Mechanical Fatigue and Load-Induced Aging of Loudspeaker Suspension

Wolfgang Klippel[1,2]
[1]*Klippel GmbH, E-Mail:wklippel@klippel.de*
[2]*TU Dresden, Institut für Akustik und Sprachkommunikation,*

Introduction

Spiders, surrounds and other soft parts used as a mechanical suspension in electro-acoustical transducers vary significantly over time. The time varying properties of the suspension are caused by reversible processes such as the viscoelastic behavior of the suspension. The temporary decrease of the stiffness after large peak displacement recovers slowly after removing the stimulus. The stiffness also varies with the ambient temperature, humidity of the air and the absorbed moisture in the suspension material. Non-reversible changes which can be interpreted as an “aging” of the suspension having the following causes:

- Initial exposure to mechanical load opens some bonded joints in the impregnated fiber structure (break-in effect).
- Accumulated mechanical load causes cracks growing slowly, destruction of the micro-fibres and other mechanical deformations (fatigue [3]).
- High ambient temperature or voice coil heating changes the suspension properties permanently.
- Humidity, direct water contact and reaction with other chemicals change the material properties.
- Gravity changes the geometry of the suspension part and the coil’s rest position if the loudspeaker is mounted in horizontal position.
- Instability of the chemical compounds causes decomposition over time.
- UV light promotes chemical reactions and decay processes in diaphragms and surrounds.

It is the target of this paper to develop a model describing the aging process for any kind of stimulus and a new measurement technique for identifying the free model parameters.

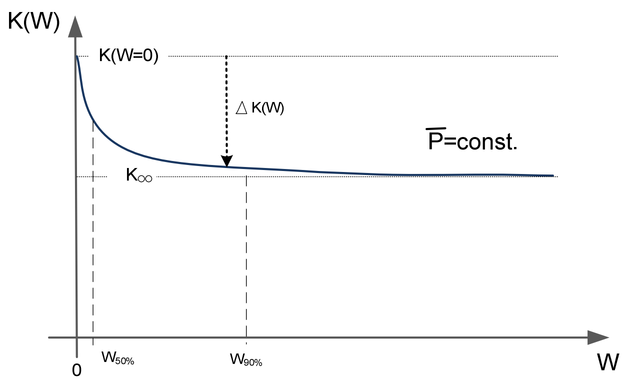

Fig. 1. Stiffness $K(W_k)$ versus accumulated work W measured at constant mechanical power $\overline{P}$

Dosage Model

The load-induced variation of the stiffness depends on

- the potential energy temporarily stored in the suspension considering the nonlinear force-deflection characteristic,
- energy dissipated into heat by losses in the material,
- frequency of an alternating stimulus [5],
- accumulation of the total power transferred to the suspension part during life time of the suspension.

An empirical model [1] of the aging process is presented which describes the variation of the stiffness K from a macroscopic view as an analytical function of the mechanical load accumulated during life time cycle. The mechanical load as the apparent mechanical power

$$P(t) = \left|F_k(t)v(t)\right| \tag{1}$$

which is the absolute value of the product of restoring force $F_k(t)$ and velocity $v(t)$. This value changes the potential energy and heat dissipation in the suspension and considers the nonlinear stiffness $K(x)$ generating an increase of the restoring force at high peak displacement $x(t)$. For a sinusoidal excitation with constant peak displacement $x(t)$ the apparent mechanical power rises with frequency f.
Fig. 1 shows the variation of the stiffness $K(x=0, W)$ measured at the voice coil rest position $x=0$ as a function of the accumulated work

$$W(t_m) = \int_0^{t_m} P(t)dt = \overline{P}t_m. \tag{2}$$

The curve shape of $K_{ms}(W)$ as shown in Fig. 1 is very similar to the curve shape of the original stiffness $K_{ms}(t)$ versus measurement time t_m as long as apparent power P(t) supplied to the suspension part is constant during the test.
The instantaneous stiffness

$$\hat{K}(x=0,W) = K(x=0,W=0) - \Delta K(W) \tag{3}$$

can be predicted by using the stiffness variation

$$\Delta K(W) = \sum_{i=1}^{N} C_i \left(1 - e^{-W/w_i}\right) \tag{4}$$

with the free model parameters C_i and w_i and a constraint $w_1 < w_2 < ... < w_i < ... < w_N$ ensuring uniqueness of the representation. Two exponential functions (N=2) usually give a good fitting of the measured data as discussed in detail below.

Measurement

The suspension system in an assembled transducer can be simply measured by monitoring electrical signals such as voltage and current [4] at the loudspeaker terminals as illustrated in Fig. 2.

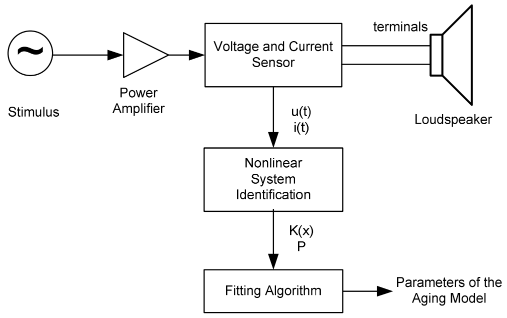

Fig. 2. System identification based on voltage and current signals measured at the loudspeaker terminals.

The apparent mechanical power

$$
\begin{aligned}
P(t) &= \left|F_{\mathrm{k}}(x)v(t)\right| = \left|K(x)x(t)v(t)\right| \\
&= \left|\frac{K(x)}{Bl(x)}x(t)Bl(x)v(t)\right| \\
&= \left|i_{\mathrm{k}}(t)u_{\mathrm{emf}}(t)\right|
\end{aligned} \tag{5}
$$

corresponds to the electrical power calculated by the electrical current $i_k(t)$ representing the restoring force $F_k(x)$ of the suspension and the voltage U_{emf} representing the back EMF generated by the velocity $v(t)$.
The nonlinear force factor characteristic $Bl(x)$ has to be considered in the calculation as a relative quantity. Both, electrical signals $i_k(t)$ and $u_{emf}(t)$ can be determined by nonlinear system identification [4]. This technique requires minimal equipment and is capable of measuring the linear and nonlinear parameters while the loudspeaker reproduces an ordinary audio signal. Neither information about the mechanical system (state variables, parameters) nor an additional sensor (laser or microphone) are required.

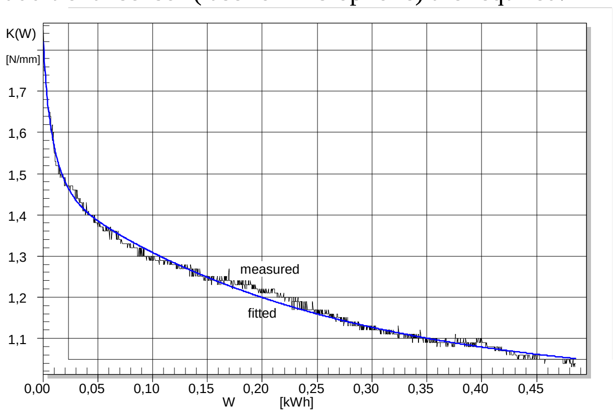

Fig. 3. Measured (thin line) and modeled variation (thick line) of the stiffness K(x=0) at the rest position x=0 versus mechanical work W accumulated in a suspension part.

Diagnostics

A spider having an inner and outer diameter of 39 and 130 mm, respectively, excited by the Suspension Part Measurement (SPM [6]) performs a sinusoidal vibration of 11 mm peak displacement for 250 hours. This corresponds with a constant mechanical apparent power of 2 Watts approximately supplied to the suspension part during the test. Fig. 3 shows the stiffness $K(x=0)$ at the rest position $x=0$ measured in the large-signal domain by on-line monitoring [2] versus the accumulated work W.

Half of the initial stiffness will disappear during the life-cycle of the suspension part. Unfortunately, only half of the changes occur during the relative short break-in process requiring only w_1= 0.02 kWh. High fatigue causes a permanent but slow decay of the stiffness at later times. This process approaches 90 percent of the final value $\hat{K}_\infty$=0.9 N/mm after applying a high value of the accumulated work $W_{90\%}$ = 0.42 kWh ≈ $11W_{50\%}$. This suspension part does not provide sufficient long-term stability for many applications.

Conclusion

The load-induced aging of the suspension can be described by a dosage model [1] using the mechanical apparent power as a state variable and a few model parameters. This model considers the velocity and force of the nonlinear vibration generated by an arbitrary stimulus. The free parameters can be easily calculated from results of power tests and other long-term measurements using the recorded stiffness $K(t)$ and apparent power $P(t)$ versus measurement time t. The model parameters can be used for predicting the final stiffness value $\hat{K}_\infty$ and for assessing the intensity and dynamics of the aging process. The model supports the separation of the break-in and fatigue effects which is important for assessing the quality and stability of a suspension part.

The model has been verified on a variety of suspension parts and loudspeaker drive units showing a good agreement between measured and predicted stiffness.

References

[1] W. Klippel, "Mechanical Fatigue and Load-Induced Aging of Loudspeaker Suspension," presented at the 131st Convention of Audio Eng. Soc., October 20-23, 2011, New York, preprint 8474.

[2] F. Kochendörfer, "Long-Term Monitoring of Loudspeaker Systems in Automotive Applications," Diploma thesis, May 2011, Dresden University of Technology, Institute of Acoustics and Speech Communication.

[3] S. Suresh, „Fatigue of Materials", Cambridge University Press 1998.

[4] IEC 62458, "Sound System Equipment – Electro-acoustical Transducers – Measurement of Large Signal Parameters," International Electro-technical Commission, 2009.

[5] ASTM E 1049-85. (Reapproved 2005). Standard practices for cycle counting in fatigue analysis. ASTM International.

[6] KLIPPEL GmbH Homepage, URL: http: // www.klippel.de/