Floor coverings in the form of carpets with or without compliant
backings act as noise abatement components with respect to footfall
and other types of impact noise. This is mainly due to lengthening
of the force pulse $F(t)$ produced by the impacting body, thus decreasing
the high frequency content of corresponding spectrum.

The compliance varies from fairly linear to very non-linear depending
on impact and type of compliant layer. The non-linear "bottoming"
gives with $F = \text{force}$ an increasing differential stiffness $\frac{dF}{dx}$ as a
function of indentation $x$. 4 simple cases $n = 1 - 4$ in $F = K_n \cdot x^n$
are shown in figure 1. The four curves absorb the same energy at maximum indentation $x_{\text{max}}$. So each $K_n$ was calculated from the given
$x_{\text{max}}$. Measured curves with the same character are shown e.g. in
ref [1:Lindblad].

Fig.1. $F(x)$ curves with the same given energy and $x_{\text{max}}$, $n = 1 - 4$. 611
The indentation pulse \( x(t) \) and force pulse \( F(t) \) for a hitting hard body, \( M \), with velocity \( v_0 \) can be calculated from \( M \ddot{x} + K x = 0 \). The linear case gives \( x = x_{\text{max}} \sin \left( \frac{2\pi}{f_b} t \right) \) for \( 0 \leq t \leq t_p = 1/2f_b \). The body rebounds at \( t = t_p = 1/2f_b \) with \( f_b = \sqrt{K/M/2\pi} \). We solve the case numerically by putting acceleration \( a_1 = -(K/M) \cdot x_1^2 \), velocity \( v_{i+1} = v_i + a_1 \cdot \Delta t \) and indentation \( x_{i+1} = x_i + v_i \cdot \Delta t \) in a loop.

![Graph showing indentation and force pulses](image)

Fig. 2. \( x(t) \) and \( F(t) \) curves with the same given \( x_{\text{max}} \), \( M \) and \( v_0 \).

Figure 2 shows indentation and force pulses calculated for the ISO hammer (0.5 kg, 4 cm height, \( v_0 = \sqrt{2 \cdot 9.81 \cdot \text{height}} = 0.88 \text{ m/s} \)). The normalization is maximum indentation 1.2 mm. The compliance is as in figure 1. The indentation \( x(t) \) maintains its form fairly much here but tends from sinusoidal to triangular form for large \( n \). The total pulse length \( t_p \) is only shortened some 20 \% for \( n = 4 \) compared to \( n = 1 \). The force pulse on the other hand alters significantly with \( n \) and by sight there is a short significant part \( t_p ^* = t_p \) for \( n = 4 \).

The corresponding normalized (DFT-calculated) force spectra are shown in figure 3. They are "white" up to some break frequency \( f_b \) and drop for \( f > f_b \). \( f_b = \sqrt{K/M/2\pi} \) in the linear case and increases with \( n \). In the linear case \( f_b \) is also \( = (v_0/x_{\text{max}})/2\pi \) or in the shown case.
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117 Hz. In the linear case the spectrum has dropped -2 dB at $f_b$. Using -2 dB to define $f_b$ also for $n \neq 1$ we get approximately in the four cases from figure 3: 125, 160, 200 and 250 Hz. In the linear case $t_p = 1/2f_b$ so if analogously we put $t_p = 1/2f_b$ in the non-linear cases we get e.g. $t_p = t_p/2$. It is evident that with maximum indentation given, the linear case minimizes high frequency content and also A-level and $I_1$ (Impact index).

Fig.3. Normalized spectra for force pulses from non-linear compliance corresponding to figure 2.

Many carpets are too soft at the "beginning" leading to strong non-linearity at the end. This can be the case already for the ISO-hammer and still more for jumping. The non-linearity leads to problems concerning optimization. This could be done for the smaller forces when nicely walking in light shoes, for just ISO-force or for the greater forces from e.g. jumping children. An adaption to the first case was discussed earlier (ASTM-hammer). Some practical malfunction of light-weight constructions with soft carpets, in spite of good ISO test values, has now turned our interest towards the last case. This holds especially for Canada and Scandinavia.

Just to demonstrate the effect of increasing starting stiffness we have put a layer of solid plastic carpet on top of a soft, needle punched carpet. The plastic acts as load spreading device. Figure 4 shows that for a small force $f_b$ was moved a little upwards and for
greater force $f_b$ was lowered considerably. The curves are time average third octave spectra from a force transducer in a hammer. Thus the increased stiffness is favorable for stronger impacts and further experiments will be performed with real forces from jumping et c.

![Graph showing 1/3-octave spectra for weak and strong hammer impact. Only carpet plus extra layer. "White" gives +10 dB/decad as bandwidth ~ freq.]

**Fig. 4.** Measured 1/3-octave spectra for weak and strong hammer impact. Only carpet plus extra layer. ("White" gives +10 dB/decad as bandwidth ~ freq.).

**REFERENCE**