Esterline

Weston Aerospace Vibrating Cylinder Technology

1.1 Introduction

The Weston pressure sensor is based around a vibrating cylinder, where the natural frequency of cylinder depends upon the applied pressure. This is classed as a 'vibrating element' sensor and exhibits exceptional measurement performance by virtue of its operating mechanism.

The advantage of the vibrating cylinder technique lies in the mechanism that converts from pressure to frequency change. When pressure is applied, the stress generated in the wall of the cylinder affects the frequency directly and, although strain is generated in the material, this has only a small effect on the frequency. The consequence of this is that hysteresis and creep of the material have very little effect on the pressure measurement. In addition, no other mechanism is required to read out the measurement (like a strain gauge). The cylinder acts as the complete measurement system and it is only necessary to maintain it in resonance so that the frequency can be measured.

The consequence of the directness of this measurement technique is that high measurement accuracy <0.01% of full scale pressure (FSP) is achieved with very low drift rates <0.01%FSP/year. Pressure hysteresis is extremely small and less than 0.001% FSP.

1.2 Construction

Figure 1 shows a photograph of a 7881 type pressure sensor. The main components are the vibrating cylinder pressure module and the maintaining amplifier hybrid. The latter consists of an oscillator circuit which sustains the cylinder in resonance.

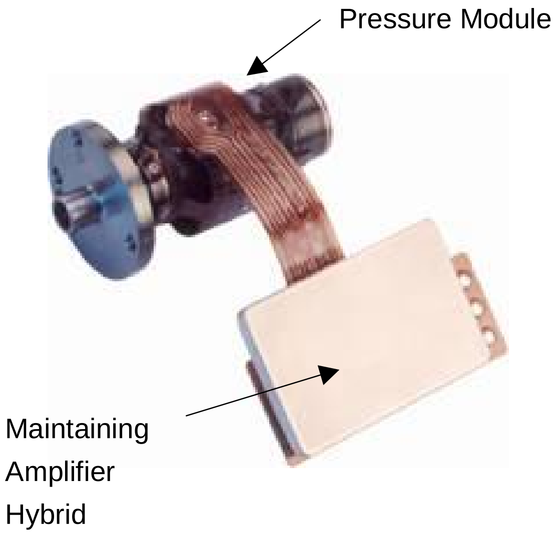

Figure 1 7881 Type Pressure Sensor

1.2.1 The Pressure Module

Figure 2 shows a sectional drawing of the pressure module. This is a fully electron beam welded structure. Apart from the filter and some of the coil components the module is made entirely from Ni-Span-C (see 1.2.1.1) to provide optimum performance.

The pressure to be measured is applied to the inside of the cylinder via a stainless steel mesh filter to exclude contamination.

The cylinder has a thin precision ground wall. The thickness of the cylinder wall varies with pressure range and the tolerance on this thickness is in the region of 0.001mm. One end of the cylinder is closed by an electron beam welded cap.

The cylinder is enclosed in an evacuated housing which provides the measurement reference. Pressure measurement is 'Absolute', i.e. made relative to absolute vacuum.

Four coil assemblies are positioned around the cylinder. Two of these are used to drive the cylinder and the other two are used to detect the resulting motion of the cylinder wall. The coils are bonded into non-magnetic cups that are brazed into the wall of the outer housing.

A diode is potted into the base of the cylinder that provides a means for temperature measurement. The hybrid electronics supplies a constant forward bias current to the diode, which provides a voltage related to temperature with a sensitivity of approximately 2mV/°C. This signal is used to correct the cylinder frequency for the effects of temperature.

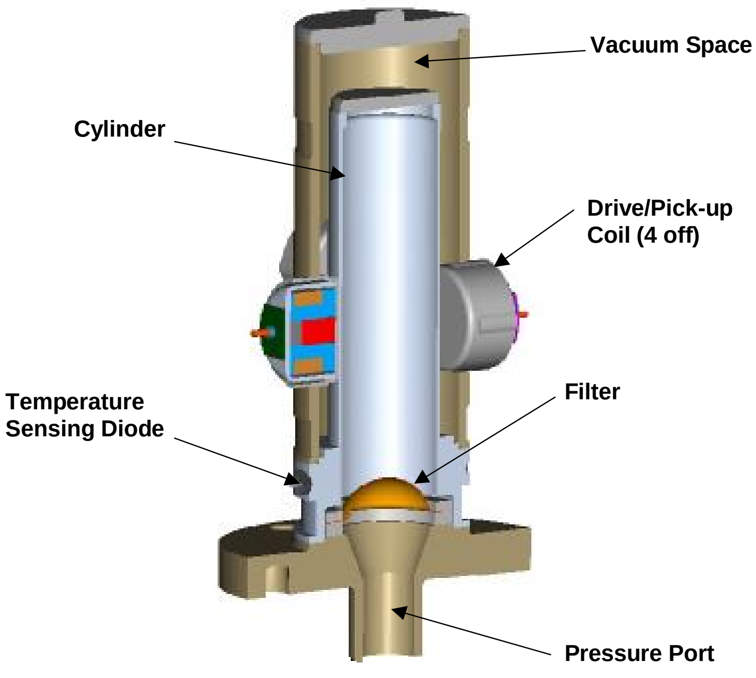

Figure 2 Cross Section of 7881 Pressure Module

1.2.1.1. Material

The cylinder, outer housing, pressure port and end-caps are machined from Ni-Span-C. This material is used for its very low thermoelastic coefficient (change in modulus with temperature), which results in only small changes in the cylinder frequency with temperature, and excellent long-term stability. This minimises the required level of correction for temperature errors and increases the overall accuracy of the unit.

Weston purchases Ni-Span-C to its own specification to optimise its properties. As a result, Weston is required to purchase whole material melts. Sample units are built and tested for drift performance using material from each new batch. Only when the future drift performance can be assured is the batch released for production use.

1.2.1.2. Construction

All joints of the pressure module are electron beam welded except for the coil cups, which are vacuum brazed into the outer housing. High levels of cleanliness are employed at all stages to prevent internal contamination.

Heat treatments are employed at a number of stages throughout the construction. These have been optimised over many years to maximise the unit stability and accuracy.

Each unit is exposed to an overpressure of 3 times full-scale operating pressure (2 times for 5000kPa range).

1.2.2 The Maintaining Amplifier Hybrid

The maintaining amplifier hybrid is connected to the pressure module coils and temperature sensing diode via a robust flexible circuit. The hybrid pin connections are suitable for direct mounting onto a printed circuit board.

The maintaining amplifier, together with the pressure module, form an oscillator where the resonant frequency is solely determined by the cylinder and hence the applied pressure.

The hybrid requires +15V, 0V, and –15V supplies. The outputs are a square wave frequency signal with TTL levels and an analogue temperature signal from the diode.

The hybrid is of a hermetically sealed, high reliability, chip and wire construction. All hybrids are burnt in for 160 hours at 125°C.

1.3 Principle of Operation

The cylinder in the sensor is sustained in a high Q resonance by the maintaining amplifier and electromagnetic drive/pick-up system as shown schematically in Figure 3.

The cylinder vibrates in a hoop mode shape as shown in Figure 4. The symmetry of the mode shape makes the sensor immune to the effects of external vibration. This also results in a high Q and hence high stability and accuracy.

When pressure is applied to the inside of the cylinder, tensile stresses are generated in the cylinder wall. These cause the resonant frequency to increase due to load stiffening. This is the same mechanism that causes the resonant frequency of a stretched string to increase with tension. Between vacuum and full scale pressure the resonant frequency of the cylinder increases by approximately 20%.

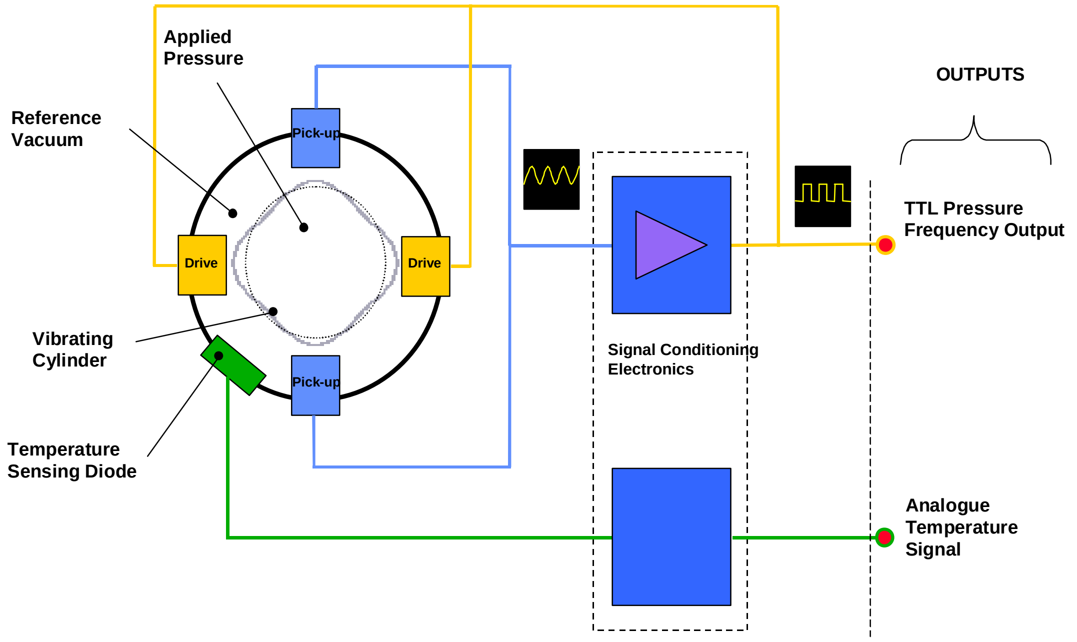

Figure 3 Schematic Showing Sensor Operation

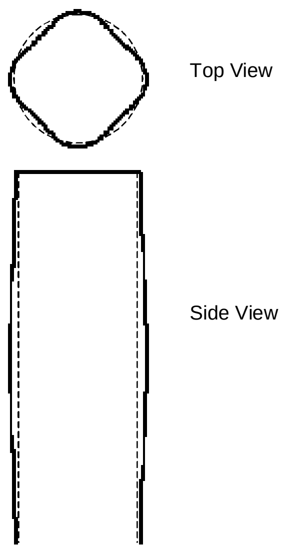

Figure 4 Cylinder Resonance Hoop Mode Shape (exaggerated, actual deflection ~2 microns)

1.4 Calibration and Testing

1.4.1 Calibration

All sensors are calibrated using a fully Automated Pressure Test System (APTS). Weston has 8 of these systems each with a pressure standard that is fully traceable to national standards. Calibration takes approximately 2 to 3 days depending on pressure range.

Each sensor is fully characterised by measuring its frequency and temperature outputs at 11 pressures at 7 temperatures between –55 and 125°C (77 points). A surface fit is applied to these measurements so that pressure can be calculated for a given frequency and temperature signal as shown below.

Input values are: -

Tp = Timeperiod in microseconds

Vd = Diode voltage in volts

Pressure P in kPa is given by: -

$$P = S\sum_{m=0}^{2}\sum_{n=0}^{4} K_{mn} X^{n} Y^{m}$$

This can also be written as: -

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P  =  S * (   ( k00 + k01*X + k02*X^2 + k03*X^3 + k04*X^4 )
          +   ( k10 + k11*X + k12*X^2 + k13*X^3 + k14*X^4 ) * Y
          +   ( k20 + k21*X + k22*X^2 + k23*X^3 + k24*X^4 ) * Y^2 )
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Where: -

S is a scaling factor

X is related to Vd

Y is related to Tp

K_{mn} are curve fit curve coefficients unique to each sensor

The calibration data can either be supplied on a paper certificate, electronically, or in the case of a digital output unit, the coefficients are written into non-volatile memory.

1.4.2 Testing

As well as the calibration, the APTS system also tests many of the performance parameters of each sensor and applies acceptance limits. A summary of tests is as follows: -

- Residual Curve fit errors
- Temperature Hysteresis
- Change in frequency with pressure (sensitivity)
- Time to start after application of power
- Limits on frequency and temperature outputs
- Temperature signal stability
- Internal signal levels

1.5 Specification Summary for 7881 Type Sensor

Available Pressure Ranges [kPa Absolute]	**Accuracy** (-55 to 125°C) [% of Full Scale]	**Max Over Pressure** * [kPa Absolute]
3.4 to 130	0.010	390
3.4 to 262	0.014	786
3.4 to 345	0.018	1035
10 to 1000	0.018	3000
34 to 5000	0.040	10000

* Maximum over pressure with no calibration shift

Table 1 Available Pressure Ranges

Measurement Drift	<0.010% FS/year maximum <0.005% FS/year typical
Pressure Hysteresis	<0.001%FS
Repeatability	<0.001%FS
Calibration/Operating temperature range	-55 to 125°C
Burst Pressure	> 5 times FSP
Vibration	MIL –STD-810. Method 514.3, Category 5, Procedure I, fig 514.3-26, Wo = $0.2g^2$/Hz.
Acceleration	20g
Shock	40g, 6ms with no derangement
Acoustic Noise	150db OSPL, Operating
Outputs	TTL frequency Analogue Temperature

Table 2 Specification Summary