Frequency of rotation and angular position measurement

Frequency of rotation measurement:

Frequency of rotation is defined as the number of rotations around a fixed axis in one second. The basic SI unit of frequency of rotation is s^{-1}. In practice often other unit is used and denoted as RPM (revolutions per minute). Devices that measure frequency of rotation are called tachometers.

Using Hall effect sensor for RPM measurement:

Consider having a shaft with magnetic marker created using a permanent magnet. Then it is possible to sense this marker using a Hall effect sensor located nearby. Now we compare the amplified voltage output of Hall effect sensor with some known threshold using a voltage comparator. We can determine the frequency of rotation by counting the output pulses of comparator per unit of time. Measurement based on counting the pulses derived from shaft rotation is the most accurate method.

Using inductive sensor for RPM measurement:

This type of sensor is made using a simple coil with permanent magnet core or a ferrite core with permanent magnet attached to it. By placing such sensor nearby a rotating shaft with any ferromagnetic marker the change in magnetic flux of the coil is created. Thus a small voltage will be induced at the coil output. Because the amplitude of the induced voltage is proportional to the frequency of rotation the disadvantage is that the voltage is very small when the speed of rotation is low. Not only the induced voltage amplitude but also a number of induced pulses could be considered as the output quantity of the sensor. If so, then it is possible to shape the pulses using a voltage comparator so the voltage level will be no longer dependent of the frequency of rotation. Then it is sufficient to count the pulses in exactly the same way as in the case of Hall effect sensor.

Optical encoders and angular position measurement:

Among the most popular position measuring sensors, optical encoders find use in relatively low reliability and low resolution applications. An incremental optical encoder (left-hand diagram in Figure 1) is a disc divided into sectors that are alternately transparent and opaque. A light source is positioned on one side of the disc, and a light sensor on the other side. As the disc rotates, the output from the detector switches alternately on and off, depending on whether the sector appearing between the light source and the detector is transparent or opaque. Thus, the encoder produces a stream of square wave pulses which, when counted, indicate the angular position of the shaft. Available encoder resolutions (the number of opaque and transparent sectors per disc) range from 100 to 65,000, with absolute accuracies approaching 30 arc-seconds. Most incremental encoders feature a second light source and sensor at an angle to the main source and sensor, to indicate the direction of rotation. Many encoders also have a third light source and detector to sense a once-per-revolution marker. Without some form of revolution marker, absolute angles are difficult to determine. A potentially serious disadvantage is that incremental encoders require external counters to determine absolute angles within a given rotation. If the power is momentarily shut off, or if the encoder misses a pulse due to noise or a dirty disc, the resulting angular information will be in error. The absolute optical encoder (right-hand diagram in Figure 1) overcomes these disadvantages but is more expensive. An absolute optical encoder's disc is divided up into N sectors (N = 5 for example shown), and each sector is further divided radially along its length into opaque and transparent sections, forming a unique N-bit digital word with a maximum count

of 2^N. The digital word formed radially by each sector increments in value from one sector to the next, usually employing Gray code. Binary coding could be used, but can produce large errors if a single bit is incorrectly interpreted by the sensors. Gray code overcomes this defect: the maximum error produced by an error in any single bit of the Gray code is only 1 LSB after the Gray code is converted into binary code. A set of N light sensors responds to the N-bit digital word which corresponds to the disc's absolute angular position. Industrial optical encoders achieve up to 16-bit resolution, with absolute accuracies that approach the resolution (20 arc seconds). Both absolute and incremental optical encoders, however, may suffer damage in harsh industrial environments.
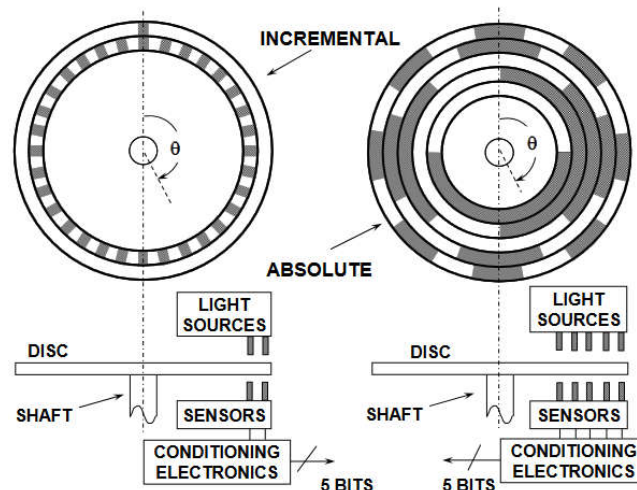

Figure. 1

Exercises:

1. Get familiar with experimental measurement set
2. Check functionality of particular sensors used for measurement of frequency of rotation
3. Calculate the conversion between frequency of the measured signals and RPM
4. Measure the dependence between the voltage induced on the inductive sensor and the frequency of rotation
5. Get the angular position of shaft using incremental encoder and find the difference between available encoding modes
6. Use absolute encoder to get angular position of shaft. Check the difference when sensing by binary and Gray code disks.

Measurement guide:

1. The experimental measurement set contains a small DC electric motor. The encoder discs are mounted on the motor shaft and sensed using two transmisive optocouplers in the case of incremental encoder and three reflective optocouplers in case of absolute encoder. Nearby a motor shaft there is also a Hall effect sensor and small 100μH coil used as an inductive sensor. The output voltages of both Hall effect and inductive sensor are amplified and shaped using comparator. The motor is controlled using a driver which allows to adjust its speed (using PWM) and direction of rotation using digital output of DAQ card connected to computer.
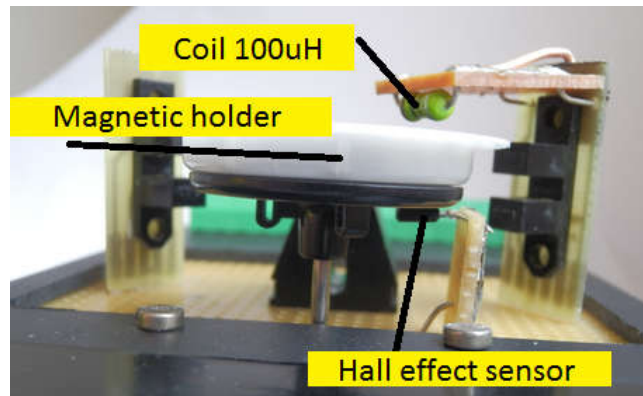
Used Hall effect sensor type UGN3130 already contains an integrated amplifier and pulse shaping circuit. Encoder discs are held on shaft using magnetic holder made of permanent magnet. This permanent magnet also serves as a shaft marker for Hall effect and inductive sensor.
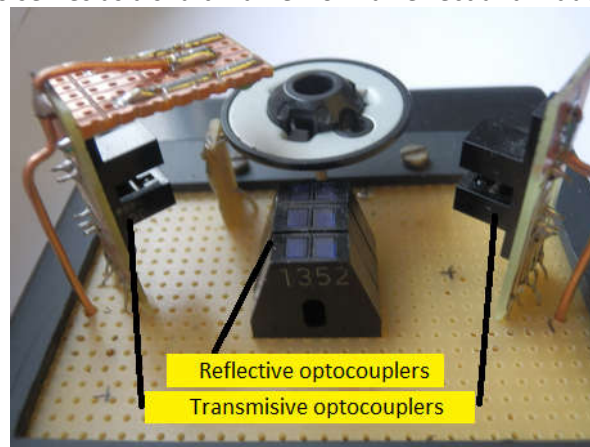
Sensor outputs are acquired using analogue and digital inputs of DAQ card and corresponding measurement software applications "otacky.exe" (for frequency of rotation) and "enkoder.exe" (for angular position)

2. Launch the otacky.exe application. Try to control the motor by pressing START/STOP button and change the motor speed using slider "Motor speed". Pulses acquired from each particular sensor should appear in graph. Indicators named *Hall f*, *L f* and *Opt. f*, show current frequencies of the pulses for each sensor separately in units of Hz (L stands for inductive sensor and Opt. for optical). Optical sensor is based on one of the transmisive optocouplers used for optical encoder.

3. Using graph in application try to find out how many pulses are given by particular sensors per one revolution. (hint: Hall effect sensor gives one pulse per revolution). According to the found number of pulses per revolution calculate the suitable numeric constant which when multiplied by a pulse frequency equals to frequency of rotation in RPM for each sensor separately. Enter your constants to the boxes *Hall const.*, *L const.*, *Opt. const*. The same RPM value should appear in boxes below denoted as "RPM". How is the conversion between pulse frequency and RPM value done in general?

4. Using oscilloscope display the signal waveform present at the output of the induction sensor amplifier (L. ZOS terminal). Then check the reshaped signal output from the comparator (L. TVAR terminal). Notice the shape of the signal, its amplitude and how it get changed if you change the motor speed. Stop the motor using *START/STOP* button, take soldering gun and place its transformer very near to the coil of the induction sensor and turn it on. What you can observe at the *L. ZOS* a *L. TVAR* terminals and why? Now find the dependence between the amplitude of induced voltage and frequency of rotation. (Indicator "*L voltage [Vpp]*" in application shows the peak-to-peak value of induced voltage). Start the motor and measure the RPM-voltage curve for at least 10 values of motor speed.) What is the dependence you have found? How we can determine the RPM using voltage?

5. Connect two input channels of the oscilloscope to the terminals denoted as *INK.1* and *INK.2*. Turn on the motor and watch the waveforms. Try to change the direction of motor rotation. Notice if the order of waveforms has changed. Exit the computer application and launch "enkoder.exe". Set the numbers of sections on disc (control "pulses per revolution") and choose some type of encoding.
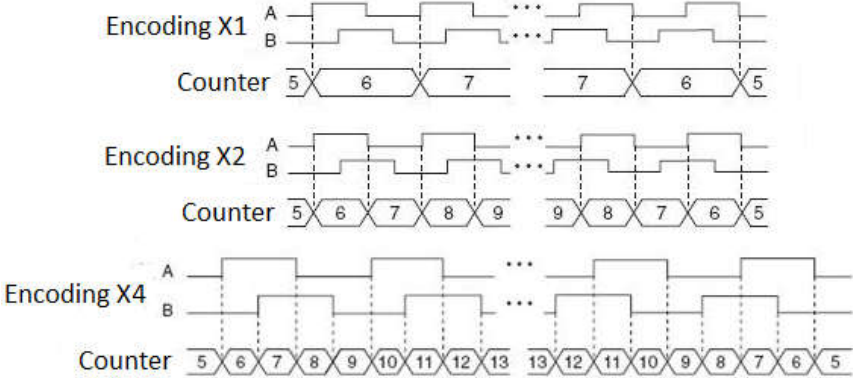
After making any adjustments to these values in application always press button "CHANGE SETTING". Keep turning the encoder disc by hand and notice the angular position displayed in units of degrees. Now try the influence of various encoding modes (do not forget to press "CHANGE SETTING" button). What is the difference between particular encoding modes? Now set the X1 mode and rotate the disc into some known position. Turn off the power supply of the device and then turn it on again. Does the display show the same angular position? If not, why?

6. Take off the magnetic holder and change the encoder disk for binary one. The sections of disc are sensed by reflective optocouplers located under the encoder disc, thus put the disc in holder with sections located on the bottom. Put the magnetic holder back and slowly rotate the disc by hand. Notice the binary word sensed from disc and the position displayed as 0-7 steps in computer application. Now rotate the disc faster and observe the graphical display. Have you noticed some irregularity? If yes, what is the cause of irregularity? Now change the disc for a Gray code one and flip the switch in application to "Gray" position. Now the Gray code read from the disc is being converted to binary and then displayed as a decimal number 0-7 in position graph. Now check if the same irregularity keeps occurring. If not, why? Rotate the disc to some known position and turn off the power supply of the device. Rotate the disc to another known position, turn on the power supply then rotate the disc to its former position and check if there is a correct position reading.