Encoders

Introduction

The encoder converts motion into a series of pulses which are counted to determine position. A pattern of on or off marks moves past the detector to create the pulses. The figures show optical encoder patterns. An incremental encoder pattern is just a sequence of black and white marks like gear teeth or spokes, which must be counted. The marks are typically black marks on a transparent or reflecting medium or something similar.

Types

Absolute and incremental
- Absolute: Exact position is always readable
- Incremental: Position is counted by counting marks and spaces from a starting point.
  - Position is lost if power is lost

Linear and rotary (rotary most common)

Incremental variations

Incremental with end mark. Every time the end mark is detected the system knows where it is absolutely. At all other positions the system must count and remember pulses (steps). This requires an extra sensor for the end mark.

Incremental with direction: requires at least two sensors. Senses direction by checking which of the two sensors changes first. (see figure on right above)

Incremental with direction and end mark: Combination of both the above

Absolute Encoders

Absolute encoders
- Gray code and binary code (See diagrams above)

When a sensor is positioned exactly at the point where the mark changes from black to white there is uncertainty in the value that the sensor will read. Since absolute encoders require several
sensors which will all change at the same time that uncertainty will apply to all the sensors that are changing.

Binary systems count in familiar positional notation. Grey code is also based on counting using 1 and 0 but is designed to only change a single bit as you transition from one number to the next in sequence. Examine the table below and note how the values in the bit positions change from one number to the next. In the binary code one, two or three bits will change. The least significant bit (rightmost) changes at every step. The more significant bits change less frequently. The most significant bit (leftmost) only changes twice in a complete cycle. For example moving from 3 (011) to 4 (100) all three bits change. In the grey code only a single bit changes for any transition. Using the same example, 3 (010) changes to 4 (110) and only the left-most bit changes.

<table>
<thead>
<tr>
<th>Dec.</th>
<th>Binary</th>
<th>Grey</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>000</td>
<td>000</td>
</tr>
<tr>
<td>1</td>
<td>001</td>
<td>001</td>
</tr>
<tr>
<td>2</td>
<td>010</td>
<td>011</td>
</tr>
<tr>
<td>3</td>
<td>011</td>
<td>010</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>110</td>
</tr>
<tr>
<td>5</td>
<td>101</td>
<td>111</td>
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<tr>
<td>6</td>
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<td>101</td>
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<tr>
<td>7</td>
<td>111</td>
<td>100</td>
</tr>
<tr>
<td>0</td>
<td>000</td>
<td>000</td>
</tr>
</tbody>
</table>

With Grey code, since only one bit changes at a time the uncertainty in position if the sensing elements are positioned right on the change-over line is limited to that one bit. With binary code multiple bits could be sensed wrongly and there are multiple errors in position that could occur.

**Methods (technology)**

Optical, magnetic or contact

Optical: light shines through or is reflected off marks. Non-contact(no load), commonly available, cheap, subject to dirt obscuring light path (must be sealed in dirty environments), subject to light interference (not usually a problem)

Magnetic: Relatively new, rugged, non-contact, minimal load. Largely immune to dirt

Electrical: Simple, subject to wear, affected by dirt, relatively high currents

**Applications**

Computer mouse: incremental with direction

Printer with traveling print head: Incremental with start mark

Positioning servo: absolute
Robot arm: incremental with direction and end point.

Speed sensing for unidirectional motor; incremental with timer.

**Problems and review questions**

1. An absolute rotary encoder has 7 concentric tracks each with an optical sensor. The tracks are configured in Grey code. What is the rotary position resolution of this sensor in degrees/bit?

2. The figure on the right shows portions of two encoding systems. The symbol @ indicates the optical sensors.

   a. For each one state whether the coding is Grey code, binary code or neither (unknown).

   b. What is the relative benefit(s) or disadvantage(s) of Grey code vs. Binary?

3a. What is the resolution of each of the three rotary encoders shown in the diagrams above?
3b. Does it make any difference whether the most significant bit or the least significant bit of the absolute encoders is on the inside track? Explain.
3c. Using the same technology (printing, sensors etc., what is the maximum resolution that could be achieved for the incremental encoder if there is no requirement for directional sensing.

4. The uncertainty caused by the sensor(s) being positioned exactly on a black/white changeover line is very important for absolute encoders. Is it an important issue for incremental encoders in
any of their variations?