Industrial Electronics

3. Inductive and capacitive displacement transducers

by Richard Graham

The absolute method of displacement and position measurement described in the last article is one of the most accurate and reliable known to man of positioning the workpiece in a machine tool. It must be admitted, though, that it comes expensive. Furthermore, other applications in which position measurement is carried out may not need the ultimate in accuracy, long-term stability, digital read-out and friction-free operation. The engineer must be a practical man, and it makes good sense to provide the required performance at a reasonable cost, and not to saddle whoever is paying the bill with more accuracy, etc. than he can use.

Inductive transducers

Considerably cheaper, but still accurate and extremely sensitive, is the linear variable differential transformer — a device which is substantially easier to use than to say. Fig. 1(a) is a sketch of the transducer in which are shown a primary and two secondary windings on a common, cylindrical former. The secondaries are wound in phase opposition, and the three windings are penetrated by a core, which is movable axially. When the core is in the centre position, the magnetic flux linking the primary to the secondaries, *via* the core, is equally distributed, so that the output difference voltage is zero. As the core moves to favour one secondary, the voltage from that secondary increases at the expense of the other and a difference voltage appears. Moving the core in the opposite direction by the same amount produces a difference voltage of the same amplitude but of opposite phase. The core movement/output voltage characteristic, neglecting phase, is shown in Fig.1(b). Departures from linearity are of the order of 0.25% of end-to-end output, and at the origin, there is not a perfect null unless steps are taken to provide one by external electrical means.

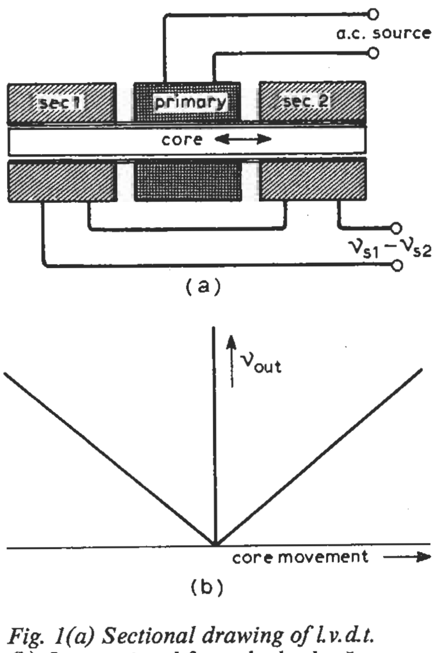


Fig. 1(a) Sectional drawing of l.v.d.t. (b) Output signal from the l.v.d.t. In a phase-sensitive detector the left side would be negative.

Unless the core is required to pass the centre position, the output can be indicated directly by an ordinary pointer-type instrument of high impedance or by digital voltmeter. For full-range indication, a phase-sensitive meter is, of course, required. The transducers can be obtained in ranges from 0.05in to 10in, full-scale, the output being in the order of 0.02mV to 2mV per volt applied per 0.001in displacement.

This transducer has much to recommend it. Mechanically, it is simplicity itself. There is no friction and the device is invulnerable to hard use and hostile industrial environments. The alignment of the moving core is not critical and there are no rubbing surfaces to wear. Electrically, while not as linear as the digital type of transducer, it is adequately accurate for the majority of applications. It has a continuous characteristic, providing an infinitely small resolution, and it is mechanically and electrically stable.

Applications of the l.v.d.t. are numerous and range from pressure measurement to the determination of acceleration; any parameter, in fact, in which the variable can be turned into a linear movement can be measured by an l.v.d.t. system. An interesting application is that shown in Fig.2, where the static l.v.d.t. is being used to determine the eccentricity of a lorry tyre. The system is by Sturge Automation[3] and is capable of detecting eccentricities of 0.002 inch on a 40-inch tyre. Similar systems, using multiple transducers, are in use to detect variations in the thickness of continuous sheet material during manufacture. The output is presented digitally.

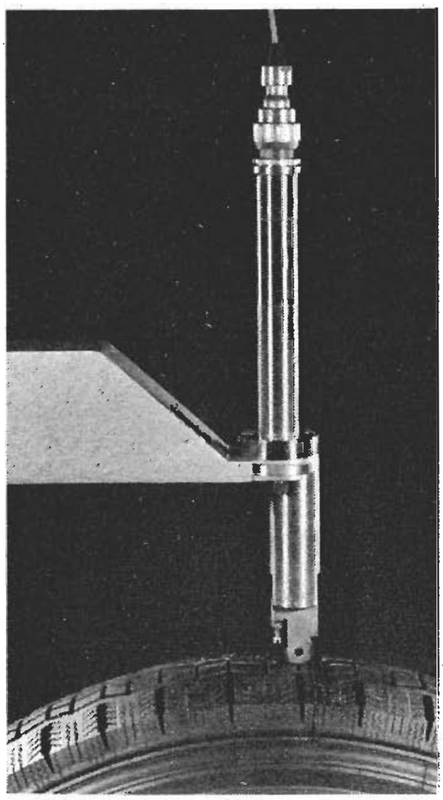


Fig. 2 Tyre eccentricity measurement by Sturge Automation. As the tyre turns, the output of the transducer is recorded.

L.v.d.ts can be used to measure acceleration by the arrangement of Fig.3. In this type of instrument, the windings are stationary relative to the body whose acceleration is being measured, the mass of the core and associated spring flexures being free to move. The deflection of the core is proportional to the applied force due to acceleration.

The testing of metallurgical specimens is an application in which the l.v.d.t. excels by virtue of its linearity and stepless output. Fig.4 shows such a measurement suggested by Schaevitz[1], in which a tensile test specimen is being extended, the

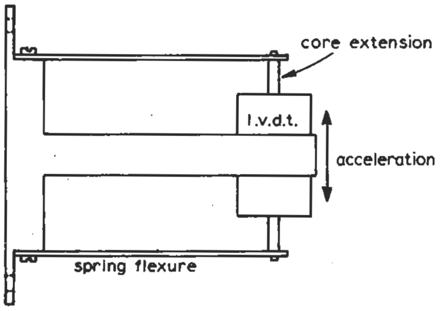


Fig.3 The l.v.d.t. in an accelerometer application.

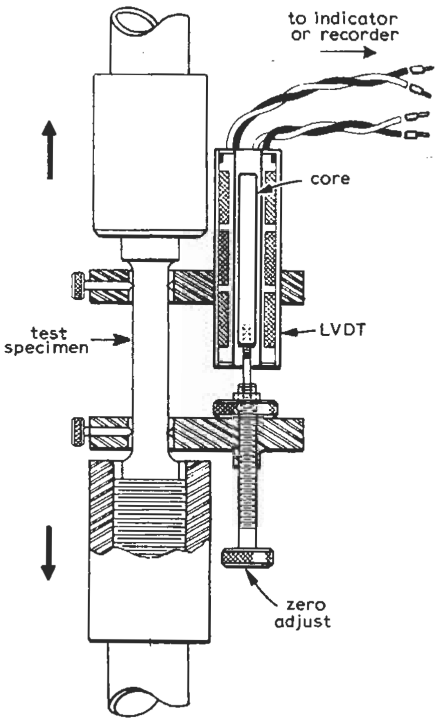


Fig. 4. When used in an extensometer, the core is completely free to move and is not damaged when the specimen breaks.

l.v.d.t. being used to measure the extension. The core and windings are, of course, completely separate, so that when the specimen ruptures, no precautions are necessary to prevent damage to the l.v.d.t.

Similar, in some respects, to the l.v.d.t. is the half-bridge inductive transducer. It consists of a tube of non-magnetic material, on which are wound two coils forming two arms of a bridge network. A ferromagnetic core moves in the tube, varying the inductance of the coils differentially and unbalancing the bridge, which is completed by resistive arms. These devices possess the advantages of the l.v.d.t. and are cheaper to make, measuring from ± 1 millimetre to ± 150 millimetres at a maximum non-linearity of less than 2% of stroke. Philips[2], in common with other manufacturers, provide a range of signal generation and handling equipment. In conjunction with this equipment, it is possible to obtain full-scale deflection at the indicator for a deflection of one micron.

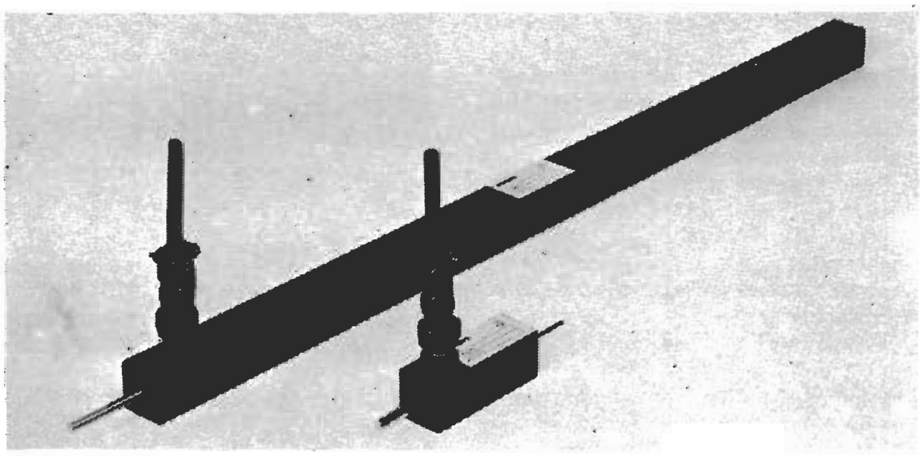
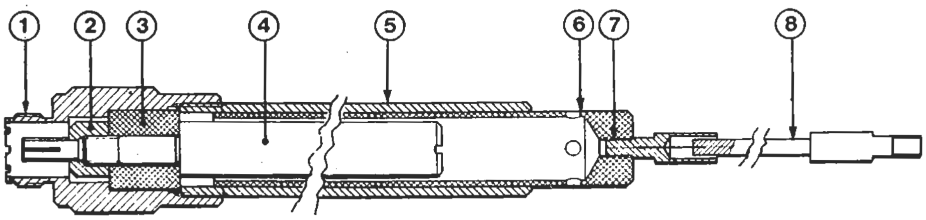


Fig.5 The LD5000 inductive half-bridge transducer by Philips.



1. Adapter, stainless steel, 27 mm dia.
2. Special nut, brass
3. Insulating bushing, polystyrene
4. Inner electrode, stainless steel
5. Outer electrode, stainless steel, 20 mm dia.
6. Dielectric tube, polystyrene, 16 mm dia.
7. Threaded insert, 3-mm metric thread
8. Coupling section, aluminum

Fig.6 The DISA dielectric-change transducer type 51DO5.

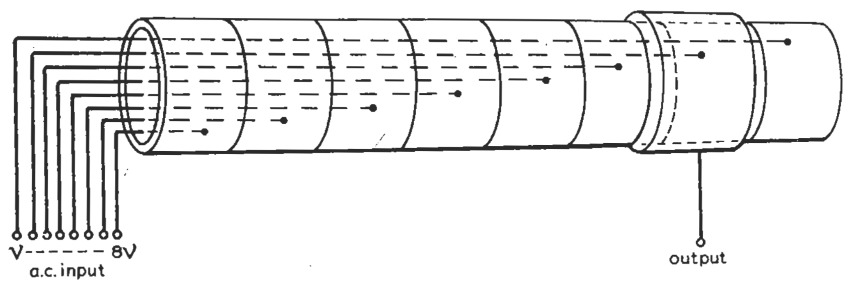


Fig.7 Rank Precision capacitive displacement transducer.

Capacitive transducers

As may be expected, the "other" property, capacitance, can also be exploited to obtain displacement measurement. The capacitance of two plates is proportional to kA/D, where A is the area of overlap, k is the dielectric constant and D is the distance between the plates. The variation of any one of these parameters will produce a capacitance change, and all three have been used in commercial equipment. To derive a useful output from the capacitance change, the variable capacitor is made a part of the tuning element in an oscillator's tuned circuit, the resulting frequency modulation being detected and used to operate the desired output device. In the case of the transducer working with plate separation as the variable, the distance/capacitance characteristic is hyperbolic and requires an electronic linearizer to give a true indication. Disa[4] manufacture a range of capacitive displacement transducers, together with signal processing equipment, and Fig.6 shows their Type 51DO5, which is of the dielectric-change variety. The change in capacitance as the dielectric tube moves axially is linear with displacement. This type is intended to measure large axial movements up to 7cm and, as the coupling section is hinged, can be used to convert rotary movement into linear displacement. In this way, it is valuable as a piston stroke transducer in the investigation of i.c. engine operation.

The measurement of large displacements is also the function of a system made by Rank Precision[5] (originally by Reilly Engineering) shown in Fig.7. In this case, a series of cylindrical electrodes are arranged end-to-end in the form of a rod. Sliding over the rod is a cursor cylinder exactly equal in length to one stator segment or a multiple thereof. Each segment is fed from a tap on a voltage-dividing transformer, the voltages increasing arithmetically in amplitude. The cursor is coupled purely capacitively to the stator segments and the voltage output

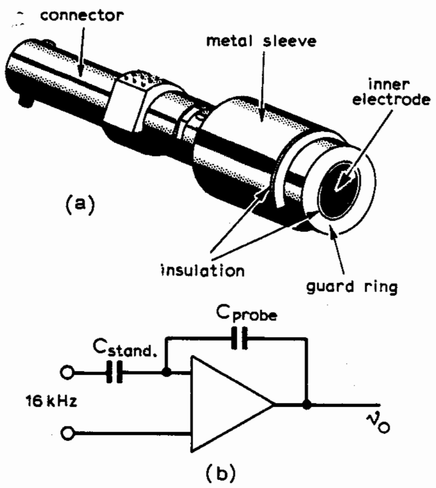


Fig. 8 Wayne Kerr capacitive probe system.

from the cursor increases continuously as it moves from the low-signal end to the other. To take account of any errors in length of the stators or inaccuracy in the transformer taps, additional variable voltage sources are connected in series with the taps, the voltages applied to the stators thereby being capable of slight variations. The output of the cursor is measured by nulling a bridge circuit, which gives a degree of immunity to supply voltage variations. Accuracy of measurement is extremely high, the error over a 20-in transducer amounting to no more than 0.0001 in peak to peak.

Applications include the calibration of automatic machine tools, high-speed measurements on machines where a digital system may be subject to error, and materials testing where long-term stability is required as in the measurement of creep. Short-range transducers are also made, and consist of only two stator segments and a cursor, an arrangement which is effectively a differential capacitor.

The Wayne Kerr[6] Dimeq TE200 range of equipment is another embodiment of the variable capacitance technique. Fig.8 shows a sketch of the principle, in which one "plate" of the capacitance in question is the transducer. The other electrode is the metallic structure under examination, which is connected to the instrument ground. The capacitor formed by the probe and structure is made the negative feedback element in a high-gain amplifier, to which is applied a constant-amplitude 16kHz signal. If it is assumed that the open-loop amplifier gain is very high, there is a virtual earth point at the junction of the fixed *C stand* and the probe capacitance *C probe*. The closed-loop gain of the amplifier is proportional to the reactance of the probe capacitance, which is proportional to *d*, the distance between the probe and the earthed structure. The output signal is therefore directly proportional to this distance. The application of the system lies in the measurement of vibration, thickness, bore diameters and eccentricities and is capable of indicating displacements in the range 0.5mm to 2.5mm.

The transducers and systems described in these two articles have been selected from a large number of devices currently in use, employing the properties of capacitance, inductance, resistance and ultrasonics to provide the detection and measurement of position, displacement and distance. Many more exist, and it is not intended to imply that the types that are not described are inferior — it is simply that the choice is limited by space.

In the next article, I shall deal with the use of electronics in the weighing industry.

References

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2. Pye Unicam Ltd., Philips Electronic Instrument Dept., York Street, Cambridge CB1 2PX.
3. Sturge Automation Ltd., Lifford Lane, Birmingham B30 3JP.
4. DISA, 116 College Road, Harrow, Middlesex HA1 1HQ.
5. Rank Precision Industries Ltd., Leicester House, Lee Circle, Leicester LE1 9JB.
6. The Wayne Kerr Co. Ltd., Durban Road, Bognor Regis, Sussex, PO22 9RL.

Sixty Years Ago

This was the first issue after the launch of the journal under its new name. Although wireless telegraphy ceased to be our prime concern some time ago, the broad aims of *Wireless World* appear to have remained substantially the same.

"In presenting the first number of THE WIRELESS WORLD last month, we do not think we were unduly sanguine in thinking that it would occupy a place in periodical literature which has hitherto been left unfilled. Its reception has justified the opinion that the magazine would meet a distinct need, and the cordial welcome which it has received from all quarters and from the technical and general Press encourages us to look for the rapid achievement of our object to make it 'a magazine for everyman'. The first number had an issue of fifty thousand copies, but, large as this quantity may appear, it was by no means too large to cope with the demand. An encouraging feature was the numerous 'repeat' orders from newsagents and booksellers in all parts of the country. These facts are worth mentioning because they illustrate more strikingly than anything else can the great public interest in the subject of wireless telegraphy, and their eagerness to read about it when the subject is presented in such a manner that it will not be beyond their scope."