Fast Quality Testing of Loudspeaker Suspension Parts

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1 Introduction

The overall performance of loudspeaker drivers and complete audio systems is directly related to the quality of the single components. Testing these components as early as possible, before being assembled to a complete driver or system, is crucial to ensure consistent product quality, close to the R&D specifications. Additionally, the overall yield at the end of the production is maximized to reduce cost and resource usage.

Clearly, the weakest mechanical part of a loudspeaker usually is the suspension system, namely spider and cone/dome surround. As the quality may vary remarkably among or even within different batches, the influence on the small and large signal behavior of the final driver can be significant. Even Rub&Buzz defects may occur as a consequence.

This article discusses an approach for time efficient testing of loudspeaker suspension parts close to the final operating conditions. It refers to the Linear Suspension Test set (LST Lite), a hard- and software add-on for the Klippel QC loudspeaker end-of-line testing system. It is dedicated to fast and simple testing of suspension parts and passive radiators in the linear operation range (small signal domain). The system may be applied to 100% or random sample testing for incoming goods inspection or end-of-line testing.

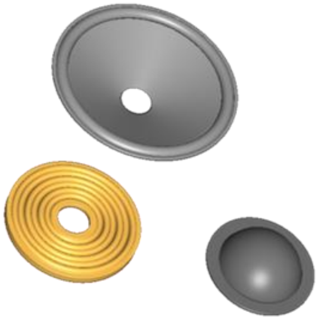


Figure 1 Loudspeaker suspension parts

2 Principle

During loudspeaker design the performance at both small and large excursions is relevant. As the force deflection rises significantly versus displacement, suspension parts are in general highly nonlinear. Thus the $k(x)$ is an important design parameter that determines the system performance at high levels significantly. However, this characteristic is mainly dominated by the geometry and the general material properties and may not necessarily be checked for quality control as the required clamping effort and measurement time is high.

Therefore, testing the suspension part in the linear range offers several benefits, as it provides easy interpretable single value parameters like resonance frequency f_r and the effective (small signal) stiffness k_0 as a quality finger print.

2.1 Hardware Setup

Figure 3 gives an overview of the complete test setup containing a cross section of the *Klippel LST* test bench which is also shown in Figure 2. It comprises a test box with a built-in low frequency driver, a cost efficient laser displacement sensor and a mounting platform with optional clamping components (ring and cone set). The volume flow generated by the driver provides pneumatic excitation for the device under test (DUT) that may be any kind of suspension part. Generated by the *Production Analyzer* hardware, the stimulus signal is amplified and fed to the *LST Bench*. The displacement response of the mounted suspension part is measured by the triangulation laser sensor, which is connected to the signal input of the *Production Analyzer*. A host PC comprising the *QC* software and the *LST* module performs the signal processing as well as the overall system control.

Since the target peak displacement of the DUT during the measurement is low, the clamping effort can be minimized to ensure fast mounting and thus a minimal overall test time. As shown in the close up view in Figure 4 the DUT is mounted horizontally on top of the test bench. A variable ring set provides the outer seating while the inner clamping cone fixes the spider by gravity providing a defined additional moving mass. The bolt attached to the cone acts as handle and a reflective surface for the laser beam with adjustable distance. All components of the inner clamping are made of lightweight plastics to keep the static displacement of the DUT minimal.

Alternatively, a free-air setup without any additional mass may be applied as shown in Figure 5. In this case the DUT requires additional fixture, putting another matched ring on top the outer rim. The complete platform is lifted by narrow stands to bypass the test box compliance.

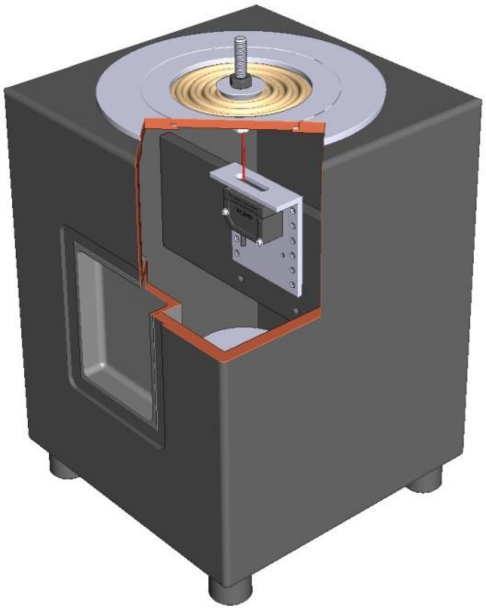


Figure 2 CAD model of the LST test bench including a mounted spider

Due to the higher mounting effort the setup is less practical for fast testing but it provides parameters like the fundamental resonance frequency in free air f_0. Additionally, static displacement due to gravity is reduced. This can be beneficial for very soft suspensions.

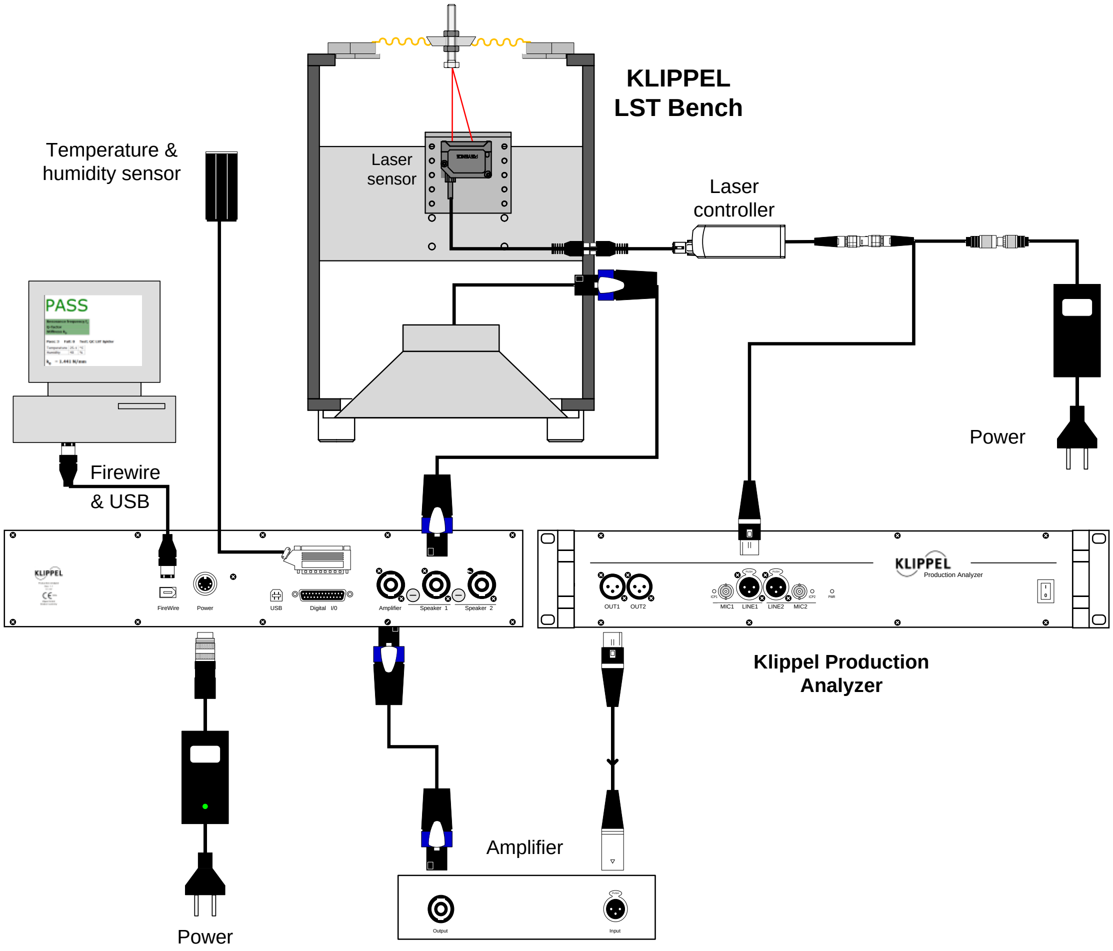


Figure 3 Schematic view of the measurement hardware setup

2.2 Measurement & Analysis

The total moving mass m consists of the dominant mass of the inner clamping m_c and the effective moving mass of the test object m_s that may be approximated by its total mass:

$$m = m_s + m_c$$

Using a broad band stimulus signal like a sine sweep, resonance will occur at a certain frequency where the restoring force of the suspension part equals the inertia of the moving mass. The resonance frequency is a simple and very characteristic parameter. However, since it is determined by both stiffness and total moving mass it is not a universal parameter to characterize a suspension part, unless it was measured without additional mass (fundamental resonance frequency f_0). Separating the mass allows to determine the effective stiffness k_{eff} which is a more general linear design parameter, independent of the attached mass.

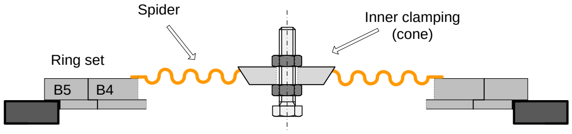


Figure 4 Cross section view of a mounted spider on top of the LST test bench

For the added mass setup the total moving mass is usually dominated by the inner clamping. Thus the moving mass may be assumed constant for the complete setup among different DUTs of the same type.

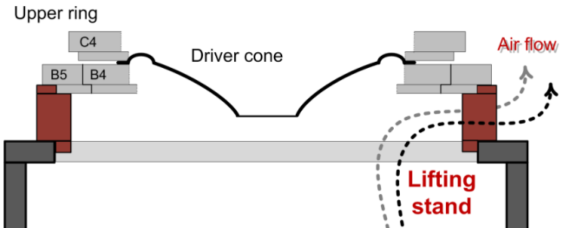


Figure 5 Free-air mounting of a loudspeaker cone without additional mass

The stiffness can be derived from the resonance frequency and the moving mass:

$$k_0 \triangleq k_{\mathrm{eff}}\left(x_{\mathrm{peak}}, x_{\mathrm{dc}}\right) \approx m(2\pi f_{\mathrm{r}})^2.$$

This relation is valid as long as the damping is low (Q>2) to make sure that the measured resonance frequency f_r corresponds to the undamped resonance frequency f_0. It is also assumed that the air stiffness of the test bench is negligible or the measurement is performed in free air.

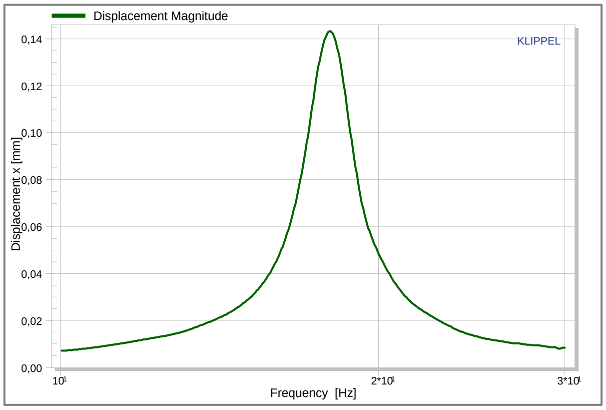


Figure 6 Magnitude of the displacement response

As stated before, the stiffness generally varies significantly with the displacement x. Thus the measured effective stiffness depends on the peak displacement during the measurement x_{peak} (stimulus level) as well as on the static displacement x_{dc} caused by the inner clamping (additional moving mass).

The resonance frequency is extracted from the displacement magnitude response which is shown in Figure 6.

It corresponds to the frequency where the maximal displacement occurs:

$$f_{\mathrm{r}} = \arg\max\left(\left|\underline{X}(f)\right|\right).$$

Additionally, the Q-factor is extracted from the -3dB decay bandwidth.

2.3 Testing Limits

For quality testing, tolerance limits for the selected parameters like resonance frequency or stiffness need to be defined to derive a clear pass/fail verdict. Defining absolute limits is the most basic approach. However, as the results strongly depend on the measurement conditions (see section 3), relative limits based on a set of reference units offers several benefits.

Representative reference units may be selected under defined conditions and transferred to the production line. Performing basic statistical analysis, relative tolerance limits can be defined by shifting the ensemble average with a fixed tolerance or the standard deviation. Outliers can be detected and removed from the reference pool easily as shown in Figure 7.

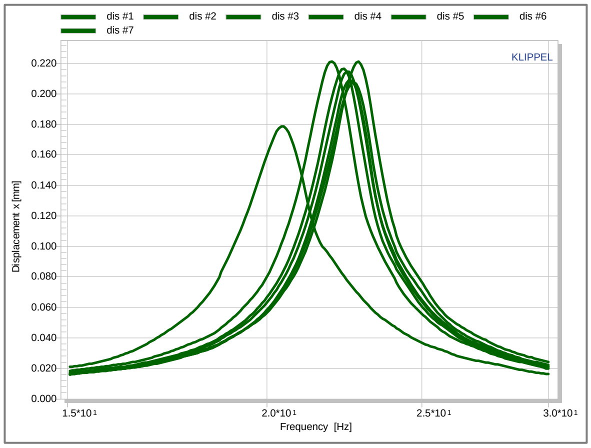
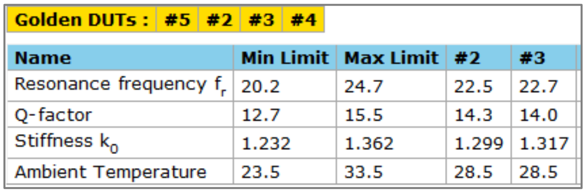


Figure 7 Displacement responses of various spiders of the same batch

The most average reference unit with respect to the displacement response is assigned as the so called “golden DUT”. Kept close to the testing site, this unit can be used for on-line limit recalibration to account for short and long term climatic conditions and other systematic drifts at the testing site.



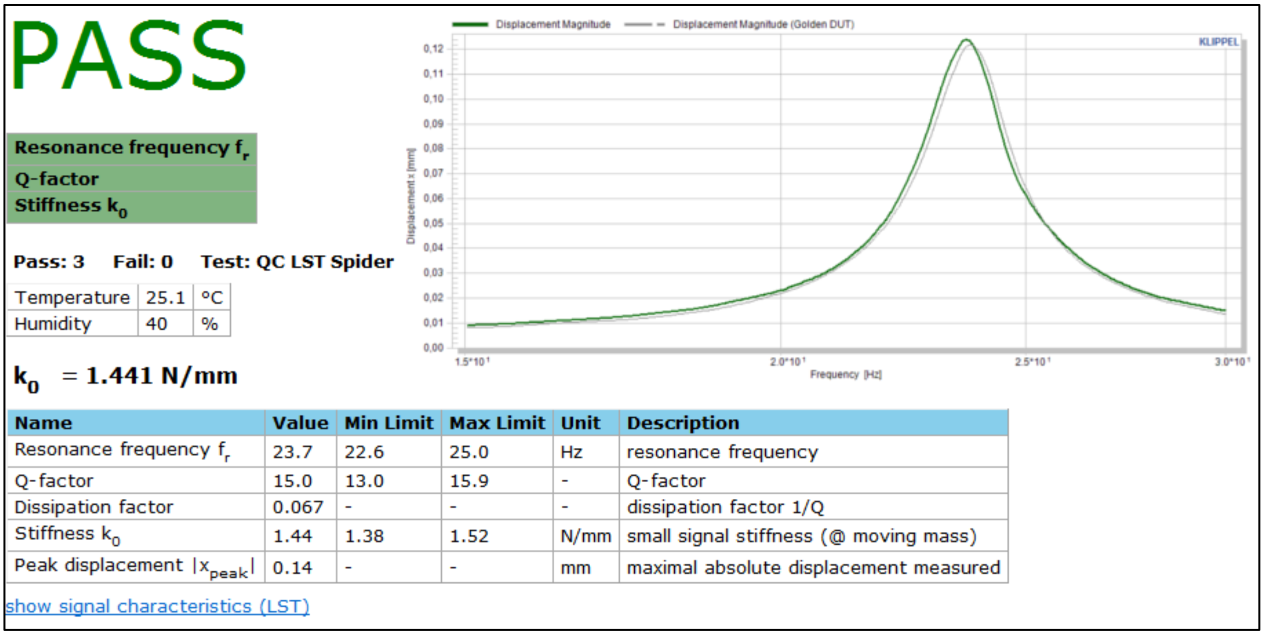
Golden DUTs : #5 #2 #3 #4

Name	Min Limit	Max Limit	#2	#3
Resonance frequency f_r	20.2	24.7	22.5	22.7
Q-factor	12.7	15.5	14.3	14.0
Stiffness k_0	1.232	1.362	1.299	1.317
Ambient Temperature	23.5	33.5	28.5	28.5

Figure 8 “Golden DUT” list and resulting limits derived from multiple reference units

Depending on the material used, most suspension parts show significant parameter drift related to the ambient temperature and humidity. Especially the material temperature considerably influences the compliance, even at typical variations of the room temperature. This effect is difficult to handle using static testing limits.

Figure 8 shows a screenshot of the limit calculation output including the ranked list of golden DUTs. As soon as the tolerance limits are defined, testing can be performed using a simplified user interface for the operator. An example screenshot is shown in Figure 9. The screen consists of three elements: a chart showing the most recent and the golden DUT’s displacement responses, a result window displaying the derived single value results and limits, the current climatic environmental conditions and the test verdict followed by a single verdict list. A simple control panel offers a reduced set of actions, like test start and limit calibration for the operator (not displayed).



PASS

Resonance frequency f_r
Q-factor
Stiffness k_0

Pass: 3 Fail: 0 Test: QC LST Spider

Temperature	25.1	°C
Humidity	40	%

k_0 = 1.441 N/mm

Name	Value	Min Limit	Max Limit	Unit	Description
Resonance frequency f_r	23.7	22.6	25.0	Hz	resonance frequency
Q-factor	15.0	13.0	15.9	-	Q-factor
Dissipation factor	0.067	-	-	-	dissipation factor 1/Q
Stiffness k_0	1.44	1.38	1.52	N/mm	small signal stiffness (@ moving mass)
Peak displacement $\lvert x_{peak} \rvert$	0.14	-	-	mm	maximal absolute displacement measured

show signal characteristics (LST)

Figure 9 Operator view of an LST test (rearranged, without user interface)

3 Comparison of measurement techniques

Various measurement techniques have been developed to characterize loudspeaker suspension parts. As the compliance is typically very nonlinear versus displacement and additionally time variant due to reversible and irreversible ageing effects, the measurement method and conditions have a significant influence on the results. Therefore it is often difficult to keep results comparable, especially when the boundary conditions are not defined.

IEC standard 62459 introduces several static and dynamic methods for measuring suspension parts under different conditions. A short overview including a practical example shall be given here to interpret and compare the results of the addressed approach correctly. Additionally, the origin of the deviation is explained.

3.1 Static Measurement

A very basic technique is the static measurement method. A defined mass is attached to the suspension part to cause a static displacement as shown in Figure 10.

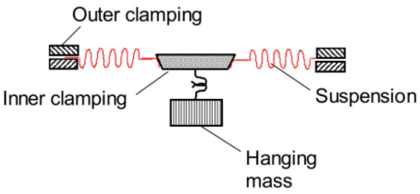


Figure 10 Schematic view of static measurement technique

After a certain time the static displacement x_{dc} is measured to derive the static stiffness

$$k_{stat}(x_{dc}) = \frac{F_{dc}}{x_{dc}}$$

Usually, a long settling time is required due to viscoelastic effects of the material (creep). This means that the displacement increases gradually after the mass is attached until it approaches a final static value.

3.2 Dynamic Measurement (Large Signal)

A completely different approach is the dynamic measurement, which is much closer to the operating conditions in the final application. This method may be performed in both large and small signal domain, which again leads to different measurement conditions, signal analysis and thus results for the stiffness.

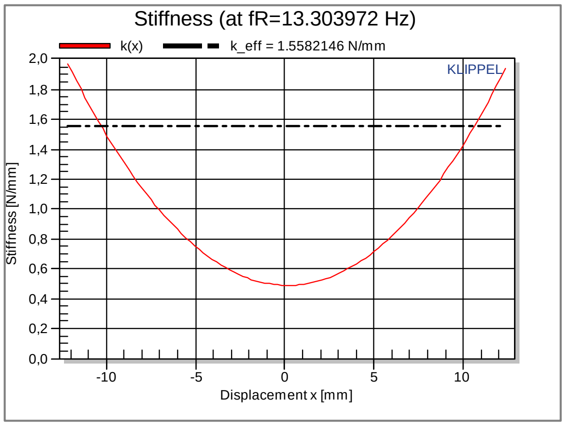


Figure 11 Nonlinear stiffness $k(x)$ versus displacement, Effective Stiffness k_{eff}

Driving the suspension part dynamically in the large signal domain results in a varying force deflection vs. displacement and thus a (nonlinear) dynamic stiffness

$$k(x_{ac}) = \frac{F_{ac}}{x_{ac}}.$$

Performing measurements at high peak displacements requires a powerful driving unit and stable clamping. The *Klippel SPM* set provides an adequate test bench which is shown schematically in Figure 12. The red result curve in Figure 11 shows a resulting example curve (stiffness vs. displacement). The spider is getting less compliant at higher displacements.

Still, a single value effective stiffness can be derived from the resonance frequency f_r at the current ac peak displacement x_{peak}:

$$k_{\mathrm{eff}}(x_{\mathrm{peak}}) = (2\pi f_r)^2 m$$

The dashed line represents k_{eff} in the example measurement. It may be plotted together with the dynamic stiffness $k(x_{ac})$ for comparison. Obviously, the effective stiffness is located between the maximal (@ x_{peak}) and minimal (@ x=0) value of the dynamic stiffness.

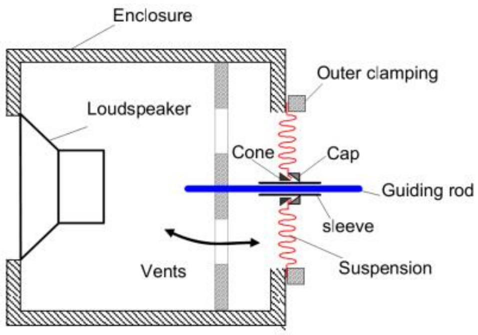


Figure 12 Cross section of the SPM measurement bench (Klippel RnD System)

It is important to be aware that this measurement principle affects the tested device reversibly and irreversibly due to viscoelastic and break-in effects as well as material ageing caused by mechanical stress. Typically, the stiffness is dropping significantly with the applied mechanical work before it approaches a final long-term value. Thus the tool can be used to analyze the load induced ageing which may affect the final system performance significantly.

3.3 Dynamic Measurement (Small Signal)

Performing the dynamic measurement in the small signal domain for very small displacements (x_{peak} → 0) gives a more universal result for the effective stiffness in the linear range, similar to the small signal parameters (*Thiele-Small*) of a complete driver.

The measurement setup introduced in Section 3.2 is also capable of performing small signal measurement at low levels as the principle is similar to the setup discussed in this article. However, there are some differences that should be considered.

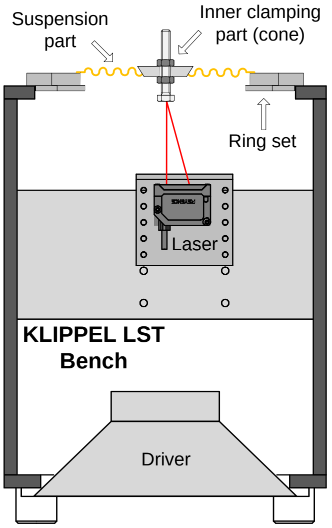


Figure 13 Cross section of Klippel LST bench

The DUT is clamped vertically to minimize the influence of gravity but this requires a complex clamping procedure which is time consuming. Additionally, undesired damping is generated by the guiding rod which may be removed for small signal measurement, however.

Using the LST bench, the DUT is mounted horizontally on the measurement bench to minimize clamping effort.

This causes a small static displacement x_{dc} and thus a small bias of k relative to the rest position.

$$k_0 \triangleq k_{\mathrm{eff}}(x_{\mathrm{dc}}, x_{\mathrm{peak}}) = (2\pi f_r)^2 m$$
$$\text{for} \quad x_{\mathrm{dc}}, x_{\mathrm{peak}} \to 0$$

Method	**k in N/mm**	**x_{peak} in mm**	**x_{dc} in mm**	**f_r in Hz**	**m in g**
Static	1.01	0	0.97	-	100
dynamic small signal (LST)	1.34	0.28	0.5	22.5	67
dynamic small signal (SPM)	1.19	0.27	0	11.7	223
dynamic large signal (SPM)	1.56	12.3	-	13.3	223
dynamic small signal (LST) - after large signal test	1.15	0.25	0.5	20.9	67

Table 1 Results of different suspension measurement techniques for the same 6'' spider

3.4 Comparison

To evaluate systematic differences among the introduced measurement methods, Table 1 shows practical results for a standard 6'' spider. The small signal measurement (LST) was performed twice, before and after the large signal test to show the influence of load induced ageing. The measurement results reveal several clear statements:

- The static stiffness is lower than the effective dynamic stiffness due to material creep – the suspension seems to be softer than it is under real dynamic operation conditions.
- The effective stiffness in the large signal domain is usually higher than in the small signal due to rising stiffness with displacement (behavior might be different in transition range!)
- The deviation between small signal results of SPM and LST (< 10%) is mainly related to the orientation of the mounted DUT. The LST measurement includes a static displacement bias x_{dc} due to weight of inner clamping which results in a slightly higher k_{eff}.
- Material ageing due to mechanical stress needs to be considered for comparable testing results.

The observed differences show that the results of all techniques depend on several boundary conditions. Therefore, these conditions should always be given along with the measurement results (e.g. k_{eff} @ x_{peak}) for data comparability.

4 Summary

This article discussed an effective approach for fast testing of loudspeaker suspension parts for quality control. The dynamical measurement of the displacement response in the linear operation range delivers easy interpretable parameters which are close to design and the final operating conditions. Time efficient and repeatable testing can be performed due to simple clamping and fast measurement using the infrastructure of a loudspeaker related end-of-line testing system.

The measurement approach is not limited to suspension parts only. It is also applicable to passive radiators (drones). However, as the performance is determined by both moving mass and suspension stiffness, both parameters should be monitored independently in this case. Further signal processing, implemented in an extended version of the LST, provides mass and stiffness separation for improved diagnostics.

5 References

[1] IEC Standard 62459 “Measurement of Suspension Parts”, 2009

[2] W. Klippel, “Dynamical Measurement of Loudspeaker Suspension Parts”, presented at the 117th Convention of the Audio Engineering Society, San Francisco, October 28–31, 2004

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[4] Klippel GmbH, C2 Suspension Part Measurement, Module specification for the Klippel R&D System

[5] Klippel GmbH, C6 QC Linear Suspension Test, Module specification for the Klippel QC System