LST - Linear Suspension Test C6

Module for the KLIPPEL ANALYZER SYSTEM (QC Ver. 6, dB-Lab Ver. 210)

Document Revision 2.13

FEATURES

- Test linear parameters like f_r, Q-factor and stiffness *k*
- Test mass and stiffness deviation from *Golden Unit* (LST Pro)
- Dynamic method in small signal domain according to IEC 62459
- Short measurement time
- Fast and simple clamping
- Model-based parameter fitting

BENEFITS

- Ensure quality of final speaker at an early stage
- Ensure consistency and validity of production
- Interface between manufacturer and customer
- Superior to static methods

This software module and hardware accessory for the KLIPPEL QC System is dedicated to the quality control of suspension parts (spiders, cones, surrounds) and passive radiators (drones).

Round test objects are quickly mounted on the measurement bench using a set of mounting parts (rings, cones). No time-consuming clamping is required. The built-in loudspeaker of the test bench drives the device under test pneumatically in order to find resonance frequency using a log sweep.

Linear mechanical parameters like resonance frequency, stiffness (LST Lite) or relative mass and stiffness deviation (LST Pro) are measured using a laser sensor which may be enhanced by an additional microphone for improved accuracy.

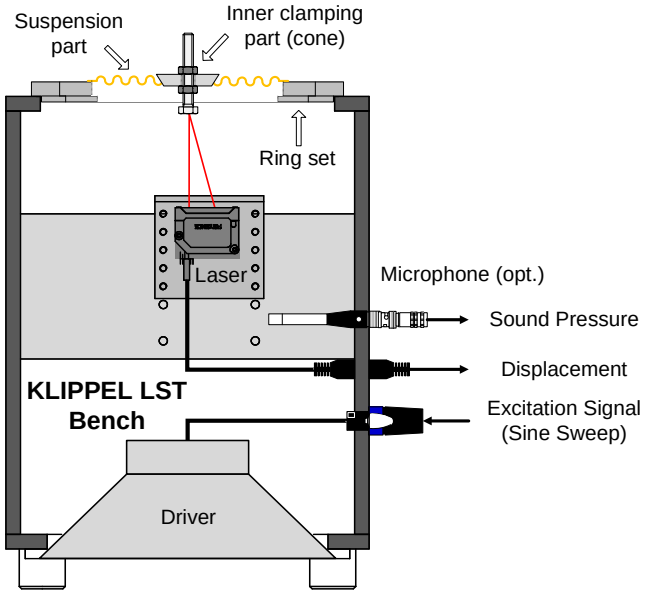
APPLICATIONS

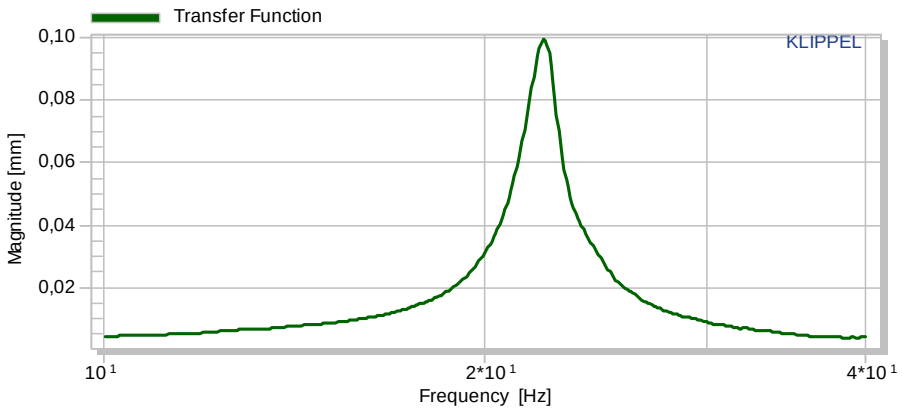
- Spiders, surrounds, cones, domes, diaphragms & passive radiators
- DUT diameter 30-222 mm
- extension for small speaker diaphragms with *MSPM Bench* or DUTs up to 490 mm with *SPM Bench* possible
- Quality control in suspension part manufacturing
- Quality control of incoming goods

CONTENT

1 General Information

1.1 Principle

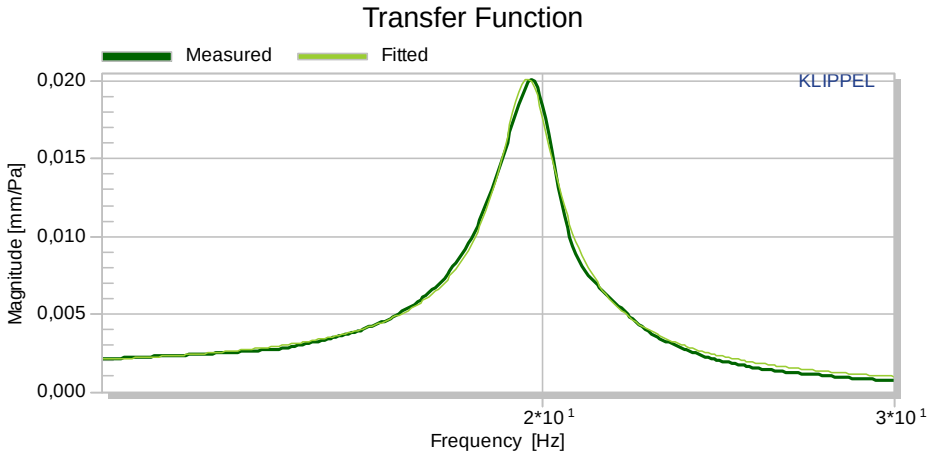
General	The test method of the LST is based on dynamic measurement in small signal domain of the device under test (low displacement). The built-in speaker of the *LST Bench* is driven with a logarithmic sine sweep generating sound pressure in order to stimulate the DUT mounted on top of the bench. The response is measured with a laser displacement sensor and an optional microphone. The transfer function provides resonance frequency, Q factor and other derived parameters. 
Resonance Tracking Methods	Two measurement methods are available, depending on the hardware setup used. The selected method defines how the initial parameters resonance frequency and Q factor are identified. **Simple Method (laser only)** Using simple laser-based method the resonance parameters are determined from the measured displacement magnitude (transfer function between shaped stimulus and displacement)



The resonance frequency is read at maximal amplitude, Q factor is defined by -3 dB drop.

Parameter Fitting (two signal method: laser + mic)

The transfer function between sound pressure and impedance is used to fit a mass-spring resonator model. By this, the resonance frequency and Q factor can be determined more accurately. The accuracy of this method does not depend on the selected frequency resolution and parameter falsification due to the LST Bench is avoided. Additionally, this method may handle noisy signals more successfully.



For large size test objects resonance may be hardly detectable in displacement. Therefore, sound pressure measurement might be mandatory.

Stiffness Calculation (LST Lite)

For suspension part testing the moving mass m is assumed constant because it is dominated by the inner mounting part (cone). Therefore, the small signal stiffness k_0 may be calculated from the resonance frequency of a simple mass-spring-resonator

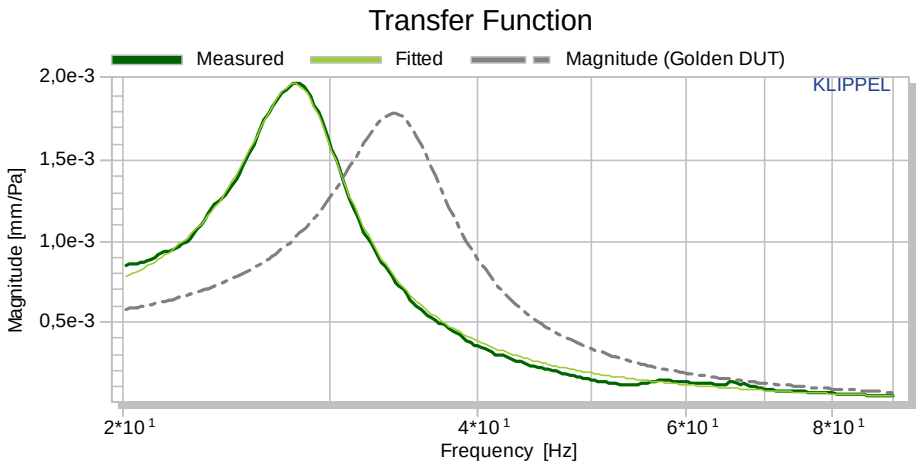
$$f_r = \frac{1}{2\pi}\sqrt{\frac{k_0}{m}} \quad \text{with } m = \text{const}$$

See [1] for more information.

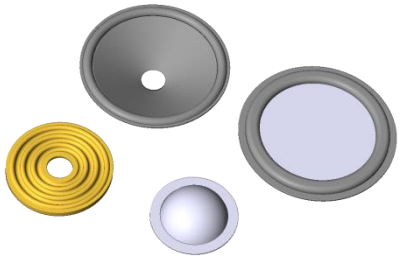
Mass and Stiffness Deviation (LST Pro)

For passive radiators, the assumption of constant moving mass among a series of DUTs is not valid. Therefore, both mass and stiffness variation shall be monitored for root cause analysis in case of a resonance frequency failure.

To avoid time consuming two-step perturbation methods (e.g. added mass method), a different approach is applied which requires a dedicated reference sample (Golden Unit). The relative mass Δm and stiffness deviation Δk0 of DUT and reference sample is calculated from the deviation of resonator parameters and transfer functions.



1.2 Test Objects



The LST is suitable for all kinds of suspension parts (spiders, cones with suspension, domes) and passive radiators.

Devices with circular geometry and a maximal diameter of 222 mm can be measured immediately using the standard clamping set (rings cones). Devices with irregular geometries require custom clamping which may be attached to the test bench.

1.3 Procedure

Setup

The initial setup typically takes 5-10 minutes by performing the following steps:

1. Measure the inner and outer diameter of device under test (DUT)
2. Look at the tables to find the optimal mounting parts using the nomenclature
3. Mount the selected set of rings on the test bench
4. Put the first DUT on the ring
5. Prepare the inner mounting parts (fitting cone + bolt and two nuts).
6. Adjust the laser head distance

Testing

1. Attach the DUT and the inner clamping parts
2. Start the measurement which usually takes 1-2 second
3. See the transfer function magnitude, the resonance frequency and other derived parameters such as stiffness in the chart and the summary window
4. Measure reference units and calculate limits for quality control

2 Components of the LST Set

2.1 Test Bench

The central part of the LST hardware set is the test bench. Different types and versions are available depending on the target application

LST Bench (Art. #: 2500-300)		The LST Bench consists of a sealed enclosure with a volume of 9 litres and a 10” driver to provide the stimulating sound pressure signal. It contains an internal and adjustable mounting platform for the laser displacement sensor and a mounting hole which is compatible to the optional ring set. For fast and easy mounting, the clamping platform is orientated in a horizontal position. The device under test is attached to the bench using a set of rings for the outer rim as well as inner mounting parts (cone and nuts, not for passive radiators) providing a defined mass and reflective surface for the laser. The measurement is performed in the small signal domain thus gravity ensures sufficient clamping in most cases. Passive radiators are mounted without additional mass pieces. Custom clamping platforms may be used in case of irregular geometries. The LST Bench set is delivered with the required cables to connect it to *Klippel QC Production Analyzer*.
LST Bench with external laser boom (Art. #: 2500-310)		An extended version of the LST Bench providing an external boom. The laser rack including the laser rod and platform is mounted externally to provide an easy accessibility and adjustability. This technique is beneficial to quickly adjust the laser distance in case the type of test object is changed frequently or mainly passive radiators are measured.

MSPM Bench (extension) (Art. #: 2500-604)		The MSPM bench is dedicated to testing small speaker diaphragms with custom mounting platforms. It is an extension for the LST bench with external laser mounting for laser adjustment. **Note**: clamping is very crucial, but also time-consuming for micro-speaker and headphone diaphragms in order to ensure meaningful and reproducible results. In many cases, the sample needs to be glued. Therefore, EOL test applications may be limited.
SPM Bench (Art. #: 2500-101)		The LST Bench is capable of handling test objects up to a diameter of 222 mm which corresponds to the largest ring of the optional clamping ring set. For larger test objects up to 18'', the SPM Bench may be used instead of the LST Bench. This test bench was originally designed for the *Suspension Part Measurement* module of the KLIPPEL R&D System) with horizontal orientation of the DUT and extended clamping. For LST applications the SPM bench may be operated facing upwards to allow simple clamping. For test objects which do not fit the optional ring set, custom rings must be provided.

2.2 Displacement Sensor

The measurement principle of the LST is based on the displacement (and optional sound pressure) frequency response of sound pressure stimulated suspension parts and passive radiators. The *LST Bench* is designed to be used with various laser heads.

Laser Set IL-65 (Art. #: 2102-042)		This laser and controller set is the default solution for vibration measurement in LST providing a very good cost-performance ration. The laser set is provided preconfigured for optimal operation. Note: IL-30 laser head is also available on request providing higher resolution but lower measurement distance and range. For *MSPM Bench* application, the LK-H series laser heads are required.
Laser Sets LK-H52 (Art. #:2102-130) LK-H82 (Art. #:2102-055)		The laser sensor of the LK-Hxx series provide best resolution and bandwidth as required for test applications with *MSPM Bench*. However, they can be used for all LST applications.

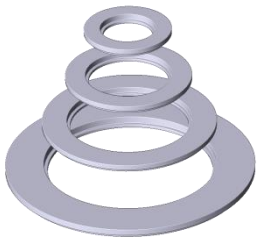
2.3 Microphone

Sound pressure measurement inside the test bench is optional but recommended in order to enable result calculation based model parameter fitting. Especially for large size DUTs and LST Pro mode this is highly recommended for best result accuracy.

Various ¼'' measurement microphones may be used. Please refer to specification *A4 Microphones*.

MIC 40PP-S1 IEPE (Art. #: 2400-007)		The G.R.A.S. 40PP-S1 is the default microphone for LST application. This cost-efficient microphone with a sensitivity of 10 mV/Pa can be connected directly to the IEPE powered MIC inputs of the *Production Analyzer*. With default configuration of the microphone inputs this microphone may handle up to 140 dB SPL before clipping occurs.

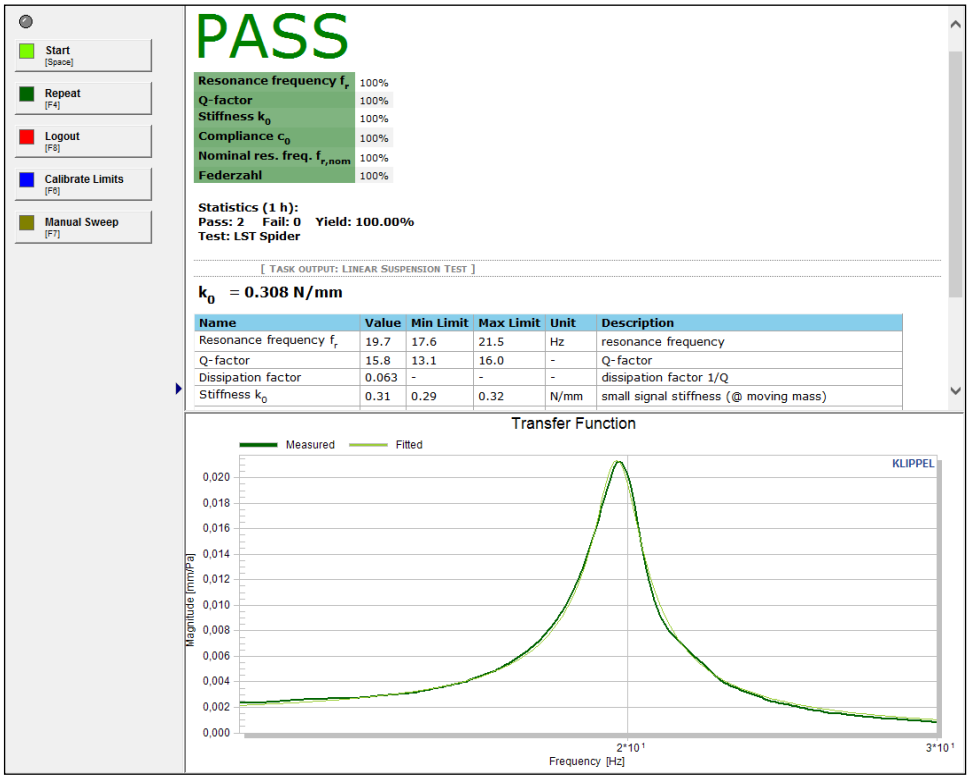
2.4 Clamping Parts (Optional)

Ring Set (Art. #: 2500-302)		The ring set is designed for mounting round test objects with a diameter between 30 and 222 mm to the test bench. After measuring the DUT's outer diameter and the width of the rim the fitting ring set can easily be identified by using a table and nomenclature. The rings are made of 10 mm aluminum. The subsets are designed in a way that the neighbor set of the lower ring can be used for upper clamping of the DUT (optional).
Cone Set (plastic) (Art. #: 2500-301)		The cone is attached to the neck of the suspension part providing a defined moving mass and a reflective surface for the laser beam (together with the included bolt and nuts). To avoid static displacement, the cones are made of lightweight plastic. Multiple cones are organized in a set with a simple nomenclature to cover neck diameters from 14 mm to 111 mm. The set includes three bolts with different lengths (M10x80 and M10x40) and four M10 nuts.

2.5 Software

LST Lite (Art. #: 4000-242)	The LST task is a licensed add-on module for the *KLIPPEL QC System* (Basic, Std & Prog). The software and dedicated test templates are part of the normal QC software; operation and user interface are very similar to standard QC tests. Common features like limit calculation based on reference units and limit calibration using a golden reference sample are available. LST Lite version is suitable for all suspension parts. The dominant property is compliance / stiffness which is derived from the resonance frequency. Mass is assumed constant (dominated by inner clamping parts). LST Lite is also suitable for passive radiators, if only

resonance frequency and Q factor shall be tested.



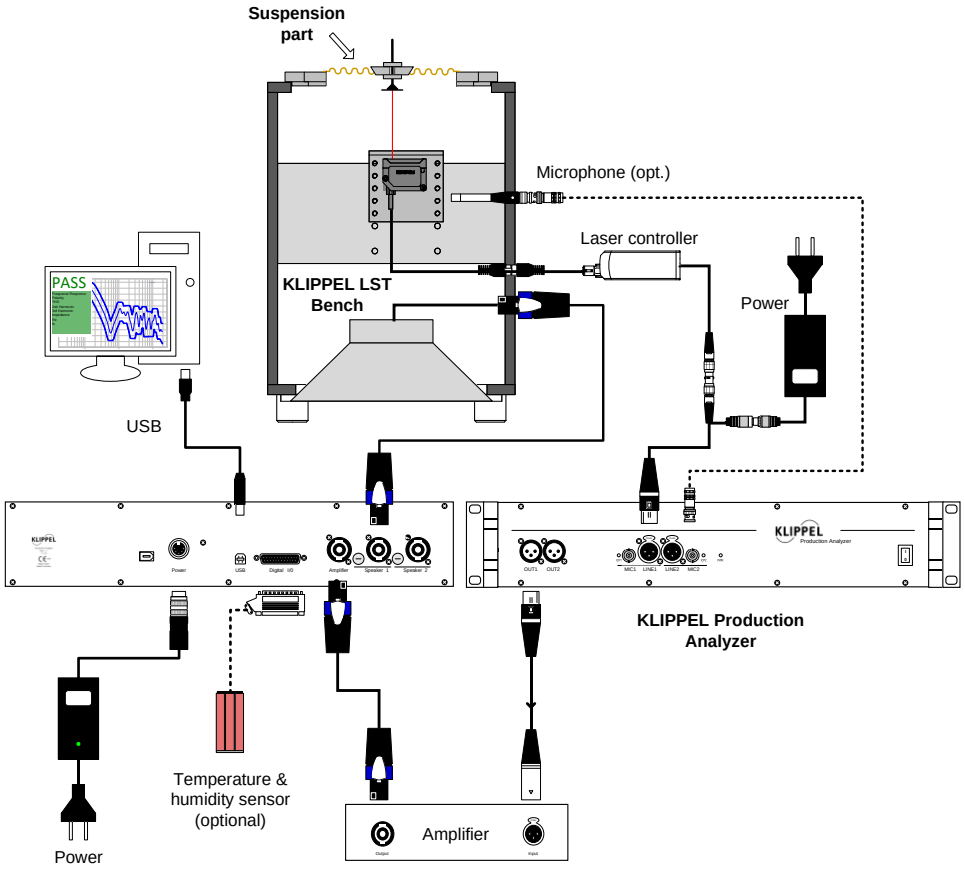
Name	Value	Min Limit	Max Limit	Unit	Description
Resonance frequency f_r	19.7	17.6	21.5	Hz	resonance frequency
Q-factor	15.8	13.1	16.0	-	Q-factor
Dissipation factor	0.063	-	-	-	dissipation factor 1/Q
Stiffness k_0	0.31	0.29	0.32	N/mm	small signal stiffness (@ moving mass)

LST Pro (Art. #: 4000-244)	LST Pro extends the light version with additional signal processing and two more measures: mass deviation and stiffness deviation. The LST Pro is specially dedicated for advanced testing of passive radiators identifiying the root cause of resonance frequency deviation. **Note**: LST Pro features are not recommended for application with normal suspension parts because leakage cannot be controlled and stiffness is the dominant parameter.

3 Requirements

3.1 Hardware

LST Hardware Setup (with Production Analyzer)



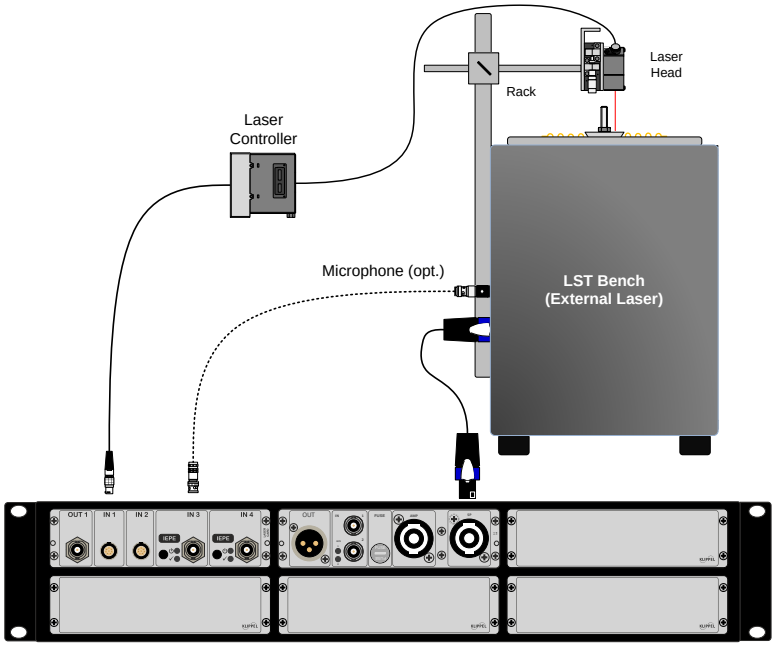
The figure above shows the equipment required to run the LST

- Measurement bench (incl. cone and ring clamping set)
- Displacement laser sensor
- Microphone (opt., recommended)
- KLIPPEL Production Analyzer
- PC
- Power amplifier and cables

Optional equipment of the QC System

- Temperature/humidity sensor
- barcode reader
- foot switch
- assembly line control via digital I/O connector

→ more information in the KLIPPEL specification “C3 - QC End of Line Test System”

LST Hardware Setup (with KA3)	 The schematic above shows a simplified alternative hardware setup with *Klippel Analyzer 3* (*KA3 LQ*) hardware, *LST Bench* with external laser mounting and *LK-H52* laser set. Using the recommended configuration with *QC Card* and Laser Card, the integrated power amplifier is used to drive the *LST Bench* connected to the *Speaker* output of the *QC Card*. The sensors (mic, laser) are both connected to the corresponding inputs of the Laser Card.
Production Analyzer	 The *KLIPPEL Production Analyzer* is the standard measurement hardware of the QC System. It provides the stimulus signal to the amplifier and acquires the displacement and sound pressure signals. Please find more information in *H4 – Production Analyzer Hardware* for detailed specification.
KLIPPEL Analyzer 3	 In order to use the LST with KLIPPEL R&D System (from version 210), the KA3 hardware is required. The analyzer is also supported from QC Version 6. It is recommended to use a configuration with an internal power amplifier (QC Card or Amp Card) for an integrated setup. The *KA3 LQ* configuration is the best value setup: • Laser card • QC Card (with internal power amplifier) An alternative KA3 conguration (AL) with dedicated *Amplifier* and *Speaker Card* is also suitable and provides one more speaker channel (e.g. for transducer tests). For use with an external amplifier, the *KA3 LQ* is also suitable (note that the *QC Card* needs to be configured for use with external amp). Also KA3 default configuration *LSX* is highly suitable.
Power Amplifier	A power amplifier is required to drive the LST Bench. In case the KA3 hardware is used to operate the LST, it is recommended to use the integrated amplifiers (*QC Card, Amplifier Card*), if available. Any external audio amplifier meeting the power and bandwidth requirements of the tests may be used as well. The lower cut-off frequency should be below mounted DUT resonance frequency to ensure sufficient excitation.
PC	Please refer to general PC requirements of the QC System

3.2 Software	
QC Framework	The LST works with all versions of the QC software (Basic, Standard, Prog) from QC release version 3.0. LST is installed with the QC software, no additional setup is required. An LST Lite or Pro license is required for operation. **Note**: some restrictions apply in QC Basic version. Please refer to *QC System Feature Specification* for details.
RnD Framework	From release version 210, the LST may be operated within the KLIPPEL RnD software release. No additional setup, only an LST Lite or Pro license is required for operation. **Note**: KLIPPEL Analyzer 3 (KA3) hardware is required to operate the LST in the RnD software framework.
3.3 Further Requirements	
Test Environment	The LST measures vibration (displacement) as well as sound pressure (optionally). To ensure stable and reproducible testing, structure-borne noise should be minimized by placing the bench on a heavy base or using other means to minimize coupling. Sound pressure measurement improves robustness of the test due to the applied fitting algorithm, but heavy ambient noise may degrade results. A warning is generated if the required signal to noise ratios are not fulfilled.
Custom Clamping	Custom clamping parts may be required for special test object shapes or over-sizes. Technical drawings of the test benches can be provided on request.

4 Limits and Results

4.1 Setup Parameter Limits

Parameter	Symbol	Min	Typ	Max	Unit
STIMULUS					
Start -Start frequency of sine sweep	f_{start}	1	10	var	Hz
Stop – Stop frequency of sine sweep	f_{stop}	1	100	var	Hz
Time – Measurement time	t	0.5	2	20	s
Voltage (rms) – stimulus voltage (amp output)	$\widetilde{U}_{\text{stim}}$	0	0.5	10	V
PROCESSING					
Resolution – frequency response resolution	R	50	200	400	pts/oct
Smoothing	-	1	30	99	pts/oct
Moving Mass	m		-	1000	g
Temperature Deviation	ΔT	1	-	20	K
Input Gain – analog mic input pre-amp gain	$G_{\text{pre,mic}}$	-70	0	30	dB

4.2 Specification Limits

Frequency Range					
- LST Bench + Microphone	f	10	-	200	Hz
- SPM Bench + Microphone	f	10	-	100	Hz
- displacement only	f	10	-	1000	Hz
Displacement (IL-65)	x	0.002	-	15	mm
Sound Pressure (40PP-S1)	p	50	-	140	dB SPL

4.3 Measurement Results

Measured Quantity	Symbol	Unit	QC Limits Applicable
Resonance Frequency	f_{r}	Hz	✓
Quality Factor	Q	-	✓
Dissipation Factor	DF	-	-
Stiffness (for *m*=const)	k_0	N/mm	✓
Compliance (for *m*=const)	c_0	mm/N	✓
Nominal Resonance Frequency	$f_{\text{r,nom}}$	Hz	✓
Federzahl (displacement @ ref. mass)	Fdz	mm*10	✓
Mass Deviation* (relative to *Golden Unit*)	Δm	g	✓
Estimated Total Moving Mass*	m'	g	-
Stiffness Deviation* (relative to *Golden Unit*)	Δk	N/mm	✓
Estimated Total Stiffness*	$k_0{}'$	N/MM	-
Displacement Magnitude	$L_x(f)$	dB (re 1 mm)	-
Displacement THD+N	$L_{x,THD+N}(f)$	dB (re 1 mm)	-
Sound Pressure Magnitude**	$L_p(f)$	dB (re 20 µPa)	-
Sound Pressure THD+N**	$L_{p,THD+N}(f)$	dB (re 1 mm)	-
Transfer Function ***	$H_x(f)$	dB	-

**LST Pro*

***Only if LST is operated with microphone*

****Transfer function between sound pressure and displacement or stimulus and displacement (no mic)*

5 Examples

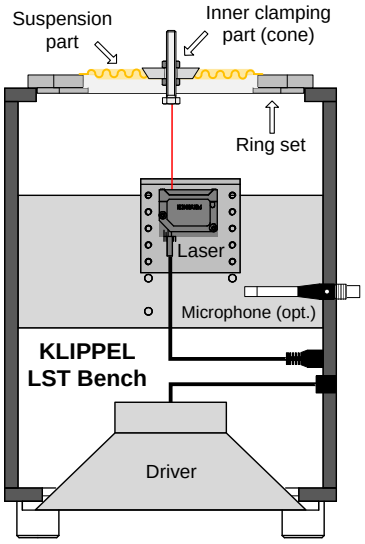
5.1 Spider Test

A standard application of the LST Lite module is testing spiders (dampers). For this application, resonance frequency f0, Q-factor and the stiffness k_0 are measured.

Normal round spiders can be attached to the measurement bench using a subset of the modular ring set. The cone for inner clamping is selected by the neck diameter of the spider. The laser distance may be adjusted with the mounting bolt. For this application sound pressure measurement is optional but recommended for best accuracy.

For measuring stiffness, the moving mass which is dominated by the inner mounting parts must be entered in the property page.

Once the measurement bench is adjusted and the software properties are set, large batches of spiders can be tested with a very short cycle time. The test objects are only attached by gravity to minimize mounting time. For soft suspension parts, an additional upper clamping ring may be used as well.



5.2 18'' Cone Test

For testing large size objects with a diameter of more than 222 mm, it is required to use the SPM test bench and custom clamping rings.

The 18'' cone in this example is attached to the test bench using a custom wooden ring which fits the rim diameter. The ring is attached to the SPM test bench using the provided standard clamps. No upper ring is required. For inner clamping, a suitable cone has been selected from the standard plastic cone set.

Testing large size objects requires two-signal measurement method. The laser is used for displacement measurement while a microphone (not visible) is picking up the sound pressure within the SPM Bench. The resulting transfer function allows accurate measurement of the resonator parameters.

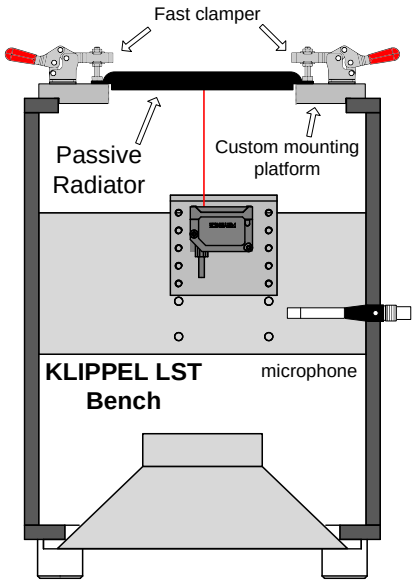
5.3 Passive Radiator Test

For testing passive radiators, the LST Pro is recommended as both suspension and moving mass might vary in production. In addition to LST Lite results there are two more measures. Mass deviation and stiffness deviation are based on a physical model and defined relative to a reference unit ("Golden Unit"). This unit may be selected according to R&D specifications or automatic Golden Unit selection based on a batch of reference units.

All subsequently measured radiators are related to the reference unit. If the reference moving mass is known (e.g. from R&D or added mass method) the parameter deviation can be monitored in absolute values, otherwise in percent.

If the passive radiator is not round, a custom platform may be mounted on top of the LST Bench. The outer frame must be fixed for reproducible conditions (e.g. using clampers).

In case the ambient conditions (temperature/humidity) have changed over time, the limits may be calibrated using the golden unit. It should be kept under the same ambient conditions close to the test station.



5.4 Headphone and Micro-Speaker Diaphragms, Tweeter Domes

Since most small and miniature speakers (e.g. micro-speaker, headphone) do not have spider, the diaphragm defines the main compliance of the final driver. Testing the shaped, mostly thin foil parts is a difficult task. Also, tweeter domes mostly exceed the frequency range limitations of the LST Bench.

For such applications, the MSPM Bench extension may be attached to the LST Bench providing a smaller volume with a dedicated driver for excitation and a different clamping system.

The DUT is mounted on a custom tray. For reproducible and defined conditions, gluing the DUT to the sample tray is recommended. Therefore, this application is rather recommended for sample testing than for 100% EOL check.

6 Look Up Tables for Clamping Set

Cone Number	Minimal Diameter D_C (mm)	Weight (g)
1	11	2.1
2	18	5.2
3	25	9.5
4	32	14.9
5	39	21.3
6	46	28.9
7	53	37.6
8	60	47.3
9	67	58.3
10	74	70.1
11	81	83.1
12	88	97.3
13	95	112.4
14	102	128.6

Part	Mass (g)	Type
Hexagon bolt	7	M10x80
Hexagon bolt	4.5	M10x40
Knurled nut	3.2	M10

Ring Label	Mounting Diameter D_R (mm)
A1	30
B1	33
C1	36
D1	39
E1	42
F1	45
G1	48
H1	51
A2	54
B2	57
C2	61
D2	65
E2	69
F2	73
G2	77
H2	81
A3	85
B3	89
C3	93
D3	98
E3	103
F3	108
G3	113
H3	118
A4	124
B4	130
C4	136
D4	142
E4	148
F4	154
G4	160
H4	166
A5	173
B5	180
C5	187
D5	194
E5	201
F5	208
G5	215
H5	222

7 LST Test Bench Specification

7.1 Specification for revision 1.1 and below

Physical Dimensions (LxWxH)		
Dimensions of Bench only in mm	297x297x413	
Maximum Dimensions of Bench with attachments in mm	297x297x785	
Maximum/Minimum Ratings		
Parameter	**Minimum**	**Maximum**
Driver Nominal Impedance in Ω	8	
Driver Voltage in V rms (Sinusoidal Stimulus, Long Term)		35
Driver Voltage in V rms (Sinusoidal Stimulus, Short Term)		50
Driver Voltage in V rms (Multitone Stimulus)		15

Driver used: SICA 10 BS 2,5 PL 8 Ohm (Code Z005910)

7.2 Specification for 1.2 and above

Physical Dimensions (LxWxH)		
Dimensions of Bench only in mm	297x297x448	
Maximum Dimensions of Bench with attachments in mm	410x310x785	
Maximum/Minimum Ratings		
Parameter	**Minimum**	**Maximum**
Driver Nominal Impedance in Ω	4	
Driver Voltage in V rms (Sinusoidal Stimulus, Long Term)		25
Driver Voltage in V rms (Sinusoidal Stimulus, Short Term)		40
Driver Voltage in V rms (Multitone Stimulus)		10

Driver used: SICA LP266.65/1430 SG 4 Ohm (HK Audio OEM 9940224)

8 References and Related Information

[1] W. Klippel, "*Dynamical Measurement of Loudspeaker Suspension Parts*", Convention Paper, 117th AES Convention, October 2004, San Francisco

[2] Klippel GmbH, "C7 SPM Lite", Specification of the KLIPPEL R&D System, http://www.klippel.de/our-products/rd-system/modules/spm-suspension-part-measurement.html

[3] Klippel GmbH, "*AN 53 - Fast QC of Suspension Parts*", Application Note of the KLIPPEL QC System, http://www.klippel.de/our-products/qc-system/additional-modules/lst-linear-suspension-test.html

[4] Klippel GmbH, "C3 QC Set", Specification of the KLIPPEL QC System, http://www.klippel.de/our-products/qc-system/qc-standard-system.html

[5] IEC Standard 62459 "*Measurement of Suspension Parts*", 2009

9 Patents

GERMANY	102007005070
USA	8,078,433
CHINA	ZL200810092055.4
JAPAN	5364271

Find explanations for symbols at:
http://www.klippel.de/know-how/literature.html
Last updated: April 08, 2020

KLIPPEL MODULE OVERVIEW FOR MOVING PARTS MEASUREMENT

	SPM Lite	SPM Pro	MSPM Lite	MSPM Pro	QC LST Lite	QC LST Pro
R&D System	✓		✓		✓[5]	
QC System	-		-		*QC Basic* or *Standard*	
Base Module	TRF		TRF	LPM	-	
Analyzer Hardware	Distortion Analyzer 2 Klippel Analyzer 3 [5]		Distortion Analyzer 2 Klippel Analyzer 3 [5]		Klippel Analyzer 3 [5] QC Production Analyzer	
Test Bench	SPM or LST	SPM	MSPM[6]		LST, MSPM[6] or SPM[7]	
Laser Sensor (Default) (Measurement Range)	IL-030 (+/- 12.5 mm)	LK-H082 (+/- 18 mm)	LK-H052 (+/- 10 mm)		IL-065 (LK-H052[8]) (+/- 10 mm)	
Laser Sensors (Alternative) (Measurement Range)	LK-H022 LK-H052 LK-H082 LK-H152 LK-G32	LK-H052 (+/- 10 mm) LK-H152 (+/- 40 mm)	LK-H022 (+/- 3 mm) LK-H082 (+/- 18 mm) LK-G32 (+/- 5 mm)		LK-H022 LK-H052 LK-H082 LK-H152 LK-G32	
Microphone	✓	-	✓		Opt.	✓
Linear Parameters f_0, Q, k, c, m, r	✓	- (only k_{eff})	✓ (only effective)		✓ (*m* import, no *r*)	✓ (*m* & *k* relative, no *r*)
Nonlinear Parameters $K(x)$, $C(x)$	-	✓	-	✓	-	
Mass Import	✓	-	✓		✓	
Added Mass	✓	-	✓	-	-	
DUT Ø in mm	30 – 222[1] (490[2])	30 – 222[1]	< 70		30 – 222[1] (490[2]) <70[8]	
Frequency Range in Hz	1 – 100[4] (200[3])	1 – 100	100 - 2500		1 – 100[4] (200[3]) 100 – 2500[8]	

1) *Standard Ring Set*
2) *SPM Bench (with custom ring)*
3) *LST Bench*
4) *SPM Bench*
5) *Min. dB-Lab Release 210*
6) *MSPM Bench requires additional equipment for laser positioning (SCN Vibrometer, LST-Bench or Pro-Stand)*
7) *For DUTs with Ø >= 222 mm / <= 490 mm, customized clamping rings required*
8) *MSPM Bench*