Materials with internal cracks or dislocations has a certain type of slow recovery towards equilibrium after a disturbance of its thermodynamic state. This concept is called Slow Dynamics (SD) which is a reversible process accompanied by nonlinearity [1–9]. In a solid material the slow dynamics is connected to the presence of cracks and dislocations. It can be utilized to determine a material’s quality or its damage level. It is an actual material property, and it is therefore important that it can be quantified. A measurement which only measures the SD is needed, and this is what is provided in this article.

One effect of the presence of Slow Dynamics is that a disturbance will decrease the material sound speed, evidenced by an immediate shift of the acoustic resonance peak to a lower value [10]. The peak will then slowly recover towards its equilibrium value. Any reaction to a new disturbance on the material before having reached equilibrium will depend on the current state. This means that the material state is dependent on its time history.

An advantage of resonance methods is that they have in general a very high sensitivity. The commonly used acoustic test is a frequency sweep with a constant input force with the frequency being changed step by step. It monitors the maxima of the wave responses indicating the resonant frequencies from which the sound speed of the material can be obtained. A threshold between different strain level regions has been observed. Below it the behavior can be described only by regular Nonlinearity, while above it also non-equilibrium Slow Dynamics occur [6, 11, 12]. This method is here called method A. When the frequency changes in the constant input force sweep, the actual amplitude inside the object varies. It is not unusual for factors of 100–1000 to appear, where the maxima are found at the resonant modes’ eigenfrequencies. Therefore the material is affected by the strain history, and due to the Slow Dynamics the material is constantly both in a state of recovery and influenced by the time dependent excitation.

It would be better if one could either: B—measure the fast non-linear response while being able to ignore the time history (the Slow Dynamics); or C—measure only the Slow Dynamics while being able to ignore the influence of any fast non-linear dynamics. Method B was presented in [13], and method C is presented in this article.

When the nonlinear responses are accompanied by the Slow Dynamics non-equilibrium recovery, it is difficult to interpret the results and to fit the results to theories. The first method (here called B) which to a significant degree managed to separate the two influences was reported in an earlier Letter [13], where a constant strain resonance frequency test measured the nonlinearity at a minimum of Slow Dynamics. There, the measurements (probing) of the sound velocity were made at the same strain level as the conditioning, followed by another sound velocity measurement at a constant low strain amplitude. There was a time delay on the order of minutes between the conditioning and the low strain measurements during which the material had time to recover. The material state was constant during each of the different strain levels, but the state was by necessity different for each level. These were measurements of the pure nonlinear distortion,
Fig. 1. Details of the test protocol. The probe strain level input $\varepsilon_p$ is the same for every cycle resulting in a varying output. The measurement points $A_k = A(\varepsilon_p, f_0 + k\Delta f)$ are taken at the five $\tau = \{1, 2, 3, 4, 5\} = \{0.2, 0.5, 1, 2, 5\}$ seconds for every conditioning level $\varepsilon$ and for every frequency $f_k = f_0 + k\Delta f$. The result are the amplitudes $A(\varepsilon, f_k, \tau)$. $T_0$ is the 30 minutes during which the conditioning is on before the start of the measurements.

where the otherwise omnipresent non-equilibrium slow dynamics had been minimized. Method B is described thoroughly in [13] where also a comparison between methods A and B is found. The advantage of method B was that the nonlinearity was measured without any $SD$ influence, but its disadvantage was that the protocol was slow and it took minutes after the end of conditioning before the actual nonlinearity was recorded.

In this article is described a third method denoted C, which, as an inverted method B, measures the Slow Dynamics without presence of nonlinearity. It is characterized by that the probing wave amplitude is always at a very low strain level, where the nonlinear effects are very weak. On top of that, the nonlinear effect is also constant for all data points, which means that even that small effect is cancelled out because the measurements are comparative.

The novel test protocol that measures the acoustical response at a low probing strain right after being exposed to a high strain conditioning is shown in Figs. 1 and 2 and will now be described in detail. In order to set the object in the specific state related to the conditioning strain level, it is first conditioned for 30 minutes by an acoustic wave at frequency $f_0$ and a drive amplitude $a_{cl}$ corresponding to a strain level $\varepsilon_1$. The equivalent resonance frequency for this steady state strain level is $f_1(\varepsilon_1)$, which in this article is the same as the conditioning frequency $f_{c1}$. (To provide for a faster return to equilibrium for every conditioning set, all the used resonance frequencies were determined in advance.) The strain is there after changed to a lower strain wave which has a constant low input voltage—the probe wave—at a specific frequency $f_0$ and amplitude $a_{0}$. The response amplitude in the object $A(\varepsilon_1, f_{0}, \tau) = A(\varepsilon_1, f_0, \tau_1)$ is recorded at the time $\tau_1 = 0.2$ seconds. Then the conditioning wave is put back on, at the same strain ($\varepsilon_1$) and at the same frequency ($f_{c1}$) as before, for $\tau_2 = 5$ seconds. The conditioning brings the material back to the same state (more or less) irrespective of that the recovery times $\tau$ are of different length because conditioning is much faster than recovery. The low amplitude probe wave is moved in frequency to $f_0 + \Delta f$ and the response is recorded as the value $A(\varepsilon_1, f_1 = f_0 + \Delta f, \tau_1)$. This frequency sweep process continues for several frequencies $f_k = f_0 + k\Delta f$, each yielding points to the response curve $A(f, \tau)$. It will have a maximum value at the resonance frequency $f_1(\varepsilon_1, \tau_1)$, which is the first point that goes into the resulting plot. For example, in the sche-

Fig. 2. The schematic protocol for conditioning level $\varepsilon_p$. The probe strain level input $\varepsilon_p$ is the same for every cycle resulting in a varying output $\varepsilon_p = A$ similar to a normal frequency sweep. The lower curve has a maximum $\varepsilon_{max}(\varepsilon_p, f, \tau) = \varepsilon(\varepsilon_p, f, \tau)$ which defines the resonance frequency $f_r$.

Fig. 3. A schematic plot of expected test results. The time $\tau$ is zero when the conditioning wave input ceases.