Industrial Electronics

2. Displacement and position

by Richard Graham

One of the rôles of industrial electronics is, as was mentioned in the introductory article last month, the rendering of aid to humans to enable them to work at much higher efficiency. The subject for discussion in this article is an illustration of just such a field of activity and is concerned with measurement of movement, position and length.

Of what? Yes, well almost anything, but in the main the devices to be described are part of machine tools and the movement or position being measured is that of the work-piece or tool. They also make possible the attainment of more and more accurate inspection, can be used as mechanical-to-electrical transducers in weighing and are finding new applications constantly in many branches of engineering.

As a class, these paragons are termed displacement transducers, a name which covers several different techniques — although each application has its own favourite method. Machine tools being perhaps the most widespread application, we can start with the type of transducer most commonly used by them — the optical variety.

Optical transducers

Two distinct types of optical displacement transducer are now in widespread operation. In the first type to be described, position is determined by counting techniques, starting from an arbitrary zero, and the equipment is categorized as "incremental". The second kind is a development of this, based on experience of the use of incremental equipment in an industrial environment, and is known as the "absolute" type of transducer.

Incremental. The first class of equipment, upon which much early work was done by Ferranti[1] and the National Physical Laboratory[2] (and later the National Engineering Laboratory), relies on the moiré effect observed when slightly crossed gratings are placed next to each other. In principle, the system is simple in the extreme; in practice, the production of gratings and the processing of the signal is fairly complex.

Assume, for a moment, that the movement of interest is that of a slide on a machine tool, and that we wish to know the amount of movement to a resolution of 2.5mm. (If this really were the required resolution, we might equally well use a piece of string, but it serves to illustrate the principle.) All that is required is a transparent sheet of glass — a grating — with opaque stripes at 2.5mm centres, a lamp, a photocell and a counter. As the slide moves with its attached grating, the photocell is alternately darkened and illuminated, the resulting pulses being displayed by the counter.

This process would work well down to a resolution where one complete cycle on the grating was small enough to compare with the size of the photocell, at which point pulses would no longer be produced and the system would be useless. At 2.5mm cycle length this situation is almost upon us, and any improvement in resolution requires a new approach. Using two gratings and the moiré effect, it is possible to recognize grating movements to a resolution of 0.0025mm or better, and by use of prismatic gratings and refined techniques to a much smaller resolution.

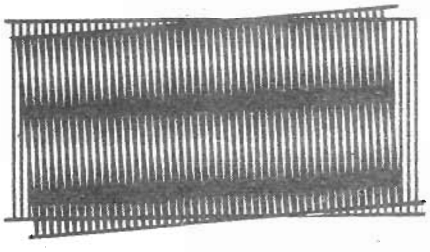

Fig. 1. Crossed gratings demonstrating the production of moiré fringes.

Fig. 1 shows the basic moiré principle. As the gratings move relative to each other in a direction perpendicular to the lines, the interference pattern of fringes moves in a direction parallel to the lines, and a grating movement of one line moves the fringe pattern one fringe. The size of the fringes is adjustable by altering the angle at which the lines on the two gratings cross.

It is clear that the use of the gratings has apparently magnified the relative movement, the magnification being often 1000 times or more. An additional benefit conferred by the principle is that each "mark", instead of consisting of one dark line whose positional accuracy influences the whole system, is a "fringe" caused by the crossings of perhaps 500 pairs of lines, and the averaging effect of this reduces the need for accuracy. It must be admitted though that the producers of gratings do not allow this to get in the way of truly staggering degrees of accuracy.

Having obtained the fringes, some care must be directed towards the derivation of an electrical signal which will provide information on both the amount and direction of the relative movement. Fig. 2 shows a frequently used scheme in outline.

The use of four photocells is concerned with need to recognize direction. The gratings, or rather the grating and an index made from a small section of the larger grating, are adjusted so that one complete cycle of the interference pattern occupies the width of the four cells, so that each cell is 90° out of phase with the adjacent ones. Fig. 3 shows the waveforms from each cell as the grating moves, and subsequent signal processing. The final result is seen to be a train of pulses on either the "forward" or "reverse" outputs, and four times the number of pulses appear as would be produced by the scanning of fringes by one photocell.

It only remains to feed the pulses to a reversible counter and display to obtain a position and displacement measuring device of high accuracy, of high resolution and with digital display. For the

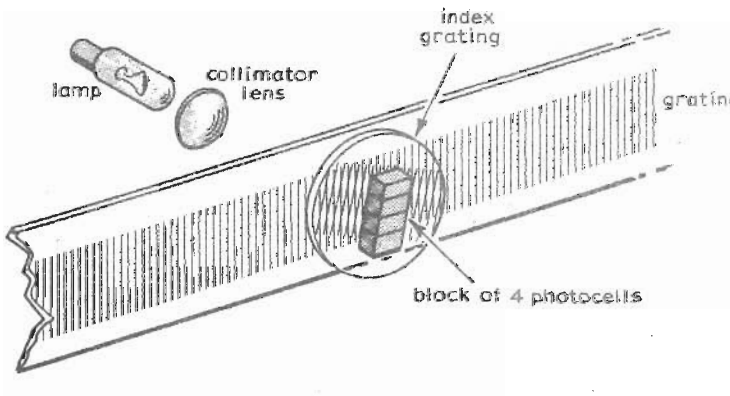

Fig. 2. A typical arrangement for the detection of fringes.

conversion of rotary motion to electrical signals, circular gratings with radial lines are made to the same order of accuracy. Increased resolution can be obtained by the use of spectroscopic gratings in which the "lines" are formed by microscopic prismatic rulings in transparent plastic, but for anything other than the most precisely controlled working conditions (the reading head gap is very important) these gratings are difficult to apply. Line densities of up to 6350 lines per inch are available.

The method of measurement just described is virtually ideal in most respects. It is unfortunate that it is somewhat vulnerable in the precise area in which the industrial environment is most inimical — it is susceptible to noise.

One of the advantages of the incremental equipment is that it can be arbitrarily set to zero at any point, because no part of the grating is different to any other part. However, this apparent advantage is obtained at a price which, in the end, proves far too expensive. The lack of uniqueness in each grating section means that if, anywhere in the system, a pulse is miscounted or a mains transient gets loose in among the counters, then all the information gathered to that instant becomes valueless. The only way to rectify such a situation is to return to the zero position and throw again.

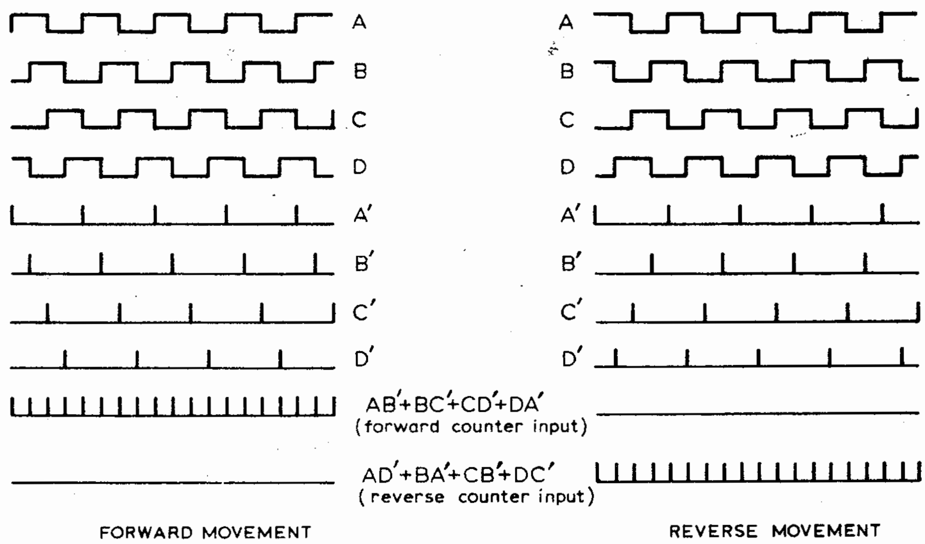

Fig. 3. The derivation of direction and count signals from four cells spaced at 90° intervals over one fringe "wavelength".

Absolute. Workers at the National Engineering Laboratory, East Kilbride, Glasgow, whose researches are chiefly directed towards machine-tool applications, evolved a hybrid analogue/digital method of using gratings in conjunction with coarse coded tracks[3]. In operation, the newer system is absolute in that, although its accuracy is entirely dependent on the finest incremental track of a multi-track grating, it does not rely on counting techniques. Interruption of the supply or transient interference do not affect results and, if a machine-tool fitted with the system is switched off, it can be re-started without the necessity of running each axis back to zero or datum.

Fig. 4 shows the relevant waveforms; the method of interpolation will be described later. A is the signal produced by the first (finest) track of a three-track grating. B is derived from A electronically, A being interpolated to provide a sub-division by 10. Also derived from A are C and D which, in antiphase, have switching points at transitions 4/5 and 9/0 of B. An "up" condition is considered to be "on". The second grating track is divided into two signals, each providing counts of 0-9, shifted in phase to each other by 180°. Operation proceeds as follows.

Assume that the reading head is in the area between 0 and 4 of the first cycle of the finest track. The interrogation waveform I_1 strobes the second-track first waveform S_1 and detects the fact that a 0 is present. The reading will therefore be from 01 to 04. At the 4/5 switch-point on the first row, waveform I_2 comes "on" and strobes S_2, which also shows 0. The readings are therefore 05-09. At this point, I_2 goes "off", I_1 comes "on" and strobes S_1, which has meanwhile changed to 1, giving readings of 10 to 14, whereupon I_1 goes "off", I_2 comes "on", strobing S_2 and finding 1 again. It will be seen that the switch points of the second track cause no error provided that they are within $\frac{1}{4}$ cycle of the first track (2.5 digits).

The process is repeated for the second and third tracks, coarser information being obtained by any suitable means, such as a coded digitizer on the lead-screw of a machine tool. The method affords many advantages over the incremental variety of grating system. Foremost, of course, is the absolute nature of the measurement and the elimination of counting and storage elements. The accuracy of the whole system is that of the first track.

The method of sub-division of each cycle of the grating pattern is basic to the system and is responsible for the uniqueness of each digit. If it can be assumed that the waveforms from the reading head are triangular instead of sinusoidal, the diagram becomes fairly easy to draw, and Fig. 5(b) is the result.

From the resistor network shown in Fig. 5(a), fed with processed reading head waveforms as indicated, each tapping point will give a signal shifted in phase by 36° from the adjacent one (Fig. 5(b)). Passed through a zero-crossing detector there emerges a ten-line shift-register code which can fairly easily be combined by means of simple logic to provide a unique one-out-of-ten code. Very fine gratings will produce sinusoidal waveforms rather than triangular ones, and the resistor network must be modified to suit.

The investigation of measurement by optical methods still continues but by the means described it is possible to measure movements up to 10 inches to a resolution of 0.0001 inches, and a rotary motion to within 3 seconds of arc.

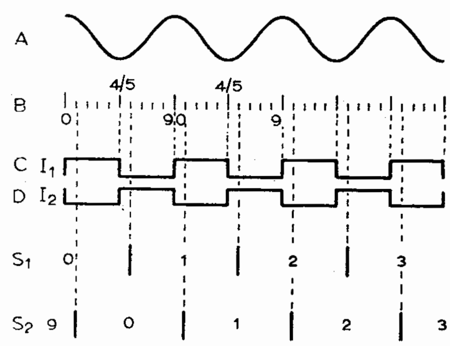

Fig. 4. N.E.L. absolute system. The first track strobes the second track to establish a reference.

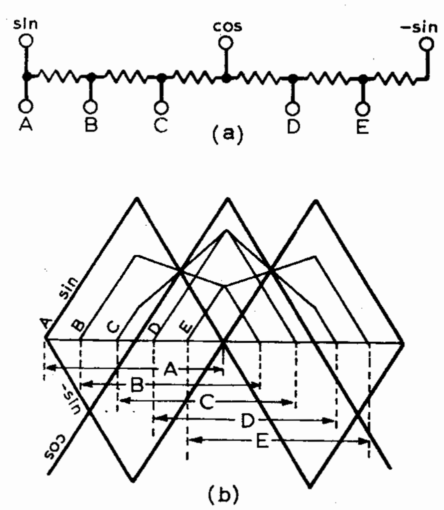

Fig. 5. (a) Resistor network to give family of phase-shifted waveforms. (b) Waveforms at tapping points of (a). Negative halves of curves are ignored. Arrows indicate zero crossings.

References

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3. A. Russell. "Technical Aspects of the N.E.L. Absolute Grating Measuring System" N.E.L. Report No.366. Min. of Tech. 1968.