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Guidelines for Processing Biomechanical Digital Signals

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In an earlier discussion presented at the Fifth Annual meeting of this Workshop (New Orleans, October '77), the authors (Alem et al. from HSRI) expressed their concern over the inadequacies of the current practices for processing digital signals obtained in biomechanics research, and proposed several guidelines to be applied in processing signals for 9-accelerometer 3-D motion analyses.

The objectives of this presentation are to re-iterate this concern, and to stimulate the interest of this year's participants in unifying the data processing methods, so that biomechanical data, obtained by various research groups, is uniform and compatible.

There are two areas in digital processing of signals that lack uniform and adequate guidelines, both of which pertain to filtering. These are

1) the cutoff frequency of the filter applied to a given signal, i.e., the highest frequency (Hz) allowed to be passed by the filter, and

2) the type of filter to be designed and used with that signal, e.g., analog filter, digital finite impulse response (FIR) filter, or a truncation of the Fourier series expansion of the given signal.

In the first area, the guideline that is most often used is SAE J211-b which specifies Channel Class 1000 filter for head accelerations. The characteristics of this filter is to allow frequencies up to 1650 Hz (-3dB) to pass, with attenuation rates between 12 and 24 dB/octave for higher frequencies. Our experience at HSRI with direct head impacts (which have the potential of producing high frequencies) is that no significantly strong signals higher than 400 Hz are present in the resulting head acceleration signals. This conclusion was initially based on evaluation of noise in the time history, and recently confirmed by examination of power spectrum vs. frequency plots of over 15 head impacts to cadavers as well as primates, as shown in the typical spectra of Figure 1.

Another example of inadequacies of current guidelines is in chest accelerations (also in J211-b) which would apply when processing signals from accelerometers attached to ribs in thoracic impacts. While the guideline allows the passage of frequencies up to 300 Hz (-3dB), power spectra of these signals reveal that no frequencies higher than 100 Hz are present at a significant strength level, as seen in the typical spectra in Figure 2.

The second area that equally lacks uniform and adequate guidelines is the type of filter to be applied to an unfiltered signal before it can be analyzed. Again, SAE J211-b is the only recognized formal standard for specifying the dynamic response (attentuation vs. frequency) of filters, even though a variety of methods and filter types are currently being used, each resulting in a different frequency response, making direct comparisons of the generated data virtually impossible.

Essentially, the filtering techniques known to be practiced fall in one of 3 categories:

A) Analog filters, or the equivalent Infinite Impulse Response (IIR) digital filter, which produce significant and non-linear phase distortions.

B) Finite Impulse Response (FIR) digital filters with linear phase responses which can be implemented to produce phaseless filters.

C) Truncation of the Fourier series expansion of the signal, by cutting off (setting to zero terms of the series) all frequencies above the desired corner of the filter.

Each filtering method produces a different frequency response (dynamic characteristics) and has some advantages over the other. The choice of the filter by a user is usually dictated by the availability of the hardware and software and by the convenience of application.

The type of filter which has been in use at HSRI since 1974 is the FIR digital filter, where a "bank" of 18 such filters were designed and a particular one is selected for filtering a given signal. However, HSRI is experimenting with the truncated Fourier series method (a much more flexible and convenient filtering method) to see if significant differences exist between its results and those obtained with FIR filters.

In conclusion, regardless of the type of filter that is ultimately selected, there is a need for a uniform guideline which applies to digital filtering of biomechanical signals. Such a guideline can be adopted only if all individuals and groups involved in biomechanics research express their observations, requirements and preferences.

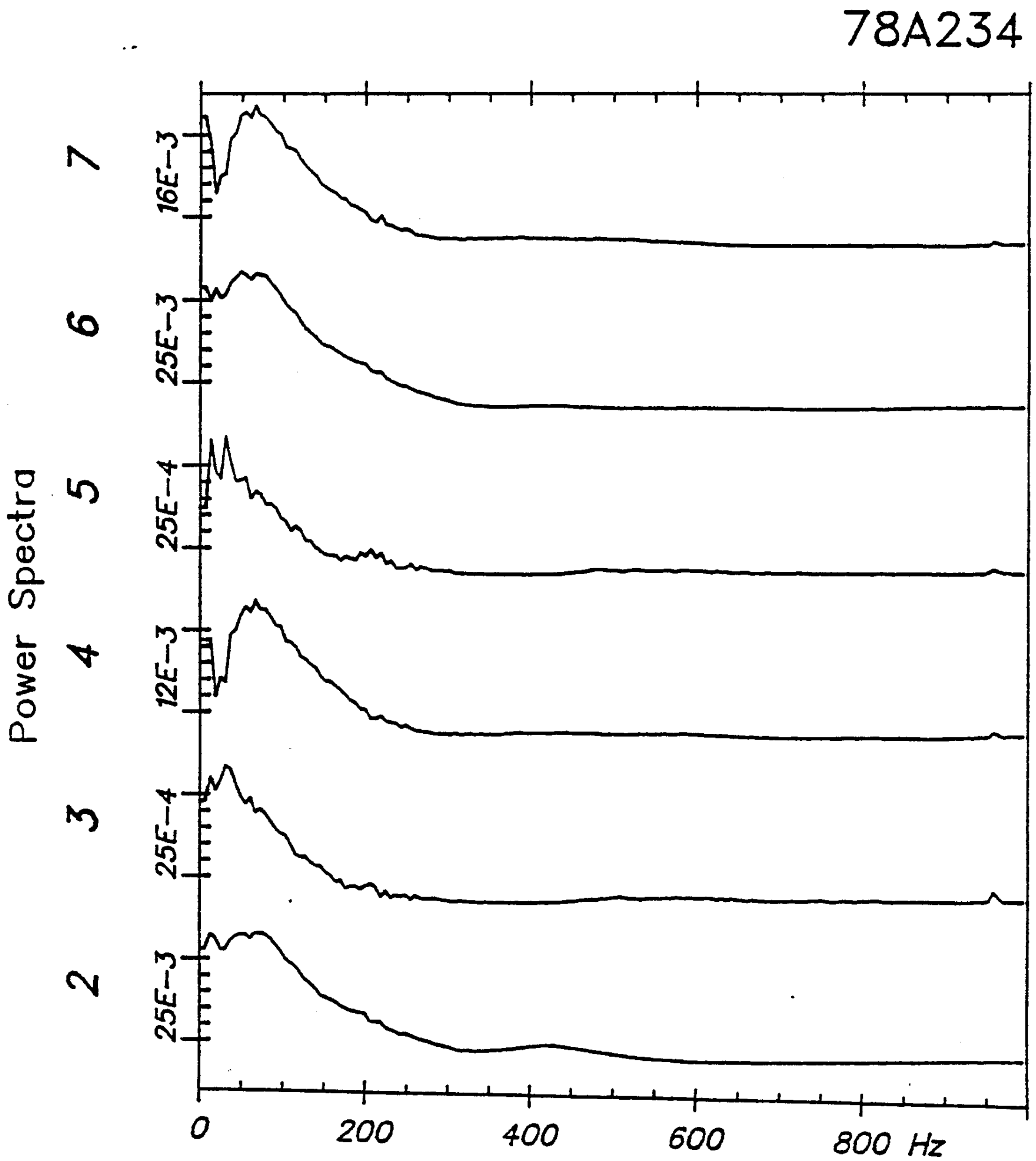

FIGURE 1. Power Spectra of Channels 2 through 7 of a primate head impact test (78A234). These are acceleration signals which contain no frequencies higher than 400 Hz. Power spectra of cadaver impact signals suggest lower frequency cutoff than primates.

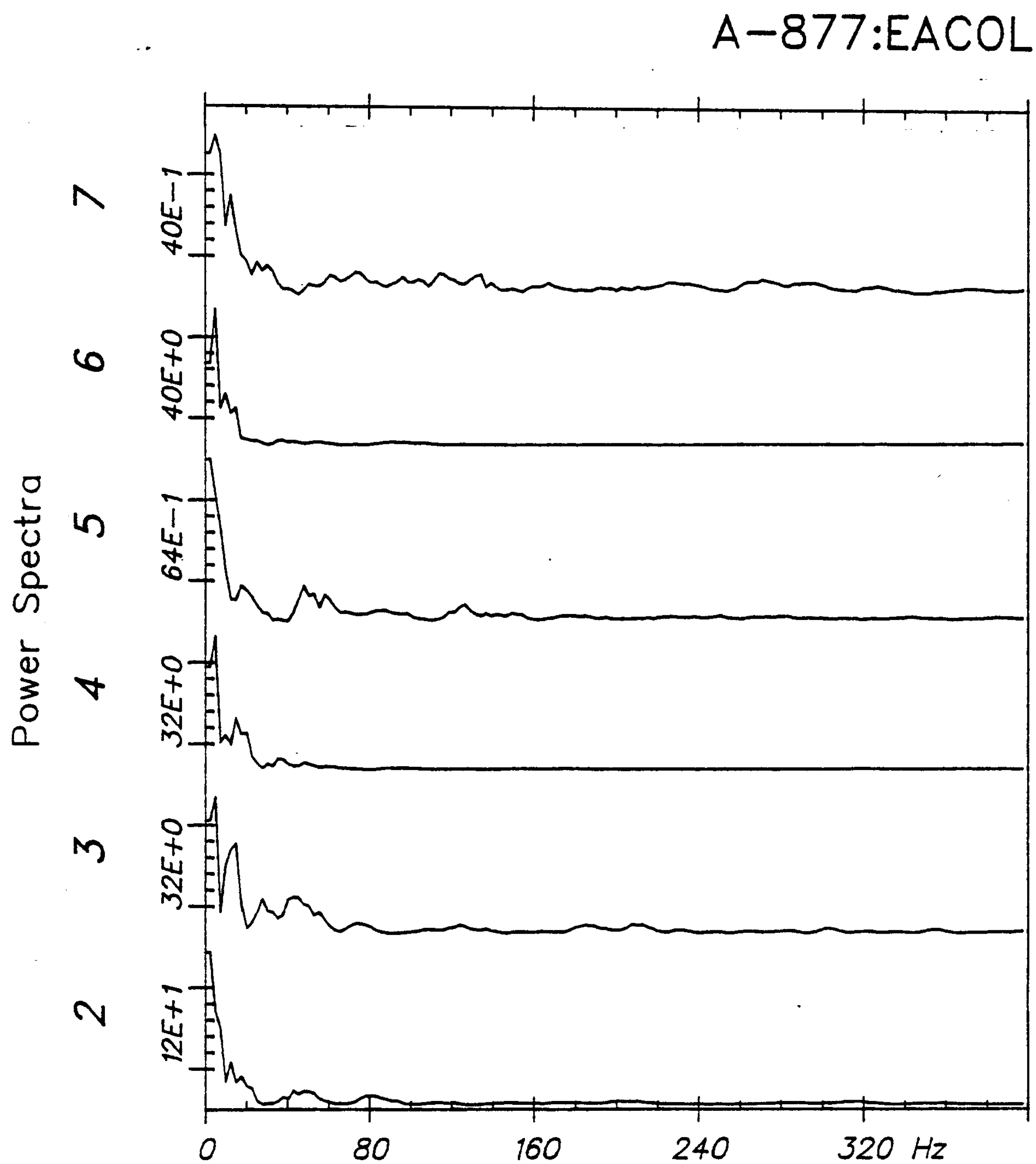

FIGURE 2. Power Spectra of Channels 2 through 7 containing signals from accelerometers attached to rib cage during EA column impact to the thorax. Note that no frequencies higher than 100 Hz are significantly strong.