Berlin Athlete Filters

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There has been some recent discussions both within ISSS and in DIN committees concerning the appropriate filters that should be used to process signals from Berlin Athlete impacts. An analysis of the frequency response of the machine would seem to be a precursor to these discussions.

The approximate frequency response of the Berlin Athlete can be evaluated by modelling it as a coupled two mass spring vibrator.
The differential equations describing the motion of such a system can be written as follows:

$$mx'' = -kx - rx' + K(X - x) + R(X' - x')$$

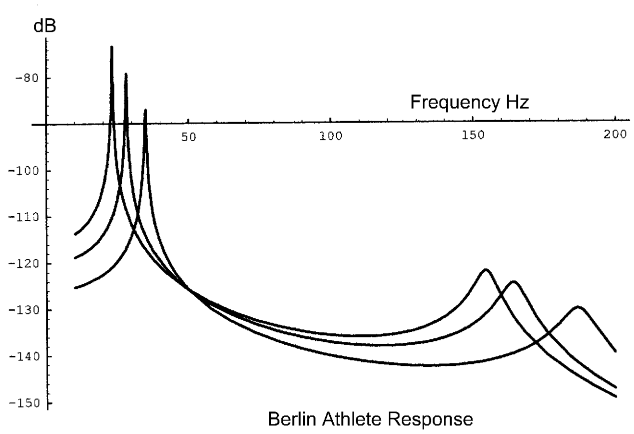
$$MX'' = F(t) - K(X - x) - R(X' - x')$$

where M, K and R represent the large mass (20 kg), the Berlin spring constant and the damping constant of the spring, and
m, k and r represent the foot mass, the effective spring constant of the surface and the damping constant of the surface,
X and x are the displacements of the 20 kg mass and foot, the primes and double primes, the first and second time derivatives of these displacements, and
F(t) is the force.

For this model it is further assumed that :
the mass of transducer and foot = 3 kg
the surface acts as a linear spring, with some damping

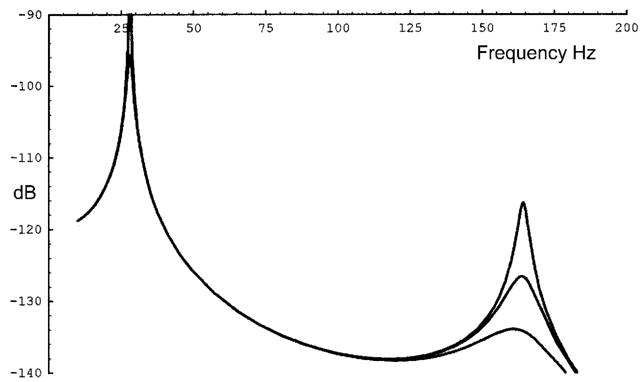
The frequency response of the transducer admittance can be determined[1] from these equations and is shown in the figure 1.

[1] J.I. Dunlop (1992), *Felt pad vibrations properties and design criteria*, J. Acoust. Soc. Am. **91** 2969 - 2702



The three curves represent the responses for surfaces with Force Reductions of 50, 40 and 30 % (from left to right). The primary peak below 50 Hz is due to the vibration of the 20 kg mass, and the secondary peak, at 155 to 200 Hz, to the vibration of the 3 kg foot. (It would be 7 % lower in frequency for a 3.5 kg foot)
The concrete response would be a single peak at 50 Hz.

Relatively low damping values were used for r, the surface damping, to compute these graphs. Decreasing the damping results in sharper peaks, but with similar relative amplitudes. Increasing the damping results in the secondary peak decreasing and with further damping disappearing, with little effect on the width of the main peak. This is illustrated in the figure below which shows the effects of three different levels of damping (damping constant per unit mass of 2.5, 10 and 25 X 10^{-6}) for a surface of FR = 40 %.



The rationale for a filter with cut-off at 120 Hz appears to be to eliminate the signal from the secondary peak. However, the intensity of the secondary peak is 35 to 50 dB below that of the main peak. So the 120 Hz filter with a reasonably steep cut-off, say 4 pole at 24 dB/Octave, would produce a 6 to14 dB attenuation at the frequencies of the secondary peak, thus reducing the energy leakage from this peak to about 0.1 to 1

% that of the main peak. Only relatively soft (FR greater than 60%) and low damping surfaces would appear to present any greater leakage of signal into the pass band.

The cut-off frequency of the filter can be reduced to 80 or 90 Hz, with greater effectiveness in eliminating the secondary peak. The 50 Hz peak generated by the concrete drop should be unaffected due its expected narrow bandwidth.

Of course in the real machine other unwanted signals are generated, especially by the impact on the spring causing various internal spring vibrations and other noise, and these need to be eliminated. These signals would probably be dominant at higher frequencies, but are also likely to contribute some energy in the pass band of the filter. This is undefined and contributes to the uncertainty of the measurement.

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