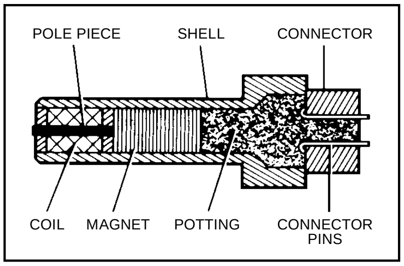
INTRODUCTION TO VARIABLE RELUCTANCE SENSORS (VRS)

GENERAL DESCRIPTION



Cut-A-Way View of VRS Magnetic Sensor

Completely self-powered, VRS (magnetic) sensors are simple, rugged devices that do not require an external voltage source for operation. They are generally used to provide speed, timing or synchronization data to a display (or control circuitry) in the form of a pulse train. Common applications include:

- Engine RPM measurement on aircraft, automobiles, boats, buses, trucks and rail vehicles.
- Motor RPM measurement on drills, grinders, lathes, automatic screw machines, etc.
- Process speed measurement on food, textile, woodworking, paper, printing, tobacco and pharmaceutical industry machinery.
- Motor speed measurement of electrical generating equipment.
- Speed measurement of pumps, blowers, mixers, exhaust and ventilating fans.
- Flow measurement on turbine meters.
- Motor RPM measurement on precision camera, tape recording and motion picture equipment.
- Wheel-slip measurement on automobiles, trucks and locomotives.
- MPH measurement on agricultural equipment.

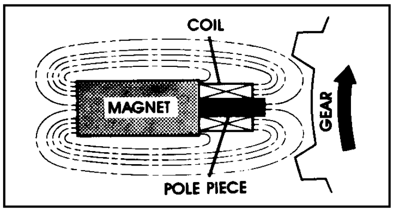
Some of the unique characteristics that make the use of VRS sensors valuable in the above applications include:

- Self-powered operation.
- Error-free conversion of actuator speed to output frequency.
- Simple installation.
- No moving parts.
- Useable over a wide speed range.
- Adaptable to a wide variety of configurations.

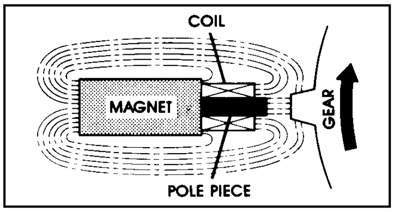
These properties have led to wide-spread utilization in a number of industries. As a result, VRS sensors have become known by many use related names such as: Magnetic Pick-Ups, Speed Sensors, Motion Sensors, Pulse Generators, Variable Reluctance Sensors, Frequency Generators, Transducers, Magnetic Probes, Timing Probes, Monopoles, and Pick-Offs.

PRINCIPLE OF OPERATION

The output signal of a VRS sensor is an AC voltage that varies in amplitude and wave shape as the speed of the monitored device changes, and is usually expressed in peak to peak voltage (V P-P). One complete waveform (cycle) occurs as each actuator passes the sensing area (pole piece) of the sensor. The most commonly used actuator is a metal gear, but also appropriate are bolt heads (cap screws are not recommended), keys, keyways, magnets, holes in a metal disc, and turbine blades. In all cases, the target material must be a ferrous metal, preferably unhardened.

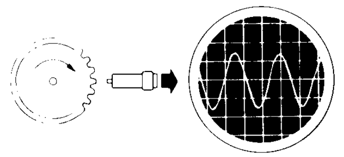


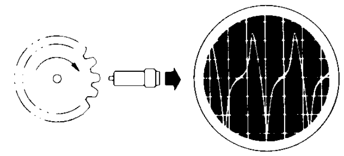
High Reluctance Position of Magnetic Circuit

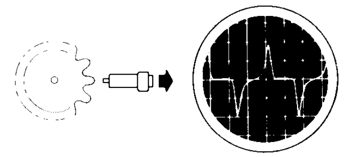


Low Reluctance Position of Magnetic Circuit

A permanent magnet is the heart of a VRS sensor and establishes a fixed magnetic field. An output signal is generated by changing the strength of this field. This is caused by the approach and passing of a ferrous metal target near the sensing area (pole piece). The alternating presence and absence of ferrous metal (gear tooth) varies the reluctance, or "resistance of flow" of the magnetic field, which dynamically changes the magnetic field strength. This change in magnetic field strength induces a current into a coil winding which is attached to the output terminals. If a standard gear is used as an actuator, this output signal would resemble a sine wave if viewed on an oscilloscope.


Steel Fine Tooth Gear


Steel Coarse Tooth Gear


Steel Sprocket

APPLICATION CONSIDERATIONS

VRS sensors are not designed for sensing extremely low speeds. The target passing the pole piece of the sensor must be traveling at a minimum velocity, or surface speed, to provide an adequate output voltage. Typical minimum surface speeds for each sensor type can be found in the specifications section. The bottom line in proper VRS sensor selection is to choose one that will meet the following two conditions:

1) Provide the required peak to peak voltage at the minimum speed of interest.

2) Will still function properly at the maximum operating frequency of the application.

To choose an appropriate sensor, the following data must be obtained:

1) Minimum and maximum speed of interest.

2) Diameter of gear (or shaft) and number of teeth (or actuators) per revolution.

3) Load resistance – the input resistance of the device being driven.

4) Air gap setting – distance between sensor face (pole piece) and top of gear tooth (or other actuator).

5) Minimum acceptable peak to peak voltage level (V P-P) of the device being driven – typically a display or frequency to DC convertor.

6) Mounting requirements and package size limitations.

STANDARD TEST CONDITIONS AND POLARITY OF OUTPUT

Throughout the VRS section of the product data sheets, you will see an output voltage specification, expressed in V P-P, for each sensor. This “reference” voltage is the minimum guaranteed peak to peak output voltage of the sensor as tested by the factory, and is the starting point for the series of calculations that will provide the “actual” output voltage the sensor will provide in your application. The “reference” voltage value is established by testing the sensor under one of the following conditions:

	TEST CONDITION A	TEST CONDITION B	TEST CONDITION C
SURFACE SPEED	1000 IPS (25M/Sec)	1000 IPS (25M/Sec)	1000 IPS (25 M/Sec)
GEAR	20 DP (Module 1.27)	8 DP (Module 3.17)	8 DP (Module 3.17)
AIR GAP	.005" (.127mm)	.005" (.127mm)	.005" (.127mm)
LOAD RESISTANCE	100K Ohms	1.25K Ohms	100K Ohms

Unless noted otherwise, all VRS sensors are tested to Condition A.

The polarity of the output signal is usually of no concern for most applications. For those situations where polarity is important, the following definition applies to all VRS Industrial Sensors:

When ferrous metal approaches the pole piece of a given sensor…
Pin B will be positive with respect to Pin A,
The white lead will be positive with respect to the black lead.

CALCULATING ACTUAL OUTPUT VOLTAGE FOR A GIVEN APPLICATION

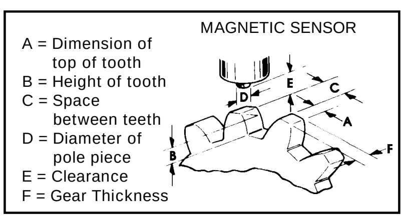
In order to determine if a certain VRS sensor will work in a specific application, you should use the following sequence of calculations. In this example, the calculations will use U.S. Standard Terminology. For metric calculations, substitute millimeters, meters per second and module formulae as appropriate.

In this example, the size of the sensor is not critical, and we have determined that the variable data is as follows:

MINIMUM SPEED OF INTEREST:	100 RPM
MAXIMUM SPEED OF INTEREST:	1000 RPM
ACTUATOR DESCRIPTION:	20 Pitch 60 Tooth Gear
AIR GAP SETTING:	.010" (.25mm)
LOAD IMPEDANCE OF DEVICE:	10K Ohms
OUTPUT REQUIRED:	1 V P/P Min.

For every gear tooth configuration, there is an optimum pole piece size and shape to achieve maximum output voltage from the sensor. This relationship is noted below.

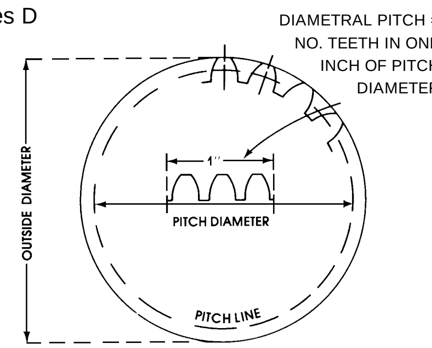
The optimum dimension of A, B, and C are given as they relate to D the diameter of the pole piece of the VRS sensor being used. The optimum relationship for maximum output is as follows:



Optimum Gear Tooth Configuration

A equal to or greater than D
B equal to or greater than C
C equal to or greater than three times D
E as close as possible
F equal to or greater than D

The above configuration is usually not available in a stock gear, but it is seldom necessary to have the maximum output. Very close to the maximum output may be generated by conventional stock gears if the tooth width A is equal to or greater than the pole piece diameter D and C is 1.5 times D. For ease of alignment, gear thickness should be 2 or 3 times the pole piece diameter.



Gear Pitch

Invensys Sensor Systems / Electro Corporation, U.S.A.
Tel. 941-355-8411 www.speed-position.invensys.com Fax 941-355-3120

When the actuator is a gear, an excellent starting point in choosing a sensor is to match the pole piece diameter as close as possible to the gear pitch. Since overall sensor size is of no concern in this example, a look at the 5/8 diameter VRS sensor reveals that a 20 pitch gear is ideal for both the 3010 and 3030 type units. You will note that the 3010 unit has lower inductance and resistance and also a lower output voltage than the 3030. The low resistance and inductance are desirable characteristics for areas of high electrical noise and for high frequency applications. The 3030's higher output is desirable for lower speeds. We'll look at the 3010 first.

Remember, if a VRS sensor is going to be an appropriate choice at all, it must be able to work at the lowest speed of interest. Our first calculation will be to determine the minimum surface speed of our sample application:

$$\text{MIN SURFACE SPEED} = \frac{\text{MIN RPM x GEAR DIA x 3.14}}{60}$$

Since we are not given the gear diameter, we must back up one step and calculate it:

$$\text{GEAR DIAMETER IN INCHES (U.S. Std.)} = \frac{\text{TOTAL \# OF TEETH + 2}}{\text{GEAR PITCH}} = \frac{62}{20} = \text{3.1 INCHES}$$

$$\text{MINIMUM SURFACE SPEED} = \frac{100 \times 3.1 \times 3.14}{60} = \text{16.2 INCHES PER SECOND}$$

(Note: Gear diameter in mm (metric) = Gear Module x Total # of Teeth)

The product data shows the output of the 3010 series sensors is 40 V P-P, but this is at 1000 IPS. Now we must determine the output of the 3010 series sensor at 16.2 IPS surface speed. Since output voltage changes in an approximate linear response to speed, we can use the following ratio formula:

$$\frac{\text{REF VOLTAGE OUT}}{\text{REF SURFACE SPEED}} = \frac{\text{UNKNOWN VOLTAGE OUT}}{\text{ACTUAL SURFACE SPEED}}$$

$$\frac{40}{1000} = \frac{X}{16.2} = .648 \text{ V P-P}$$

Since our device needs a minimum of 1 V P-P to operate, the 3010 unit has already been disqualified as an acceptable choice. Lets try the higher output 3030 series sensor. The output of the 3030 series sensors is 190 V P-P at 1000 IPS. Using the same formula:

$$\frac{190}{1000} = \frac{X}{16.2} = 3.078 \text{ V P-P}$$

So far so good, but next we must consider the gear pitch/pole piece factor. By referring to Table 1, we see the output from a sensor having a .106" Dia. pole piece (3030 series) when sensing a 20 pitch gear is 100%. Therefore, no correction factor is applied. Our output voltage remains at 3.078 V P-P.

TABLE 1

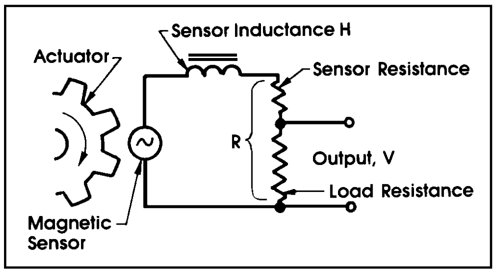
RELATIONSHIP BETWEEN GEAR PITCH/POLE-PIECE DIAMETER/OUTPUT VOLTAGE								
Pole-Piece Diameter	CONICAL POLE PIECES					CHISEL POLE PIECES		
	0.187	0.106	0.093	0.062	0.040	0.045	0.030	0.010
Gear Pitch	Output Voltage vs Gear Pitch Expressed As a Percentage of Standard Voltage							
6	125	187	146	123	134	138	117	139
8	100	172	147	118	132	135	113	134
10	98	162	149	118	130	115	120	125
12	63	157	154	114	126	110	120	118
16	29	118	130	107	124	108	120	112
20	—	100	100	100	100	100	100	100
24	—	85	99	100	100	88	83	100
32	—	23	33	77	80	70	77	81
48	—	—	20	30	53	23	47	49
64	—	—	—	—	24	—	30	36
72	—	—	—	—	—	—	13	10

Now we will consider the effect of the load resistance of the device being driven, in this example, 10K Ohms. Since this change is also a linear function, we can once again use a simple ratio formula:

$$\frac{\text{PRESENT VOLTAGE OUT}}{\text{TOTAL RESISTANCE*}} = \frac{\text{UNKNOWN VOLTAGE OUT}}{\text{LOAD RESISTANCE}}$$

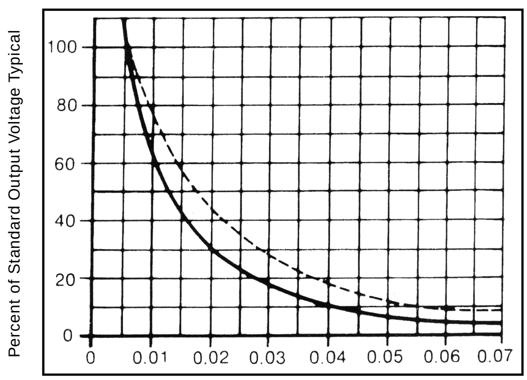
* Total Resistance is Load Resistance Plus Sensor Resistance

$$\frac{3.078}{11200} = \frac{X}{10000} = 2.748 \text{ V P-P}$$



Equivalent Circuit

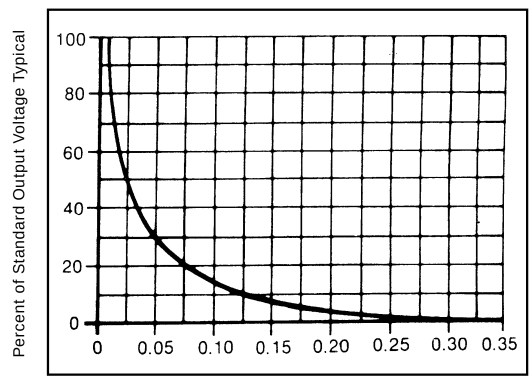
The only factor left to consider is the allowable air gap, also known as pole piece clearance. In this example, this is .010". By referring to the graph, we can see that the output of the 3030 series sensor at .010" air gap is 60% of the present value.



For < .187" Dia. PP

Pole Piece Clearance (Inch)

- - - - - Indicates Blind-End Sensor



For ≥ .187" Dia. PP

Pole Piece Clearance (Inch)

$$2.748 \times .6 = 1.649 \text{ V P-P}$$

We have now taken into consideration all of the variables that have an effect on our actual output voltage at the lowest speed of interest, and found the 3030 series sensor to be appropriate. If our result at this point would have been less than 1V P-P, it would have been necessary to look at a near-zero or zero-speed sensor for this application.

Finally, we need to make sure the 3030 series sensor will function at the maximum frequency (Hertz) of the application:

$$\text{MAX FREQUENCY} = \frac{\text{MAX RPM} \times \text{NUMBER OF GEAR TEETH}}{60}$$

$$\text{or} \quad \frac{1000 \times 60}{60}$$

or 1000 Hertz (or 1KHz)

A look at the 3030 series specifications reveals a typical frequency response of 15 KHz. We are obviously well within this limit.

To summarize the selection process, consider the following guidelines:

Applications with limited mounting space will necessarily move you to the smaller diameter sensors, then apply the previous calculations.

When possible, select a sensor with lower coil resistance/inductance to minimize unwanted noise signals, drive lower impedance loads, and operate at higher frequencies.

When the target allows, use a sensor with a larger pole piece diameter to provide maximum output voltage and allow use of larger air gap settings.

Use a chisel tip pole piece to maximize output from fine gear pitch's or to provide an accurate timing pulse from a similar "knife edge" type actuator.

VRS CALCULATOR ON DISK

If you find yourself involved in a large number of calculations, you may want to obtain a copy of our VRS calculator disk. This 3.5" disk performs all the above calculations and works on MS-DOS/Windows based PC's. Due to included variable data, it will provide a more accurate answer than the hand calculations just described. To obtain a copy, fax your request with shipping address to our customer service department at 941-355-3120, or download the program by clicking on this icon VRS CALC

VRS SENSOR GENERAL NOTES

All housings unless otherwise noted are 303 Stainless Steel. Recommended cabling is twisted pair, shielded type.

All pole pieces are conical, except .187" units which are straight, and chisel units which are indicated where used.

All sensors are designed to operate in moderate oil/fluid splash applications up to the rated temperature. For heavy oil/fluid splash, immersion, or if any differential pressure exists, sealed front end sensors are recommended.

If a VRS sensor is mounted completely surrounded by ferrous metal, a 10 to 20% output voltage reduction can occur.

Recommended maximum mounting torque for stainless steel units:

Thread Size	Max. Ft. Lbs.	Max. N/m
3/4	27	36
5/8, M16	15	20
3/8, M10	3	4
1/4, M8	1	1.4
10/32	.3	.4

1 Ft./Lb. = 12 In./Lbs. = .74 N/m