Berlin Athlete Filters II

John Dunlop
Acousto-Scan Pty Ltd
26 October 2000

The frequency response of the Berlin Athlete has been previously analysed (ISSS Web Page, 1April 2000) in terms of a coupled two mass, two spring mechanical system and shows two resonances – a principal one at 50 Hz due to the 20 kg mass and the 2 MN/m spring, and a secondary one in the region 130 - 200 Hz, the exact frequency being influenced by the mass of the foot and the spring constant of the sample being tested.

In this investigation I measure and analyse the actual frequency response of the Athlete and discuss the significance of the different filters proposed.

The Berlin Athlete employed features a Rein spring of 2 MN/m and a strain gauge Transducer (Transducer Techniques Inc) of compliance about 0.5 % that of the spring. The output electrical signal was processed through a smoothing filter of Channel Class 1000 (f_c = 1650 Hz) and a digital recorder sampling at 32 kHz. The mass of the anvil was 550 g and that of the transducer and foot 1.5 kg.

Concrete Test

A typical voltage time signal from the Berlin Athlete acting on a rigid concrete surface is shown in Fig. 1

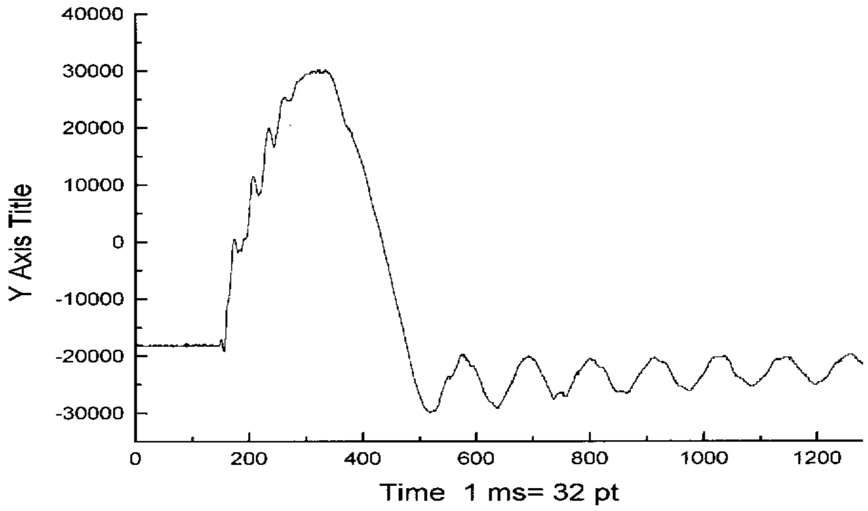

Fig 1. Time signal from concrete drop (1000 CC filter)

. The Figure shows the expected force half cycle (50 Hz) as the 20 kg mass is dropped onto the 2 MPa spring. This is followed by an oscillation of the anvil and the spring as the 20 kg mass separates after the bounce. Superimposed on the main half cycle is a parasitic oscillation around 1000 Hz due probably to internal vibrations in the spring.

Figure 2. shows the frequency spectrum of the signal in Fig. 1. This was computed using the 1280 point data sample padded for an 8192 point FFT with rectangular window. The spectral line (or point) frequency increment is then approximately 3.91 Hz.

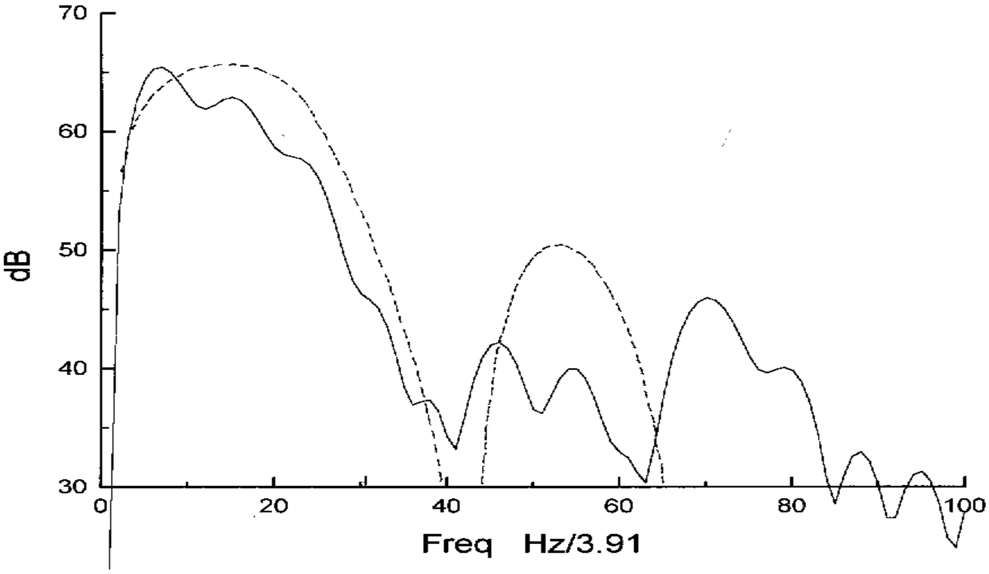

Fig 2. Spectrum of concrete drop
(Note frequency scale)

The spectrum shows a strong component in the 15 – 90 Hz region, corresponding to the 50 Hz half cycle, with an upper side band peaking at about 200 Hz . It is a broad peak due to the short time of the sample – a half cycle and agrees reasonably well with the theoretical spectrum of a half cycle of 50 Hz, shown in dotted line - a broad peak centred at 50 Hz, half width 100 Hz and upper side band (-14 dB) at 200 Hz.

There is another spectrum peak around 300 Hz corresponding to the anvil/spring vibration.

What is noticeable about the spectrum is its departure from the theoretical spectrum, particularly the main component. This may be due to a combination of FFT artifacts and the nature of the input signal in Fig. 1. Discrepancies from the half sine force peak may be expected from a real mechanical system as opposed to a mathematical model. They may occur for example if the spring is not seated square to the falling mass which is likely with the domed foot sitting on a hard plane.

Reference Normal Test

Fig 3. shows the output signal from the Berlin Athlete testing Reference Normal M3 (which has a Force Reduction of about 42 %).

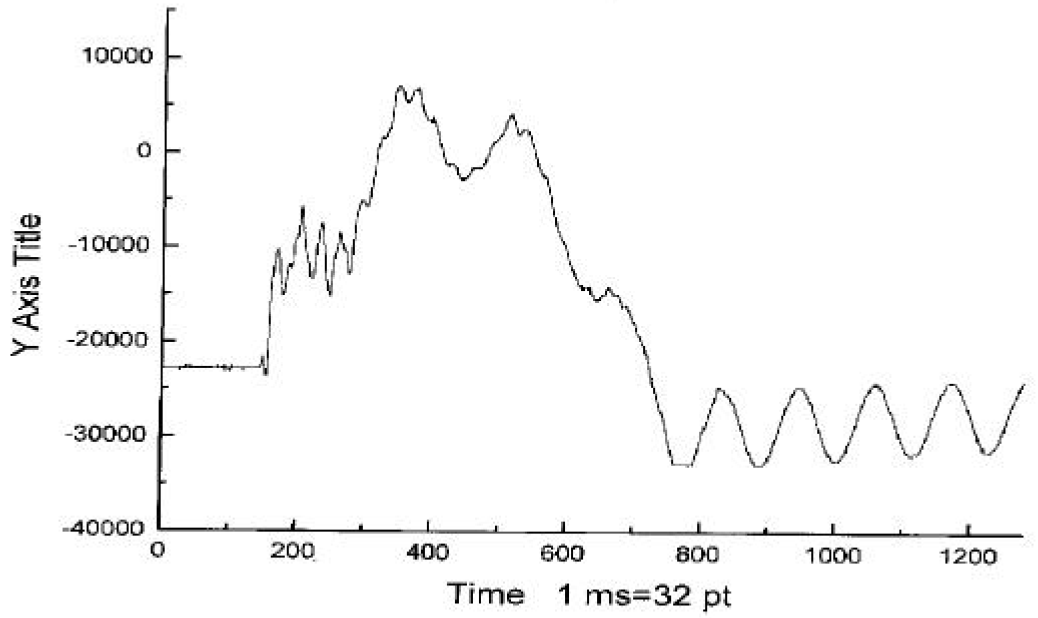

Fig 3. Time signal from drop on Reference Normal M3

This signal contains a principal half cycle on which is superimposed a secondary vibration (or ripple) of frequency 238 Hz (period 4.2 ms) as well as the parasitic 1000 Hz signal. These are followed by the anvil spring vibration as for concrete.

The previous work indicated a secondary vibration of about 170 Hz for a 40 % FR sample using a 3 kg foot which implies a 240 Hz signal for a 1.5 kg foot corresponding to the signal seen here.

Fig. 4 shows the spectrum of this Reference Normal M3 signal.

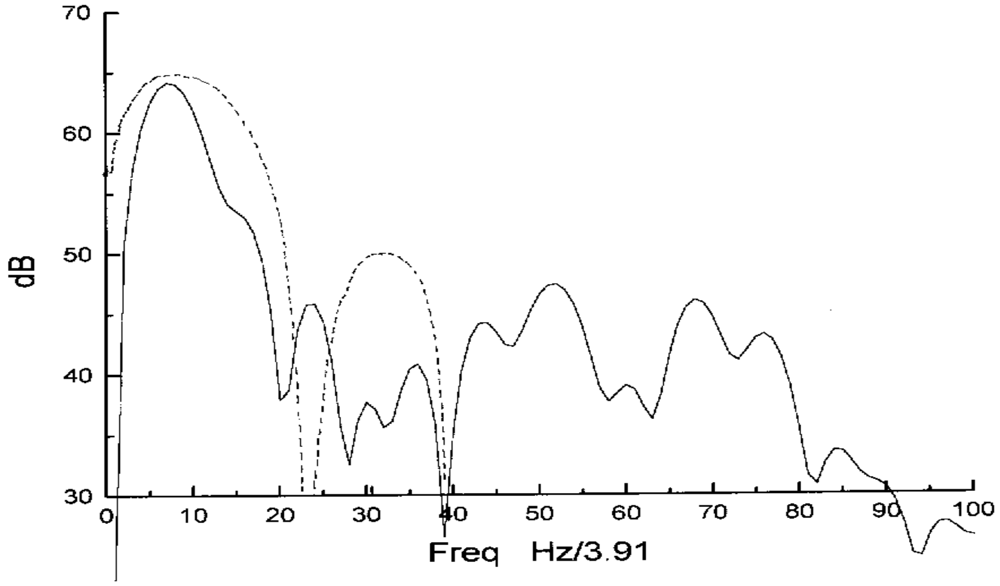

Fig 4. Spectrum of drop on RN M3 (1000 cc filter)

This spectrum features a principal component around 40 Hz with what may be upper sideband components between 100 and 150 Hz.
The theoretical spectrum of a half cycle of 32 Hz (indicated by a FR = 42 % sample in the previous work) and upper side band at 128 Hz, is shown in dotted lines on the figure.
There are also spectrum maxima above 160 Hz which may contain the energies of the secondary vibration as well as that of the anvil vibration.

Discussion

The Berlin Athlete seeks to measure the peak values of the principal force half cycle for concrete and for a sample.

Additional signals are generated - those due to the parasitic spring vibrations, the anvil/spring vibrations and the secondary mass vibrations - and the use of low pass filters seeks to reduce the magnitudes of these.
Some form of low pass filtering is required. Fig 1 & 3 suggest that the 1000 Hz filter leave some level of noise on the signals which may lead to undesirable variations in the peak forces measured.

Some of these extra signals are “unwanted”, but careful choices must be made as the filters may also affect the “wanted” components in different ways.
For example, any 120 Hz filter, say 9-pole as per ISSS, will reduce the magnitude of the concrete peak force more than that of the peak force from an absorbing surface such as Reference Normal M3. This is because the main force peak of the concrete signal contains energy in the upper side band frequencies, which is at a higher and more critical frequency than the signals from softer surfaces. This will result in a reduced concrete signal and produce a lower (harder) value for Force Reduction.
An earlier specification of using a 240 Hz filter for concrete and 120 Hz for the sample may have had some basis for leaving the relationship between the concrete and sample peaks measurements unaffected.

The aim of choosing the filter at 120 Hz is apparently to eliminate ripple that is characterised by frequencies above 130 Hz. This ripple, caused by the secondary mass vibration signals, may only be seen in highly elastic, low damping samples such as steel springs or perhaps wood floors, so this justification is limited.

Then again, in the case of the Reference Normal M3 or a corresponding surface, some of the energy of the falling mass goes into the secondary mass vibration so its main force component would to smaller. However the peak force developed, which is what the athlete experiences, is composed of both signals. Thus there may be a case for leaving the ripple on the signal and measuring the resulting peak force ie. for using a filter with cut off significantly above 160 Hz.

Conclusion

The low pass 120 Hz filters currently used to process Berlin Athlete signals may have a significant effect on the determined values of Force Reduction. For example, the ISSS 9-pole 120 Hz filter is likely to give significantly different (harder) results than the DIN 2-pole 120 Hz filter.

Some form of low pass filtering is required to condition the signal before peak measurement, but the filtering need not have a break frequency in such a sensitive part of the spectrum of the output signals.

End