May 25, 1948. W. C. FIELDS ET AL 2,442,268

APPARATUS FOR STRETCH BENDING STRUCTURAL ELEMENTS

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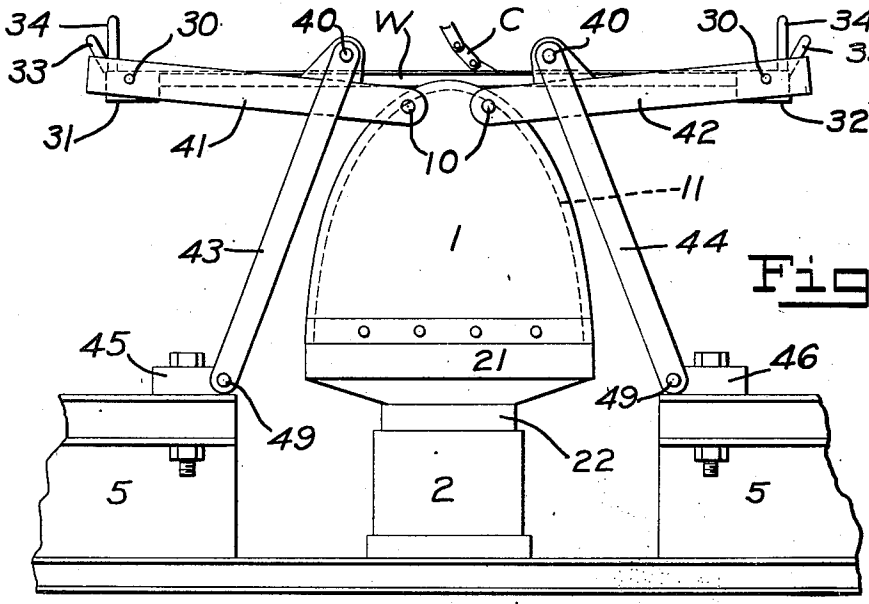


Fig. 1.

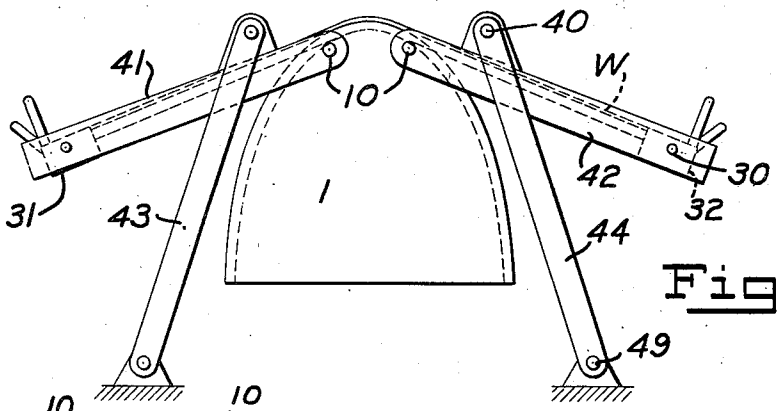


Fig. 2.

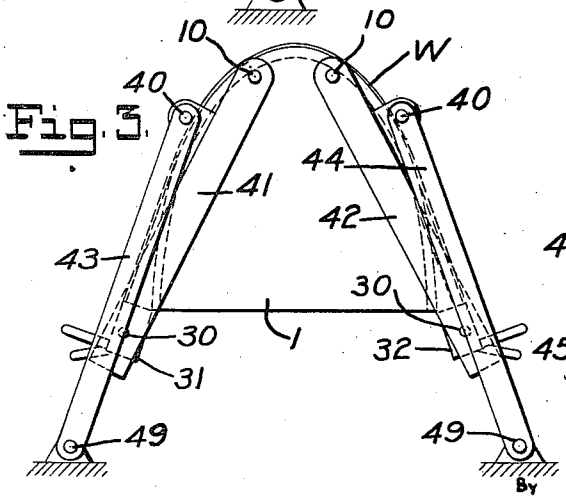


Fig. 3.

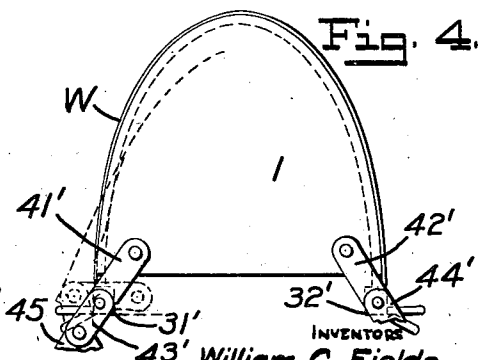


Fig. 4.

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May 25, 1948. W. C. FIELDS ET AL 2,442,268

APPARATUS FOR STRETCH BENDING STRUCTURAL ELEMENTS

Filed July 16, 1942 4 Sheets-Sheet 2

Fig. 5.

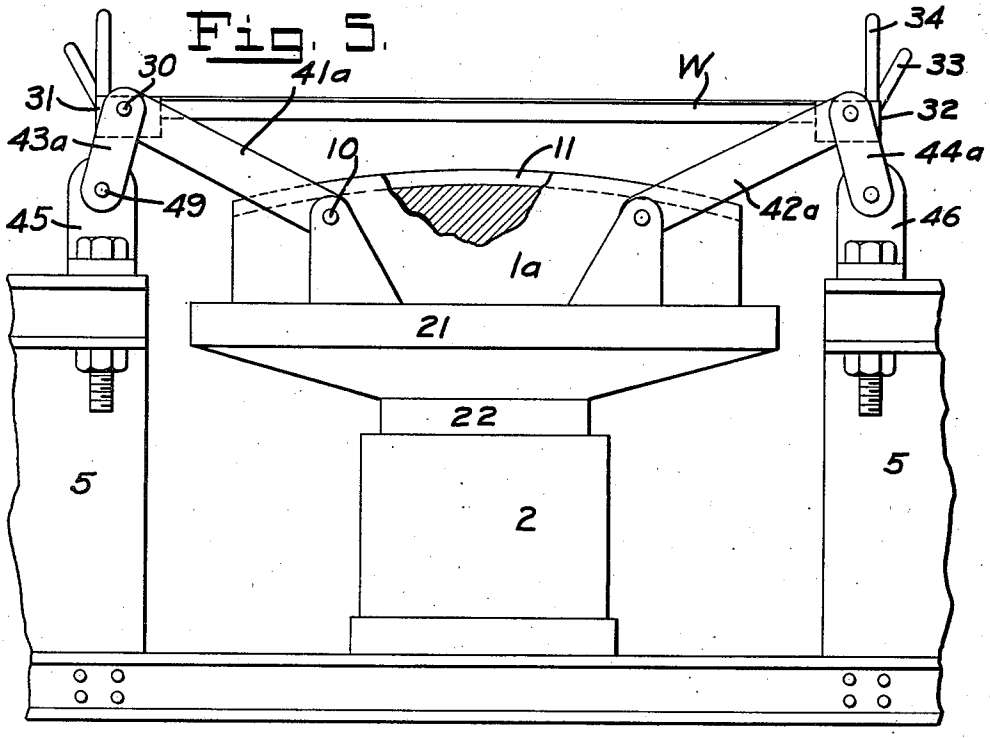
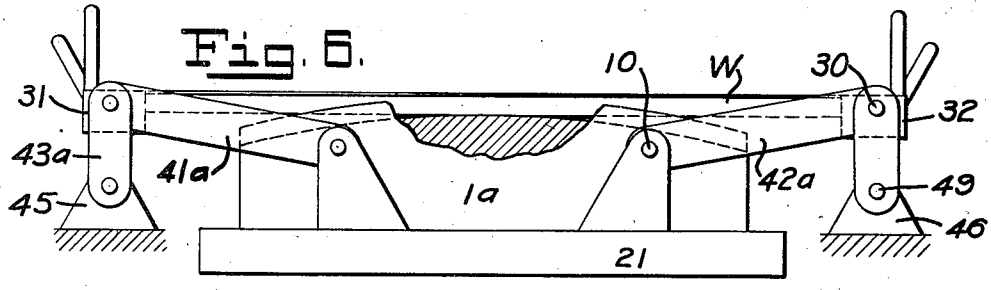


Fig. 6.



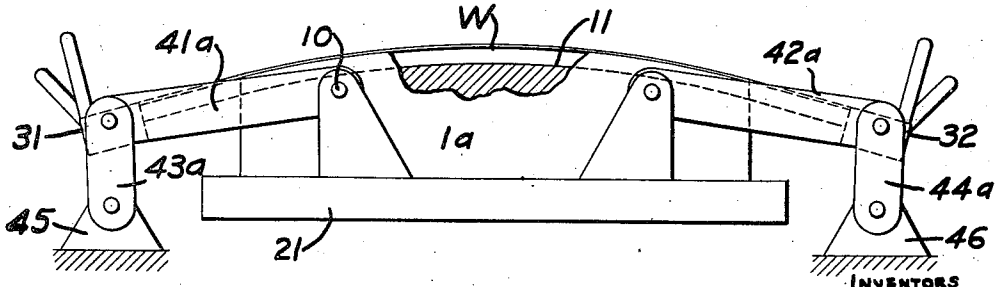


Fig. 7.

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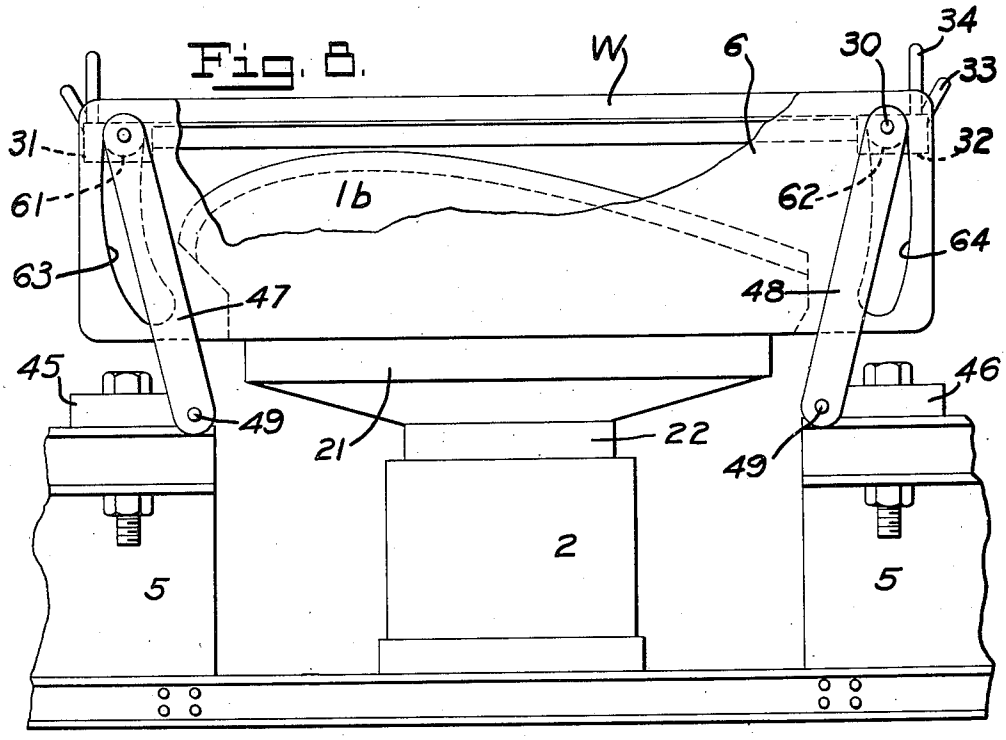
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May 25, 1948. W. C. FIELDS ET AL 2,442,268

APPARATUS FOR STRETCH BENDING STRUCTURAL ELEMENTS

Filed July 16, 1942 4 Sheets-Sheet 3

Fig. 8.



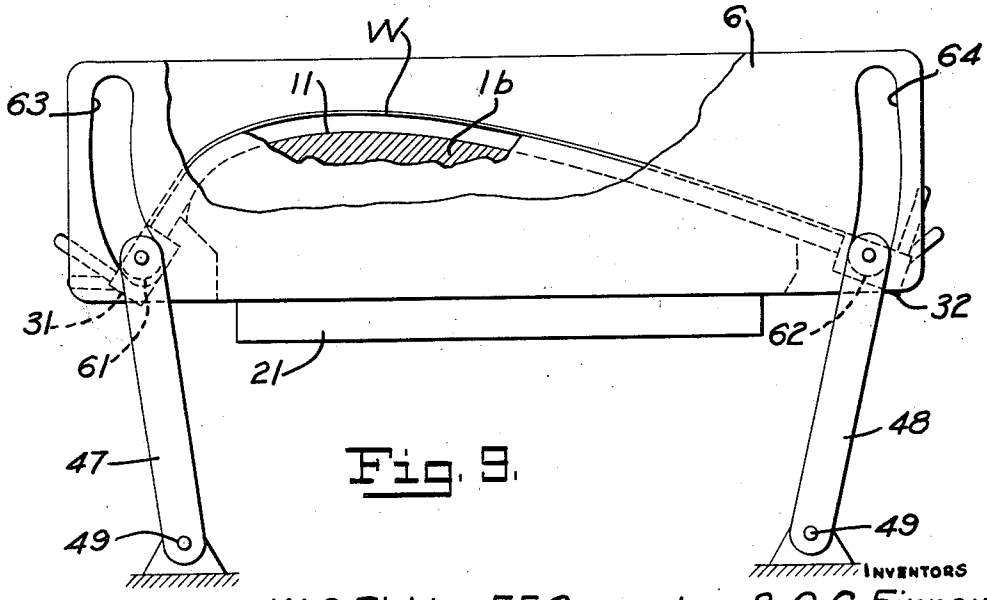


Fig. 9.

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May 25, 1948. W. C. FIELDS ET AL 2,442,268

APPARATUS FOR STRETCH BENDING STRUCTURAL ELEMENTS

Filed July 16, 1942 4 Sheets-Sheet 4

Fig. 10.

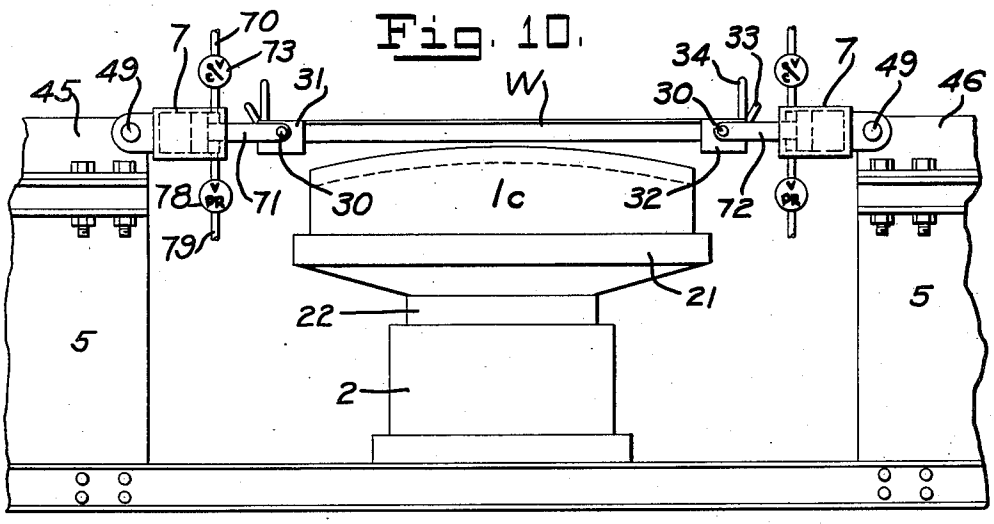
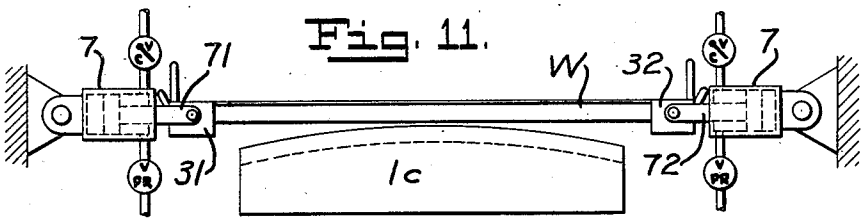


Fig. 11.



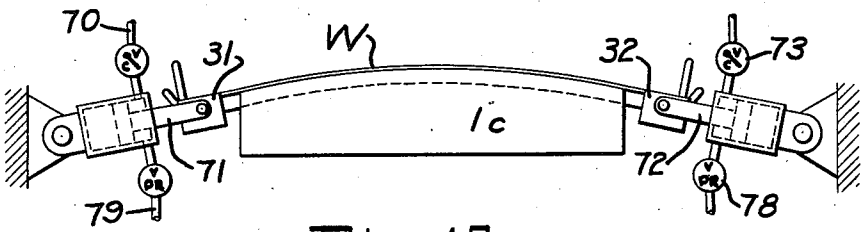


Fig. 12.

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UNITED STATES PATENT OFFICE

2,442,268

APPARATUS FOR STRETCH BENDING STRUCTURAL ELEMENTS

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Application July 16, 1942, Serial No. 451,160

7 Claims. (Cl. 153—48)

1

The bending of structural or framing elements, such as the nose rib chords of airplane wings, the interspar or center wing rib chords, the flap cut-out ribs, and the like, presents a problem, namely, to avoid wrinkling of the flange portions of the structural element, particularly the flange at the interior of the bend. The problem arises because in the process of bending such an element in the general plane which includes its web the bending produces tension forces about the exterior margin of the bend, and inwardly to a neutral axis intermediate its interior and exterior margins, but likewise produces compressive stresses within the interior margin of the bend, and these compressive stresses, transmitted to the flanges, cause wrinkling thereof. Where the curvature is severe, as for instance about the nose rib chords of an airplane wing, it has been customary heretofore either to form the entire nose section of the rib as a stamping, or to form it of separately bent stringers, and then to rivet or otherwise secure together these bent stringers at or near the point of maximum curvature. This, of course, meant two bending operations and a securing operation, and the formation and securement of gussets or splices, and thereby increased the cost and weight of the part, and limited severely the rate of production.

The present invention concerns a method and a machine, whereby such bending of structural elements can be accomplished, whether the bend be severe or slight, in a single operation, rapidly performed, without the necessity of allowing for spring-back, automatically straightening parts warped from heat-treating or otherwise, and preserving to as high a degree as may be necessary the structural strength characteristics and cross-sectional shape of the element.

The present method resembles, but must not be confused with, the method of stretch-bending sheet metal, even though the machines used in carrying out the present invention are the same machines as are used for stretch-bending sheet metal, with certain modifications. The present invention concerns the bending of structural elements, particularly of relatively soft metals such as aluminum alloys, which elements have relatively deep webs, that is to say, webs of appreciable depth relative to the thickness of the web material. Such structural elements are normally

2

formed by bending or shaping sheet metal strips into the desired cross section. They may be single webbed or multiple webbed, and in some instances the bend may be in such a plane that the portion of the element which would normally be considered its flange becomes in effect its web. The form used, for purposes of illustration in the accompanying drawings, is a hat section, but the invention is applicable to any analogous form. It is also applicable to extrusions as well as sheet metal elements, that is to say, to any element capable of appreciable permanent elongation or stretching, without rupture or undue weakening.

The method has been used on a modified hat section (the flanges whereof are turned up to a depth of $\frac{5}{16}$'') of .032'' No. 24 S. O. aluminum alloy, the web spacing being ½'', and its depth 1'', with ½'' flanges. It has also been used on a hat section of ¼'' No. 24 S. O. aluminum alloy, 6'' deep, 4'' wide, and having 1¼'' flanges. Other sections can be bent, and other materials; annealed stainless steel has been successfully bent by this process. The nose rib chords illustrated represent about the shortest radius which it is practicable to bend thus; in general, all contours encountered in normal aircraft wings can be so bent.

Briefly, the method consists in applying bending forces to such an element, in the general plane of its web, and simultaneously applying or maintaining a previously applied tensional force in a direction and, combined with the tensional component of the bending force, of a value to elongate the structural element. The effect of thus elongating the element is to neutralize the compression component of the bending forces, and to displace the neutral axis of the bend from its normal location, along a line intermediate the exterior and interior margins of the bend, substantially to or inside of the interior margin. It may be desirable to permit the neutral axis, in the most severe portion of the bend, to remain slightly inside the interior margin, and thereby to compromise between the maximum tendency to wrinkle the flange and complete absence of such tendency, but ideally the neutral axis is displaced throughout the entire length of the structural element inside of the interior margin of the bend.

The actual permanent elongation of the element should occur not later than the application

of bending forces, and may occur prior thereto. The elongating force is, therefore, of a value sufficient, by itself, to effect elongation, without adding to it the tension component of the bending forces, or so nearly sufficient that a very slight addition from the tension component will effect permanent elongation.

One of the principal advantages of the method is that the work is bent directly and precisely to the desired shape or contour, and no allowance is required for spring-back.

The method is conveniently carried out by modification of machines already available, such as are shown in the accompanying drawings in various forms. These drawings are largely diagrammatical in character.

Figure 1 is an elevation of the machine set up for the start of the operation of bending a wing nose rib chord. Figure 2 is a view similar to Figure 1, showing an intermediate stage in the same operation, and Figure 3 is a similar view showing the final stage of the first step. Figure 4 is a similar view, showing, however, a finishing or second step in the formation of the wing nose rib.

Figure 5 is a view similar to Figure 1, showing the start of the operation of bending an interspar rib chord or stringer. Figure 6 is a similar view showing an intermediate stage of the operation, and Figure 7 is a similar view showing the final stage of this operation.

Figure 8 is a view similar to Figures 1 and 5, showing a modified form of the machine, set up for the initial stage of bending a flap cut-out rib, and Figure 9 is a similar view showing the final stage in this operation.

Figure 10 is a view similar to Figure 5, showing a modified form of the machine for performing the same operation. Figure 11 is a similar view, showing an intermediate stage, and Figure 12 is a similar view showing the final stage of this operation.

The invention will be best understood by following through a representative operation, such as that shown in Figures 1 to 4 inclusive. The work may be preliminarily heat-treated and chilled, or if the bend is not too severe this may be omitted. The structural element, or work W, is clamped and held by any suitable means, such as the clamps represented at **31** and **32**. Any suitable form of clamp or releasable securing means may be employed. Preferably it is of such type as will clamp the tighter with increasing tension. Each such clamp is pivoted at **30** to some immediate support, which in the form shown in Figures 1, 2, and 3 is an arm or link **41** or **42**. The clamp is supported from a fixed (though preferably adjustably positioned) support, such as the shiftable slides **45, 46**, supported in the bed frame **5**, the support being by means such as the links **43, 44**, pivoted to their respective links **41** and **42** at **40**, and to their respective slides **45, 46** at **49**. The pairs of links **41, 43**, and **42, 44**, thus become toggle links, and in the initial position of the parts shown in Figure 1 they assume a relative dog-leg position.

A form **1** of suitable material (hard board suitably reinforced has been used, or steel), having a marginal groove **11** shaped to receive at least the web portion of the element W, has a curvature corresponding to and preferably identical with the desired final shape. This form is interposed between the fixed supports **45, 46**, and is capable of movement, in the general plane of the web of the structural element W, and in a direction transverse to its extent as it is held between the clamps, to engage the structural element and to bend it. Thus the form **1** may be supported upon the table **21** of the plunger **22** of a hydraulic jack or jacks **2**.

Since preferably the elongation of the structural element W is accomplished by and during the upward movement of the form **1** (although as is illustrated in Figures 10, 11 and 12, it may be accomplished by independently operable means), it is preferable to connect the toggle linkage to the form, or to the press table, which in effect becomes part of the form for such purposes. To this end the links **41, 42** are pivotally connected at **10** to the form **1**, adjacent its upper end. It will be recognized that the jack **2**, the bed frame **5**, and the form **1**, together with a means to hold down the extremities of the work to the bed frame, is substantially identical with sheet metal stretch-forming machines. The toggle linkage, however, and its operation, as will shortly be described, and the bending of deep-webbed structural elements by such machines, has not been accomplished heretofore, to our knowledge.

In starting such an operation, then, the element W which is to be bent is clamped by its opposite ends in suitably formed clamps **31, 32**, controlled by the handles **33** and **34**. To support the open interior of the illustrative hat section against inward collapse of its thin walls it is desirable to insert a filler, such as the flexible chain C, which may be formed of fiber or like material. Except for completion of the insertion of the filler C the apparatus is substantially ready to initiate the bending operation, as it is set up in Figure 1.

To initiate the operation the form **1** is moved upwardly in this instance, and the first result is to stretch and permanently elongate the element W, even before the web of the structural element W is fully received within the marginal groove or channel **11** of the form. Upward movement of the form with respect to the fixed supports **45, 46** immediately causes separation of the clamps **31, 32**, measured along the work, by reason of the movement of the toggle links of the respective pairs towards alignment. The linkage is so calculated and designed that this separation of the clamps effects permanent elongation of the work. This elongation does not necessarily occur in all parts of the length of the element throughout all stages of the operation, nor does it necessarily occur to an equal degree in all parts of the length. These factors are controlled by proper design of the linkage or equivalent elongating devices, of the form, its radius, and the like, as will be apparent to the designer. However, wherever and whenever bending is actually occurring, there and then elongation should also occur.

As upward movement of the form continues, through the position shown in Figure 2, and into the position shown in Figure 3, the stretching and the simultaneous bending continues, and the structural element takes a permanent set. Care is taken that the bending is not so severe as to materially weaken the form, which, of course, can be provided initially with excess strength, if that is found necessary. In the position of Figure 3 the pivots **49, 40, 30**, and **10**, which previously had been arranged in a crossed or scissors relation, are now nearly in alignment, drawing the ends of the structural element inwardly towards the bottom end of the form's periphery.

Due to mechanical limitations it has been

found simpler to effect the complete bend of a nose rib chord in two operations, rather than in a single operation, and the final operation is shown in Figure 4. The structural element, bent to the shape shown in Figure 3, is reengaged by the clamps 31' and 32', carried by the toggle links 41', 43', and 42', 44', respectively, with the fixed supports, such as that illustrated at 45, adjusted inwardly, and now upward movement of the form 1 tends to move the pairs of toggle links into or towards alignment with each other within the respective pairs, and thereby draws inwardly the clamps 31', 32', further stretching and elongating the structural element W while at the same time bending it to conform to the shape of the form 1.

Sloping of the flanges, to accommodate the sweep-back of the wing's leading edge, can be accomplished all in the same operation, without appreciable wrinkling, for the metal is or can be substantially wholly in tension, and the tension can be sufficient to stretch that flange which requires it for such sloping. The forms may have flats, for junction of stringers, and the work can be struck with a mallet, after or during bending, to apply these flats.

Figures 5, 6, and 7 illustrate a bend which is relatively slight, but which, because it is slight, is difficult to accomplish. Because there is so small a tension component of the bending force, substantially all the tension required to displace the neutral axis inside the interior margin of the bend, and to make the structural element W conform throughout the length of the form 1*a*, without spring-back, must come from the longitudinal stretching. It has been found necessary, therefore, to effect greater elongation of the structural element, and in this instance in particular to effect its elongation previously to applying any bending force to it, and to maintain that elongating force at a relatively high value during the bending to assure that the material will exceed its elastic limit during the bending operation, and consequently that the element will preserve its bent formation without springback. While in bending to such a curvature as is shown in Figures 1 to 4 it may also be necessary to effect elongation previously to effecting any bending, this is required to an appreciably greater degree in effecting a slight curvature throughout a long structural element of the nature shown in Figures 5 to 7.

The result is accomplished, as in the previous example, by an arrangement of toggle links such as is shown in Figure 5. The clamps 31, 32 are supported as before from one of the toggle links 41*a* or 43*a*, or, in the other pair, 42*a* or 44*a*. In effect, the clamps are supported by the common pivot 30 between the two links of each pair. One such link is pivotally supported at 49 to an adjustable but now fixed support 45 or 46, and the other link of the pair is pivotally connected at 10 to the form 1*a* or to the table 21, which, so far as the method is concerned, is in effect a part of the form. The initial position is shown in Figure 5, and by comparison of Figures 5 and 6 it can be seen that prior to any contact of the form 1*a* with the structural element W, and, of course, prior to any application of bending forces to the structural element, there has been appreciable and permanent elongation of the structural element effected by stretching it to stress the material beyond its elastic limit. As upward movement of the form continues the elongation of the structural element continues, until parts reach the final position shown in Figure 7.

It may be noted here that the structural element can be released from its clamp either by manipulation of the handles 33, 34, or by snipping the structural element just inside of one of its clamps, particularly in the arrangement shown in Figures 5 to 7. In the latter case the tension in the structural element causes any fracture to continue almost instantaneously, and to sever the structural element between the form and the clamp, after which it is readily removed from the form.

This particular piece can be turned out at the rate of 75 an hour (using dual forms), as compared to 3 or 4 an hour, using the old system of forming on the draw former and hand-working to contour. This prior system required allowance for spring-back, and because of difference in spring-back in different lots of material the parts could never be quite accurate. The present method forms to precise shape, and there is no spring-back, hence it not only promotes speed but also accuracy and uniformity.

The arrangement shown in Figures 8 and 9 applies the stretching forces otherwise than through toggle linkage, and also differentially as between the two ends of the structural element. Here links 47 and 48 support the clamps 31 and 32, respectively, at their swinging ends, while their other ends are fixedly pivoted at 49 to the fixed supports 45 and 46, respectively. The swinging ends of these arms carry cam followers 61 and 62, which engage in and are guided by cam slots 63 and 64, respectively, formed in a cam plate 6, placed alongside of and preferably secured to the form 1*b*.

The form 1*b* is shaped to provide the most severe curvature at the left-hand end, as viewed in Figures 8 and 9. It is necessary to effect more elongation proportinately at this end of the structural element than at its opposite end, therefore the cam slots 63 and 64 are differentially shaped, to the end indicated. The cam slot 64 may be in effect substantially an epicyclic curve with respect to the curvature of the right-hand end of the form 1*b*, and the effect of this is to hold the structural element, particularly after an initial elongation, which occurs prior to engagement of the work with the form, against further elongation, while still holding the work tensioned. At the left-hand end, however, the cam slot 63 is formed to effect initial elongation, and in addition to effect continuing elongation between the clamp 31 at this end and the point of maximum curvature, or between the clamp and the point of tangency of the work to the form.

By the use of dual forms, on a 75-ton stretch press, 800 such pieces can be completed in an eight-hour shift, by two operators. Previously they had been formed with hammer dies, then heat-treated and straightened by rehitting the parts, and then flattened in still another operation. The present process represents a large gain in speed, efficiency, and economy.

In all forms, but in this form in particular, it will be evident that the form might be held, and that the supports 45 and 46, which have been termed the fixed supports, might be movable instead with relation to the fixed form. It is also clear that the movement of the clamps with relation to the form might be accomplished by engaging the clamps with a downwardly moving press ram instead of with an upwardly moving press table.

In the forms heretofore described the stretching of the structural elements has been caused by the relative movement of the form and the fixed supports, although the stretching is a separate and independent or additional force besides the bending force. In the arrangement shown in Figures 10, 11 and 12 the stretching force is wholly separate from and independent of the bending force, and can be applied at any stage of, prior to, during, or after the application of bending force. Also the stretching force is accomplished in this arrangement, not by cam means or toggle links, but by fluid pressure means.

The form 1c, its support, and its moving means may all be the same as that previously described. The structural element W is held between the clamps 31 and 32, as before. The pivot 30 for the clamps is supported, however, from the plungers 71 and 72, respectively, of fluid-pressure jacks 7, which are pivoted at 49 to the respective fixed supports 45 and 46, adjustable laterally on the main frame 5. A supply line 70 with a check valve 73 runs to each jack, and fluid can be drained therefrom under control through the drain line 79 in which is a pressure reducing valve 78.

At the outset of a bending operation the work W is secured by the clamps 31 and 32, and the next step may be the application of pressure to the jacks 7, to separate the clamps 31 and 32, and thus to stretch and permanently elongate the structural element W stretched between the clamps. The disposition of parts can be seen in Figure 11, and the stretching can be observed by comparison of this figure with Figure 10.

The next step is to apply bending forces to the stretched structural element by relative movement of the form 1c. With the additional tensioning component of this bending force it may be that the total tension in the structural element will exceed that necessary to effect the proper set in its bent shape. The arrangement shown permits automatic slacking off of the total tension in the structural element, the pressure relief valve 78 acting to prevent the total pressure within the hydraulic cylinders exceeding the amount for which the valve 78 is set. This value, of course, is readily set or changed at will. It may happen, then, that the plungers 71, 72 are permitted to approach one another rather than to separate during the bending action, and yet the objective is accomplished of maintaining a sufficient total tension in the element that the neutral axis of the structural element is displaced substantially to or inwardly of the interior margin of the bend.

Various forms of mechanism and various modifications of the method have been described, yet clearly various others may be devised which still embody the present invention. The methods and machines herein described are therefore to be taken as illustrative only, and not as restrictive of the scope of the invention, and its scope is not to be restricted except as may be specified in the claims.

What we claim as our invention is:

1. A machine for bending elongated deep-webbed structural elements, comprising a pair of spaced fixed supports, a pair of clamps and a link supporting each clamp from its corresponding support, for movement relative to the latter, a form interposed between the fixed supports, shaped to the desired curvature, means to move said form transversely into engagement with the clamp-held element, to bend it in the general plane of its web, and a pair of arms each secured at one end to the form, and each operatively connected at its opposite end to the respective clamp-supporting links, and by transverse movement of the form cooperating as a toggle linkage with the corresponding clamp-supporting link to effect permanent elongation of the element during bending.

2. A machine for bending elongated deep-webbed structural elements, comprising a form shaped to the desired curvature, and vertically movable, a fixed support at each end of the form, two pairs of toggle links pivotally connected by horizontal axes, one pair at each end of the form, one link of each pair being pivotally connected to the form, and the other link of each pair being pivotally connected to the adjacent fixed support, the two links of each pair being arranged, prior to initiation of bending, in dog-leg relation, two clamps, one carried by one link of each pair, for securement to opposite ends of the structural element, and means to move the form vertically relative to the fixed supports, thereby shifting the form-carried link pivot, and moving the toggle link pairs towards aligned position, to stretch the structural element.

3. A machine for bending elongated deep-webbed structural elements, comprising a form shaped to the desired curvature of such an element, holding means engageable with one end of such element to resist lengthwise pull on the element, an arm pivotally connected at one end to said form, a second holding means carried by the swinging end of said arm, for engagement with the end of said element remote from that end which is engaged with the first holding means, said arm and form being relatively proportioned and arranged so as to incline said arm from its pivot upon the form outwardly at a small angle to each successive tangent to the form which the element makes throughout a major portion of the bending, a support, the form and said support being relatively movable transversely of the element, a link pivotally connected between the support and said arm, and in the initial rectilinear condition of such element being disposed at an inward inclination towards the form, the link and arm being relatively proportioned and arranged to swing said arm towards the form upon relative movement of the form and support, to bend the element about the form, and coincidentally to stretch the element during bending.

4. A machine for bending elongated deep-webbed structural elements, comprising a pair of spaced-apart supports, a pair of holding means each engageable with one end of such an element, a link supporting each holding means from its corresponding support, for movement relative to the latter, a form interposed between said supports, shaped to the desired curvature, means operable to effect relative movement between said form and said supports, to engage said form with an element so held, and to bend such element in the general plane of its web, and a pair of arms each secured at one end to the form, and each operatively connected at its opposite end to the respective links, and by such relative movement of the form and supports cooperating as a toggle linkage with the corresponding link to effect permanent elongation of the element during bending.

5. A machine for bending elongated deep-webbed structural elements, comprising a pair of spaced-apart clamps engageable with the respective ends of such an element, a pair of spaced fixed supports corresponding to the respective clamps, a form interposed between the fixed supports, shaped to the desired curvature, means to

move said form generally parallel to the element's web into engagement with the element to bend it, two pivotally joined links, one whereof is pivotally connected to said form and the other of which is pivotally connected to one of said fixed supports, one of said clamps being pivotally mounted upon one of said links, for guided movement therewith during and as a result of, and in predetermined relation to such movement of said form, along a predetermined path away from the other clamp, as measured along the element, to effect permanent elongation of the clamp-held element to a predetermined extent during at least a portion of such movement of the form.

6. A machine as in claim 5, including a second pair of pivotally joined links similarly connected, upon one whereof the second clamp is pivotally mounted, whereby such second clamp is similarly guided and moved relative to the first such clamp.

7. A machine for bending elongated deep-webbed structural elements, comprising a pair of supports, a form curved in a given plane, and located between said supports, means to effect relative operative transverse movement in such plane between the supports and said form, to bend a work-piece about such form, a pair of work-engaging clamps disposed at opposite sides of the form, and two sets of links, the links in each set being pivotally connected to each other and to the support, the form, and the clamp, at the respective sides of the form, the links being relatively sized and having their said pivotal connection arranged, relative to the curvature of the form, to effect tensional stretching of the work-piece as the form and supports are relatively operatively moved.

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