for frequencies in excess of externally induced vibration and media noise. One such advanced filter technique is known as Finite Duration Impulse Response FIR (Reference 4: Kobayashi, M., Kuruso, S., Ohnishi, h., Tasaki, R., Yamazaki, T., 2003). This appears to achieve a type of critical damped condition, but only at frequencies > 100 Hz. Plant induced frequencies and media noise of liquids and slurry in a pipe have frequencies normally < 100Hz, and can commonly occur as low as 0.25 Hz. In this reference it is admitted that at such low frequencies, "It is practically impossible to separate the measured signal from the noise." Various algorithms have been consequently developed in an attempt to detect and account for lower frequency disturbances (References 2, 3, 5: Kameoka, K. et al, 1996; Lee, W.G. et al, 1994; Ono, T., 1999). However, such algorithms have had limited success when used with liquid and slurry in pipe lines. These references are more applicable to conveyor belt weighing machines with predictable loads occurring at regular time periods. Flowing liquids and slurry in a pipe, compared to media transported on a conveyor belt, induce a wider variety of relatively low frequencies, typically 0.25 - 100 Hz. The Density Meter described herein teaches a different approach to achieve critical or over-damped conditions, while still having an acceptable response time.

In summary, zero and first order linear sensors, often incorporating small displacement diaphragms, or strain gauges fixed to a stiff metallic or ceramic substratum, have a natural frequency significantly higher than typically 200 Hz, which is higher than the normal maximum natural frequency of externally generated vibrations and media noise. Consequently, such high natural frequency sensors cannot respond effectively to the lower external induced vibration and media noise, and vibration compensation cannot be suitably accomplished.

A NEW TECHNOLOGY

Mining engineers have always sought the simplest and most accurate method of continuously measuring the density of slurry. The most direct method would be to continuously weigh a calibrated volume. But the biggest problem with weighing in mining applications has always been the effect of externally induced vibration and media noise superimposed on the weigh signal, as well as considerable changes in media or ambient temperature. The non-nuclear Density Meter described herein, referred hereafter as a SCIAM Density Meter, has overcome these problems, with exciting additional benefits (Reference 8: www.SCIAMworldwide.com)

As a preamble, an understanding of 'externally induced vibration and media noise' is beneficial. Normal externally induced vibration, such as from pumps and other machinery, as well as noise from such media as liquids and slurries flowing in a pipe, is described as 'pink noise'. Every day examples of pink noise is that generated by sand running through an egg timer, by a multitude of vehicles traveling over a bridge, or by a distant ocean roar. It is understood that most pink noise in this respect is in a frequency range up to 1000Hz, although in applications in the mining industry, concern is primarily with frequencies 0.25 to 100 Hz. Figure 3 shows a typical periodogram of such pink noise, with typical magnitudes of 30 dB at various periodic times. Random pink noise has a typical trend of decreasing by 3 dB per octave, and the decibel magnitude is proportional to 1/f, where the frequency f is presented on a logarithmic scale.

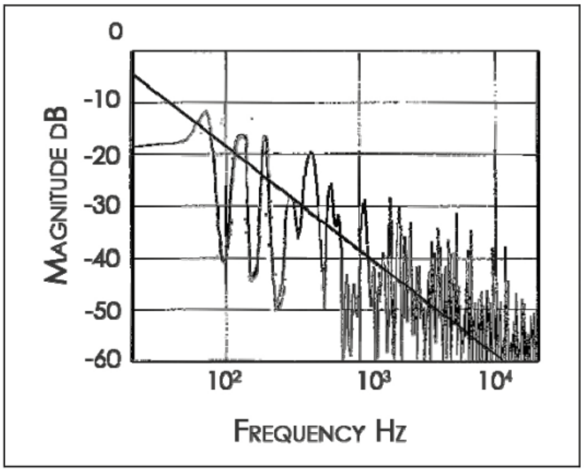

Figure 3. Periodogram of pink noise.

SECOND ORDER LINEAR SCIAM DENSITY METER

The SCIAM Density Meter provides an output which is given by a classical non-homogeneous second order linear differential equation

$$d^2y(t) / dt^2 + 2\rho.\omega.dy(t) / dt + \omega^2 .y(t) = k.\omega^2 .x(t) \quad (5)$$

where ρ is the damping factor and ω is the natural frequency of the SCIAM Density Meter. The input of a second order linear instrument oscillates about its position of equilibrium, typically restrained by a spring or, in the case of a SCIAM Density Meter, by a stainless steel rope, upon which the flow tube is suspended. The natural frequency ω is the frequency of these oscillations. The restraint of the stainless steel suspension rope opposes these oscillations with a force proportional to the rate of change of the vibration forces caused by internal media noise and externally induced vibration applied to the SCIAM density Meter. The damping factor ρ determines the force in opposition to the oscillation frequency.

A simple example of a second order linear instrument is a U-tube manometer for measuring differential pressure. Due to measurement noise the indicator liquid in the manometer tends to oscillate from side to side at a frequency determined primarily by the weight of that liquid. Here the dampening is normally caused by the liquid viscosity and friction between the liquid and the U-tube walls. Although in appearance a U-tube manometer is nothing like a SCIAM Density Meter, the second order sensing techniques are similar, except uniquely the amplitude of oscillation in a SCIAM Density Meter is so small it may be described as virtually solid state.

With the initial condition **$y(0) = 0$, then $dy(0) / dt = 0$** and the response time depends on the damping factor ρ.

Using an algorithm in remote electronics of the SCIAM Density Meter, an undampened condition is achieved with **$\rho = 0$** and y(t) oscillates as shown, with period **$2\pi\omega$**. Further conditioning in the SCIAM Density Meter algorithm is achieved as follows, with Figure 4 showing graphically the function **y(t)** for various values of dampening ρ:

- Under-damping is achieved with **$\rho = 0.3$, $k = 1$, $\omega = 1$**
- Critical damping is achieved with **$\rho = 1$, $k = 1$, $\omega = 1$**
- Over-damping is achieved with **$\rho = 3$, $k = 1$, $\omega = 1$**
- Optimum damping is achieved with **$\rho = 0.7$, $k = 1$, $\omega = 1$**