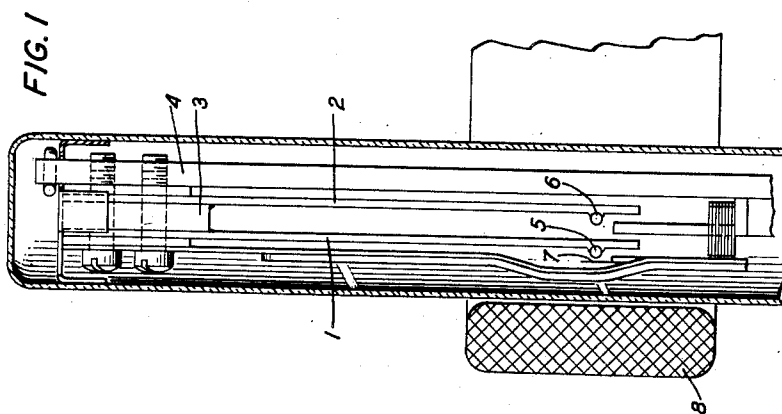
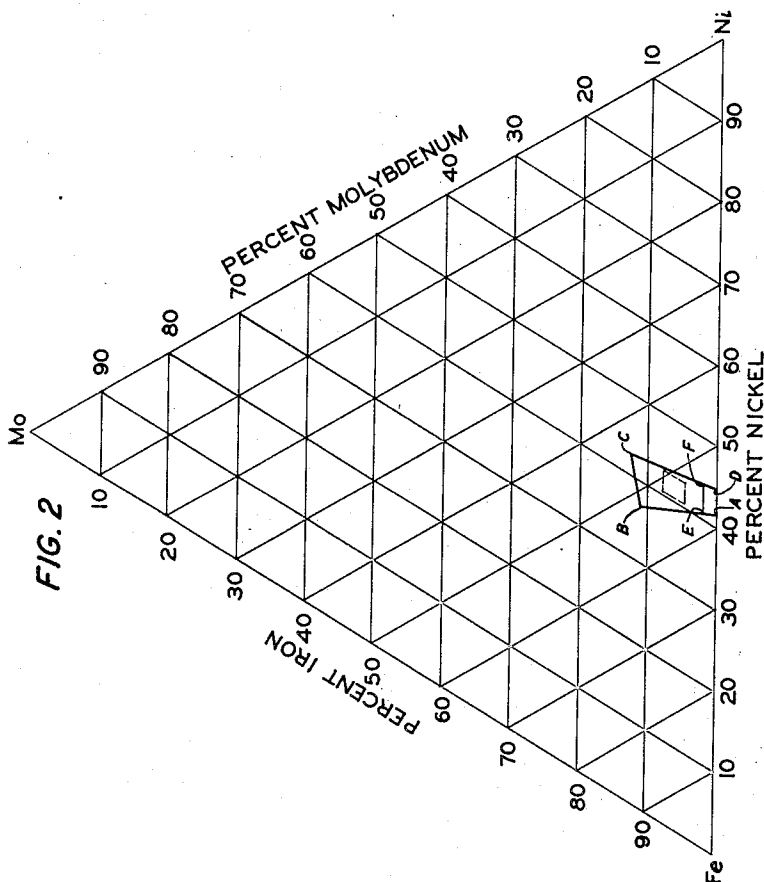


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LOW ELASTIC COEFFICIENT BODIES, DEVICES EMBODYING
THEM AND METHODS OF PRODUCING THEM
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LOW ELASTIC COEFFICIENT BODIES, DEVICES EMBODYING THEM AND METHODS OF PRODUCING THEM

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This invention relates to metal bodies the modulus of elasticity of which varies but little over a wide temperature range, to devices which function through the elastic distortion of such bodies, and to methods of forming such bodies.

When devices which function through elastic distortion of a metal member, such as devices embodying mechanical vibratory elements, such as vibrating reeds, tuning forks, or devices embodying springs for applying or measuring force, are designed to operate under widely varying climatic conditions, and when it is required that the operating characteristics of these devices be essentially constant under these varying conditions, it is necessary that the member be a body which exhibits as little change in modulus of elasticity as possible over the entire temperature range to which the device may be subjected. In order to provide the temperatures encountered, for instance, in aircraft at high altitudes or in tropical climates, in proximity to other apparatus which may generate heat, it is ordinarily necessary, in order to achieve these essentially constant operational characteristics, that provision be made for limiting any changes in the modulus of elasticity to small values over the temperature range of -50°C. to 150°C.

It has been known that binary iron-nickel alloys containing in the vicinity of 45 per cent nickel have a temperature coefficient of modulus of elasticity which is zero in the vicinity of room temperature. However, this low temperature coefficient of elasticity obtains for fully annealed material over only a very small temperature range and is, therefore, of little value in insuring a small change in modulus of elasticity over a wide temperature range such as that referred to above. The present invention is based upon the fact that the range over which the temperature coefficient of elasticity remains small in iron-nickel alloys (which may contain molybdenum as well as other modifying ingredients) can be broadened by cold reduction of bodies of the alloys and the fact that the position on the temperature scale at which these low values of coefficient occur can be controlled by control of the composition of the alloy, the degree of cold working and the subsequent heat treatment. Bodies of such alloys, when cold reduced and subsequently heat treated, can be given a stable average temperature coefficient of modulus of elasticity which has a low value over the temperature range set forth above.

A type of apparatus in which bodies so produced can be utilized is exemplified by vibrating

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reed selector switches, the construction and operation of which can be most readily understood by reference to the accompanying drawing, in which:

5 Fig. 1 is an elevation in section of a portion of a vibrating reed selector switch; and

Fig. 2 is a triaxial diagram on which is shown the range of alloys utilized in carrying out the present invention.

10 The critical elements in the vibrating reed selector switch shown in Fig. 1 (which switch is more particularly described and claimed in the copending application of G. E. Perreault, Serial No. 782,528, filed October 28, 1947, which issued as Patent 2,502,339 on March 28, 1950) are the vibrating reeds 1 and 2. These two reeds are separated at one end by a metallic spacer 3 and are fastened at that end to a support 4. The two reeds and spacer together make up a tuning fork. The reeds 1 and 2 carry tuning bars 5 and 6, respectively, which extend beyond the edges of the reeds so that their ends can be bent in order to change the vibrational frequency of the reeds. An electrical contact member 7 is so mounted with respect to the tuning bar 5 on the reed 1 that it is out of contact with the tuning bar while the reed is stationary, but it makes periodic contact with the tuning bar when the reed is vibrated. The switch is provided with two external terminals (not shown) one of which is electrically connected to the contact member 7 and the other of which is electrically connected through the reed 1 to the contact bar 5.

35 A plurality of the assemblies described above (only one being shown) are positioned side by side within a common surrounding magnetic winding 8. The reeds in each selector switch unit are tuned to a frequency different from that of the reeds of the other switch units within the magnetic winding. In the operation of the selector the magnetic winding is fed with an alternating current. When the alternating current is of the same frequency as the natural frequency of vibration of the reeds within one of the selector switch units, the resulting alternating magnetic field causes the vibration of the reed. The vibration of the reed establishes periodic contact between the reed and the contact member in that switch. By supplying currents of different frequency to the magnetic winding any one of the switches may be actuated as desired.

50 The vibrating reeds of these switches are illustrative of elements operating through elastic distortion which can be fabricated according to the present invention so that their operating

characteristic, in this case frequency, does not vary excessively over a wide temperature range.

The substantially isoelectric bodies of the present invention can be formed with a modulus of elasticity which changes not more than five parts per thousand over the entire temperature range of -50°C. to 150°C. by using alloys having compositions falling within the quadrangle A, B, C, D on the ternary diagram shown in Fig. 2. This figure represents a ternary diagram for the system iron-nickel-molybdenum in which the three coordinates are weight per cent nickel, weight per cent iron, and weight per cent molybdenum. The quadrangle referred to above is formed by straight lines joining the points A, B, C and D.

Point A represents a composition of 41.5 per cent nickel and 58.5 per cent iron. Point B represents a composition of 37 per cent nickel, 11 per cent molybdenum and 52 per cent iron. Point C represents a composition of 42.5 per cent nickel, 45.5 per cent iron and 12 per cent molybdenum. Point D represents a composition of 44.5 per cent nickel and 55.5 per cent iron. All alloys falling within this area can be treated according to the present invention to yield the results set forth above.

Preferably, alloys containing at least 2 per cent molybdenum are used. This preferable range of compositions containing at least 2 per cent molybdenum is defined by the area EBCF on the diagram of Fig. 2. The point E on this diagram represents a composition of essentially 41 per cent nickel, 2 per cent molybdenum and 57 per cent iron. The point F represents a composition of essentially 44 per cent nickel, 2 per cent molybdenum and 54 per cent iron.

Particularly for the application to the vibrating reed selector switches described above, the preferable range of alloy compositions lies between 38.5 per cent nickel and 43 per cent nickel, and between 4.5 per cent molybdenum and 9.5 per cent molybdenum, the remainder being iron. An even more desirable range lies between 40.5 per cent nickel and 43 per cent nickel and between 4.5 per cent molybdenum and 8 per cent molybdenum, the remainder being iron. This latter range of compositions is shown as the dotted quadrangle on the diagram of Fig. 2. An alloy well suited for use as a vibrating reed in a selector of the type described above contains 43 per cent nickel, 5 per cent molybdenum and the remainder iron.

To the basic iron-nickel or iron-nickel-molybdenum alloys referred to above may be added certain modifying ingredients which alter the other properties of the alloy but do not have a substantial effect upon the modulus of elasticity. Thus, up to 2 per cent manganese may be added to improve the working properties of the alloy. Up to .25 per cent carbon, up to 6 per cent aluminum and up to 5 per cent silicon may be present in the alloys and serve to harden them as well as having minor effects on certain other properties. Incidental impurities which have no effect upon the modulus of elasticity may also be present, though in total amount less than 2 per cent and preferably less than 1 per cent.

The alloys referred to above are given the advantageous properties of the present invention by first subjecting them to a cold working operation, such as swaging, rolling, drawing or the like, which reduces their cross-sectional area and then subjecting them to a low temperature anneal at a temperature substantially above any tempera-

ture to which the bodies may be expected to be exposed during their normal operation. The area reduction induced by cold working should be at least 3 per cent and preferably at least 5 per cent in order to have the required effect upon the alloy. The upper limit to the amount of cold reduction is set only by the amount to which the alloy can be subjected without fracture. This cold working results potentially in the required broadening of the low temperature coefficient of modulus of elasticity of the alloys referred to above over the broad temperature range referred to above.

However, in this cold worked state the modulus of elasticity will be altered by a change in the crystalline condition of the alloy as the temperature is raised above that at which the cold working took place. In order to stabilize the alloy against such a change in modulus it is necessary to anneal it at a temperature above that to which the alloy will be subjected during its normal operation but below the temperature for full recrystallization of the alloy. Therefore, with an operating range of -50°C. to 150°C. as set forth above, it is necessary that the cold worked body be annealed at at least 150°C. Ordinarily this annealing will take place in the range of 200°C. to 750°C. or preferably in the range of 300°C. to 600°C. A convenient annealing temperature which yields good results is 400°C. The annealing time is not critical, it being necessary only that all parts of the body be allowed to reach the annealing temperature. A convenient annealing time is from one hour to five hours.

Treatment within the range of conditions as set forth above, when applied to the range of alloys described above, results in bodies having a modulus of elasticity which varies by not more than .5 per cent over the range of -50°C. to 150°C. By a selection of alloy compositions and conditions of treatment within this range considerably smaller changes in modulus can be achieved.

If modulus of elasticity for any of these bodies is plotted against temperature, there occurs somewhere over the temperature scale a point in the curve at which the value of modulus is a minimum, which point corresponds to a zero temperature coefficient of modulus of elasticity. In order to secure the smallest change in modulus over the temperature range of -50°C. to 150°C. , it is necessary to make the curve in the vicinity of this minimum as shallow as possible and to cause the minimum to fall somewhere near the center of the temperature range.

As may be inferred from the statements above, the curve is made shallow by the operation of cold reduction. The alloys containing molybdenum are also somewhat more shallow than those which do not. The position of the minimum modulus on the temperature scale can be shifted by varying the composition of the alloy (within the ranges set forth above), by varying the degree of cold reduction, and by varying the annealing temperature.

In general, the point of minimum modulus on the temperature scale is shifted to a higher temperature with decreasing nickel content and with increasing molybdenum content in the alloy. The point of minimum modulus is also moved to a higher temperature by increasing the degree of cold reduction and by increasing the annealing temperature. By varying these factors one against the other, it is possible to bring the point of minimum modulus to that point on the tem-

perature scale which results in a very low over-all change in modulus over the entire temperature range.

The following four typical examples illustrate the low variation in modulus which can be achieved by the application of these principles. A binary alloy containing 42.7 per cent nickel, 0.66 per cent manganese and the remainder iron was subjected to a cold area reduction of 78 per cent and was then annealed at 400° C. The resulting body had a modulus of elasticity which changed by only .1 per cent over the range from -50° C. to 150° C.

Similarly, a ternary alloy of 42.1 per cent nickel, 5.1 per cent molybdenum, .37 per cent manganese and the remainder iron, which had a modulus of elasticity which changed only .15 per cent over the range of -50° C. to 150° C., was produced by subjecting a body of the alloy to a cold area reduction of 56 per cent and then annealing it at 400° C. A ternary alloy of 40.1 per cent nickel, 10.8 per cent molybdenum, .17 per cent manganese and the remainder iron, having a modulus of elasticity changing less than .025 per cent over the range of -50° C. to 150° C., was produced by subjecting a body of the alloy to cold area reduction of 5 per cent and then annealing at 400° C. An alloy of 38.4 per cent nickel, 10.7 per cent molybdenum, .13 per cent manganese and the remainder iron, having a modulus of elasticity changing less than .15 per cent over the range of -50° C. to 150° C., was produced by subjecting a body of the alloy to a cold area reduction of anywhere between 41 per cent and 67 per cent and then annealing at 400° C.

The invention has been described above as particularly applied to vibrating reed selector switches. It is apparent that the advantages of the invention can be employed in any device containing an element which functions through elastic distortion, as for instance in devices embodying a vibratory element such as a vibrating reed or a tuning fork. The invention will also be of value for use in devices utilizing springs for measuring or applying force or for other purposes, such as balance springs in clocks and watches. The invention has been described in terms of its specific embodiments and, since certain modifications and equivalents may be apparent to those skilled in the art, these embodiments are intended to be illustrative of and not necessarily to constitute a limitation upon the scope of the invention.

What is claimed is:

1. A metal element which functions through elastic distortion comprising a body of an alloy annealed, at a temperature above 150° C. and below the temperature of full recrystallization of the alloy, from a cold worked state produced by subjecting said body to a cold area reduction of at least 3 per cent, said alloy consisting of a composition defined within the area of an iron-nickel-molybdenum ternary diagram bounded by the quadrangle having as its corners the four points defined by (1) 41.5 per cent nickel and 58.5 per cent iron; (2) 37 per cent nickel, 11 per cent molybdenum and 52 per cent iron; (3) 42.5 per cent nickel, 12 per cent molybdenum and 45.5 per cent iron; and (4) 44.5 per cent nickel and 55.5 per cent iron; and, in addition to said composition, up to .25 per cent carbon, up to 2 per cent manganese, up to 6 per cent aluminum, and up to 5 per cent silicon, together with incidental impurities.

2. An element as defined in claim 1, wherein the cold worked state is that produced by a cold area reduction of about 78 per cent, the annealing is at about 400° C., and the alloy consists of about 43 per cent nickel, 0.66 per cent manganese and the remainder iron together with incidental impurities.

3. A mechanical vibratory element in which the change in natural frequency over the temperature range of -50° C. to 150° C. is small, said element comprising a body of an alloy annealed, at a temperature above 150° C. and below the temperature of full recrystallization of the alloy, from a cold worked state produced by subjecting said body to a cold area reduction of at least 3 per cent, said alloy consisting of a composition defined within the area of an iron-nickel-molybdenum ternary diagram bounded by the quadrangle having as its corners the four points defined by (1) 41 per cent nickel, 2 per cent molybdenum and 57 per cent iron; (2) 37 per cent nickel, 11 per cent molybdenum and 52 per cent iron; (3) 42.5 per cent nickel, 12 per cent molybdenum and 45.5 per cent iron; and (4) 44 per cent nickel, 2 per cent molybdenum and 54 per cent iron; and, in addition to said composition, up to 2 per cent manganese, up to 0.25 per cent carbon, up to 6 per cent aluminum, and up to 5 per cent silicon, together with incidental impurities.

4. An element as described in claim 3 wherein the annealing temperature is between 200° C. and 750° C. and the iron, nickel and molybdenum in the alloy are in the proportions of about 43 per cent nickel, 5 per cent molybdenum and 52 per cent iron.

5. A body, which exhibits only a small change in modulus of elasticity over the temperature range of -50° C. to 150° C., formed of an alloy annealed, at a temperature above 150° C. and below the temperature of full recrystallization of the alloy, from a cold worked state produced by subjecting a body of said alloy to a cold area reduction of at least 3 per cent, said alloy consisting of a composition defined within the area of an iron-nickel-molybdenum ternary diagram bounded by the quadrangle having as its corners the four points defined by (1) 41 per cent nickel, 2 per cent molybdenum and 57 per cent iron; (2) 37 per cent nickel, 11 per cent molybdenum and 52 per cent iron; (3) 42.5 per cent nickel, 12 per cent molybdenum and 45.5 per cent iron; and (4) 44 per cent nickel, 2 per cent molybdenum and 54 per cent iron; and, in addition to said composition, up to 2 per cent manganese, up to 0.25 per cent carbon, up to 6 per cent aluminum and up to 5 per cent silicon, together with incidental impurities.

6. A body as described in claim 5 wherein the cold area reduction is about 56 per cent, the annealing temperature is between about 400° C. and 600° C., and the alloy consists of about 41 per cent nickel, 5.1 per cent molybdenum, 0.37 per cent manganese and the remainder iron together with incidental impurities.

7. A body as described in claim 5 wherein the cold area reduction is about 5 per cent, the annealing temperature is about 400° C., and the alloy consists of about 40 per cent nickel, 10.8 per cent molybdenum, 0.17 per cent manganese and the remainder iron together with incidental impurities.

8. A body as described in claim 5 wherein the cold area reduction is between 41 per cent and 67 per cent, the annealing temperature is about 400°

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C. and the alloy consists of about 38 per cent nickel, 10.7 per cent molybdenum, 0.13 per cent manganese and the remainder iron together with incidental impurities.

9. The method of reducing the amount by which the modulus of elasticity of a metal body varies with temperature over the range of -50°C. to 150°C. , which comprises subjecting to a cold area reduction of at least 3 per cent, a body of an alloy consisting of a composition defined within the area of an iron-nickel-molybdenum ternary diagram bounded by the quadrangle having as its corners the four points defined by (1) 41 per cent nickel, 2 per cent molybdenum and 57 per cent iron; (2) 37 per cent nickel, 11 per cent molybdenum and 52 per cent iron; (3) 42.5 per cent nickel, 12 per cent molybdenum and 45.5 per cent iron; and (4) 44 per cent nickel, 2 per cent molybdenum and 54 per cent iron; and, in addition to said composition, up to 2 per cent manganese, up to 0.25 per cent carbon, up to 6 per cent aluminum and up to 5 per cent silicon, together with incidental impurities, and annealing said body at a temperature above 150°C. and below the recrystallization temperature of the alloy.

10. The method described in claim 9 wherein

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the annealing is carried out between 200°C. and 750°C.

11. The method described in claim 9 wherein the annealing is carried out between 300°C. and 600°C.

12. An element as described in claim 3 wherein the composition contains between 38.5 per cent nickel and 43 per cent nickel and between 4.5 per cent molybdenum and 9.5 per cent molybdenum, and wherein the annealing temperature is between 200°C. and 750°C.

13. An element as described in claim 3 wherein the composition contains between 40.5 per cent nickel and 43 per cent nickel and between 4.5 per cent molybdenum and 8 per cent molybdenum, and wherein the annealing temperature is between 300°C. and 600°C.

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