

May 21, 1968

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3,383,900

METHOD OF SIZING OF METAL OBJECTS

Filed Aug. 13, 1965

2 Sheets-Sheet 1

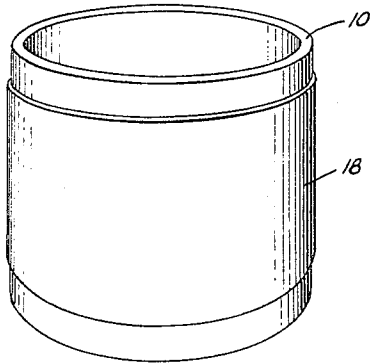


FIG. 1

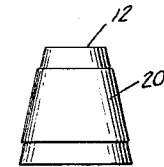


FIG. 2

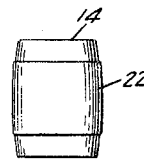


FIG. 3

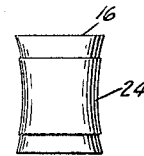


FIG. 4

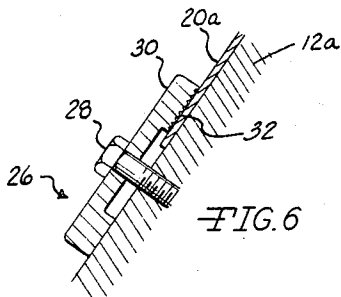


FIG. 6

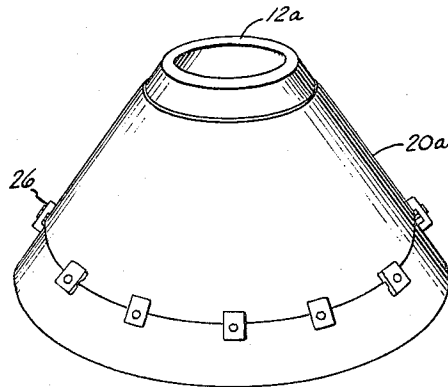


FIG. 5

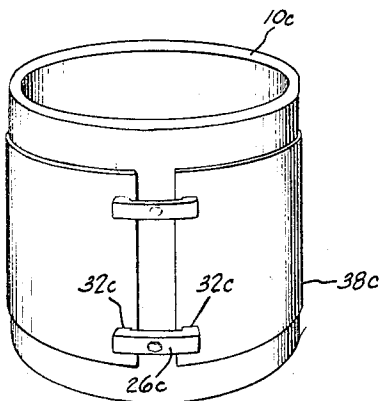


FIG. 8

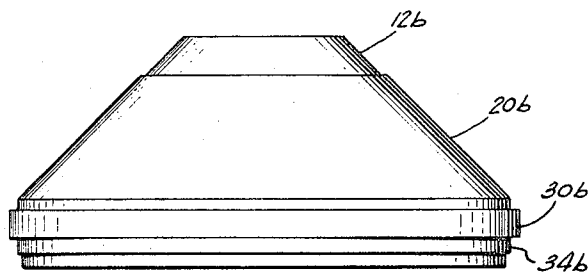


FIG. 7

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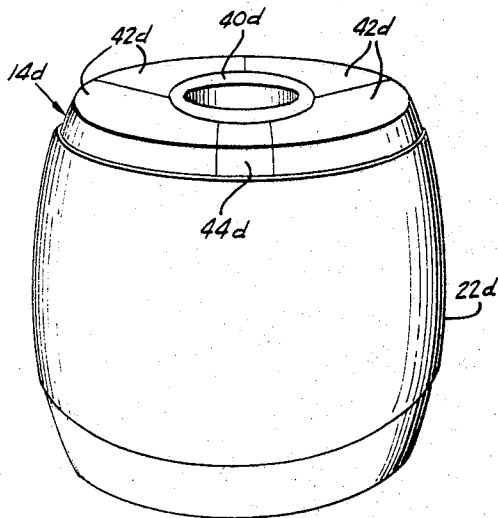


FIG. 9

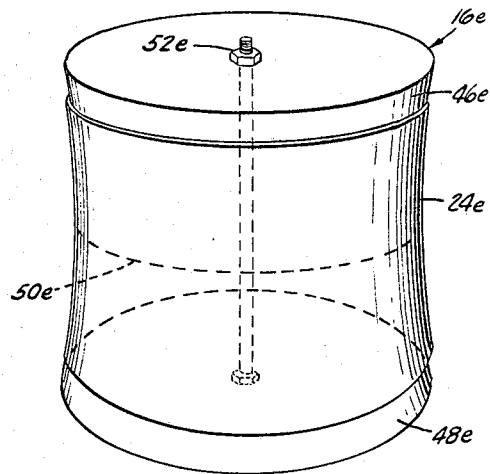


FIG. 10

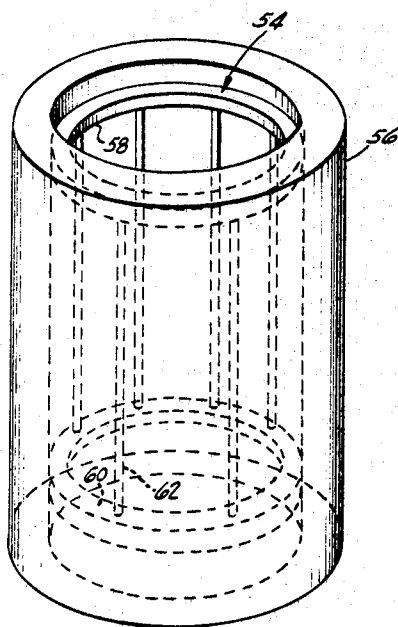


FIG. 11

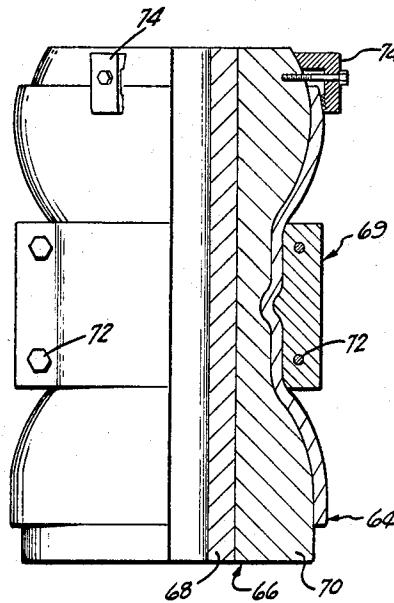


FIG. 12

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1

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METHOD OF SIZING OF METAL OBJECTS

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ABSTRACT OF THE DISCLOSURE

A method of precision forming a metallic article to predetermined dimensions by thermally expanding the article with respect to a forming element having a different coefficient of thermal expansion. The article and the element are fitted together in mating relationship with the element being selected from a material such that the male member of the mated parts has a higher coefficient of thermal expansion than the female member. The fitted members are then heated to a predetermined temperature to which the article will be accurately sized and shaped. A product which is particularly adapted to be formed by this method is a titanium alloy belt of large size.

The present invention relates to an improved method of precision forming metal structures or articles. In particular, it relates to such a method wherein the differential thermal expansion of at least two mating parts is utilized to size accurately at least one of the parts.

Numerous similar methods of fitting or sizing are known in the prior art, and in order to better understand the present invention, some of these methods will be described, and the present invention will be distinguished from such prior methods.

A method of fitting parts together which is old in the art and which has certain similarities of the present invention is shrink fitting or expansion fitting of one metal component to another. Thus, iron tires have been expanded by heating them, placing them over wooden wheels and allowing them to cool and shrink tightly into place. Similarly, valve seat insert rings have been refrigerated sufficiently to fit loosely into a recess so that upon warming and growing the fit will become tight. In most of such cases, care must be taken to avoid excessive effective deformation as cold work, thereby leaving too much distortion in the part when temperature equilibrium is attained.

A temporary shrink fit for exerting pressure to effect brazing or welding at an interface between a core and a sleeve is also known wherein a core of high coefficient of thermal expansion is used with a sleeve of a lower coefficient. The two parts are made to fit as close as is mechanically possible, and they may even be sized together after assembly. Subsequent heating with a brazing compound between the two parts then generates pressure between them, causing the brazing to occur at the interface when the temperature is sufficiently high.

Another known method is that of inflating a cylinder by the internal expansion of a bulk material in which the confined material has a higher coefficient of thermal expansion than the metal container, as is disclosed in U.S. Patent No. 1,409,562. This method has the drawbacks of the part being subjected to greater permanent expansion at this sections, greater permanent expansion at sections which are hotter, difficulty of sealing the expansion material at part openings where the gauge is thin, and a bulging of areas not restrained by the sealing or capping members, or uneven bulging of areas subject to disproportionate forces when the shape of the part is not symmetrical.

It is also known, as shown, for example in U.S. Patent No. 926,898, to size hollow sleeves and similar articles

2

by heating them and dropping them over a cold mandril so that they will size themselves by distortion during shrinking. This method, however, has fundamental drawbacks stemming from the fact that the final sizing is done cold. This means that the sleeve will form itself by cold-working and can also be stretched to its elastic limit in the final condition. These forces are so large that forcible removal could break the part unless internal disassembly of the form with parting lines is used. Residual cold-work can lead to subsequent distortion upon annealing or aging. This would be particularly true if the part were not symmetrical. To insure that excessive cold-work which may be destructive is not imparted, accurate machining of the part to be sized is necessary. Therefore, the parts as well as the form must be accurate to start with, greatly diminishing the value of the final sizing operation. Another difficulty that occurs when using this prior method is that of handling relatively light gauge metal assemblies during the step of fitting the assemblies on the cold mandril when the assemblies are sufficiently hot to be soft and formable.

With the foregoing prior art teachings in mind, it is one of the objects of the present invention to provide an improved method of precision forming metal articles or structures utilizing differential thermal expansion of mating parts.

According to the present invention, a method is carried out in which there are several novel aspects in the steps employed and in the results obtained. Briefly, the method comprises constructing a male form from a metal of high coefficient of thermal expansion (usually a stainless steel) or a female form of a low coefficient of thermal expansion (Kovar or suitable ceramics). The preform or part to be formed and sized is then placed loosely into or over the form, as the case may require, and the assembly of mating parts is placed into an oven and heated. Differential thermal expansion then produces expansion-forming of the female part by the male form, or a forming by up-setting the male part which is expanded in the female form. Final deformation is accomplished at the elevated temperature chosen to minimize residual elastic stress (as low as 100–200 p.s.i.) and sufficient time can be taken at this temperature to achieve the annealing desired. Thereafter, the assembly is cooled, and the loose, formed part can be removed readily.

As will be apparent to those skilled in the art, this method does not require the exact initial fit of the brazing method; the preform need not be accurate in form or dimensions; the final forming can be to the same degree of precision attainable in machining the male or female forms that are used; handling complex, light gauge preforms or structures when they are hot and weak (virtually impossible if inert gas is necessary to avoid oxidation) is not required; it is possible to do two shapes at a time where it is essential that the double part hold itself onto a double form or be confined entirely within a double cavity; a succession of forms can be used for progressive forming to an extent not possible with one heat; successive pieces can be formed not only to the accuracy desired but exact duplicates can be made from piece to piece within the limits of the oven temperature control. For example, a temperature variation of $\pm 10^\circ \text{F.}$ would produce a 60 inch stainless steel mandril dimension of $60.000 \pm .006$. However, "soaking" could greatly reduce this variation due to the good heat conduction in the mandril.

Although the type of forming comprising the present invention can be thought of as analogous to "stretch-forming," it actually has a fundamental difference. In stretch forming such as is shown, for example, in U.S. Patent No. 3,021,887, the part being stretched must slide on the form over which it is being pulled and elongated.

This tends to produce more deformation along paths of low thickness dimensions, and other variations stemming from more or less drag over certain areas of the form. In "expansion" forming, such as is used in connection with the present invention, the high coefficient of friction between dry metals or mating parts produces a "glued on" effect which is essential to uniform stretching despite variations in gauge of the part. Thus, as the mandril utilized in the present invention expands uniformly, the female part being formed thereon is expanded uniformly.

Other objects, advantages and features will become apparent with the disclosure of the preferred embodiments of the invention in the specification, claims and drawings, in which:

FIGURE 1 shows one assembly of an article on an expansion element that may be used in the method comprising the present invention;

FIGURES 2, 3 and 4 are modifications of the assembly of FIG. 1;

FIGURE 5 is another modification of the assembly of FIG. 1 wherein clamps are employed in holding the article on the expansion element;

FIGURE 6 is a fragmentary enlargement in section showing the clamp mechanism of FIG. 5;

FIGURE 7 shows a modified clamp mechanism for holding an article on an expansion element;

FIGURE 8 shows still another assembly, similar to that of FIG. 1, but employing clamp mechanisms for holding the article in place on the expansion element;

FIGURE 9 shows still another assembly wherein a split expansion element is employed for forming an article having a convex surface;

FIGURE 10 shows still another assembly wherein another form of split expansion element is employed;

FIGURE 11 shows still another assembly wherein the article comprises the male or internal part of an assembly; and

FIGURE 12 shows, partially in section, another assembly which utilized various arrangements illustrated in the other figures of the drawings.

Before explaining the present invention in detail, it is to be understood that the invention is capable of other embodiments and of being practiced or carried out in various ways. It is also to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation.

Referring now to the drawings, the various assemblies illustrated will be described in greater detail. As indicated by the drawings the various assemblies represent male and female parts, and in FIGS. 1-10, inclusive, the male part is the expansion element and the female part, which is fitted on the expansion element, is the article or structure that is to be sized and shaped accurately to predetermined specifications. In FIG. 11 the male and female arrangement is reversed so that the article or structure comprises the male part and the female part is the low expansion element into which the male part is fitted. FIG. 12 shows an assembly of parts wherein a plurality of expansion elements are utilized with an article and represent male and female parts so as to size accurately an article having irregular configurations. In all of these various assemblies the male part will be made of a material having a greater coefficient of thermal expansion than the material of the female part.

In FIGS. 1-4, the expansion elements are indicated, respectively, by reference numerals 10, 12, 14 and 16 and the articles, respectively, by reference numerals 18, 20, 22 and 24. In each instance the expansion element will be made of a material having a greater coefficient of thermal expansion than the article. Thus, by way of example, if the articles should be preformed roughly to the configuration of a titanium or titanium alloy belt, the expansion elements will be made from suitable metals, such as a stainless steel, having a higher coefficient of thermal expansion than that of the titanium or titanium

alloy of which the belt is made. Also, it is to be understood that the shapes of the elements 12, 14, and 16 are exaggerated, so as to show more readily the configurations thereof. Normally, these elements can be one piece elements only to the extent that the article can be removed therefrom after shrinkage of the element following the sizing step at an elevated temperature. Thus, the expansion element 16 can have a difference in radius between the horizontal midsection and an end section only of sufficient magnitude to permit removal of the smallest radius of the article 24 when in its cold state. Otherwise, the sized article would have to be cut to remove it from the expansion element. It will be observed that this same situation exists with respect to the assembly of FIG. 3 wherein the upper or lower edge of the belt 22 must have a sufficiently large dimension in its cold state which will allow removal of the belt from the element 14. When the finished articles require shapes and dimensions which prevent their removal from a one piece element or which normally prevent their retention on such one piece element, other arrangements are required, which will now be described.

When it is desired to size articles having frusto-conical shapes such as is shown in FIG. 2 it may be necessary to utilize clamping means to prevent the article from shifting axially on the expansion element during the sizing operation. For this purpose a plurality of clamp mechanisms 26 may be employed with the element 12a. Each of these mechanisms 26 comprises a bolt 28 threadably secured to the element 12a and a clamp member 30 having a serrated surface 32 for holding the article 20a against axial displacement during thermal expansion of element 12a.

Still another arrangement that may be used in connection with expansion forming a conical or frusto conical article or structure 20b is shown in FIG. 7. Here the article 20b has an integral skirt 34b over which a clamp ring 36b is fitted. This ring can be made of any suitable metal or material having a relatively low coefficient of thermal expansion so that when the heating step is performed, the expansion of the element 12b relative to the clamp ring 36b will result in the article 20b being firmly held against axial displacement on element 12b.

In some instances it may be desired to size a sheet of metal, and for this purpose a clamping arrangement such as is shown in FIG. 8 may be used. Here the element 10c may be used with a pair of clamping mechanisms 26c, which are essentially the same as the mechanism 26 shown in FIG. 6, except that the clamping mechanisms 26c will have serrated gripping portions 32c for holding the article 38c from circumferential displacement relative to the element 10c during thermal expansion of the latter.

Next, expansion elements that are split or in sections will be described for use in connection with articles or structures having curvatures or shapes which create problems of separating the sized article from the expansion element. These elements will be described with reference being made to FIGS. 9 and 10.

In FIG. 9 is shown a barrel shaped article or structure 22d mounted on a multi-piece expansion element 14d. Here, the element 14d is constructed and arranged to allow its disassembly after the sizing operation so that article 22d can be removed without destroying or altering the accurate sizing of article 22d. As shown, the element 14d has a cylindrical core 40d surrounded by a plurality of segments 42d and a key 44d. The latter is the last member to be inserted in place when making the assembly shown in FIG. 9 and the first to be removed after the sizing operation.

In FIG. 10 is shown another split element construction wherein the element 16e is split into two segments, 45e and 48e along the dividing plane shown in broken lines at 50e. There two segments 46e and 48e can be secured together or separated axially by means of the tie rod means 52e. By virtue of this arrangement, the ther-

5

mal expansion element 16e can easily be fitted into a preform of article 24e, and can be removed from sized article 24e after the thermal expansion step of operation.

Attention is now directed to FIG. 11 wherein is shown an assembly in which the article 54 is positioned internally of the sizing element 56. The illustrated article 54 can be any desired configuration or construction, and as shown here is a frame work or cage which is to be accurately sized radially. The article has rings 58 and 60 at its opposite ends which are joined by a plurality of axially extending rods 62. The sizing element 56 will be made of a material, such as a ceramic product, which has a lower coefficient of thermal expansion than that of the material of which the article 54 is made. Thus, when the heating operation is performed to a preselected temperature, the external dimensions of rings 58 and 60 of the article 54 will be accurately sized by the upsetting action that occurs. If desired, the internal dimensions of rings 58 and 60 can also be accurately sized simultaneously by inserting another cylindrical element in the manner described with respect to FIG. 1. Also, the article being sized may be of a configuration requiring clamping mechanisms to be employed as will be readily understood by those skilled in the art.

Thus, in FIG. 12 is shown an article 64 of an irregular shape which has an internal or male expansion element 66 for sizing certain of its portions and an external or female expansion element for sizing other portions of article 64. As can be understood, the internal or male element 66 has a central cylindrical core 68 and segments 70 surrounding the latter. It can be seen that this element 66 is constructed essentially the same as the element described in connection with FIG. 9. Surrounding the article 64 is the female expansion element 69 which can be two semicircular rings of low thermal expansion material which are bolted together, as at 72. Also, if desired or necessary to prevent axial displacement of the article 64 during the expansion operation, a plurality of clamping mechanisms 74 may be employed. In this assembly, the element 66 must necessarily have a coefficient of thermal expansion greater than that of article 64 and the element 69 must have a coefficient of thermal expansion less than that of article 64.

In carrying out the present invention, a finished article can be obtained which is characterized by its accurate dimensions and desired internal stress conditions. It is necessary to form to accurate and predetermined dimensions the expansion elements for use with preforms of an article of known thermal properties. This is accomplished by first establishing the temperature to which the article should be heated for sizing it where essentially no elastic return will occur. Then it must be determined what the dimensions of the article should be at this elevated temperature so that it will have the desired dimensions at the original or normal temperature. Thereafter, the dimensions of the expansion element must be established so that when the assembly of the element and article are heated to the elevated temperature, the expansion element will expand the article to the required dimensions at the elevated temperature. Thereafter, when cooling the assembly the article will have the desired finished dimensions. The procedure to be followed will now be described in connection with the forming of a relatively large sheet metal belt having accurate dimensions and being of true "cylindricity."

A true cylinder of 6Al-4Va titanium alloy was desired with a wall thickness of 0.028 ± 0.001 in. and a precise diameter of 57.536. The height of the cylinder was to be 51 in.

To expansion form a cylindrical preform, produced by welding a plurality of sheets of metal together, to the size and true "cylindricity" desired it was necessary to predetermine the size of a stainless steel cylinder to be used for this purpose. This was done as follows:

The stainless steel chosen was a grade containing 25%

6

chromium and 20.5% of nickel (Allegheny Ludlum #310). This metal has good oxidation resistance and good strength up to 2100° F. and its coefficient of thermal expansion is 9.76×10^{-6} in. per in. per degree, F. over the range of 70 to 1200° F. This latter temperature was chosen because of the high degree of plasticity of the titanium alloy at this temperature (see table below). The titanium alloy's coefficient of thermal expansion is 5.6×10^{-6} in. per in. per degree F. Because the titanium cylinder outside diameter at room temperature is to be 57.539, the inside diameter at 1200° F. would be

$$[57.539][1 + 5.6 \times 10^{-6} \times (1200 - 70)] - (2)(.028)$$

or

$$(57.539)(1.00633) = 57.903 - .056 = 57.847$$

This means that the stainless steel cylinder should have an outside diameter of this dimension at 1200° F. At room temperature, then, the stainless steel cylinder should be:

$$[57.847][1 - 9.76 \times 10^{-6}(1200 - 70)]$$

or

$$(57.847)(.988971) = 57.209$$

A stainless steel cylinder of the material specified was then formed of plate $\frac{1}{16}$ in. thick, welded, rough turned, annealed and turned on a vertical boring mill. Its finished dimensions were:

Distance from top (Inches):	Diameter (inches)
3	57.209
13	57.208
23	57.208
33	57.210
43	57.212
53	57.212
55	57.212

Titanium alloy sheets were obtained with a flatness of 3% (waves of 3 high in every 100 of length), which were ground to the desired thickness and then welded into a cylinder with two transverse and one longitudinal welds. A diameter of 57.350 was sought as the initial size to allow easy placement on the cylinder and an expansion of about 0.2 in., but actual diameters obtained were as follows:

6 in. from top edge	57.369
Middle	57.345
6 in. from bottom edge	57.339

In addition to the lack of constancy in diameter and flatness variation, distortion along the welds was prominent. Waves as great as $\frac{1}{8}$ in. high over an amplitude of approximately 6 in. were the result of distortion from the welding.

The welded titanium cylinder was then placed over the stainless cylinder and the assembly placed in an oven where it was heated to 1200° F. ± 10 . Upon cooling, the titanium cylinder was measured and found to have the following dimensions:

Distance from top (Inches):	Diameter (inches)
3	57.537
12	57.539
21	57.534
36	57.536
48	57.538

The removal of waves by the expansion effected was as nearly absolute as measurement could determine. Areas of the belt were pressed lightly to a surface plate in an identical manner both before and after expansion. The distortion waves that existed prior to the thermal expansion operation were found to have been completely eliminated.

In the example given above it is possible that dents in the sheet could be so sharp and deep that the expansion

forming described above would not remove them. The flattening of such dents could be accomplished by placing a cylinder with low thermal expansion over and around the titanium alloy cylinder after it is placed on the stainless steel cylinder. Then, as the temperature of the assembly is increased, the titanium alloy cylinder, expanded by the stainless steel cylinder, would come into contact with and then be pressed hard against the more slowly expanding outside cylinder.

The chief requirement for an alloy to be used as the forming shape is high strength at the maximum temperature to be used compared to the strength of the metal to be formed. Resistance to oxidation and reasonably good machineability are also desirable. Fortunately, the high expansion alloys are stainless steels with excellent strength and oxidation resistance and can be selected with either high or low expansion properties. Ceramic materials are useful for the low expansion forms but care is needed to avoid over-stressing these brittle materials. For the cylinder expansion described above the stainless steel selected for the forming cylinder has the following composition:

Standard analyses, percent

C	max	.25
Mn	max	2.00
P	max	.045
S	max	.03
Si	max	1.50
Cr		24.00-26.00
N		19.00-22.00

Yield strengths of the above material and the 6Al-4V titanium alloy formed are as follows:

Temperature, ° F.	Yield Strength—P.s.i.	
	6-4 titanium alloy	Stainless
600	70,500	25,700
1,000	58,000	21,200
1,100	3,000	23,400
1,200	(¹)	22,600
1,500	(¹)	19,700

¹ Not reported.

In addition to the specific strength advantage at high temperature, the use of forms massive in comparison to

the piece being formed multiplies the overall strength advantage.

From the foregoing, it can be seen that a method has been described which can be used to size accurately articles of male or female configuration. Furthermore, that such articles will have desired physical properties when sized and the method can be repeated to form a plurality of such articles of uniformly the same dimensions.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of precision forming a metallic article to accurate predetermined dimensions comprising the steps of performing a metallic article approximately to said predetermined dimensions, fitting the preformed article as the male member into mating relationship with a female element having a lower coefficient of thermal expansion than that of the article and having dimensions accurately established in proportion to said predetermined dimensions, heating the element and the fitted preformed article to an elevated temperature sufficient to minimize the elastic return of the article and to conform accurately at said elevated temperature the dimensions of the article to the dimensions of the element, said article being conformed to the dimensions of the element at the elevated temperature solely by relative differences in thermal expansion of the article and the element, the dimensions of the element being pre-selected so that the dimensions of the article are changed by forces of a magnitude sufficient to create stresses in said article above the elastic limit of the metal of the article at said elevated temperature, and thereafter cooling the article and the element so as to effect changes in their relative dimensions to permit removal of the accurately sized article from the element.

2. A method according to claim 1, wherein said female member is constructed from a low thermal expansion ceramic material.

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