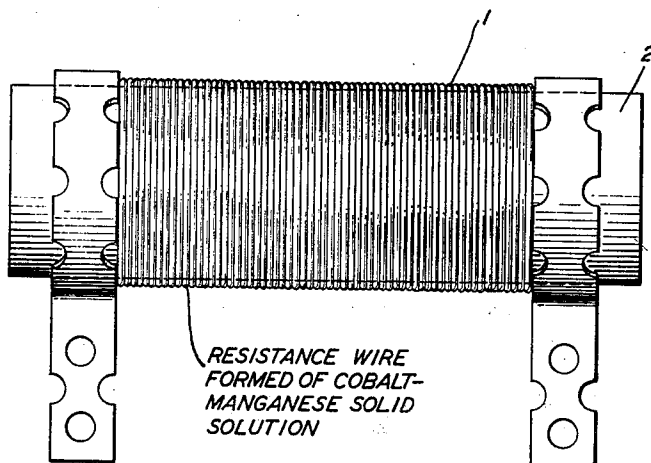


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COBALT BASE ALLOYS AND RESISTANCE
ELEMENTS FORMED THEREFROM
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COBALT BASE ALLOYS AND RESISTANCE ELEMENTS FORMED THEREFROM

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This invention relates to novel metal alloys useful for forming electrical resistance elements, to electrical resistance elements formed from such alloys and to electrical devices embodying such resistance elements.

In the formation of electrical resistance elements, particularly those in the form of a fine wire, such as a wire of 10 mils or less in diameter, the following properties, among others, are important in the alloy from which the element is formed:

1. A relatively high electrical resistivity
2. Satisfactory tensile strength
3. The ability to be mechanically worked as by swaging or by drawing into a wire
4. Stability of electrical properties with time
5. An electrical resistivity independent of previous thermal history.

In accordance with the present invention desirable combinations of these properties are achieved through the use of alloys which are solid solutions of cobalt and manganese, preferably containing minor proportions of additional ingredients, also in solid solution, for the purpose of increasing electrical resistance and appropriately modifying the physical and metallurgical properties.

In the accompanying drawing is shown, in front elevation, a conventional wire wound resistor which is one type of device in which the resistance elements and resistance alloys of the present invention may be employed. In this drawing a resistance wire 1 made in accordance with the present invention is wound upon a ceramic base 2. It is obvious that the invention is adaptable to the formation of other wire wound resistance devices, such as potentiometer cards, and that the formation of resistance elements other than resistance wires are encompassed within the scope of the present invention.

It has been found that an alloy of substantially the following composition is outstanding for the formation of fine resistance wires:

	Per cent by weight
Cobalt	54.5
Manganese	39.6
Copper	4.5
Aluminum	1.4

This composition may be made of substantially pure ingredients or can be made of commercial grade ingredients containing incidental impurities, which preferably do not exceed 2 per cent and are ordinarily less than 1 per cent.

A cylindrical bar $\frac{3}{4}$ inch in diameter cast from

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this alloy could, after hot swaging to approximately $\frac{1}{4}$ inch in diameter and cold swaging to .1 inch in diameter, be cold drawn. A wire drawn in this manner to .06 inch in diameter possessed a resistivity at 20° C. of 110 microhm-centimeters. That the resistivity of the alloy is independent of thermal treatment is shown by the fact that a deviation in the resistivity no greater than plus or minus 2 microhm-centimeters was produced by any of the following treatments of the drawn wire:

- a. Heating at 400° C. for 67 hours followed by cooling in air,
- b. Heating at 620° C. for 24 hours followed by cooling in air,
- c. Heating at 800° C. for 5 minutes followed by cooling in air,
- d. Heating at 990° C. for 1 minute followed by quenching in oil.

The temperature coefficient of resistivity of the alloy was found to be 260×10^{-6} per degree C. between 30° C. and 100° C. The alloy also possesses the above-enumerated desirable properties of a resistance alloy. The wire of .06 inch in diameter referred to above was further cold drawn to a diameter of 6 mils without difficulty.

Alloys of similar composition having somewhat varied proportions will be found to have similarly desirable properties. A suitable range of proportions of these ingredients is the following:

	Per cent by weight
Cobalt	50 to 60
Manganese	35 to 45
Copper	2 to 10
Aluminum	1 to 5

Other alloys which are solid solutions made up primarily of cobalt and manganese are also desirable for the formation of resistance elements.

The cobalt in such alloys should be present in an amount in which it will retain the manganese in solid solution and for that reason the cobalt should ordinarily be present in an amount of at least 45 per cent by weight of the total cobalt and manganese. In order to provide a desirable resistivity the manganese should be present in an amount of at least 5 per cent by weight of the combined cobalt and manganese. Preferably the manganese is present in an amount of at least 20 per cent by weight of the total cobalt and manganese.

It is not ordinarily desirable that ingredients other than cobalt and manganese entering into the alloys be present in amounts greater than 15 per cent by weight of the alloy. Preferably such

ingredients do not exceed 10 per cent of the weight of the alloy. Any additional ingredients which are present should enter into solid solution. They may act to improve the resistivity, improve the physical and metallurgical properties

ences in a 60Co-40Mn alloy is -1.8 or roughly -2. The following table shows the effect on resistivity of substituting iron, chromium, copper and aluminum for a small proportion of the cobalt in the alloy referred to above.

Percent by Weight Manganese	Percent by Weight Cobalt	Percent by Weight Modifying Element	Resistivity in Microhm-centimeters	Corrected Resistivity in Microhm-centimeters	Valence of Modifying Element	Valence Difference between Modifying Element and 60Co-40Mn Alloy	Change in Resistivity per Atom percent of Modifying Element
40	60	0	83	83	---	---	---
40	50	10Fe	84	83	-2	0	0
40	55	5Cr	94	93	-4	2	1.8
40	55	5Cu	93	92	+1	3	2
40	58	2Al	100	100	+3	5	4.1

or reduce the cost of the alloy, or they may even be without substantial effect.

An alloy made up of 82.1 per cent by weight of cobalt and 17.9 per cent by weight of manganese, when swaged and drawn from a cast bar $\frac{3}{4}$ inch in diameter to a wire having a diameter of .06 inch as described above, had a resistivity of 71 microhm-centimeters at 20° C. and a temperature coefficient of resistivity of 610×10^{-6} per degree C. between 30° C. and 100° C. An alloy made up of 63.3 per cent by weight of cobalt and 36.7 per cent by weight of manganese, when cast into a $\frac{3}{4}$ inch diameter bar, hot swaged to a diameter of $\frac{1}{4}$ inch then cold swaged to .1 inch in diameter, had a resistivity of 83 microhm-centimeters at 20° C. and a temperature coefficient of resistivity of 640×10^{-6} per degree C. between 20° C. and 100° C. This alloy was capable of being cold drawn.

The basic cobalt-manganese solid solution may be modified with up to about 15 per cent by weight of any additional element which enters into solid solution. Preferably additional elements are added which substantially increase the resistivity of the alloy although the addition of other ingredients which do not have this effect but which improve the physical properties of the alloy or reduce its cost may also be desirable.

It has been found that the greater the amount by which the valence of the added ingredients differs from the weighted average of the valences of the cobalt and manganese in the alloy, the greater is the effect of the added element in increasing the resistivity of the alloy. The weighted average of the valences is the sum of the product of the valence of the cobalt and the atomic fraction of cobalt in the total cobalt and manganese and the product of the valence of the manganese and the atomic fraction of manganese in the total cobalt and manganese. The term valence is used in this connection to mean the number of electrons relative to the closed d shell of the solute. In other words, it is the difference between 10, which is the number of electrons in the closed d shell and the number of electrons in the unfilled d shells of the transition elements or the number of valence electrons in the non-transition elements. (The s electrons of the transition elements are regarded as having been moved into the d shell.)

The effect of valence difference upon resistivity is clearly shown by comparing the resistivity of an alloy consisting of 60 per cent by weight of cobalt and 40 per cent by weight of manganese with the resistivities of similar alloys in which small proportions of the cobalt are replaced by modifying ingredients. Since the valence of cobalt is -1 and the valence of manganese is -3 the weighted average of these val-

In this table the column headed "Resistivity" gives the actual measured resistivity for the alloy in microhm-centimeters. The column headed "Corrected resistivity" gives the calculated resistivity of an alloy containing the same amount of modifying ingredient in which the ratio of cobalt to manganese is 60 to 40 in place of the slightly lower ratio actually present in the alloy.

It may be seen from the table that iron which has a valence of -2, which is not significantly different from that of the basic cobalt-manganese alloy, has no substantially effect upon the resistivity. Chromium, copper and aluminum which have valences differing from the cobalt-manganese alloy by 2, 3 and 5, respectively, increase the resistivity by 1.8, 2 and 4.1 microhm-centimeters, respectively, per atomic per cent of added element.

Thus where a higher resistivity is sought than is possessed by an alloy containing cobalt and manganese alone, this may be achieved by incorporating in the alloy a modifying element which enters into solid solution and which has a valence which differs by at least 1 from the weighted average of the valences of the cobalt and manganese in the cobalt-manganese alloy. Although iron, as indicated above, produces no significant increase in the resistivity of a 60Co-40Mn alloy, the addition of iron to these alloys, as well as to other alloys containing cobalt and manganese, will often be found advantageous since it will materially lower the cost of the alloy.

The above-indicated increase in resistivity per atom per cent of added modifying element decreases as the total amount of modifying ingredient increases. The effect of the addition of more than one resistivity increasing element is additive. This is illustrated by observing the effect upon the resistivity caused by substituting small amounts of other modifying ingredients for a part of the cobalt in the alloy listed in the table above which is made up of 40 per cent manganese, 58 percent cobalt and 2 per cent aluminum. When 2 per cent of silicon (which differs in valence from the 60Co-40Mn alloy by 6) is added to this alloy in place of a corresponding amount of cobalt, the corrected resistivity of the resulting alloy quenched from 980° C. is 115 microhm-centimeters as compared to 100 microhm-centimeters for the alloy containing no silicon.

When 5 per cent copper is added to the aluminum-containing alloy, the corrected resistivity is 109 microhm-centimeters as compared to 100 microhm-centimeters for the alloy containing no copper and as compared to a corrected resistivity of 92 microhm-centimeters for the corresponding copper-containing alloy which contains no aluminum.

When 10 per cent iron is added to the alu-

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minum-containing alloy, the corrected resistivity is 93 microhm-centimeters as compared to 100 microhm-centimeters for the aluminum-containing alloy without iron, and as compared to a corrected resistivity of 83 microhm-centimeters for the corresponding iron-containing alloy without aluminum. It will be seen that in the latter case the addition of aluminum to the iron alloy increases the resistivity considerably. On the other hand, the addition of iron to the aluminum-containing alloy decreases the resistivity because it dilutes the effect of the aluminum by increasing the total amount of modifying ingredient which is present.

Each of the specific alloys above, as well as other alloys containing these ingredients in different proportions, is useful as a resistance alloy. All of those alloys referred to above, except that containing silicon, are capable of being cold drawn to wires. The silicon-containing alloy, although not as workable as the other alloys, is capable of being hot or cold swaged. All of the alloys referred to above may be formed of substantially pure ingredients or of ingredients of commercial quality containing incidental impurities, which will ordinarily not exceed 2 per cent by weight and which will preferably not exceed 1 per cent of the alloy.

Any other modifying ingredients in addition to or in place of the iron, chromium, copper, aluminum and silicon referred to above, may be employed which are capable of entering into solid solution with the cobalt and manganese. When modifying ingredients are added it is desirable that they be present in amounts of at least 1 per cent by weight in order to exert a reasonable effect on the alloy. As indicated above, it is not desirable that the modifying ingredients be added in amounts greater than about 15 per cent. A concentration of modifying ingredients which has been found desirable is from about 2 per cent to about 5 per cent by weight, although larger amounts up to 10 per cent or even 15 per cent may be found desirable.

The specific embodiments of the invention described above are intended to be illustrative and not limitative and it is intended that the invention include within its scope those modifications and equivalents which would be apparent to one skilled in the art.

What is claimed is:

1. An electrical resistance wire made up of an alloy having the following ingredients in the following proportions together with incidental impurities:

	Per cent by weight
Cobalt	54.5
Manganese	39.6
Copper	4.5
Aluminum	1.4

2. An electrical resistance element made up of an alloy consisting of the following ingredients

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in the following proportions together with incidental impurities:

	Per cent by weight
Cobalt	50 to 60
Manganese	35 to 45
Copper	2 to 10
Aluminum	1 to 5

3. A resistance alloy containing the following ingredients in the following proportions:

	Per cent by weight
Cobalt	54.5
Manganese	39.6
Copper	4.5
Aluminum	1.4

4. A resistance alloy consisting of the following ingredients in the following proportions:

	Per cent by weight
Cobalt	50 to 60
Manganese	35 to 45
Copper	2 to 10
Aluminum	1 to 5

5. A wire-wound electrical resistor, the resistance wire of which is made up of an alloy having the following ingredients in the following proportions, together with incidental impurities:

	Per cent by weight
Cobalt	54.5
Manganese	39.6
Copper	4.5
Aluminum	1.4

6. A wire-wound electrical resistor, the resistance wire of which is made up of an alloy consisting of the following ingredients in the following proportions, together with incidental impurities:

	Per cent by weight
Cobalt	50 to 60
Manganese	35 to 45
Copper	2 to 10
Aluminum	1 to 5

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