Filters in Artificial Athlete Berlin
Determination of Force Reduction

Bernd Härting, IST Leipzig, 10 December 2006

This document is to contribute to the ongoing discussion about filters with the Artificial Athlete Berlin.

First, the impact on concrete must be discussed. A typical voltage versus time signal trace is shown in Dunlop´s paper (Fig. 1 Berlin Athlete Filters II, Acousto-Scan Pty. Ltd., 26 October 2000).

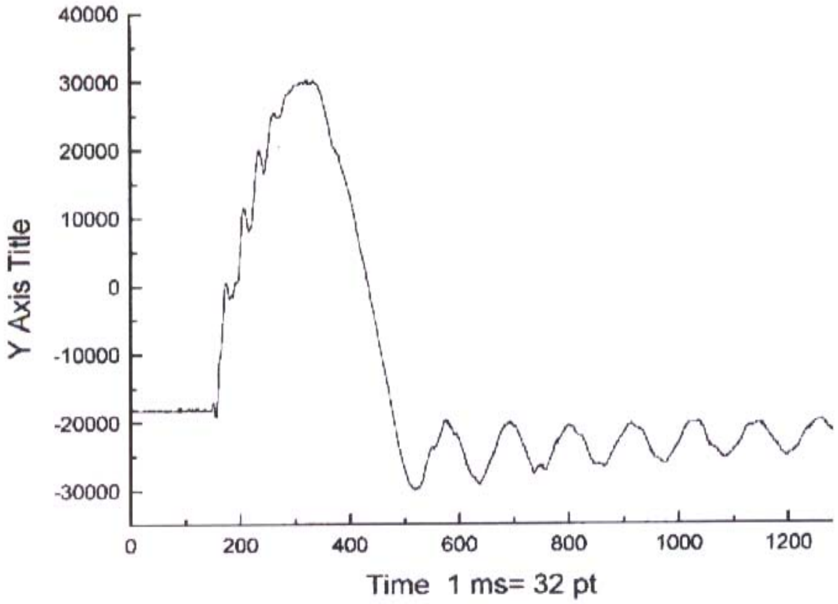

Fig. 1 Time signal from concrete drop (1000 cc Filter)

Figure 2. shows the frequency spectrum of the signal in Fig.1.

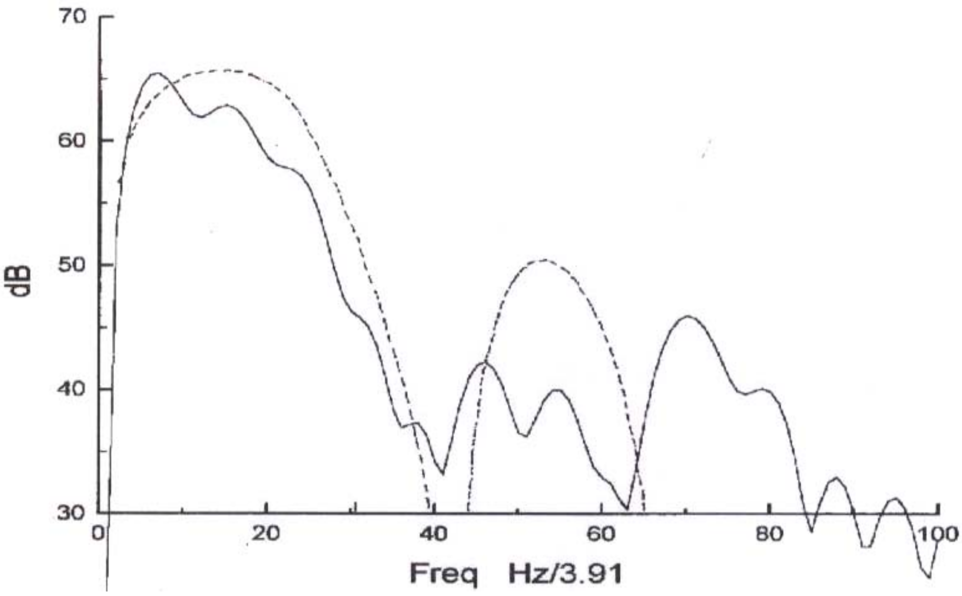

Fig. 2.Spectrum of concrete drop

Dunlop wrote : „The spectrum shows a strong component in the 15 – 90 Hz region, due the spring compression and release, with an upper side band peaking at about 200 Hz. It is a broad peak due the short time of the sample – a half cycle. The theoretical spectrum of a half cycle of 50 Hz, shown in dotted line, is a broad peak centred of 50 Hz with a half width 100 Hz and upper side band (-14 dB) at 200 Hz. There is also another spectrum maximum around 300 Hz corresponding to the anvil vibration."

In 1996, Härting found the same result which was reported in a paper to the DIN 18032-2 Committee (Fig. 3. and Fig. 4.). Figure 4 shows the frequency spectrum of the signal in Fig.3. In both spectra (Fig. 2 and Fig. 4.) higher frequencies than 120 Hz occur. Dunlop and Härting concluded that a 120 Hz cut off frequency is wrong since the signal contains frequency components up to 200 Hz.

Dura was right when he wrote that theoretically 99 % of the spectrum is below 120 Hz (Artificial Berlin Athlete: Notes about Butterworth filters, Juan V. Dura, 6 June 2005), but the frequency components above 120 Hz are responsible for the build-up of the signal peak. Therefore, it is physically wrong to eliminate frequency components above 120 Hz.

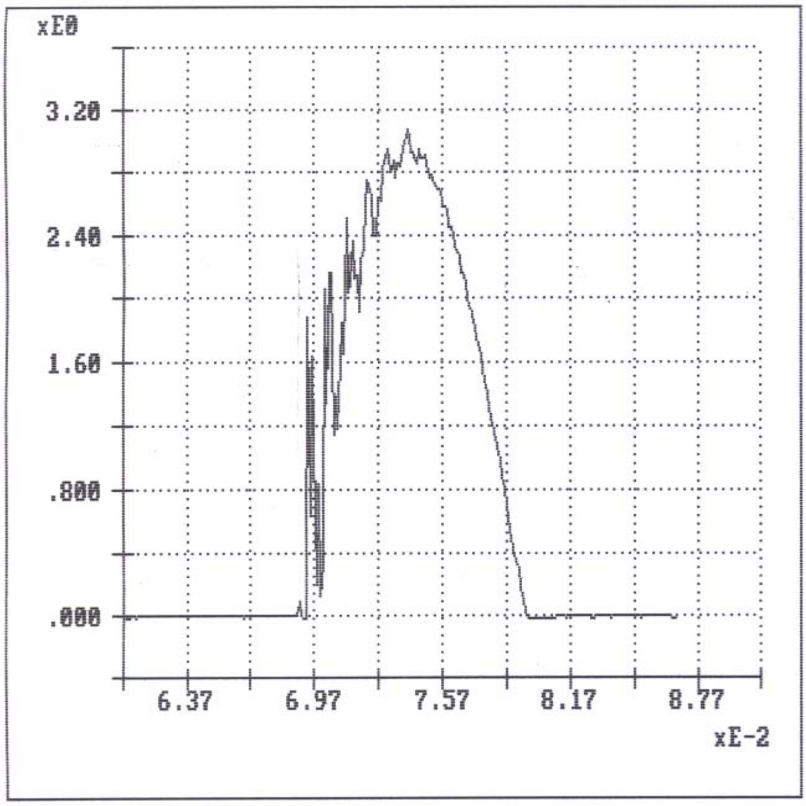

Fig. 3.Time signal from concrete drop without filter
Amplifier frequency range 0…3000 Hz

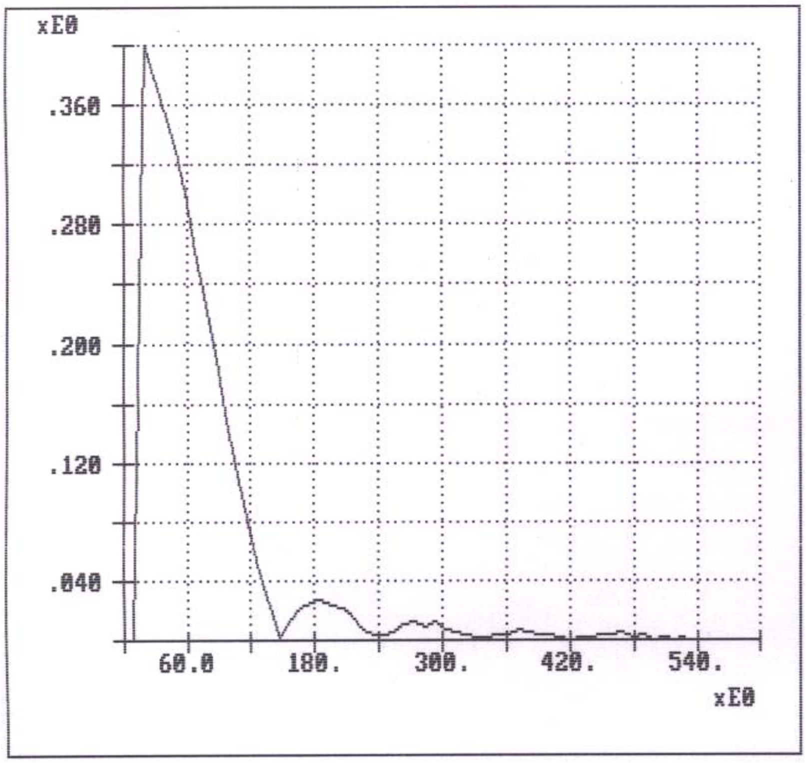

Fig. 4. Spectrum of concrete drop

Fig. 5. shows that all the main-signal overlaid components, electrical noise and mechanical vibrations, are eliminated after low pass filtering with a cut-off frequency of 250 Hz. Therefore, it is not necessary to filter with a lower cut-off frequency.

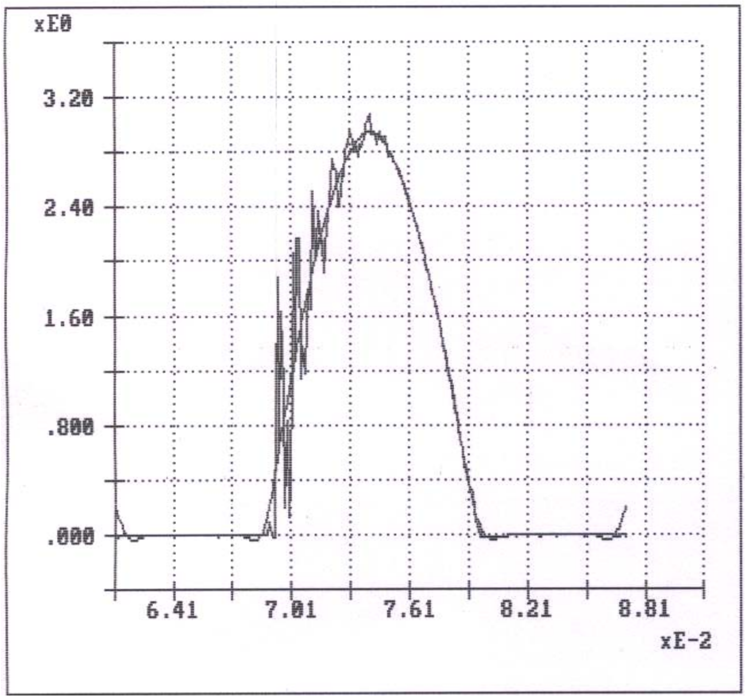

Fig. 5. Original time signal and filtered signal
Digital Low pass, f_g = 250 Hz

Lower cut-off frequencies eliminate the components which build up the peak of the signal. This reduces the peak value of the impact on concrete as we can see it in Fig. 6 and ends up in a decrease of the Force Reduction measurement.

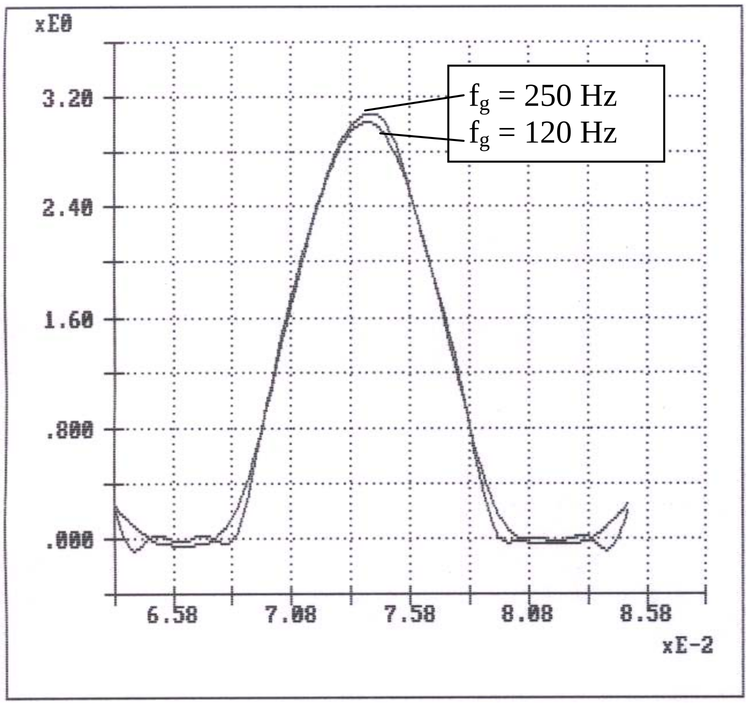

Fig. 6 Filtered curves

In 2000, Wagner (Rosenheim School of Engineering)also reported that the peak in the signal of the concrete drop is reduced by filtering with a 120 Hz 2nd order Butterworth Low Pass filter as compared with the results after filtering with a higher order filter (Fig. 7). Unfortunately, he did not compare with the results of filtering with a higher cut-off frequency, but he confirmed in this way that a 2nd order 120 Hz Butterworth Low Pass is wrong for filtering the signal of impacts on concrete.

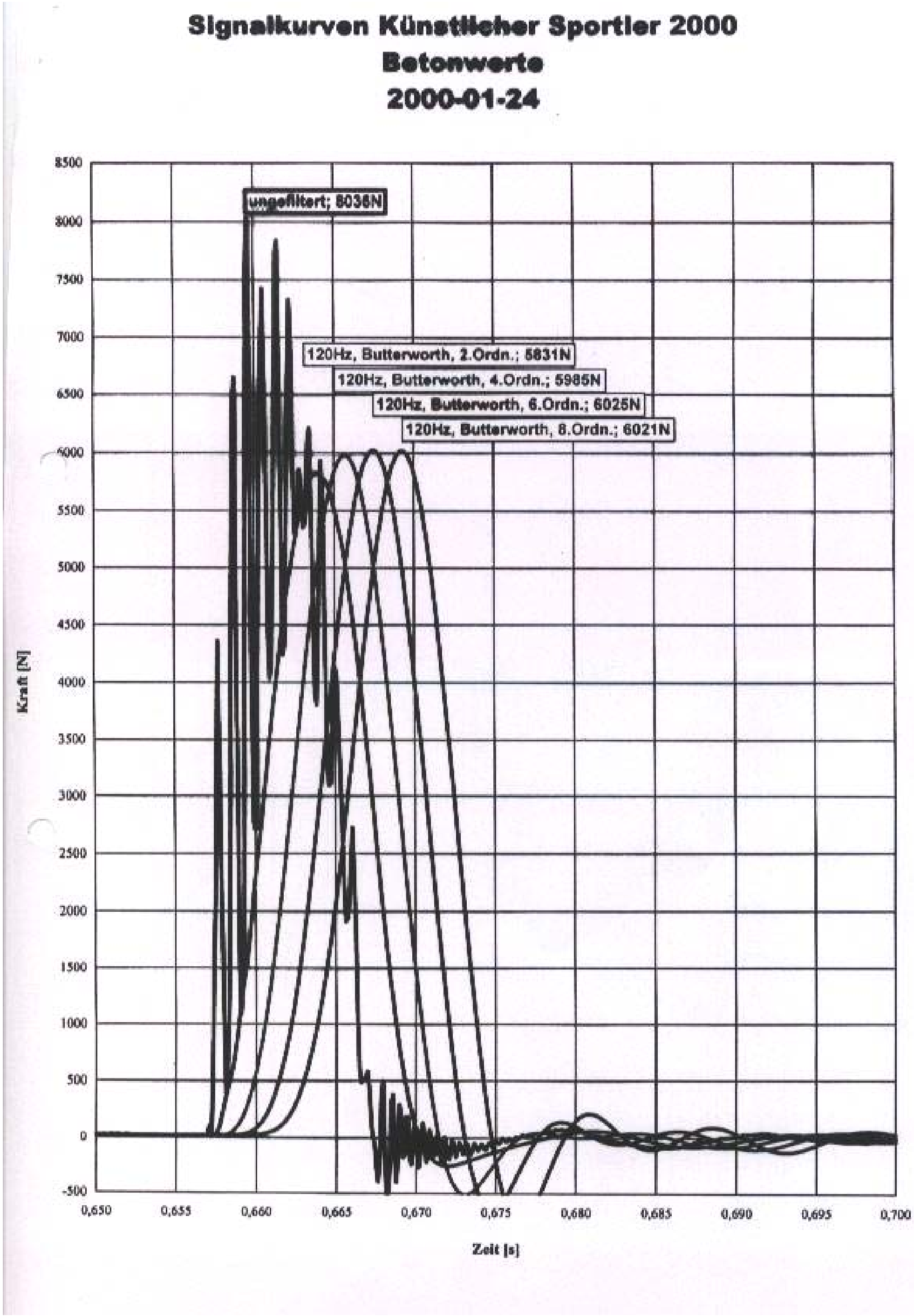

Fig. 7 Results of College of Rosenheim

The second part of the filter discussion addresses the impact on sports surfaces. Fig. 8. shows the force versus time signal resulting from a test on an area-elastic sports hall surface with an elastic layer.

We can see that the mechanical vibration is not completely eliminated with the 2nd order Butterworth filtration (blue trace, original trace is black). This mechanical vibration is a resonance vibration of the artificial athlete which is typical for every Artificial Athlete. In 1996, a German round robin test showed that every artificial athlete has his own inherent frequency, depending on its design. The frequencies of 6 devices ranged from 184 Hz to 233 Hz.

In Fig. 8 we see a small remainder of the mechanical vibration after 9th order Butterworth filtration (green trace) and the complete elimination after FFT-filtering (red trace).The peak values of both curves are approximately the same.

However, it is the aim of the filtration to eliminate this vibration completely from the signal. Therefore, a 9th order Butterworth filtration or a filtration using the FFT is needed to achieve this.

The incompletely cleaned signal reveals a peak value which is too high. This ends up in a decrease of the Force Reduction measurement. This is confirmed by the latest test data provided by Cox (information dated November 24, 2006).

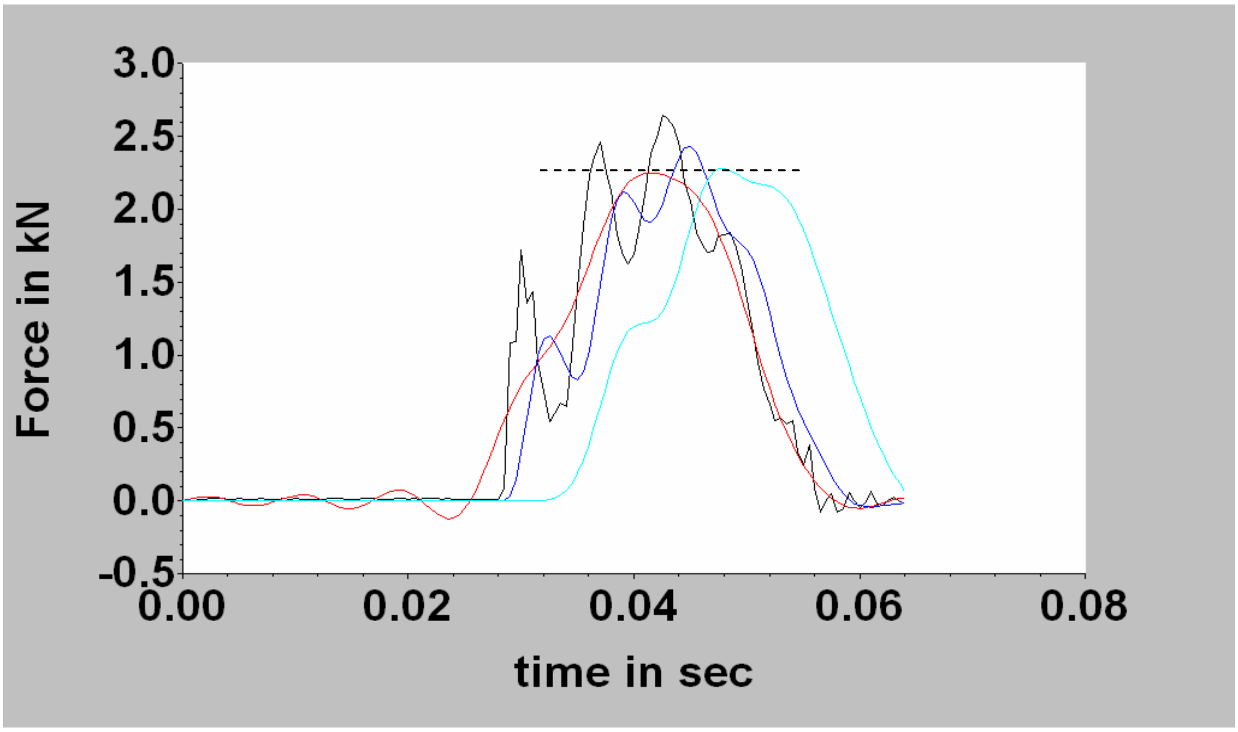

Fig. 8. Area-elastic sports hall surface impact (IST Leipzig)

Fig. 9 shows that the result of Force Reduction measurement will be reduced twice by filtering with 2nd order 120 Hz Butterworth filter.

On the left side we see two traces of the same impact on concrete: one filtered with 120 Hz cut-off frequency and the other one filtered with 250 Hz. The right curves show an impact on an area-elastic sports hall surface. The blue trace was filtered with 2nd order 120 Hz Butterworth filter, the red trace with FFT Low Pass 120 Hz (similar to 9th order Butterworth, but no phase delay). Using the 120 Hz concrete value, which is too low, and the 2nd order 120 Hz Butterworth filtered surface value, which is too high, for calculation of Force Reduction results in a too low FR value.

Thus, the physically correct filter method is:

1. the reference value on concrete is to be determined with a low pass cut off frequency not lower than 220 Hz

2. the peak force value on sports surfaces with a 9th order Butterworth filter or an equivalent filter (i.e. FFT) with 120 Hz cut-off frequency .

Both conclusions were suggested by Mark Harrison in 1999 (Factors affecting the results of the “Berlin Artificial Athlete” shock absorptions test, Mark Harrison, 3 September 1999)

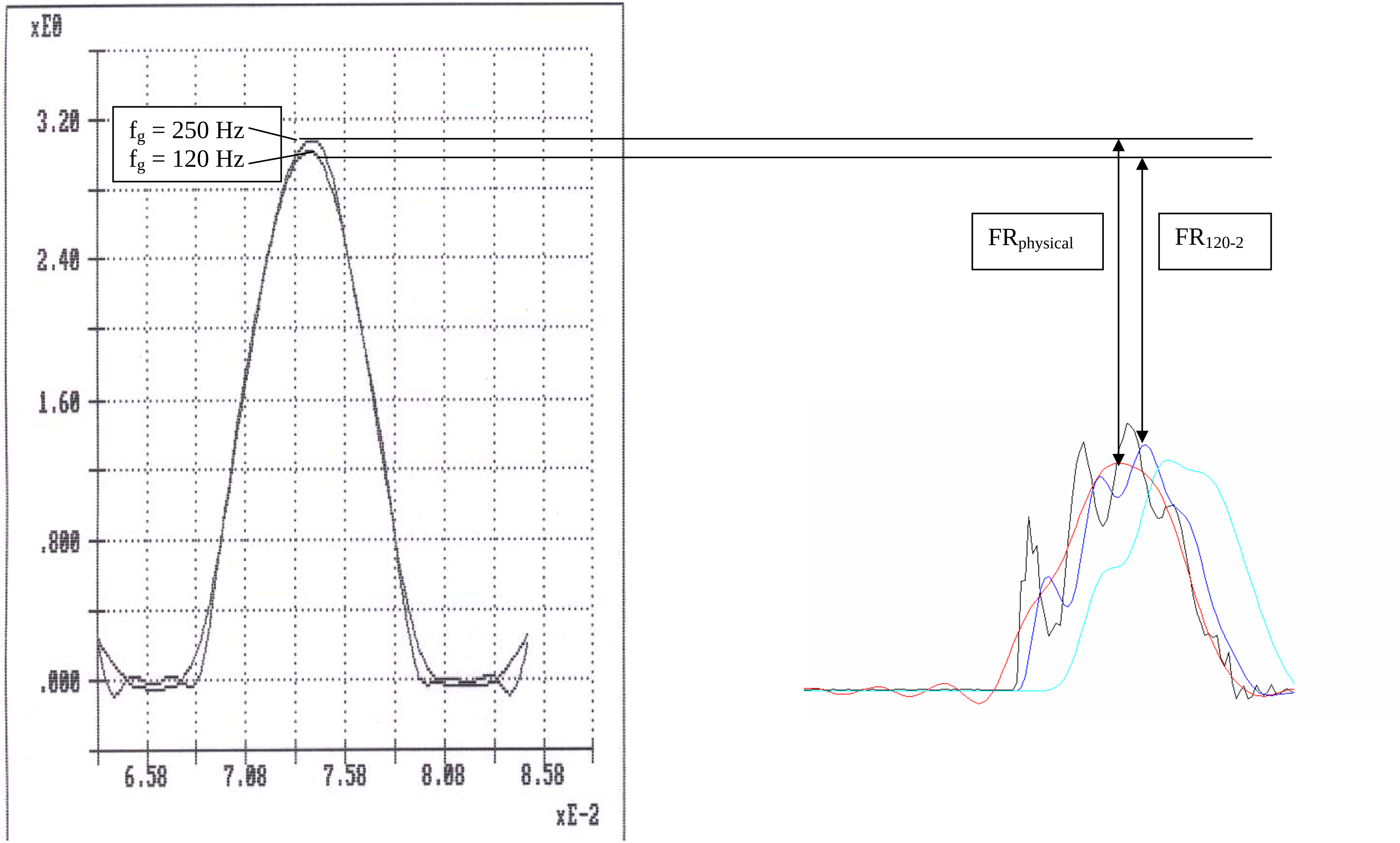

Fig. 9. Differences in measurement of Force Reduction, principle fig.