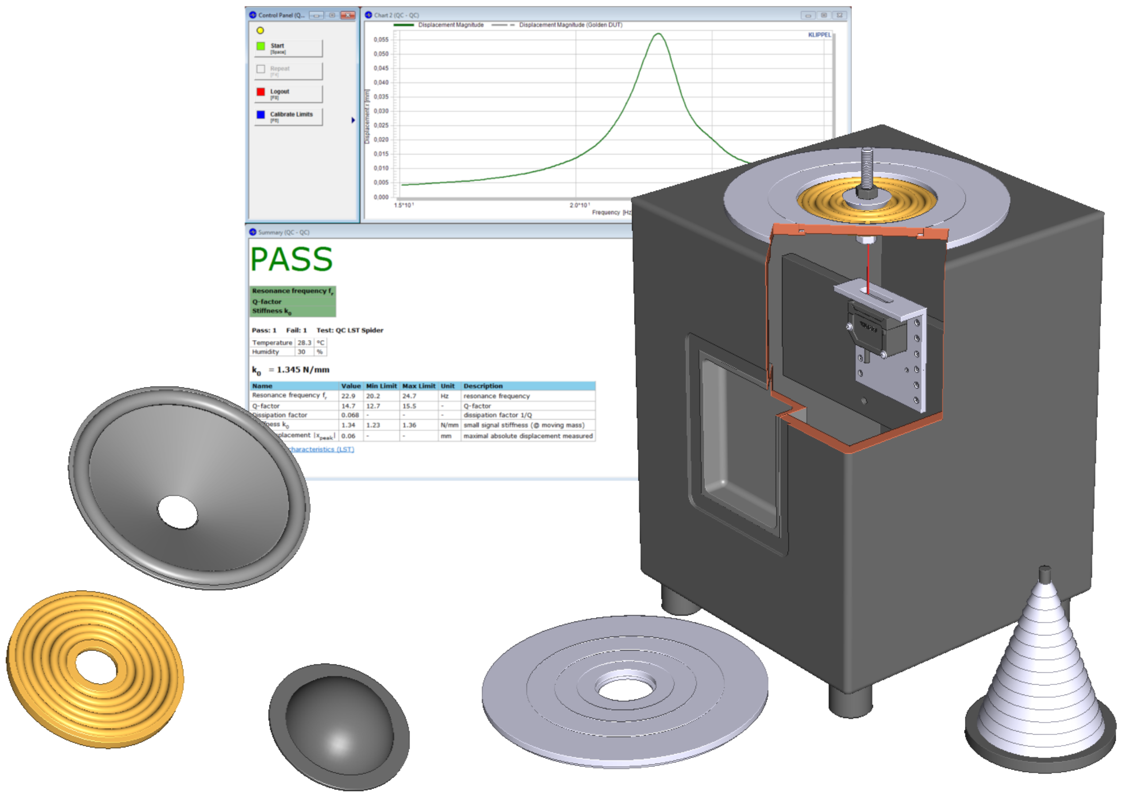
Fast Quality Control of Suspension Parts **AN 53**

Application Note for the KLIPPEL QC SYSTEM

The performance and quality of loudspeaker drivers and complete audio systems is mainly determined by the quality of the single components. To ensure a consistent product quality close to the R&D specifications, it is beneficial to check the components as early as possible, before full assembly. This optimizes resource usage and minimizes cost.

The weakest mechanical part of loudspeaker drivers is usually the suspension system, namely the spider and the cone/dome surround. As the quality may vary significantly among different batches, the influence on the small and large signal behavior of the final driver can be significant. Even defects may occur as a consequence.

This application note refers to the Linear Suspension Test set (LST Lite), a hard- and software add-on for the KLIPPEL QC System, which is dedicated to fast and simple testing of suspension parts and passive radiators in the linear operation range (small signal domain).



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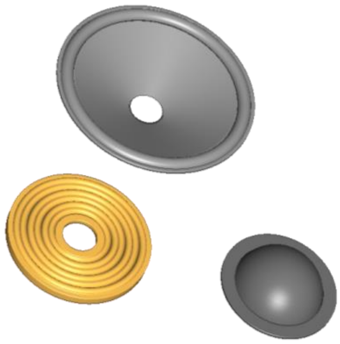
Scope

Device under test

This Application Note is dedicated to common suspension parts applied in electro-dynamic transducers.

This includes:

- Spiders
- Surrounds (cones)
- Domes



All of the three above mentioned test objects will be considered here including their peculiarities.

Limitations

As the standard mounting set for the LST Bench (ring and cone set) is designed for circular geometries this document will only refer to circular test objects up to a maximal diameter of 222 mm. However, the facts stated here are also valid for oval and other irregular geometries. These objects may be attached to the measurement bench with a custom mounting platform.

Objectives and content

The main target of this application note is setting up a test for fast quality control of standard spiders, cones and domes with the standard LST set for the QC System. It may be applied for 100% or random sample testing for incoming goods inspection or end-of-line testing.

The following aspects are considered:

- Setting up the QC System and the LST bench
- Mounting the device under test (DUT)
- Setting up the QC test
- Optimizing the setup parameters
- Creating relative limits based on reference units
- Limit calibration
- Interpretation of results – comparison of different measurement methods

Requirements and Setup

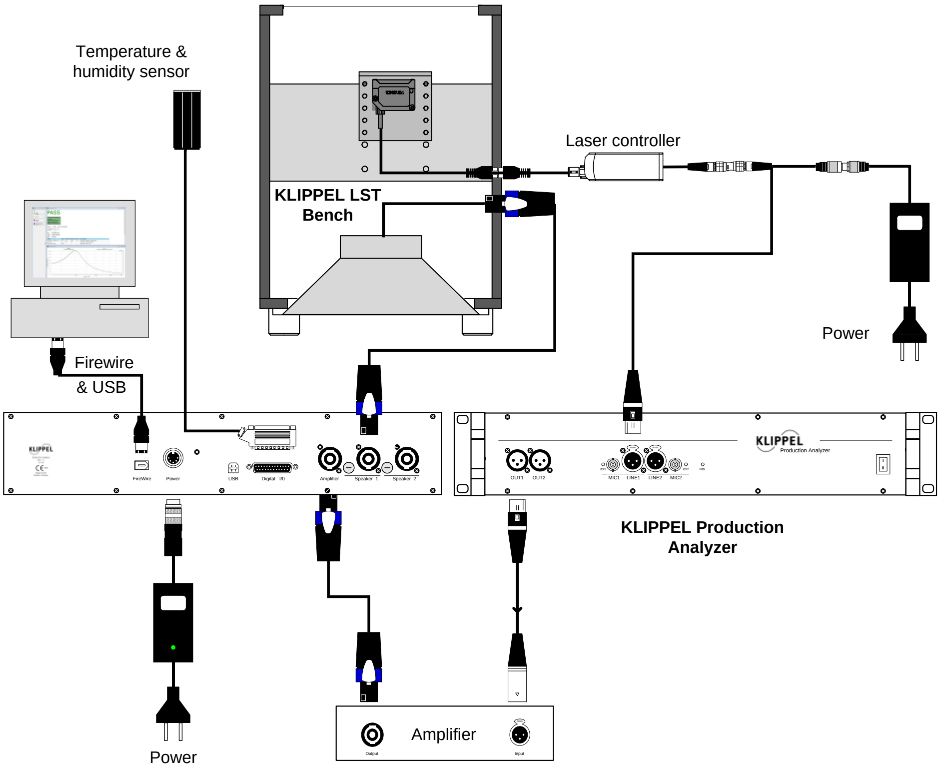
Software requirements

The following software components are required:

- Any version of the QC software (some general features are limited/not available with QC Basic license) from version 3.1
- Additional Modules: LST Lite

Hardware components and setup

The schematic below shows the standard hardware setup of the QC System for LST applications.



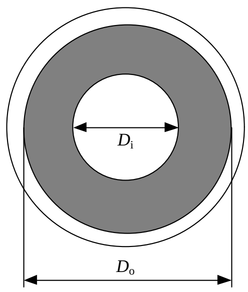
The following hardware components are required:

- LST Work Bench (incl. LST speaker cable)
- LST clamping set (ring set, cone set incl. bolt and nuts)
- Laser displacement sensor (Keyence IL-30 or 65 laser head + controller IL-1000 incl. connecting cables, power supply and mounting platform)
- Production Analyzer (Standard Sensitivity, incl. cables and power supply)
- Power amplifier (if required incl. custom connecting cables)
- Personal computer (IBM compatible, Windows XP or Windows 7)

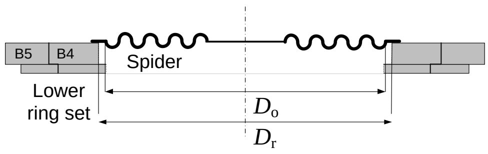
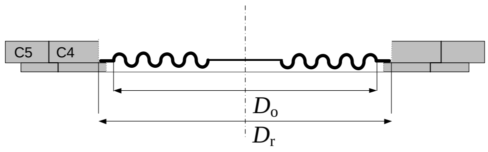
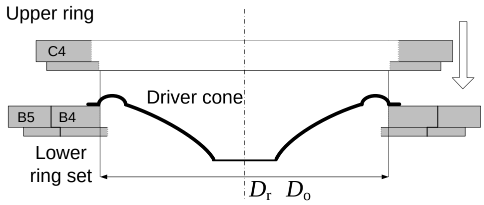
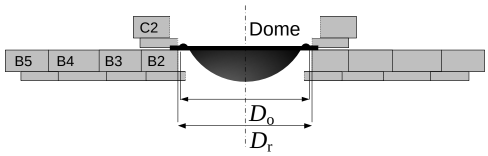
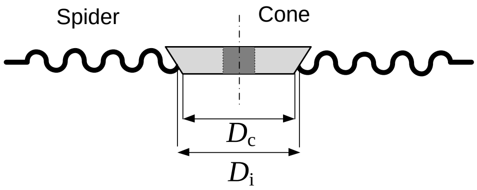
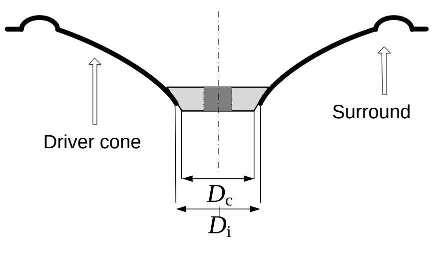
Please connect the hardware components as shown in the schematic. For further details please refer to the user manual of the LST.

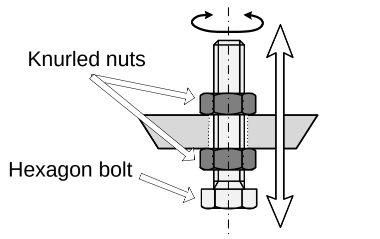
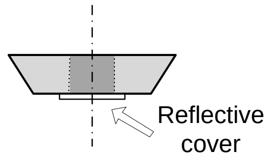
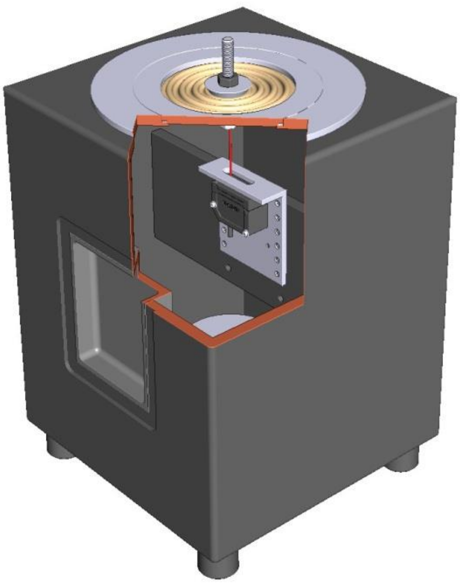
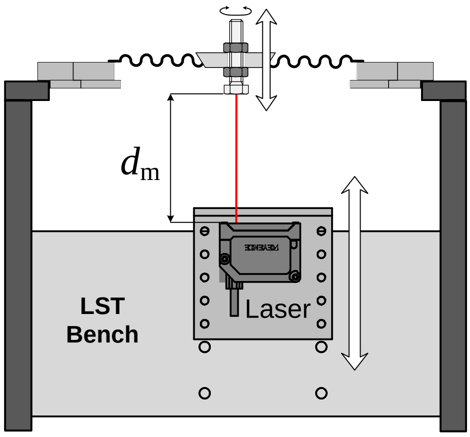
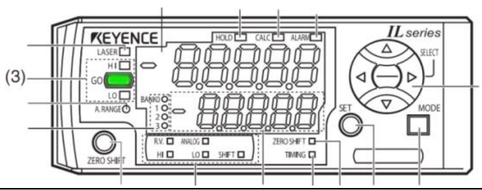
Clamping the Suspension Part

Dimensions of the Suspension



1. Measure the outer diameter D_o of the suspension part (without rim)
2. Measure the inner diameter D_i of the suspension part (if available)

Find the lower clamping ring	Var 1  Var 2  	3. See the look up table for dimensions of rings (LST Manual) to find a proper lower clamping ring (for example **B4**) having an inner diameter D_r which is just larger than the measured outer diameter D_o. Alternatively, for easier centering, you may choose a ring where the inner diameter D_r is equal to the complete diameter of the DUT. To find a proper ring just choose the one with the same number, but a higher letter (e.g. **C4**). The DUT will rest on the lower rim of the ring (Note: this inhibits using an additional upper ring for clamping) 4. Complete the lower ring set by selecting all rings which have the same character in the nomenclature (e.g. **B**) and are larger than the lower clamping ring (e.g. **B4**, **B5**) to complete the lower ring set.
Find the upper clamping ring (optional)	  	5. This step is recommended in case the suspension is very soft and the DUT is slipping off the rim with inner clamping attached (cones). However, an upper ring is strongly recommended for domes. Find the one-step larger ring (related to inner ring) used as upper clamping ring (for example **C4**). It will exactly fit the upper rim of the lower ring and thus clamp the rim of the DUT.
Selecting the cone*	  	6. Select the mounting cone that fits best to your DUT. The inner diameter D_i of the part has to be larger than the cone diameter D_c. See the look up table for dimensions of cones (LST Manual) or slide the suspension on the cone stack to find the optimal cone part.

Inner Clamping*	a)  b) 	7. a) To complete the inner clamping the hexagon bolt has to be attached to the selected cone using the knurled nuts. The head of the bolt acts as the reflecting surface for the laser displacement sensor. The screw may be shifted relative to the cone by turning it to adjust the distance to the laser head later on. b) If the full inner clamping causes too much DC displacement (especially for driver cones with soft surround) leave out the bolt and put a reflective cover (e.g. tape) on the lower mounting cone hole. 8. Weigh the DUT incl. the complete inner clamping (approx. moving mass *m* in g)
Attaching the mounted DUT to the LST Bench		9. Attach the mounted DUT by putting the lower ring set on top of the LST Bench. The groove of the outer ring will exactly fit the top hole.
Adjusting the measurement distance	 	10. The required distance d_m between laser head and inner clamping (or DUT) is determined by the laser head. The center of the measurement range is around 33 mm for IL-30 and 70 mm for IL-65. This target distance may be adjusted roughly by shifting the laser platform. If the complete inner mounting set is used, the distance may be additionally adjusted by shifting the hexagon bolt relative to the mounting cone. At the end of the process the green "GO" light (3) on the laser controller should be lit.

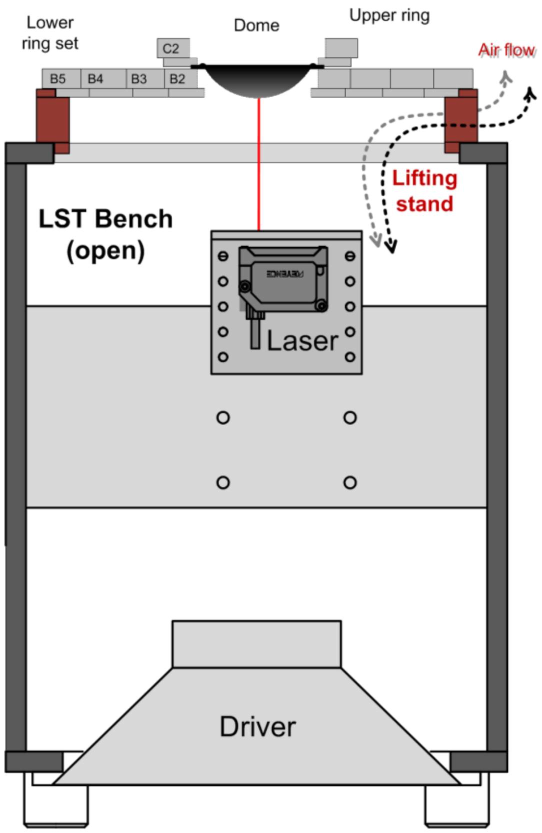
** This step is obsolete for domes*

Special Concerns of Domes

General comments

For small (tweeter) domes in general it is difficult to attach additional moving mass. The intrinsic moving mass is often too low to measure a clear resonance peak when attached to the LST Bench. However, there are two possibilities to get good results. Either a small piece of additional mass may be put on the dome or the fundamental resonance frequency may be measured under free air conditions.

Var 1: Free air setup

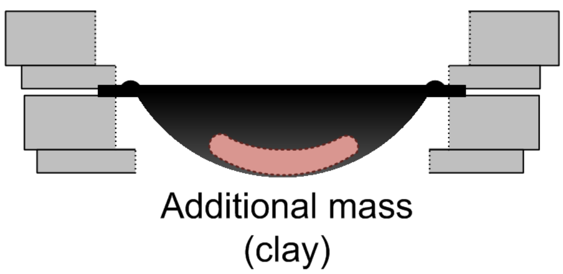


According to IEC standard 62459 the fundamental resonance frequency of the clamped suspension part is measured with acoustical excitation through a speaker mounted in a baffle. In this case the influence of the measurement setup is minimized. The fundamental resonance frequency (as the effective stiffness) is a general parameter of the DUT and may be exchanged between manufacturer and customer.

The standard may be adapted here by raising the mounted DUT (incl. rings) to use the LST Bench as an open box. This setup gets close to the setup proposed by the standard as the leakage now dominates and the air stiffness of the box is bypassed.

To raise the lower ring set, lifting stands may be used that fit the outer ring dimensions.

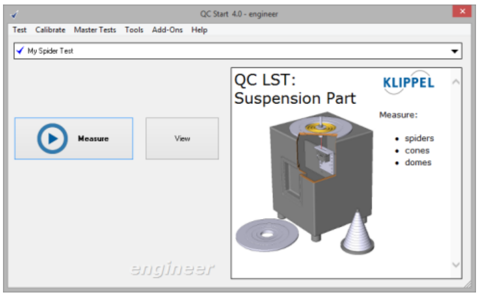
Var 2: Attaching additional mass



An alternative to the free air method is measuring the dome with a small additional mass. A small, shaped piece of clay may be used for this purpose which may be put on the inside surface of the dome which should be orientated upside down. It is not necessary to fix it with pressure as the target displacement (and acceleration) is low. With this setup the test object can be measured on the closed LST Bench without an additional stand.

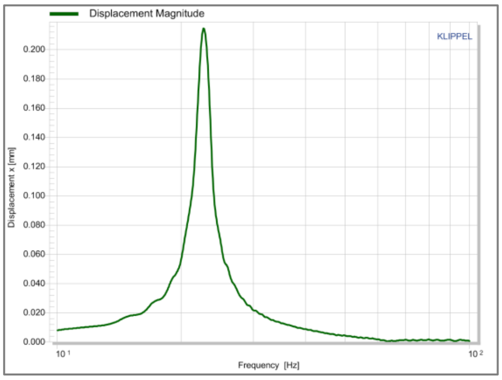
Setting up the QC Test

Creating a new test



11. Create a new test by opening QC Start in Engineer mode and selecting *Test – New…*
    Select test template *Components – LST Suspension Part* and enter a test name.
12. You may adjust the HTML test info as shown in the example by editing the *testinfo.htm* in the test folder (Click *View – Current Test Folder*)
13. Press *Measure* to log in

Tracking the resonance frequency



No limits defined.

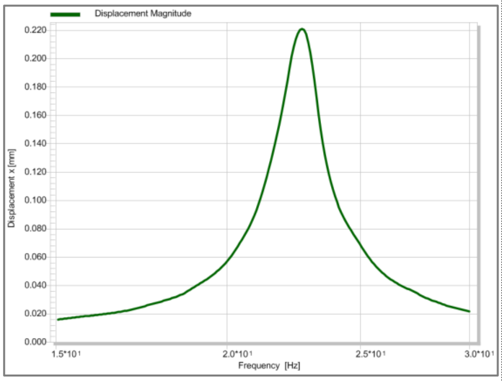
Name	Value	Unit	Des
Resonance frequency f_r	22.7	Hz	reso
Q-factor	13.4	-	Q-f
Dissipation factor	0.075	-	diss
Stiffness k_0	-	N/mm	sma
Peak displacement $\lvert x_{peak} \rvert$	0.20	mm	max

14. Start the test with the default settings to track the resonance frequency of the DUT. The default task settings are a good starting point for this purpose, as the initial sweep bandwidth covers a wide frequency range.
    If the resonance frequency is close to or even above the upper band limit, adjust the frequency range.
    You may also adjust the voltage if the displacement signal is noisy or distorted. In case of warnings or error messages, please refer to the section *Troubleshooting* of the LST User Manual.

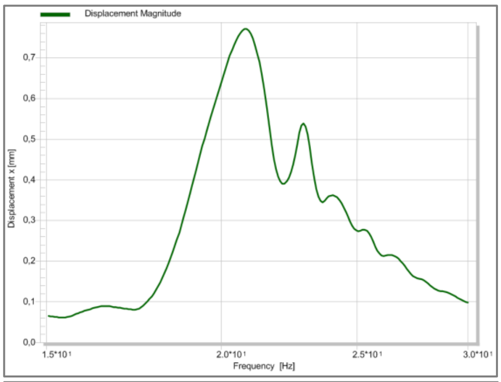
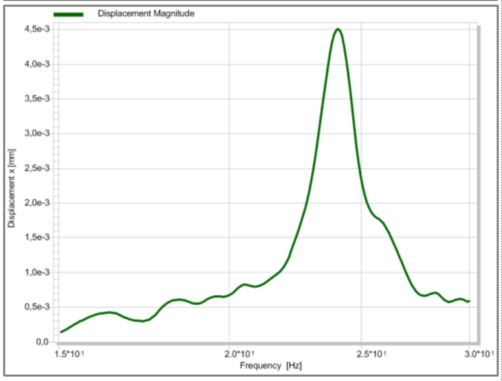
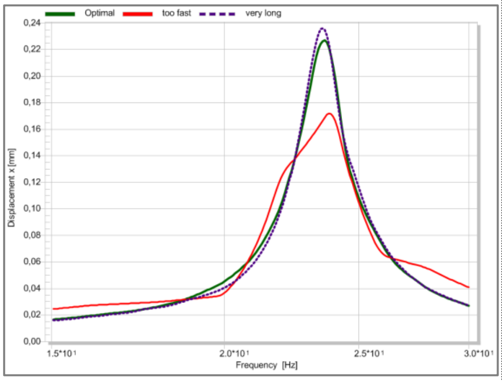
Adjusting the frequency range

Parameters

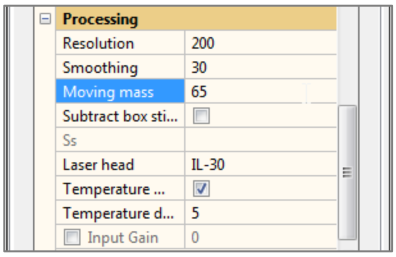
Stimulus	
Start	30
Stop	15
Time	2
Voltage (rms)	0.5
Speed Profile	[1, 50, 1; ...]
Level Profile	[1, -6; ...]



15. The result table of the first test run will show the detected resonance frequency, in this case around 23 Hz. Adjust the start and stop frequency of the sweep to narrow the test bandwidth. The total bandwidth should be at least one octave around the resonance frequency.

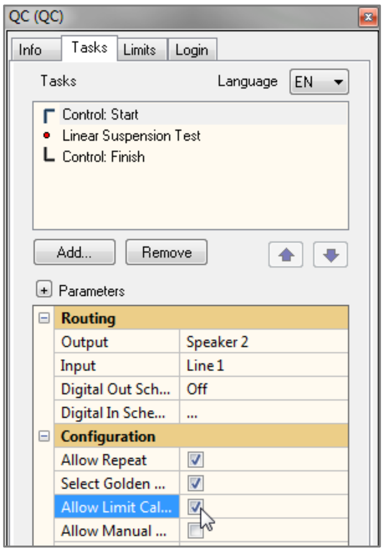
Optimizing level	 	16. The stimulus voltage may be adjusted if the displacement magnitude looks distorted. The target is driving the DUT in the small signal domain while having a good signal-to–noise ratio in the displacement laser signal. The upper chart shows the resulting curve if the voltage is too high and the inner mounting cone starts jumping. There will be small sub peaks around the main resonance. In the lower chart the signal stimulus voltage was too low; the curve is dominated by noise, especially far off the resonance. The max displacement in this example is only 5 µm. The target should be around 100 µm or more in this case.
Optimizing time		17. The most crucial parameter for efficient testing is the measurement time. The desired optimum is a short testing time with meaningful and reliable results. The optimum strongly depends on the DUT. Start with a very long time (e.g. 5s, dotted blue curve) to obtain a reference curve. Keep the curve by copying it to the clipboard (right click – *Copy Curve*). You may paste it again after the next measurement with other settings to compare the results. Decrease the time until the curves start to deviate (green curve) to find a good time setting. The red curve shows the result of a sweep which was too short. The resonance is not excited properly.

Set moving mass and other parameters



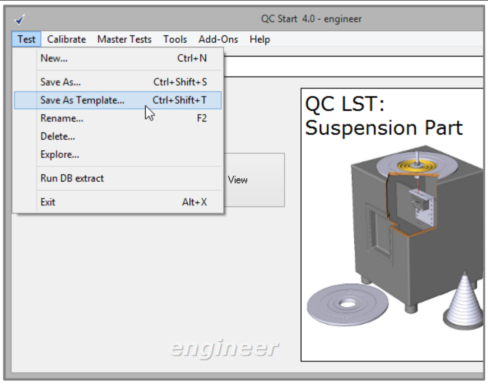
k_0 = 1.317 N/mm

Name	Value	Unit	Descr
Resonance frequency f_r	22.7	Hz	resona
Q-factor	15.0	-	Q-fac
Dissipation factor	0.067	-	dissip
Stiffness k_0	1.32	N/mm	small



18. So far the stiffness k_0 was not measured as the moving mass needs to be specified first. Please enter the total weight of the DUT and the inner clamping in g (approximation if clamping mass is dominant, please see LST Manual for details). Alternatively the exact moving mass may be entered. Please refer to the LST Manual for instructions
    In the next measurement performed k_0 will be available in the summary window.
19. If a temperature sensor for the QC system is available, you may connect it and activate *Temperature monitoring*. *Temperature deviation* defines the warning threshold for a temperature change relative to the mean temperature during reference measurement. Generally, using a climate sensor is recommended as the suspension parameters may vary significantly
20. Also check that the correct laser head is selected in the property page. This mainly affects the default laser calibration factor for correct displacement display
21. Activate *Allow Limit Calibration* in the *Control:Start* task to allow compensating for climatic drifts later on.

Creating a test template



22. As soon as the test setup is finished you may derive a test template for backup or similar test objects. To do this, please log out to get back to QC Start Engineer and select *Test – Save as template…* .
23. Specify a name for the template and confirm. It will now be available in the user template folder for future tests.

Setting QC Limits**

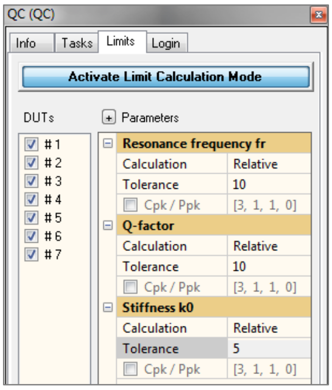
General remarks

There are different approaches to set limits for the QC test. A typical way is transferring R&D specification data (e.g. target stiffness) to the QC test and adding a certain tolerance. As all parameters strongly depend on several boundary conditions (measurement setup/method, max displacement …) this approach may be difficult and hard to realize.

It is very convenient to setup limits using so called *Golden DUTs*. These units may have been selected under certain standard conditions. These units can be measured in the QC environment to derive relative limits.

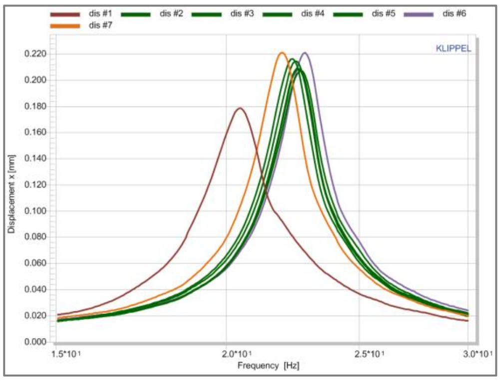
In many cases no dedicated *Golden DUTs* are available and the limits may be setup on statistical analysis (e.g. a batch of samples) to ensure consistent production. The following section of this guide will focus on this process. However, the set of reference units is reduced to seven for better overview. It is not an adequate amount of units for real statistical analysis.

Collecting reference data and adjusting limit settings



24. Activate *Limit Calculation Mode* and measure a batch of units with unknown classification. Here, seven spiders of the same type have been measured. A reference DUT will be added to the DUT list with every measurement. All displacement magnitude responses are shown in Chart 2.
25. Adjust the relative tolerance limits according to the requirements or switch to another limit calculation type (e.g. *Statistic*)

Calculating limits and removing outliers



Failed DUTs: #1 #7

show details of failed reference DUTs

Measure	#1	#2	#3	#4	#5	#6	#7
Resonance frequency f_r-Max	ok	ok	ok	ok	ok	ok	ok
Resonance frequency f_r-Min	ok	ok	ok	ok	ok	ok	ok
Q-factor-Max	ok	ok	ok	ok	ok	ok	ok
Q-factor-Min	ok	ok	ok	ok	ok	ok	FAIL
Stiffness k_0-Max	FAIL	ok	ok	ok	ok	ok	ok
Stiffness k_0-Min	ok	ok	ok	ok	ok	ok	FAIL
Ambient Temperature-Max	ok	ok	ok	ok	ok	ok	ok
Ambient Temperature-Min	ok	ok	ok	ok	ok	ok	ok

Name	Min Limit	Max Limit	#1	#2	#3	#4	#5	#6
Resonance frequency f_r	19.9	24.4	22.8	22.5	22.7	22.3	22.4	22.
Q-factor	12.4	15.1	14.4	14.3	14.0	14.2	13.9	13.
Stiffness k_0	1.199	1.325	1.336	1.299	1.317	1.281	1.290	1.2
Ambient Temperature	23.5	33.5	28.5	28.5	28.5	28.5	28.5	28.

26. One clear outlier can already be identified visibly from the displacement magnitude (highlighted manually). Two other units also slightly deviate from the curve ensemble.
27. For a first overview press the *Calculate* button to initiate limit calculation for the single value measures. A table will be shown in the summary window showing the single value results for all reference DUTs and the resulting limits.
28. During limit calculation all reference units will be checked against the limits to identify outliers automatically. Here, unit #1 and #7 violate the limits and should be removed by unchecking them in the reference DUT list. These units will not be considered for limit calculation anymore. Unit 6 may also be excluded.
29. Press *Calculate* again. Now there should be no failed units anymore.

Selecting the Golden DUT

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

30. After limit calculation a list of *Golden DUTs* will be shown. This list is a ranking of the most representative reference DUTs. The first DUT in the list is the closest to the ensemble average.

    Note: the automatic golden DUT selection is only based on the displacement magnitude.
31. The *Golden DUT(s)* (e.g. #5) should be stored safely, close to the testing station. It can be used for limit recalibration to compensate for climatic changes later on.

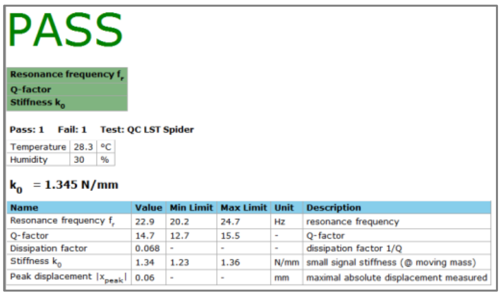
***This section describes QC Standard features. QC Basic is limited to one reference DUT only.*

Performing the Test

Entering Operator mode

32. Log out of the test after the limit setup has been completed.
33. Open QC Start in Operator mode and log in.

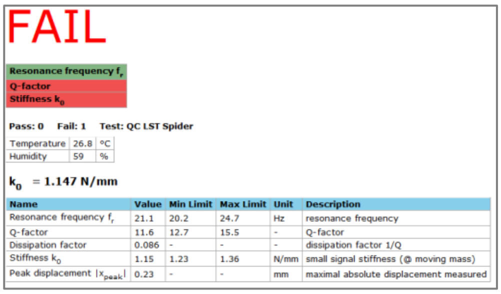
Testing the first unit



Name	Value	Min Limit	Max Limit	Unit	Description
Resonance frequency f_r	22.9	20.2	24.7	Hz	resonance frequency
Q-factor	14.7	12.7	15.5	-	Q-factor
Dissipation factor	0.068	-	-	-	dissipation factor 1/Q
Stiffness k_0	1.34	1.23	1.36	N/mm	small signal stiffness (@ moving mass)
Peak displacement $\|x_{peak}\|$	0.06	-	-	mm	maximal absolute displacement measured

34. Mount the first DUT and press *Start* to start the test. If the tested unit's characteristics are close to the reference unit's, the results will be within tolerance and the test will PASS.

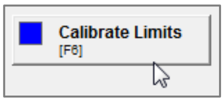
Failed test

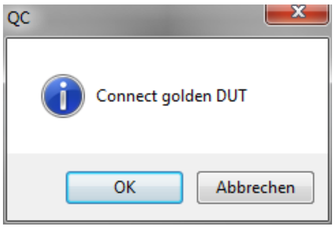


Name	Value	Min Limit	Max Limit	Unit	Description
Resonance frequency f_r	21.1	20.2	24.7	Hz	resonance frequency
Q-factor	11.6	12.7	15.5	-	Q-factor
Dissipation factor	0.086	-	-	-	dissipation factor 1/Q
Stiffness k_0	1.15	1.23	1.36	N/mm	small signal stiffness (@ moving mass)
Peak displacement $\|x_{peak}\|$	0.23	-	-	mm	maximal absolute displacement measured

35. If a DUT deviates significantly from the reference ensemble, the limits will be violated. The corresponding measure will fail, indicated by a red verdict bar. This results in an overall FAIL of the test.

Recalibrating limits





36. Due to climatic changes the test results may drift and violate the tolerance limits. The Golden DUT may be used to recalibrate the limits if stored under the same conditions.
37. Mount the Golden DUT and press *Calibrate limits.* Click *OK* to confirm. The limits are recalibrated according to the current conditions now.

Note: If a temperature sensor is connected and *Temperature monitoring* is activated an automatic warning is generated if the temperature deviates significantly (according to settings).

Comparison with other measurement techniques

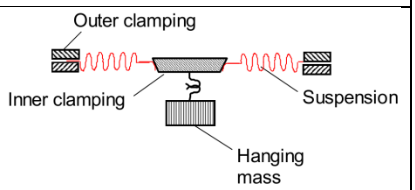
Preliminary remarks

As suspension parts behave strongly nonlinear (stiffness vs. displacement) the measurement method and conditions have a significant influence on the results.

IEC standard 62459 introduces different 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 LST correctly. Additionally, the origin of the deviation is explained.

Static measurement

In this method a known mass is attached to the suspension part to cause a static displacement. After a certain settlement time the static displacement x_{dc} is measured to derive the static stiffness



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

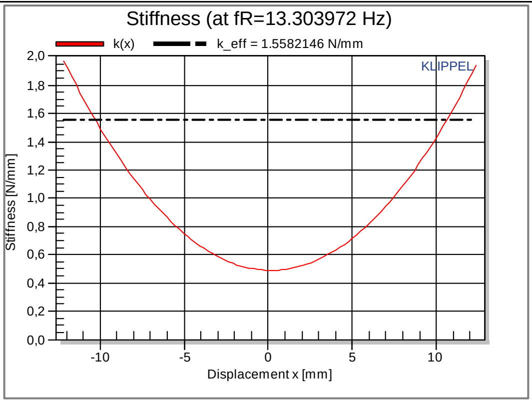
A long settlement time is required due to viscoelastic effects (creep). This means that the displacement increases with time as the mass is attached.

Dynamic measurement (large signal signal) - SPM

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

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

This parameter may be measured with the SPM module for the KLIPPEL RnD System. The red curve 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}:

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

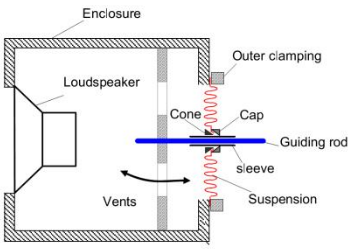
The dashed line represents k_{eff} in the example measurement. It may be plotted together with the dynamic stiffness $k(x_{ac})$ for comparison. Obviously, the value of the effective stiffness is somewhere between the maximal (@ x_{peak}) and minimal (@ x=0) dynamic stiffness.

Dynamic measurement (small signal) – LST & SPM

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.

SPM

The SPM module can also be used for a small signal measurement at low levels. The picture shows a schematic cross section of the SPM bench. The principle is similar to the LST in general. However, the DUT is clamped vertically to minimize the influence of gravity. The clamping procedure is time consuming. Additional damping is generated by the guiding rod which may be removed for small signal measurement.

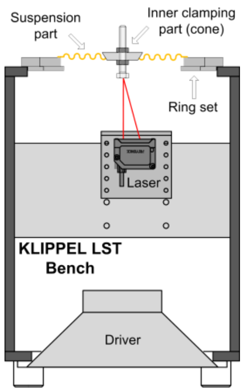


$$k_{eff}(x_{peak}) = (2\pi f_r)^2 m \quad \text{for} \quad x_{peak} \to 0$$

LST

The LST is also focused on the dynamic small signal behavior of the suspension. However, 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.

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



Example: 6'' spider

To evaluate systematic differences among the introduced measurement methods, the table below shows practical results for a standard 6'' spider. The table is discussed in the following section.

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	0	13.3	223

Interpretation and summary

- Static stiffness is lower than effective stiffness due to material creep – suspension seems to be softer as under real dynamic operation conditions
- Effective stiffness in large signal domain is usually higher than in 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}.
- The results of all techniques depend on further boundary conditions like additional moving mass and peak displacement. Therefore, these conditions should always be given along with the measurement results (e.g. k_{eff} @ x_{peak}) for proper data exchangeability.

More Information

Software documentation

- User Manual LST Module
- User Manual QC System
- Specification C6 QC Linear Suspension Test
- Specification C2 Suspension Part Measurement Set

Application Notes

- AN26 Nonlinear Stiffness of Suspension Parts (Application Note related to SPM module of the Klippel RnD System)

Papers

- W. Klippel, "Dynamical Measurement of Loudspeaker Suspension Parts", presented at the 117th Convention of the Audio Engineering Society, San Francisco, October 28–31, 2004.

Standards

- IEC Standard 62459 "Measurement of Suspension Parts", 2009

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