10. Velocity measurement

Velocity (speed or rate of motion) may be linear or angular; that is, it shows how fast an object moves along a straight line or how fast it rotates. The measure of velocity depends on the scale of an object and may be expressed, say, in millimeters per second or km per hour. Currently, the speed of a large object, especially of a land or water vehicle, may be very efficiently determined by a GPS (Geo Positioning System) that operates by receiving radio signals from a number of the Earth's satellites and by computing the time delay of signals received from one satellite as compared with the other. For smaller objects and shorter distances, GPS is not a solution. Detecting the velocity for such objects requires different references.

10.1 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 of an object with respect to some reference object which, in many cases, is an integral part of the sensor.
It is always possible that measuring velocities is to differentiate the signal of displacement or angular sensors. However, this has the disadvantage of amplifying the noise relative to the usable signal. However, this has the disadvantage of amplifying the noise relative to the usable signal. Therefore, direct measuring methods for velocity measuring are more suitable. However, displacement can be used to very accurately measure average velocity.

10.2 electromagnetic Induction based sensing elements

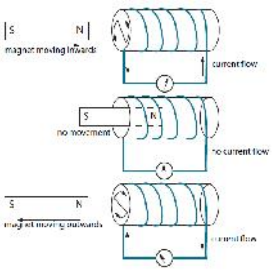
Electromagnetic induction is the production of electric current across a conductor moving through a magnetic field. It underlies the operation of generators, transformers, induction motors, electric motors, synchronous motors, and solenoids:
Faraday's Laws of electromagnetic Induction:

1. 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.
2. The magnitude of the induced EMF is equal to the rate at which the magnetic flux linked with the circuit changes.

Method to change magnetic field may be:

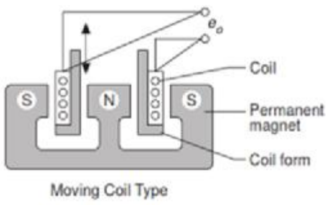
- By moving a magnet towards or away from the coil
- By moving the coil into or out of the magnetic field.
- By changing the area of a coil placed in the magnetic field
- By rotating the coil relative to the magnet.

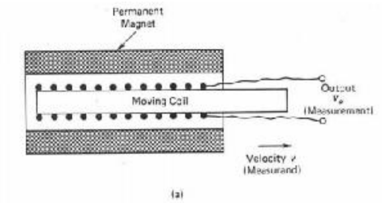
Faraday's laws of electromagnetic induction do not say anything about the direction of the current. The direction is given by Lenz's law.



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

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 (i.e., electrodynamic and electromagnetic) to measure the velocity.
Electrodynamic linear velocity transducer: In electrodynamics velocity transducer, moving coil scheme is employed. In this configuration the coil and the magnet are arranged in housing such that the magnet forms the stator and the coil is wound on a guided cylindrical core which moves inside the housing. In some cases, the core is suspended with spring to compensate initial force bias due to gravity. The body whose velocity is too measured is connected to the core of the coil.

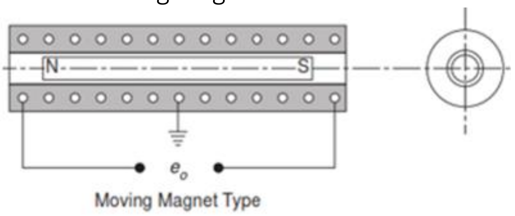




Due to the displacement of the body, the core also gets displaced which in turn caused a displacement of the coil in the magnetic field.
This movement of the coil causes a change in the flux linkages between the Magnet and the coil, and thus according to the electromagnetic induction principle an electrical voltage gets induced in the coil. This induced voltage is proportional to the relative velocity of the spring and is given by the equation:

$$e = -NBlv$$

Electromagnetic linear velocity transducer: In electromagnetic velocity transducer, moving magnet scheme is employed. The sensing element which is a rod is a permanent magnet as mentioned. The rod is rigidly coupled to the body whose velocity is being measured. There is a coil surrounding the permanent magnet forming stator. The permanent magnet armature is again guided via stator structure so that it can move in and out of the coil.



The core of the instrument is fixed to the body whose velocity is to measured. 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 (change in length produced by velocity). 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. The polarity of the output voltages determines the direction of the velocity.

Sensors for rotation:
As mentioned above, a coil rotating in a constant magnetic field arising from a permanent magnet will have a generated voltage which is proportional to its rotational speed.

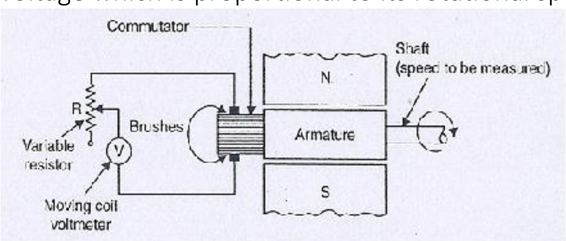
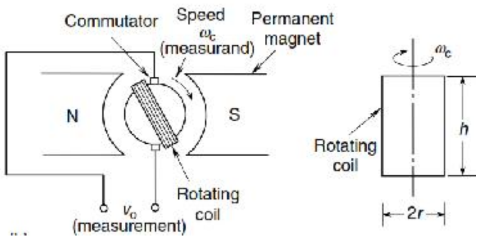


Fig. 32. D.C. tachometer generator.

The distinctive feature of permanent magnet transducers is that they have a permanent magnet to generate a uniform and steady magnetic field. 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 (i.e., the rate of change of flux linkage). 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 (i.e., measured signal) itself. The entire device is usually enclosed in a steel casing to shield (isolate) it from ambient magnetic fields.

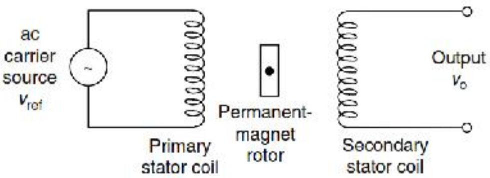
DC Tachometer is a common transducer for measuring angular velocities. Its principle of operation is the same as that for a dc generator (or back-driving of a dc motor). The dc tachometer (or tachogenerator) is a permanent-magnet dc velocity sensor in which the principle of electromagnetic induction in a conducting coil due to variations in the magnetic field of a permanent magnet is used.
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.



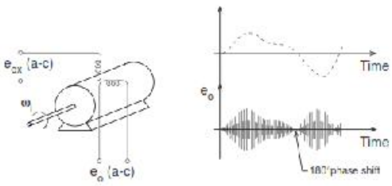
The principle of operation of tachometer is as follows: The rotor is directly connected to the rotating object. The output signal that is induced in the rotating coil is picked up as dc voltage using a suitable commutator device—typically consisting of a pair of low-resistance carbon brushes—that is stationary but makes contact with the rotating coil through split slip-rings so as to maintain the direction of the induced voltage the same throughout each revolution.
According to Faraday's law, the induced voltage is proportional to the rate of change of magnetic flux linkage. For a coil of height h and width 2r that has n turns, moving at an angular speed ω in a uniform magnetic field of flux density B, this is given by:

$$e = -2NBlrw$$

Permanent-Magnet AC Tachometer: This device has a permanent magnet rotor and two separate sets of stator windings. One set of windings is energized using an ac reference (carrier) voltage. Induced voltage in the other set of windings is the tachometer output.
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.



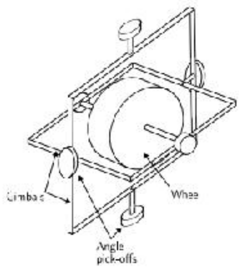
In an ac permanent-magnet tachometer, a dc magnetic flux is generated by the magnetic rotor, and when the rotor is stationary it does not induce a voltage in the coils. The flux linked with the stator windings changes because of the rotation of the rotor, and the rate of change of linked flux is proportional to the speed of the rotor.
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.



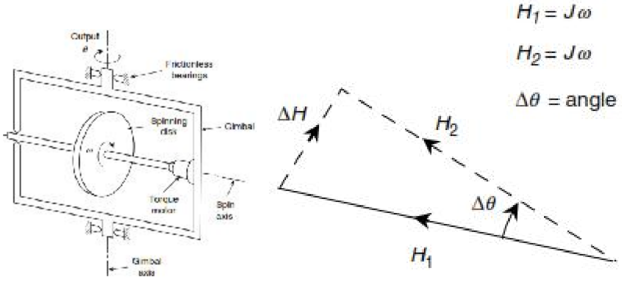
The overall output from the secondary coil is an amplitude-modulated signal whose amplitude is proportional to the rotor speed. For transient velocities, it becomes necessary to demodulate this signal in order to extract the transient velocity signal (the modulating signal) from the overall (modulated)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

10.3 Gyroscopic sensors

Gyroscopic sensors are used for measuring angular orientations and angular speeds of aircraft, ships, vehicles, and various mechanical devices. These sensors are commonlyused in control systems for stabilizing various vehicle systems.



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



$H_1 = J\omega$

$H_2 = J\omega$

$\Delta\theta$ = angle of precession

$$\frac{dH}{dt} = \tau \quad \sin\Delta\theta \approx \Delta\theta = \frac{\Delta H}{H} \quad \frac{d\theta}{dt} = \frac{dH}{H}\frac{1}{dt} = \frac{1}{H}\frac{dH}{dt}$$

$$\frac{d\theta}{dt} = \frac{\tau}{H}$$

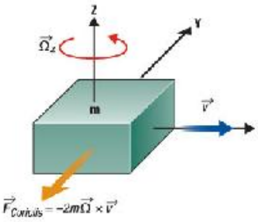
However the angular speed about an orthogonal axis can be determined via rate gyros; for example, by measuring the precession torque using a strain-gage sensor; or by measuring using a resolver, the deflection of a torsional spring that restrains the precession. The angular deflection in the latter case is proportional to the precession torque and hence the angular speed.
A rate gyro is used to measure angular speeds. The same arrangement with a slight modification can be used as rate gyro. 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. By analyzing this gyro, we note that the relative angle of rotation u gives the angular speed V of the structure (vehicle) about the axis that is orthogonal to both gimbal axis and spin axis
Assume that the angles of rotation are small and that the moment of inertia of the gimbal frame is negligible:

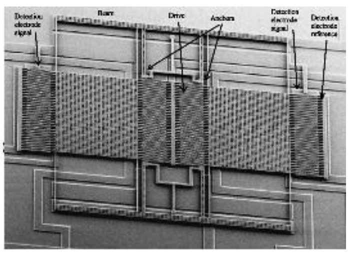
$$\frac{d\theta}{dt} = \frac{\tau}{H} = \frac{\tau}{Jw} \quad Jw\frac{d\theta}{dt} = \tau = K\theta + B\dot{\theta} \quad \frac{d\theta}{dt} = \frac{K\theta + B\dot{\theta}}{Jw}$$

When B is negligible, angular displacement on springs are proportional to the angular velocity:

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

10.4 Coriolis Force Devices





A mass m moving at velocity v relative to a rigid frame. If the frame itself rotates at an angular velocity v, it is known that the acceleration of m is given by 2wxv. This is known as the Coriolis acceleration (Note: the vector-cross-product is denoted by x). The associated force 2mwxv is the Coriolis force. This force can be sensed either directly using a force sensor or by measuring a resulting deflection in a flexible element as mentioned above, and may be used to determine the variables (v or v) in the Coriolis force. Note that Coriolis force is similar to gyroscopic force even though the concepts are different. For this reason, devices based on the Coriolis effect are also commonly termed gyroscopes.