Interface Pressure Compensated Downhole Load Cell

A Technical White Paper by Interface

FORCE MEASUREMENT SOLUTIONS.

The World Leader in Force Measurement Solutions™

The downhole environment poses many challenges for well-drillers, operators, tool-string designers, and other engineers creating value in the oil and gas industry. Making force measurements in particular poses some real challenges, and while there are solutions available, they fall short in performance, reliability, or capability. A new load cell designed specifically for this environment is poised to set a new standard for force measurements downhole.

Challenges in Force Measurement in the Downhole Environment

The downhole environment is characterized by high temperatures and extreme pressures. The high temperatures make for difficulty in force measurement. Typical "high temperature" load cells are only rated to 100ºC (≈200ºF); however, downhole temperatures often reach 175ºC (≈350ºF) or higher. At these temperatures, load cells may be susceptible to instability, changes in zero balance or span, or even failure.

The extreme pressures of the downhole environment can be as high as 140 MPa (≈20,000 PSI), meaning that sealing a load cell will introduce large pressure sensitivities. In sealed load cells, the piston force load can also far exceed the desired measurement load. These can be overcome with hydraulic compensation designs; however, these designs require frequent maintenance and failures. Downtime for maintenance, such as replacing O-rings, can be very expensive both in labor and lost production. Additionally, these alternative compensation methods have high uncertainties and toggle due to O-ring drag and moving components.

Industry Norms and Challenges for Downhole Hardware

Another challenge facing developers of downhole tools is a lack of industry standardization. There are few standards for mechanical connections in downhole hardware. While some OEMs may implement a standard within their own architecture there is not a universal standard across industry. This means that for integrators and operators trying to connect tools from multiple OEMs into a single string, there is always a challenge of making the necessary mechanical connections.

Digital communication also contributes to another barrier for integration. Different manufacturers use different protocols, logic levels, and standards. Sensor data needs to be handled carefully to avoid errors or inaccuracies. Sign handling, unit errors, or other issues can cause catastrophic problems if sensor data is not carefully transmitted via digital means.

The Interface Standard IPCD Load Cell

The new Interface Pressure Compensated Downhole Cell Model (IPCD) offers a solution to many of the challenges related to high performance downhole force measurement. Interface has been building custom downhole load cells in the oil and gas industry for several decades. Each one has been customized to the customers preferences. Interface is leveraging the experience, engineering design, and production skills to provide a standard model solution. It is also simple to modify the adapters for the IPCD Load Cell which the customer can use to integrate with their hardware.

IPCD Performance

The IPCD boasts an impressive temperature range of up to 175ºC (≈350ºF), compensating for both span and zero shift with temperature. Competitor products in the market often only compensate for zero shift. This wide operating range is a result of a proprietary design and construction process that ensures the utmost stability, allowing for accurate measurements in high temperatures.

The pressure performance of the IPCD includes revolutionary technology to ensure that only force applied is measured, while canceling out the piston force that is inherently problematic. It accomplishes this without complicated hydraulic compensation that requires dynamic O-ring seals, back-filling with silicone oil, or relying on a secondary pressure measurement to digitally cancel out pressure influences. The IPCD provides a true force measurement, regardless of the hydrostatic pressure surrounding it up to 140 MPa (≈20,000 PSI).

For integrators who do not want to worry about making measurements and stacking errors to provide an overall accuracy of the force measurement, the IPCD also offers a solution in the form of a combined error specification. This feature limits force, temperature, and pressure-based errors to a combined 3% within the specified limits. More precision is achievable using individually specified error limits for each parameter; however, the 3% limit provides a simple way to provide an error estimate without additional effort.

IPCD Safety

The IPCD is designed to be accurate in a certain range as well. Working downhole, it is useful to know the maximum limitations. The IPCD is accurate up to 10,000 lbf (44.5 kN). It can safely see overloads up to 30,000 lbf (133.4 kN). Should higher tension values be needed due to stuck tooling, the IPCD has been pull tested to failure at 90,000 lbf (400kN) at room temperature. Beyond force, the IPCD can handle bending loads up to 250 lbf*ft (339 N*m) and torque loads up to 850 lbf*ft (1152 N*m) without damage.

IPCD Design

The IPCD is a standardized design. A baseline design for adaptors is available, including tolerances, to allow for customers to easily design and manufacture adaptors to readily mate the IPCD to their tool string. This includes dimensions and tolerances for O-ring, threads, lengths, and diameters. This adaptor can be designed to accommodate keying features, a connector, or simply adapt to different threads and sealing features. CAD files and product design drawings are provided upon request to allow for simple design integration into components, machines or use in OEM products.

The make-up length is optimized to be as short as possible, while maintaining good load cell performance. The diameter is also designed to be minimal to reduce material and machining costs for mating adaptors. Standard pin-spanner holes are provided for tightening threads. The IPCD is made from a high strength stainless steel that is corrosion resistant (not NACE compliant) and retains good mechanical properties across its working temperature range. A standard thread was used to ensure machine shops will not have difficulty machining and inspecting threads, compared to other specialty threads that are sometimes used in downhole applications.

IPCD Electrical

The IPCD is a 100% analog device. Any device capable of mV/V ratio metric reading will be able to interface with the IPCD. This means it is straight forward for a variety of downhole instruments to interface with the IPCD if they are capable of microvolt resolution. A pass-through hole down the center of the device allows for wires to be passed through it to connect to other devices.

Testing should be done to ensure that the use of these wires does not cause interference to the IPCD. In most cases, any noise is easily resolved through thoughtful shielding and insulation of the pass-thru wires. The IPCD was designed and tested with constant DC voltage supply in mind. It will readily accommodate more sophisticated methods of excitation, including AC voltage and constant current.

IPCD Testing

Each IPCD is furnished with a test report that shows testing results under force, pressure, and temperature loads for the unit sold, as well as various electrical tests. This includes a coefficient or calculating force. These can be used by the customer in several ways, from simply plugging in the coefficient to using the test data to generate more precise curves that also account for pressure and temperature based on inputs from other sensors in the tool string.

The information in the next section details portions of the test report, along with an explanation.

Resistor Bridge Data Tests

Resistor Bridge Data

Test Excitation:	10	VDC
Input Resistance (Red/Black):	354.8	Input ohm
(350+/- 10 Ohms)	PASS	
Output Reistance (Green/White)	351.1	ohm
(350 +/- 5 Ohms)	PASS	
RTD Resistance	1091.4	ohms at Rm Temp (°F): 76
Insulation Resistance:	>5000	Mohm @ 50 VDC

Electrical inspection data such as input and output resistance, and insulation resistance can be used in checking the health of the load cell.

Nonlinearity, Hysteresis, and Repeatability Test

Load (lbf)	Signal (mV/V)	Best Fit* (mV/V)	Difference (mV/V)	%FSO
0	0.0140	0.0138	0.0002	0.02
2000	0.2094	0.2103	-0.0009	-0.09
4000	0.4057	0.4067	=0.0011	-0.11
6000	0.6024	0.6032	-0.0009	-0.09
8000	0.7993	0.7997	-0.0004	-0.04
10000	0.9963	0.9962	0.0001	0.01
8000	0.8007	0.7997	-0.0004	-0.0
6000	0.6033	0.6032	0.0001	0.01
4000	0.4079	0.4067	0.0011	0.11
2000	0.2106	0.2103	0.0003	0.03
0	0.0142	0.0138	0.0005	0.05
0	0.0138	0.0138	0.0000	0.00
2000	0.2093	0.2103	-0.0010	-0.10
4000	0.4056	0.4067	-0.0012	-0.12
6000	0.6023	0.6032	-0.0010	-0.10
8000	0.7991	0.7997	-0.0006	-0.06
10000	0.9961	0.9962	-0.0001	-0.01
8000	0.8005	0.7997	0.0008	0.08
6000	0.6043	0.6032	0.0010	0.11
4000	0.4078	0.4067	0.0011	0.11
2000	0.2109	0.2103	0.0006	0.06
0	0.0141	0.0138	0.0003	0.03
Max (0.25% FSO max allowed)				0.12

	73	
RTD	1089.0	**ohms**

The load column indicates the load applied during testing.

The signal column indicates the signal from the IPCD. This data is used to calculate the full scale output and best fit line slope, indicated at the bottom of the page.

The best fit column is the best fit line slope multiplied by the applied load for that row.

The difference columns indicate the difference between the signal (actual) and best fit (theoretical) columns in both mV/V signal and as a percentage of the full scale output.

Regression Output

Constant	0.0137856
Std Err of Y est	0.0007896
R Squared	0.9999943
No. of Observations	22
Degrees of Freedom	20
X Coefficient(s)	9.82388E-05
Std Err of Coef.	5.25879E-08

Full Scale of Output (FSO)	0.9823	**mV/V (0.85500 to 1.1500 mV/V allowed**
Best Fit* Line Slope:	9.8239E-05	**mV/V / lbf**
Zero Offset Constant:	0.0138	**± mV/V (0.0650 mV/V allowed)**

***Best fit = constant + slope (load)**

No Load Temperature Test

Temp F	Temp (actual) °F	Signal (mV/V)	Difference (mV/V)	Difference %FSO	% FSO / 100 °F	RTD ohms	Test Date
80 °F	86 °F	-0.0001	0.0000	0.00	(REF)	1118.8	20-Dec-21
200 °F	203 °F	-0.0043	-0.0042	-0.43	0.37	1373.4	20-Dec-21
300 °F	305 °F	-0.0100	-0.0099	-1.01	0.46	1589.4	20-Dec-21
350 °F	356 °F	-0.0140	-0.0139	-1.42	0.52s	1697.8	20-Dec-21

Maximum Difference Between Any Reading and Initial Reading at Room Temp / 0 psig=

	0.0139
% FSO / 100 °F	1.42
	0.52

The signal column records the output of the load cell at the temperature indicated in the temp (actual) column. The difference columns indicate the difference between the value in the signal column at a given temperature and the value in the signal column at the initial temperature.

The %FSO / 100 ^{o}F column indicates the temperature error per 100 ^{o}F as a percentage of the full-scale output of the load cell. The RTD column indicates the resistance of the RTD and its lead wires at the temperature indicated in the temp (actual) column.

Pressure Test

		74	RTD	1088.0

Pressure (psig)	Signal (mV/V)	Difference (mV/V)	Difference %FSO
0	0.0094		
10000	0.0060	-0.0034	-0.35
15000	0.0050	-0.0044	-0.45
20000	0.0044	-0.0050	-0.51
15000	0.0027	-0.0067	-0.68
10000	0.0035	-0.0059	-0.60
0	0.0083	-0.0011	-0.11

The signal column records the output of the load cell at the gage pressure indicated in the pressure column.

The difference columns indicate the difference between the value in the signal column at a given pressure and the value in the signal column at the initial pressure.

Additional Testing for Quality Purposes

In addition to the tests outlined in the report, other testing is done on a sampling basis to ensure quality. These tests are for properties that are extremely consistent but also important to accurate operation. These tests include repeating the nonlinearity, hysteresis, and repeatability test at elevated temperatures, repeating the pressure test at elevated temperatures, and performing a pressure creep test at both room temperature and elevated temperature. These tests serve as quality control to ensure consistent performance.

Interface is the world's trusted leader in technology, design and manufacturing of force measurement solutions. Our clients include a "who's who" of the aerospace, automotive and vehicle, medical device, energy, industrial manufacturing, test and measurement industries.

Interface engineers around the world are empowered to create high-level tools and solutions that deliver consistent, high quality performance. These products include load cells, torque transducers, multi-axis sensors, wireless telemetry, instrumentation and calibration equipment.

Interface, Inc., was founded in 1968 and is a US-based, woman-owned technology manufacturing company headquartered in Scottsdale, Arizona.

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