MEE303 Sensor Systems

W10
Velocity Sensing

Velocity Measurement

Velocity Sensing

The scale

Velocity shows how fast an object moves along a straight line or how fast it rotates.

the speed of a large object, especially of a land or water vehicle, may be very efficiently determined by a GPS

For smaller objects and shorter distances, GPS is not a solution. Detecting the velocity for such objects requires different references.

Velocity measurement from displacement sensing element

A basic idea behind many sensors for the transduction of velocity or acceleration is a measurement of the displacement

Measuring velocities is to differentiate the signal of displacement or angular sensors

$$v = \frac{dx(t)}{dt} \qquad \omega = \frac{d\theta(t)}{dt}$$

However, this has the disadvantage of amplifying the noise relative to the usable signal

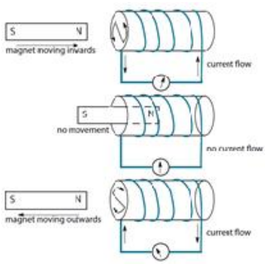
Electromagnetic Induction Based Sensing Elements

Electromagnetic Induction

the production of electric current across a conductor moving through a magnetic field

Faraday's Laws of electromagnetic Induction:

Whenever the magnetic flux linked with a circuit changes, an EMF is induced in the circuit, which lasts as long as the change in magnetic flux associated with the circuit continues.



The magnitude of the induced EMF is equal to the rate at which the magnetic flux linked with the circuit changes.

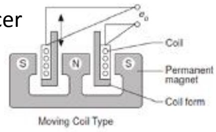
$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

Method to change magnetic field may be:
- By moving a magnet towards or away from the coil
- By moving the coil into or out of the magnetic field.
- By changing the area of a coil placed in the magnetic field
- By rotating the coil relative to the magnet.

Velocity Measurement

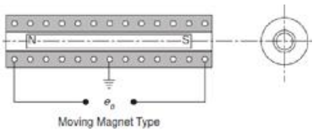
Sensors for translation

The main elements of a velocity transducer are coil and a permanent magnet. These two elements can be arranged in two different configurations



Electromagnetic linear velocity transducer

The sensing element which is a rod permanent magnet



There is a coil surrounding the permanent magnet forming stator.

Due to the application of the velocity, the permanent magnet moves in or out of the coil

When a permanent magnet moves inside a coil, the change in the length of the air gap varies the reluctance.

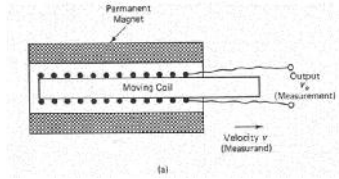
Hence the output voltage is directly proportional to the rate of change of the length of the air gap

Thus the output voltage becomes a measure of the velocity when calibrated.(no direct relationship) and the amplitude of the voltage is directly proportional to velocity.

Electrodynamic linear velocity transducer

A Linear velocity transducer/sensor consists of a moving coil suspended in the magnetic field of a permanent magnet stator.

The velocity is given as the input, which causes the movement of the coil in the magnetic field.



This causes an emf (DC Voltage) to be generated in the coil.

This induced emf will be proportional to the input velocity and thus, is a measure of the velocity.

$$eE = evB \qquad E = \frac{\varepsilon}{L}$$

$$E = vB \qquad \varepsilon = vBL \qquad \varepsilon = -NBlv$$

The polarity of the output voltages determines the direction of the velocity

Velocity Measurement

Sensors for rotation

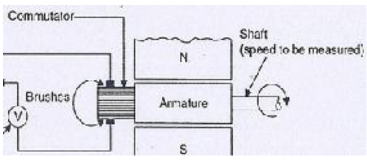
Permanent magnet transducers have a permanent magnet to generate a uniform and steady magnetic field and a rotating coil.

A relative motion between the magnetic field and an electrical conductor induces a voltage, which is proportional to the speed at which the conductor crosses the magnetic field.

In some designs, a unidirectional magnetic field generated by a dc supply (i.e., an electromagnet) is used in place of a permanent magnet.

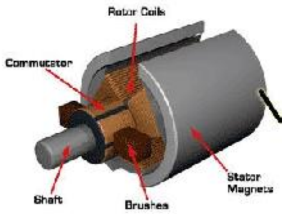
Permanent-magnet transducers are not variable-reluctance devices.

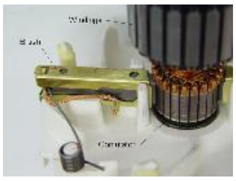
These are passive transducers, because the energy for the output signal v is derived from the motion



Permanent-Magnet DC Tachometer

DC Tachometer is a common transducer for measuring angular velocities. Its principle of operation is the same as that for a dc generator (or back-driving of a dc motor).





DC tacho generators consist of a commutator and a coil rotating in a constant magnetic field arising from a permanent magnet.

The generated voltages are then proportional to the rotational speed. This sort of sensing element has a linear characteristic but a rippled voltage signal because of the commutation

Velocity Measurement

Sensors for rotation

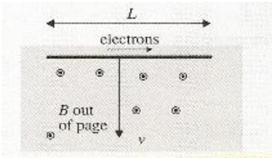
Magnetic Force on a Moving Charge

$$\vec{F} = q(v \times B)$$

$$|\vec{F}| = F = qvB\sin\theta$$

Magnetic Force on a charge inside a Moving Conductor

Induction current : the wire is not connected to anything, the current has no place to go, so we build up negative charges on the right side and positive charges on the left side which is an electric field of magnitude



E – electric field
V – potential difference
L – length of wire

$$E = \frac{\Delta V}{\Delta x} = \frac{V}{L}$$

Induced voltage: The resultant field causes a reaction electric force on charges. Actually voltage drop on wire is a result of force equivalance:

$$eE = evB$$

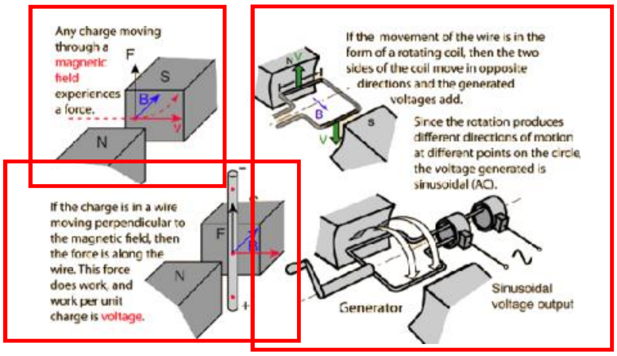
eE – electric force
evB – magnetic force

created a motional emf:

$eE = evB \Rightarrow E = vB$ *Derivation from equality*

$E = \dfrac{V}{L}$ *Definition of voltage*

$V = vBL$ motional emf



$V = 2NBLwr\sin\theta$ Sinusoidal Voltage

$|V| = 2NBLrw = Kw$ Its magnitude is proportional to angular velocity of shaft

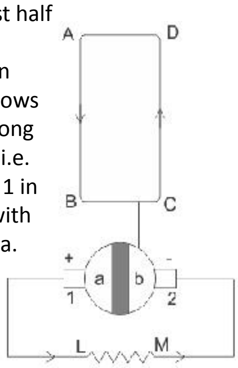
constant k is known as the back-emf constant or the voltage constant.

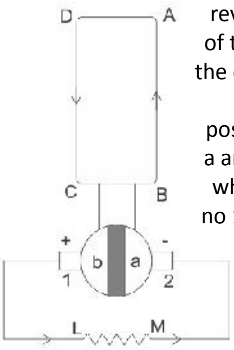
Velocity Measurement

Sensors for rotation

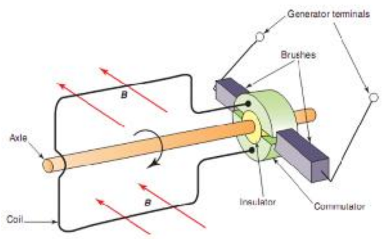
Permanent-Magnet DC Tachometer

In the first half of the revolution current flows always along ABLMCD i.e. brush no 1 in contact with segment a.



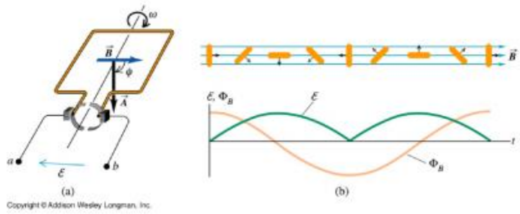


In the next half revolution, the direction of the induced current in the coil is reversed. But at the same time the position of the segments a and b are also reversed which results that brush no 1 comes in touch with the segment b.

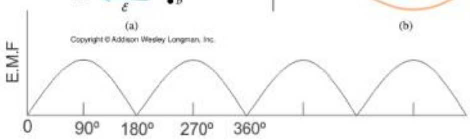


The current in the load resistance again flows from L to M.

Hence, the current in the load resistance again flows from L to M.



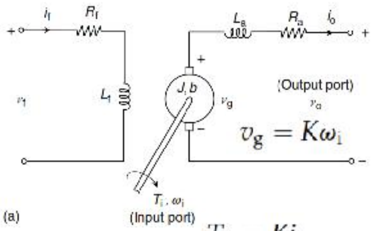
The wave from of the current through the load circuit is as shown in the figure. This current is unidirectional



Velocity Measurement

Sensors for rotation

Permanent-Magnet DC Tachometer



$v_g = K\omega_i$

$T_g = Ki_o$

Electrical and mechanical variables coupled to each other

The equation for the armature circuit is

$$v_o = v_g - R_a i_o - L_a \frac{di_o}{dt}$$

Newton's second law for a tachometer armature having inertia J and damping constant b is expressed as

$$J\frac{d\omega_i}{dt} = T_i - T_g - b\omega_i$$

the time derivatives are replaced by the Laplace variable s. This results in the two algebraic relations

$$v_o = K\omega_i - (R_a + sL_a)i_o$$

$$(b + sJ)\omega_i = T_i - Ki_o.$$

Desirable feature for practical transducers is to have a static (algebraic, nondynamic) input–output relationship so that the output instantly reaches the input value, and the frequency dependence of the transducer characteristic is eliminated. Then the transducer transfer function becomes a pure gain and independent of frequency. This happens when the transducer time constants are small (the transducer bandwidth is high).

$$\tau_e = \frac{L_a}{R_a} \qquad \tau_m = \frac{J}{b}$$

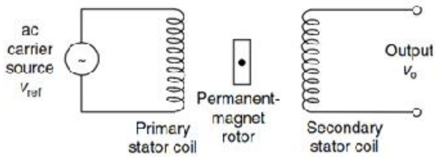
electrical time constant mechanical time constant

Velocity Measurement

Sensors for rotation

Permanent-Magnet AC Tachometer

This device has a permanent magnet rotor and two separate sets of stator windings.



Induced voltage in the other set of windings is the tachometer output.

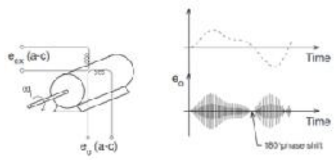
One set of windings is energized using an ac reference (carrier) voltage.

Operation Principle

When the rotor is stationary or moving in a quasi-static manner, the output voltage is a constant-amplitude signal much like the reference voltage, as in an electrical transformer

The direction of velocity is determined from the phase angle of the modulated signal with respect to the carrier signal

As the rotor moves at a finite speed, an additional induced voltage, which is proportional to the rotor speed, is generated in the secondary coil. This is due to the rate of change of flux linkage into the secondary coil as a result of the rotating magnet.



The overall output from the secondary coil is an amplitude-modulated signal whose amplitude is proportional to the rotor speed. For transient velocities, it becomes necessary to demodulate this signal in order to extract the transient velocity signal (the modulating signal) from the overall (modulated) output.

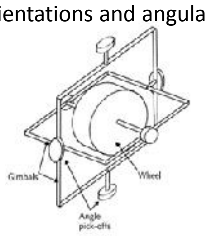
Typical operating frequencies are 60 Hz and 400 Hz. This carrier frequency should be 5 to 10 times the required frequency response of the ac generator tachometer

Velocity Measurement

Absolute Angular Rate Sensors

Gyroscope

Gyroscopic sensors are used for measuring angular orientations and angular speeds

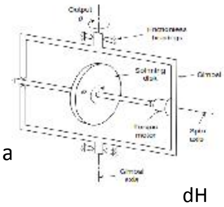


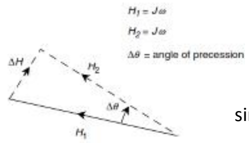
A conventional gyroscope consists of a spinning wheel mounted on two gimbals which allow it to rotate in all three axes.

An effect of the conservation of angular momentum is that the spinning wheel will resist changes in orientation because there will be no external torque transferred to wheel.

Hence when a mechanical gyroscope is subjected to a rotation the wheel will remain at a constant global orientation and the angles between adjacent gimbals will change.

To measure the orientation of the device the angles between adjacent gimbals can be read using angle pick-offs. A conventional gyroscope measures orientation





$$\sin\Delta\theta \approx \Delta\theta = \frac{\Delta H}{H}$$

$$\frac{dH}{dt} = \tau \qquad \frac{d\theta}{dt} = \frac{dH}{H}\frac{1}{dt} = \frac{1}{H}\frac{dH}{dt} \qquad \boxed{\frac{d\theta}{dt} = \frac{\tau}{H}}$$

A rate gyro is used to measure angular speeds. Its structure similar to mechanical gyros. In this case, the gimbal is not free and may be restrained by a torsional spring. A viscous damper is provided to suppress any oscillations.

To analyze this gyroscope, iti is assumed that the angles of rotation are small and that the moment of inertia of the gimbal frame is negligible

$$\frac{d\theta}{dt} = \frac{\tau}{H} = \frac{\tau}{Jw} \qquad Jw\frac{d\theta}{dt} = \tau = K\theta + B\frac{d\theta}{dt} \qquad \frac{d\theta}{dt} = \frac{K\theta + B\dot{\theta}}{Jw}$$

Coriolis Force Devices

$$\frac{d\theta}{dt} = \frac{K}{Jw}\theta$$