 on the hydraulic cylinder rams 18. A simple wire circlip can be used to retain the pads on the rams after forming, when the hydraulic cylinders retract to their rest position.

To further approximate a continuously curved surface and to assist the interpolator 24 to produce smooth workpiece curvature, the upper surfaces of the tilting pads 20 are formed with a spherical radius approximating the curvature of the required panel.

If the range of panels to be stretch formed requires widely varying radii of curvature, a number of sets of tilting pads with a range of spherical radii, differing by, say, 1m increments, could be fitted to the tool as required.

Alternately, the top of each tilting pad could be made flat, with provision for clipping inserts of varying spherical radius into place.

Where an individual panel has areas of high and low curvature, a set of pads with appropriate incrementally different radii could be clipped to the stretch form tool to accommodate such variations.

Fig. 5 shows a possible design of tilting pad 20, and illustrates the features 38 and 40 that interlock with adjacent pads to form an articulated surface, and the socket for mounting the pad on the hydraulic ram. Fig. 6 illustrates the interlocking of a number of pads 20.

Fig. 7(a) illustrates a model of an array of rams and tilting pads 42 below an array of stops 44. Fig. 7(b) shows how the array of pads 42 tilt and orient to form the curve defined by the stops 44 when they are brought into contact with each other.

Stresses developed in reconfigurable tools.

In one example, an antenna of 15m diameter with an f/d of 0.4 gives a focal length of 6m. As a the minimum instantaneous radius of a parabola equals twice the focal length, it is necessary to stretch form of a section of a spherical surface with a radius of 12m, from aluminium sheet with a thickness of 1.2mm. The material considered is grade 5005-H34, which has a yield stress of 138 MPa [9].

This stretch forming process is analogous to hydroforming, where hydraulic pressure is used to deform a flat sheet. If allowed to proceed unrestrained, both processes will tend to produce a spherical radius. As the tensile stresses in the wall of a spherical vessel subject to internal hydraulic pressure are equal in all directions, and the tensile stresses are proportional to the pressure, treatment of stretch forming as a hydraulic pressure problem is sufficiently valid to check the viability of the proposed stretch forming process.

In this case, the yield stresses generated in the workpiece by the stretch forming grippers are equivalent to the tensile stresses in the walls of a pressure vessel. Therefore the contact pressure on any of the tilting pads is equivalent to the internal pressure in a vessel of the same radius with the same tensile wall stress.

Tensile stress in a thin-walled spherical pressure vessel equals:

$$f = Pr/2t$$

Where:

f =stress (MPa);

P = internal pressure (MPa);

r = radius of vessel (m) and

t = wall thickness (m).

For a vessel of radius 12m, with a wall thickness of 1.2mm and a tensile wall stress of 138 MPa, the equivalent internal pressure is therefore 0.276 MPa. This is the nominal surface pressure that would be present on a tilting pad to stretch form a panel to a radius of 12m.

A model of a possible tilting pad design subject to this load was studied using a linear mechanical finite element analysis package, COSMOSXpress, and the results show the maximum stress developed in this part is approximately 8.5 MPa. If the pad is made from mild steel with a yield stress of 250 MPa, this represents a factor of safety in the design of at least 29.

The load carried by the tilting pad will also be supported by the hydraulic cylinder. If a cylinder with a piston diameter of 75mm is assumed, the hydraulic pressure required can be found.

The pressure load of 0.276 MPa on the top of the tilting pad, together with the top face area, 0.019m2, indicates a normal load on one ram of 5.25 kN. The hydraulic pressure necessary to produce this load on a 75 mm piston is 1.19 MPa. When allowances for losses are considered, a minimum system pressure of approximately 2.5 MPa is required. Industrial hydraulic systems built from off-the-shelf parts typically operate at system pressures ranging from 20 MPa to 60 MPa, so the hydraulic pressure requirements are very modest.

Another area considered was the bending stress applied laterally to the rams of the hydraulic cylinders by frictional resistance as the workpiece and or interpolator slides across the tops of the pads during stretching. It is anticipated that the interpolator would be a type of urethane rubber. These materials are available in a wide range of compounds with varying degrees of hardness. Manufacturers of polyurethanes for coatings on conveyer rollers claim the coefficient of friction (μ) for these materials can be tailored to suit the application, with $\mu = 0.4$ being a minimum value.

To cover all eventualities, a worst case coefficient of friction of $\mu = 1.0$ was assumed, as was a cylinder ram with a diameter of 50mm, cantilevered with a free length of 250mm.

As before, an axial load on one tilting pad of 5.25 kN is assumed. When $\mu = 1.0$, the lateral load at the tip of the ram will also be 5.25 kN, applied simultaneously with the axial cylinder load. Analysis of a model representing an allow steel ram from a hydraulic cylinder under this combined load gives a factor of safety around 6. Whilst the factor of safety in the ram is lower than that in the tilting pad, this brief analysis demonstrates that the stresses generated in the major components of a tool to implement this concept are modest, and that implementation is feasible. Optimisation of the design and selection of appropriate hydraulic components will lead to a reliable a robust system.

References

[1] US Patent 5,976,287 "Method and Apparatus of Stud Array Upstand Setting", Parsons, Barker, Yabsley, Kesteven, Bird, Harrigan. November 2 1999.

[2] Daniel F. Walczyk, Yong-Tai Im, Rensselaer Polytechnic Institute, "Hydraulically-Actuated Reconfigurable Tool for Flexible Fabrication: Implementation and Control". Transactions of the American Society of Mechanical Engineers, Volume 122, pp562-568. August 2002.

[3] John M. Papazian, Northrop Grumman Corporation, "Tools of Change", Mechanical Engineering Online Magazine, American Society of Mechanical Engineers, February 2002.

[4] Daniel F. Walczyk, Jean F. Hosford, Rensselaer Polytechnic Institute, John M. Papazian, Northrop Grumman Corporation. "Using Reconfigurable Tooling and Surface Heating for Incremental Forming of Composite Aircraft Parts". Journal of Manufacturing Science and Engineering, Volume 125, pp 333-343, May 2003.

[5] US Patent 6,012,314 "Individual Motor Pin Module", Sullivan et al, January 11 2000

[6] US Patent 6,053.026 "Block Set Form Die Assembly", Nardiello et al, April 25 2000

[7] US Patent 6,089,061 "Modularised Reconfigurable Heated Forming Tool", Haas et al, July 18 2000

[8] US Patent 6,578,399 "Single Die Modularised Reconfigurable Honeycomb Core Forming Tool", Haas et al, June 17 2003

[9] http://www.matweb.com/index.asp?ckck=1 Accessed September 2005.

Although the invention has been described with reference to a particular example, it will be understood that it may be extended to place an array of rams is both above and below the workpiece. This will allow the production of panels with both concave and convex curvature. Alternatively, the invention may also be used with designs that locate panel joints along lines of inflection between concave and convex areas.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

Claims

1. An active reconfigurable stretch forming tool for forming a three dimensional shape in a solid sheet metal or mesh workpiece, to produce a panel for a reflector antenna; the tool comprising:

an array of extensible shape forming elements which are driven in extension to produce the same force per unit area across a workpiece during shape forming; and,

an array of limit switches located in front of the array of shape forming elements, such that each shape forming element is driven in extension towards a respective limit switch during shape forming;

wherein, in use, each limit switch is activated by the workpiece as it is shaped and each switch, upon activation, prevents further extension of the respective driven element.

2. An active reconfigurable stretch forming tool according to claim 1, wherein, the array of limit switches defines the shape to be imparted to the workpiece.

3. An active reconfigurable stretch forming tool according to claim 1 or 2, wherein, the tool incorporates shape-control feedback or error correction as shaping proceeds.

4. An active reconfigurable stretch forming tool according to claim 1, 2 or 3 wherein the shape forming elements comprise hydraulic cylinders and rams each of which is powered from a single hydraulic power supply.

5. An active reconfigurable stretch forming tool according to claim 4, wherein each ram is surmounted by a tilting pad and each tilting pad is interlocked with its adjacent pads to form a continuous articulated surface.

6. An active reconfigurable stretch forming tool according to claim 5, wherein the tilting pads are provided with a spherical seat to fit spherical ends on the hydraulic cylinder rams.

7. An active reconfigurable stretch forming tool according to any preceding claim, wherein an interpolator is located on the articulated surface to receive the workpiece.

8. An active reconfigurable stretch forming tool according to any one of claims 4 to 7, wherein the rams are arranged below the workpiece to produce concave workpieces.

9. An active reconfigurable stretch forming tool according to any one of claims 4 to 8, wherein there is an array of rams both above and below the workpiece.

10. An active reconfigurable stretch forming tool according to claim 5, wherein the limit switches are aligned vertically over respective tilting pads.

11. An active reconfigurable stretch forming tool according to any preceding claim, wherein each limit switch is connected to a simple solenoid valve in the hydraulic line leading to its respective cylinder such that, as the workpiece is shaped it will contact one or more of the limit switches, and as soon as this occurs the switch operates to close the solenoid valve and prevent further movement of the respective tilting pad.

12. An active reconfigurable stretch forming tool according to any preceding claim, wherein the limit switches are constant-contact analogue devices.

13. An active reconfigurable stretch forming tool according to claim 12, wherein, the limit switches are programmed or set to trigger at a predetermined height.

14. An active reconfigurable stretch forming tool according to any one of claims 4 to 13, wherein the shaping surfaces of the tilting pads are formed with a spherical radius approximating the curvature of the required panel.

15. An active reconfigurable stretch forming tool according to claim 14 wherein a number of sets of tilting pads with a range of spherical radii are provided for the tool.

16. An active reconfigurable stretch forming tool according to claim 14 wherein the top of each tilting pad is made flat, with provision for clipping inserts of varying spherical radius into place.

17. A method for forming three dimensional shapes in a solid sheet metal or mesh workpiece, to produce a panel for a large reflector antenna, the method comprising:

stretching a metal workpiece in a flat state in front of an array of extensible shape forming elements;

driving each shape forming element of the array in extension to produce the same force per unit area across the workpiece, to form a shape in the workpiece;

extending each shape forming element towards a respective limit switch during shape forming until the workpiece activates the limit switch; and,

preventing further extension of a shape forming element upon activation of the respective limit switch.

18. A method according to claim 17, comprising the further step of applying shape-control feedback or error correction as shaping proceeds.

19. A method according to claim 17 or 18, wherein each limit switch is connected to a simple solenoid valve in the hydraulic line leading to its respective cylinder such that, as the workpiece is shaped it will contact one or more of the limit switches, and as soon as this occurs the switch operates to close the solenoid valve and prevent further movement of the respective tilting pad.

20. A method according to claim 17, 18 or 19, wherein, the limit switches are programmed or set to trigger at a predetermined height.

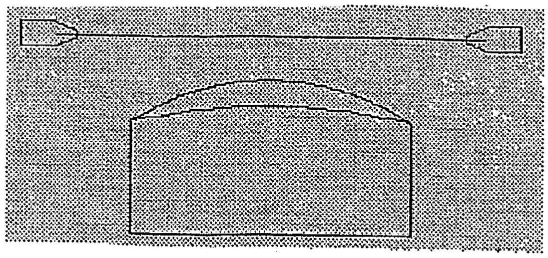

Fig. 1(a)

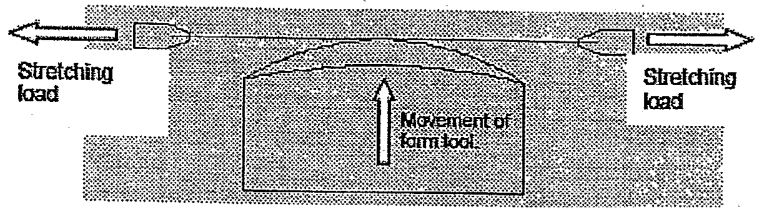

Fig. 1(b)

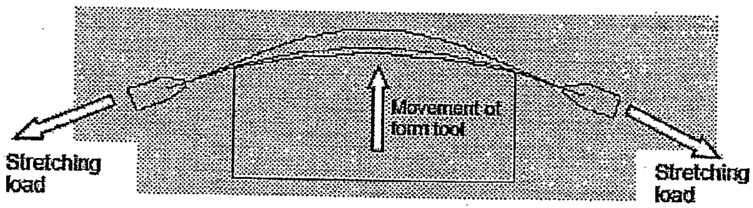

Fig. 1(c)

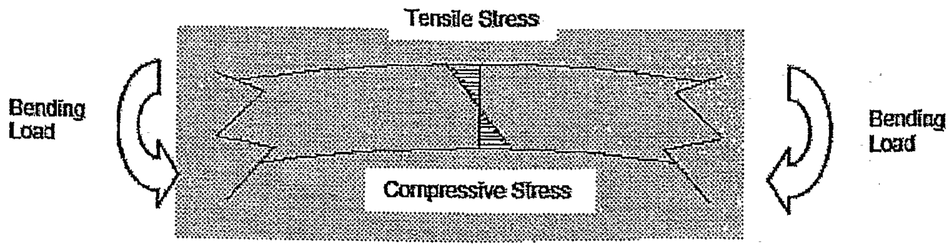
Tensile Stress
Bending Load
Bending Load
Compressive Stress

Fig. 2(a)

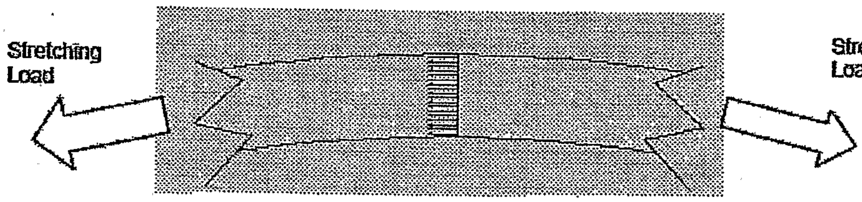
Stretching Load
Stretching Load

Fig. 2(b)

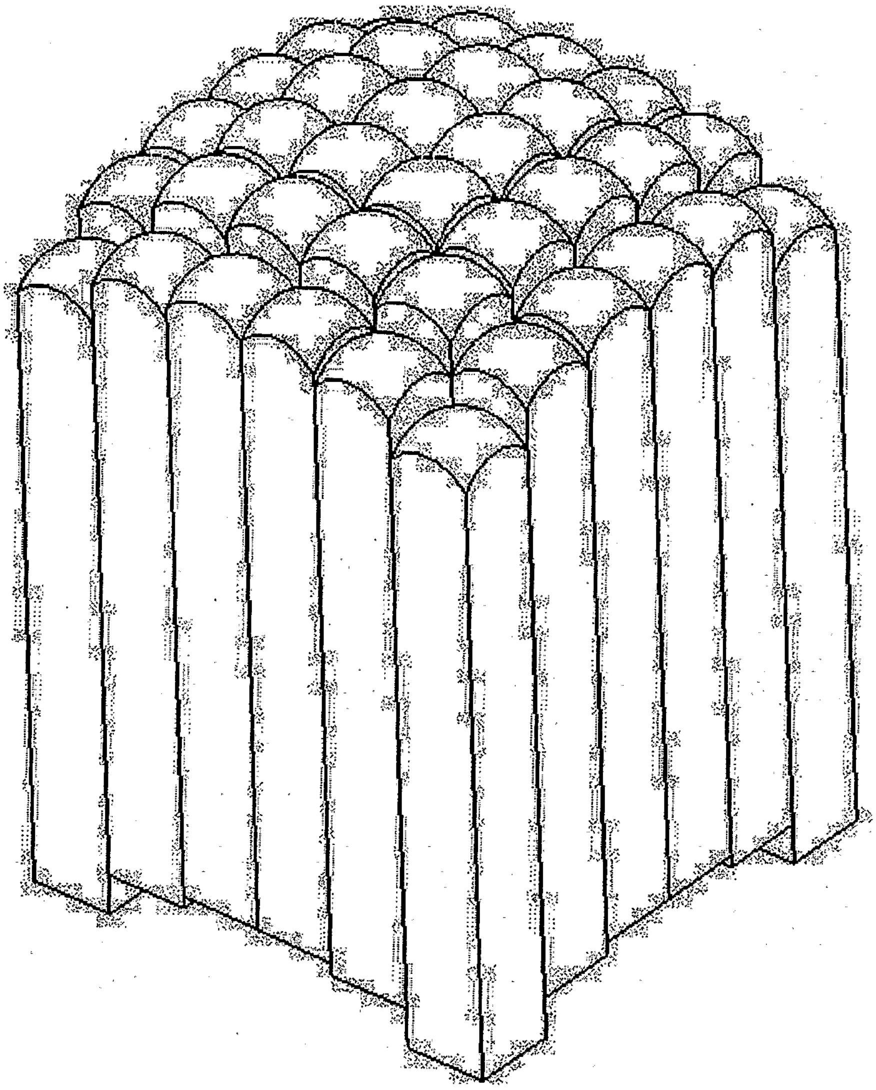

Fig. 3

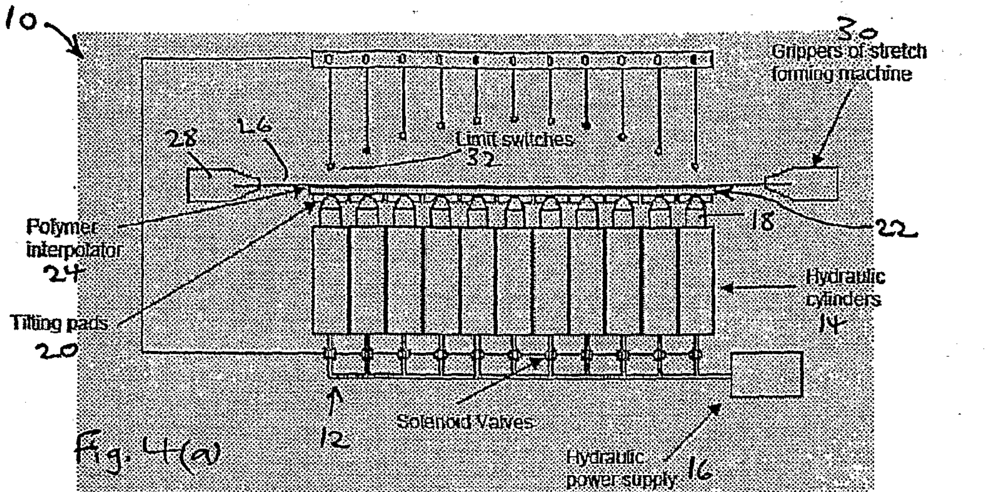

Fig. 4(a)

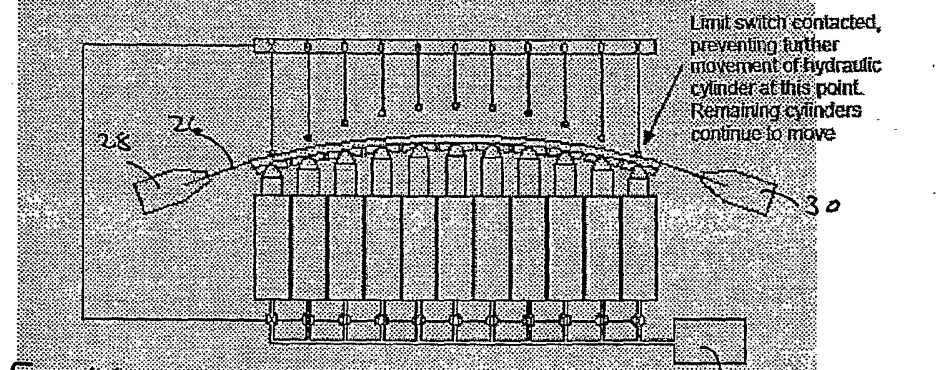

Fig. 4(b)

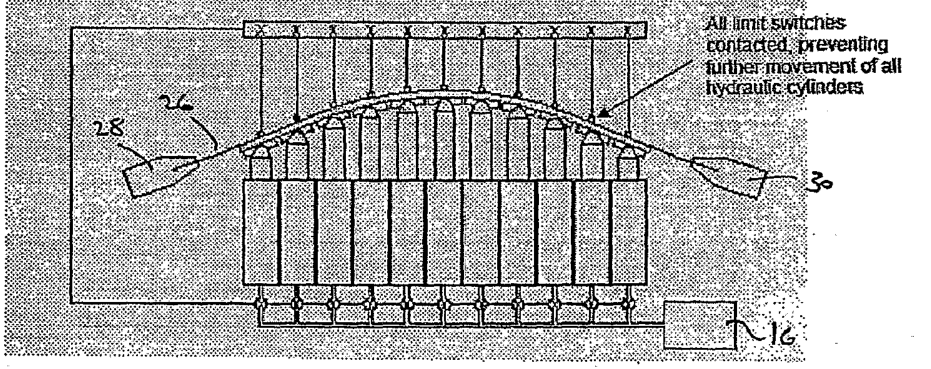

Fig. 4(c)

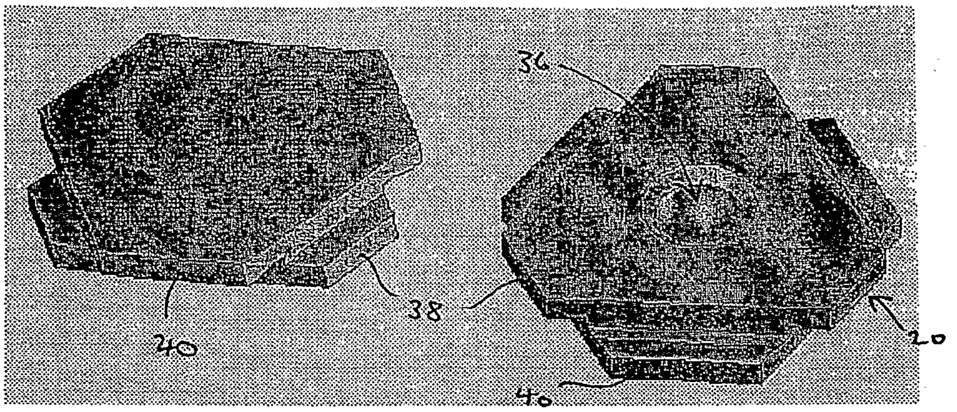

Fig. 5(a) Fig. 5(b)

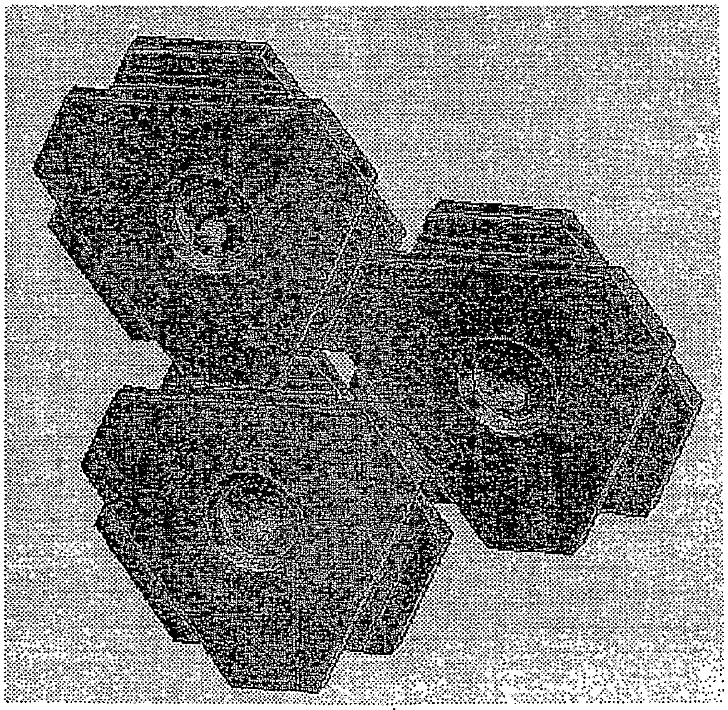

Fig. 6

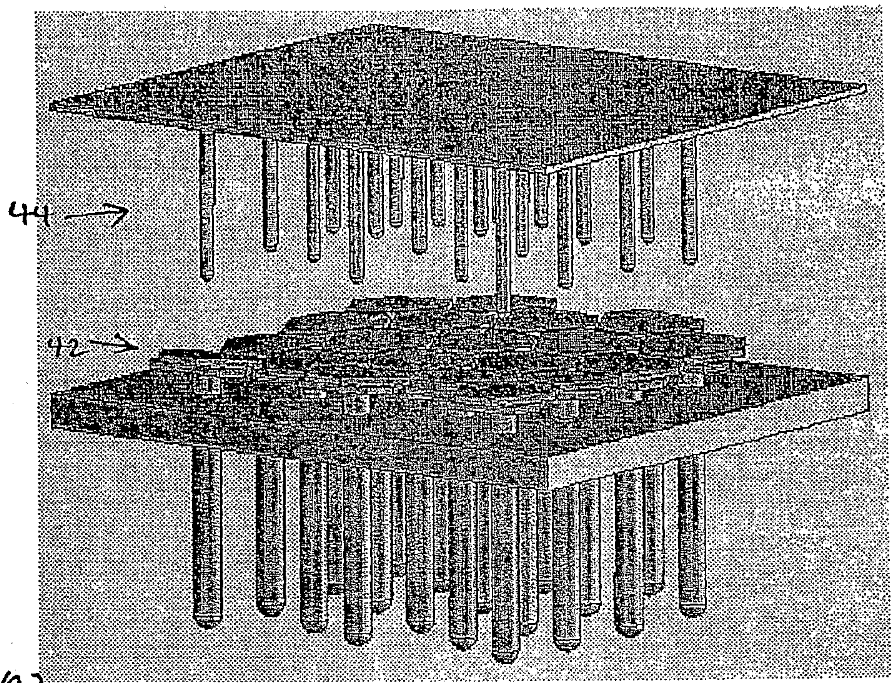

Fig. 7(a)

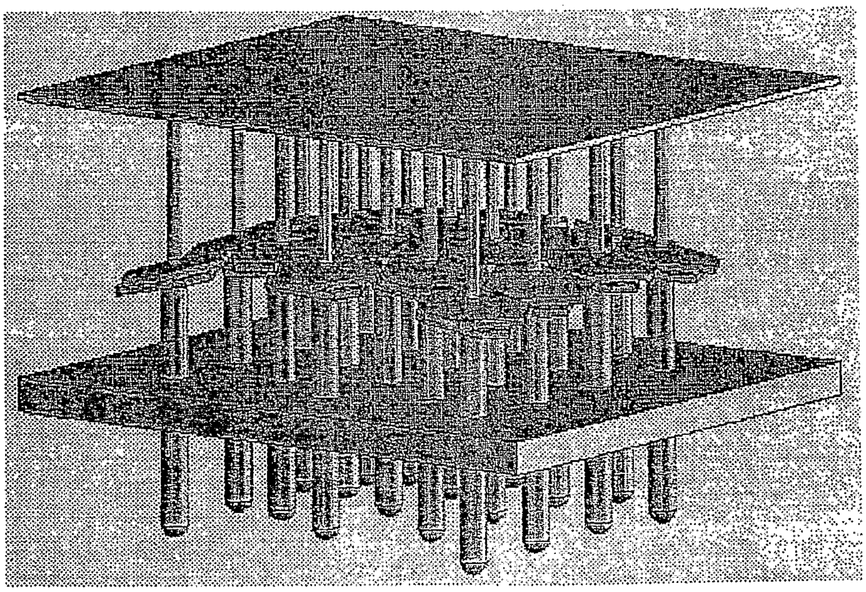

Fig. 7(b)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2007/000059

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

B21D 24/00 (2006.01) ***B21D 24/10*** (2006.01)
B21D 22/26 (2006.01) ***B21D 24/14*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI - IPC B21D 024/00, 024/10, 024/14, 022/26 & Keywords SHAP+ OR PROFIL+ OR CURV+ OR DIMENSION+, EXTEN+ OR ARRAY+ OR PUSH+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Derwent Abstract Accession No.2000-348518/30, Class No. M21, RU 2133163 C1 (National Aviation Techn Inst stock Co.) 20 July 1999	1
A	Derwent Abstract Accession No. 1999-420923/36, Class No. P52, DE 29908237 U1 (Umformtechnik Stade GMBH) 29 July 1999	1
A	Derwent Abstract Accession No. A8047 E/04 , Class No. P52, FR 2484297 A (Etab Durlumen) 18 December 1981	1

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
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- "O" document referring to an oral disclosure, use, exhibition or other means
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- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 April 2007	- 7 MAY 2007

Name and mailing address of the ISA/AU	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/AU2007/000059

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member	
RU	2133163		
DE	29908237	DE	19921176
FR	2484297		

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX