trade it is, there is almost bound to be a mention of some electronic apparatus for that trade. Electronics can help industry, it cannot make it. Careful investigations and understanding are necessary before its introduction.

There is another aspect I must mention before concluding—electronics in defence. Although we have progressed greatly in science, developing and controlling many hitherto hidden forces, we have developed but little in the control of ourselves as human beings. Until we do so, we must consider the problem of, shall we say, defence. If another war is fought, it is certain that the machines of war, the rocket, atomic bomb, the interception rocket, or other weapons, will be electronically controlled. The man-piloted bomb carrier will be soon a thing of the past. The training in electronics and the development of electronics are essential parts of any defence programme.

MEASUREMENT OF STRAIN BY ELECTRICAL RESISTANCE GAUGES.

By W. B. Dunn.

Types of Gauge.

Within a reasonable degree of accuracy, the engineer has long been aware of the properties of various materials used in construction—e.g., aluminium, wood, etc. However, he has in the past failed to achieve a comparable knowledge of the effect of loads, pressures, earthquakes, etc., on the structures he has designed. Hitherto to solve the problem of complex strains has been a job of complicated mathematical treatment, protected by large factors of safety or ignorance. Modern equipment for stress analysis, such as electronic strain gauges, photo-elasticity, etc., provide useful means of solving such problems. The most popular method of measuring surface stresses in structures is by means of the resistance strain gauge, developed by Dr. Simmons at the California Institute of Technology.

Essentially the gauge consists of a length of fine wire, firmly attached to an insulating layer, usually of paper. In use, the complete gauge is glued to the surface of the object to be tested. Such a gauge is capable of registering minute changes in strain, both tension and compression, by corresponding changes in electrical resistance measured on an accurate Wheatstone Bridge. In a few cases a single length of wire can be used, but usually the total length of wire necessary to meet the needs of accuracy and sensitivity is greater than the gauge length, and the wire is formed into multiple layers. This may be done in one of three ways:—

1. The wire is cemented to the surface of a piece of paper in a series of parallel lengths, joined by semi-circular arcs.
2. Wire is wound around a piece of paper so that alternate lengths are parallel and at a slight angle to intermediate lengths.
3. Wire is wound as the weft of a composite fabric.

Each form has its advantages and disadvantages as summarised below:— No. 1: This gauge has a short drying time and is the easiest to build, but is in itself mechanically weak. No. 2: This gauge has a long drying time, due to the fact that more paper is used and a stronger bond is required. The gauge has increased mechanical strength over type No. 1, and can be made in very short gauge lengths. Gauge 1-16in. long have been made. No. 3: This gauge is hard to make and is not in use in New Zealand. The makers claim for this gauge a very short drying time.

Strain Sensitivity.

The strain sensitivity of the gauge is the figure representing the ratio of change of resistance for change of strain.

$$S = \frac{\frac{dR}{R}}{\frac{dL}{L}} = \frac{dR}{Re}$$

where R = original resistance $\left\{ = \frac{sL}{a} \right\}$

L = original length

e = strain

a = area of wire.

This figure must be known with a greater degree of accuracy than that required from the strain measurements.

The nature of the figure for strain sensitivity is still a point of dispute, and at the moment is not fully understood. From a purely theoretical aspect, the figure should depend on Poisson's ratio for the wire, and can be proved to be approximately equal to $1 + 2\sigma$, where σ = Poisson's ratio. With a normal figure of 0.3 for σ, this means that the strain sensitivity equals 1.6. However the strain sensitivity varies between wide limits for different materials, and ranges from — 12.1 for pure nickel to + 5.1 for platinum-iridium (5%). It appears that the strain affects the specific resistance of the material in varying manners. The strain sensitivity is the same for tension and compression.

Gauges are wound commercially to a resistance tolerance of ± 0.25% and to a sensitivity factor of 1% tolerance. This is sufficient for normal engineering purposes.

As gauges once stuck to a surface cannot be used again, any form of testing means their destruction, and consequently calibration, etc., is done by batch method under a rigid form of statistical control. The usual form of testing is to attach the gauge to a beam, which is bent so as to form the arc of a circle. The stresses set up in the beam can be calculated from first principles and converted to strain for comparative purposes. The calibration consists of plotting change of resistance against the radius of the arc formed by the stressed beam.

Wire.

To make a good gauge the wire used must have certain desirable features:

1. The wire should have a high strain sensitivity, so that any change in strain will make a large change in resistance.

2. The resistance should be as high as possible so that any change in resistance will be reasonable for the accuracy and sensitivity of the galvanometer, or other measuring instrument used. In U.S.A. gauges of 120 ohms are commonly used over 1in. gauge length.

3. The change of resistance with change of temperature should be negligible.

4. The coefficient of expansion should be as small as possible, to prevent strain being set up when in contact with structural members varying in temperature.

5. A high fuse point is required so that as many amperes as possible may be used.

6. Thermo-electric effects when in contact with dissimilar metals, should be negligible.

7. The size of the wire is very important, as the load transmitted through the glue depends on this figure. Glues will transmit only a certain load, which is passed on to stretch the wire. The load is proportional to the area of the wire. The surface of the wire in contact with the glue is the area through which the load is transmitted, therefore to prevent slip through the glue, the ratio $\frac{\text{circumference}}{\text{area}}$ should be high. This calls for small wires, and the common gauge wire used is 50 (.001in.).

The wires used mostly for strain gauge work, are tabled below.

	Strain Sensitivity	Temp Coefficient
1. Nichrome—80% Ni, 20% Cr	2.0	High
2. Manganin—4% Ni, 12% Mn, 84% Cu ..	0.47	Very low
3. Constantan—45% Ni, 55% Cu	2.0	Negligible
4. Iso-elastic—36% Ni, 8% Cr, 0.5% Mo, 55.5% Fe	3.5	High

No. 3 is used for nearly all static work, where temperature changes are liable to invalidate results.

No. 4 is used for dynamic work, where temperature changes are not so important.

The gauge wire under strain has a linear strain; change of resistance ratio beyond the elastic limit, in fact it continues almost up to the breaking point. Repeatability, however, is usually limited to strains below the elastic limit.

The requirements of gauges are the same as those for the wire used, with one or two additions. The gauge should be built to allow a maximum voltage to be applied, and yet to allow any heating effect from the wire to dissipate into the surrounding air. The three models mentioned are designed to allow for this.

Glue.

The glue is one of the most important parts of gauge production. The wire is bonded to the insulating paper layer by glue, and the whole gauge is attached to the test member by a similar glue. For normal work the best glue to use is celluloid dissolved in butyl acetate. This glue dries out quickly and develops a high bond strength. It suffers in that it softens at temperatures over 90° to 100° F.

For moderate temperatures fish glue is used, but unless the humidity is low this becomes very brittle. For temperatures in the vicinity of 212° F., the thermo-setting resins, such as bakelite, are more commonly used.

The glues are allowed to set by the evaporation of the solvent, which takes about 24 hours. It is possible, when conditions warrant, to speed up the drying time by the application of heat at about 50° C. The temperature must be raised slowly, otherwise bubbles form and give poor bond strength.

Sources of Error.

Any change of resistance other than that derived from strain, must be considered as due to some fault in the apparatus. The more common sources of error are as follows:—

1. *Creep.* This is a change of resistance at any strain, and is usually due to unsatisfactory adhesion. This may be caused by solvent being left in the glue, impurities in the glue, or an excessively thick layer of cement. A subsidiary cause is poor welding of leads from gauge to measuring box. Creep can usually be eliminated by running a load on and off for a few cycles, before commencing the test.

2. *Leakage to Earth.* If any moisture is left in the glue, or infiltrates between the edges of the gauge and the test specimen, the resistance between gauge and earth is considerably reduced. This means that a short circuit is formed across the gauge and will affect the results. A drop of 1 megohm to earth means a change of 180lb. per square inch in the 120 ohm U.S.A. gauge. Prevention is possible by thoroughly drying out the gauge and the waterproofing over the whole area. The waterproof material must be an insulator, and must not react with the cement. The common substances used are paraffin wax, or a solution of polystyrene in xylene.

3. *Corrosion.* This may be duê to water as above and can be prevented by waterproofing. However electrolysis between leads and gauge is hard to prevent.

Conclusion

The above only describes the strain gauge itself and does not cover the electrical circuits used to measure the strain. There have been many problems solved by the use of such gauges, in both static and dynamic conditions. The performances of aircraft parts in flight, rotors under torsion, and bars under straight tension have been investigated. Though their use in New Zealand is not widespread they soon will become an important part of mechanical testing in this country.

Discussion.

Mr. R. A. McLennan: Is the 7% change in length meant in terms of total length?

Mr. Dunn: Yes, but this does not mean that this figure is reached in practice. The maximum elongation is usually of the order of 1/100in. The tested material will usually break before the gauge breaks. Only with materials like rubber the gauge might break first.

Mr. R. A. McLennan: What are the variations between individual gauges in a batch?

Mr. Dunn: The variations are only small, and so far we have never re-calibrated overseas gauges and are relying entirely on their figures.

Mr. Toynbee: Can these gauges be used to measure weight?

Mr. Dunn: Yes, with the help of a tie bar and by using the area of the tie bar and the modulus of elasticity of the material the load applied can be calculated.

Mr. Mouat: What is the speed of response of the strain gauge?

Mr. Dunn: Response is possible up to 10,000 cycles per second.

Mr. Toynbee: How accurately can you measure the applied load?

Mr. Dunn: Stresses up to 30 lb. per square inch, $\pm$ 2.5%.