Electric Motor Feedback Devices

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Feedback devices found on motors used by industry come in a wide variety. Some of the more common devices would be:

1. Incremental / serial encoders
2. Hall effect sensors
3. Resolvers
4. Tachometer Generators

These devices are utilized to send information back to the control about speed, direction of rotation, position, acceleration / deceleration rate, and the relative position of the rotor to the stator.

<u>1. Incremental encoders</u> generate a group of square wave pulses that will be from 100 to several thousand pulses for each rotation of the shaft. These pulses will usually be labeled A, B, and Z. The A pulses are offset from the B pulses. That is, they are offset so that the A pulse occurs first and then the B pulse in one rotation (normally forward) and the B pulse occurs first for the other rotation (usually reverse). The Z pulse will occur one time for each revolution. Thus the Z pulse is the indexing pulse or the start pulse.

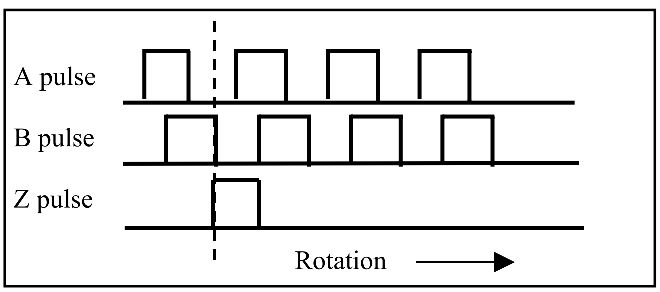


Figure: 1

Encoders are being used more and more and they are being designed to assume more feedback functions that were formerly done by other devices such as tachometers, Hall effect sensors, and photosensitive pick-ups. In addition to the A, B, and Z signals output by an encoder there may also be commutating signal tracks added to the encoder disc so that it will replace sensors such as the Hall effect devices for commutation signals. Optically generated sine and cosine signals are added to some units. This would allow an encoder to be used in place of a resolver. These simulated sine and cosine signals then could be used for commutation, speed and direction of rotation similar to the way a resolver would be used.

Still others use computer algorithms to develop the commutating signals for the control to use. It is possible to have an encoder function for all of the feedback signals needed by the control. By combining the needed output signals into one unit, makes this device very cost effective.

<u>Encoder operation</u>

Incremental optical encoders operate on the principle of photoelectric scanning of the very fine lines on a rotating disc.

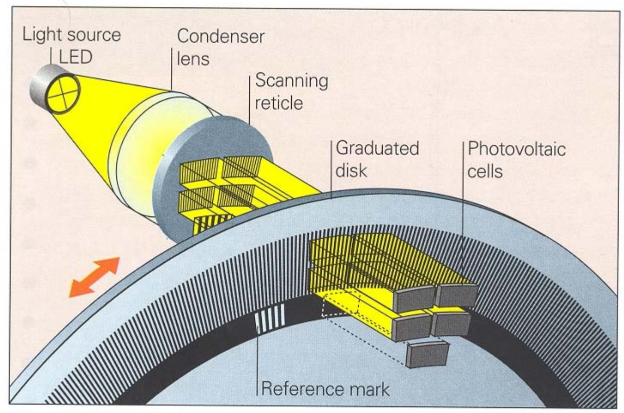


Figure 2 Courtesy of Heidenhain Corp.

The photoelectric scanning of the disc along with processing electronics generate incremental output of pulses that when counted by the electronics of the drive will determine speed, direction, incremental movement, and total movement of the shaft to which it is connected.

<u>Encoder disc</u>
This is a picture of a disc from an incremental optical encoder. The outside track is opaque except for one set of lines that will produce the Z and Z* output pulses.

The next track has many small lines from which the A, A*, B, and B* channels are produced. The * is used to indicate the complementary signal (180 degrees out of phase).

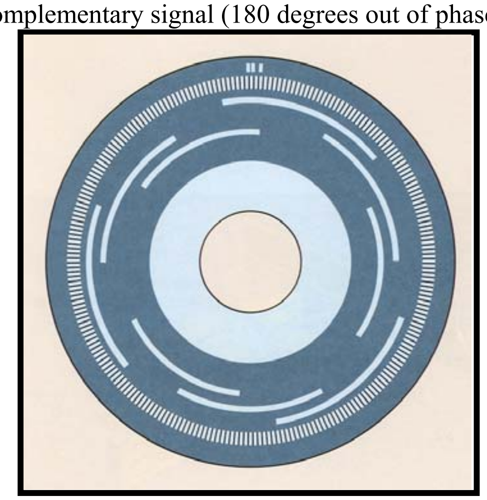


Figure 3 Courtesy of Heidenhain Corp.

The three inside three tracks will be used to produce the commutating signals com1, com2, com3, etc.

Additional tracks may be utilized to produce the complements of the above signals such as A*, B*, and Z* or complementary signals for the commutation signals.

The complimentary signals may also be produced by the electronics within the encoder.

The outputs of an incremental optical encoder normally will be:

A, A* incremental shaft movement and position
B, B* direction of shaft movement
Z, Z* one pulse per turn for indexing

Additional outputs that may be present are:

U, U* commutation signal one
V, V* commutation signal two
W, W* commutation signal three
C, C* sine signal
D, D* cosine signal

Those outputs with asterisk designations are usually referred to as "not". This would be for example: A "A" and A* "A not". The outputs referred to as "not" are the complement of the outputs without the asterisk. This means that they are always opposite of each other. When A is high then A* is low etc.

These letter designations are common however there are no universal standards. There are other designations used by the manufacturers, however their functions may be similar. An understanding of the purpose of each signal is very important since the labels may vary from one manufacturer to another.

The typical tests that are performed on an incremental encoder to assure that they meet original specifications are:

1. Check the pulse stream waveforms with an oscilloscope

2. Check the relationship of the A to B signal with an oscilloscope

3. Check the Z signal with an oscilloscope

4. Do a line count with a digital pulse counter

5. Run a continuous count test at operating speed for dependability check

6. Measure the offset from signal A to signal B.

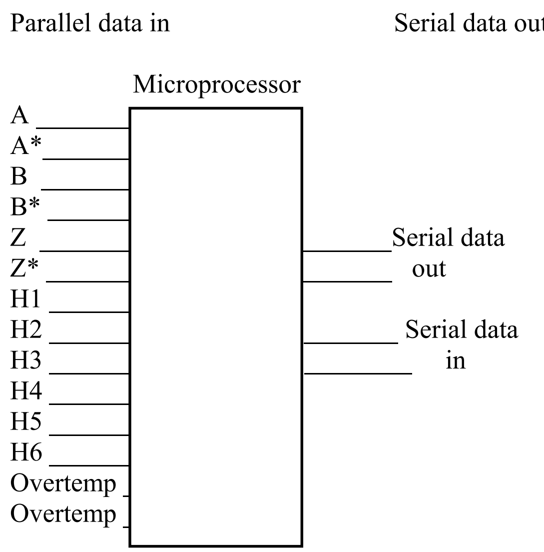
7. Measure the "on" time versus the "off" time of the pulses

Serial pulse encoders do not send the A, B, and Z pulses that the incremental encoders send to the control. For this reason they must be tested differently.

Serial pulse encoders perform the same functions as the incremental encoders perform. However, instead of putting out incremental pulses, they communicate to the control with a serial "word". This "word", or string of binary characters that make up the word, is a string of characters that the control is programmed to interpret. The same information (and in some cases more) is communicated to the control as would be sent by an incremental encoder by this method. It would do so by using only two wires instead of a separate wire for each signal.

The serial encoder construction is similar to the incremental encoder except that it has processing electronics built in that processes the information and then communicates this information to the control. If you are to test these serial encoders separate from their control, then it will require that you must have a computer interface that is programmed to interpret this serial data.

Serial encoder using an internal microprocessor



The serial encoder reduces the number of lines between the motor and the controller. For controllers that are already computer based this form of communication is more logical.

There can also be additional information in the serial data stream such as a self-check bit, battery condition, error checking, etc.

Some manufacturers may make use of encoders with a combination of both serial and incremental output signals.

2. Hall effect switches are solid-state devices that will change output when placed in a magnetic field. This output will change state if the magnetic field is reversed. These sensors are used to return a signal that corresponds to the position of the permanent magnet rotor.

If they are placed in close proximity to the rotor, then the signal from the sensors will represent the position of the rotor's magnets. Alternatively, the Hall effect switches could be mounted external to the rotor if a separate permanent magnet rotor that has magnetic poles, which match the poles on the rotor, acts upon them. These sensors have been widely used on permanent magnet servo motors for commutation feedback signals to the control.

Most Hall effect switches provide an open collector or open drain type of output. The Hall switch acts as a switch and therefore does not output any voltage on its own. To derive a useful output signal, a pull-up resistor connected between the supply voltage and output of the Hall switch must be added.

The controller for the motor usually furnishes this pull-up resistor and the power supply voltage to produce the signal from the sensor.

The value of this pull-up resistor is not critical but should be high enough in resistance that it does not overload the output transistor. Usually two to ten thousand ohms is sufficient.

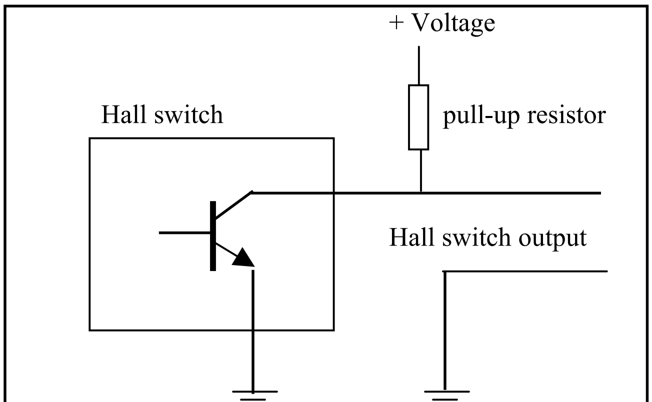


Figure 4

Hall switches may be operated upon by the rotor magnets directly, however most manufacturers choose to locate them away from the internal heat of the motor and put them in the enclosure at the end of the motor away from the output shaft.

In this enclosure they may be operated upon by a small permanent magnet rotor which would be mounted on the shaft and have the same number of poles as the motor rotor.

Another arrangement shown in figure 5 will not use rotating magnets, but instead use a disc made of magnetic material such as a sheet metal. This disc would have cutaway openings. This arrangement would have the number of openings that match the number of poles of the motor. With the Hall effect switch located in a sensor that has its own magnetic source, the disc would then interrupt the magnetic flux to cause the sensor output to match the position of rotor magnets.

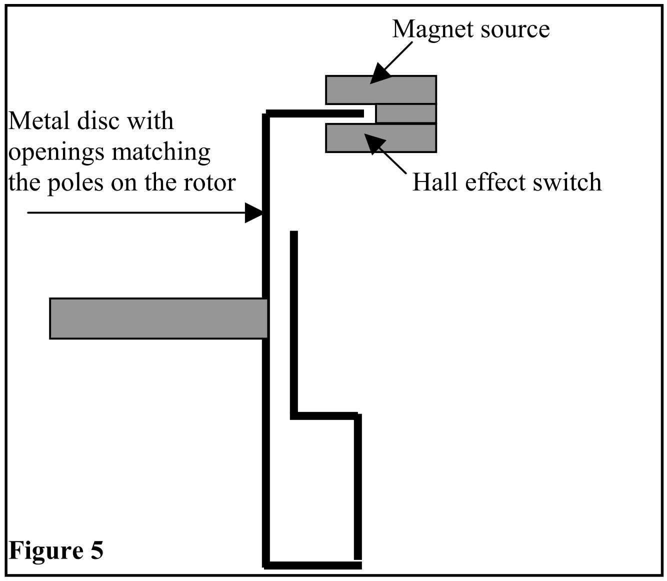
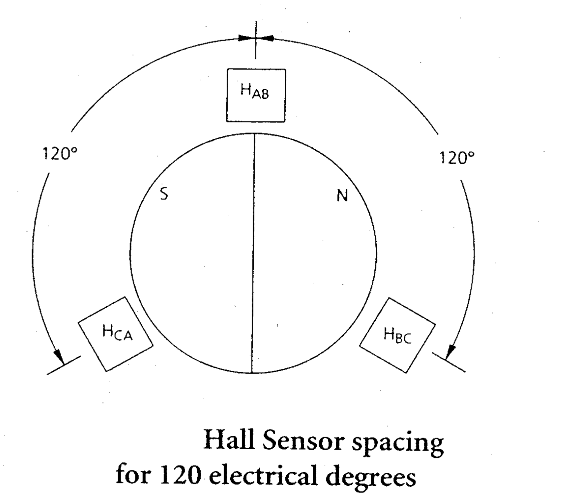


Figure 5

Shown below is a graphical representation of the usual setup of Hall switch sensors for sensing the position of the permanent magnet rotor. Notice that they are always spaced one hundred twenty "electrical" degrees.



Sensing rotor position

Figure 6

The physical spacing of the Hall sensors shown here would only be true for a two-pole motor.

If this were a four-pole motor instead, then the physical spacing of the sensors would be sixty mechanical degrees. For a six pole motor physical spacing of the sensors would be forty mechanical degrees. For an eight pole motor thirty mechanical degrees etc.

The permanent magnets operating on the Hall sensors shown in figure 6 are for a two-pole motor. These would also be changed to match the number of poles in the motor if the motor were to be a different number of poles.

If the sensors were photosensitive pickups, then the number of opaque and clear areas would also match the number of poles in the motor. This would allow the output signal to correspond to the counter EMF of the stator winding.

So long as the rotating part of the position sensing setup will accurately correspond to the rotor and the stationary part will correspond to the stator winding, the relative position of stator and rotor may be represented.

Fig 6 shows the electrical spacing of Hall sensors for an output that will represent the position of the rotor. They may also be considered as outputting a signal that will represent or correspond to the three counter generated voltages from the motor when the rotor is turning.

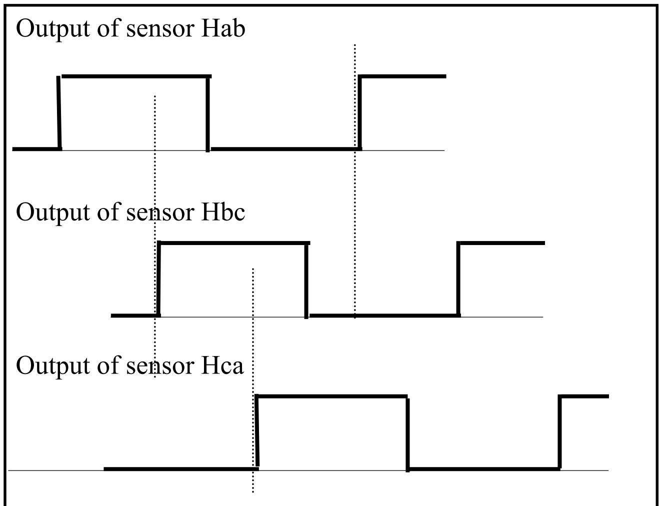


Figure 7

From figure 7 it can be seen that the Hall effect sensor switches will be high for one hundred eighty electrical degrees and low for one hundred eighty electrical degrees.

They are displaced from each other by one hundred twenty electrical degrees. These signals can then be mated to corresponding counter generated voltages being generated in the stator windings that will be positive for one hundred eighty electrical degrees and negative for one hundred eighty electrical degrees, and also be spaced one hundred twenty electrical degrees apart.

It can be seen from this that the signals from the Hall sensors may then be matched up with the counter voltages from the stator windings as shown in figure 8. This would then be the alignment that could be used for the control to properly commutate the power to the motor. Shown below in figure 8 is the alignment of one position sensor signal that could come from Hall sensor or an encoder and one signal that might be obtained from the generated counter voltage of the motor.

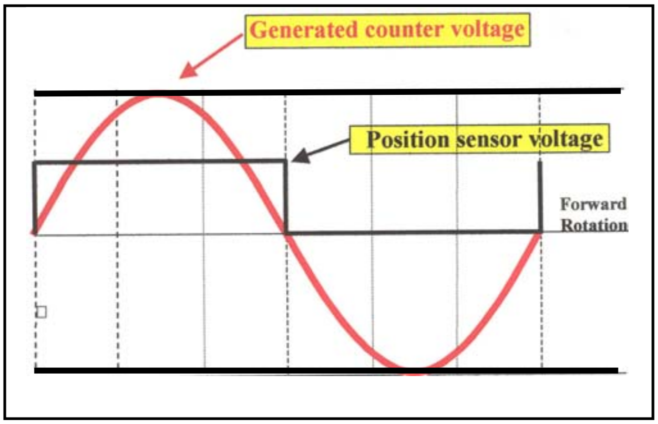


Figure 8

3. Resolvers are rotating transformers that have an inductively coupled rotor winding (brushless). The stator windings are two identical windings, which are ninety electrical degrees apart. One of the stator windings is identified as the sine and the other as cosine.

From the output of these stator windings, the angle of the rotor can be resolved. Knowing the relative angular position of the shaft allows this device to be used for speed, direction, and commutation feedback. Other sensors, such as Hall effect sensors, give switch points but do not have anything to indicate position between these switch points. The fact that a resolver indicates the position continuously makes it an ideal choice for a control that will be designed to have sinusoidal power output from the control to the motor.

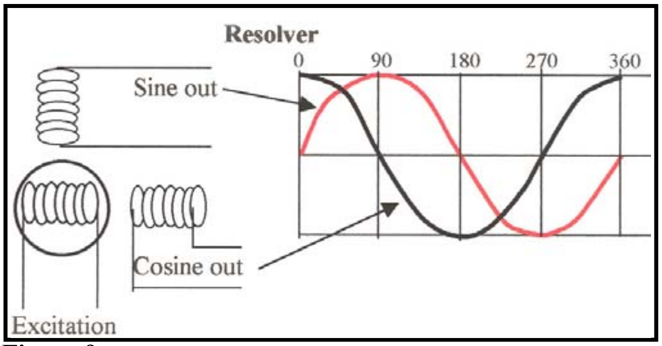


Figure 9

- At zero degrees, the sine output is zero and the cosine output is high and in phase with the excitation voltage.
- At ninety degrees the cosine is zero and the sine is high and-in-phase.
- At one hundred eighty degrees the sine is zero and the cosine output high and out of phase with the excitation.
- At two hundred seventy degrees the cosine is zero and the sine is high and out of phase with the excitation voltage.

The angle of the resolver shaft can be determined by the combination of voltage level and the phase relationship of the sine and cosine voltages to the excitation voltage for a full three hundred sixty electrical degrees of rotation.

For a one-speed resolver, three hundred sixty electrical degrees would also be three hundred sixty mechanical degrees. A two-speed resolver would have three hundred sixty electrical degrees output for one hundred eighty mechanical degrees of rotation. This ratio of mechanical to electrical degrees would be true for three, four, or five speed resolvers etc.

There are no standards for the lead markings on resolvers. However, there are commonly found color codes used.

These would be:

Red – Cosine high (S1)
Black – Cosine low (S3)

Yellow – Sine high (S2)
Blue – Sine low (S4)

White/red – Excitation high (R1)
White/yellow or White/black – Excitation low (R2)

Normal rotation would be CCW when looking at the shaft.

1. Interchanging the sine leads will reverse rotation.
2. Interchanging the cosine leads will reverse rotation and move zero one hundred eighty-degrees.
3. Interchanging the excitation leads will move zero one hundred eighty degrees.
4. Interchanging the sine leads with the cosine leads will move zero ninety degrees and reverse rotation.

Resolvers are not as susceptible to dirty, oily, or hot surroundings as the electronic circuits in other devices may be. Devices such as encoders will be more susceptible to these conditions. Consequently the resolver has been the feedback device of choice by many manufacturers.

Many manufacturers will place a mark on the rotor winding and on the stator winding, when these marks are lined-up with each other, the resolver will be at zero angle. That is, the output of the sine winding will be zero and the output of the cosine winding will be maximum and in phase with the excitation voltage.

The sine winding will be identical to the cosine winding in resistance. These are identical windings except that they are physically located in the stator to give ninety electrical degrees shift in their outputs. The excitation winding will have a different resistance than the sine or cosine. This usually makes it easy to identify the excitation winding.

If the leads are not marked or color coded according to the normal standard above, then the line placed on the windings may be used to help determine which winding is which (sine or cosine). Because, as stated above, the sine winding will have zero voltage output when the resolver is set on zero degrees.

By exciting the rotor windings and taking measurements with a digital meter or oscilloscope the sine and cosine windings may be identified.

Assuming that the lines on the rotor and stator indicate the zero angle for the resolver, then by setting the resolver with these lines physically aligned the electrical conditions at zero angle would be sine winding output would be low (near zero) and the cosine winding output would be high (and in phase with the excitation).

There are two variables that must be kept in mind when working with resolvers. These variables are:

1. The frequency of the voltage that is applied to the excitation winding. The input frequency range of these units is usually from two kilohertz to twenty kilohertz. Most commonly a frequency of five to ten kilohertz.
2. The magnitude of the voltage that is applied. The input voltage range of these units is usually from two to ten volts.

If the frequency is a greatly different than the frequency for which the resolver is designed to operate, then a phase shift between the excitation (or input) and the sine / cosine (or outputs) may result. See figure 10.

If the voltage magnitude is too high, then the waveform may be become distorted due to core saturation. See figure 11.

These conditions may be observed by connecting a variable frequency supply to the excitation winding and viewing the waveforms of the input and output on a dual channel oscilloscope as the frequency and the amplitude are adjusted.

Resolver frequency and excitation level waveforms.

Figure 10 excitation frequency too high or too low causing phase shift making zero crossings out of phase

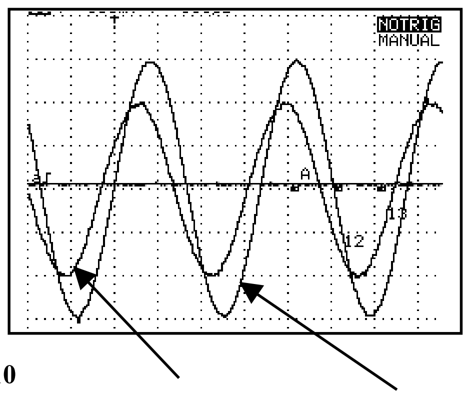


Figure 10

Figure 11excitation level too high causing distortion of the output waveform.

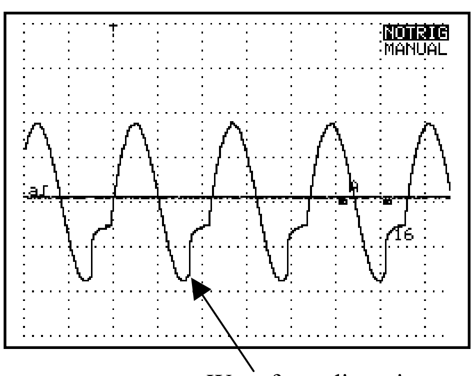


Figure 11

Figure 12 shows excitation level and frequency correct. Notice that there is not any distortion of the waveform and they cross the zero line at the same time.

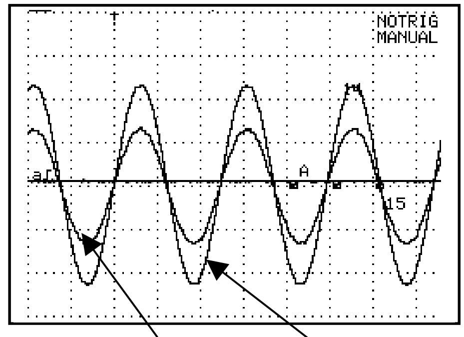
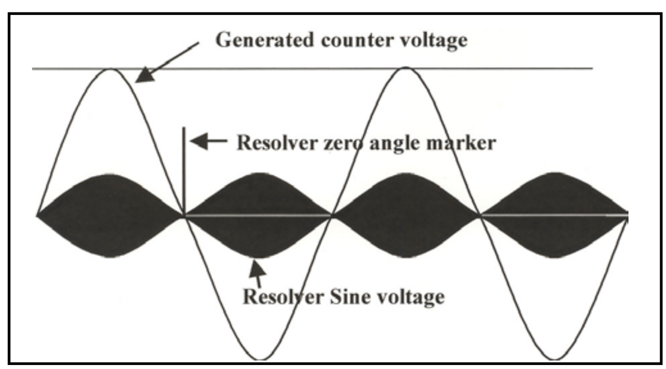


Figure: 12 Sine voltage Excitation voltage

Waveform relationships between the counter voltages produced by a permanent magnet brushless servo motor and the rotating resolver may look similar to the waveforms in figure 13. The generated counter voltage from the stator would depend upon the speed and number of poles.

The sine voltage is a high frequency of two to twenty kilohertz that is modulated by the rotation of the shaft. As the shaft passes through zero degrees the sine voltage would be zero; at ninety degrees it would be high and in phase with the excitation; at one hundred eighty degrees the sine voltage would again be zero; at two hundred seventy degrees the sine would be high and out of phase with the excitation. This modulated high frequency sine waveform could be aligned with the generated counter voltage which also varies in magnitude and phase with the rotation of the shaft as shown here in figure 13.

Figure: 13



4. Tachometer generators

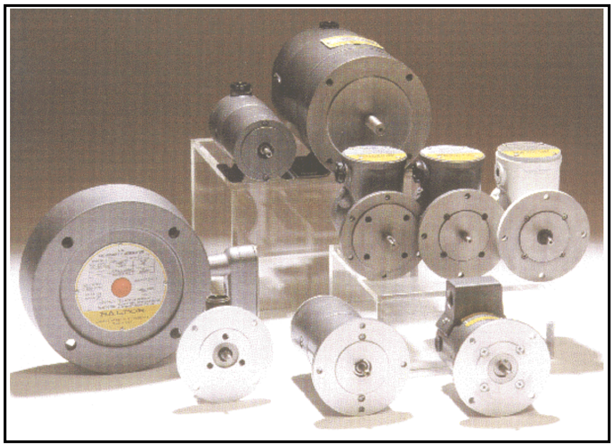


Photo courtesy of Baldor Elect.
Figure: 14

Tachometer generators come in a variety of sizes and designs. It is important, to assure the proper operation of the motor when it is installed, that the tachometer operates properly. It should be rotated in both directions and the following checks performed:

1. The output value should be compared to the rated output at the test speed. Normally this would be done at 1000 RPM and the voltage at this speed compared to the rated voltage.

2. The polarity and voltage level of the output of a DC tachometer should be noted for both directions of rotation of the tachometer. Reversed polarity of the tachometer may cause a runaway condition by the-motor.

3. The ripple content and irregularities of a DC tachometer generator should be checked with an oscilloscope. This will indicate the condition of the tachometer commutator, brushes, and windings. Most good tachometers will have less than two percent ripple. Some have a one percent rating. Over two percent ripple could cause a problem. Example: For 10 VDC two percent equals 0.2 volt ripple.

   The ripple content should be checked with the oscilloscope in the AC coupled setting. By using AC coupling the DC voltage is blocked by the capacitive coupling and the ripple content may be measured in the milli-volt range giving the needed sensitivity. The over all DC voltage may then be measured using DC coupling on the oscilloscope.

4. There are also some AC tachometers that have a three-phase AC output that are required to be aligned with the rotor position feedback devices.

Test filter for checking a DC brush type tachometer with an oscilloscope.

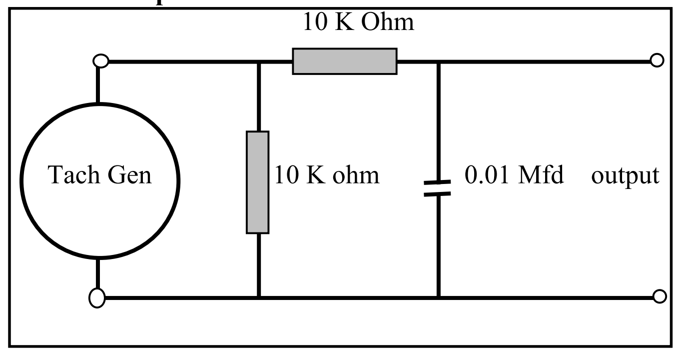
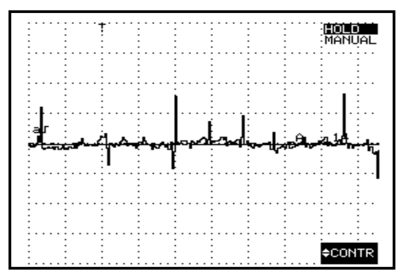


Figure: 15

The above filter may be used for looking at the output of a DC tachometer. The filter is not intended to mask or smooth any ripple from the generator.

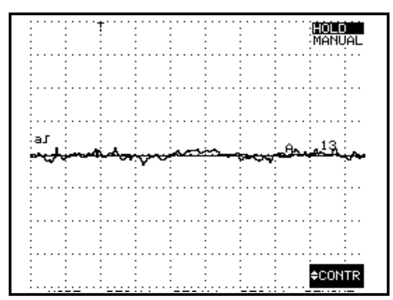
It is intended to filter electrical noise that may be present from the power being supplied to drive the motor that may be attached to the tachometer. This noise will be transferred through the common frame to the tachometer.

Figure: 16



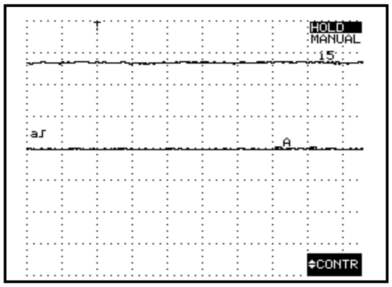
.5 volts/div

Figure: 17



.5 volts/div

Figure: 18



10.0 volts/div

All three of the above oscilloscope waveforms were taken from the same DC tachometer generator.

Figure 16 is unfiltered AC coupled waveform. Notice the noise on the waveform.

Figure 17 is the same waveform with a filter inserted between the tachometer and the oscilloscope.

Figure 18 is the output of the tachometer with DC coupling on the input to the oscilloscope. Notice the waveform is offset from the zero line by the amount of the DC voltage of the tachometer.