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CONSTANT COEFFICIENT MECHANICAL
ELEMENT

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The present invention relates to ferrous alloys. More particularly it relates to ferrous alloys intended chiefly for use in making elements which operate through elastic distortion and which depend for their usefulness upon the uniformity of their operation regardless of moderate temperature change, such as springs and mechanical vibratory elements such as tuning forks. It also relates to vibratory or other elements made from these alloys. More particularly, the invention is concerned with vibratory elements composed of alloys, the properties of which are such that a substantially constant frequency of vibration is maintained despite change in temperature; it is also concerned with springs made of alloys which impart to the springs a substantial uniformity of operation despite temperature change.

It is necessary that the frequency of tuning forks used for frequency standards and for timing, as in athletic timing systems and picture transmission systems, or those used for maintaining frequency on carrier telephone systems have a high degree of constancy. In carrier telephone systems, for example, it is desirable that the change in frequency with temperature be not greater than two or three parts per million per degree centigrade. Two primary factors are involved in the change of frequency of a vibratory element with temperature. One factor is the change in the mass distribution of the element due to the expansion or contraction of the metal with temperature change. In the case of a tuning fork or similar vibratory element which operates through flexure, such as a rod or reed, expansion of the metal causes an increase in frequency. Since most metals and alloys have a positive coefficient of expansion, an increase in temperature usually causes an increase in frequency. In order to counteract the undesirable characteristics caused by a high coefficient of expansion, it has been proposed to use invar, a nickel-iron alloy, having a coefficient of expansion which is substantially zero.

Although the use of invar overcame the disadvantages caused by expansion, it tended to aggravate the change in frequency due to the other factor, change of modulus of elasticity. As the modulus of elasticity increases, the frequency of vibration increases and as the modulus decreases, the frequency decreases. In most metals and alloys the modulus varies greatly with temperature. In the case of a tuning fork or a similar vibratory element the condition desired is that the coefficient of expansion and the coefficient of modulus of elasticity should be of op-

posite sign and have their values so related that they compensate one another as nearly as possible, thereby producing a constant frequency over a wide temperature range.

In an attempt to achieve this result, it has been proposed to add chromium to invar, thereby producing an element made up of an alloy of iron, nickel and chromium.

According to the present invention this result is achieved to a high degree and with advantages not obtainable with the chromium alloy by forming a vibratory element of an alloy containing principally iron, nickel and molybdenum in controlled proportions. By the use of molybdenum, the production of the alloy may be accurately controlled so as to produce consistently tuning forks whose coefficient of frequency is maintained at a uniformly low value. One reason for this ease of control is the purity of commercial molybdenum as compared with commercial chromium. Molybdenum can be purchased in a substantially and uniformly pure form whereas commercial chromium varies in purity from 97 to 100 per cent. Further, tuning forks made of the molybdenum alloy are not so sensitive to a change in molybdenum content as the chromium alloys are to a change in chromium content. Thus a change of .1 per cent of molybdenum results in a change in the temperature coefficient of frequency of one part per million per degree centigrade, whereas a change of .1 per cent in the chromium content results in a change in the temperature coefficient of frequency of from two to three parts per million per degree centigrade. Therefore the inherent inaccuracies in proportioning are not so likely to produce a fork outside of the permissible range of temperature coefficient of frequency in the case of the molybdenum alloy as in the case of the chromium alloy.

Another advantage of the alloy of the present invention is the fact that it is more readily machinable than are the prior used chromium alloys. Furthermore, the molybdenum alloys produce sounder castings than do the alloys of chromium since the latter are prone to the formation of gas pockets and inclusions, due largely to the high oxide content of commercial chromium.

A further advantage is that vibratory elements made of the molybdenum alloy are more constant in frequency over a period of time. All vibratory elements, even those which have been heat-treated, tend to "age" slightly causing a change in frequency over a period of time. The molyb-

denum alloys possess this defect to a much lesser extent than do the chromium alloys.

Although the principal constituents of the alloy of the present invention are iron, nickel and molybdenum, small amounts of other ingredients such as carbon, manganese, cobalt, vanadium, tungsten or other metals capable of modifying the properties of the alloy without causing too great a change in the temperature coefficient of frequency may be added. It is extremely desirable that small amounts of carbon be added since the presence of this element tends to render the alloy much more stable, thereby producing much more uniform results upon heat treatment. Since it is more desirable to work the alloy in forming the vibratory elements rather than to use castings, it is usually desirable to add small amounts of manganese, since this element renders the alloy more easily workable. Where the vibration of the element is to be maintained by a magnetic system, it is also desirable to add small amounts of cobalt, since this ingredient raises the Curie point of the alloy. In the case of low temperature coefficient alloys the Curie point is often very close to the normal operating temperature range of the tuning fork.

It is necessary that the constituents of the alloy be carefully proportioned in order to produce a temperature coefficient of frequency as close to zero as possible within the temperature range in which it is proposed to operate the vibratory element. A specific example of an alloy which has been found to be preferable for tuning forks is the following:

	Per cent
Iron.....	45.8
Nickel.....	34.8
Molybdenum.....	15.7
Manganese.....	2.2
Cobalt.....	1.2
Carbon.....	.3

These proportions may be varied somewhat within limits. However, since a change in the content of each constituent changes the coefficient of frequency, it is necessary that when the amount of one ingredient is changed, the amount of one or more of the others also be changed, in order to balance the effect of the first change. Thus an increase of .1 per cent molybdenum decreases the temperature coefficient of frequency one part per million at room temperature, an increase of .3 per cent nickel decreases the coefficient about two parts per million and an increase of .008 per cent carbon increases the coefficient about one part per million. With proper proportioning the constituents may be varied within about the following limits:

	Per cent
Nickel.....	32 to 42
Molybdenum.....	13 to 18
Manganese.....	0 to 3
Carbon.....	0 to .9
Iron.....	Remainder

The coefficient of expansion of the alloy remains fairly constant over a wide range of proportions and has a value in the neighborhood of about seven to eight parts per million per degree centigrade. Therefore, the principal variant is the temperature coefficient of modulus of elasticity. The proportions may be varied in each case to produce a coefficient of elasticity which will balance the coefficient of expansion in such a manner as to produce a material with a zero tem-

perature coefficient of frequency at the desired operating temperature.

Mechanical vibratory elements made from iron-nickel-molybdenum alloys have been described above. Similar alloys having proportions within the limits set forth above may also be used for making other elements, the characteristics of which are altered by expansion and by change in modulus of elasticity. Among such elements may be mentioned balance springs and springs for applying or measuring force. In each case, however, consideration must be given, in proportioning the constituents of the alloy, to the different characteristics of the element imparted to it by its shape and the different uses to which the element is to be put.

Thus in the case of a spirally coiled balance spring, as contrasted with a tuning fork, expansion of the metal causes a decrease in frequency of oscillation. Therefore, in order to compensate for expansion, the composition of the alloy must be so chosen that the temperature coefficient of modulus of elasticity is of the same sign as the temperature coefficient of expansion. By carefully proportioning the constituents of the alloy within about the limits set forth above the two chief factors affecting frequency can be made to compensate for one another so that the temperature coefficient of frequency at the desired temperature of operation is substantially zero. As in the case of the tuning fork or similar vibratory element, the principal ingredients of the alloy are iron, nickel and molybdenum but it is desirable to add one or more of carbon, manganese or cobalt or other elements capable of modifying the properties of the alloy.

In the case of springs for measuring or applying force the change in the characteristics of the spring with expansion and with change in modulus of elasticity depends upon the type of spring, whether it is a leaf, spiral or helical spring, and upon the type of force applied, whether it is compressive, tensional or torsional. In each case the manner in which the characteristics change with temperature will be determinable by one skilled in the art. The ingredients of the alloy can then be so proportioned within about the limits set forth above that the temperature coefficient of modulus of elasticity will compensate the temperature coefficient of expansion in such manner as to produce a spring which exhibits substantially no change in operation with moderate temperature change.

In preparing the alloy it is desirable that oxidation or other chemical reaction of the ingredients be prevented to avoid a substantial variation in the proportions of the constituents and to avoid the introduction of undesired compounds which would tend to alter the characteristics of the alloy. Therefore, the melting together of the constituents is preferably carried out in an inert atmosphere, such as purified helium.

After the alloy has been cast, it may be subjected to hot rolling. After rolling, the billet is preferably annealed at about 950° C. and allowed to cool in the furnace. The annealing, by homogenizing the alloy and removing strains introduced during rolling, renders the final product more stable and the results more uniform. The billet may then be machined to the desired form. After machining the article is preferably again annealed at about 950° C. and allowed to cool in the furnace to remove the strains introduced during machining.

It can be seen from the description above that

the invention is of broad as well as specific application and is to be limited only by the scope of the appended claims.

What is claimed is:

1. A mechanical vibratory element made of an alloy comprising the following ingredients in about the following proportions:

	Per cent
Iron	45.8
Nickel	34.8
Molybdenum	15.7
Manganese	2.2
Cobalt	1.2
Carbon	.3

2. An alloy having about the following composition:

	Per cent
Iron	45.8
Nickel	34.8
Molybdenum	15.7
Manganese	2.2
Cobalt	1.2
Carbon	.3

3. An element which operates through elastic distortion formed of an alloy comprising about 32 per cent to about 42 per cent nickel, about 13 per cent to about 18 per cent molybdenum and 30

the remainder essentially iron, the ingredients of the alloy being so proportioned that the temperature coefficient of elasticity substantially compensates the temperature coefficient of expansion at normal temperatures, thereby giving the element substantially constant operating characteristics for a normal temperature range.

4. A mechanical vibratory element made of an alloy comprising about 32 per cent to about 42 per cent nickel, about 13 per cent to about 18 per cent molybdenum, a small amount of carbon less than about .9 per cent, a small amount of manganese less than about 3 per cent, and the remainder substantially all iron.

5. A mechanical vibratory element made of an alloy comprising about 32 per cent to about 42 per cent nickel, about 13 per cent to about 18 per cent molybdenum and the remainder essentially iron.

6. A mechanical vibratory element made of an alloy comprising about 32 per cent to about 42 per cent nickel, about 13 per cent to about 18 per cent molybdenum, 0 per cent to about 3 per cent manganese, 0 per cent to about .9 per cent carbon and the remainder essentially iron.

7. A spring member made of an alloy comprising about 32 per cent to about 42 per cent nickel, about 13 per cent to about 18 per cent molybdenum and the remainder essentially iron.

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