



## Application Note for Ground Vehicles/Transportation

### Introduction

This Application Note was developed to assist engineers and technicians with the process of selecting, installing, and using Firstmark Controls miniature and subminiature position transducers for ground vehicle and transportation-related applications. It details why, where, and how Firstmark Controls position transducers are used in automotive and other vehicle environments.

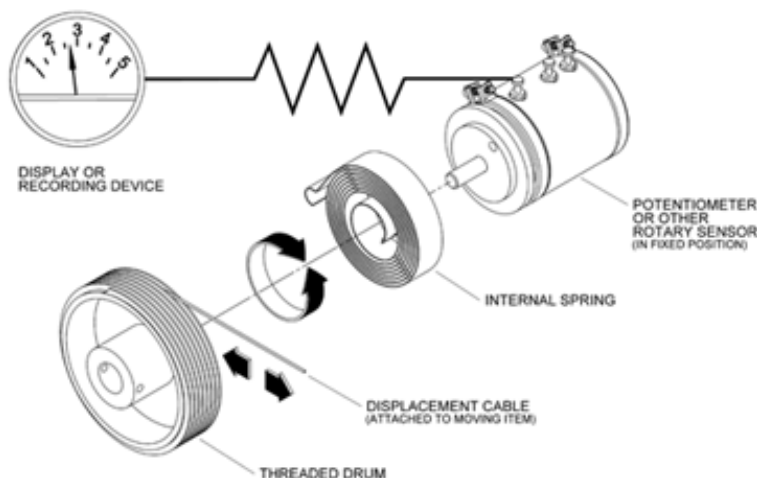
### Product Technology Summary

Firstmark Controls position transducers are cable-actuated displacement-sensing devices. The majority of ground vehicle and transportation applications use the analog electrical output provided by precision potentiometers, but encoders, synchros, and resolvers are also available.

Figure 1.0 shows how a position transducer works. Operationally, the products work by mounting in a fixed position and attaching the displacement cable to a moving object such as a suspension component or vehicle control component. As movement occurs, the cable extracts and retracts.

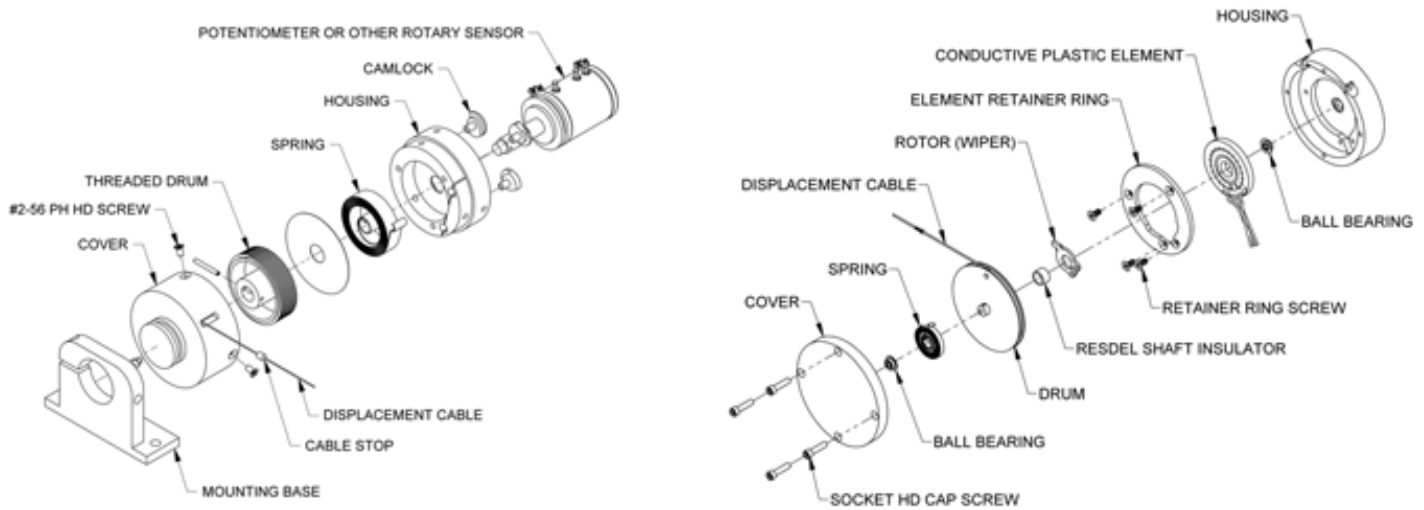
An internal power spring maintains cable tension. The threaded cable drum rotates a precision potentiometer, encoder, servo, or synchro that produces an electrical output proportional to the cable travel. Depending on the mounting arrangement and signal conditioning, the electrical output can indicate any number of lengths, motions, angles, or rates.

**Figure 1.0: How a Position Transducer Works**



**Series 160 Position Transducer**

**Series 173 Position Transducer**



## Introduction

Known also as string pots, yo yo pots, cable-displacement transducers, and draw wire transducers, Firstmark Controls position transducers have been used in a broad range of vehicle-related programs since they were first developed in 1968 to support NASA flight test programs. Since that time, these products have been used in projects ranging from truck and car development to crash impact research and from solar-powered vehicles to Formula 1 racing. Please contact us for a representative list of our ground vehicle and transportation customers and programs.

## Benefits

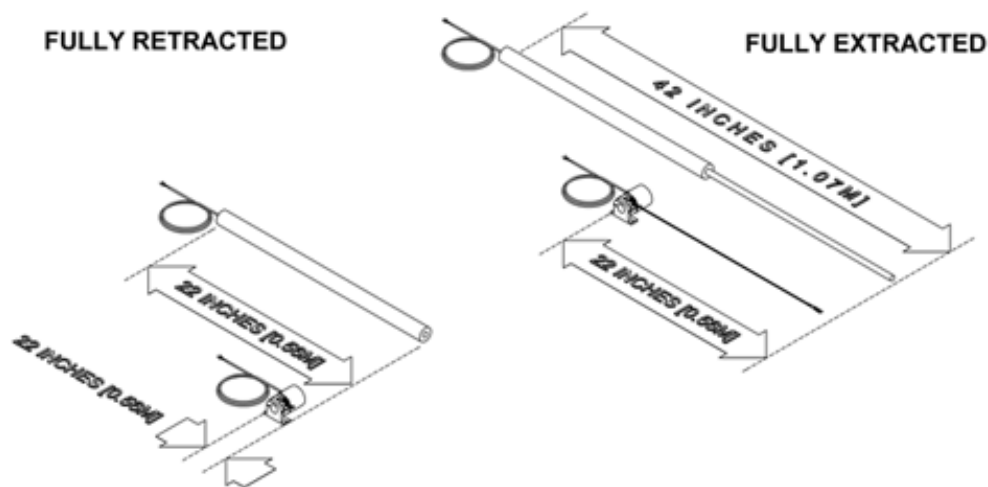
Before discussing where and how to use Firstmark Controls position transducers, let's look at what benefits these products bring to position measurement challenges and why you might want to consider the products for your application.

### Small Size and Light Weight

The realities of physics mandate that size and weight be considered in nearly every engineering design. This is especially true in the ground vehicle and transportation industries. Because the significant aspect of the cable-actuated position transducer is a stainless steel cable, Firstmark Controls products have an inherent size and weight advantage compared to other choices.

Rod-and-cylinder products such as linear potentiometers and LVDTs require room to store the rod and cylinder when the product is in its fully retracted state. For example, a typical rod-and-cylinder solution requires 42 inches (1.07 m) of operating space to measure 20 inches (0.51 m). A Firstmark Controls product can measure the same distance using less than 22 inches (0.56 m). When fully retracted, the rod-and-cylinder product takes up over 20 inches (0.51 m) of linear space. The Firstmark Controls product takes up less than 2 inches (0.05 m). See Figure 2.0.

**Figure 2.0: Comparison - Rod-and-Cylinder vs Cable Position Transducer**



Correspondingly, a rod-and-cylinder design will weigh significantly more than the Firstmark Controls product. A representative comparison for products with a 20-inch (0.51-m) range show rod-and-cylinder designs weighing 22 to 32 oz. (0.62 to 0.91 kg) while the Firstmark Controls product weighs around 3 oz (0.09 kg).

While a non-contact sensor may seem to provide slight size and weight advantages over a cable position transducer, often that advantage is outweighed once the non-contact sensor electronics and signal conditioning are taken into account.

## Mounting Flexibility

The flexible cable combined with innovative mounting bases and mechanisms enable these position transducers to be mounted in accordance with your application requirements. There is no need to re-design your project or product. This flexibility is particularly useful when measuring suspension components that simultaneously rotate and extend or when monitoring crash test objects that are moving unpredictably in three dimensions. It is also useful when tight spaces provide no room for the transducer. Cable pulleys can be used to re-route the displacement cable through conduit and other channels, letting the transducer be placed remotely from the measurement location.

## Ease of Installation

Quick-connect displacement cable connectors and varied mounting arrangements make the products easy to install and remove. This saves time in setup as well as reduces time spent at the design station and in the machine shop creating specialized installation fixtures.

## Accuracy

Firstmark Controls products use threaded cable drums and precision potentiometers (providing infinite resolution), high-resolution encoders, servos, or synchros. Firstmark Controls's threaded cable drum design ensures the cable is laid in the same place each cycle. Non-threaded drums allow the cable to wind over itself in a haphazard fashion. This reduces repeatability.

These Firstmark Controls design features combined with precision-machined aluminum parts and assembly by skilled technicians result in unparalleled repeatability and resolution. Accuracy for a 30-inch (0.76 m) Series 161 unit has been shown to be better than  $\pm 0.025\%$  of full-scale output.

## Safety and Damage

A final benefit is the safety and reduced damage factor that exists with these products relative to other choices available. The predominant alternatives to these types of transducers are:

1. Rod-and-cylinder transducers based on a number of technologies including variable resistive (potentiometric), magnetic induction, and magnetoresstriction.
2. Non-contact transducers using laser, Hall effect, ultrasonic, or other technologies.

The safety benefit of a cable-actuated position transducer over a rod-and-cylinder device is that a cable-actuated position transducer has no inflexible components that have the potential to bind, bend, or otherwise disrupt the free movement of the object being monitored. Rod-and-cylinder products need to be precisely aligned and mounted to ensure long-life and disruption-free operation. Mounting errors, non-linear application movement, and simple accidents can cause the rod-and-cylinder device to malfunction and restrict the movement of the application. If the application is a throttle, brake, or other critical part, this restriction of movement can have serious consequences.

The inherent flexibility of a cable-actuated position transducer eliminates any binding or bending problems. Should a mounting or product malfunction occur, the displacement cable connection assembly can be designed to have a minimum breaking strength of less than 10 lbs. (44.48 N).

While non-contact transducers do not present a restriction of movement hazard, they do present difficulties in ensuring data integrity due to the dirty environments ground vehicles and transportation systems are exposed to.

Leaking hydraulic and lubricating fluids, smoke, mist, and other visual and atmospheric elements reduce or eliminate the effectiveness of non-contact technologies. The result is data that cannot be relied upon and possible safety consequences if a control or feedback loop is involved.

## Durability

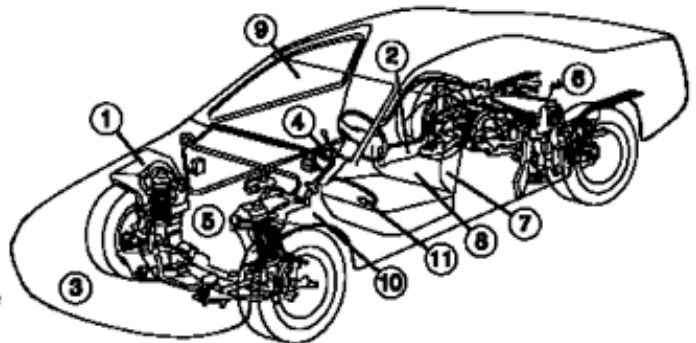
Using high-quality precision sensing elements and anodized machined aluminum with ball-bearing-mounted shafts, Firstmark Controls position transducers will often outlast the vehicle itself. When used properly, some models are rated to exceed 50 million cycles of operation.

## Uses

Due to the sensitive nature of many ground vehicle and transportation development projects, we frequently never know how our products are used. Nevertheless, for over 40 years, we have found the most frequent uses of our products to be those shown in Figure 3.0.

**Figure 3.0: Position Transducer Usage Areas**

- |   |  |
|---|--|
| ① Suspension Tracking<br>Spring<br>Shock<br>McPherson Strut<br>Axle Motion<br>Chassis | ⑤ Engine Torque  |
| ② Crash Test - Dummy<br>Chest<br>Rib Cage<br>Knee<br>Other                            | ⑥ Emission/Exhaust   |
| ③ Crash Test - Other  | ⑦ Seat Position  |
| ④ Throttle/Brake/Clutch/Gear Shift  | ⑧ Seat Belt/Harness  |
|   | ⑨ Ingress/Egress   |
|   | ⑩ Steering System<br>Steer Arm<br>Front Wheel Differential Angle |
|   | ⑪ Transmission   |



## Representative Applications

Next are a few recent ground vehicle and transportation applications of Firstmark Controls position transducers with notes on product usage. Contact us if you would like more details on these applications.

## NASCAR Racing: Rear Spoiler Angle

Firstmark Controls Series 160 position transducers are used to measure the rear spoiler deflection during highspeed NASCAR race vehicle test runs. Any spoiler deflection results in less downforce and a higher riding car with a slower top speed. By quantifying the amount of spoiler deflection occurring, race engineers are able to stiffen the spoiler to reduce deflection to an acceptable level. Other Firstmark Controls products are used to measure a variety of Formula 1, rally, Indy, and NASCAR race vehicle components including suspension, weight jacker, brake, throttle, and steering wheel parts.

## Anthropomorphic Dummy Chest Ribcage Displacement

**Figure 3.1: Dummy Displacement Measurement**

Various Hybrid III and BioSID crash test dummies use modified 4-inch Model 160-0321 position transducers to measure crash test induced displacements of the dummy thoracic cavity and rib cage area. These units have special mounting plates, crimped ball cable connectors, and 56 oz. of cable tension. Other units are used to measure dummy knee shear and leg travel.



## Lifecycle Testing

Eighteen subminiature Firstmark Controls products were used in an 18-month vehicle lifecycle test. Vehicle doors, hatches, and compartment access devices were instrumented to determine usage patterns. The test was completed successfully without a single position transducer malfunction.

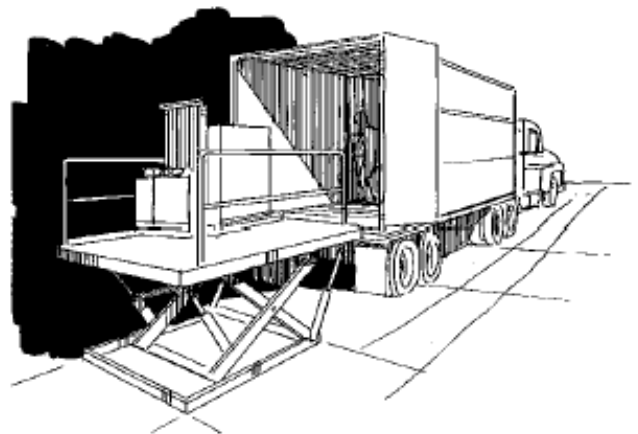
## Truck Suspension Monitoring

Series 160 and 161 units are used to obtain performance data at several vehicle proving ground locations. Tests incorporate high shock and vibration inputs as well as rapid sinusoidal cycling. Position transducers are mounted both from axle to body and from wheel to body.

## Hydraulic Actuation Verification

**Figure 4.0: Hydraulic Actuation Verification**

To verify the movement of heavy and utility vehicle hydraulically-actuated mechanisms, numerous Series 150 and Series 162 products are mounted either alongside the hydraulic cylinder or along one of the mechanisms' axis of displacement. Data is acquired and compared to control data to determine if performance specifications are being met. See Figure 4.0. requirement for any pulleys for cable re-routing.



## Product Usage Notes

### Which Series To Use

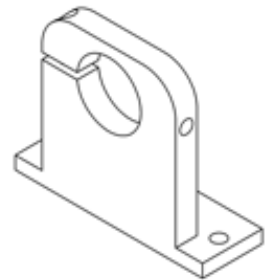
In general, the product size, displacement, and resolution will determine which Firstmark Controls position transducer is best suited to your application. An exception to this guideline is when increased cable tension is required for very-high-frequency response applications. Due to product sizes, Series 150, 17X, and 180 products are not available with ultra-high cable tension and therefore ultra-high cable tension requirements must be met with Series 16XH products.

### Position Transducer Mounts

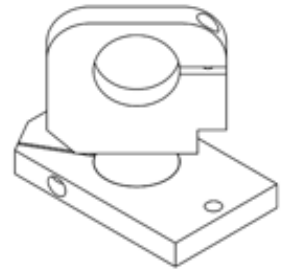
Mounting of Firstmark Controls products is simple using a choice of mounting bases and designed-in mounting flexibility. Rotation ability of most bases allows precise alignment of the product after it has been mounted.

#### Series 6, 160, 161, 162, 161H, and 161H

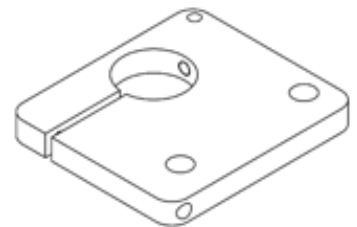
**Standard Base (part number 160015)** - Allows 360° rotation of the position transducer about the cover.



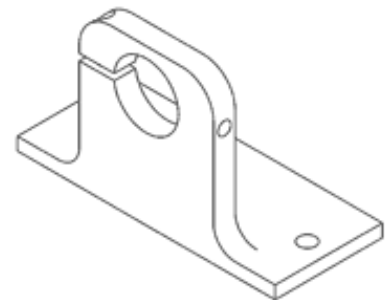
**Universal Base (part number 160030)** - Similar to the standard base but with the added capability for 360° rotation about the base itself.



**Flat Base (part number 160040L)** - Mounts the position transducer in a prone position. Provides 360° rotation about the cover.



**Big Foot Base (part number 160015-13 or 160015-15)** - Similar to the standard base but with a wider mounting platform for quicker mounting.



**Steering Column Base (part number 160015-G1)** - Allows easy mounting of the position transducer to vehicle steering columns for measuring fore-and-aft steering wheel deflection. Attaches to the steering column using hose clamps or similar mechanism.

## Series 150 through 180

**Integrated Mounting Capability** - All products come with #2-56 mounting screwholes.

**Series 173 Mounting Base (part number 173015)** - The Series 173 product is available with an upright base that allows 90° rotation about the cover.



## Other Mounting Methods

**Magnetic Base** - In some environments, quick and clean mounting and dismounting can be accomplished by using magnetic bases.

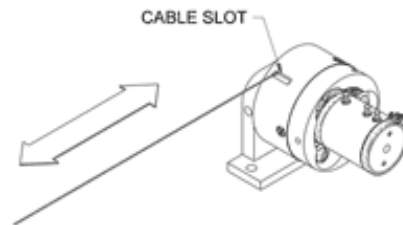
**Double-Sided Tape** - Double-sided tape provides a relatively secure and fast method of mounting the position transducers.

**Industrial Adhesives** - Adhesives can be directly applied to the rugged anodized aluminum cases and the application. This is particularly useful in a fast-paced test environment.

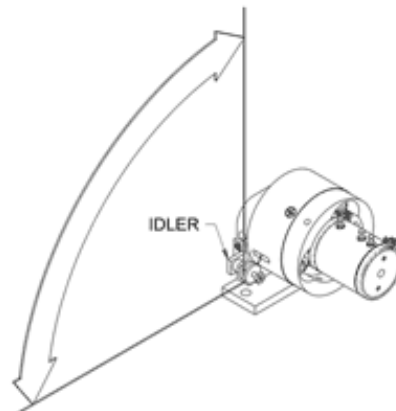
**Custom Mounts** - Custom mounts and configurations can be developed if your application has unique requirements.

## Accessories

**Cable Guide (part number 160045)** - Prevents the cable from departing the threaded cable drum. Recommended when straight cable motion cannot be guaranteed. Allows cable movement within a 20° cone, providing quick setup for three-dimensional movement applications such as suspensions. For Series 16X products only. See Figure 4.0.



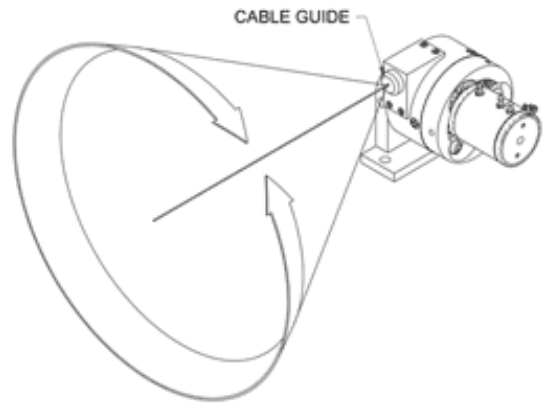
**Idler (part number 160022 or 161022)** - Compensates for off-center cable travel when non-linear motion is created at the cable point of contact. Compensates for up to 90° of off-center misalignment. For Series 16X products only. See Figure 4.0.



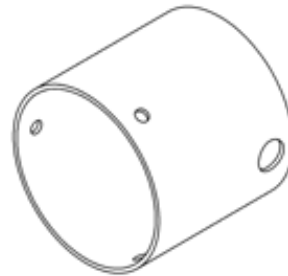
Note that the Cable Guide and Idler cannot be installed together (unless the Idler is mounted off the position transducer and being used as a pulley).



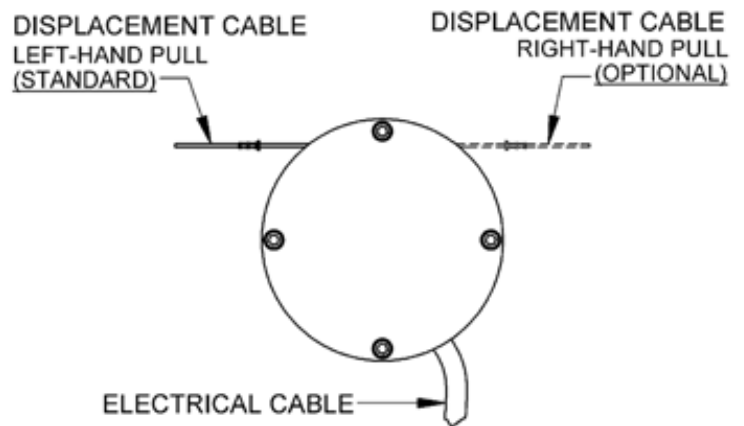
**Pulley** - An Idler or pulley can be used to remotely position the transducer in high-temperature areas as well as to allow measurement through conduits and similar inaccessible areas.



**Potentiometer Cover (part number 160060)** - Protects the potentiometer on Series 16X products in adverse environments.

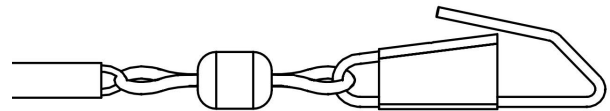


**Cable Pull** - Series 150, 173, 174, 175, and 180 products provide a choice of either left-hand or right-hand displacement cable pull that provides increased mounting flexibility.



## Displacement Cable Attachment

**Swivel (part number 805-5)** - Rotatable connector with easy-connect clasp



**Line Connector (part number 217)** - Non-rotatable connector with more rugged construction than the Swivel; minimum breaking strength exceeds the displacement cable.





**Crimped Ball (part number 160034)** - 1/8-inch (3.175-mm) or 3/16-inch (4.7625-mm) diameter stainless steel ball swaged onto displacement cable for placement into specialized fixture located on the application.



**Custom Connectors** - Unique application- specific connectors have been developed including magnetic, movable, and screw-in connectors.

**Locating the Swivel or Line Connector** - If you use the Swivel (part number 805-5) or Line Connector (part number 217) that comes standard with every Firstmark Controls position transducer, you will need to crimp the brass Eyelet (part number 160032) at the position of your choice. To crimp the Eyelet, loop the displacement cable through the Eyelet, through the Swivel or Line Connector, and then back through the Eyelet. Crimp the Eyelet using a 4-pronged electrical connector crimping tool or equivalent. See Figure 4.1 on prior page.

**NOTE:** If you need to cut uncoated displacement cable, you should anneal the cable with a flame at the cutting point to ensure the cable does not fray after cutting.

## Other Considerations

**Displacement Cable Construction** - The standard displacement cable used is of 7 x 7 stainless steel construction with a minimum breaking strength of 40 lbs. (178 N). It has a diameter of 0.018-inch (0.457 mm). A larger 0.027-inch (0.686-mm) diameter cable with 90-lb. (400 N) minimum breaking strength is available for applications using ultra-high cable tension (greater than 56 oz. (15.57 N)). This type of cable is used frequently in crash test applications.

**Synchros, Servos, and Encoders** - Historically, most automotive applications specify precision potentiometers as the sensing element. Note that standard and custom encoders, synchros, and servos may also be specified.

**Custom Designs** - If your application has unique requirements not met by our standard products, please contact us. We have extensive experience modifying existing products and developing new products to meet demanding requirements. Some examples include high-frequency-response displacement transducers for vehicle vibration measurement, low-profile units for racing suspensions, and custom signal conditioning for crash test instrumentation.

## More Information

To learn more about products and accessories not mentioned in this Application Note, visit the [Literature Room](#) or the [data sheet](#) for mounting bases and accessories

## Conclusion

If you have any questions not answered by this Application Note or would like to discuss your application, please contact us by phone, fax, or e-mail.

A representative list of ground vehicle and transportation applications where Firstmark Controls position transducers have been used:

- Passenger cars
- Rail-based transportation
- Utility vehicles
- Earthmoving equipment
- Light, medium, and heavy trucks
- Racing: Indy, NASCAR, Formula 1, rally, and others

- Bus and public transport
- Motorcycles
- Recreation vehicles
- Military vehicles
- Agricultural vehicles
- Monorails
- Snowmobiles and snow-moving equipment

## Additional Resources

- [Calculators](#)
- [Frequently Asked Questions \(FAQs\)](#)
- [String Potentiometer and String Encoder Engineering Guide](#)
- [Sensor Total Cost of Ownership](#)
- [Application Note for Aircraft/Aerospace](#)
- [Application Note for Draw Wire Transducer Accuracy](#)
- [Application Note for Motorsports](#)
- [Position Transducer Data Sheets](#)
- [Position Measurement & Control Archives](#)

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