

Pedals Instrumented with Six-Component Force-Torque Sensors and Encoders



1. INSTRUMENTED PEDALS DESCRIPTION

The instrumented pedals are adapted for measuring the forces generated by the cyclist during pedaling. The three Force components (F_x , F_y , F_z) and three Moment components (M_x , M_y , M_z) are thus measured.

The measurement of the forces exerted on the pedals became essential in the analysis of cycling tests. This measure quantifies the cyclist pedaling technique in terms of effectiveness, efficiency and equity of symmetry between the right and left lower limb.

In addition, these instrumented pedals are essential for the analysis of muscle forces generated by the cyclist. These measures combined with those of the angular position of the cranks allow calculation of muscle and joint modeling efforts.

1.1. Definition

Each pedal is equipped with a six-component force-torque sensor that measures the applied mechanical torque-effort components. It quantifies the three components of the Force (F_x , F_y , F_z) and the three components of the Moment (M_x , M_y , M_z).

1.2. Functioning principal

The sensor consists of a mechanical structure which is strained under the action of an effort applied on its upper side. Extensometry is the technology used to measure this strain and to infer from a linear relation the effort components.

The mechanical structure consists of a rigid upper and lower part and six bendable beams linking these two parts. The beams are equipped with strain gages.

The strain gages number and their location have been chosen in order to constitute 6 (complete) Wheatstone full-bridges. Supplied with a stabilized reference voltage, each bridge provides a measurement voltage which is amplified by an instrumentation amplifier.

The 6 voltages obtained allow calculating the 6 effort components as follows:

$$\mathbf{F} = \mathbf{G}\mathbf{U}$$

With

- \mathbf{F} the torque effort: (F_x , F_y , F_z , M_x , M_y , M_z)^t which components are expressed in N for the forces and in Nm for the moments.
- \mathbf{U} the vector gathering the six voltage measurements expressed in Volt (U_1 , U_2 , U_3 , U_4 , U_5 , U_6)^t.
- \mathbf{G} the 6X6 calibration matrix.

1.3. Presentation of the measuring chain different element

The measuring chain consists of:

- a) A set of two pedals equipped with
 - Six-force-torque sensor
 - Scancon encoder
 - 2m cables LEMO FGG.0B.312 (at sensor ends)/ LEMO FGG.1B.314 connector
- b) A RLS crank encoder with one 2m cable LEMO PHG.0B.305/ LEMO FGG.0B.305 to connect to the junction box or any other connector.
- c) A junction box gathering all cables at one end and a VHDCI at another end to connect either to a PC or to a PDA equipped with I-CrankSet software interface. The PDA allows making outdoor measurements.

2. TECHNICAL CHARACTERISTICS OF I-CRANKSET

Choosing I-CrankSet version can be done according to:

- Bike type
- Maximal vertical force F_z
- Clipless system

| ICS version | Bike | Maximal Force | Clipless System |
|-------------|-----------------|------------------|--|
| ICS-MB | Mountain - BMX | $F_z \leq 3500N$ | Shimano SPD |
| ICS-RM | Road - Mountain | $F_z \leq 2000N$ | Look Keo2 – Shimano SPD – Shimano SPD-SL |
| ICS-M | Mountain | $F_z \leq 1500N$ | Crank Brother |

2.1. Force-Torque Sensor Technical Characteristics

PEDAL DIMENSIONS

| ICS version | Height | Diameter | Weight |
|-------------|--------|----------|--------|
| ICS-MB | 45.2mm | 84mm | 450g |
| ICS-RM | 42.2mm | 84mm | 400g |
| ICS-M | 42.0mm | 84mm | 500g |

SENSOR NATURAL FREQUENCY

| | F_x | F_y | F_z | M_x | M_y | M_z |
|--------|-------|-------|-------|-------|-------|-------|
| ICS-MB | 13 | 13 | 13 | 13 | 13 | 13 |
| ICS-RM | 15 | 15 | 15 | 15 | 15 | 15 |
| ICS-M | 5 | 5 | 5 | 5 | 5 | 5 |

SIMULTANEOUS MEASURING RANGE (MR)

| | F_x | F_y | F_z | M_x | M_y | M_z |
|--------|-------|-------|-------|-------|-------|-------|
| ICS-MB | 1200 | 1200 | 4700 | 90 | 90 | 40 |
| ICS-RM | 250 | 250 | 2000 | 40 | 40 | 25 |
| ICS-M | 250 | 250 | 2000 | 40 | 40 | 27 |

The sensor consists of six 5000 ohms strain gages. The above measuring range is the sensor maximum load when the effort is multi-components. These measuring ranges could clearly be higher when the loads are mono-components. Thus, we obtain the following characteristics:

MEASURING RANGE BY COMPONENT: By stimulating only one component at a time

| | F_x | F_y | F_z | M_x | M_y | M_z |
|--------|-------|-------|-------|-------|-------|-------|
| ICS-MB | 6470 | 6110 | 20734 | 185 | 210 | 230 |
| ICS-RM | 2830 | 2710 | 9060 | 90 | 100 | 110 |
| ICS-M | 2565 | 2297 | 6115 | 96 | 111 | 162 |

| | | |
|--------------------------------|---|--------------------|
| Precision | Combined error (linearity and hysteresis) | 1 % MR |
| | Crosstalk between the components | 1.5 < % MR |
| Electronic Conditioning | Integrated | |
| Channel number | 6 | |
| Output voltage range | ±10V | |
| Power Supply | Voltage range (V) | 4.5–5.5V |
| | Current (A) | 0.090 |
| Temperature | Operating range | -20...+70 °C |
| | Temp. Shift span | 0.0020% of M.R./°C |
| | Temp. Shift zero | 0.0075% of M.R./°C |
| Altitude | <2000m | |
| Humidity | 10-90% | |
| Index Protection | IP 54 | |



Clipless system: **LOOK KEO 2**



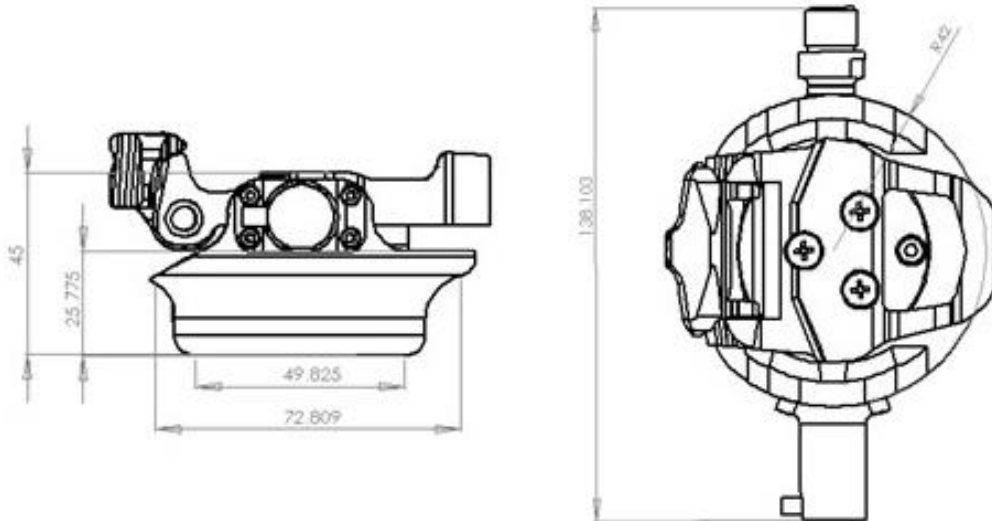
Clipless system: **SHIMANO SPD-SL**



Clipless system: **SHIMANO SPD**



Clipless system: **CRANKBROTHER**



2.2. Encoder Technical Characteristics

| Pedal encoder | | Crank encoder | |
|------------------|-----------------|------------------------|-----------------|
| Diameter | 16 mm | Magnetic sensor | |
| Height | 20 mm | Length | 36mm |
| Mass | 15 g | Width | 13 mm |
| Precision | 5000 pulses/rev | Magnetic ring | |
| Output | A, B, Z | Diameter | 75.4 mm |
| | | Height | 10mm |
| | | Precision | 6000 pulses/rev |
| | | Output | A, B, Z |

3. CONNEXIONS

3.1. Force-torque sensor connections

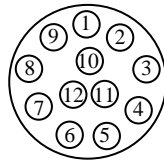


The output/input connector on the force-torque sensor is a 9 pins LEMO connector corresponding to the 6 measuring channels, (related to) their signal ground and to two power conductors. The all sensor connectors and cable are described below:

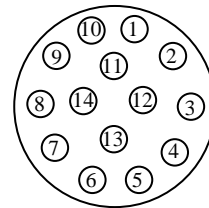


LEMO EGG.0B.312.CLL

Sensor



LEMO FGG.0B.312



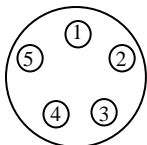
LEMO FGG.1B.314

Cable

The 5V supply voltage can be provided by a USB port, a DAQ-Card or an external power supply. If you need an adapter specific to your material of acquisition, please contact us.

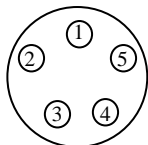
3.2. Crank Encoder connection

The crank encoder connector and cable are described below:

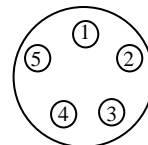


LEMO FGG.0B.305

Encoder



LEMO PHG.0B.305



LEMO FGG.0B.305

Cable

3.3. Junction box

The junction box allows the centralization of all the sensors to transmit their signals on a DAQ-Card.



The 68 pins-VHDCI connector is compatible with the NI DAQ-Card X, M, E series.

For the **E series**, digital encoder signals are converted to analog (U pedal L, U pedal R, U crank) to be acquired and synchronized with the analog signals of force sensors.

For the **M series**, only the digital crank encoder signals are converted to analog. The left and right pedals encoder signals are acquired directly through two counter inputs present on all the M series DAQ-Card.

For the **X series**, digital encoder signals are acquired directly through the three counter inputs present on all the X series DAQ-Card. DAQ-Card M and X series are always preferred because counter inputs allow not to decrease the encoder resolution.

3.4. Switching on voltage

In order to maintain the sensor integrity, it is highly recommended to connect the whole sensor outputs (Signal mass, V1, V2, V3, V4, V5, V6) to your instrumentation of acquisition before connecting to the power supply.

The power supply of force-torque sensors should imperatively be between 4.5V and 5.5V. Two components located at the conditioning card input protect the sensor of transitional overvoltage and overcurrent.

4. MEASURE, ACQUISITION AND PROCESSING

4.1. Adjustment of the zero balance

The adjustment of the zero balance is performed during the mounting of the instrumented pedal. This setting is obtained from six trimmers integrated into each sensor. They are no longer accessible after the complete installation of the pedal.

We therefore recommend performing a digital offset before calculating forces whose method is presented below.

4.2. Efforts calculation

The 6 components of the efforts in the sensor reference location are obtained by the matrix product:

$$F = GU$$

With

- **F** the torque effort: (Fx, Fy, Fz, Mx, My, Mz)^t which components are expressed in N for the forces and in Nm for the moments.
- **U** the vector gathering the six voltage measurements expressed in Volt (U1, U2, U3, U4, U5, U6)^t
- **G** the 6X6 calibration matrix.

Left Pedal Matrix with Shimano SPD or Look Keo 2 or Shimano SPD-SL Adapter (Example)

| | | | | | |
|----------|----------|----------|----------|----------|----------|
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

Right Pedal Matrix with Shimano SPD or Look Keo 2 or Shimano SPD-SL Adapter (Example)

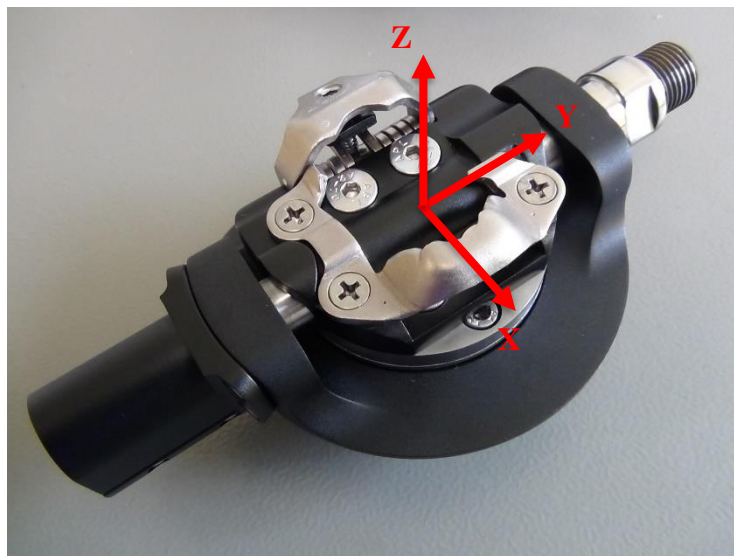
| | | | | | |
|----------|----------|----------|----------|----------|----------|
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

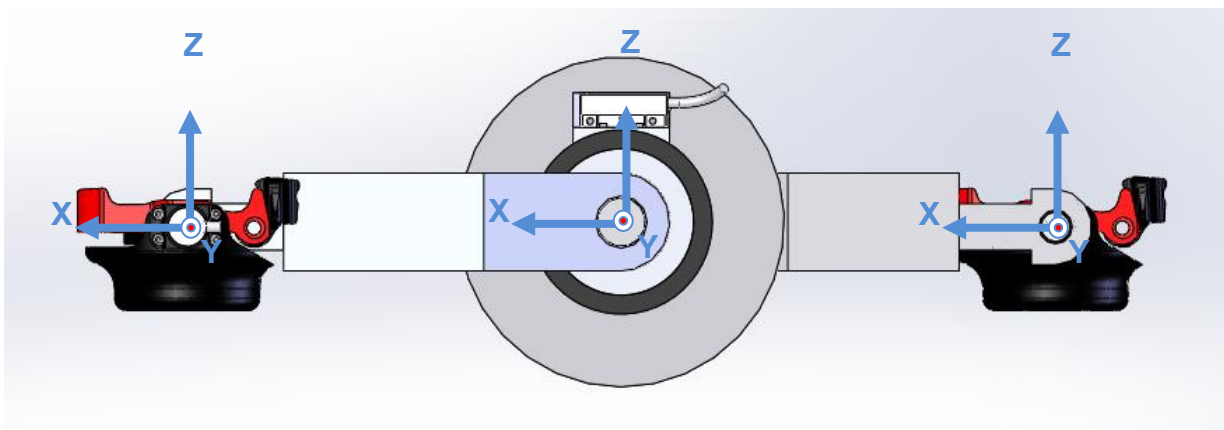
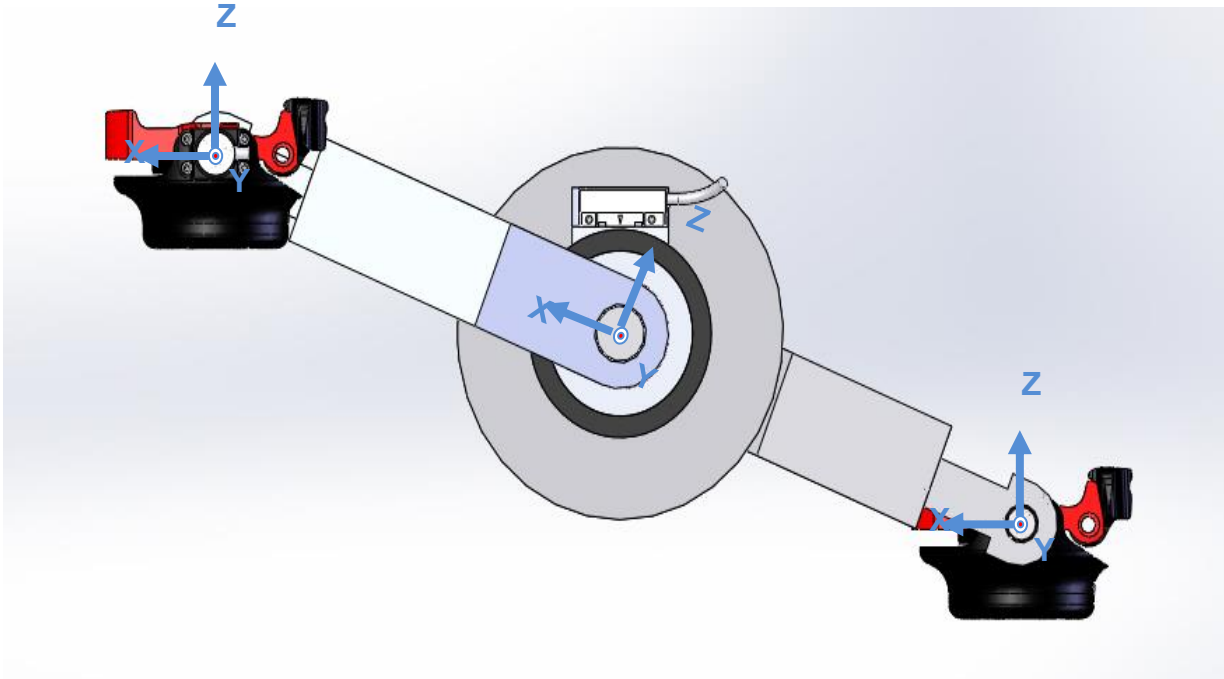
4.3. Bandwidth (natural frequency, bandwidth)

The sensor’s bandwidth is the combined result of the electronic bandwidth (2 KHz) and the sensor’s natural frequency (higher than 15 KHz for the force components). This natural frequency decreases with the mass of the mechanical interfaces fixed to the sensor. Actually, the bandwidth of the sensor corresponds to the lowest bandwidth between the one coming from the electrical conditioning and the other coming from the mechanical behavior of the measuring body.

4.5. Sensor reference

The location of the sensor reference is as indicated below.





5. SENSORS CERTIFICATION

The sensor respects the essential requirements of the European Standards in force, like modified for the CE marking, as follows:

- 2006/95/CE; Low-Voltage Directive (safety)
- 2004/108/CE; Electromagnetic Compatibility Directive (EMC)






This product has been designed to respect the requirements of safety rules standards of electrical equipment for measurement, regulation and laboratory: EN61010-1:2010

This product respects the requirements of the following EMC standards of electrical equipment for measurement, control and laboratory:

- EN 61326-1:2006; Emission: Class B; Immunity: basic level
- EN 55011:2004; Group 1; Emission: Class B

IMPORTANT: The below symbols are used on product.

Make sure to study and learn their meaning. A correct interpretation of these symbols will allow you using more efficiently your electro-medical device and reduce the risks.

| SYMBOL | NAME | DESCRIPTION |
|---|---------------------------|--|
|  | Voltage Direct Current | Voltage (potential) direct current |
| A | Ampere | Strength |
|  | "Do not throw in dustbin" | Dump into specific bin |
|  | European conformity | It falls to the manufacturer to have a product in accordance with the European requirements |
|  | Operating instructions | Operating instructions to commit the operator to refer to the operating manual |
|  | Warning | Warning, sign of general safety, underlines the fact that some specific warnings or precautions combined with the device are not mentioned on the stickers It means: "Attention, refer to the operating manual" |
| IP65 | IP Class | Protection from dust penetration (airtightness) and protection from water projected by a nozzle |

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