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IMPROVED PSEUDORANDOM ABSOLUTE POSITION ENCODER WITH RELIABLE CODE READING METHOD*

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Abstract. *Pseudorandom position encoders enable an absolute position measurement using one code track based on a pseudorandom binary sequence (PRBS). Both serial and parallel pseudorandom code reading methods can be applied in these encoders. A reliable solution of an absolute position encoder that uses two mutually shifted pseudorandom code tracks is presented. The proposed solution is easier for practical realization, and has better performances regarding redundancy and reliability. The practical realization of this code reading method is also shown.*

Key words: *Pseudorandom binary sequence, Pseudorandom position encoder, Code reading*

1. INTRODUCTION

The optical pseudorandom absolute position encoders are well-known electro-mechanical digital transducers for the position measurement in industry, robotics, electrical power engineering, computer peripherals, etc. They have a single code track based on the pseudorandom binary sequences. The position measurement in pseudorandom position encoders is based on the property of *n*-bit pseudorandom binary sequence (PRBS) that each sliding window of length *n*, which passes along a sequence, will extract a unique code word in every moment [1, 2]. One code track is necessary in these encoders, no matter how many digits the code word includes, but the tolerance against yaw-angle errors becomes significantly smaller. The additional property, which makes the serial code reading in the absolute encoder possible, is that the last (*n*-1) bits of the current code word are identical to the first (*n*-1) bits of the subsequent code word. These encoders

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have high reliability due to the possibility of using advance methods for code reading error detection. Pseudorandom binary sequences are, besides in the absolute position encoders, also widely used in cryptography, bit-error-rate measurements, wireless communication systems, audio applications, etc. The PRBS generator can be implemented using different techniques, discrete electronics, microprocessor, FPGA circuit, virtual instrumentation concept [3].

Each pseudorandom absolute position encoder consists of the following functional parts: the code reading system, where different solutions can be used, with one [6], two [4] code reading heads, and the parallel code reading with integrated photodetector array [5]; the code scanning methods for the reliable code reading moment definition [7]; the pseudorandom/natural code conversion methods [8]; the code reading error detection methods [9], all of which improve the reliability of the encoder. The code scanning methods are usually based on using an external synchronization track, an internal incrementally encoded wheel or by additional coding of the pseudorandom code bits [7]. The pseudorandom binary code is not suitable for direct application in digital electronics, so different methods for the pseudorandom/natural code conversion have been developed and they can be separated in three distinct groups: parallel [10], serial [8], and serial–parallel code conversion [2]. The parallel solution for code conversion is fast, but the hardware is expensive for the high resolution encoder. The serial code conversion is a simple and cheap way for conversion of the long PRBS, but with the large conversion time. The serial–parallel code conversion is a compromise solution, which combines the serial and the parallel code conversion techniques. During mounting on the motor shaft, the pseudorandom absolute position encoder provides the possibility of the direct zero position adjustment without a significant change in the hardware, [11, 12].

In the first part of the paper the existing serial pseudorandom code reading methods with one or two code reading heads, and the parallel pseudorandom code reading method are explained in detail. One improved solution of the pseudorandom absolute position encoder which uses two code reading heads and also two pseudorandom code tracks is then proposed. Practical solution of the code reading system with components available on the market is presented in the end.

2. THE SERIAL PSEUDORANDOM CODE READING METHODS

The pseudorandom binary code provides possibility of the serial reading of the pseudorandom code with one sensor head [6] and one bidirectional shift register, Fig. 1, which is not possible in classical absolute encoders.

The code word is formed in the bidirectional shift register and later converted to more convenient natural code. This solution has a disadvantage because the initial moving of n bits is needed for forming of the first valid pseudorandom code word. The problem of losing the position information at any change of the movement direction also occurs, and solution for this problem requires an additional hardware in the encoder realization. The moving direction is defined by using heads AUT and VER in the synchronization track and the same principle as in the classical incremental encoder. The reading of the synchronization track is very important for the accurate definition of the instant for the pseudorandom code bits reading.

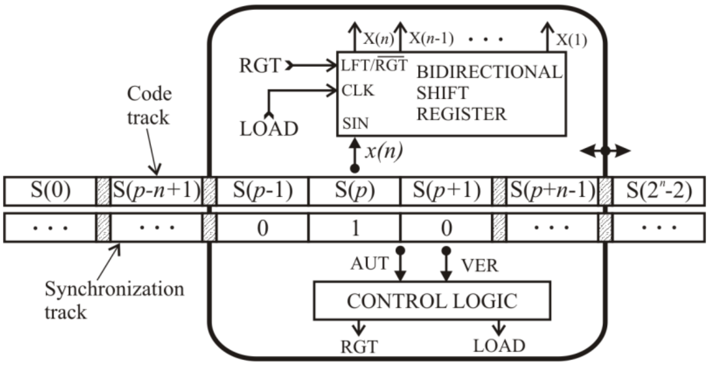

Fig. 1 Serial pseudorandom code reading with one code reading head

One improved solution of the previous serial code reading method which some manufacturers use for this type of encoder is shown in Fig. 2. One more pseudorandom code track is introduced along with the existing code track, but inverted in relation to the existing code track, in order to increase the reliability of the pseudorandom code bits reading. This pseudorandom code reading is named 'differential' because one logic comparator circuit is used to determine the difference in reading of two code reading heads. When the sensor head $x(n)$ reads a transparent segment (logical '1'), the sensor head $x(0)$ reads non-transparent segment (logical '0'). High reliability of the pseudorandom code reading is achieved in this way, especially for high resolution encoders.

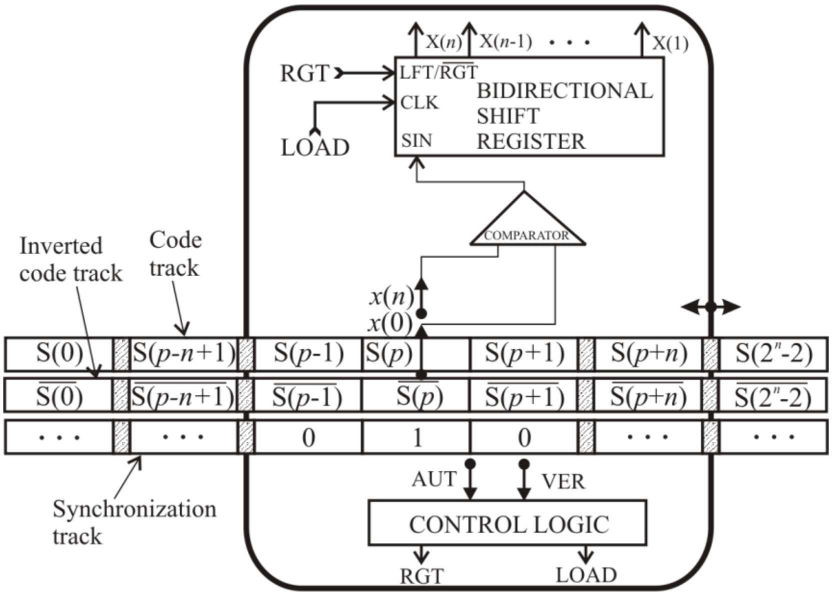

Fig. 2 Differential pseudorandom code reading with two code reading heads

The serial code reading method that eliminates drawbacks in the first described solution with one code reading head, and enables additional possibilities is shown in Fig. 3. This solution [4] is based on introducing one more reading head at the distance of nq, where q is the value of the code track quantization step. A multiplexer 2/1, consisting of two AND and one OR logic gate, is used for selecting one of the two code reading heads depending on the moving direction. When the system is moving to the left, the shift register is loaded with bits from the reading head $x(n)$, and when moving to the right with bits from the reading head $x(0)$. The presented solution provides much easier realization of continuity in the pseudorandom code word forming. Also, this solution provides a reliable method for permanent checking of the code reading correctness, which significantly improves reliability of the position encoder. However, this code reading method requires correction of the position information for one of the two moving directions, and this arrangement of the code reading heads is not suitable for the practical encoder realization.

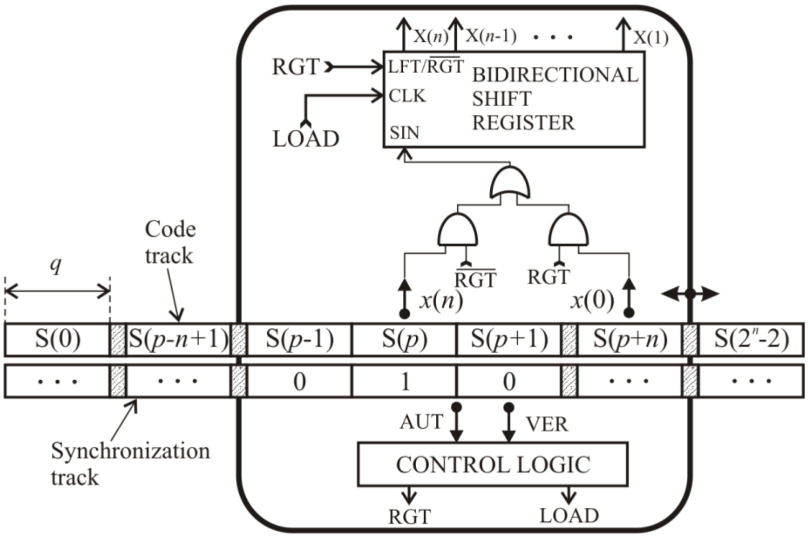

Fig. 3 Serial pseudorandom code reading with two code reading heads

The code scanning in this solution is also solved by using an external synchronization track next to the pseudorandom code track. The sensor heads AUT and VER provide the synchronization pulses and the information about the movement direction (RGT = ‘moving to the right'). The formed pseudorandom n-tuples code words are then converted to the natural code using the pseudorandom/natural code converter.

However, practical application of the previous solution for high resolution encoders is difficult because the two sensors must be very close to each other. Different environmental conditions such as temperature and vibrations can also cause variations in the distance between the two sensor heads, and this may cause errors in the code reading. This paper proposes an improved solution by introducing one additional pseudorandom code track, which is the same as the first code track, but shifted for (n–1) bits, Fig. 4. The application of this code reading method is especially convenient in systems where oscillations of the movable system can occur.

There are multiple sources of errors in the pseudorandom absolute encoder: quantization error (due to digitalization), assembly errors (eccentricity), structural limitations (ellipticity of disc, disc deformations due to loading), manufacturing tolerances (inaccurately imprinted code patterns, positioning of code reading sensors), and ambient influences (temperature, vibration, contamination, light noise, humidity, etc.).

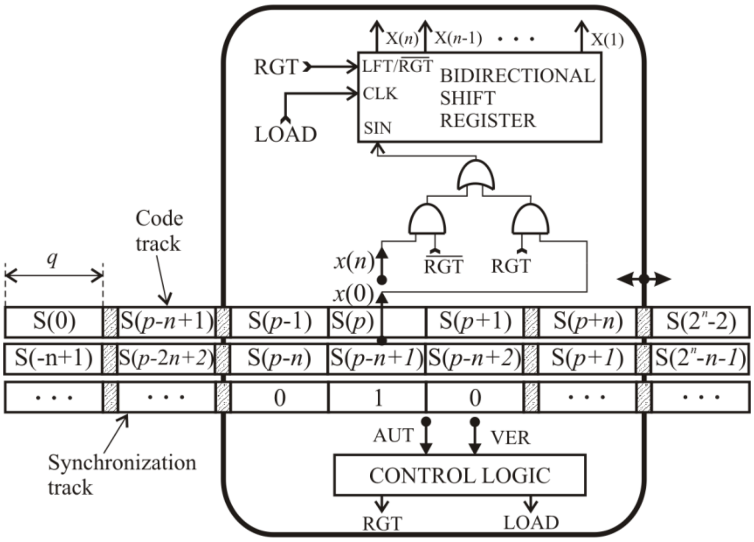

Fig. 4 Improved serial pseudorandom code reading with two code reading heads

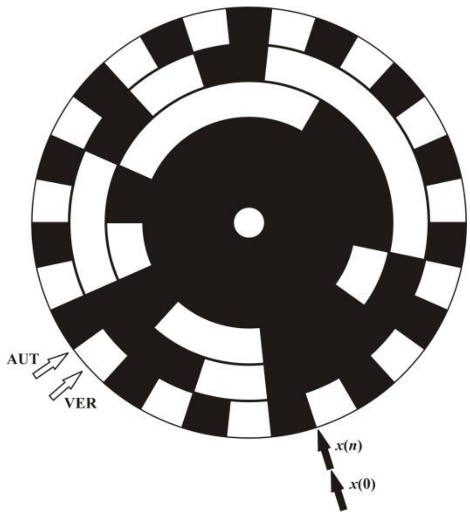

Fig. 5 Example of 4-bit pseudorandom absolute position encoder code disc

Now, each pseudorandom code track would be scanned with one code reading head and they will be arranged in line as in the classical absolute position encoders. Most of the previous solution practical problems are solved in this way, but the cost is increased by the introduction of one more code track. This improved solution also provides continuity in the code word forming, simpler hardware realization, improved redundancy of the systems, and also realization of very good code reading error detection method. If one code reading head fails, then the encoder can continue to work according to the algorithm based on using one code reading head. If both reading heads operate correctly, two new bits are obtained from the two sensor heads at the instant of the pseudorandom code reading, which can be used for reliable checking for code reading errors [9].

One example of the code disc and arrangement of the code reading heads of 4-bit resolution pseudorandom absolute position encoder is shown in Fig. 5. A 4-bit pseudorandom binary sequence 111101011001000 is used in this example. There is one synchronization code track and two pseudorandom code tracks shifted for three bits from each other. The synchronization track can also be used for increasing the encoder resolution.

3. THE PARALLEL PSEUDORANDOM CODE READING METHOD

The code words on the code track are longitudinally arranged in the pseudorandom absolute position encoder. The pseudorandom absolute position encoder with the serial code reading method requires the initial movement during the first code word forming. Therefore, it is necessary to apply the parallel code reading method in order to realize a true pseudorandom absolute encoder [5], which would have the absolute position in every moment even in the case of the power loss. One possibility which enables realisation of the encoder with a satisfactory resolution is to use the integrated photodetector array. Commercial integrated photodetector arrays are available on the market with distances between the photodetectors about 10 μm, and even smaller. A number of photodetectors can be up to a several thousands, thus multiple sequential sensors may be used for one bit reading. One simplified block diagram of the pseudorandom encoder with the parallel code reading is shown in Fig. 6. Electronic block of encoder can be realized using discrete electronic components or using microprocessor and appropriate software, Fig. 6. The algorithms developed for proper functioning of this kind of the encoder solution can be found in the reference [5]. According to the proposed improved algorithm, the absolute position determination is divided into rough and fine position determining.

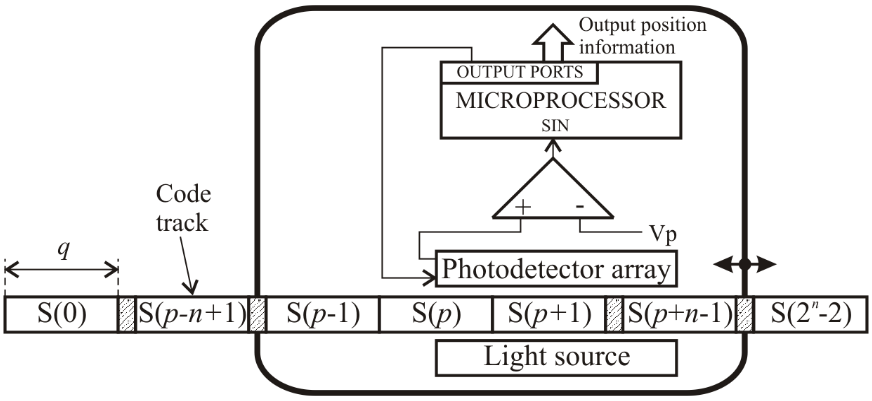

Fig. 6 Parallel pseudorandom code reading with photodetector array

4. THE PRACTICAL IMPLEMENTATION OF CODE READING METHOD

High speed and high sensitivity optical sensors, which are normally used for incremental encoders, can be found in the market. However, they can also can be used for the proposed code reading solution in the pseudorandom absolute position encoder. One chip with 9 silicon P/N photodiodes is shown in Fig. 7, where the active area of each photodiode is 0,236 mm^2. This chip can be used for the previously described solution with two shifted pseudorandom code tracks. Separate reticle for guidance of infrared light beam depends on concrete disk diameter and used encoder resolution.

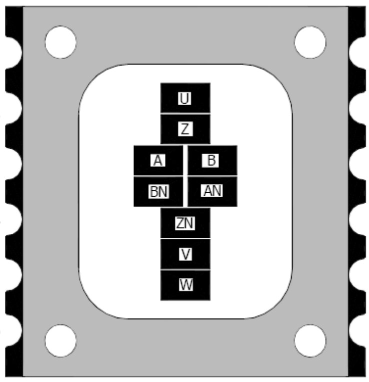

Fig. 7 MO-PMD09 optical sensor for encoder (www.micropto.com)

The layout of the entire electronic system for the code disc reading of this pseudorandom absolute position encoder is illustrated in Fig. 8. The photodiodes array MO-PMD09 (made by 'Micropto') comprises four diodes (A, AN, B, and BN) for differential scanning of the synchronisation track, one diode ZN for scanning of the pseudorandom code track, and also one diode W for scanning of shifted pseudorandom code track. The remaining diodes U, Z, and V are not used in this realisation. Because the syncronization track has higher resolution compared to the pseudorandom code track, 4 photodiodes (A and AN for obtaining of signal A; B and BN for obtaining of signal B which is shifted for 90°compared to signal A) are used for differential scanning of this track.

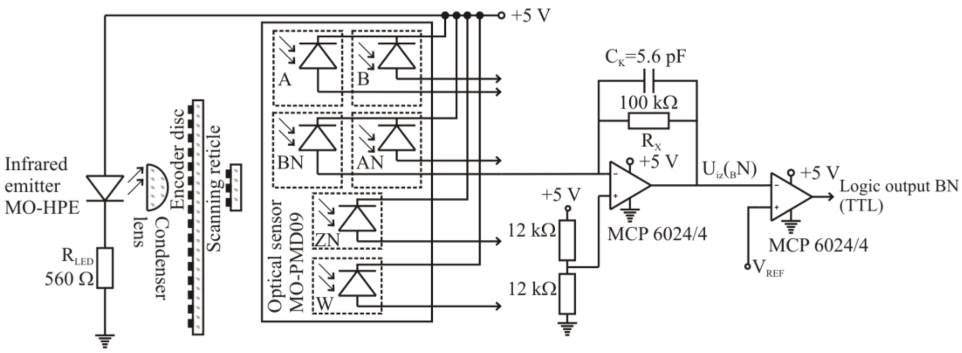

Fig. 8 Electronic system for code reading of pseudorandom absolute position encoder

The photodiodes are inversely polarized and used in a ‘photoconductive' mode, their internal P/N junction capacitance is then smaller, which assures higher operating frequencies compared to the 'photovoltaic' mode. The quad CMOS rail-to-rail input and output MCP6024 operational amplifiers (made by 'Microchip') are used for the photodiodes' current-to-voltage conversion in a single V_{DD}=+5V supply circuit in Fig. 8. Non-inverting input pin is polarized to $V_{DD}/2$, ie. +2.5V. Quasi-sine wave, the amplitude of which is 1.4V_{PP}, is obtained at the operational amplifier output due to both the encoder disk rotation and the photodiodes being illuminated by the infrared emitter MO-HPE (made by 'Micropto'). The quasi-sine wave should then be shaped into digital (TTL) signal. Since MCP6024 has a wide gain-bandwidth product of 10MHz and a high slew rate of 7V/μs, it is also used as a voltage comparator for wave-shaping. Its input pins are polarized in a way which enables logical '1' at its output to be obtained when photodiode reads transparent segment, as well as logical '0' for non-transparent segment. The reference voltage for the voltage comparator (V_{REF}) is set at half the amplitude of the total output voltage swing of 1.4V_{PP}. The electronic circuit for processing the signal received only by the BN photodiode, and for providing only the BN logical output, is shown in Fig. 8. Another five identical circuits are used for processing the signals received by the remaining five photodiodes. In total, 3 MCP6024 chips with 12 operational amplifiers are used for 6 optical channels.

If MCP6024 is to be used for frequencies close to 100kHz, or above, then a small capacitor C_K=5.6pF must be connected across the 100kΩ R_X resistor. It stabilizes the circuit and produces a flat frequency response with a bandwidth of 370kHz. However, when used as a voltage comparator, MCP6024 gives a satisfactory digital (TTL) output for frequencies up to 200-250kHz. For frequencies higher than that, a fast voltage comparator should be used.

5. Conclusion

The three different methods of the serial pseudorandom code reading, with one and two code reading heads, are explained in detail. Then, one modified method of the serial pseudorandom code reading with two code reading heads and two shifted pseudorandom code tracks is proposed and explained. Easier practical realization of the pseudorandom code reading process is obtained with this modification, and also better reliability and redundancy of the encoder itself. Optical sensors which are normally designed for the incremental encoders can be used for the proposed method of the serial pseudorandom code reading. Because of that, there is no need for custom solutions of the optical sensors which would increase the encoder price. The practical realization of the electronic circuit for code reading of this improved pseudorandom absolute position encoder is also shown.

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