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MAGNETORESISTIVE EFFECTS IN METALLIC RESISTANCE STRAIN GAGES

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ABSTRACT

This paper presents empirical information on the resistance change in Elinvar strain gages when used in a steady magnetic field. The errors resulting from this effect can be large. Means are presented to prevent the occurrence of this effect, and to correct for it should it occur in practice.

INTRODUCTION

The little-known effect of magnetoresistance can cause a spurious strain reading, IN CERTAIN GAGES, of over 100 microinches per inch, when in fact no strain exists. Such a reading corresponds to a stress level of 3,000 psi for steel. Thus, an error amounting to 10% of the strength of the material might be due solely to the presence of a STEADY magnetic field in which the stress measurement was made.

The strain-caused resistance changes in metallic strain gages (both wire and foil types) are very small. Consequently,

phenomena, other than strain, which change resistance must be understood. The usual application of wire or foil strain gages involves bridge-type circuitry to measure resistance changes to a small fraction of 1%. There are approximately thirty known effects which can cause resistance changes of this order⁽¹⁾. For ordinary circuit work, most of these can be considered as minor second-order effects. This is not true of strain gage work! To be so bold as to infer that the resistance change measured is due to strain alone, it is necessary to eliminate, compensate, or to correct for the other 29 effects.

Very few workers are called upon to make strain measurements in magnetic environments. Consequently, this effect is seldom encountered in practice, but when it does occur, it can ruin an otherwise satisfactory measurement. It is important to note that this effect is distinct from simple induced voltages due to changing magnetic flux linkages. This latter difficulty is one of the most common type of spurious signals encountered in electrical measurements.

NOTE: Superior numbers refer to similarly numbered references at the end of this paper.

THEORETICAL BACKGROUND

Considerable work has been done to investigate magnetoresistance⁽²⁾, but quantitative application to strain gages is difficult. This is because the magnitude depends upon the degree of cold work of the material. The three interrelated phenomena involved are:

- a. Elastoresistance
- b. Magnetoresistance
- c. Magnetostriction

ELASTORESISTANCE is the change in resistance with externally applied strains and forms the basis for the use of metallic resistance strain gages. For certain materials this effect is larger than that which would be predicted by simple conservation of volume and the application of Poisson's ratio. Such materials are said to have high "strain sensitivity" and are used to make metallic-resistance strain gages.

MAGNETORESISTANCE is the change in resistance of a ferromagnetic conductor under the influence of an external magnetic field. This change may be either positive or negative depending upon the material and its orientation with respect to the magnetic field. When the field is parallel to the conductor, its resistance increases with increasing field. At extremely high fields, resistance may decrease again. However, when the magnetic field is perpendicular to the conductor, and hence to the current, the resistivity usually decreases with increasing fields.

MAGNETOSTRICTION is really several effects, but is commonly considered as the Joule effect, which is the change in dimension of the material along the axis of the applied magnetic field. Magnetostriction is exhibited by iron, nickel, cobalt and their alloys. Iron has positive magnetostriction, nickel negative; and iron-nickel alloys may have either, depending upon the composition.

Magnetoresistive and elastoresistive effects are interrelated and may be qualitatively understood by consideration of the Joule effect. The magnitude of the change in resistance due to a magnetic field will be different for a strained than for an unstrained specimen. For example, in positive magnetostrictive materials, this change with parallel field will be less as the external tension on the gage increases. This is because the Joule effect is caused primarily by reorientation of the magnetic domains in the material. These domains are randomly oriented in unstrained metals. Thus, the magnetic field can have a strong effect.

Tensile strain tends to line up the domains in the direction of strain, thus leaving fewer domains available for orientation by the flux and thereby decreasing the magnetic Joule effect. If the strain, or degree of cold work, is large enough, the magnetoresistive effect may thus become negligible. The effects of external compressive strains are opposite to those for tension. To further complicate the matter, negative magnetostrictive materials display a reversal of the above-described effects.

Other magnetic effects such as the Hall effect and ferromagnetic attraction are negligible under the conditions of most strain gage applications.

RESULTS

The most important result of these tests is that ONLY GAGES OF FLINVAR ALLOY showed the magnetoresistive effect. Thus, the widely used Constantan and Nichrome gages are suitable for applications in magnetic environments. Unfortunately, Flinvar gages are most useful because they have about twice as much "strain sensitivity" as other common alloys. This conclusion is drawn from tests performed on bonded-wire and foil resistance strain gages of the following alloys: Flinvar (57% iron, 34% nickel), Constantan (92% platinum with 8% tungsten), and the heat-resistant alloy Nichrome.

The tests were performed simply with the test gages mounted on an aluminum cantilever beam which could be inserted into an accurately known magnetic field. An adjusting screw and dial indicator provided means to measure the deflection of the cantilever beam. The strain gage bridge information was obtained with a Baldwin Type L strain indicator, a 2,000-cycle reference bridge type instrument.

The test results shown in Fig. 1 and 2 are consistent with the foregoing theory. They show the change in resistance versus magnetic field strength, with applied external strain as the parameter. Curves were obtained for each of the three orthogonal orientations of the gage with respect to the field. No measurements were made of the effect for other orientations. However, the magnitude of the effect is quite sensitive to small changes in orientation with respect to the magnetic field.

MINIMIZING THE ERRORS

No measurable magnetoresistive effects were found in Constantan or Nichrome gages, either foil or wire. When gages must be

used near magnetic circuits, the less sensitive Constantan or Nichrome gages should be used. The use of the high-sensitivity Elinvar gages is not recommended. It is important to note that the stray magnetic field around large electrical machinery may easily be 50 gauss. For example, electromagnetic shaker tables are frequently used in laboratories. They have high stray fields.

From Fig. 1 we can see that an Elinvar gage with an applied real compression of 400 microinches per inch would have a spurious strain error of approximately 90 microinches per inch when used in a 50-gauss field. A simple magnetic shield of quarter-inch steel can reduce such a field to a negligible amount.

CORRECTING THE ERRORS

When the DIRECTION AND MAGNITUDE of the magnetic field are known, the Elinvar gages can be used by applying the corrections implied by Fig. 1 and 2. Note that under usual conditions (flux less than saturation and magnetomotive force approximately at right angles to the surface) the magnetic field is at right angles to ferromagnetic surfaces. This case is shown in Fig. 2.

Correction involves an iterative-type solution following the steps outlined below.

1. Assume a real strain approximately that measured.
2. Using its curve find the corresponding "magnetic strain."
3. Add this "magnetic strain" to the assumed real strain (add algebraically).
4. Compare with the measured strain.
5. Adjust Step 1 and repeat so as to reduce the error to the desired degree of accuracy.

When the amount of data to be taken is large enough to warrant use of computers for data reduction, information from these curves may be fed into the computer which will then perform the required correction.

The exceptionally high degree of consistency among strain gages is due to an elaborate system of quality control which the makers exercise. Because of this it is unlikely that the degree of cold work will vary much between lots of gages of the same material. Nevertheless, when work of high accuracy is required and Elinvar gages must be used in magnetic fields, the appropriate sections of the accompanying curves (Fig. 1 and 2) should

be spot-checked to detect possible variations between lots and individual gages.

REFERENCES

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- (2) "Ferromagnetism," H. M. Bozorth. D. Van Nostrand Co., 1951.

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FIGURE LEGENDS

Fig. 1. Effective "Magnetic Strain in Elinvar gages, for steady magnetic fields parallel to the gages.

Fig. 2. Effective "Magnetic Strain" in Elinvar gages, for steady magnetic fields perpendicular to the gages.

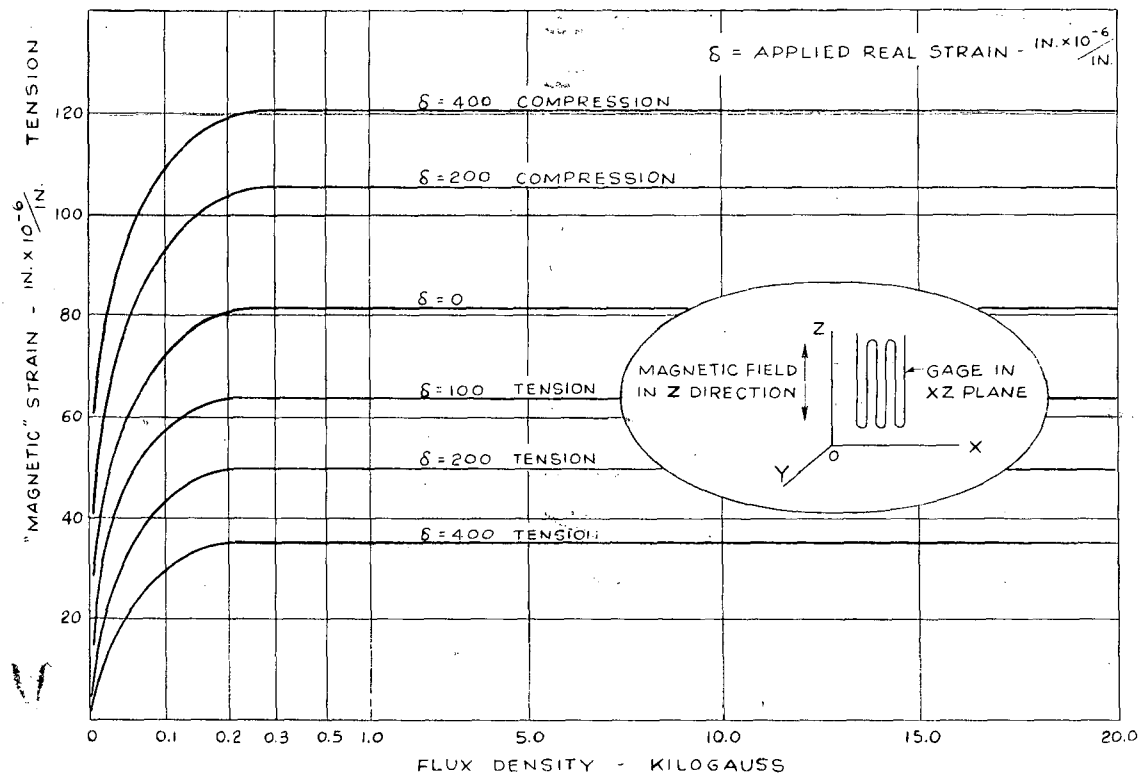


Fig 1

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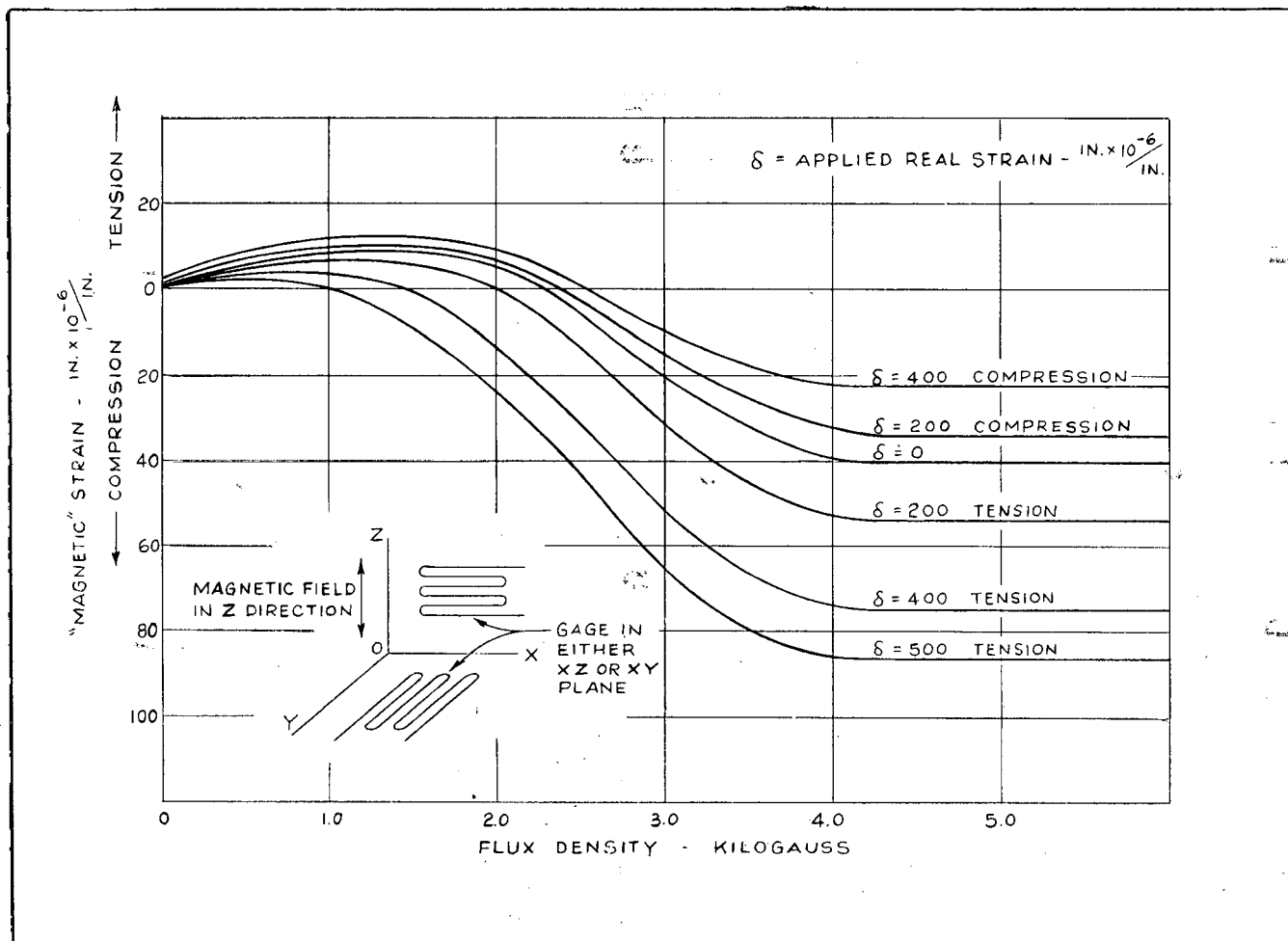


Fig 2

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