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NON-LINEARITY PROBLEMS CONNECTED WITH IMPACT SOUND INSULATION MEASUREMENTS

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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 = force an increasing differential stiffness 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 absorbe the same energy at maximum indentation x_{max} so each K_n was calculated from the given x_{max}. Measured curves with the same character are shown e.g. in ref [1:Lindblad].

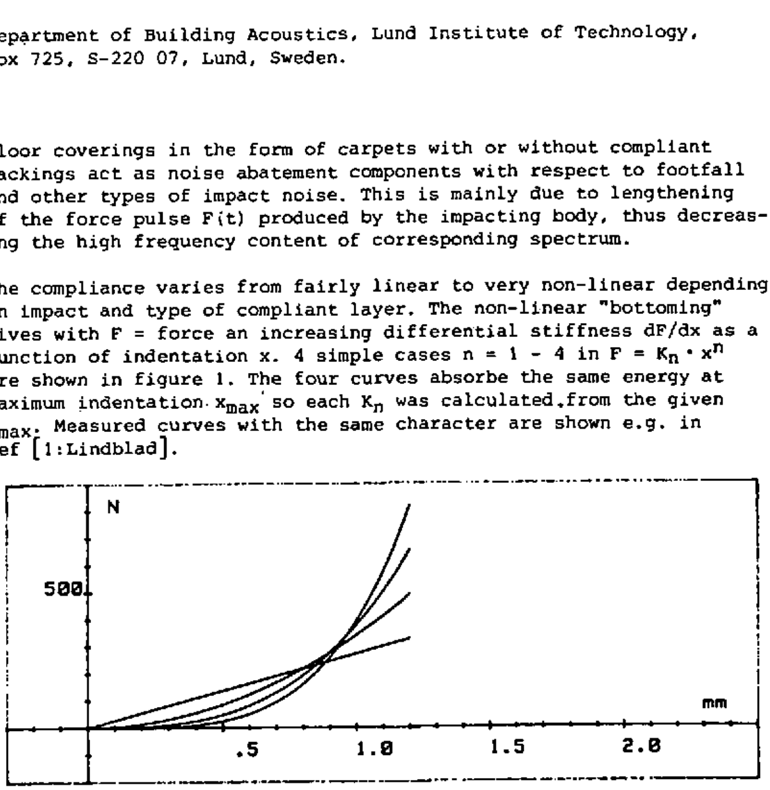

Fig.1. F(x) curves with the same given energy and x_{max}. n = 1 - 4.

The indentation pulse $x(t)$ and force pulse $F(t)$ for a hitting hard body, M, with velocity v_0 can be calculated from $Md^2x/dt^2 = -K_n \cdot x^n$. The linear case gives $x = x_{max} \cdot \sin(2\pi f_b t)$ for $0 \leq t \leq t_p = 1/2f_b$. The body rebounds at $t = t_p = 1/2f_b$ with $f_b = \sqrt{K_1/M}/2\pi$. We solve the case numerically by putting acceleration $a_i = -(K_n/M) \cdot x_i^n$, velocity $v_{i+1} = v_0 + a_i \cdot \Delta t$ and indentation $x_{i+1} = x_i + v_i \cdot \Delta t$ in a loop.

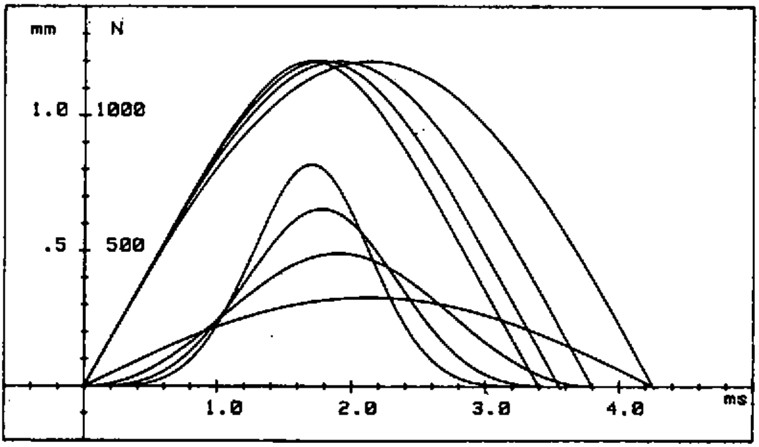

Fig.2. $x(t)$ and $F(t)$ curves with the same given x_{max}, M and v_0. $n = 1 - 4$.

Figure 2 shows indentation and force pulses calculated for the ISO hammer (0.5 kg, 4 cm height, $v_0 = \sqrt{2 \cdot 9.81 \cdot \text{height}} = 0.88$ 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 $f > f_b$. $f_b = \sqrt{K_1/M}/2\pi$ in the linear case and increases with n. In the linear case f_b is also $= (v_0/x_{max})/2\pi$ or in the shown case

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. $t_{p4}' \approx t_{p1}/2$. It is evident that with maximum indentation given, the linear case minimizes high frequency content and also A-level and I_i (Impact index).

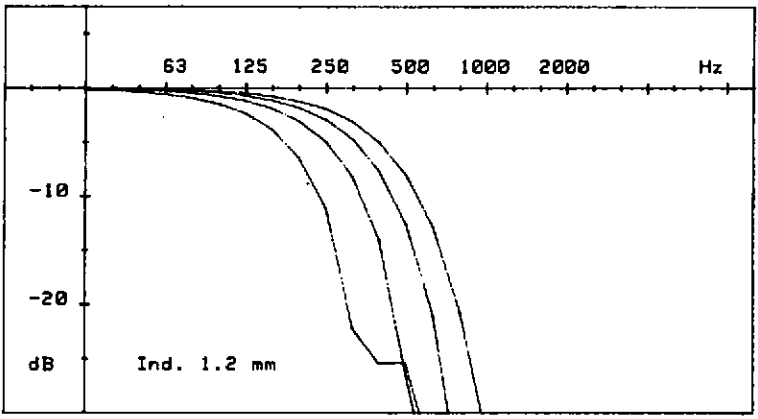

Fig.3. Normalized spectra for force pulses from non-linear compliance corresponding to figure 2.

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 lightweigt 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.

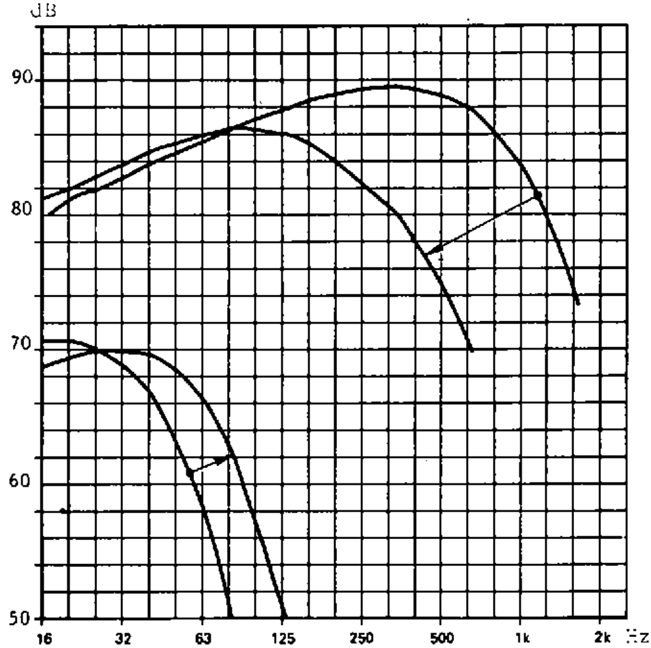

Fig.4. Measured 1/3-octave spectra for weak and strong hammer impact. Only carpet •———▸ plus extra layer. ("White" gives +10 dB/decad as bandwidth ~ freq.).

REFERENCE

[1] Seminar on Impact Sound Insulation Test Methods. ELAB report STF44 A82022. Editor J. Trampe Broch.