A High-Pressure Wire Gage Using Gold-Chrome Wire

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Precision experiments with manganin wire for the measurement of high pressures are made difficult by virtue of the temperature-resistance response of the manganin. The equilibrium time required for this material to steady out after rapid pressure changes makes manganin generally unsuited for uses in industrial-control applications. For this reason, a study was made of the pressure and temperature response characteristics of several new materials. An alloy of 2.1 per cent chromium in gold was found to have much less sensitivity to temperature, varying from +1 to −1 ppm per deg F over the range of 40 F to 200 F, while manganin varies from +5 to −40 ppm in this same interval. This alloy also has a strong pressure coefficient. Typical values are 0.67 to 0.72 × 10^{-7} ohm/ohm/psi for gold chrome as compared to 1.69 to 1.72 × 10^{-7} ohm/ohm/psi for the manganin tested. Although the pressure sensitivity is only 33 per cent that of manganin, the smaller temperature sensitivity of the gold chrome results in good discrimination between temperature and pressure changes. Gold chrome responds rapidly to pressure changes, quickly coming to equilibrium, and does not show the annoying drift so characteristic of manganin. It is generally pressure seasoned with a single application of pressure, as compared to several cycles usually required for manganin. Its long-term stability compares favorably with manganin.

INTRODUCTION

In the laboratory investigation of high-pressure phenomena, the use of a coil of manganin wire whose resistance changes linearly with exposure to fluid pressure, has been adopted, universally as a pressure-sensing device, as a result of the pioneering work of Dr. Bridgman.[3]

Manganin is especially suitable for the measurements of pressure from 50,000 psi up to values that are limited only by the structure used. Its resistance changes in the order of 1.7 ohms per 100 ohms of wire per 100,000 psi, a value which makes accurate resistance measurements quite simple.

It is well known that manganin changes its resistance slightly with temperature, and this resistance change is small only over a fairly narrow temperature range. If the temperature of the fluid departs very much from room temperature, an appreciable change in coil resistance results, and this cannot be distinguished from a pressure change. When precision measurements are attempted on fluids whose pressure has undergone a rapid change, a fairly long period of time is usually required for the manganin coil to come to equilibrium. This is due in part, at least, to the temperature change produced in the liquid by the pressure change. Although the equilibrium time is a nuisance in laboratory measurements, it can be tolerated, but this is not the case where high-pressure sensing devices are required for control of continuous industrial processes.

A great deal of work has been done in Germany on the development of alloys of gold, silver, and copper, for the purpose of developing resistance wire that has better temperature-resistance properties than manganin.[4] Of these, alloys containing 2 to 4 per cent chromium in gold have shown the most promise. The remarkable temperature properties of these alloys have been investigated at length by the Bureau of Standards with the objective of using gold chrome as a primary standard of resistance.[5] Material similar to that supplied to the Bureau of Standards was obtained from Sigmund Cohn and tested at Foxboro. An excellent agreement between our samples and those reported by the Bureau has been a gratifying check on the accuracy of our measurement technique. Their probable sensitivity to pressure also was predicted by the Germans. Experiment has shown that gold chrome is suitable for measurement of high pressure to values of the same order as manganin.

Gold-chromium wire has properties which make it particularly suitable for a pressure-sensing element for industrial purposes. It responds rapidly to pressure changes, it has a high degree of discrimination between temperature and pressure effects, it has adequate pressure-resistance sensitivity, and material with a high degree of uniformity is available.

TEMPERATURE VERSUS RESISTANCE PROPERTIES—EXPERIMENTAL PROCEDURE

Manganin. Samples to be tested were either loosely wound on a ceramic bobbin of small size to facilitate handling, or were self-supporting coils as in the case of pressure-sensing units. The coils thus wound contained locked-in mechanical strains which of necessity had to be removed before the coils became stable. For manganin coils, this stabilizing process was accomplished by the use of the Bridgman cycle. This consisted of exposing the completed coils to temperatures of −100 F for a period of at least 2 hr, and then placing them in an oven at a temperature of +250 F for a period of at least 8 hr. This cycle was recommended by Dr. Bridgman to produce the greatest stability in manganin wire, and frequently it was found that several such cycles were necessary before complete stability was attained. Coils were wound noninductively, since all measurements were made at 1000 cycles, in order to avoid contact-potential difficulties.

Measurements of the resistance of the coils were made by an automatic two-function recorder developed at Foxboro for this purpose. The recording chart was positioned according to the temperature of an oil bath in which the sample was placed, and the recording pen moved across the chart in response to resistance changes. The temperature sensitivity of this instrument had a

[1] The Foxboro Company, Foxboro, Mass.

[2] Harwood Engineering Company, Inc., Walpole, Mass.; formerly with The Foxboro Company. Jun. ASME.

[3] "The Physics of High Pressure," by P. W. Bridgman, The Macmillan Company, New York, N. Y., 1931.

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[4] "Werkstoffe für Widerstandsmanometer und Widerstandsthermometer," by Alfred Schulze, *Chemiker-Zeitung*, vol. 19, July, 1943, p. 228.

[5] "Gold Chromium Resistance Alloys," by J. L. Thomas, U. S. Bureau of Standards, *Journal of Research* (Research Paper No. 737), vol. 13, 1934, pp. 681–688.

reproducibility of $^1/_2$ deg F, while the resistance measurement was accurately repeatable to 10 ppm change. Samples were placed in a well-stirred oil bath, and the temperature of the bath slowly raised through the temperature interval desired. When the temperature cycle was completed, a continuous record of resistance changes was obtained. From such records, the accompanying curves were plotted. Thus several spools of manganin were found which had exceptionally good temperature characteristics for the construction of pressure coils.

Gold Chromium. Samples were prepared by either winding the wire on ceramic bobbins or were formed into self-supporting coils, as in the case of the manganin samples. It was found that the gold-chrome wire was quite sensitive to mechanical handling or cold-working. These locked-in strains disappear with extensive baking at 300 F. Subjecting the wire to temperatures of −100 F was found to have little effect on its temperature properties, so the Bridgman cycle, as used in the preparation of manganin coils, was abandoned in favor of extensive baking at 300 F. Care must be taken not to expose the wire to temperatures greater than 350 F, as the material will be many times more sensitive to temperature change after such a treatment.

The gold-chrome wire amalgamates readily with solder, so care must be exercised when the soldering technique is used. Spot-welding is recommended.

Experimental Results. The temperature-resistance properties of a typical sample of gold chrome are shown in Fig. 1. This illustrates the effect upon the temperature properties by extensive baking at 300 F. A temperature coefficient of from −1 to +1 ppm per deg F can be obtained readily over a temperature range of 80 deg F. The sample shown contained 2.1 per cent chromium in gold and was in a dead-soft annealed condition. This appears to be the combination that has the least sensitivity to temperature.

A comparison of the temperature-resistance properties of gold-chrome, manganin, and Advance wire are shown in Fig. 2, all being plotted to the same scale. The advantages of the use of gold chrome over manganin are at once evident. Advance, which also has an excellent temperature property, unfortunately has a very small pressure coefficient.

The properties of alloys containing different percentages of chrome in gold are shown in Fig. 3, from which it is evident that almost any coefficient, positive, negative, or nearly zero, can be obtained by suitable choice of alloy composition and heat-treatment. Hard-drawn wires of all alloy proportions do not respond to baking procedures, but always have a large temperature coefficient. For this reason, half-hard or dead-soft wire is recommended for precision resistors and pressure coils. Half-hard wire will have a 2 to 4 per cent elongation, while soft wire will have 15 to 16 per cent elongation on a rupture test.

Pressure Measurements

Experimental Procedure. The material used in the construction of manganin coils was selected on the basis of uniformity of resistance, and minimum temperature-resistance properteis. The manganin wire was of No. 38 gage, double-silk and double-silk plus nylon-braid insulation. Coils were wound noninductively, using a small piece of spaghetti as a starting form, and were interleaved for several layers. Then the coil was lashed securely with strong thread, forming a firm, self-supporting unit, which could be handled readily for mounting in pressure cells. Although the finished coil appears bulky, its cross section is mostly porous insulating material, allowing pressure fluids readily to penetrate the structure. Where a smaller physical size was required, the nylon braid was omitted, and the coils were wound as before with thin paper between layers to minimize the possibility of shorts. Coils were usually of 60 or 120-ohm resistance.

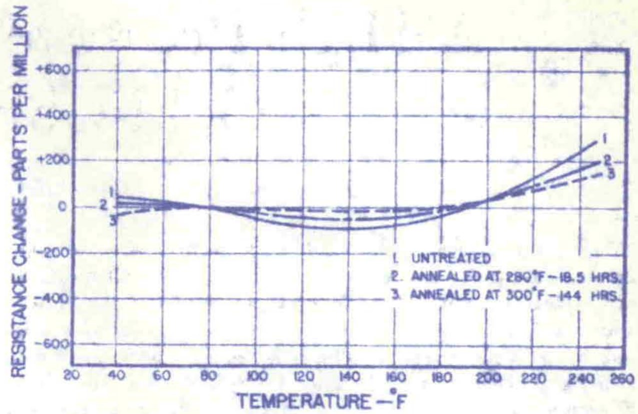

Fig. 1 Temperature Versus Resistance Change of 2.1 Per Cent Gold Chrome

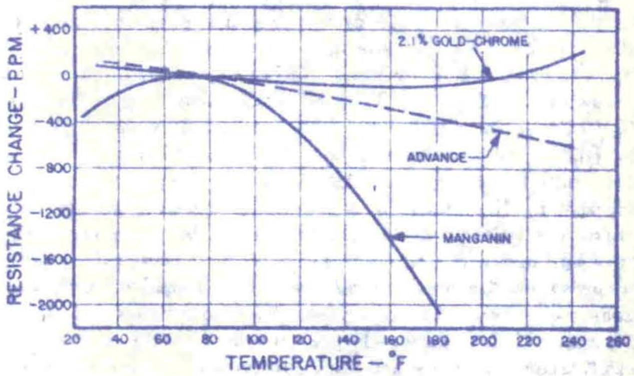

Fig. 2 Comparison of Temperature Versus Resistance Change for Gold Chrome, Advance, and Manganin

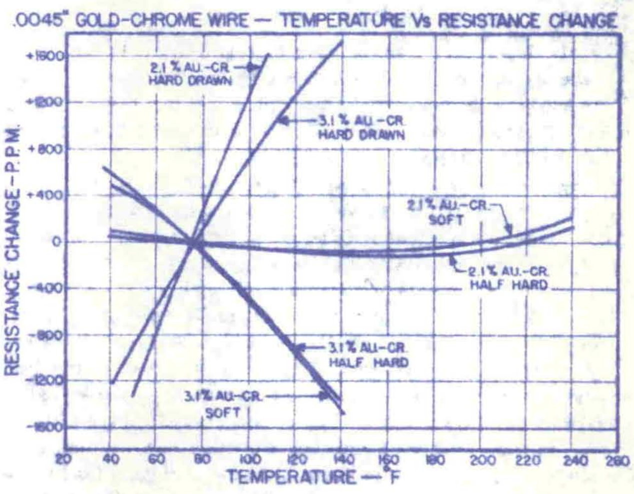

Fig. 3 Temperature Versus Resistance Change for 0.0045-In. Gold-Chrome Wire

Manganin coils were first stabilized by the use of the Bridgman cycle, and then exposed to several applications of pressure to a value greater than that for which they were to be used.

The gold-chrome wire was of No. 36 gage, and was specially covered with a quadruple layer of nylon. Coils also were wound noninductively, starting with a spaghetti core, and using a double layer of onionskin paper between layers to minimize the possibility of shorts and to make a firmer coil. Lacing of the coil with thread, as before, makes a firm structure.

The gold-chrome coils are stabilized by baking at 300 F for at least 36 hr. Pressure-seasoning was accomplished by a single application of pressure.

Finished manganin and gold-chrome coils are shown in Fig. 4.

Pressure Equipment. Initial pressure measurements were made with the co-operation of the high-pressure laboratory of the Watertown Arsenal, where pressures up to 150,000 psi were available. Measurements were referred to the manganin-coil standards as calibrated in Dr. Bridgman's laboratory.

Later measurements were made in the Foxboro high-pressure laboratory with equipment designed and built by D. H. Newhall. A typical pressure-cell assembly is shown in Fig. 5.

Our present high-pressure laboratory was designed and built by the Harwood Engineering Company. A view of the laboratory

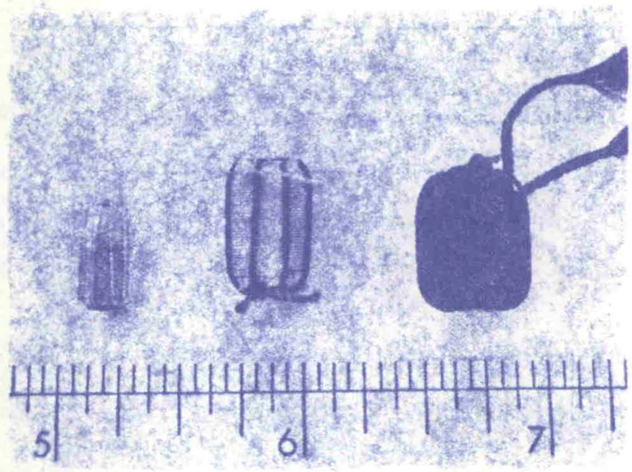

FIG. 4 FINISHED MANGANIN AND GOLD-CHROME COILS

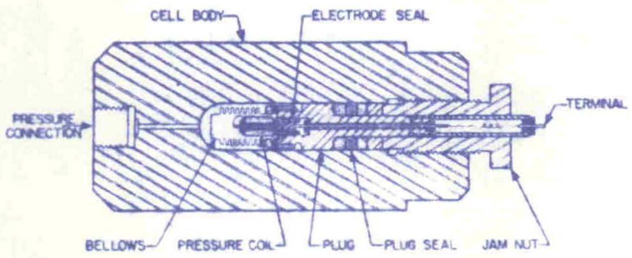

FIG. 5 ASSEMBLY OF 150,000-PSI PRESSURE CELL

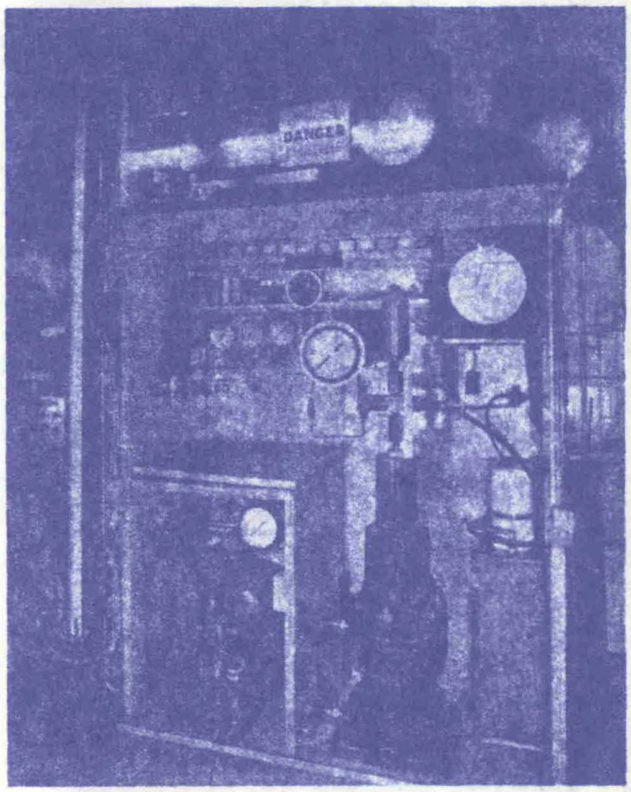

FIG. 6 VIEW IN HIGH-PRESSURE LABORATORY

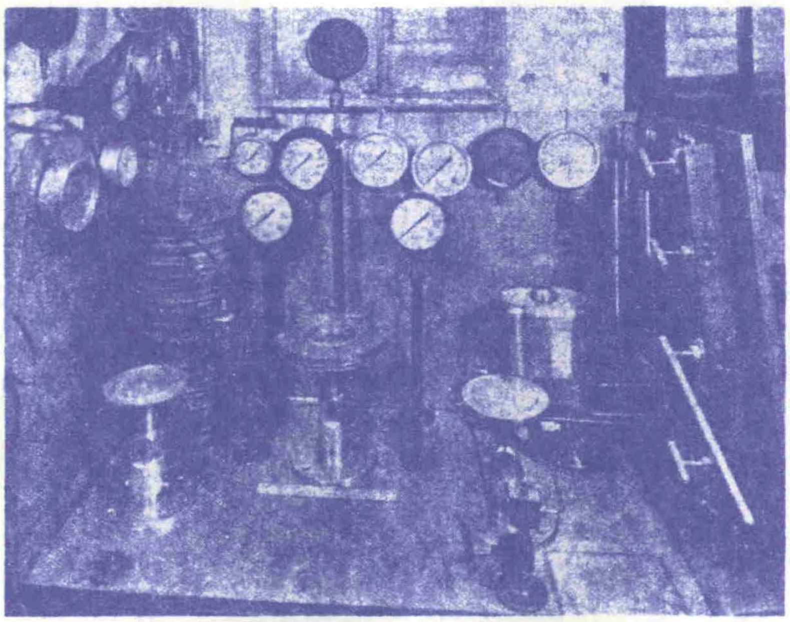

FIG. 7 DEAD-WEIGHT ASSEMBLY FOR MEASURING PRESSURES UP TO 30,000 PSI

is shown in Fig. 6. The low-pressure pump, intensifier, controls, and pressure cell are plainly visible in this view.

In addition to the high-pressure equipment, a dead-weight assembly was constructed for measurement of pressures up to 30,000 psi, Fig. 7. Pressure coils were calibrated with reference to this dead-weight assembly, and periodic checks were made with the Watertown standard and Dr. Bridgman's laboratory.

All measurements were made with specially adapted Foxboro instruments or with specially designed alternating-current bridges. Accuracies of measurement were in most cases better than 0.1 per cent.

Experimental Results. All measurements on gold chrome were compared to manganin standards. Fig. 8 shows the pressure-resistance characteristics of two typical gold-chrome samples. The two samples had received a different degree of annealing after the drawing process, and had been baked after being formed into a coil as described previously.

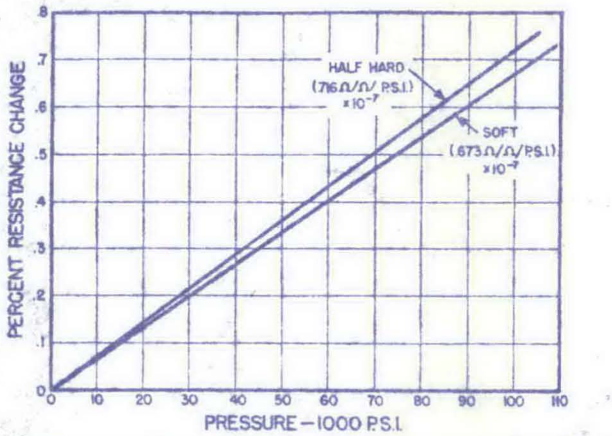

Fig. 8 Pressure Versus Resistance Change for 2.1 Per Cent Gold Chrome

The pressure coefficients of 0.716 and 0.673×10^{-7} ohm/ohm/psi are typical of several samples tested. A remarkable degree of linearity of resistance change versus pressure was noted and, even more important, the complete absence of drift, so annoying with manganin. Linearity was good to less than 0.25 per cent.

The gold-chrome alloy was found to follow rapid changes of pressure, coming to equilibrium within a second or so. No hysteresis during pressure-cycling was observed. When first exposed to pressure, the gold-chrome coils showed an initial zero shift, but in all cases this was well under 1 per cent of the initial value. Furthermore, all measurable zero shift occurred in the first pressure cycle, as compared with manganin, which often required several cycles before repeatable results would be obtained.

Fig. 9 shows the temperature-resistance properties of a 2.1 per cent gold-chrome coil which had been pressurized to greater than 100,000 psi several times. It is interesting to note that one of the effects of exposure to pressure-cycling is to perform the same type of stabilization to temperature as accomplished by extended baking of the new coil.

For purposes of comparison, Fig. 10 shows the pressure sensitivity of a Foxboro manganin coil as compared to a typical gold-

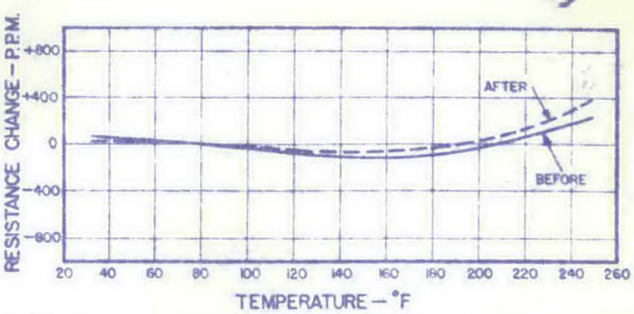

Fig. 9 Effect of 100,000-Psi Pressure Cycle on Temperature Versus Resistance Change for 2.1 Per Cent Gold Chrome

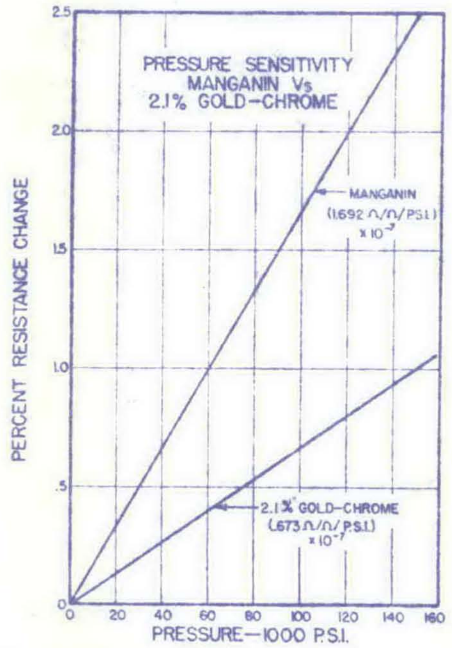

Fig. 10 Pressure Sensitivity of Manganin Versus 2.1 Per Cent Gold Chrome

chrome coil. The manganin coils had pressure coefficients ranging from 1.69 to 1.72×10^{-7} ohm/ohm/psi. Therefore it appears that gold chrome has about 33 per cent of the sensitivity of good-quality manganin, but its ability to discriminate between pressure changes and temperature changes more than overweighed this loss in sensitivity.

Conclusion

Recent observations on gold chrome have confirmed these earlier findings on the linearity and stability of the pressure characteristics. Since 2.1 per cent gold chrome so nearly fulfills all of the requirements of a pressure-sensing device for industrial-control applications, it is recommended that this material be considered seriously as a standard for pressure measurements, replacing the existing manganin standard for application to industrial-control problems.