Dytran by HBK
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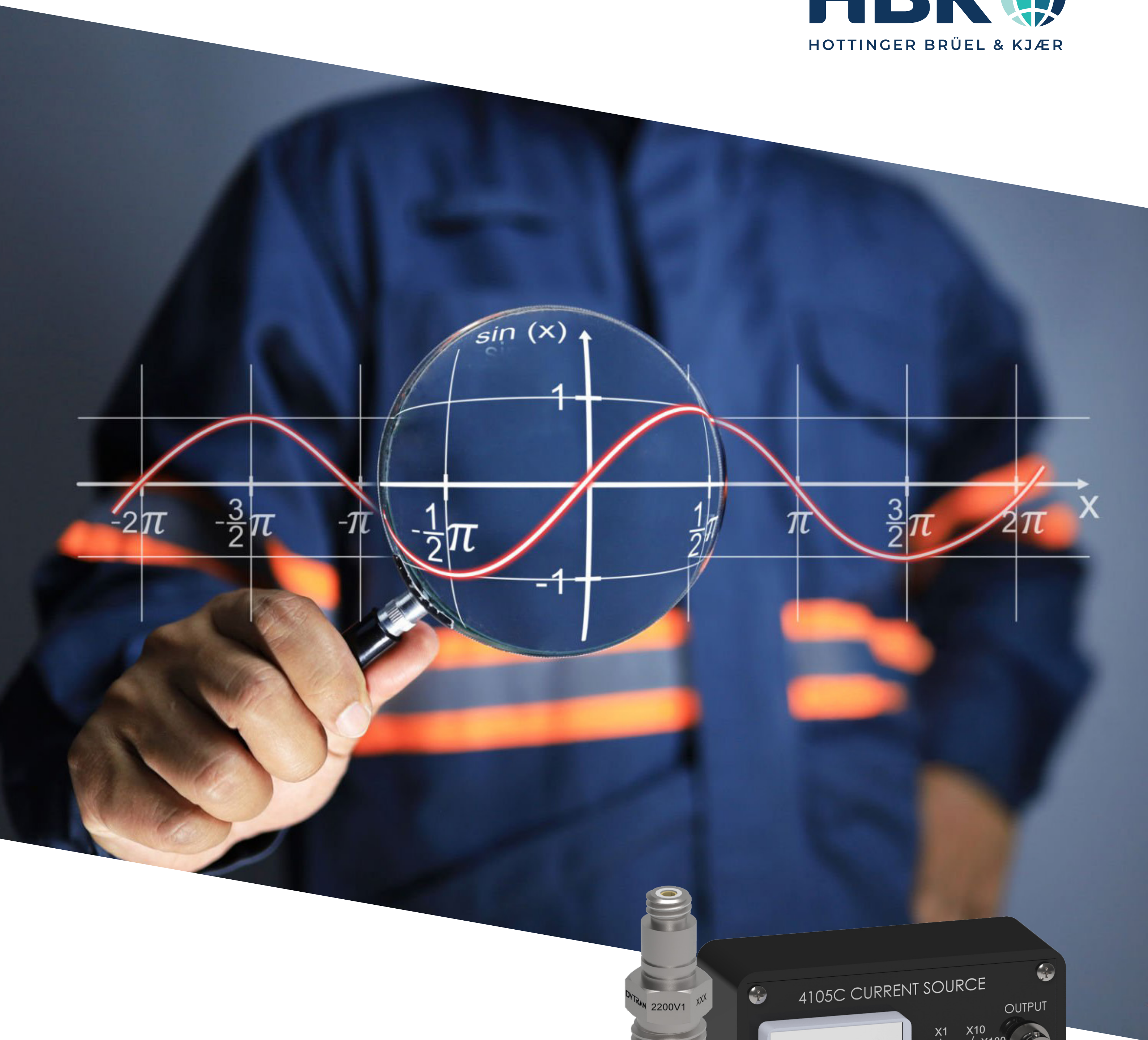

WHITE PAPER

Quasistatic measurements

UNDERSTANDING QUASISTATIC MEASUREMENTS AND SIGNAL REFERENCING CHALLENGES WITH AC-COUPLED AND IEPE SENSORS

AC-coupled devices are not designed for static measurements. Due to certain technical details, the static response of devices has been sacrificed to higher resonant frequencies and faster rise time. AC-coupled sensors are designed to measure "change" of a measurand, not a measurand itself. However, with proper consideration of discharge time constant [1], it is possible to use AC-coupled sensors to measure static events. However, even though the event is static, the measurement should be named "quasistatic" to reflect the changing nature of the signal produced by an AC-coupled sensor.

The use of IEPE sensors for such an application adds even more considerations to one's plate. The essence of an IEPE sensor is so-called "two wire operation", meaning that the powering scheme of a sensor also serves as a way to conduct a signal. This means that the signal "rides" on top of the bias voltage [2]. This fact introduces a certain inconvenience in referencing the signal. Now a signal cannot be referenced to true zero, because from a signal stand point, the true zero is the value of the bias voltage. The bias voltage generally differs from sensor to sensor, and even though it's reported on the calibration certificate of an instrument, it highly depends on ambient temperature and the time it takes to settle its true value (the longer the discharge time constant of a sensor, the longer it takes for a bias voltage to settle).

A quick way out of the trouble is to AC couple the output of the signal conditioner. This will treat a bias voltage as a signal at 0 Hz and will annihilate its value to zero. It will also create an illusion of a signal riding around zero.

Even though it might seem to be a quick problem solver, one must be aware of the consequences of such a configuration. Now there are two time constants involved and it is not a trivial matter to predict system behavior in this situation.

In order to describe the behavior of a system with double AC coupling, the following example has been used:

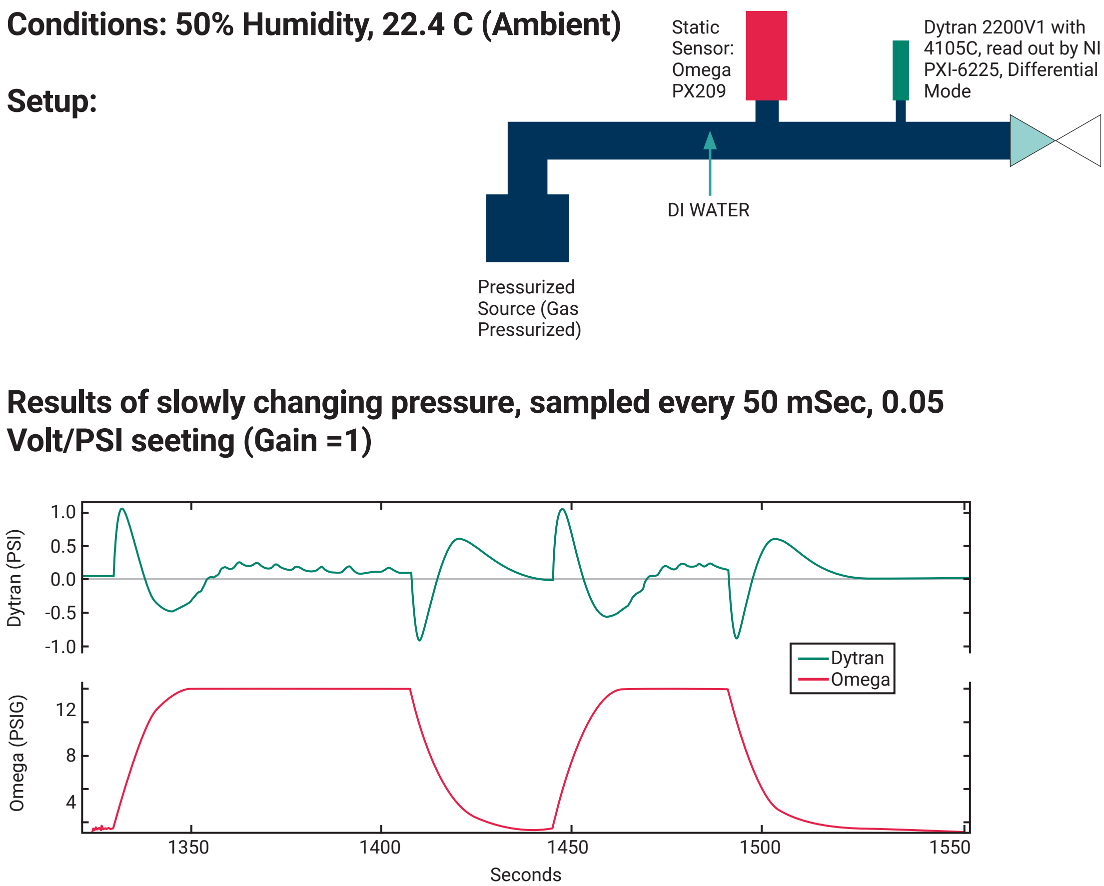

Figure 1: Test Setup

Figure 1 shows a test setup where pressure is being gradually raised to certain level (the red line on the graph shows the output of a static pressure sensor Omega PX209). The green line on the graph shows the response of a typical AC-coupled, IEPE sensor. The AC-coupled sensor used in this experiment is Dytran's 2200V1 model with 4105C signal conditioner (AC-coupled on the output).

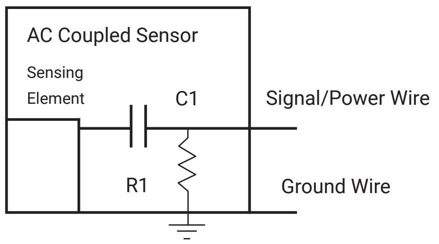

Figure 2: Ac-coupled IEPE sensor

Figure 2 shows a typical coupling scheme of an AC-coupled sensor. The discharge time constant is usually reported on the calibration certificate of an instrument.

The purpose of this paper is to explain hardly predictable behavior of the Dytran sensor and point out the advantages and disadvantages of using AC-coupled sensors in measurement applications.

> Discarge time constant depends on the values of C1 and R1 and can be easily calculated by multiplying them together:
>
> TC = R1 × C1
>
> Dytran 2200V1 has a typical discharge time constant of 0.4 s

Let's see what is going on with the sensor as it sees the input described in the Figure 1. In order to represent this input as a mathematical function, one can do the following:

$$u(t) = \begin{cases} u = 0; & t < 1 \\ u = log(t); & 1 \leq t < 10 \\ u = 1; & t \geq 10 \end{cases} \qquad (1)$$

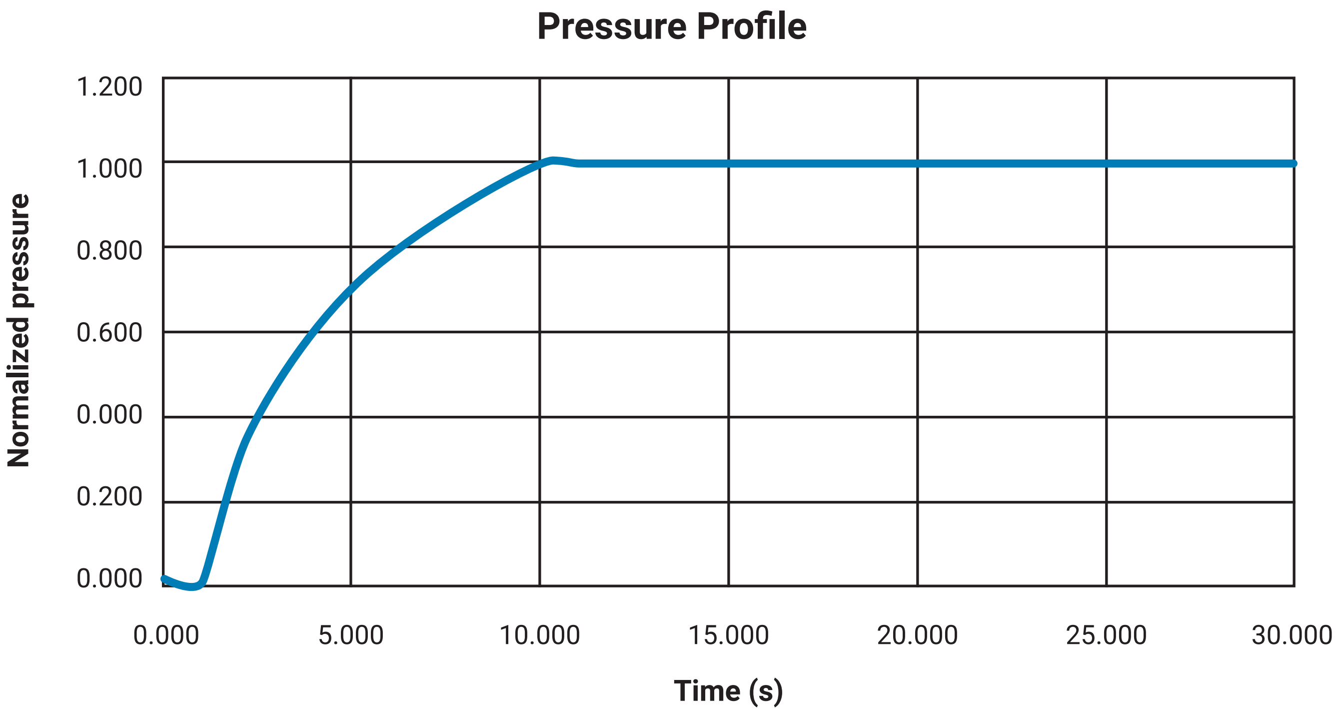

Figure 3: Pressure Profile as Mathematical Function

One can compile a differential equation of the system response based on the known discharge time constant and known pressure input:

$$\frac{dy}{dt} + \frac{1}{TC_1} y = \frac{du}{dt} \qquad (2)$$

Appendix A shows an attempt to solve this differential equation analytically and it also explains why a numerical solution using Euler's methods is preferred. Plotting the numeric solution of this equation in Figure 4 shows the output of the AC-coupled sensor for 0.4 seconds discharge time constant, in comparison with true pressure applied to the sensor.

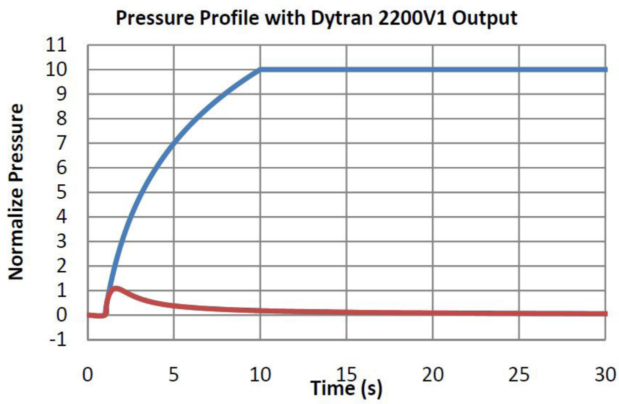

Figure 4: Sensor Output in Comparison to the True Pressure

In Figure 4 the red line is the sensor's output and the blue line is the pressure applied to the sensor.

This is, pretty predictable picture. The capacitor can only pass through so much of low frequency input; at some point it starts discharging. One can see on Figure 5 how much more data can be captured by increasing the discharge time constant value to 10 seconds, for example.

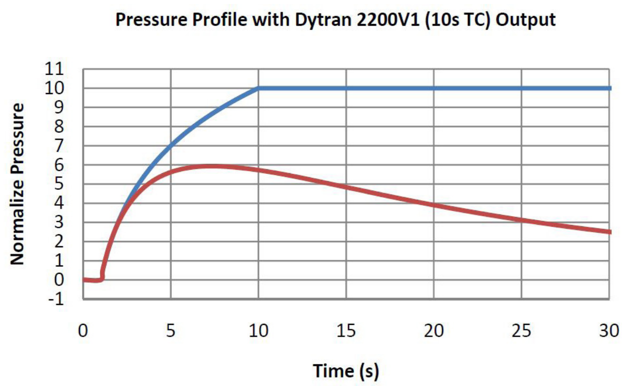

Figure 5: Sensor Output (with 10 s TC) in Comparison to the True Pressure

One has to remember that the output presented in Figures 4 and 5 represent the sensor's output riding on top of the bias voltage. What would happen if one decides to use the AC-coupled signal conditioner? In that case Figure 2 would look like the following:

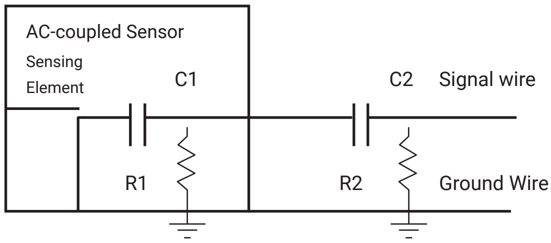

Figure 6: Schematic using the AC-coupled power supply

Now, one has to consider two time constants, one following the other. Even though the time constant of the signal conditioner is usually higher than the time constant of the sensor, it is necessary to consider the effect of the "double AC coupling " In order to investigate the effect of double AC coupling, one might put together a system of differential equations:

$$\begin{cases} \frac{dx}{dt} + \frac{1}{TC_1} x = \frac{du}{dt} \\ \frac{dy}{dt} + \frac{1}{TC_2} y = \frac{dx}{dt} \end{cases} \qquad (3)$$

One might notice that the first equation in the system (3) is the same as the one used (2) to describe the output of the sensor alone. This makes a lot of sense if one considers the AC-coupled signal conditioner as a recipient of the signal when it comes out of the sensor. So, the same type of differential equation needs to be solved but the input function is different this time.

Instead of building up pressure, now it is more like a long impulse. Function x(t) is known from previous example, TC2 is 5 seconds (typical TC value for 4105C Dytran signal conditioner). Using Euler's method to solve this system numerically, one can observe the following results:

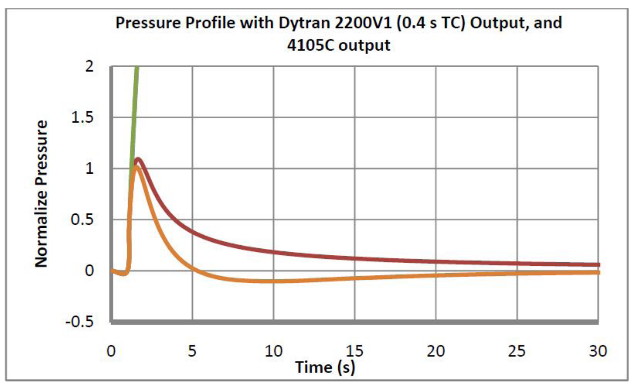

Figure 7: Applied Pressure (Green), 2200V1 Output (Red), and 4105C Output (Orange)

One might notice an interesting result of the calculation. The equations say that the decay is going to be faster than the 0.4 second time constant. So even though the signal conditioner (4105C) has a 5 second time constant the overall decay is less. It makes sense in the way that Figure 6 shows two capacitors in series and two resistors in parallel. Such a combination makes the resistance less as well as the capacitance. This results in the lower overall time constant. Another interesting result is the “overshoot” that one can observe in Figure7. This overshoot is a typical reaction of the AC-coupled device to the impulse input (red trace looks to the 4105 as a some sort of an impulse).