Sept. 9, 1958 P. E. R. FAUVELOT 2,851,621

PROCESS FOR THERMALLY COMPENSATING SPRING BIASED MAGNETIC APPARATUS, SUCH AS TACHOMETERS

Filed Oct. 12, 1955 2 Sheets-Sheet 1

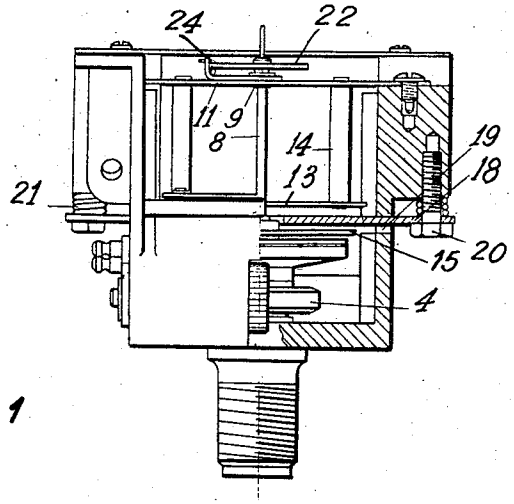


Fig. 1

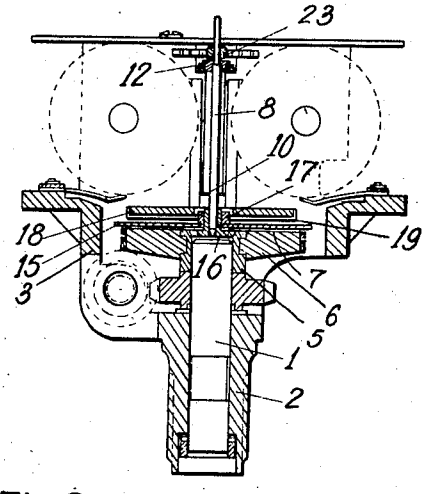


Fig. 2.

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PROCESS FOR THERMALLY COMPENSATING SPRING BIASED MAGNETIC APPARATUS, SUCH AS TACHOMETERS

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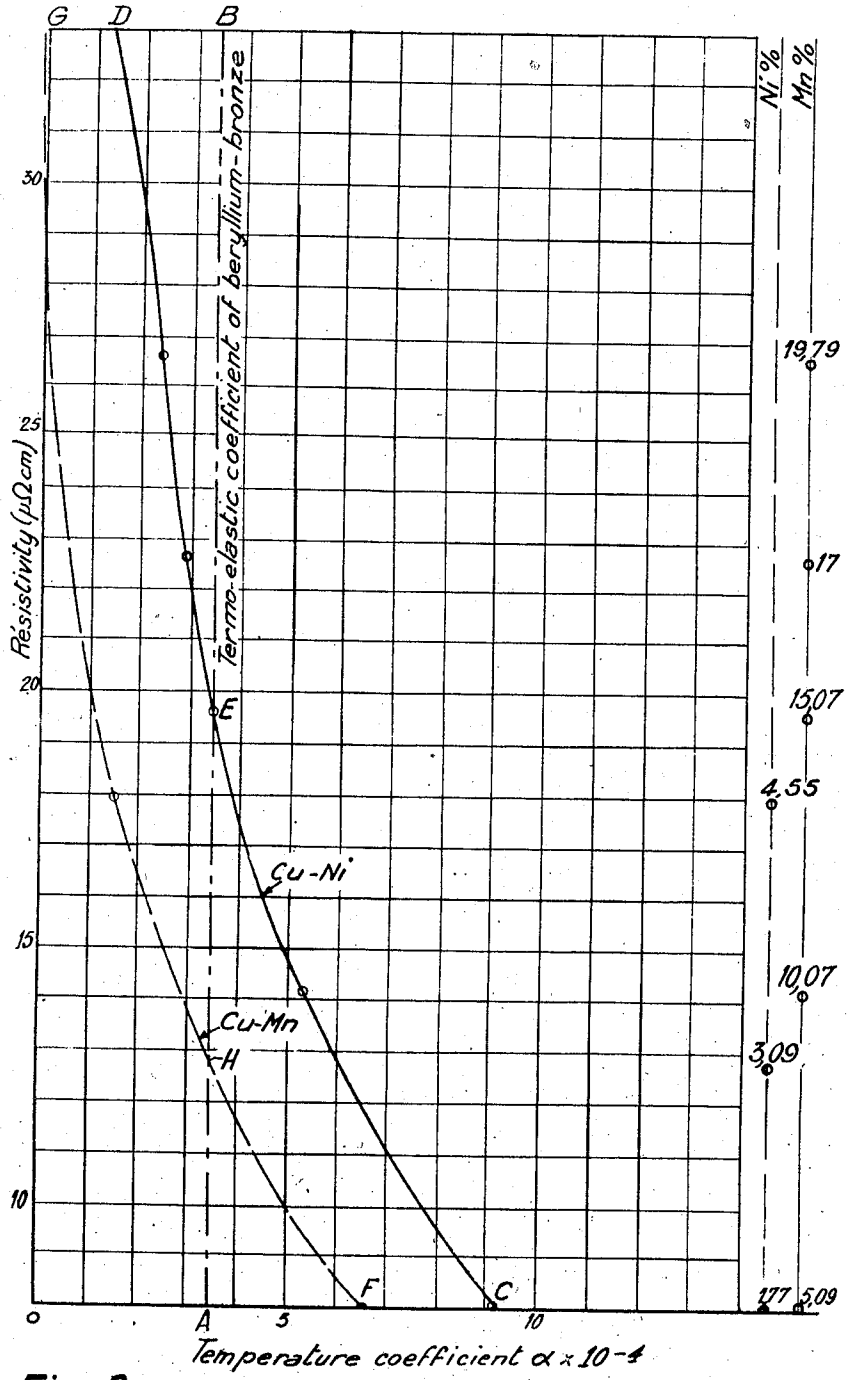


Fig. 3.

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PROCESS FOR THERMALLY COMPENSATING SPRING BIASED MAGNETIC APPARATUS, SUCH AS TACHOMETERS

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14 Claims. (Cl. 310—97)

The present invention relates to processes for thermally compensating magnetic apparatus, such as magnetically-acting tachometers and any apparatus having similar characteristics, and also to devices obtained by means of said processes.

A magnetically-acting tachometer comprises a spindle connected with a shaft the speed of which is to be measured, said spindle being adapted rotatably to drive a permanent magnet driving in turn, against the antagonistic action of a spiral spring, a movable assembly rigid with an index needle and comprising a movable plate or bell-shaped member of non-magnetic metal set in motion by the eddy currents generated in said plate or bell-shaped member by the displacement of the induction field of the magnet.

Devices of this general type are characterized by the serious inconvenience arising from variations in the torque generated by the magnet action on the movable assembly as a function of temperature variations. If the variation in the inherent properties of the magnet remains relatively moderate, the variation in resistivity of the bell-shaped member or disk is very important, especially for pure metals wherein the thermo-resistivity by degree has a high value ranging from 36 to 42×10^{-4}. The replacement of pure metals with alloys having an extremely low thermo-resistivity by degree, such as for example, constantan in which this coefficient is as low as 1×10^{-5}, cannot be contemplated because these alloys have an extremely high resistivity such as, for example, 49 microohms per cm. constantan, so that the torque drops to insignificant values.

It has been proposed to overcome this drawback by varying the flux intensity of the magnet by utilizing a magnetic shunt made of a metal having a low Curie point. However, an efficient compensation cannot be obtained with these metals except within a relatively narrow temperature range of about 50° C., this making it necessary to superpose a plurality of shunts. However, such a superposition becomes nearly impossible when the number of shunts exceeds two.

An object of the invention is to provide a process for thermally compensating magnetic apparatus of the type in which a rotary permanent magnet drives, against the antagonistic action of a spiral spring, a movable assembly comprising at least one member of non-magnetic material, such as tachometers and apparatus equipped with wound movable frame, wherein the reaction torque of the spiral spring is varied as a function of temperature in a direction opposite to that of the variation in the torque applied to the movable unit, in the case of tachometers, or in the wire constituting the frame winding, in the case of apparatus equipped with wound movable frames, in order to render the torque applied to the movable assembly less sensitive to temperature variations.

According to an advantageous mode of applying said method, the spiral spring is made of a metal having a high thermo-elastic coefficient, preferably equal to, and in any case of a direction opposite to that of, the thermo-

resistivity of the metal constituting the active non-magnetic element or elements of the movable assembly. Also preferably the metal employed in the manufacture of said spiral spring will be either phosphor-bronze or beryllium-bronze, because both these substances have a ductility sufficient to enable them to be worked into narrow, thin strips having a resiliency sufficient to constitute an edequate material for the manufacture of spirals. In a practical temperature range from −50° C. to +50° C. the thermo-elastic coefficient by degree of phosphor-bronze and beryllium-bronze ranges from 34×10^{-5} to 40×10^{-5}. Then the only requirement will be to manufacture the active non-magnetic element or elements of the movable assembly from an alloy having a reasonable resistivity and a thermo-resistivity by degree substantially equal, in absolute value, to the thermo-elastic coefficient of the metal employed for manufacturing the spiral spring, these two coefficients leading to variations of opposite direction in the resistivity of the non-magnetic element or elements and in the resiliency of the spiral as a function of temperature respectively.

Another object of the invention is to provide magnetic tachometers and movable-frame apparatus comprising metal spiral springs having a coefficient of thermo-elasticity equal to and of opposite direction to the thermo-resistivity of the non-magnetic metal or metal alloy constituting the plate or bell-shaped member, in the case of magnetic tachometers, or the frame winding in the case of movable-frame apparatus.

The following description, considered in connection with the accompanying drawings will enable the particular features of the invention to be readily understood. In said drawings:

Fig. 1 is a view in elevation and partly in section of a tachometer according to the invention.

Fig. 2 is a side view partly in section of Fig. 1.

Fig. 3 is a diagram showing the resistivity in microohms per cm. plotted against the temperature coefficient or coefficient of thermo-elasticity by degree of various materials.

A flexible drive cable extending from the member the speed of which is to be measured is made rigid with the drive spindle **1** of the tachometer through any known means not shown, such as a square drive socket for instance. Said spindle **1** is centered in a bearing **2** integral with the general support **3** of the apparatus. On said spindle there is mounted in a manner known per se, a pinion **4** adapted to drive the totalizing device which may be of any general type.

Said spindle supports at its top end a ring **5** on which is rigidly mounted a flat magnet **6** having six poles on its face **7**.

In alignment with the axial line of the drive shaft **1**, a spindle **8**, the movable structure spindle, is mounted on two bearings **9** and **10**. The bearing **9** rigid with the strip **11** secured to the frame **3** comprises a cup member **12** through which extends the spindle **8**. The second bearing **10** of the spindle **8** is formed by a bore made in a cage **13** rigidly connected with the strip **11** through posts **14**, the assembly as a whole constituting a cage.

In overhanging relation with respect to the bearings **9** and **10**, the spindle **8** supports a disc **15** of a non-magnetic metal, the external diameter of which is substantially greater than that of the flat magnet **6**. Said disc **15** is mounted on the spindle **8** through the medium of a shouldered ring **16** and a washer **17** press-fitted over said ring.

The field-closing plate **18**, made of soft steel or silicon-containing sheet iron for instance, is provided with a port allowing it to be mounted above the movable disc **15**. It moreover traverses two slots **19** formed in the body of the frame **3** and is secured by means of bolts **20**.

Between the plate **18** and the frame **3** springs **21** are inserted tightly surrounding the bolts **20**. The bolts **20** serve to adjust the position of the field-closing plate **18** with respect to the flat magnet **6** and consequently the total air-gap, thus allowing the determination of the various ranges for the maximum amplitude of the disc **15** under the influence of the eddy-currents generated in said disc by the flat magnet **6**. The same constituent elements may, by way of example, serve to construct tachometers which, for an angular scale of 360° cover speed ranges comprised between 2,300 and 4,350 R. P. M.

The spiral spring **22** which supplies the antagonistic action against the drive of the movable disc **15** by the flat rotating magnet **6** has one of its ends secured to a ring **23** rigidly mounted on the spindle **8**. Its other end is secured to a hook **24** for effecting the zero-adjustment of the tachometer.

In order to enable the tachometer to be substantially insensitive to temperature variations in a wide range of temperatures, the spiral spring **22** is made of a metal having a high thermo-elastic coefficient, preferably equal to, and in any case of a direction opposite to that of, the thermo-resistivity of the metal constituting the non-magnetic disc **15**, whereby the reaction torque of the spiral spring **22** is varied as a function of temperature in a direction opposie to that of the variation in the torque applied to the movable structure.

Preferably the metal employed in the manufacture of said spiral spring **22** is either Phosphor bronze or beryllium-brone, while the non-magnetic disc **15** consists of an alloy having a minimum resistivity at a thermo-resistivity by degree substantially equal, in absolute value, to the thermo-elastic coefficient of the relevant bronze.

Such an alloy is determined as illustrated in Fig. 3 wherein the parallel AB to the abscissa axis shows the thermo-elastic coefficient by degree of beryllium-bronze, 35×10^{-5}. The curve CD illustrates the resistivity and thermo-resistivity by degree of a copper-nickel alloy having a variable nickel content; this curve intersects at E the aforesaid parallel AB, which corresponds to a nickel content of 15.07% and to a resistivity in microhms per cm. of 19.6. Similarly, the curve FG illustrates the resistivity and the thermo-resistivity by degree of a copper-managanese alloy having a variable manganese content; this curve intersects at H the aforesaid parallel AB, which corresponds to a manganese content of 3.09% and to a resistivity in microhms per cm. of 12.7.

Consequently the desired thermal compensation is obtained when using a spiral spring **22** made of beryllium-bronze and a non-magnetic disc **15** made either of a copper-nickel alloy having a nickel content of 15.07% or of a copper-managanese alloy having a manganese content of 3.09%.

In order to make due allowance for the variation in the properties of the magnet and of the geometric displacements of thermal origin of certain parts of the tachometers, the thermo-elastic coefficient of the spiral spring metal may be chosen slightly different than the thermo-resistivity of the metal constituting the active non-magnetic element or elements of the movable assembly, the thus obtained assembly being so adjusted, in this case, as to give these two parameters the same values.

For a given metal constituting the spiral spring **22**, the alloy constituting the non-magnetic disc **15** is chosen so that its thermo-resistivity by degree is smaller in absolute value than the thermo-elastic coefficient of said metal. By example, if the spiral spring **22** is made of beryllium-bronze having a thermo-elastic coefficient of 35×10^{-5}, the non-magnetic disc **15** is made of a copper-nickel alloy having a nickel content of 17% corresponding to a resistivity in microhms per cm. of 22.5 (Fig. 3) and to a thermo-resistivity by degree equal to 28×10^{-5}. The adjustment is made in order to decrease in absolute value the minimum resistivity of the disc **15**, i. e. 22.5 microhms per cm., so that its thermo-resistivity by degree becomes substantially equal to the thermo-elastic coefficient 35×10^{-5} of the beryllium-bronze.

This adjustment may be effected by either electroplating the surface of the active non-magnetic element with a pure metal such as copper to the thickness required for making the thermo-resistivity of this coated element equal to the thermo-elastic coefficient of the spiral spring or depositing by electroplating a metal coating thicker than the aforesaid thickness and subsequently removing by machining part of this coating to restore the equality between the values of the thermo-elasticity of the spiral spring and the thermo-resistivity of the electro-plated and machined element.

The above-disclosed method is applicable to any apparatus comprising a frame movable in the field of a permanent magnet, wherein the frame winding is associated with a spiral return spring, the adjustment for making the coefficient of thermo-elasticity of the spiral spring equal to the thermo-resistivity of the winding being effected as specified hereinabove by electroplating pure metal on the winding wire and subsequently removing if necessary any excess metal by machining.

It will be readily understood by anybody conversant with the art that many modifications may be brought to the method described hereinabove without departing from the scope of the invention defined in the appended claims.

What I claim is:

1. In a process for thermally compensating magnetic apparatus such as tachometers or the like of the type in which a rotary permanent magnet drives, against the antagonistic action of a spiral spring, a movable frame assembly comprising at least one member of non-magnetic material electromagnetically cooperating with said magnet for the transmission of torque, the improvement which consists in making the spiral spring of a metal having a high thermo-elastic coefficient substantially equal to, and of a direction of variation opposite to that of, the thermo-resistivity of the metal constituting each non-magnetic member of the movable assembly.

2. A process, according to claim 1, wherein the metal constituting the spiral spring is phosphor-bronze.

3. In a process for thermally compensating magnetic apparatus such as tachometers or the like of the type in which a rotary permanent magnet drives, against the antagonistic action of a spiral spring, a movable frame assembly comprising at least one member of non-magnetic material electromagnetically cooperating with said magnet for the transmission of torque, the improvement which consists in utilizing for the manufacture of each non-magnetic member of the movable assembly an alloy having a resistivity less than 25 $\mu\omega$/cm. and a thermo-resistivity between 1×10^{-4} and 4×10^{-4} and for the spiral spring a metal having a thermo-elastic coefficient between between 3×10^{-4} and 4×10^{-4}.

4. A process, according to claim 3, wherein the metal constituting the spiral spring is beryllium-bronze and the alloy constituting each non-magnetic member of the movable assembly is a copper-nickel alloy having a nickel content of 15.07%.

5. A process, according to claim 3, wherein the metal constituting the spiral spring is beryllium-bronze and the alloy constituting each non-magnetic member of the movable assembly is a copper-manganese alloy having a manganese content of 3.09%.

6. A process according to claim 3 wherein the alloy for the manufacture of each non-magnetic member of the movable assembly has a minimum resistivity at a thermo-resistivity by degree smaller, in absolute value, than the thermo-elastic coefficient of the metal constituting the spiral spring, and said process further comprising adjusting the thus obtained assembly to bring these two coefficients to equality.

7. A process, according to claim 6, wherein the adjustment step consists in electroplating pure metal on

the surface of each non-magnetic member of the movable assembly up to the thickness required for making the thermo-resistivity of each electroplated member equal to the thermo-elastic coefficient of the spiral spring.

8. A process, according to claim 7, wherein the pure metal consists of copper.

9. A process, according to claim 6, wherein the adjustment step consists in electroplating pure metal on the surface of each non-magnetic member of the movable assembly up to a thickness greater than the thickness required for making the thermo-resistivity of each electroplated member equal to the thermo-elastic coefficient of the spiral spring, and subsequently removing mechanically one portion of this coating to restore the equality between the thermo-elasticity of the spiral spring and the thermo-resistivity of each coated and machined member.

10. A process, according to claim 9, wherein the pure metal consists of copper.

11. In a magnetic apparatus such as a tachometer or the like of the type in which a rotary permanent magnet drives, against the antagonistic action of a spiral spring, a movable frame assembly comprising at least one member of non-magnetic material electromagnetically cooperating with said magnet for the transmission of torque, the improvement which comprises a spiral spring consisting of a metal having a thermo-elasticity substantially

equal to, and of a direction opposite to that of, the thermo-resistivity of the metal constituting each non-magnetic member of the movable assembly.

12. A magnetic apparatus according to claim 11 which comprises a spiral spring consisting of beryllium-bronze, and each non-magnetic member of the movable assembly consisting of a copper-nickel alloy having a nickel content of 15.07%.

13. A magnetic apparatus according to claim 11 which comprises a spiral spring consisting of beryllium-bronze, and each non-magnetic member of the movable assembly consisting of a copper-manganese alloy having a manganese content of 3.09%.

14. A magnetic apparatus according to claim 11 which comprises a spiral spring consisting of a metal having a coefficient of thermo-elasticity between 3×10^{-4} and 4×10^{-4}, and each non-magnetic member of the movable assembly consisting of an alloy having a thermo-resistivity between 1×10^{-4} and 4×10^{-4} at a resistivity less than 25 $\mu\omega$/cm.

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