INDUCTOSYN-TO-DIGITAL CONVERTERS

For the Accurate Measurement of Displacement; Their Use in Linear Measurements for Control Systems

by D. McDonnell

With the coming of computer control of machine tools and drafting systems, the need arose for a linear measurement system that could work with digital data that was fed from the computer-controller. Optically-encoded discs at the end of leadscrews, Moiré-fringe techniques using optical gratings along the machine bed, and other such devices have been used, including lasers, in applications for which they were suitable. However, none of these devices has the combination of ruggedness and low cost of the Farrand Linear Inductosyn.

Until recently, the use of the Inductosyn with digital-control systems has been limited by the lack of high-speed methods of accurately interpolating within one period of the scale. The high-speed tracking Inductosyn-to-Digital converter provides an elegant solution to this problem. The Analog Devices IDC1701 and IDC1703 are converters* specifically designed for this purpose.

THE INDUCTOSYN

For machine-tool and other control systems, the use of the Farrand Linear Inductosyn† has been recognized for many years as an accurate method for performing linear measurements. Inductosyns are manufactured in forms suitable for measuring either straight-line distances or angles. Here we consider the use of linear Inductosyn measurements, though nearly all aspects of the discussion can be easily applied for rotary measurements.

The linear Inductosyn is an especially-useful tool in the high-resolution measurement and control of linear motion over relatively-large distances (many meters). It consists of two magnetically-coupled parts, one usually fixed to the bed of a machine, the other movable with the tools or work. The fixed portion consists of joined lengths of material with a printed rectangular "square-wave" pattern; the movable portion has two short lengths of the same pattern, displaced by one-quarter period ("90°"). The two parts which form the Inductosyn are shown in principle in Figure 1. The fixed "ruler" is typically available in either 10" or 250mm lengths, depending on whether the metric or the English scale is to be used. (The fixed scales are also available as continuous strip in lengths up to 30 feet – 9.144m.)

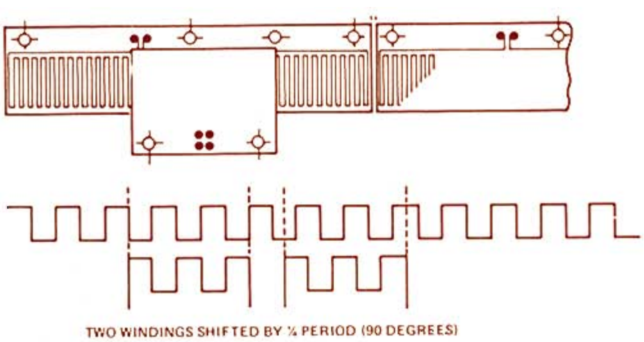

Figure 1. The Inductosyn track and slider system.

*Use the reply card to request information on these devices.

†Farrand, Inc. trademark

Like the two-phase synchro resolver, the Inductosyn utilizes the inductive coupling between a reference winding and two mutually-orthogonal windings to provide an output that is a function of position. In the Inductosyn, the electromagnetic circuits are rearranged in two parallel flat plates, with an intervening electrostatic shield to minimize capacitive coupling. The Inductosyn is a bilateral device; that is, either (1) the fixed winding can be driven by an ac reference, with the slider position manifested in the relative amplitudes of the voltages induced in the two orthogonal windings, or (2) the two windings could be driven by orthogonal resolver outputs, with the fixed winding providing a measure of the difference between the resolver angle and the corresponding positional displacement of the slider.

The second mode of operation is used in conventional Inductosyn feedback-control systems, with the slider driven to maintain nil error between the "set point", applied by the resolver, and the incremental slider position (within a given modulus (cycle) of the printed stator). Although effective in analog servo systems, (2) is not as useful as (1) in digitally-controlled systems. Our discussion in these pages will deal with applications of the first alternative.

INDUCTOSYN-TO-DIGITAL CONVERSION SYSTEMS

The reference input to the fixed scale is an ac current generator at a frequency typically greater than 2.5kHz. The ac outputs at the slider windings, with amplitudes respectively proportional to the sine and cosine of the incremental angle, are preamplified and applied to the input of an Inductosyn-to-Digital Converter (IDC). A reference ac signal, in a phase relationship with the current input to the stator, is also fed into the converter, as shown in Figure 2. As the slider of the Inductosyn is moved through one cycle of the pattern, the

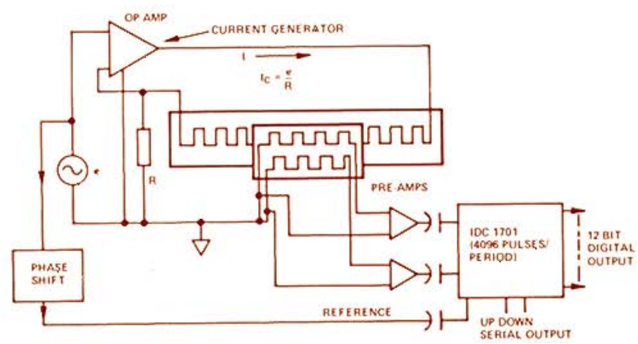

Figure 2. The Inductosyn as a resolver control transformer with digital output.

digital output of the IDC will change through 360°. For absolute positioning, relative to a datum, a counter counts half cycles, providing the most-significant bits of information, and the IDC provides the fractional information, at resolutions up to 12 bits. The outstanding degree of resolution available is quite apparent. A typical system is shown in Figure 3.

PERFORMANCE REQUIREMENT FOR THE IDC

For modern milling and drafting machines, the speed of operation is very important. A standard minimum top speed of 10 meters/minute is now accepted as being necessary in machine-tool control. The standard pitch of the Inductosyns being used is 2.0mm. Since one revolution corresponds to 2.0mm along the track, the top speed is equivalent to 83.3 revolutions per second.

For some standard European machines, a reading rate of 40 commands (or readings) per second has been adopted – providing an interval of 25ms between readings. This means that at the maximum speed, the machine will have moved by 2.08 periods between samples. This means, further, that the IDC must have two extra up-down counting stages beyond the normal MSB of 180°, or else lost periods will occur at high speed.

In addition, the IDC should be capable of following accelerations of up to 1500 revolutions/second/second more or less accurately but without saturating the error detector. This acceleration rate implies that the machine can get up to its maximum velocity of 10 meters/minute in approximately 5mm displacement; similarly, it can be brought to rest from its maximum speed in 5mm.

The choice of carrier frequency for use in the converter is a compromise, taking into account: (1) at *low* frequencies, the signals out of the Inductosyn are too small, in comparison to the amplifier input noise and system interference; (2) at *high* frequencies, the capacitances across the precision resistors and switches establish the limiting speed. From the point-of-view of acceleration performance, the higher the frequency, the better, since less smoothing is needed in the shaping circuits following the phase-sensitive detector.

Two factors influence the useful maximum resolution: (1) the precision with which the induced voltages in the two windings follow the sine and cosine laws with angle and (2) the degree of smoothness of control required. The higher the resolution required, the more difficult it becomes to meet the maximum velocity and acceleration requirements. The maximum resolution that seems justified by the overall accuracy of the system is 12 bits for a 2mm period (1 bit corresponds to 0.5μm, or 19μin, with 1-bit smoothness.

The IDC1701 and IDC1703 are tracking Inductosyn-to-digital converters which have been specifically designed to meet the needs of Inductosyn systems. They differ from other tracking resolver-to-digital converters principally in having the ability to track at 150 pitches/second and accelerate at 250/second/second with only 1LSB error. They are designed to work with carrier frequencies from 2kHz to 10kHz, and are tested at 5kHz. They accept input signals of ¼V rms, and provide digital outputs at TTL levels. Because of the low levels and high-resolution capability, the input signal amplifiers should be well-shielded and located as close to the slider as possible – preferably *on* the slider.

The stator is driven by current in order to obtain complete control over the flux generated in the stator, irrespective of differing track resistances in a series chain or tendencies by stray fields linking the track to induce parasitic currents.

The IDC1701 has parallel and serial (4096 pulses/pitch) digital outputs; the IDC1703 outputs are up-down pulses at 4000/pitch, together with carry-borrow pulses for each complete pitch. The latter is necessary to obtain a precision datum point. The price of either unit is $350 by the 1's.

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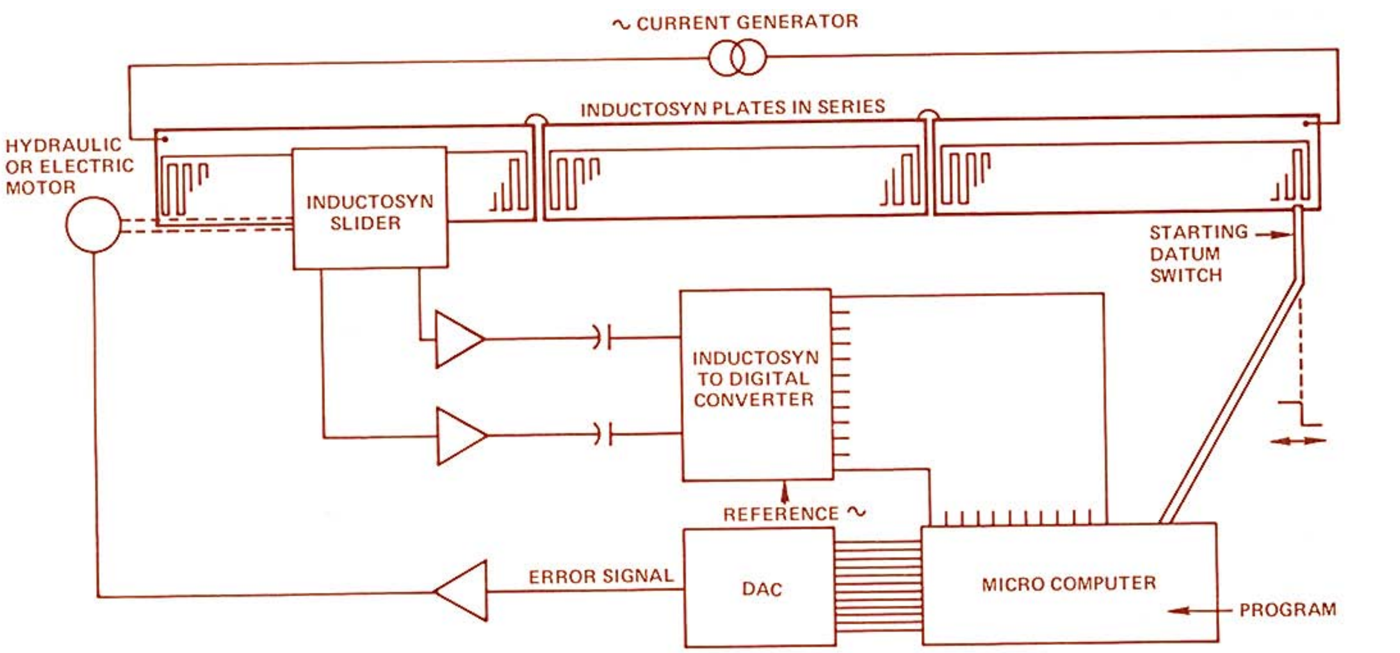

Figure 3. The use of an Inductosyn-to-digital converter in an Inductosyn control loop.