March 9, 1971 G. A. BOHMANN 3,568,490

METHOD AND APPARATUS FOR HEAT FORMING ELONGATED METAL PANELS

Filed Sept. 27, 1968 3 Sheets-Sheet 1

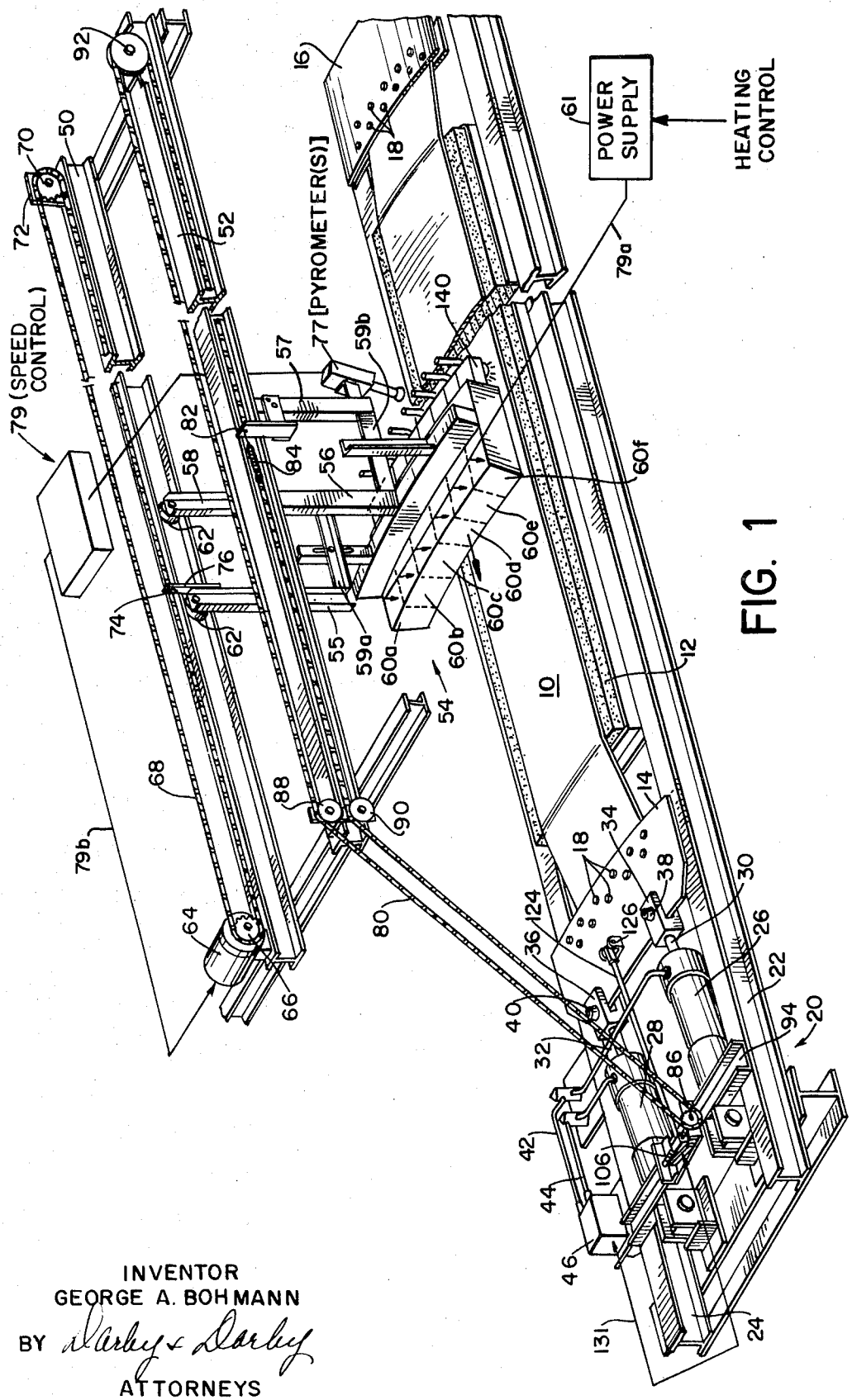


FIG. 1

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FIG. 2

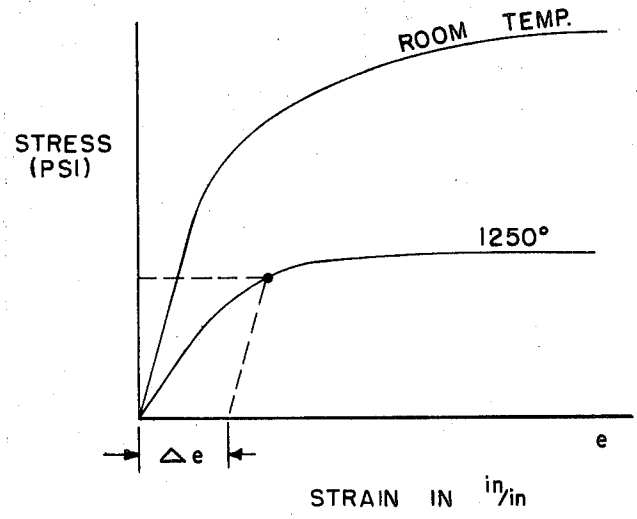
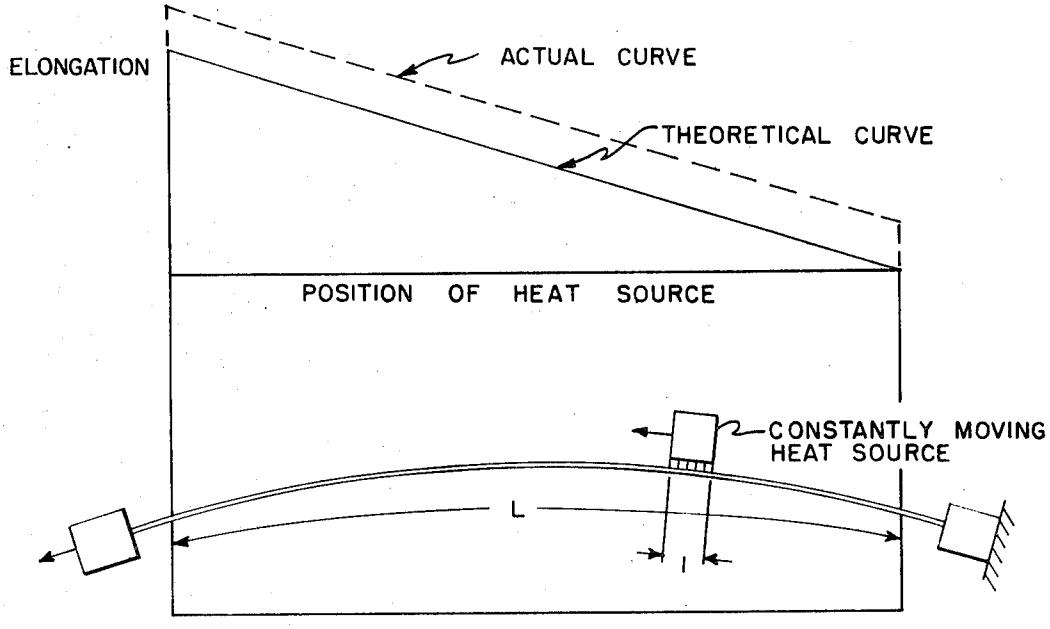


FIG. 3



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FIG. 4

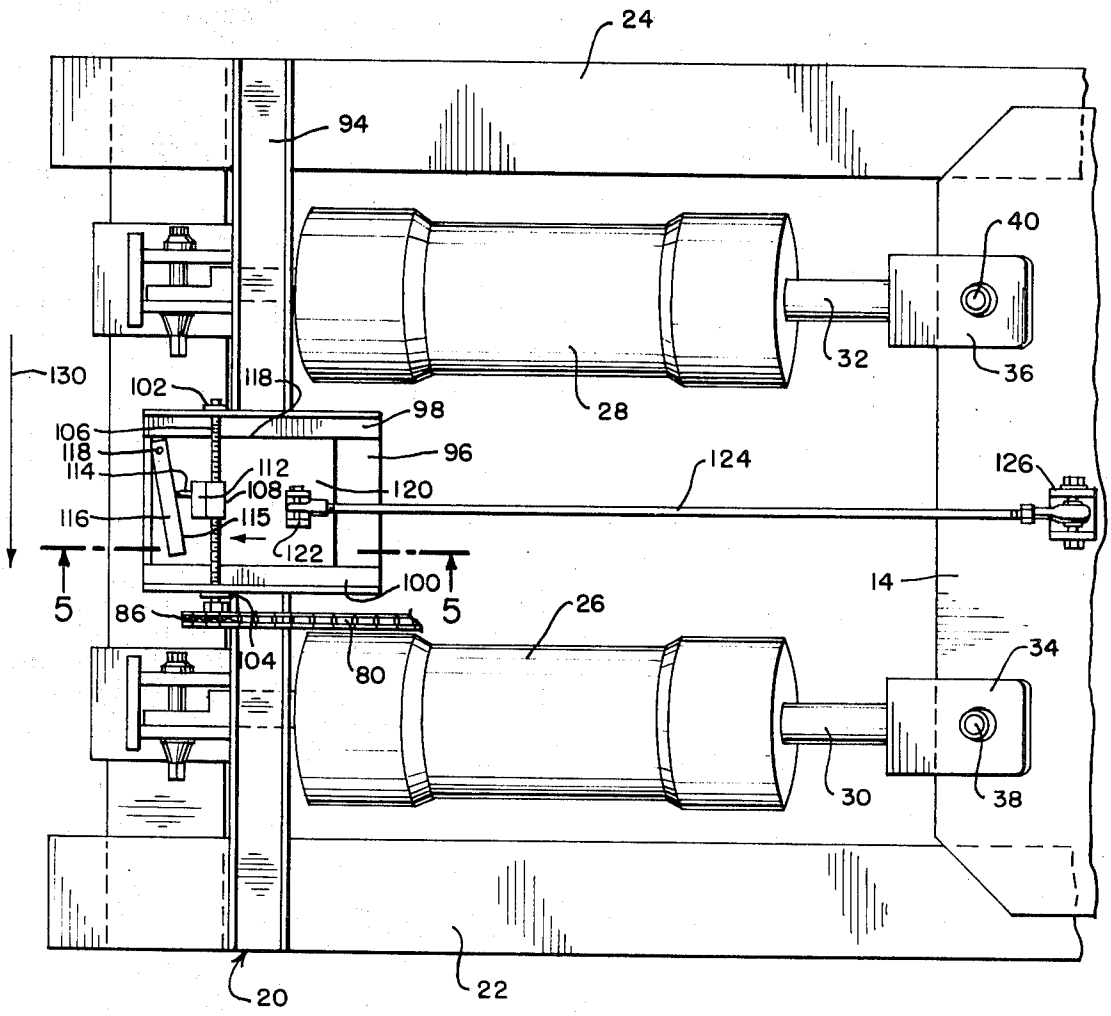
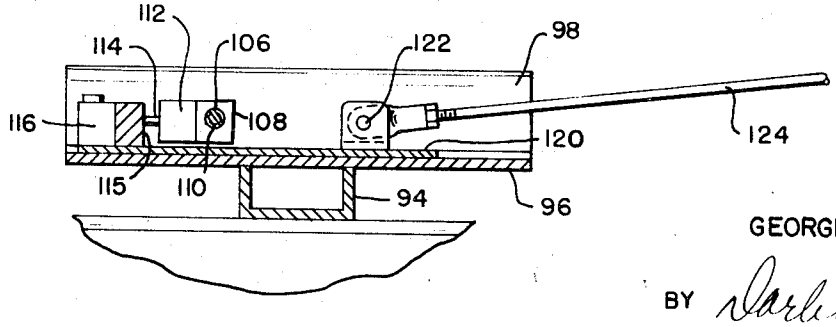


FIG. 5



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METHOD AND APPARATUS FOR HEAT FORMING ELONGATED METAL PANELS

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ABSTRACT OF THE DISCLOSURE

A method of stretch forming metal parts by the passage of a heat zone along a part held in tension against a die surface. The ends of the part to be formed are held and a tensile load is applied holding the part in contact with a die surface while a movable heat source traverses the part, locally yielding aid forming it to the die configuration. Elongation of the part is controlled as a function of the position of the heat zone permitting the forming of parts of both uniform and nonuniform cross section.

The present invention relates to the stretch forming of large metallic parts such as, for example, the panels which typically are employed to form the skin of an aircraft. It is particularly suitable for those materials, such as titanium, that are generally formed at elevated temperature.

For well known reasons, it is highly desirable that the panels forming the skin of an aircraft have low residual stresses. This requires the application of substantial heat to the panel during or subsequent to the forming process. Generally, prior art techniques involve stretching using a cold forming die in combination with a large immobile bank of heat lamps covering the entire panel, or a hot die with heat generally supplied by imbedded heating elements. A vacuum forming process is also used in which the panel is vacuum formed into a heated die of the desired contour.

Where the panels to be formed are of excessive lengths, or when the part is non uniform in cross section, the prior art panel forming techniques having proved to be impractical. This is due in part to the power requirements involved for the heat source, the difficulty in evenly heating a panel of extended length to avoid "necking" when pressure is applied, the mechanical problems of vacuum forming a long panel and the difficulty in compensating for the cumulative buildup of tangential frictional forces between the part and die.

Accordingly, it is an object of the present invention to provide a panel forming process and apparatus which can be employed to fabricate particularly large panels of either uniform or non uniform cross section in a practical and relatively economical fashion and without any post forming heating of the part for stress relieving.

Briefly, in accordance with the invention, pressure is applied to the ends of a panel, forcing the panel against a suitably contoured die. A traveling heat source, adapted to heat a relatively short increment of the panel, is mounted for movement along the length of the panel whereby the panel is incrementally heated as the heat source traverses the length of the panel. The desired elongation of the panel is controlled as a function of the position of the heat source to assure compliance with standard panel forming criteria.

In the drawings:

FIG. 1 is a perspective view of panel forming apparatus according to the invention;

FIG. 2 is a representative stress-strain curve used for explanatory purposes;

FIG. 3 is a graph of total panel elongation vs. heat source position for explanatory purposes;

FIG. 4 is a top view of the device employed to control the position of the heat source; and

FIG. 5 is a sectional view along the line 3—3 of FIG. 4.

In the drawing, an elongated panel **10** (e.g. of titanium) is shown applied to a ceramic die **12** which conforms to the desired contour of panel **10**. Each end of the panel **10** is inserted between two gripper jaws **14** and **16**, respectively and secured within the respective gripper jaws by bolts **18** or hydraulic actuators.

The ceramic die **12** rests on a framework **20** which includes longitudinal I beams **22** and **24**. The gripper jaws **16** are secured to the frame **20** at one end, and, at the other end, a pair of hydraulic cylinders **26** and **28** are suitably mounted with respective actuator rods **30** and **32** extending therefrom toward the panel **10**. The actuator rods **30** and **32** terminate in clevis **34** and **36** which are bolted to the gripper jaws **14** at **38** and **40**, respectively. The hydraulic cylinders **26** and **28** are controlled in the usual fashion by means of fluid control lines **42** and **44**, respectively, which can be opened or shut by an electrically controlled valve mechanism **46** shown in diagrammatic form.

A pair of horizontal parallel overhead rails **50** and **52**, I-shaped in cross section, are mounted above the panel **10**. A travelling heat source **54** rides on the rails **50** and **52** so as to at least traverse the length of the panel **10** supported on the die **12**. The heat source **54** includes four vertical posts, **55**, **56**, **57** and **58**, and connecting struts **59***a* and **59***b* to which is secured a standard quartz heater **60** or other suitable heating means such as induction coils. Heater **60** may be divided into a plurality (e.g. six) of heater elements **60***a*–**60***f* which are contoured to the shape of die **12** and which are independently powered by a standard power supply **61**.

A roller **62** is mounted at the top of each of the vertical support posts **55**, **56**, **57** and **58**, and adapted to ride on the inner sides of the rails **50** and **52**. A variable speed motor **64** is mounted on one end of the rail **50** and includes an output sprocket gear **66** which engages an endless chain **68** supported also by a sprocket **70** extending from a bracket **72** secured to the other end of rail **50**. The endless chain **68** is connected at **74** to a lug **76** extending upwardly from the support post **55**. Thus, operation of the motor **64** will drive chain **68** thereby causing heat source **54** to move across the length of panel **10**. Temperature sensing devices such as radiation pyrometers **77** are mounted on the heat source **54** and connected through feedback loop **79***a* to the power supply **61** and feedback loop **79***b* to the drive motor **64**. This controls the power input to heat source **54** and the speed of heat source **54** as a function of the heat-up rate of the part **10**.

The construction so far described is capable of applying pressure to the panel **10** and simultaneously heating continuous increments of the panel along its length. It is also necessary, however, to insure that a desired relationship exists between the temperature of the panel and the applied force.

In accordance with standard panel forming techniques, where a panel is to be formed to a desired contour, the force applied should be such that the elastic yield of the material is just exceeded. It is further desirable that the elongation of the panel due to this force be as small as possible. The temperature requirements will vary with the specific material employed. As a typical example, it may be desired to heat a titanium panel to a temperature between 1200° F. and 1350° F., it being desirable to maintain the part at a temperature that will inhibit the introduction of residual stresses during the forming operation. This requirement that the elongation and temperature of the panel be controlled within certain specified limits requires control of the force applied to the panel and/or the temperature of the panel.

As explained in further detail below, there are a number of different ways this control can be provided. In the preferred embodiment of the invention a simplified construction is used to accomplish this objective, wherein elongation of the panel is controlled as a function of the position of the heat source relative to the panel.

The preferred embodiment operates on the assumption that there is a near linear relationship between the position of heat source **54** relative to panel **10** and the theoretically desired elongation of panel **10** where its yield point is just exceeded. Although, in fact, this relationship is not precisely linear due to temperature and other effects, the approximation is close enough for use as a practical basis for the procedure. Thus, knowing the temperature to which it is desired to heat the panel **10** during the forming process, it is possible to examine typical stress-strain curves for the material of panel **10** at the desired forming temperature to determine the total elongation which will result if a panel of known length is stressed just beyond its yield point.

FIG. 2 shows typical stress strain curves for titanium 6Al—4 v. at room temperature and 1250° F. By examining this curve the strain Δe (measured in inches per inch) can be determined for a sheet which is heated to 1250° F. and stressed into its plastic range just exceeding the yield point. Since the length of the panel is known, the total elongation can be computed by multiplying the panel length (in inches) times Δe. A theoretical curve of elongation versus the position of the heat source can be drawn as shown in FIG. 3. Compensation should be made for the thermal expansion of the panel in the heat affected zone. This can be done by the equation:

$$E=\Delta e(L)+(l)(\Delta t)(k)+L(t_p)(k)$$

where

E=actual total elongation
L=length of panel
l=length of heating zone
Δt=forming temperature minus ambient temperature
k=thermal coefficient of expansion
t_p=average temperature in that portion of the panel previously traversed by the heat source.

Once the actual curve of FIG. 3 is determined, the movement of the pistons in the hydraulic cylinders **26** and **28** can be adjusted so that they (and thus the panel elongation) bear a desired relationship to the position of the heat source. FIG. 4 illustrates the apparatus by which this control is achieved.

In FIG. 1 an endless chain **80** is secured to a vertical plate **82** suitably attached to the support post **57** for heat source **54**. Tension spring **84** assures that the tension in the chain **80** remains constant. The endless chain **80** drives a sprocket **86** and is supported on pulleys **88**, **90** and **92**, which are mounted in an obvious fashion on the rail **52**. A horizontal support bar **94** (FIG. 4) is secured to the frame members **22** and **24**, and a base plate **96** is centrally mounted on the support bar **94**. Plate **96** includes opposed L-shaped brackets **98** and **100** containing bearing members **102** and **104** in which a lead screw **106** is suitably journalled. The lead screw **106** is directly connected to the sprocket **86** causing it to rotate as the chain **80** and heat source **54** are moved across panel **10**.

A retainer member **108** includes a longitudinal threaded aperture **110** (FIG. 5) which engages the lead screw **106** so that the retainer **108** is moved along the axis of lead screw **106** as the lead screw is rotated during movement of the heat source **54**. A small displacement transducer **112**, which may comprise a standard linear variable differential transformed is suitably secured within the retainer **108**. Transducer **112** includes a linearly movable stylus **114** adapted to engage a camming surface **115** of an adjustable camming bar **116** pivotally mounted at **118** on a plate **120**, the voltage output from the transducer being directly proportional to the linear displacement of its stylus **112***a*. The plate **120** is received between the horizontal flanges of L-shaped brackets **98** and **100** and adapted to slide over the base plate **96**. Plate **120** is pinned at **122** to a connecting rod **124**, the other end of which is pinned at **126** to the upper gripping jaw **14**.

With this construction, the displacement transducer **112** will traverse the camming surface **115** in the direction of arrow **130** (FIG. 4) as the heat source **54** traverses the length of the panel **10**. Thus, once the total desired elongation of panel **10** has been determined, the bar **116** can be rotatably adjusted so that the angle of the camming surface **115** (relative to the longitudinal axis of lead screw **106**) represents the desired linear function corresponding to the position of heating source **54** relative to the elongation of panel **10**. Thus, the output leads of the transducer **112** (shown diagrammatically at **131** in FIG. 1) may be coupled in an obvious fashion to the electrically controlled modulator valve **46** to control the fluid flow in lines **42** and **44** and thus the force applied to panel **10** by hydraulic cylinders **26** and **28** respectively. Modulation control of the fluid flow will assure that the elongation of panel **10** is linearly proportional (in accordance with the predetermined criterion) to the position of heat source **54** relative to panel **10**. For example, the amount of fluid flow will vary with the amount that the transducer stylus **114** is depressed. If the stylus **114** is not depressed then the valve will be closed. If the stylus **114** is partly depressed then the valve will be proportionately open. If the stylus is fully depressed the valve will be fully open. This modulation results in panel elongation proportional to the position of heat source **54**.

Where a transformer is used as the displacement transducer, additional circuits will be used to provide the required alternating input voltage and to convert the transformer output to direct voltage where required. Such circuits are well known and have been omitted from this description for purposes of simplification. In effect, the arrangement described is an electromechanical comparator which compares actual elongation with a theoretically desired elongation based upon the actual position of the heat source and adjusts the variables accordingly. It is contemplated that other devices, including all-electrical and tape controlled and programmed comparators, be used for this purpose if desired.

Basically, there are five variables which affect the operation of the system described. These are the rate of movement of the heat source **54**, the tensile load applied to the panel by the hydraulic system, the position of the heat source as a percentage of the total length of travel, the elongation of the panel, and the thermal output of the heat source. The present invention contemplates any possible control of these variables so as to satisfactorily provide incremental panel forming as herein described.

An important advantage of the invention resides in the ability to control the heat profile of the heat source. This renders the invention of particular utility in the forming of panels which are not of uniform (i.e. rectangular) transverse cross section. In such cases the thermal output of different ones of the individual heating zones (lamps or other elements) comprising the heat source can be adjusted (electrically or by mechanical sources) to apply more heat to thicker portions of the panel than is applied to the thinner portions. This assures that the non-uniform part is heated uniformly to the desired temperature despite the different heat-up rates. Where the panel thickness is tapered from end-to-end, the same control may be used if desired and/or the speed of the heat source can be appropriately varied. The invention further contemplates automatic control of the individual heating zones **60***a*–**60***f* either by a temperature sensing feedback loop or programmed control devices and the like.

A further important feature of the invention includes the addition to heat source **54** of a spray nozzle such as **140** through which a gas such as argon may be applied to cool the panel immediately after the heat source has

been applied. This would be a particular advantage for heat treating parts on the die, as for example, the die quenching of titanium 6A1—4 v. where the part must be quenched within 6 sec. to achieve maximum solution treated properties.

The invention can be used to form parts other than panels, such as extruded and rolled parts. Numerous modifications of the invention will also be obvious to those skilled in the art, and the invention should be defined primarily with reference to the attached claims.

What is claimed is:

1. A method of stretch forming a contoured elongated metallic part, comprising the steps of applying a tensioning force to at least a portion of said part while successively heating longitudinally displaced increments of said portion to a preselected temperature, said tensioning force being greater than the elastic yield point of said part at said temperature.

2. A method according to claim 1, including the step of tensioning said part against a die member, and wherein said step of successively heating increments comprises moving a heat source across said portion.

3. A method according to claim 2, wherein the elongation of the part is caused to bear a predetermined relationship to the position of said heat source.

4. A method according to claim 2, including the step of controlling the amount of heat applied to said heated increment in proportion to the heat-up rate of said heated increment.

5. A method according to claim 2, including the step of controlling the thermal output of said heat source to vary the amount of heat applied to said heated increments.

6. A method according to claim 2, including the step of successively cooling each of said increments after it has been heated.

7. Stretch forming apparatus, comprising a die having a surface corresponding to the desired contour of a part, means for applying a tensioning force to a part applied to said die to cause said part to conform to the shape of said die, means for heating an incremental increment of said part to a preselected temperature, and means for moving said heating means across said part, said tensioning force being greater than the yield point of said part at said temperature.

8. Apparatus according to claim 7, including means for controlling the elongation of the part relative to the position of said heating means.

9. Apparatus according to claim 8, including fluid distributing means for cooling said part after it has been heated by said heating means.

10. Apparatus according to claim 9, wherein said fluid distributing means is secured to said heating means for movement therewith.

11. Apparatus according to claim 8, wherein said means for applying a tensioning force comprises means for gripping said part, said apparatus further including means for comparing the elongation of said part with a desired elongation based upon the position of the heating means relative to the part, and means responsive to said comparing means for moving said gripping means.

12. Apparatus according to claim 8, including means for varying the amount of heat applied by said heating means to said zone.

13. Apparatus according to claim 12, wherein said heating means comprises a plurality of heating elements, and wherein said control means includes means for independently adjusting the thermal output of each of said heating elements.

14. Apparatus according to claim 12 including means responsive to the temperature of said heated increment for adjusting the amount of heat applied to said part by said heating means so as to cause each of said heated increments to attain a preselected temperature regardless of its dimensions.

15. A method according to claim 2, wherein the elongation of the part is caused to bear a predetermined relationship to the position of said heated increment.

16. A method according to claim 15, including the step of controlling the amount of heat applied to said heated increments.

17. A method according to claim 16, wherein the amount of heat is controlled by varying the rate of movement of said heat source.

18. A method according to claim 16, wherein the amount of heat is controlled by varying the temperature of said heat source.

19. A method according to claim 15, wherein different amounts of heat are applied to portions of a heated increment than to other portions thereof.

20. A method according to claim 15, wherein said tensioning force is such as to keep the total elongation of said portion at substantially a minimum value.

21. Apparatus according to claim 14, wherein said means for adjusting the amount of heat comprises means for varying the rate of movement of said heating means.

22. Apparatus according to claim 14, wherein said means for adjusting the amount of heat comprises means for varying the temperature of said heating means.

23. Apparatus according to claim 7, including means for varying the amount of heat applied by said heating means to said increments.

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U.S. Cl. X.R.

72—13, 305, 378