SOME PROBLEMS OF ANGULAR ROTATIONAL DIGITAL CONVERTERS

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Introduction

In applying computer technique for controlling industrial processes it is essential to establish a proper connection between the analog measuring or control devices and the digital computer. In order to construct a computer- or microprocessor-controlled system, rather accurate digital-analog and analog-digital converters are needed.

One of the most common analog signal in control processes is angular rotation. Opto-electronic converters have certain advantages over other as e.g. those based on the Hall effects (Siemens system). This is why here exclusively optical methods will be discussed.

1. Absolute converters

One of the possibilities in coding angular rotation is by making different combinations of codes to correspond to each angular position of the rotating system. This code-combination may be directly fed into the computer or may be decoded first. The code may be binary (Fig. 1), but in this case simultaneous changes may occur in several sensors which would increase the probability of error. This can be efficiently avoided by using the so-called "*V*-logic" as shown in Fig. 2. In this system the 2^0 bit is traced by a single sensor while the others by two ones arranged in *V*-form. By using the signals of the sensors of the 2^1 bit one can decide which of the sensors of bit 2^2 gives a signal, which is considered as true, and so on, for the subsequent bits. This way, by using a logic circuit, uniform information can be transferred.

The *V*-logic system is seen take rather complicated. It is more expedient to apply a system where unit change of the angular rotation changes only a single bit. This can be realized by the mirror-code systems, as e.g. the Gray code, as shown in Fig. 3. In this system there is no a simultaneous change but in a single channel The only disadvantage of this method is that 360° can only be divided by integer power of 2.

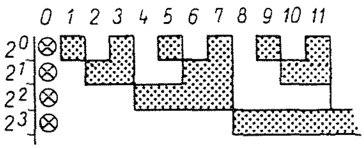

Fig. 1. Binary code

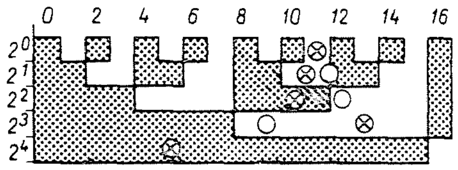

Fig. 2. V-logic

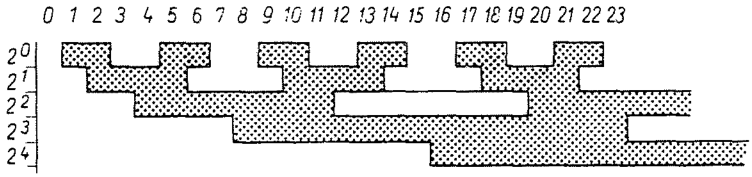

Fig. 3. Gray code

The partly binary BCG-code has the same drawback as the binary one, namely there is simultaneous change in more than one channel. This code is, on the other hand, very useful in interfacing with computers. There are some special mirror BCG-codes, as Watts, Gray-excess 3, Johnson etc. which are exempt of this disadvantage.

Watts' code was used in the device developed in our laboratory in co-operation with the Hungarian Research Institute of Measuring Instrument. This code is shown in Fig. 4.

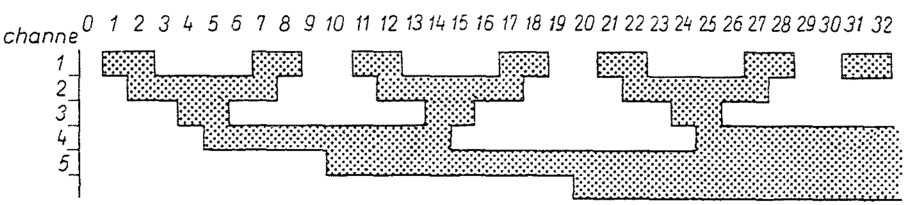

Fig. 4. Watts code

A disc of 100 divisions was prepared with this code; this accuracy was found completely satisfactory for all applications studied.

The rotating disc and the light-sensors were separated by an additional glass plate, referred to as slit-plate or sensor-plate, with the following function:

Let us suppose that in the code-carrying disc the diameter of the innermost layer is 40 mm, the corresponding circumference $K = 126$ mm. If the total number of angular divisions is 1000 then the average width of a division is $t = 0.13$ mm. The dimension of the smallest photo-sensor is, however, 1...2 mm. This problem is solved by using 0.08 mm wide slits in the sensor-disc.

The block-scheme of the absolute converter is shown in Fig. 5. The light beam of the source collimated by a lens-system passing through the code disc and through the transmitting slits of the sensor-disc is incident on the light sensors.

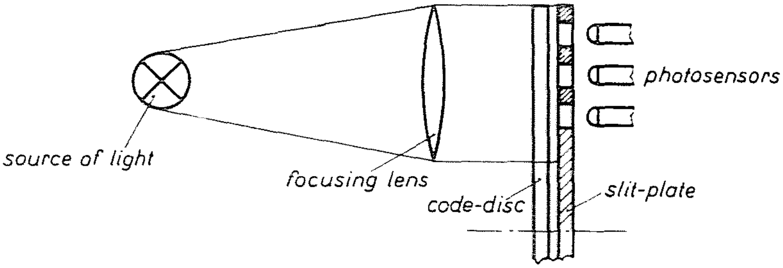

Fig. 5. The block-scheme of the absolute converter

The main advantages of the absolute converter system are the following:

1. The information (angular rotation) is at once available after switching the device on. This is useful in case of network voltage failure.
2. Decoding is simple, one code system is easily convertible into another.

The main disadvantages of the absolute converters are:

1. For converting rotational angles beyond 360° the revolutions have to be counted independently.
2. The analog system: the code-disc, light source, sensors, is a relatively complex one.

2. Incremental converters

By the incremental converters a certain number of square-pulses are detected during a complete revolution. These pulses are generated by a bistable multivibrator driven by pulses resulting from a light passing through the rotation code-disc. The block-scheme of such a converter is shown in Fig. 6. The rotating disc has a certain number of transparent and nontransparent parts, collimated light passing through produces pulses on the photoelectric sensors by which the multivibrator is driven.

In this system the direction of rotation should also be sensed. One way of this is illustrated in Figs 7 and 8. As shown, phototransistors F_{t1a} and F_{t1b} produce sinusoidal signals of opposite phase. Similar signals are produced by phototransistors F_{t2a} and F_{t2b} but these signals are by 90° shifted from the previous ones. As shown in Fig. 8, by using a zero comparator, two series of square pulses shifted by 90° are produced.

The incremental system is essentially one of the possible realizations of the Moiré grating. As it is seen in the signal-diagram (Fig. 8), the movement is sinusoidal only at the circumference of the division circle.

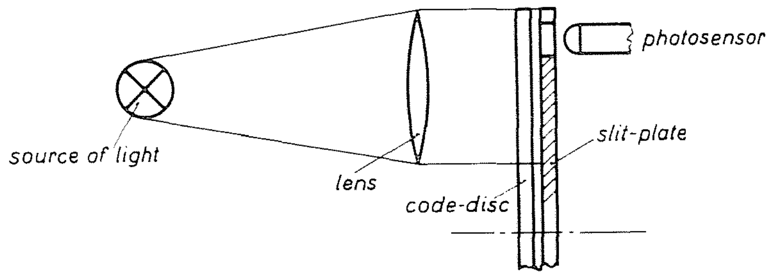

Fig. 6. The block-scheme of the incremental converter

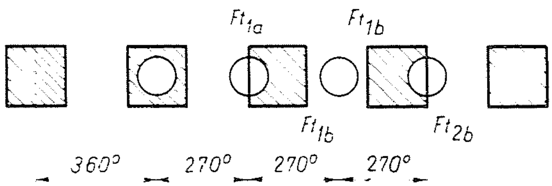

Fig. 7. Scheme of phase shift system

For noise-filtering purposes the inverse signals are also coupled out. For revolution counting, a fifth phototransistor is used. Proper design of the code disc permits to obtain a "zero pulse" of half the width of the main pulses, and their fronts coincide.

This is achieved by adjusting the zero pulse somewhat wider than necessary and cut it afterwards.

From the signal diagram in Fig. 8 it is also seen that the direction of the rotation is easy to sense and there is possibility of evaluation from two or even four signals.

Code-disc, for such converters have also been prepared in our laboratory.

The main advantages of the incremental converters are the following:

1. They suit measuring rotation over 360°.
2. They permit evaluation from two or four signals.
3. Its code and the corresponding electronic circuitry are simple.

The main disadvantages of the incremental converters are:

1. In case of network failure, the angle values get lost; an additional system is needed for their recovery.
2. Decoding is complicated.

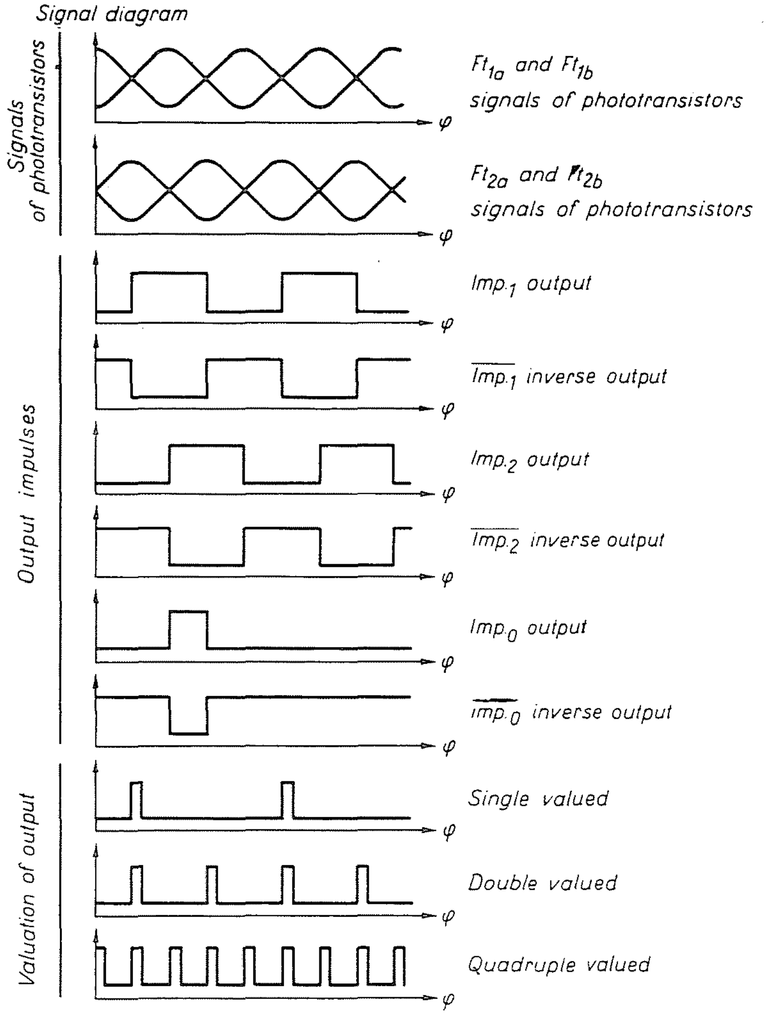

Fig. 8. Signal-diagram

3. Technological Problems

One of the most important parts of opto-electronic angular rotational digital converters is the code-disc. The accuracy of the system is basically determined by the manufacturing accuracy of the code-disc. The code-disc is essentially a highly planparallel glass-plate onto which the code-pattern can be deposited by various ways.

Only depositing techniques permitting preparation of codes are considered as satisfactory.

One of these is photographic technique. Experiments were made in our laboratory for preparing master drawings of sufficient accuracy i.e. master films of code-disc.

Excellent results were obtained by preparing of Watts code discs for absolute converters. The master drawings were done on "rubylith"-type foils using a plotter "DIGIGRAPH" on the basis of corresponding computer programs. The magnification was by 8. Master films were taken by using a minifying camera. From the master film the code-discs and slit-plates were prepared by contact copying.

Special care was taken to the good coverage of disc as the light-emitting diodes and phototransistors are usually operated in the non-visible infrared range. Good contrasts had to be achieved in this range. It was found essential to ensure good light blocking in the dark areas of the disc.

The code-disc of the incremental converter developed had 2500 divisions, the requirements for accuracy were, correspondingly, higher than those for the absolute converter. The corresponding master drawing was also prepared on rubylith foil but instead of DIGIGRAPH, the more accurate CORAGRAPH plotter was used. The highest possible magnification was 10; this was about the upper limit achievable with rubylith foil. The error between two arbitrary points may be as high as 0.2 mm which results in an error of 0.02 mm after reducing the size.

A greater accuracy could have been achieved by using a precision dividing machine with 1 : 1 mechanical division. In this method vacuum-deposited silver layer is mechanically rubbed out, resulting in a negative, from which positive code-discs can be prepared photographically. The error can be reduced to 0.1 mm by this technique.

Many other methods may also be used for preparing negative and positive code-discs as e.g. etching of vacuum-deposited layers, figure generator etc. The choice depends on the accuracy required.

Summary

The principle of operation of opto-electronic angular rotational digital converters is reviewed briefly. The advantages and disadvantages of the absolute and incremental techniques are discussed and compared. Some most often used codes are described. The technological aspects of these transducers and the possibilities of preparing master drawings are also mentioned.

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