Electrical, Computer & Energy Engineering
UNIVERSITY OF COLORADO **BOULDER**

ECEN 5053-003 Homework Assignment

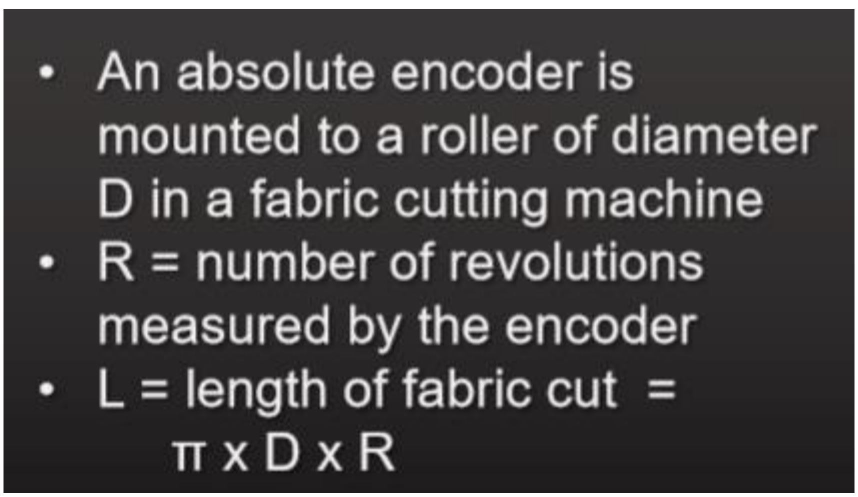
<u>Course Name:</u> Embedding Sensors and Actuators
<u>Corresponding Module</u>: C1M3
<u>Week Number:</u> 3
<u>Module Name:</u> Rotary Sensors
<u>Student Name:</u> *Rushi James Macwan*

Homework is worth 100 points. Each question is worth 10 points.

A. A spool cutting machine with spool diameter of 0.25 meters cuts a piece of fabric 7 meters long. How many revolutions would the absolute encoder measure?

Sol. $\boxed{\textbf{8.917 Revolutions}}$

To solve this problem, I have used the material provided in the class slide as a reference. I have introduced a screenshot from the class slides to better explain the solution.



Using the information provided in the screenshot as above, the following parameters have been given to solve R for the equation:

$L = \pi * D * R$

<u>Given parameters:</u>

$L = 7$ m

D = 0.25 m
R = ? [To be calculated]

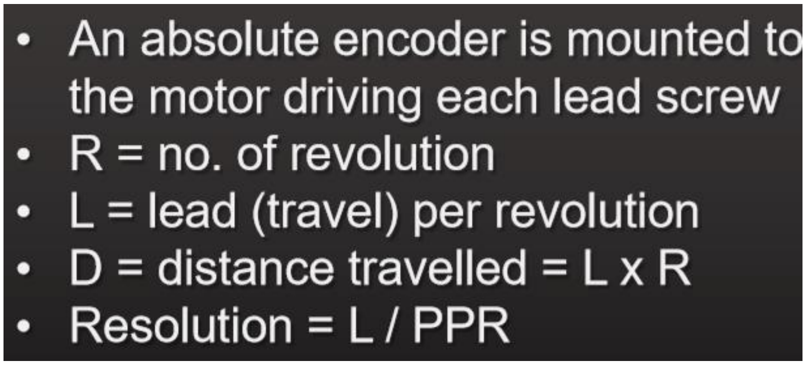
Thus, R = [(L) / (π * D)] = [(7) / (π*0.25)] = **8.917 Revolutions**

Hence, the absolute encoder would measure 8.917 revolutions or approximately 9 revolutions to sum up.

B. An absolute encoder is mounted to the motor driving the X-axis lead screw of a CNC milling machine. If the encoder has a spec of 1500 PPR, a lead of 1 mm, and the lead screw moves a distance of 200 mm, how many revolutions of the lead screw will the encoder count and what is the resolution of the X-axis?

Sol. **200 revolutions and a resolution of 6.67 x (10^ (-7))**

To solve this problem, I have used the material provided in the class slide as a reference. I have introduced a screenshot from the class slides to better explain the solution.



Using the information provided in the screenshot as above, the available parameters can be used to solve the equation for R (no. of revolutions of the lead screw):

- D = L x R
- Thus, R = D / L = (200 * 0.001) / (1* 0.001) = **200 revolutions**

Furthermore, to find the resolution of the X-axis, we can use the formula:

- Resolution = L / PPR
- Thus, Resolution = (1* 0.001) / 1500 = **6.67 x 10^(-7)**

Thus, the encoder will count **200 revolutions** of the lead screw and the corresponding resolution will be **6.67 x (10^ (-7))**.

C. An encoder has an input voltage of 24 volts and a transformation ratio of 0.475. What is the output voltage in volts?

Sol. $\boxed{\textbf{11.4 Volts}}$

The transformation ratio (T.R.) for a rotary sensor can be described as follows:

T.R. = V_o / V_{in} [at maximum coupling]

The following parameters have been provided:

V_o = output voltage of the encoder = ? (to be calculated)
V_{in} = input voltage of the encoder = 24 V
T.R. = transformation ratio of the encoder = 0.475

Thus, V_o = T.R. * V_{in} = 0.475 * 24 = $\boxed{\textbf{11.4 Volts}}$

D. Your resolver has a maximum tracking rate of 26 revolutions per second (rps) and gives rotational accuracy of 12 arc minutes. If you need a rotational accuracy of 0.25 degrees and your motor shaft rotates at 1750 rpm, can you use your resolver? Why or why not?

Sol.

Yes, but this holds true only <u>as long as the resolver can work for tracking revolutions greater than the maximum allowed limit of 26 RPS with reduced accuracy</u> which is assumed to vary linearly with the tracking rate.

The resolver, given the above conditions, can be used since the available accuracy (13.46 arc minutes (approx.) pertaining to a motor shaft rotation speed of 1750 RPM) is within the needed/expected/required accuracy limit of 0.25° (15 arc minutes).

Based on the data provided in this problem, a resolver having a maximum tracking rate of 26 RPS which equals to 1560 RPM, gives a rotational accuracy of 12 arc minutes. The motor shaft in the latter half of the question is run at 1750 RPM and a rotational accuracy of 0.25 degrees which equals to 15 arc minutes is needed/expected/required.

Now, calculating the best possible value of accuracy given by the resolver corresponding to a motor shaft rotation rate of 1750 RPM based on the assumption of prevalence of linear relationship between RPM and the rotational accuracy, we get a value of [(1750 * 12) / 1560] = 13.46 arc minutes (approx.). Now, since the resultant accuracy for the RPM value of 1750 is better than the needed/expected/required value of 15 arc minutes, the resolver can work without violating the accuracy demand of <=15 arc minutes since the available accuracy is approx. 13.46 arc minutes.

Please Note:

However, if the assumption is different where the resolver cannot track any more revolutions than its maximum tracking rate of 26 RPS or if the relationship between the tracking rate and the accuracy is non-linear, the resolver will not be able to deliver its result and therefore cannot be used. But, this is not the case that is assumed as the solution to this problem.

Courtesy: I have used a few references to frame this answer which can be accessed by clicking on the links: [1] [2] [3] [4]

E. A two-channel encoder counts the leading and trailing edges of the pulse trains of its two channels. Suppose the resolution of a single channel encoder is 400 PPR. If you add a second channel to the encoder, and change no other specs, how much can you improve the resolution of the encoder?

Sol.

Based on the referenced file for this answer, the two channel encoder will count both the leading and trailing edges of the pulse trains of its two channels. Here, the resolution of a single channel encoder is given as 400 PPR and **it is assumed based on the content provided in the referenced document that a single channel encoder will only count either the leading or trailing edges of pulse trains**.

Now, considering this information, if the specs simply don't change, it is assumed that the *newly formed two-channel encoder* will measure both the leading and trailing edges of both the channels and therefore the resolution (pulses per revolution) will become 4 times than that was earlier in the case of the single channel encoder which would count either a leading or a trailing edge of the pulse train.

Thus, the new resolution improves by **4 times** and its value now would be **1600 PPR**.

Please Note:

However, if the assumption is different where the newly formed two-channel encoder only measures either the leading or trailing edges of the pulse trains of its two channels then the resolution would simply improve by 2 times which is not the assumption in this answer.

Courtesy: I have used a reference to frame this answer and the reference document can be accessed by clicking on the link: [1]

F. A multiple speed resolver has 16 sets of secondary windings. Relative to a single speed resolver of the same basic design, how many times more accurate will it be?

Sol. **8 times more accurate**

Based on the second document referenced in the Courtesy section of this answer, the multiple speed resolver talked about in this problem has 16 sets of secondary windings which means 8 pairs of secondary windings. Therefore, there are 8 pole pairs and the speed of this multiple speed resolver is 8-speed. Again, based on the second referenced document, as mentioned on page 21, a typical 8-speed resolver will have an error of 60 arc seconds.

Also, based on the class slide, *C1M3V5 on Resolver Details*, a multiple speed resolver with 8-speed as in our case will deliver 8 cycles per 360° of mechanical rotation of the rotor. Furthermore, the multiple speed signal is 8 times the rotor angle **and the resolver will be 8 times as accurate as a single speed resolver**.

Courtesy: I have used a few references to frame this answer and the reference documents can be accessed by clicking on the links: [1] [2]

G. Explain how a resolver determines angular position.

Sol.

A resolver is an electro-mechanical transformer whose analog output voltages are a function of shaft angle. It is, therefore, an absolute position transducer, providing true angular information at any time power is applied.

a. Resolvers are rotary transformers with one primary winding and two secondary windings. The primary winding is generally on the rotor and the two secondary windings are on the stator. The stators, when specially configured for receiver applications, become the primary transformer windings. The secondary windings are arranged 90 degrees from each other such that when one is lined up with the rotor winding (full coupling) the other is at a right angle (no coupling).
b. The primary winding is driven with an alternating current signal at a specified voltage and frequency. The position measurement of the resolver is determined by the ratio of the amplitudes of the signals on the secondary windings and their phase with respect the signal on the primary winding (the reference signal).
c. Resolvers involve the reading or transmission of rotation or position information. Resolver devices (Rx) are designed to transmit their shaft angular position information (primary rotor windings) to the associated system by causing the amplitude of the signal on the

secondary windings (stators) to be changed. The devices are limited to 360 degrees of rotation. Comparing the amplitude of the stator outputs will give the angular position of the rotor shaft. It can be calculated in degrees, minutes (1/60 degree) or seconds (1/3600 degree), depending on the accuracy required. The amplitude comparison calculation defines the MECHANICAL ANGLE of the resolver shaft displacement, also known as ANGLE POSITION.

d. A resolver further outputs signal by energizing the input phase of the resolver with an AC voltage (VAC) to induce voltage into each of the output windings. The resolver amplitude modulates the VAC input in proportion to the Sine and the Cosine of the angle of mechanical rotation. The function of the resolver is to resolve a vector into its components (Sine and Cosine). Electrical Zero (EZ) is defined as the position of the rotor with respect to the stator at which there is minimum voltage amplitude across the Sine winding and the maximum voltage amplitude across the Cosine winding when the input winding is excited with the rated voltage. The rotor position or angle is simply the Arc tan of the voltage output of the Sine winding divided by the output of the Cosine winding. This ratio metric format provides an inherent noise reduction feature for any injected noise whose magnitude is approximately equivalent on both windings and also results in a large degree of temperature compensation.

Courtesy: I have used certain references to frame this answer and these references can be accessed by clicking on any of the links: [1] [2] [3] [4] [5] [6] [7]

H. What is the transformation ratio for a resolver? What aspects of the resolver determine this ratio?

Sol.

- The transformation ratio (TR) of a resolver is the ratio of its output voltage to input voltage when the output voltage is at maximum magnetic coupling.

- A resolver is a specialized transformer where the output voltage is a function of the angular position. During operation, it takes the input voltage and normally steps it down to an output voltage (sometimes it steps it up, and sometimes the TR is unity). The TR is thus a useful metric for determining whether a resolver will operate appropriately in a system.

- Winding design determines the TR of a resolver; roughly speaking, TR is approximately proportional to the ratio of the number of effective turns in the secondary winding to the number of effective turns in the primary winding. As a result, a manufacturer can customize resolver windings to produce TR required for the system without significantly affecting performance.

- The transformation ratio is driven by user requirements for input and output voltage. Within reasonable limits, a manufacturer can design the windings to deliver the desired TR; it does not affect resolver performance.

  Courtesy: I have used certain references to frame this answer and these references can be accessed by clicking on any of the links: [1] [2] [3] [4] [5]

I. What are the four impedances that a resolver exhibits? How are these impedances represented in a resolver?

Sol.

Impedances, expressed in ohms, are usually specified in rectangular form as R + jX where R is the sum of the DC and AC resistive components and X is the reactive component. Impedances are sometimes expressed in polar form where Z is the total impedance and θ is the impedance angle. The impedances which are universally defined and apply to all synchro devices are:

• Z_{PO} : Primary impedance, secondary open circuit
• Z_{PS} : Primary impedance, secondary short circuit
• Z_{SO} : Secondary impedance, primary open circuit
• Z_{SS} : Secondary impedance, primary short

For three-phase devices, the impedance is measured with two of the lead wires tied together. The impedance is measured between those two and the third wire. The names "rotor" and "stator" are sometimes used in place of "primary" and "secondary." For example, for rotor primary units the primary impedances would be ZRO and ZRS. The secondary or stator impedances would be Zso and Zss. For compensated resolvers, two additional impedances are required:

• ZCO: Compensator impedance, secondary open circuit
• ZCS: Compensator impedance, secondary short circuit

Courtesy: I have used a reference to frame this answer and the reference document can be accessed by clicking on the link: [1]

J. Why is an encoder's performance stated in terms of resolution, as opposed to accuracy? How does the repeatability of the encoder compare to its resolution?

Sol.

An encoder's performance is typically stated as resolution, rather than accuracy of measurement. The encoder may be able to resolve movement into precise bits very accurately, but the accuracy of each bit is limited by the quality of the machine motion being monitored. For example, if there are deflections of machine elements under load, or if there is a drive screw with 0.1 inch of play, using a 1000 count-per-turn encoder with an output reading to 0.001 inch will not improve the 0.1 inch tolerance on the measurement. The encoder only reports position; it cannot improve on the basic accuracy of the shaft motion from which the position is sensed.

Repeatability is the tolerance to which the controlled machine element can be repeatedly positioned to the same point in its travel. Repeatability is generally less than system resolution, but somewhat better than system accuracy. 10,000 pulses per turn can be generated from a 2500 cycle, twochannel encoder. Typically with a Dynapar encoder, this 4× signal will be accurate to better than ±1 count.

Courtesy: I have used a reference to frame this answer and the reference document can be accessed by clicking on the link: [1]