Development of compact automated benchtop pressure generator platform capable of dynamic pressure control up to 7 kilobar.

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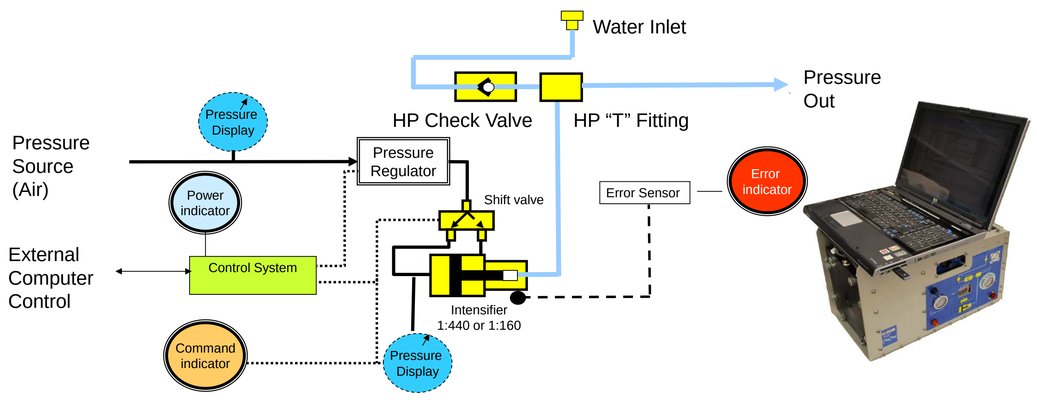
Introduction

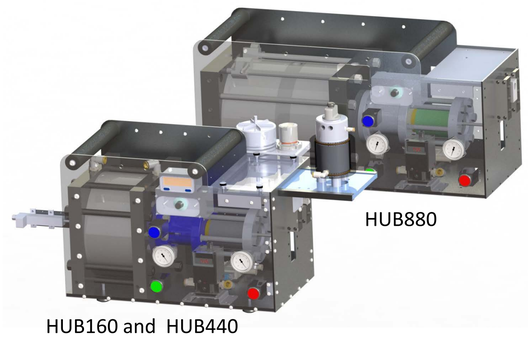
Hydrostatic pressure in the range up to several thousand bars is now recognized to have fundamental effects on the structure and function of biological systems ranging from proteins, cell, to whole organisms. Much of the high pressure equipment in use for biological applications, however, continues to be a domain for do-it-yourself enthusiasts and is not, therefore, well suited for adoption by vast majority of life science laboratories. The HUB series of pressure generators was conceived to offer life scientists a highly flexible, compact, yet simple to use source of high pressure. While high pressure research will always require some equipment customization, the availability of "plug-and-play" pressure generators will greatly simplify the required effort. Computer-based data acquisition and control allows easier integration of the pressure generator into an experimenter's custom setup. The individual instruments of the HUB series contain compressed air-driven intensifiers with piston cross-section area ratios of 1:160; 1:440 and 1:880, respectively, resulting in generation of the hydrostatic pressure up to 7,000 bar, depending on the model. This presentation highlights two advanced software control features of the HUB pressure generators. One uses proportional–integral–derivative (PID) algorithms to maintain precise (±0.01%) static pressure despite the effects of temperature fluctuation (and associated thermal expansion), and non-zero seal friction. The second illustrates the use of an active control algorithm to enable a constant pressure intensifier to emulate a constant displacement (flow rate) pump, within a defined band of operation.

HUB Pressure Generators: Platform Concept



The core of the system is an electronically-controlled air-driven reciprocating pressure intensifier equipped with a dynamic high pressure seal system with minimum friction, resulting in the ability to ramp pressure over time with a resolution of several bar per second. Water is used as the high pressure medium due to its low compressibility. An electronic regulator controls the air pressure and the direction of air flow to the front or back of the air cylinder, resulting in precise extension or retraction of the intensifier piston. Pressure is controlled either via a manual control panel on the front of the instrument, or remotely by the USB-powered Data Acquisition and Control interface. Built-in high pressure transducer permits real-time pressure feedback. The system is powered by an external 24 VDC power supply. High pressure check valves prevent the backflow of water and enable rapid refill of the intensifier with water for multi-stroke operation. Open frame packaging of the instrument provides easy access to all serviceable components and enables rapid customization. High pressure outlet is equipped with the standard high pressure type "T" fitting compatible with a wide variety of industry-standard high pressure equipment.

The HUB Family Members



HUB160 and HUB440

The HUB Series Pressure Generators share the same general design, while offering the range of displacement and pressure capabilities. HUB160 and HUB440 incorporate the same type of high pressure connectors, therefore, these two instruments can share the same peripherals. HUB440 pictured with a pressurized water bottle, a small pressure vessel and a displacement metering option installed. Currently only one type of the PBI pressure vessel (30 mL chamber) is rated up to 7 kBar and can be used with the HUB880 device. HUB880 device is currently in final phase of development.

	HUB160	HUB440	HUB880†
Maximum Pressure	1.4 kBar (20,000 psi)	4 kBar (58,000 psi)	7 kBar (103,000 psi)
Stroke Displacement	9.5 mL	3.6 mL	3.6 mL
Dimensions (HxWxD)	320x300x400 (mm)	320x300x400 (mm)	320x600x400 (mm)
Compressed Air Requirements	130 psi	130 psi	130 psi
Intensifier Ratio	1:160	1:440	1:880
Manual Operation	YES	YES	YES
Computer Control	YES*	YES*	YES*
External Analog Control	YES*	YES*	YES*
Output Connector	60ksi H.P. Connector (¼" O.D. tubing)	60ksi H.P. Connector (¼" O.D. tubing)	100ksi H.P. Connector (¼" O.D. tubing)

*Requires DAC (Data Acquisition and Control) Module Option and HUB Controls software.
†Projected Specifications

Specialized Peripheral High Pressure Components

General connecting hardware

High Pressure Thermocouples

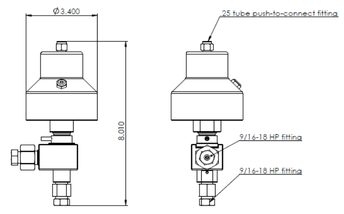
Pressure Vessels

10mL, up to 4 kBar

30mL, up to 7 kBar

60mL, up to 2 kBar

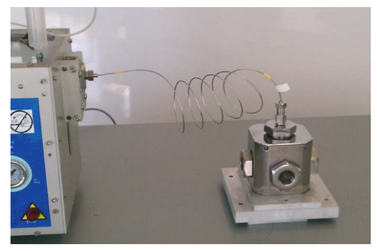
Ultra-fast pressure-jump valve



4 kBar
<1 ms

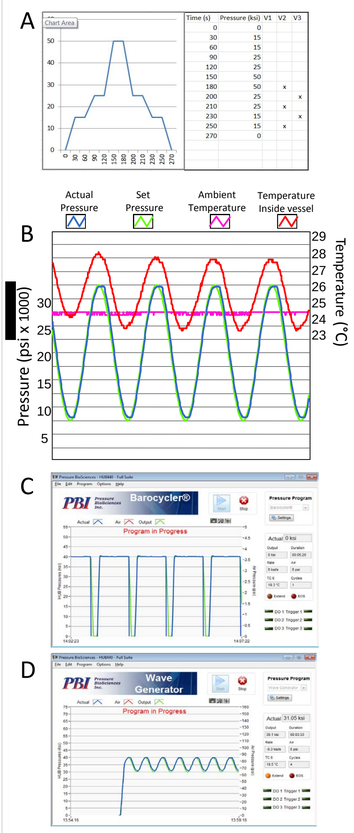
Ceramic EPR cell/mount

Optical Cells



Standard HP fittings allow connection to the high pressure optical cell from ISS Instruments (UV-Vis absorbance and fluorescence measurements up to 4 kilobar) and other optical cells.

Software Control



Although Computer interface is an optional component of the HUB platform, it enables the most sophisticated functions via dynamic programming, data logging and direct feedback-based automatic pressure control.

Computer control via optional USB-powered Data Acquisition and Control interface offers flexible programming of pressure values (Panel A). Intuitive software also offers up to 4 additional channels of data acquisition, including logging of pressure, temperature and outputs from additional sensors (Panel B).

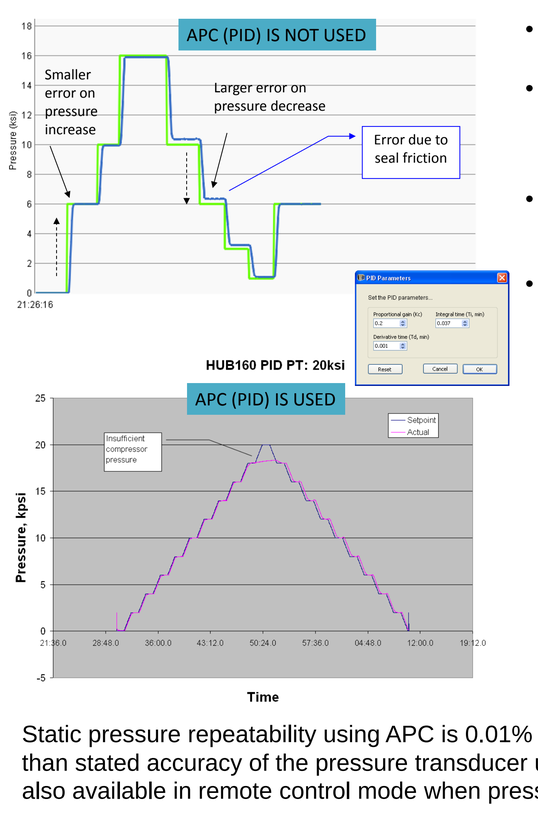
Hardware: National Instruments USB-6211 multi-functional DAQ card, electronically controlled pneumatic valves, Microsoft Windows XP/Vista/7/8 computer with available USB 2.0 port.

Software: 32-bit and 64-bit software versions are available with standard functionality: Basic pressure control, large vessel pumping (A), Barocycler and Pressure Jump (C) and Wave Generator (D). Custom software development is possible using LabVIEW 2010.

Automated Calibration (Calibration Wizard) allows the user to quickly and automatically calculate the calibration values (Slope and Y-Intercept) for the HUB channels (air pressure and intensifier pressure output) as well as auxiliary data acquisition channels. Calibration curves can contain between 2 and 100 calibration points.

External control of the HUB platform can be done via TTL or contact closure –based input and output triggers, as well as via 0-10V DC voltage input corresponding to the desired pressure output.

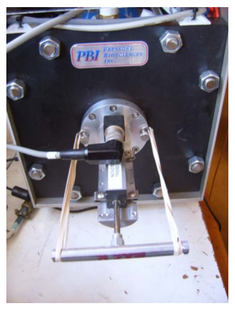
Active Pressure Control (APC): PID and Active Compensation for Seal Friction



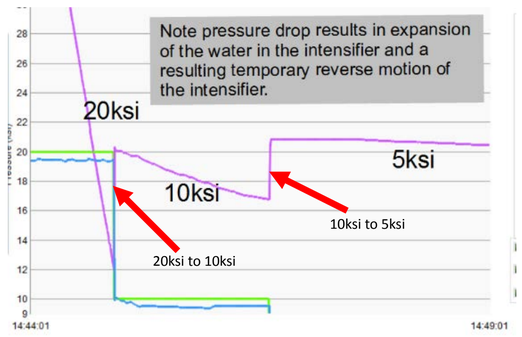
- All seals have inherent friction that alters the force needed to generate desired pressure.
- Active pressure control (APC) allows a computer to adjust for this effect in order to improve controllability. APC is based on PID (proportional-integral-derivative) control loop feedback algorithm.
- Active control is used to maintain constant pressure, while compensating for friction, thermal expansion/contraction, chemical reaction, or very small leakage effects.
- APC is turned off during dynamic pressure changes. APC "locks into" the set pressure in typically < 60 seconds.

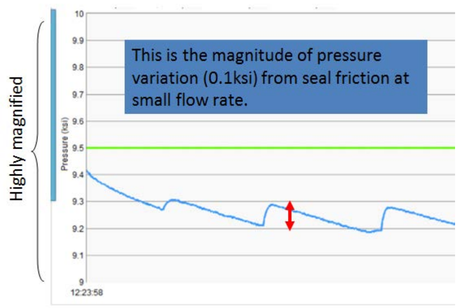
Static pressure repeatability using APC is 0.01% Full Scale (approximately +/-10psi). This value is better than stated accuracy of the pressure transducer used (in this case, 0.25% Full Scale). The APC function is also available in remote control mode when pressure value is sent to the generator as analog DC voltage.

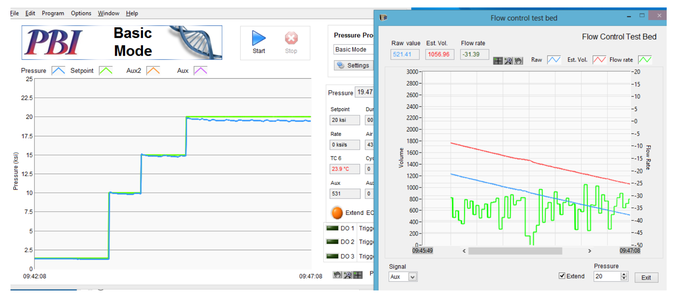
Displacement Monitoring – Prerequisite for a Constant Flow Regime



Tests on modified HUB440 show that position of the air piston, as measured on the rear of the main air cylinder can be resolved to 0.001". Position is measured by using a displacement precision potentiometer pressed against the air cylinder. The potentiometer has a reported resolution of better than 0.01mm. When air pressure is controlled using a feed back loop, flow rate within a defined band of flow conditions can be controlled. The goal of this work is to determine to what accuracy flow rate control can be achieved.







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