COMMON ART LINEAR INSTRUMENTS

Mechanical means of sensing density have been tried in the form of continuously weighing the pipe line containing the flowing media. However, unacceptable errors were hitherto predominantly caused by media noise and externally induced vibration, as well as inadequate compensation for temperature change.

Two common art types of linear instruments below have been used in attempts to measure density by measuring the deflection of a flexible pipe caused by variation in weight of the media flowing through it.

ZERO ORDER LINEAR INSTRUMENTS

These provide an output proportional to the input at all times in accordance with the equation:

$$y(t) = kx(t) \quad (1)$$

where:
y = output signal
x = input displacement

Both these parameters are a function of time t, related by a static gain constant k.

An example of this is the common strain gauge. The strain gauge is typically bonded to ceramic or metal substratum and has a high natural frequency. The change in its electrical resistance is proportional to the input measurement of the strain applied to it. This is commonly applied to continuous weight measurement of solids on a conveyor belt, whereby the output responding immediately to external plant vibration is reduced by a suitable form of electronic dampening.

In the case of an in-pipe density meter, externally induced plant vibrations result from locally installed pumps, rock crushers and similar machinery. Other sources of vibration result from the slurry itself, as it travels inside the density meter, often at high velocities. The high natural frequency of modern zero order linear devices results in externally induced high frequencies being ignored, but logically, only if such frequencies and their amplitudes are measured, can accurate compensation result. Tests show that unless the relevant spectrum of plant and media induced vibration at both low and high frequency is measured and hence compensated, unacceptable errors ensue. Consequently, zero order linear instruments have limited accuracy, resolution and range, and rely on signal dampening in an attempt to improve accuracy.

Figure 2 shows the unacceptable effect of externally induced plant vibration and media noise superimposed on a true density signal from zero to some measured amount. The output signal is particularly affected over the first 20% of the response time, known as the Time Constant, period T, of this typical natural logarithmic function. In this example, the response time, otherwise known as the dampening time, is 20 seconds. Even with a substantial 10 minute response time (5T), unacceptable errors occur over the Time Constant period. Furthermore, such long response times are undesirable, since a substantial amount of often very expensive mining slurry can pass without variations in density being measured.

FIRST ORDER LINEAR INSTRUMENTS

These provide an output given by a classical non-homogenous first order linear differential equation

$$T.[dy(t)/dt] + y(t) = k.x(t) \quad (2)$$

T = the time constant of the instrument.

Common art first order linear sensors often incorporate relatively large displacement diaphragms or movements, normally with dampened outputs. The sensing displacement of such first order instruments are relatively large compared to the double amplitude of the vibration applied to them. However, as in Figure 2, the output response of first order linear instruments, occurring particularly in the time constant of the natural logarithmic function, is still adversely affected by external vibration and media noise.

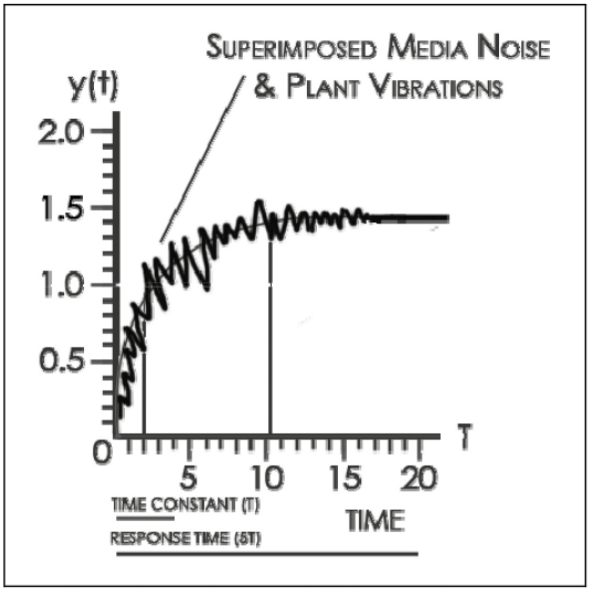

Figure 2. Undesirable vibration errors despite substantial damping.

Linear Voltage Displacement Transducers (LVDT) are classical first order linear sensor systems. However, their use is not applicable to the Density Meter described herein, since the deflection of the flexible flow tube from zero to full scale density is typically measured in thousandths of an inch (hundredths of a millimeter) and may be described as virtually solid state.

With first order linear sensors the solution is given by the classical natural logarithm e function

$$y(t) = k\,[1 - e^{(-t/T)}]$$

where
the initial rate of change of y(t) = 0 = k / T (3)
After time t = T the equation becomes

$$y(T) = k(1 - 1/e) = 0.632k \quad (4)$$

If the Time Constant T is small the instrument response time is fast, since it reaches 63.2% of its full scale natural logarithmic function. If T is large the instrument response time is slow.

Common art electronics, known as RLC circuits, incorporate resistance, inductive and capacitive techniques to dampen electrical output. However, these are normally only effective from 20% - 100% of the response time. The first 20% of the response time, defining an initial Time Constant period, contains a steep rise in output, and again is susceptible to the effects of external sources of vibration and media noise. This causes instability in the output signal and display. More advanced signal dampening incorporates digital filter techniques, but these are normally only suitable