Calibrations

1. Calibration before shipment:
Done at the factory with a calibration system. Calibrates shared force composition matrix and coordination transfer matrix. All the calibration is done with deadweights.

2. Periodic calibration
Periodic calibration has to be done at the A&D factory using a calibration system. All calibration is done with deadweights and a calibration certificate can be issued.

3. Periodic check at the vehicle
Sensor check can be done by jacking up the vehicle, lifting the WFS above the ground with the wheel, and confirming/checking the Fz.

DSP System

■AD7891 DSP system

The AD7891 DSP system supports a variety of applications with highly customized measurement and control.

- **High speed real-time processing**
  The two on-board processors perform separate functions to achieve high speed, real-time processing.
  - 1.5 GHz Celeron M CPU for model execution
  - 200 MHz SH4 CPU for user interfaces
- **Measurement, control, and simulation**
  Models made using MATLAB/Simulink and Stateflow can be executed on the AD7891, resulting in an optimal model-based calculation in real-time.
- **Combination of multiple I/O**
  AD7891 has 7 slots for the external I/O boards. I/O boards are selectable from the standard I/O board lineup according to the application demands.
- **Equipped with touchscreen**
  5.7-inch color TFT LCD (with backlight) touchscreen is provided for easy and flexible user interfaces.

Safety Warning!	●For proper use, read the instruction manuals carefully before use.

...Clearly a Better Value

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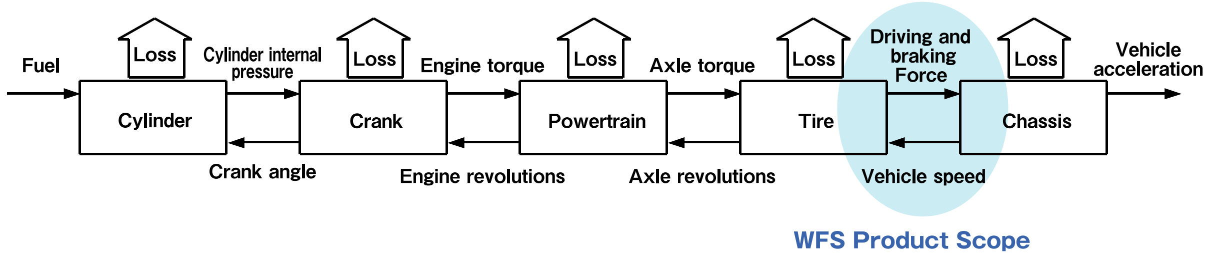
●Appearances and/or specifications subject to change for improvement without notice,
●Contents of this catalog last updated April 2011.
*WFS datasheet-ADCC-02-BP1-11402

WFS
Wheel Force Sensor

...Clearly a Better Value
A&D Company, Limited
http://www.aandd.jp

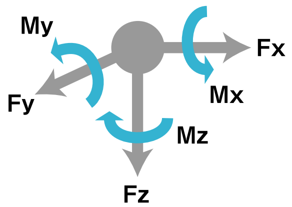
Introduction

Recent trends in the vehicle development have increasingly focused on improving the fuel consumption. This development is applied not only to powertrain development but also to the total vehicle performance, which includes analyzing the vehicle behavior in the real driving conditions. In order to pursue the fuel efficiency, there are demands for measuring how the vehicle is transferring the power generated from the engine/motor to real road surfaces in various driving conditions.
The Wheel Force Sensor (WFS) measures forces and torques with high accuracy at the vehicle's wheels, which is the vehicle element closest to the road.



Torque demand concept/energy flow model: Area of WFS measurement

The figure above shows an energy flow model of the powertrain system of the vehicle. The energy generated by the combustion engine is transferred to the tire and to the road to accelerate the vehicle. The most unknown area of this energy flow is the energy transfer of the tire and the road. Therefore, considering the total energy efficiency of the vehicle, investigation at the blue circle area under realistic conditions is essential. The blue circle area also has direct influences on the development of comfortable and safe driving. The WFS measures the torque and force of the blue circle area.



WFS(Wheel Force Sensor)

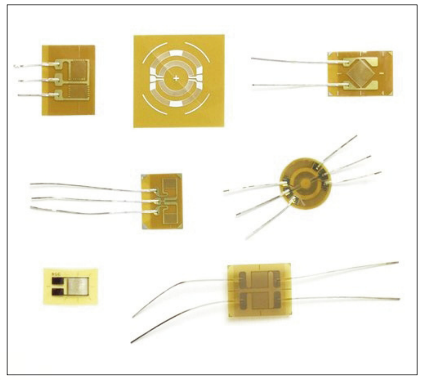
The WFS is designed to measure the 6 component forces of the wheel as near as possible to realistic driving conditions. The sensor design achieved both a low weight (sensor unit total weight: 3.6kg) and high stiffness. It also solved many technical issues, such as thermogenic effects under driving conditions, in order to provide high quality measurement data.

The shared force detection method is applied to the WFS and introduces model-based calculation with the DSP (digital signal processing) system. These technologies are applied to the WFS to precisely and independently extract 6 component forces from many types of physically measured data.
In order to apply the shared force detection method, A&D has developed a 6-arm-architecture shear beam spring element and a 4-element shear strain gauge to compose ideal shared force detection bridges. Moreover, with this gauge, ideal temperature characteristics were achieved. Therefore, the WFS has high level of measurement robustness at various driving conditions.

DSP System

Force sensing and supporting technologies

■Strain gauge



A strain gauge is attached to the spring element, which deforms with applied forces and moments, and detects the strain of the spring element as electrical resistance change. Very thin metal foil is used as the material of strain gauge, which is called a foil gauge. Metal foil has excellent and robust sensing characteristics.
At A&D, in order to guarantee the quality of the sensors, strain gauges for balance products and load cell products for industry use are designed in-house for manufacturing. Therefore, optimized strain gauges for the spring element architecture can be designed in order to extract the maximized characteristics of the spring element.
For balance products, more than 1/6,000 of measurement robustness is required. Therefore, along with strain gauges, adhesive development, temperature compensation and analog/digital conversion technologies are also totally developed at A&D in-house.
With A&D products, the technologies cultivated for load cell and balance products are fully utilized in the WFS and 6 component force sensors, and therefore can offer highly robust and highly accurate measurement data.

■Single-axis strain and shear strain

Strain can be divided into two types. One is single-axis strain generated from tension, compression or bending, and the other is shear strain generated from torsion or shearing force.
Shear strain is generated from a pair of strains, which are orthogonal to each other. Therefore, generally two single strain gauges displaced at 90 degrees (a 2-element gauge) are used as the strain detection gauge.
For the WFS and 6 component force sensors, more advanced 4-element gauges are applied and realize ideal shared force detection and temperature characteristics.

■A&D's spring element and strain gauges

Shear beam structure

In A&D's force sensors, shear beams are used, which can minimize deflection against the applied force. Therefore, the sensor is designed to be as stiff as possible. Because of the small deflection, the senor uses the elastic characteristics of the material to a significant advantage in achieving ideal linearity, hysterisis and repeatability
Shear beams at the spring element are designed to orthogonalize the necessary shared force and other forces. This architecture avoids detection of unnecessary forces and detects only the necessary shared forces at the shear strain gauges. This approach realizes ideal spring element characteristics.

Shear strain gauge

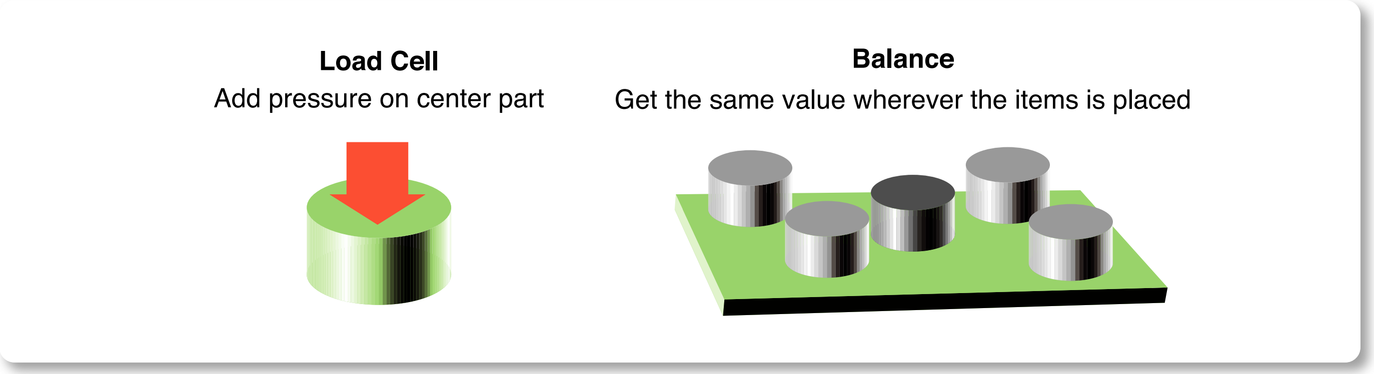
A 4-element shear strain gauge is used for the strain gauge. This bridge circuit structure is designed to minimize the detection of unnecessary forces and detects pure shear strains as much as possible.
Also, the 4-element shear strain gauges compose the bridge circuit at the inside of one sheet of the strain gauge. Therefore, relative temperature coefficients at each element can be extremely small. This enables very robust temperature characteristics, including dynamic temperature change.

Balance technology

Moment cancellation and shared force composition technology

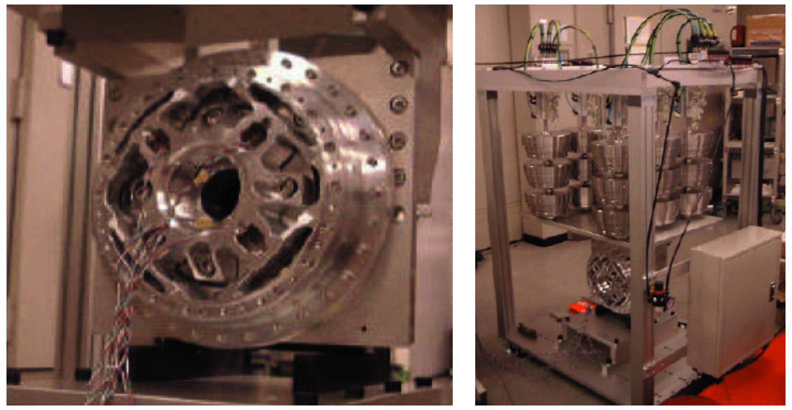
In balance products, there is a measurement plate to support the item under the measurement. The balance is tuned to show exactly the same measurement result regardless of where the item is placed on the plate. This requires cancellation of the moments.

For a small-sized balance, the cancellation of the moments is achieved by modifying the shape of the load cell. On the other hand, for a large-sized balance, 4 to 8 load cells are used and a balance computer calculates the shared forces of the load cells in order to cancel out the moments.



Modeling technology

A model-based calculation method is applied to cancel out the crosstalk effect from the measurement, and calculates the 6 component forces accurately from the detected shared forces. Cancellation of crosstalk effects is done with model-based calculation, which includes complex matrix calculations such as shared force composition matrix and coordination transfer matrix. The calibration of WFS is done by defining the parameter values of these matrixes.

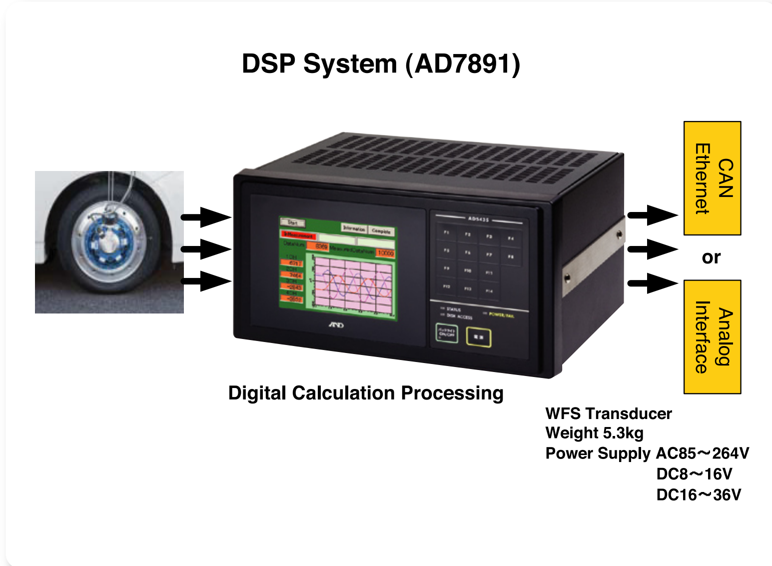


Calibration System

This new type of calibration system enables modeling of the error and produces a calibrated shared force composition matrix. The calibration system uses more than 1/50,000 class deadweight and applies 6-component force load at 3 dimensions simultaneously to the sensor. Therefore, the calibration system is able to analyze the relationship of loaded forces and shared forces and thus can create a sensor error matrix model. The inverted sensor error matrix model is applied to the shared force composition matrix and creates a calibrated shared force composition matrix.

DSP technology

Realtime digital signal processing (DSP) platform

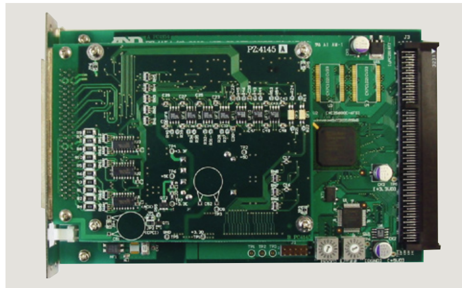


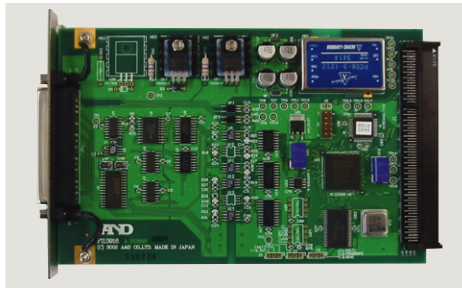
The Realtime DSP platform is developed for hardware in the loop systems (HILS) and rapid prototype controllers (RPT), which are widely used in vehicle powertrain development. The DSP platform has high computing ability to process large simulation models in realtime. This technology is applied to A&D's force measurement sensors.

Conventional analog-sensor amplifiers cannot apply complicated calculation processes. The main concept difference of A&D's 6 component force sensors is that measured analog signals are directly converted to digital signals and the signals are processed by the DSP system. Complicated model calculation, such as the shared force composition matrix and coordination transfer matrix calculation, is done within 1 ms (1 kHz). This high-speed calculation can only be applied with a high-speed DSP system. Because of this DSP technology, highly sophisticated data calculation to achieve highly accurate and robust measurement is possible. This is the reason the WFS is called a model-based sensor (MBS).

Analog to digital conversion technology

Since the force-sensing signal is directly converted to a digital signal, the electronic circuitry of sensor unit can be minimized. This avoids unnecessary electronic noise coming into the measurement. However, the raw detection signal from the shear strain gauge is small (mV order) in order to achieve high resolution. A&D's A/D converter achieves nV order conversion.

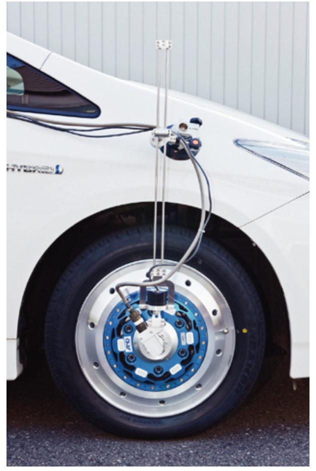


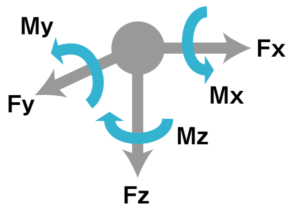


WFS

■Spring element architecture

A 6-arm architecture (shear beam) and 4-element shear strain gauges are introduced to the WFS. This architecture achieves highly robust measurement and high durability.
The largest temperature influence to which the WFS is exposed is the heat generated from breaking coming from the hub adapter.
The arm architecture with the shear beam allows orthogonalization of the material heat expansion direction and shared force detection direction. This arm design physically isolates the major temperature effects from the measurement. All of the strain gauges of WFS are 4-element shear strain gauges. They have very robust temperature characteristics and are designed to minimize the detection of unnecessary forces and detect only the forces valuable for the measurement. Also, the shear beam maximizes the stiffness of the spring element, which provides the sensor with highly accurate measurements and high durability.





■Shared forces and canceling crosstalk effects

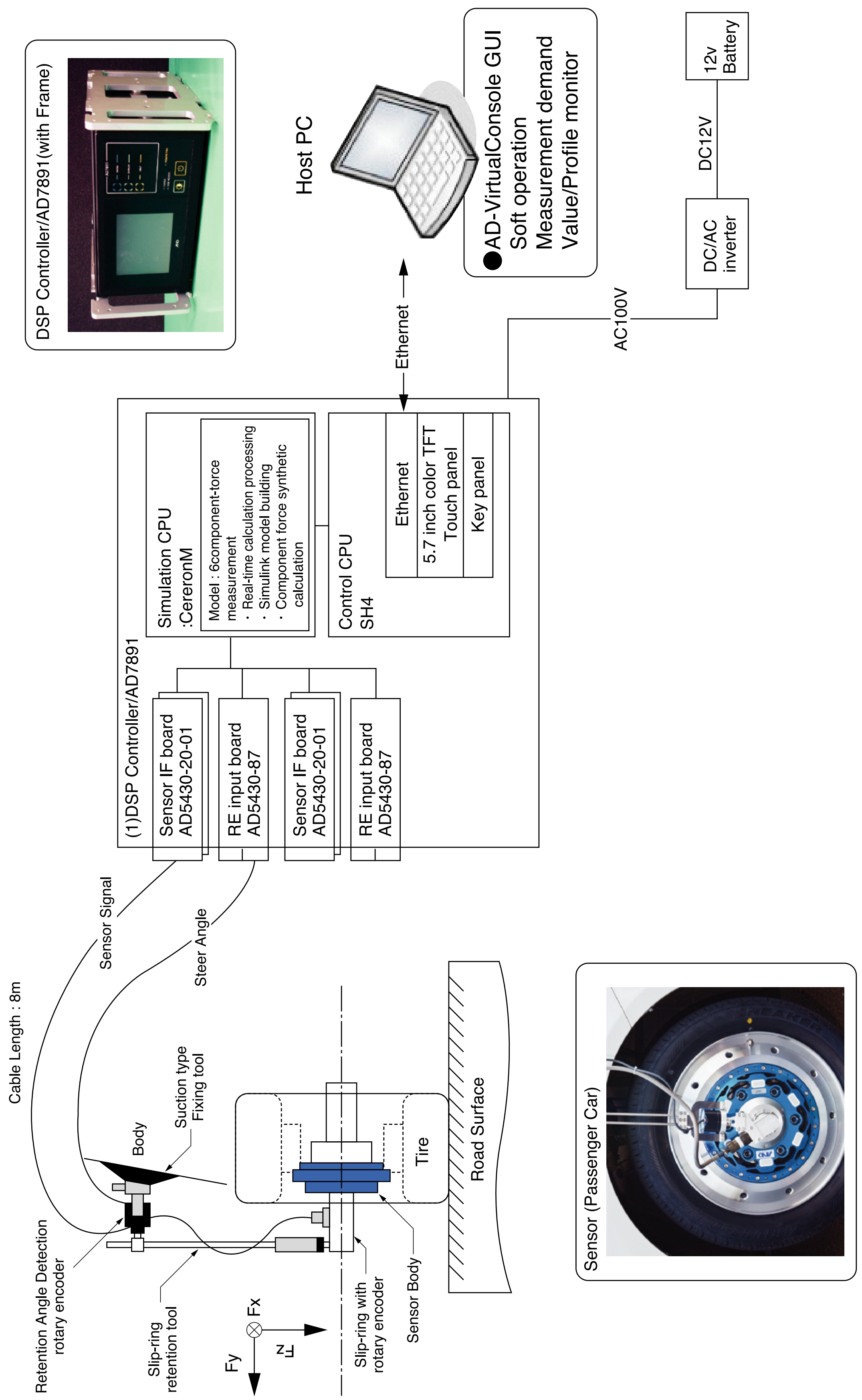
Very similar to the balance solution, 12 shear strain gauges are applied to the spring element architecture. Therefore, 12 shared forces are detected with high accuracy and the 6 component forces are composed independently by canceling crosstalk. Crosstalk cancellation is done at the signal processing level in the DSP system. Therefore, WFS receives minimum influence from crosstalk effects.

■Model-based sensor

The WFS uses the AD7891 realtime DSP platform for sensor signal conditioning where complex model calculation, such as shared force composition matrix and coordination transfer matrix calculation, is done within 1 ms (1 kHz). It also has a high-speed/high-precision A/D converter (nV order) to measure the physical values precisely without inviting unnecessary electric noise.

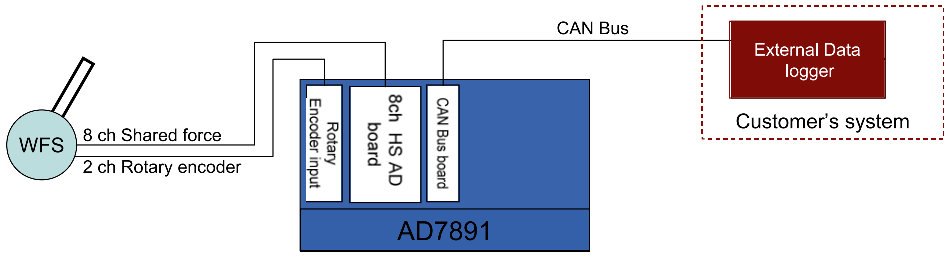
The WFS is not a simple force measurement sensor. Sensor itself is designed to detect the desired force direction with minimum parasitic noise. The sensor intrinsically measures physical forces correctly by having high sensitivity for the necessary forces and minimizing the sensitivity for unwanted forces. Complex model-based calculations are applied in the high-speed DSP system to cancel out the crosstalk effects. It is not a compensation method, but a canceling method. Therefore, it achieves excellent measurement robustness. The WFS is highly sophisticated measurement equipment that can deliver high precision and robust force measurement data.

WFS Measurement Configuration



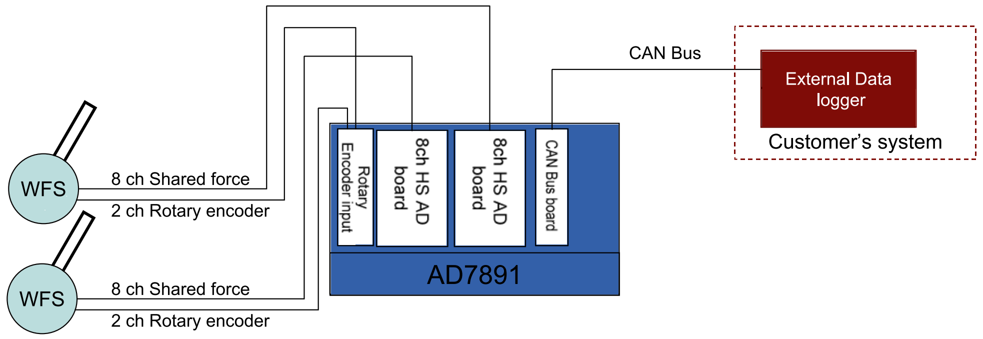
WFS System Configuration (1)

Standard Configuration 1 Wheel

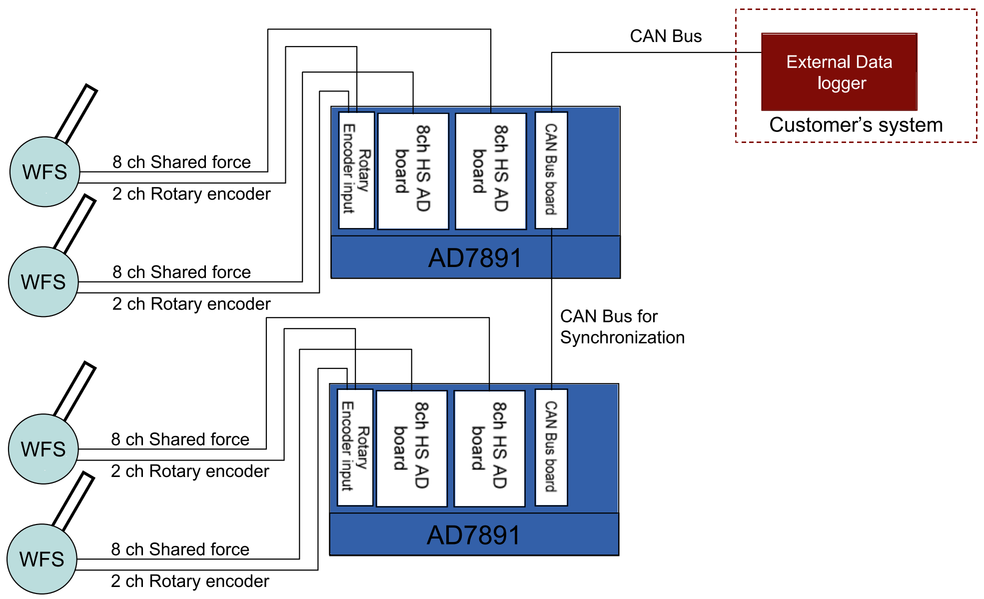


Digital Signal: CAN Bus
Sensor Output Signal : 7ch
Fx (N), Fy(N), Fz(N), Mx(Nm), My(Nm), Mz(Nm), Speed (rad/sec)

Standard Configuration 2 Wheels

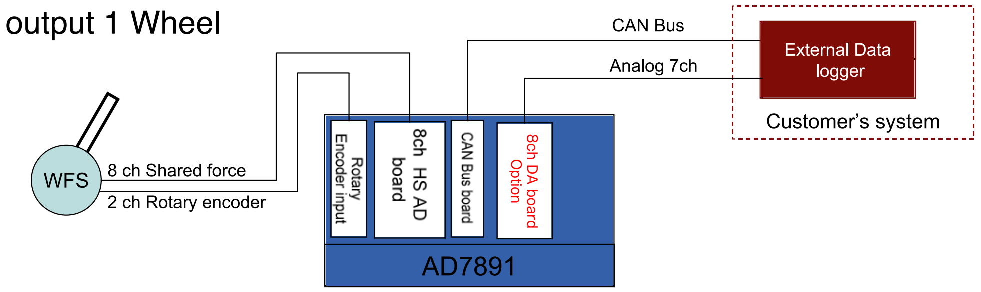


Standard Configuration 4 Wheels



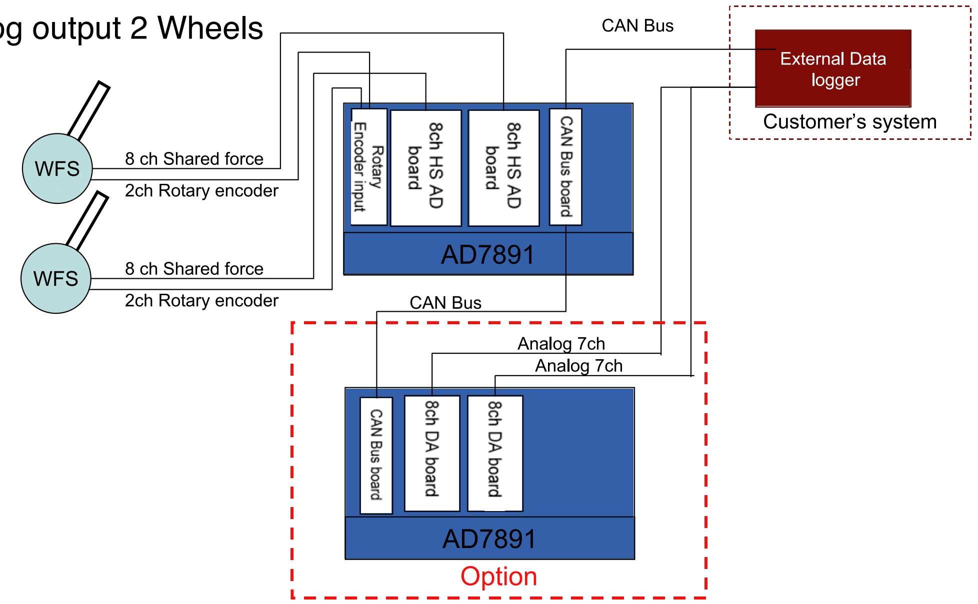
WFS System Configuration (2)

Option Analog output 1 Wheel

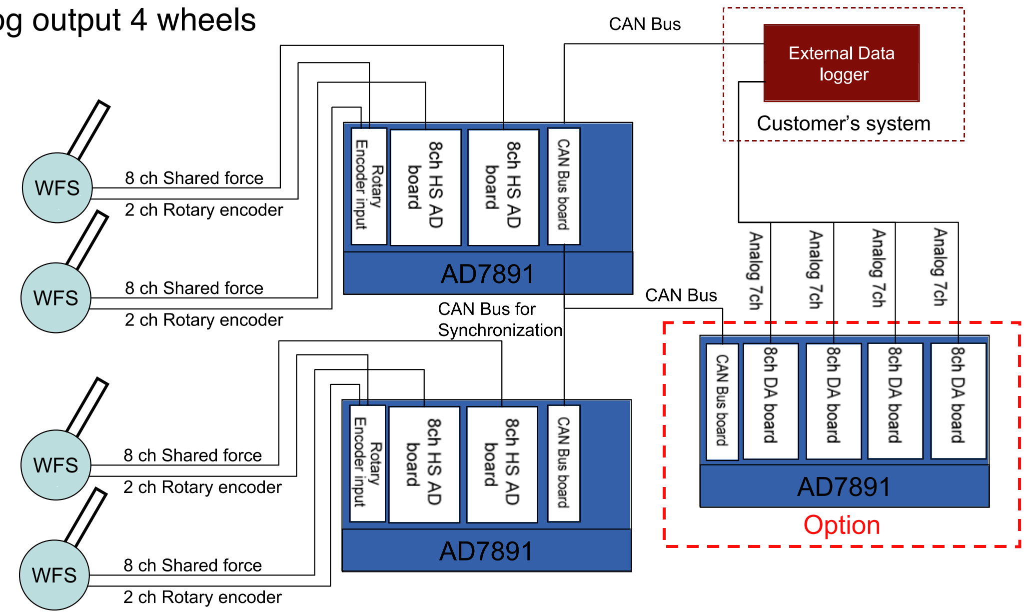


Digital Signal: CAN Bus
Sensor Output Signal : 7ch
Fx (N), Fy(N), Fz(N), Mx(Nm), My(Nm), Mz(Nm), Speed (rad/sec)

Option Analog output 2 Wheels

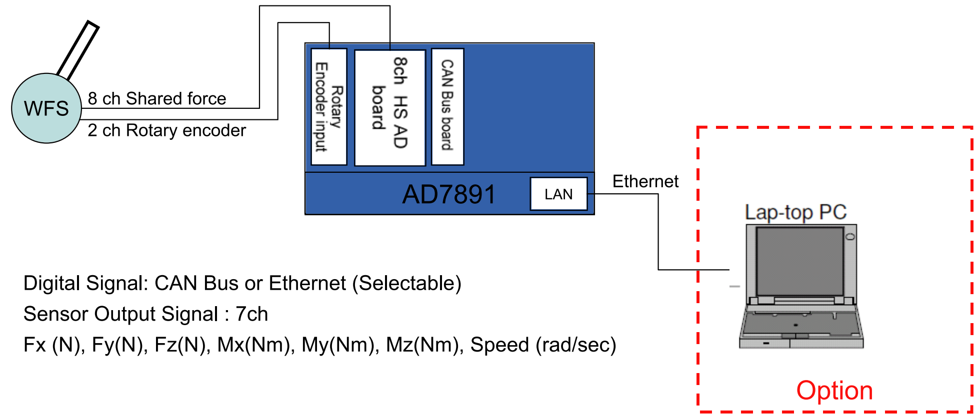


Option Analog output 4 wheels

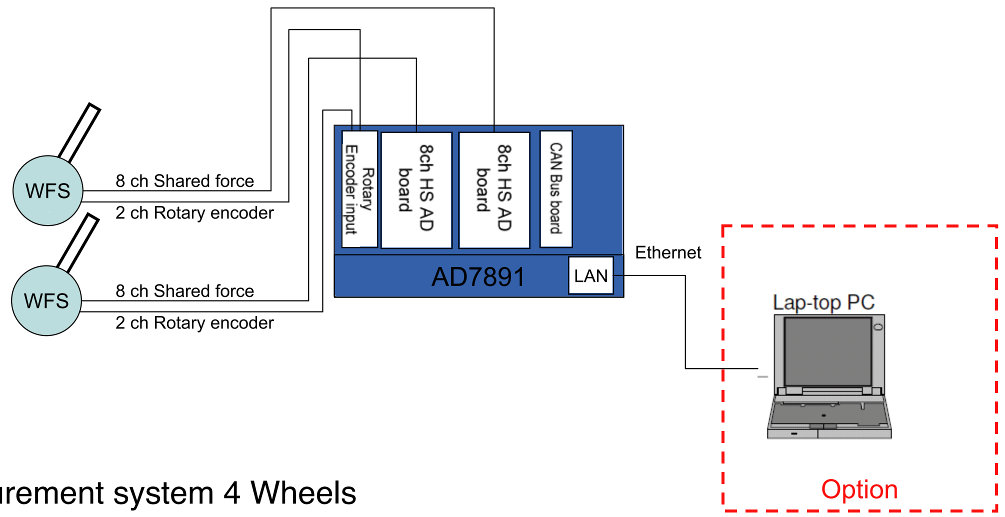


WFS System Configuration (3)

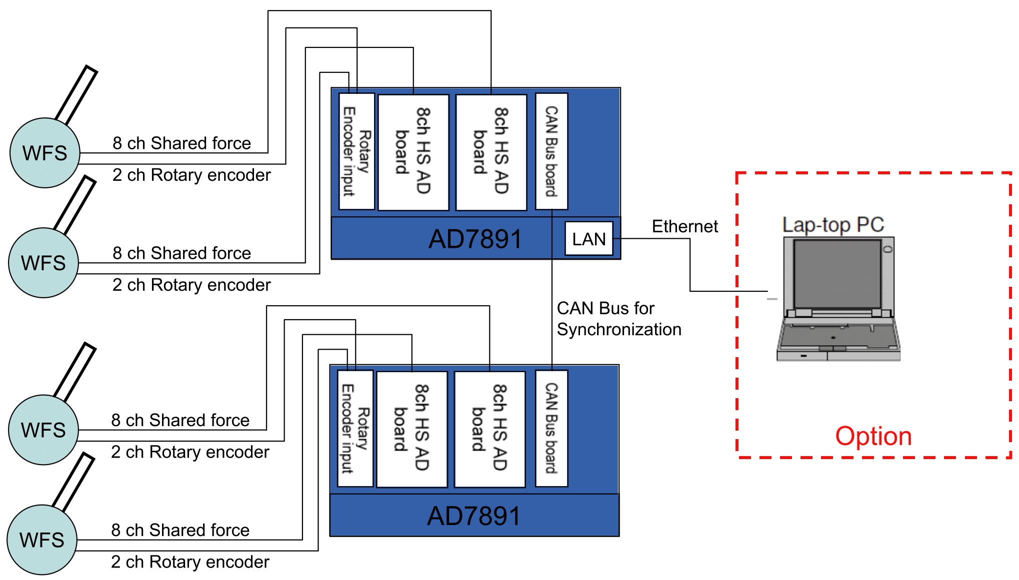
Option Measurement system 1 Wheel



Option Measurement system 2 Wheels



Option Measurement system 4 Wheels



WFS Specification

Sensor Specification

Item	Specification	Note
Method	Shared force detection method	
Coordinate direction	X: Driving/braking Y: Axle Z: Gravity	
Fx	±24 kN	
Fy	±15 kN	
Fz	±24 kN	
Mx	±4.5 kNm	
My	±4.0 kNm	
Mz	±4.5 kNm	
Acceptable rim size	14-17 inches	In the case of other customer needs, please contact us.
Acceptable hub size	4H PCD100 5H PCD100/114.3	In the case of other customer needs, please contact us.
Acceptable offset	–	Depends on customer's specification request.
Total error	±0.1%FS	Including non-linearity, hysteresis and repeatability
Modulation error	±0.5%FS	
Sensitivity	Force: 1/4000 FS Moment: 1/2500 FS	
Angular resolution	1024/360 degrees	
Speed	2000 RPM	
Temperature guarantee range	-20 to +80℃	Sensor
Operating temperature range	-40 to +100℃	Sensor
Zero temperature effect	0.005%FS/℃	
Span temperature effect	0.005%/℃	
Wet/dust condition	Equivalent to IP65	
Weight	3.6 kg (Sensor + slip ring) 22.9 kg (Sensor + slip ring + hub adapter + bolt/nut + 16x6.5 inch rim + 215/60R16 tire)	

WFS Measurement Specification

Item	Specification	Note
●Measurement / calculation		
6-component force calculation	Digital model calculation	
Calculation sampling	1 kHz	
Measurement item	X-force Fx (N), Y-force Fy (N), Z-force Fz (N), X axis moment Mx (Nm), Y axis moment My (Nm), Z axis moment Mz (Nm), Wheel speed Vr (km/h),	The wheel speed is calculated by input of the tire radius.
Ripple correction	ON/OFF Uniformity of tire/wheel/sensor is calculated and corrected.	
Low pass filter	3rd Butterworth Possible to select the cut-off frequency (1/2/5/10/20/50/100/200/500Hz)	
●Output signal		
Output signal interface	CAN bus/Ethernet/analog (option)	Outputs all measurement item.
●Display		
Display Item	Number display: Fx, Fy, Fz, Mx, My, Mz, Vr Trend display: Fx, Fy, Fz, Mx, My, Mz, Vr	
Statistic processing	Value Display: average, max, min. of each item	
Auxiliary	External input measurement value (option)	
●DSP system		
Name	AD7891	
Dimension	318 mm(W)×168 mm(H)×230 mm(D)	
Weight	Approximately 10 kg	Including handle.
Power supply	AC 85-264 V or DC 12 V (6-18 Vpp) or 24 V (16-36 Vpp)	Must be selected.
Power consumption	100 VA (Both AC and DC)	
Operational temperature range	5 to 40˚C	
Operation humidity range	5 to 90% RH	No condensation.
● Host PC (Option)	OS: Windows XP and later (English and Japanese versions)	
Data storage sampling	Select from 1/2/5/10/20/50/100/200/500/1000 Hz	
Data storage	HOST PC specified holder	
Save file form	Dedicated binary	Possible to convert to CSV using data viewer.
Measurement command	Start: Software GUI, Stop: Software GUI	
●Data viewer (PC Software)	Option	PC application software.
Display	Display the saved data file as a specified time-line graph.	
Cut-out	Possible to set parameters arbitrarily for data reading and export.	
Export	Possible to export as CSV file.	

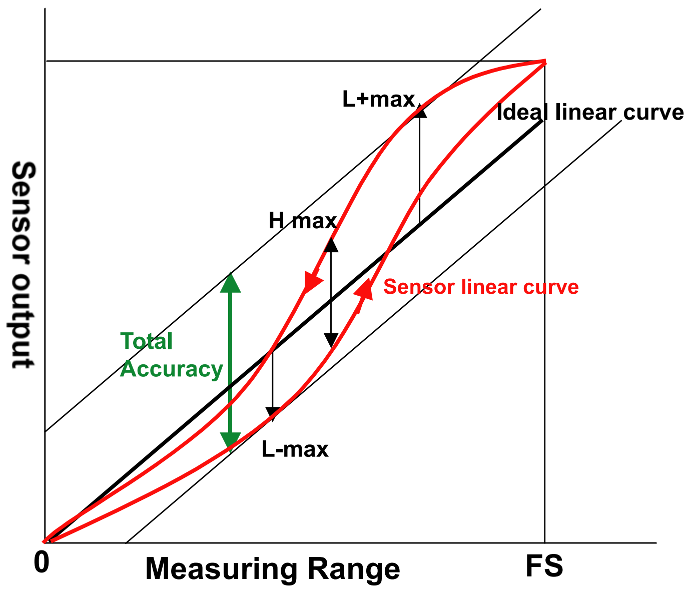
Total accuracy and sensitivity

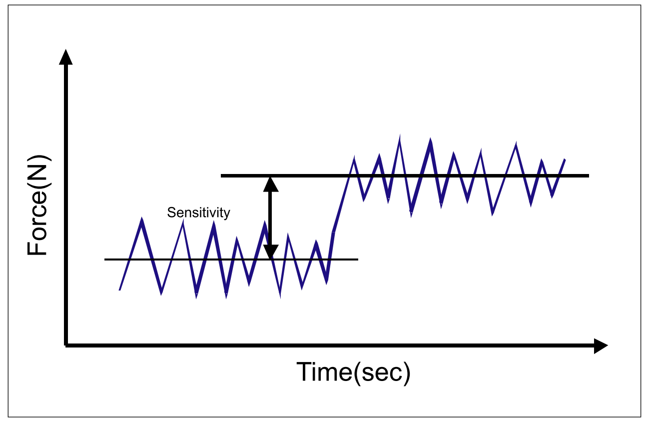
●Total accuracy

Total accuracy is defined by the figure below.
Total accuracy includes linear error and hysterisis error.
This shows the absolute error of the sensor.

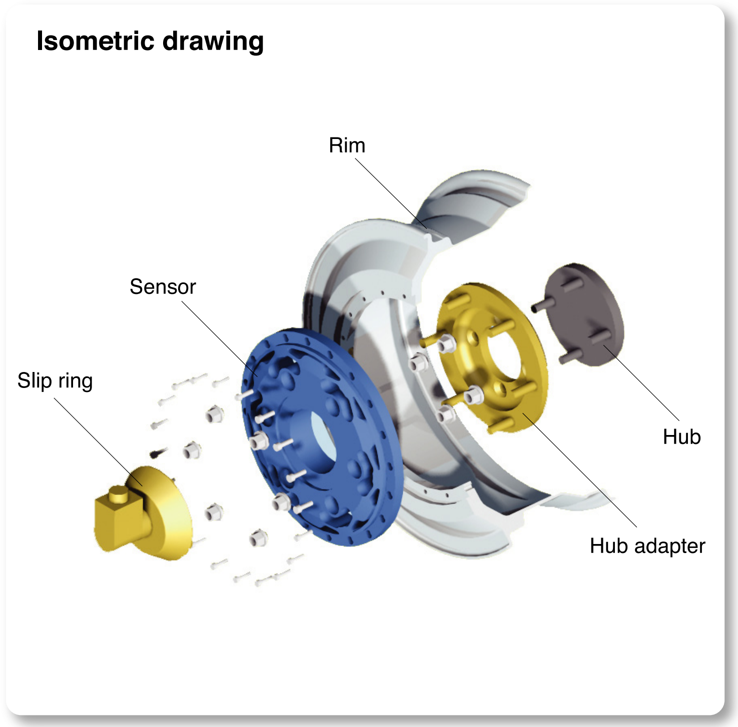
●Sensitivity

Sensitivity is the minimum observable detection force signal change of the sensor as shown in the image below. (It is not the digital resolution.)

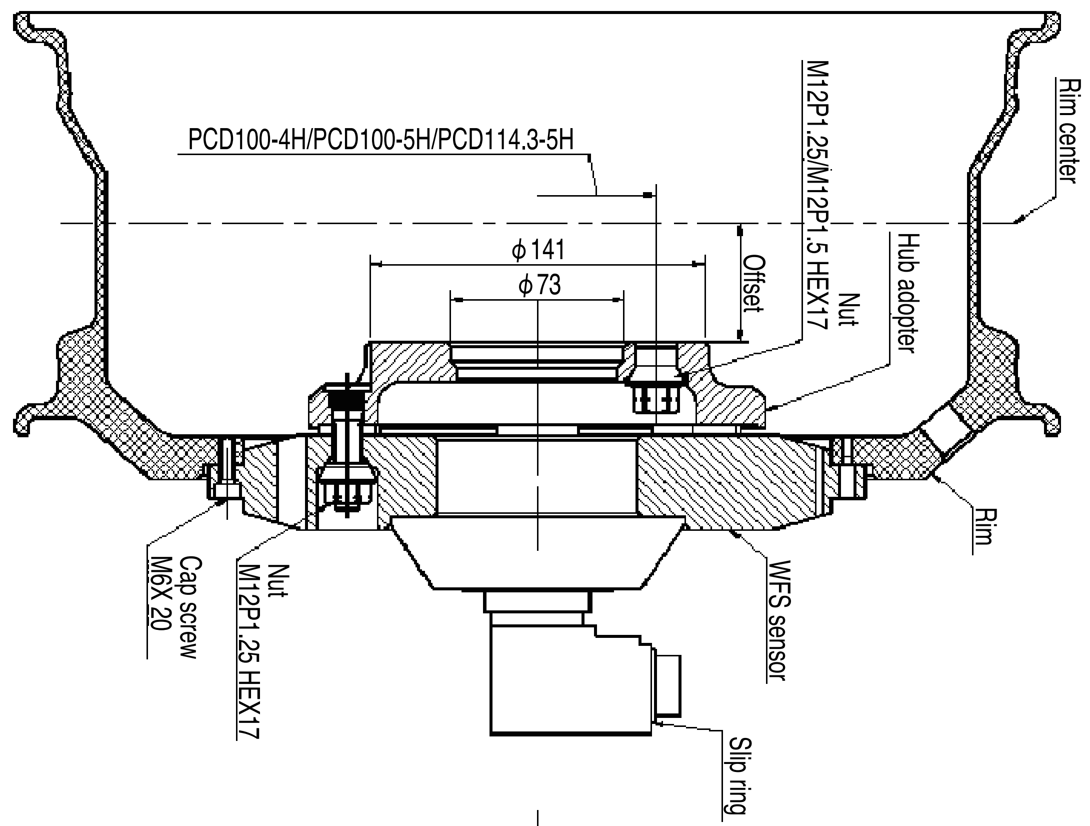


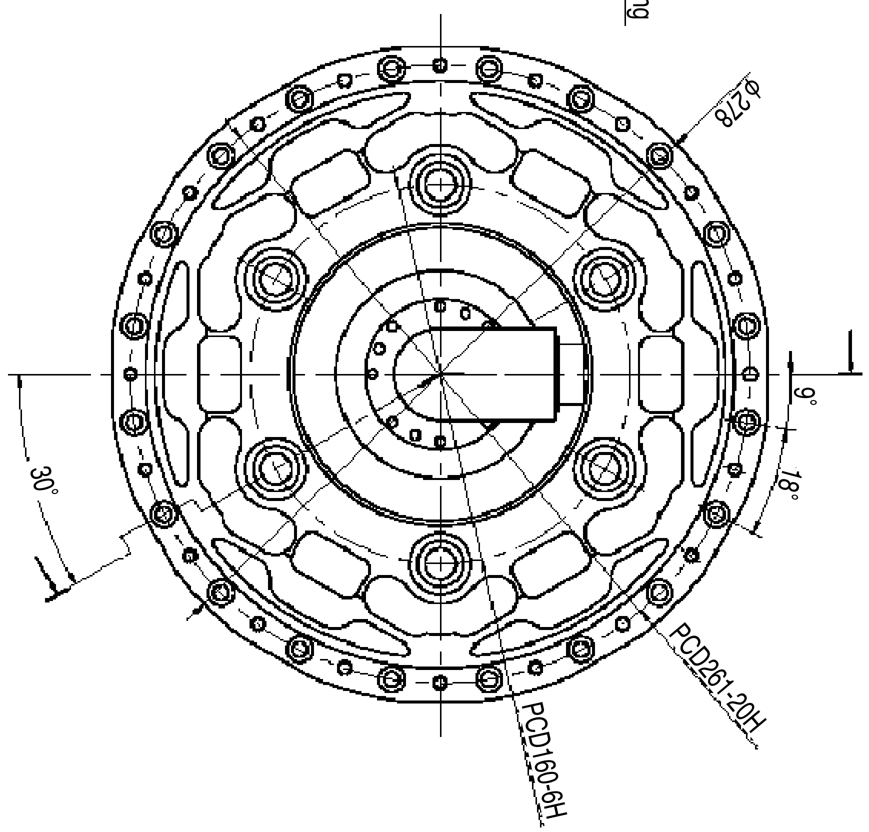


Overview of sensor and support tool



Overview for 6 Component Force Sensors





Standard Wheel List

Rim		Hub Adapter			Offset			
Rim Size	Rim Part Number	PCD-H	Attachment Method	Hub Adapter Part Number	No Spaser	Spacer:5mm	Spacer:10mm	Spacer:20mm
14×5.5	D307259-10	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+45	+40	+35	+25
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+45	+40	+35	+25
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+45	+40	+35	+25
15×5.5	D307259-11	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+50	+45	+40	+30
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+50	+45	+40	+30
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+50	+45	+40	+30
15×6,0	D307259-04	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+50	+45	+40	+30
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+50	+45	+40	+30
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+50	+45	+40	+30
15×6.5	D307259-03	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+50	+45	+40	+30
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+50	+45	+40	+30
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+50	+45	+40	+30
16×6.0	D307259-05	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+50	+45	+40	+30
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+50	+45	+40	+30
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+50	+45	+40	+30
16×6.5	D307259-01	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+50	+45	+40	+30
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+50	+45	+40	+30
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+50	+45	+40	+30
17×6.5	D307259-09	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+50	+45	+40	+30
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+50	+45	+40	+30
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+50	+45	+40	+30
17×7.0	D307259-06	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+50	+45	+40	+30
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+50	+45	+40	+30
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+50	+45	+40	+30
17×7.5	D307259-12	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+40	+35	+30	+20
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+40	+35	+30	+20
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+40	+35	+30	+20
17×7.5	D307259-02	100-4H	M12 Dedicated Nut P1.25/1.5	D308153	+55	+50	+45	+35
		100-5H	M12 Dedicated Nut P1.25/1.5	D308155A	+55	+50	+45	+35
		114.3-5H	M12 Dedicated Nut P1.25/1.5		+55	+50	+45	+35