Suspension tester specifications

SPECSUS2018

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European foreword

[NOTE: to be edited in case of submission to CEN]

Introduction

General

These specifications are based on the EUSAMA recommendations[2] and the SAE Technical Paper 960735, 1996, Tsymberov A[9], adapted for application in the Periodic Technical Inspection (PTI) after a study program carried out in 2010[3].

The EUSAMA suspension testers used before specifications [3] and [9], although designed to work within the frequency domain, have until now, been limited to the magnitude response of the suspension system. This test result, a EUSAMA value, usually referred to as “road” adhesion, is indicative of the safety of the vehicle; however, it is unreliable in determining the performance of the dampers.

The specification detailed in this document provides, along with the magnitude response (adhesion), the phase response of the wheel versus the movements of the excitation plate. The EUSAMA frequency function (established mostly by an eccentric axle) is made variable by a frequency inverter in order to increase testing time in the neighbourhood of the axle mass frequencies, thus enabling a more correct measurement by exciting more energy.

By using this ‘phase shift’ principle, the measured values from equipment operating to this specification give indications concerning the condition, the damping capacity and the “road” adhesion capacity of the suspension system of a vehicle.

An investigation of existing patents did not find any conflicting specifications.

General use for vehicle inspection

Measurement method and testing devices need to be suitable for vehicles of the categories M1 and N1. Testing devices have to be capable of measuring axle loads of up to 2200kg.

Method of measurement

The evaluation is based on introducing forces/energy into the suspension system and evaluating the characteristics of the whole suspension and damping functions. The efficiency is evaluated per wheel in order to arrive at the evaluation of the suspension system in total (as this is a check without dismantling, malfunctioning cannot be directly related to individual parts).

1 Scope

This document applies to phase shift suspension testers designed for roadworthiness tests on categories M1, N1 vehicles (as defined in Directive 2007/46/EC).

This document covers fixed-suspension testers as well as mobile suspension testers.

These suspension testers are designed to produce measurements for testing and assessing the efficiencies of the suspension systems of the M1 and N1 vehicles categories.

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2 Normative references

There are no normative references in this document.

Eusama Specification:

see Bibliography

Phase Shift vs. Damping Ratio:

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

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3 Terms and definitions

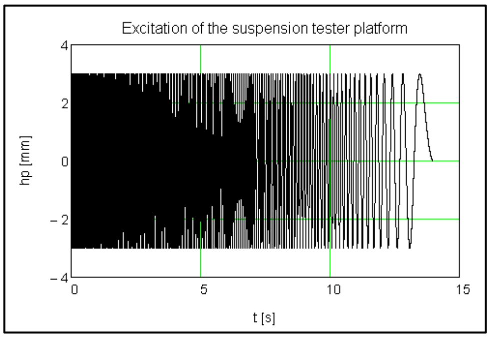
For the purposes of this document, the following terms and definitions apply.

3.1 Static force *Fst*

Force acting before the test from the wheel to the suspension tester platform. In this case (*Fst* = *F* = *Fr*)

3.2 Vertical excitation of the suspension tester platform *hp(t)*

sinusoidal excitation of the suspension tester platform during the test.

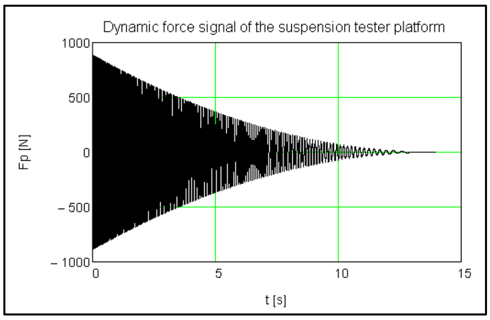


3.3 Reference position of the i^th^ period of the vertical excitation of the suspension tester platform *href(i)*

The middle point between the up and down intersections of the vertical excitation of the suspension tester platform hp(t) and zero level of this excitation (see picture in the paragraph 3.23).

3.4 Dynamic force signal of the suspension tester platform *Fp(t)*

Force generated by the unloaded suspension tester platform m_p during the test[1]. It is abbreviated as platform force *Fp(t)* and is defined by the formula $Fp(t) = m_P * \ddot{h}_P(t)$



[1] During the test with the unloaded suspension tester platform and generally during any test with the vehicle on the suspension tester platform.

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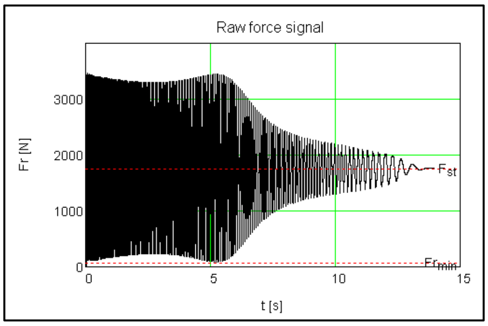
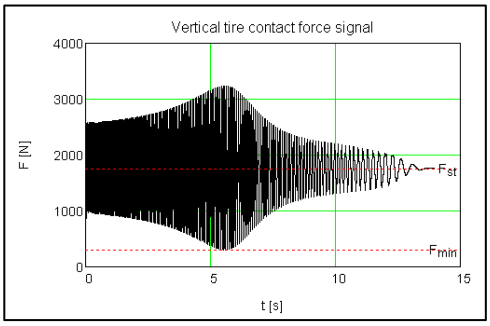
3.5 Raw force signal *Fr(t)*

Force measured directly by transducers placed below the suspension tester platform during the test. Before the test: *F = Fr, Fp = 0*, during the test: *F(t) = Fr(t) - Fp(t)*



3.6 Vertical tyre contact force signal *F(t)*

Force exerted by the tyre to the suspension tester platform during the test. It is abbreviated as tyre force signal *F(t)*. During the test: *F(t) = Fr(t) - Fp(t)*



3.7 Reference position of the i^th period of the vertical tyre contact force signal *Fref(i)*

The middle point between the down and up intersections of the vertical tyre contact force signal *F(t)* and the static weight of the wheel *Fst* (see picture in the paragraph 3.21).

3.8 Sensor Trigger *ST(i)* of the i^th period of the *Fp(t)*

point at which at the hardware level it is detected (non-precisely) the relative position of the suspension tester's platform (for instance highest, see picture below point 3.9).

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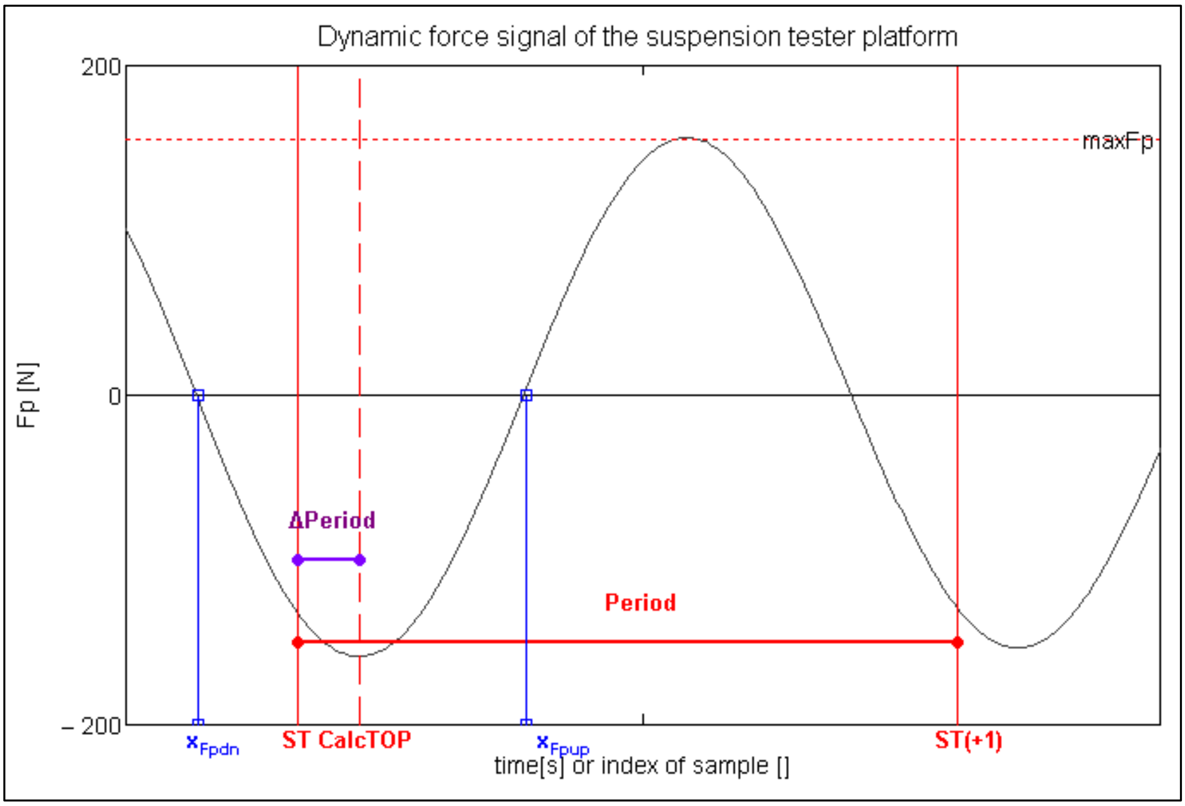
3.9 Calculated top position of the i^{th} period of the suspension tester platform *CalcTOPp(i)*

the middle point between the down and up intersections of the dynamic force of the suspension tester platform Fp(t) and 0, during the dynamic calibration of the suspension tester (point 3.9). The frequency *f* or *f(i)*[2] of force signals is calculated from the ST(i) sequence.



3.10 Dynamic calibration with the unloaded suspension tester platform

process to acquire for each *Period(i)* of the *Fp(t)* signal parameters *maxFp(i)* (amplitude) and *ΔPeriod(i)* (phase). Those parameters are then used to calculate the dynamic force signal of the suspension tester platform *Fp(t)* and the vertical tyre contact force signal *F(t)*, *F(t) = Fr(t) – Fp(t)*.

After making the dynamic calibration, if the test is done without any vehicle on the platforms, (theoretically) *F(t)=0*.

In reality, if the test is done without any vehicle on the platform it can be admitted $|F(t_{(f)})| <= DynCalErr*f$ (second picture below, lines *DynCalErr+* and *DynCalErr-*), where parameter *DynCalErr* = 4 N/Hz is the maximum allowed dynamic calibration error in the phase measuring range and *f* is the frequency [Hz] calculated from the *ST(i)* sequence. *DynCalErr* is checked[3] in the frequency range *MaxCalcFreq* (parameter *MaxCalcFreq* = 18 Hz) and *MinCalcFreq* (parameter *MinCalcFreq* = 6 Hz).

[2] Frequency *f* for each period of the ST signal is assumed to be constant value.3.21

[3] In the frequency range 25 Hz to *MaxCalcFreq* Hz *DynCalErr* is not checked, but it is recommended to keep it low to fulfil demands of the Static Amplitude *H25* measurement

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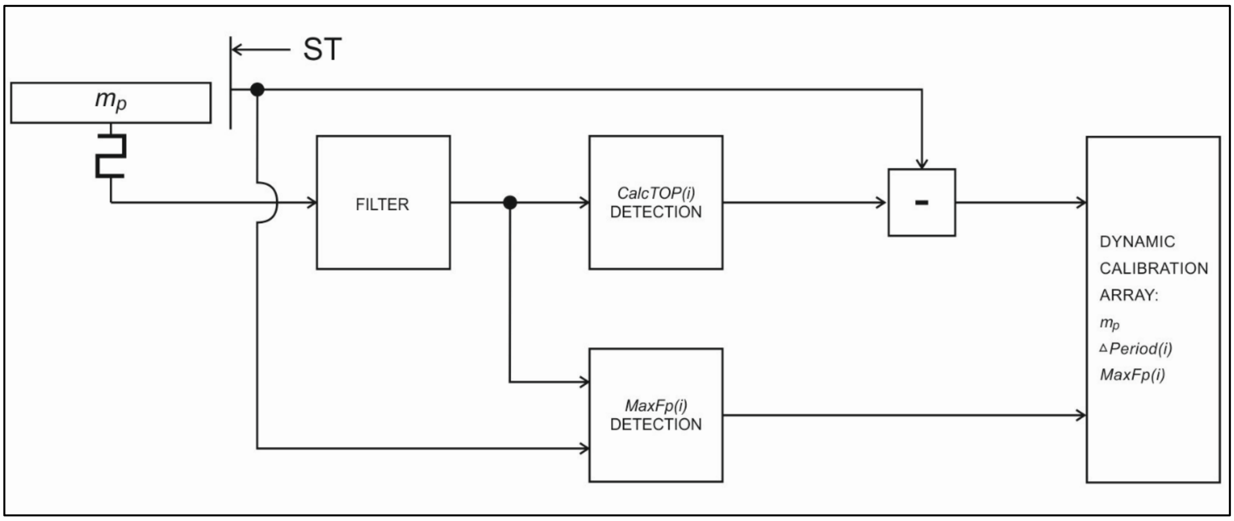

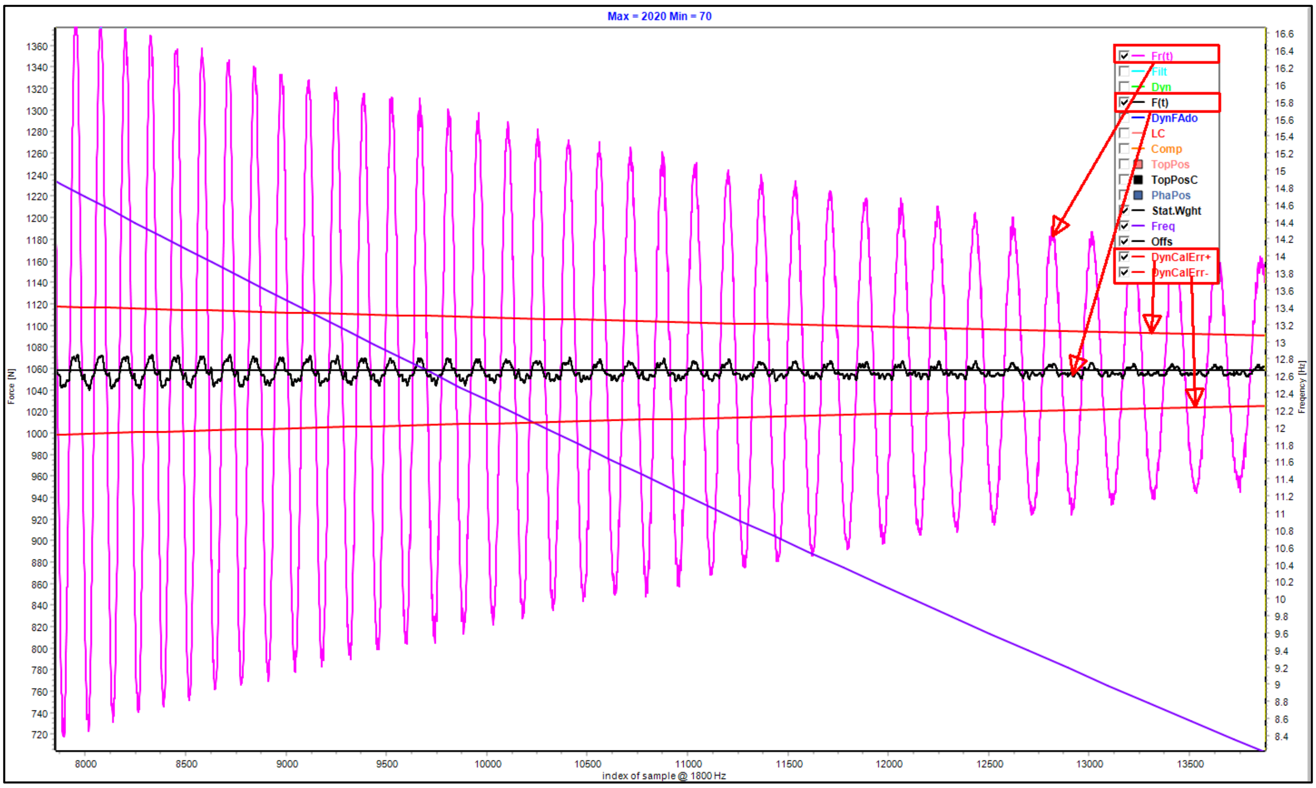

3.11 Top position of the i^{th} period of the suspension tester platform *TOPp(i)*

Is measured during the test with the vehicle on the suspension tester platform defined as $TOPp(i) = ST(i) + \Delta Period(i)$

3.12 Maximum of the i^{th} period of the *F(t)* signal *maxF(i)*

The sequence of *maxF(i)* creates the upper envelope of the *F(t)* signal.

3.13 Minimum of the i^{th} period of the *F(t)* signal *minF(i)*

The sequence of *minF(i)* creates the lower envelope of the *F(t)* signal.

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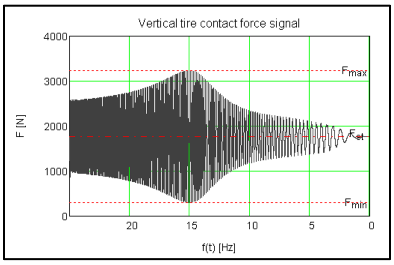
3.14 Peak to peak amplitude of the i^{th} period of the *F(t)* signal *ΔF(i)*

is expressed by the form *ΔF(i) = maxF(i) - minF(i)*

3.15 Minimum *Fmin* and maximum *Fmax* of the *F(t)* signal



Both values are defined in the natural way.

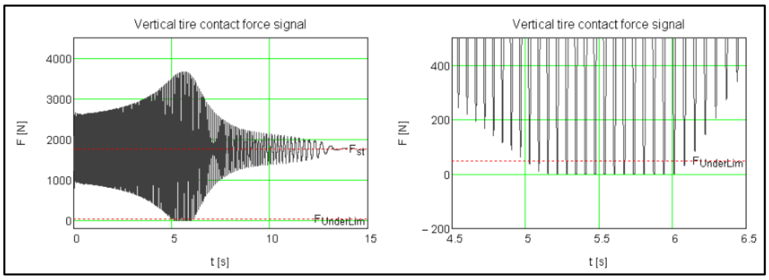
Fmin = min(F(t)).

Fmax = max(F(t)).

3.16 Treatment of F(t) signal overflow and underflow

when *Fmin < FUnderLim* is called *F(t)* signal underflow (bottom of sinewaves is cut off, picture below). Parameter *FUnderLim* is defined as a percentage of the measured static weight *Fst* by the following form:

*FUnderLim = Fst * FUnderLimPerc/100* (parameter, *FUnderLimPerc* = 1 %).



When *F(t)* signal underflows, *FUnder* flag is set.

When *Fmax > FOverLim* is called *F(t)* signal overflow (top of sinewaves is cut off). Parameter *FOverLim* is a number defined either by the system hardware or user adjustable during the approval procedure.

When *F(t)* signal overflows, the *FOver* flag is set.

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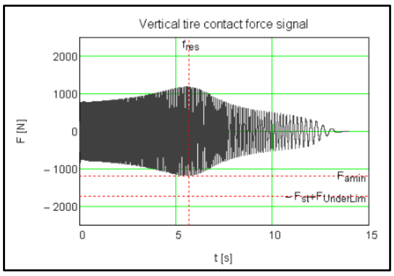
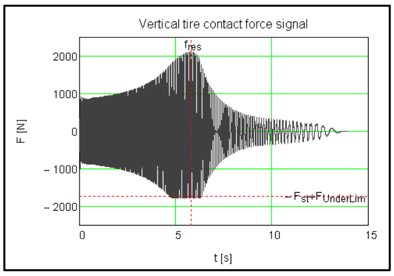
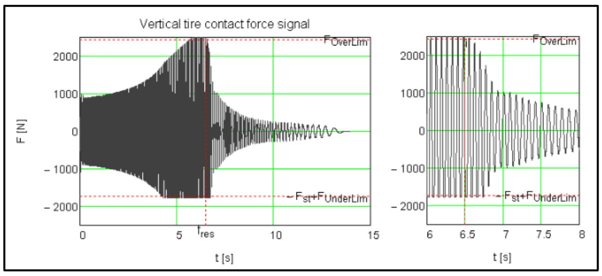
3.17 Maximum amplitude *FAmax* and resonant frequency *fres* of the *F(t)* signal



When *Fmin >= FUnderLim*, the maximum amplitude *FAmax* of the *F(t)* signal is determined as:
FAmax = Fst – Fmin
and the resonant frequency *fres* is determined in the time t_{Fmin}.



When *Fmin < FUnderLim* (signal underflow) and *Fmax <= FOverLim*, the maximum amplitude *FAmax* of the *F(t)* signal is determined as:
FAmax = Fmax – Fst
and the resonant frequency *fres* determined in the time t_{Fmax}.



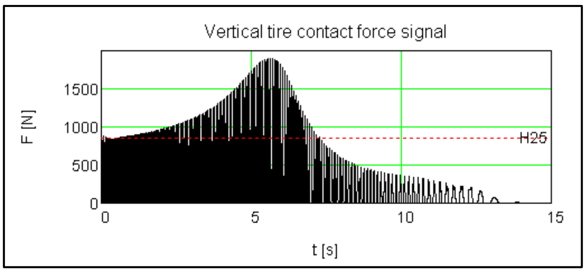
When *Fmin < FUnderLim* (signal underflow) and *Fmax > FOverLim* (signal overflow), the maximum amplitude *FAmax* of the *F(t)* signal is determined as
FAmax = max(FOverLim–Fst, Fst-FUnderLim)
and the resonant frequency *fres* is determined in the time *t* when either the overflow or the underflow flag disappears.

Maximum amplitude *FAmax* is detected in the frequency range *MaxCalcFreq* (parameter *MaxCalcFreq* = 18 Hz) and *MinCalcFreq* (parameter *MinCalcFreq* = 6 Hz).

3.18 Maximum relative amplitude *RFAmax* of the *F(t)* signal

defined as *RFAMax = FAMax / Fst * 100* [4]

3.19 Static amplitude *H25* of the *F(t)* signal



average amplitude (*ΔF(i)/2*) of approximately 10 periods of the F(t) signal, while the motor runs at 25 Hz.

[4] As the *Fst* is generally measured correctly (from the absolute point of view – see 7.18), error of the *FAMax* compared to the reference sensor could increase in the x platform direction, both sides. To remove this non-calibrated error and keep the error value small, only relative measurement of the dynamic force is used, similarly to the Adhesion test method.

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3.20 Non-rolling rigidity of the tyre[5]

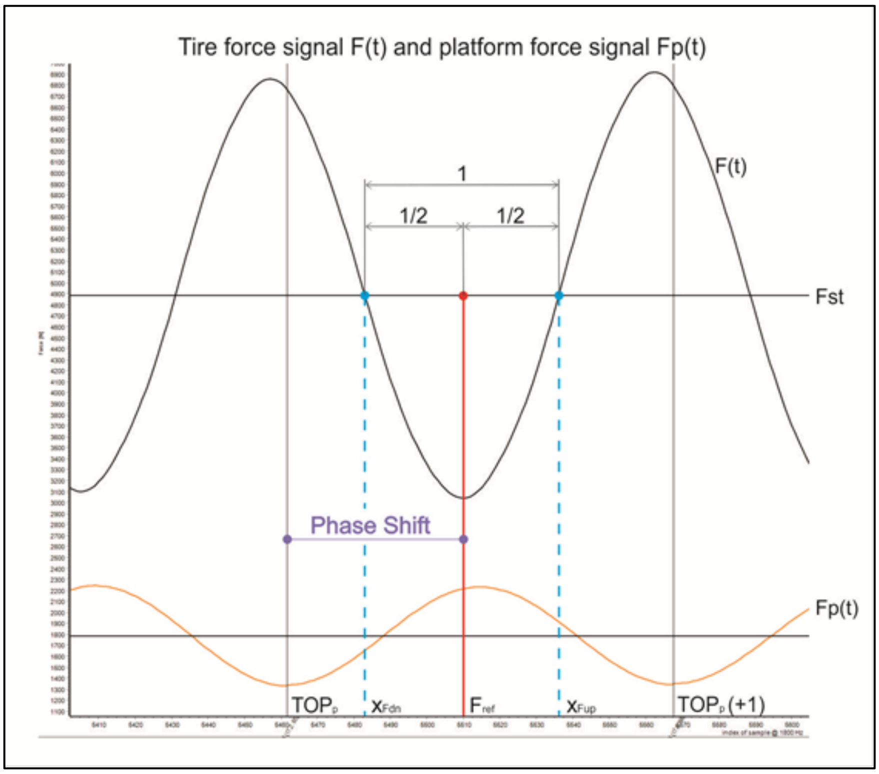
extent to which the tyre resists deformation in response to an applied force. It is measured by a frequency between the resonance frequencies of the suspension and those of the tyre; conducted at 25Hz. Further on in this specification document, this Non-rolling rigidity is shortened only as a Rigidity and is explained in further details (pages 19, 20, 21, 23 and 26).

$$rig = a_{rig} * \frac{H25}{ep} + b_{rig}$$

Where *ep* is the amplitude of the platform excitation in mm, *H25* is the static amplitude of the *F(t)* signal in N and a_{rig} and b_{rig} are parameters (a_{rig} = 0.571, b_{rig} = 46.0).

3.21 Phase shift φ

angular difference between the absolute “sinusoidal” position of the suspension tester platform and the “sinusoidal” vertical tyre contact force between the tyre and the suspension tester platform.
In practice, the phase shift $\varphi(i)$ is for each period of the suspension tester platform signal *Fp(i)* calculated from the reference position *Fref(i)* of the vertical tyre contact force signal *F(t)* and the top position *TOP(i)* of the dynamic force signal *Fp(t)*.
The top position *TOP(i)* of the suspension tester platform can be measured indirectly e.g. by means of a vertical position sensor.



[5] Tyre stiffness, tyre spring constant

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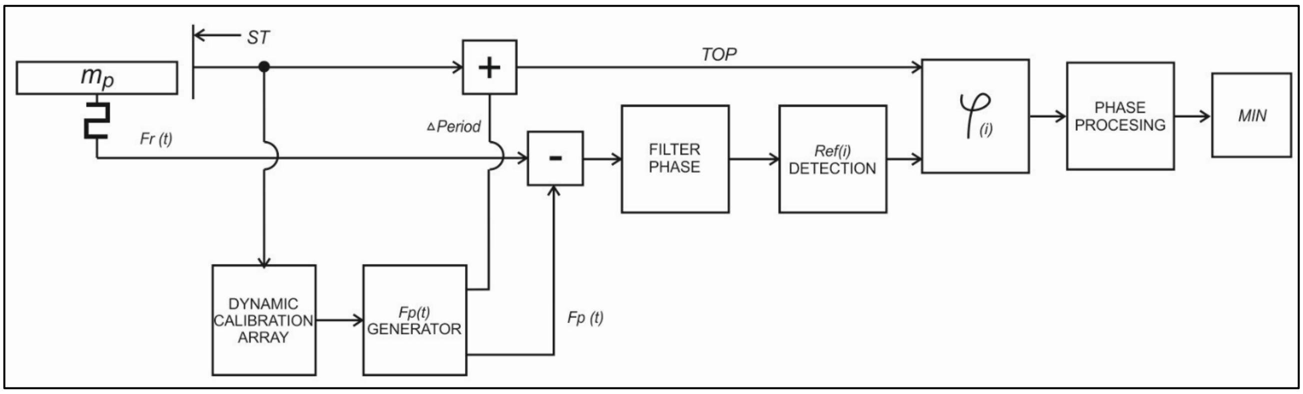
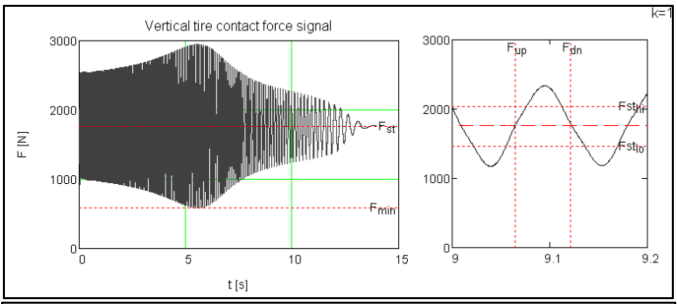


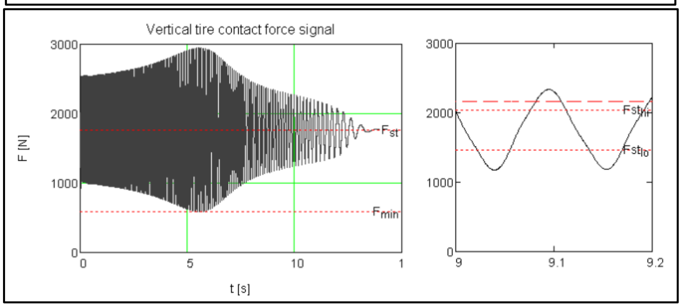
Because the static weight of the wheel *Fst* is not always about the middle of *maxF(i)* and *minF(i)*, the top position *T(i)* of tyre force signal is for each period *i* determined by the following procedure, introducing parameters *RFstFMax* = 25 % and *RFstFMin* = 25 % and two temporary variables Fst_{lo} and Fst_{hi}..

$$Fst_{lo} = minF(i) + \Delta F(i)\frac{\text{RFstFMin}}{100} < F_{up}(i) < maxF(i) - \Delta F(i)\frac{\text{RFstFMax}}{100} = Fst_{hi}$$

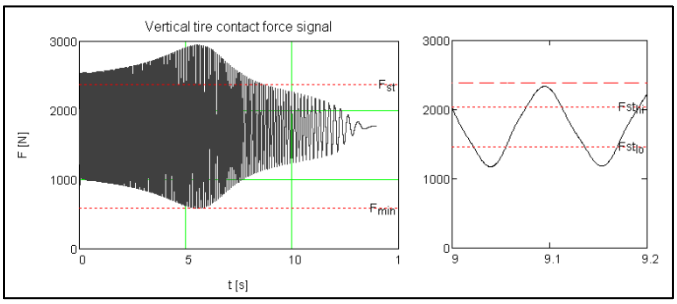
$$Fst_{lo} = minF(i) + \Delta F(i)\frac{\text{RFstFMin}}{100} < F_{dn}(i) < maxF(i) - \Delta F(i)\frac{\text{RFstFMax}}{100} = Fst_{hi}$$



Intersections *Fup* and *Fdn* are available and fulfill the above conditions - Phase shift can be calculated.



Intersections of the tyre force signal *F(t)* and the static weight *Fst* exist but don't fulfill the above conditions -Phase shift cannot be calculated.



Intersections of the tyre force signal *F(t)* and the static weight *Fst* don't exist at all. Phase shift cannot be calculated.

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Phase Shift *φ* is detected in the frequency range *MaxCalcFreq* (parameter *MaxCalcFreq* = 18 Hz) and *MinCalcFreq* (parameter *MinCalcFreq* = 6 Hz).
Phase Shift *φ(i)* value has to be in the range *0° <=. φ(i) < 180°.*
For the phase shift calculation (in the range of 18Hz to 6Hz) the force signal *F(t)* must be digitally filtered with such a filter, that doesn't change the force signal phase, but removes all parasitic influences.
Phase shift signal processing & phase shift source signal processing (Chapter Design reference 0).
For the further purposes, it is introduced parameter *FstCorr*, = 0 N, that modifies the static force when it is saved to the *Fst* (*Fst* = *Fst* + *FstCorr*).

3.22 Minimum phase shift *φmin*

lowest value of the phase shift φ determined during the test. Minimum phase shift should be detected in a frequency range that is maximum *DeltaF* (parameter: *DeltaF* = 5 Hz) below the minimum adhesion resonant frequency *fres* (paragraph 3.17) of the *F(t)* signal.
Minimum phase shift *φmin* value has to be in the range *0° <=. φmin < 180°.*
For the further processing purposes, it is introduced independently for each tester side parameter $\varphi minCorr_j$ = 0°, that modifies the Minimum phase shift when it is saved to the *φmin* result (*φmin* = *φmin*+*φminCorr*).

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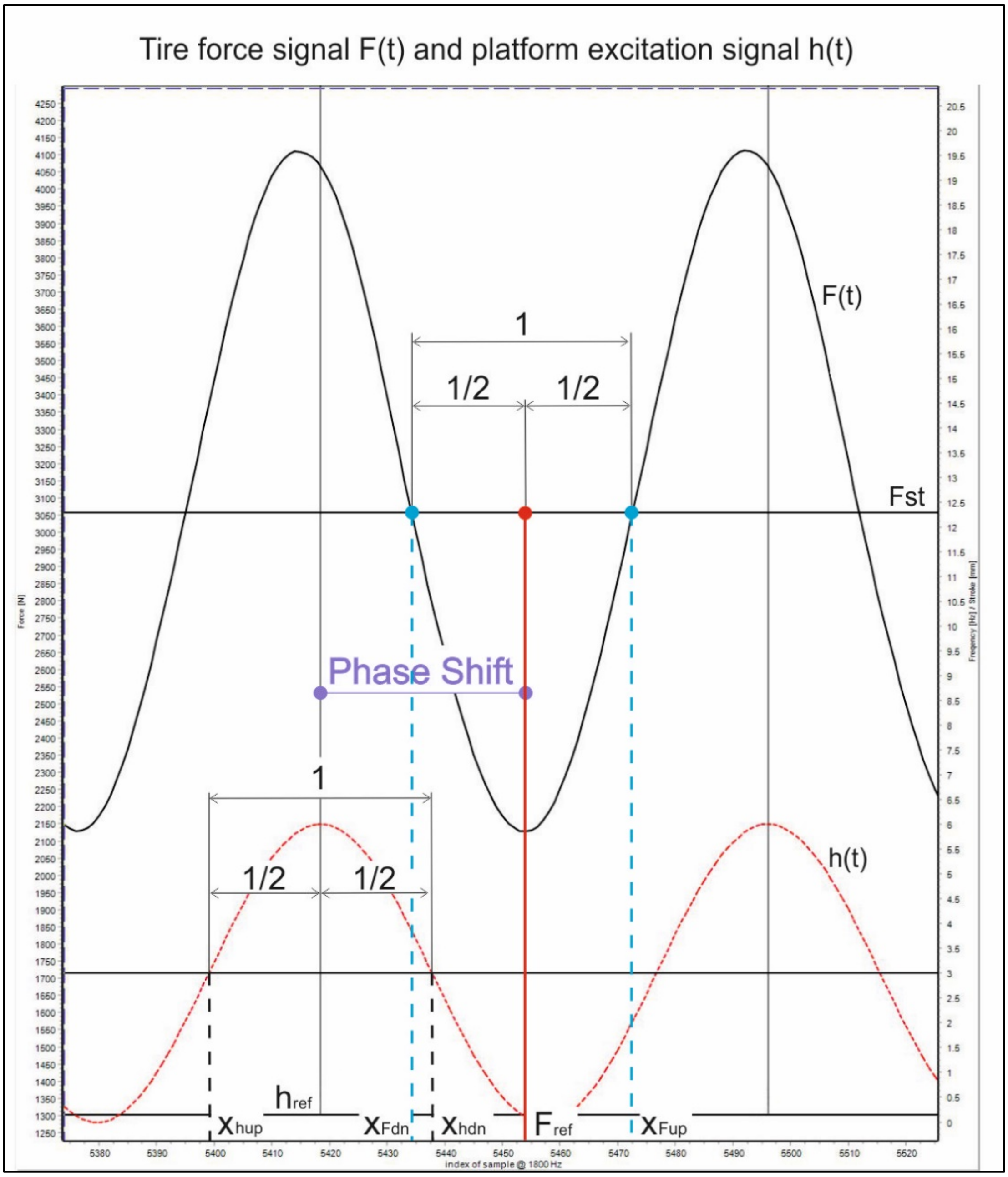
3.23 Phase shift φ – systems with low suspension platform weight m_p[6] and with direct measurement of the vertical excitation of the suspension tester platform *hp(t)*

angular difference between the absolute "sinusoidal" position of the suspension tester platform and the "sinusoidal" vertical tyre contact force between the tyre and the suspension tester platform.
The phase shift $\varphi(i)$ is for each period of the suspension tester platform signal *hp(i)* calculated from the reference position *Fref(i)* of the vertical tyre contact force signal *F(t)* and the reference position of the ith period of the vertical excitation of the suspension tester platform *href(i)*.



[6] Usually the suspension platform weight m_p is greater then 10 kg and in some cases is above 20 kg.

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4 Theoretical principle of the Minimum phase angle method

4.1 Origin

In the SAE Technical Paper 960735, 1996: "An improved Non-Intrusive Automotive Suspension Testing Apparatus with Means to Determine the Condition of Dampers" [9] theoretical principle of the Minimum phase angle method was described. The author was A. Tsymberov.

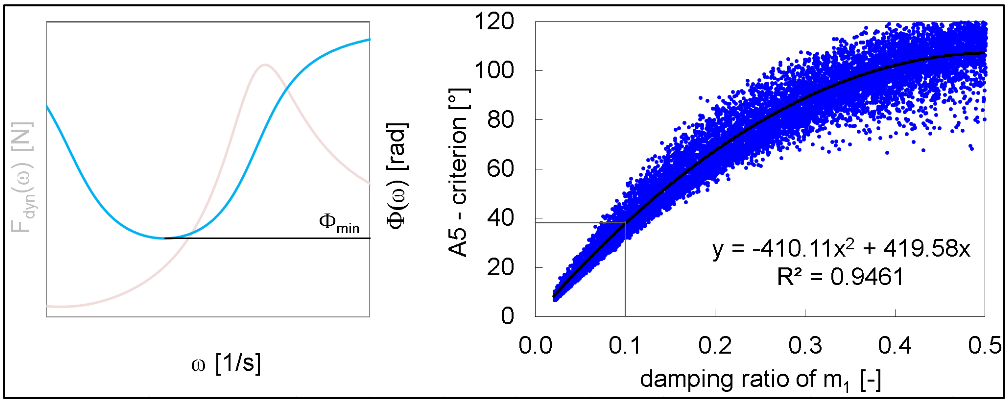
4.2 Test principle

The minimum phase angle value is indicative of the good functionality of the damping. The minimum phase angle is the lowest value of the phase angle determined during the test between the body mass[7] and axle mass[8] resonant frequencies. When adequate damping is present in the suspension system there will be a smoother response delay of the wheel to the moving platform at the axle mass resonant frequency.

4.3 Limit value

Tsymberov wrote in his SAE paper [9] that dampers with minimum phase angle less than 40 degrees, corresponding to damping ratio 0.08 of the axle mass, are considered to be weak.

In the Springer Journal Meccanica, July 2017, Vol. 52, Issue 9 in the article "Twilight of the EUSAMA diagnostic methodology" [8], authors M.Klapka, I.Mazurek, O.Machacek and M.Kubik, it is written:
"The method of determination of this criterion is simple and robust. The minimum of the phase shift curve is located beyond the frequency range affected by possible bouncing of the wheel. That is a huge advantage of given criterion. The results of linear simulations are shown in the next figure in the right graph where horizontal axis contains the values of the unsprung mass damping ratio and vertical axis contains the minimum values of the phase shift in degrees."



The above figure presents that the unsprung mass damping ratio 0.1 corresponds to the minimum phase shift 38 degrees.
Minimum phase shift is closely related to the unsprung mass damping ratio as is shown on the righthand graph. Therefore Minimum phase shift could be used for relatively accurate estimation of the unsprung mass damping ratio (assessment of suspension damping quality). However, for determination of the Minimum phase shift it is not needed to know parameters which affects unsprung mass damping ratio.

[7] Body mass – in technical literature known as sprung mass (Tsymberov, [9])

[8] Axle mass – in technical literature known as unsprung mass

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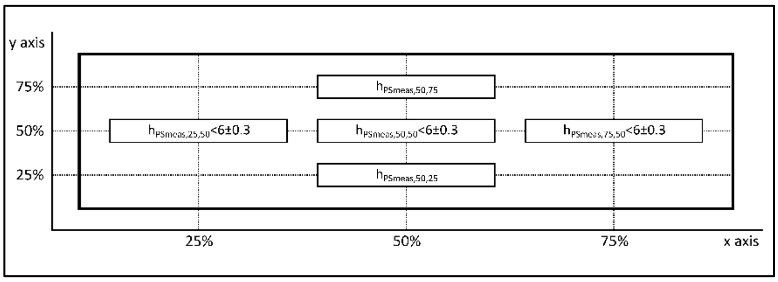
5 Description of the system

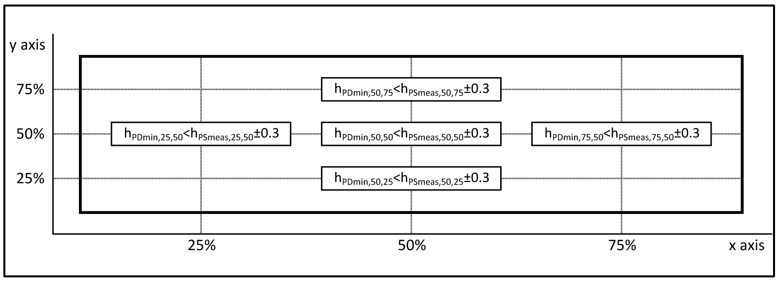
5.1 Principal components of the system

The suspension tester is an equipment capable of individually testing either of the wheels of an axle of the vehicle as described in this document by means of vibrating platforms, and all necessary hardware to comply with the specifications herein:

- Example given: Electric Motor, shaft(s), flywheel and chain / belt / … drive
- Platforms designed for vibrating vertically (maximum longitudinal/transversal continuous slope ±0.5 mm) in the range of 25 Hz -– 5 Hz with a peak to peak amplitude h_{PS} = 6 mm (tolerance ±0.3 mm) $h_{PSmeas,x,y}$ is the *P*latforms *S*tatically *meas*ured peak to peak amplitude. Peak to peak amplitude shall be measured at the cross defined by 25%, 50% and 75% of the length of both the longitudinal (y axis) and the transversal (x axis) of the platform (picture below). Values $h_{PSmeas,50,25}$ and $h_{PSmeas,50,75}$ are only informative and will be used during the dynamic tests.
- Maximum difference of statically measured peak to peak amplitude between left and right platforms shall be limited to $|h_{PSmeas,Left,50,50} - h_{PSmeas,Right,50,50}| <= 0.2$ mm[9].



- *P*latforms designed with the *D*ynamically measured peak to peak *min*imum and *max*imum amplitude $h_{PDmin,x,y}$ $(h_{PDmax,x,y}) = h_{PSmeas,x,y} \pm 0.3$ mm, including check at $h_{PDmeas,50,25}$ and $h_{PDmeas,50,75}$.
- Maximum difference of dynamically measured peak to peak amplitude between left and right platforms shall be limited to $|h_{PDmin,Left,50,50} - h_{PDmin,Right,50,50}| <= 0.3$ mm ($|h_{PDmax,Left,50,50} - h_{PDmax,Right,50,50}| <= 0.3$ mm[7]).
- Peak to peak amplitude measurements to be performed in a frequency range of 18-6Hz.



[9] We use Relative Dynamic Force Maximum amplitude imbalance. Dynamic Force Maximum amplitude is directly proportional to the excitation stroke. Maximum imbalance is extremely important to detect any problem especially on heavy fast cars, when 1 damper starts to fail. For this, it is necessary to keep excitation on both sides the same'.

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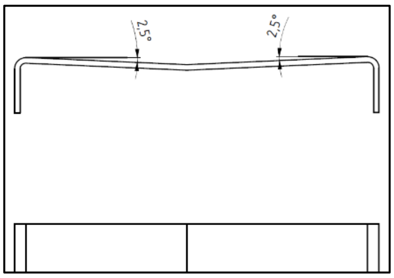
- The top face of the tyre support platform plate has to be either flat or have a shallow V shape with an angle of less than 2.5 degrees.



Each platform shall be equipped with one or more weighing device(s) able to measure raw force signals.

- Weight measuring points must be able to measure also negative force (dynamically without the car on the plate).
- Means/Sensor(s) to detect the platform's vertical position.
- The vertical position of the oscillating platform is to be determined by at least one point per cycle.
- Means/Frequency - frequency variation, as described in chapter 5.4
- Analog output of weight measuring devices shall have such amplitude/frequency characteristics that can further support all digital signal processing.
- Control system with the A/D converter.
  Sampling frequency fs of the F(t) signal and detection of the plate's top position *TOP(i)* have to be sufficient to fulfil the demands of point 6.1.4 of this document. The signal processing may not introduce a delay higher then 3 degrees between the plate position and the vertical tyre contact force signal *F(t)*. Software must be capable of performing further digital filtration of input signals. Software filtration, adhesion calculation, phase calculation, means for the correct phase calculation are described in Annex 1.

Platforms dimensions are to be designed to ensure that the equipment is able to check all vehicles of categories M1 and N1.

Equipment has to be designed in such way the vehicle is in horizontal position (±2mm) during the test. The vehicle shall not move horizontally during the test.

5.2 Calibration mode

Suspension tester has to be equipped with special calibration mode, that allows repeated tests of each vehicle wheel independently, with a manually controlled start up function.

5.3 Minimum set of parameters to be measured by the equipment

The characteristics of the system must allow the following elements to be determined, as a minimum.

The subscripts used in further values define the axle and wheel (side) of the tested vehicle: *i* stands for the tested axle (1, 2, ... with 1 as the front axle) and the *j* for the vehicle side (1 = left and 2 = right).

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Several values measured on both wheels of a same axle ($Val_{i,1}$, $Val_{i,2}$) are evaluated for their imbalance. Imbalance *DVal* of the $Val_{i,1}$, $Val_{i,2}$ is defined by the following way:

$$DVal_i = \frac{|Val_{i,1} - Val_{i,2}|}{\max(Val_{i,1}, Val_{i,2})} * 100$$

The vertical force $F_{i,j}$, defined as the vertical force of a wheel, exercised on the platform (3.6).

This force must be able to be measured statically ($Fst_{i,j}$ static) as well as dynamically ($F(t)_{i,j}$).

The vertical force $AFst_i$ of an axle, defined as the sum of the vertical forces, of the wheels from this axle of the vehicle.

$Fmin_{i,j}$ is the minimum dynamic registered tyre force $F(t)_{i,j}$, $FUnder_{i,j}$ underflow flag (paragraph 3.15).
$Fmax_{i,j}$ is the maximum dynamic registered tyre force $F(t)_{i,j}$, $FOver_{i,j}$ overflow flag.

$RFAmax_{i,j}$ is the maximum relative amplitude of the registered tyre force $F(t)_{i,j}$ (paragraph3.18)

The resonant frequency $fres_{i,j}$ of the $F(t)_{i,j}$ signal, defined in the paragraph 3.17.

$H25_{i,j}$ is the static amplitude of the registered tyre force $F(t)_{i,j}$ (paragraph 3.19).

The imbalance of the maximum relative force amplitude values $DRFAmax_i$ for each axle (see definitions of $RFAmax_{i,j}$ in3.18):

The minimum phase shift $\varphi min_{i,j}$, defined as the minimum phase shift of a wheel

The minimum phase shift frequency $f\varphi min_{i,j}$, defined as the frequency on which the minimum phase shift was detected.

The maximum phase shift $\varphi max_{i,j}$, defined as the phase shift when measured at 18 Hz.

The imbalance of the minimum phase shifts $D\varphi min_i$ for each axle.

The suspension tester shall indicate if the tyre rigidity $rig_{i,j}$ is sufficient with the purpose of having an idea of the tyre pressure. Rigidity is only an informative value.

The imbalance of the tyre rigidity $Drig_i$ for each axle. This result indicates difference in the tyre pressure between left and right wheels.

For the type approval and calibration (see chapter 8) purposes only, at least the raw force signal *Fr(t)* and vertical tyre contact force signal *F(t)* graphs (with the zoom possibility) and tables for whole measurement duration are required as a minimum. Graphs have to be accompanied by frequency scales.

The *F(t)* graph will optionally show also the maximum allowed dynamic calibration error limit (paragraph 3.10). Table indicating frequency for each period of the *Fp(t)* signal.

Phase shift graph as a function of the frequency (time, sample index). Indicate points of the raw sequence and show an approximation curve of the phase shift.

Table with phase shift values for each period of the suspension tester platform *TOPp(i)*.
Frequency as a function of the time of a whole measurement duration (paragraph 5.4).

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Everything described in this paragraph has to be displayed/printed/saved in this special calibration mode only.

5.4 The frequency variation function

The platform has been excited by a frequency variation function from Figure 1, and amplitude (about +/- 3 mm, paragraph 5.1) "sine" function.

The drive system shall be capable of driving the platform, when loaded to its maximum from the rest position to its maximum frequency of 25Hz (±1Hz) and to stabilize the vehicle after initial motors startup impact and to measure the rigidity (paragraph 3.20 of the tyre by 25 Hz the suspension tester will be at this frequency for at least ΔT_{25} *(ms)*.

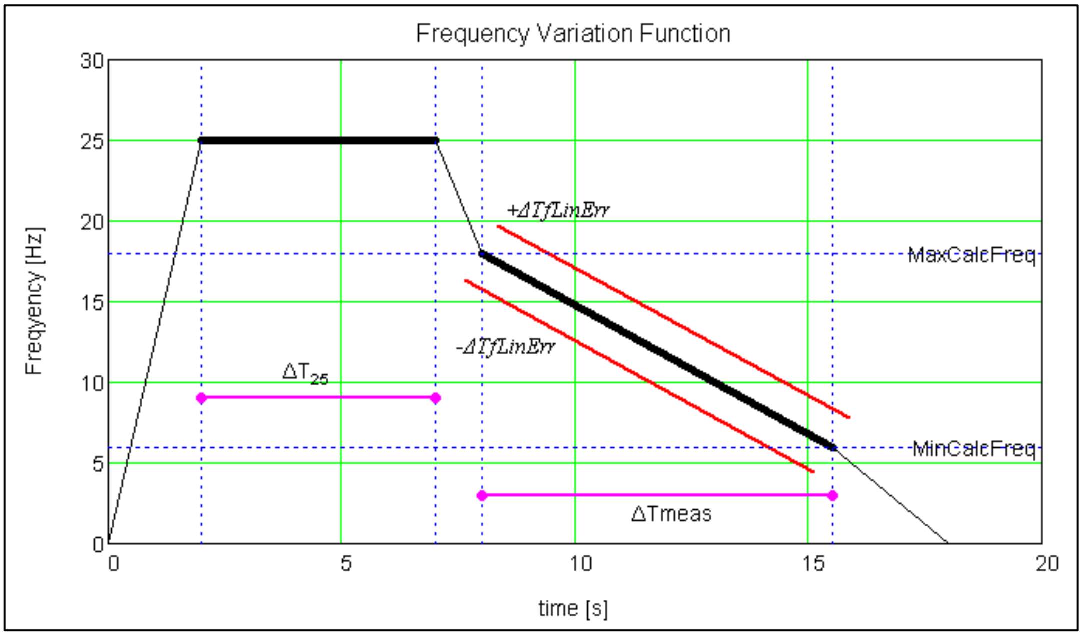
Frequency decrease from *MaxCalcFreq* (parameter *MaxCalcFreq* = 18 Hz) down to *MinCalcFreq* (parameter *MaxCalcFreq* = 6 Hz) shall be achieved in a minimum time of *ΔTmeas* = 7.5 seconds with a maximum ±*ΔTfLinErr* (parameter *ΔTfLinErr* = 2 Hz) linearity error over the whole range – see picture below.

The frequency decrease during *ΔTmeas* must be monotone with the maximum slope *ΔTfMaxSlope* (parameter *ΔTfMaxSlope* = 3 Hz/s).

Measurement of the second wheel of the axle can only start when there is no vertical movement of the first wheel plate.

Minimum duration by 25 Hz before the measurement starts:

$\Delta T_{25} = Fst * 0.16 + 1200$, ΔT_{25} unit is ms, *Fst* unit is N.



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5.5 Absolute criteria

In principle, different types of pass/fail criteria can be established. They will be explained here as absolute or relative criteria. According to known test results, a value below 35 degrees would indicate an absolute fail result.

According to 4.3 the absolute criterion for Minimum phase shift $\varphi_{min\ i,j}$ is set up to $AC_{\varphi min}$ (parameter $AC_{\varphi min}$ = 35°).

When the *rig* <*rigLoLim* (parameter *rigLoLim* = 160 N/mm, tyre underinflated) or *rig* > *rigHiLim* (parameter *rigHiLim* = 400 N/mm, tyre overinflated), a warning must be given.

5.6 Relative criteria

Relative criteria are based on comparing the set of results between the left and right wheel for each axle of a vehicle, e.g. imbalance of the results for one axle. Without any doubt, it is clear that the same level of suspension is intended for the wheels on the same axle of a vehicle. Higher differences will identify a defect of the suspension system.

The relative criteria for the Maximum relative force amplitude $RFAmax_{i,j}$ and Minimum phase shift $\varphi min_{i,j}$ is set up to 30%, (parameters RC_{RFAmax} = 30 % and $RC_{\varphi min}$ = 30 %).
The relative criteria for the tyre rigidity $rig_{i,j}$ is set up to 35%, (parameter *RCrig* = 35%).

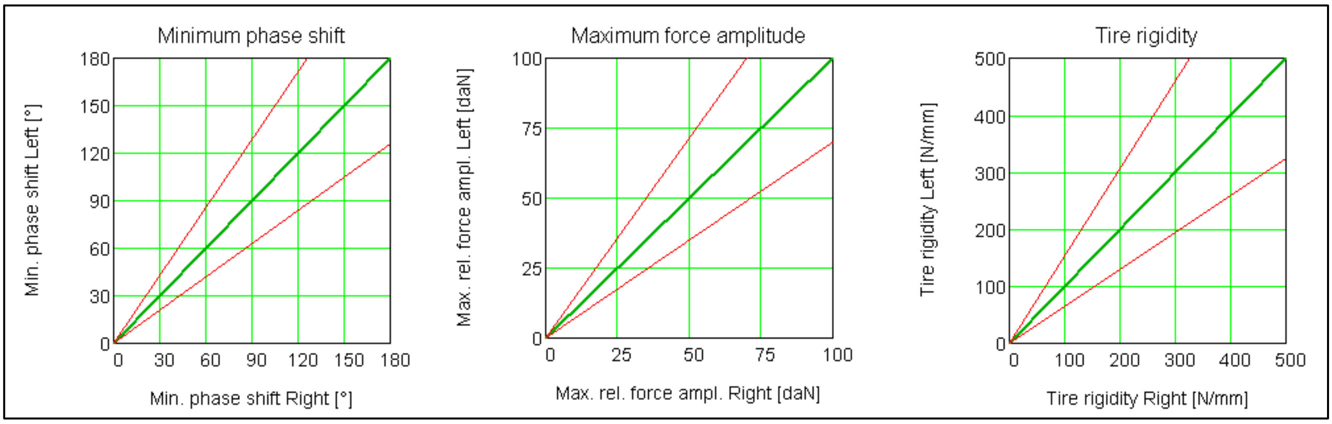

Fig 3 : Relative Criteria

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6 Requirements for testing devices

6.1 Technical requirements for testing devices

The electrical signals of the vertical forces and the vertical position of the oscillating platform measurements must be filtered so as to allow a correct evaluation of these direct measurements, as well as the derived quantities relating to damping capacity and imbalance. The response times of the different quantities measured should be very small. The filtering processes and the response times for the different direct measurements should always remain coherent, so that these measurement results themselves, as well as the derived quantities, are always based on measurements which have taken place at the same time or measurements taken within the same time interval. These filters should preferably be adjustable by setting the parameters via the testing device software.

6.1.1 Operation and characteristics of the suspension tester

- The devices will allow the measurement by successive independent sequences of left and right suspension tests from the same axle without having to manoeuvre the vehicle.
- The tests will require no action on the vehicle.
- The tester starts only after both the wheels are positioned correctly on the tester platforms.

6.1.2 Measurement device for vertical forces

6.1.2.1 Type of measurement of vertical forces

The static weight *Fst* shall be stored only when the measured value is stable.

6.1.2.2 Limit for weight fluctuation

The static vertical force will be measured at total standstill of the vehicle on the tyre support platform before and after the test. If the difference exceeds *StatWLim* (parameter *StatWLim* = 25 daN) per wheel the test is considered as not valid.

6.1.2.3 Measurement range and maximum permissible errors of measurement of vertical forces

The lower limit of the measurement range must be smaller than or equal to 100 daN static weight per wheel. The upper limit of the measurement range must not be less than 1100 daN static weight per wheel.

The resolution should be at least 1daN.

The measurement device must be able to handle at least a dynamic load of 2200 daN per wheel.

The maximum allowable total error for the static vertical force (inaccuracy, linearity and reading error included) is defined as follows:

- From 0 up to 300 daN vertical force : ±6 daN including hysteresis
- From 300 daN up to 1100 daN vertical force : ±2 % of the measured value including hysteresis

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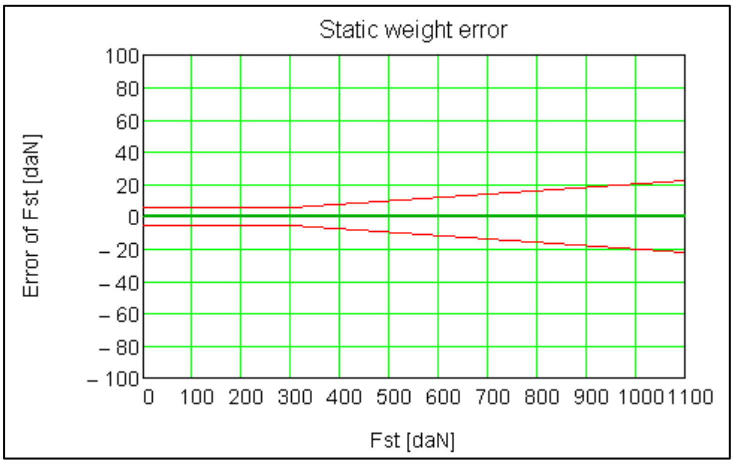

6.1.2.4 Zero point

The system for measurement of the vertical forces must be provided with a device which allows the zero point to be quickly adjusted manually or auto adjusted.
The zero setting and the setting of the sensitivity of the vertical forces must be independent of one another, in other words after the zero point is modified, the calibration of the vertical forces must not be lost.

6.1.3 Measurements to be carried out

When a suspension test is carried out on a vehicle, the following must be possible:

- $Fst_{i,j}$ static weight for each wheel
- $AFst_{i,j}$ static weight for each axle
- $RFAmax_{i,j}$ maximum relative amplitude of the *F(t)* signal for each wheel
- $DRFAmax_i$ value of the maximum relative force amplitude unbalance for each axle
- $\varphi min_{i,j}$ Minimum phase shift for each wheel
- $D\varphi min_i$ value of the Minimum phase shift unbalance for each axle
- $rig_{i,j}$ rigidity of the tyre for each wheel
- $Drig_{i,j}$ value of the tyre rigidity unbalance for each axle

6.1.4 Repeatability, reliability and total error

The evaluation of the suspension characteristics has to be based on a robust test procedure with a low or controlled influence of environmental factors (temperature, load, tyre air pressure, ….). Where influences need to be controlled, this should be explained clearly in the manuals for these testing devices. Reproducibility and accuracy need to be on an appropriate level to ensure reliable results[10].

[10] *Remark: +-Error – this may be related to the metrological requirements, but we keep the same values as they are now, but they will be split into 2 parts; error of the device under test itself + uncertainty of the measuring chain above it (loadcell, amplifier, laser, ADC, evaluation).*

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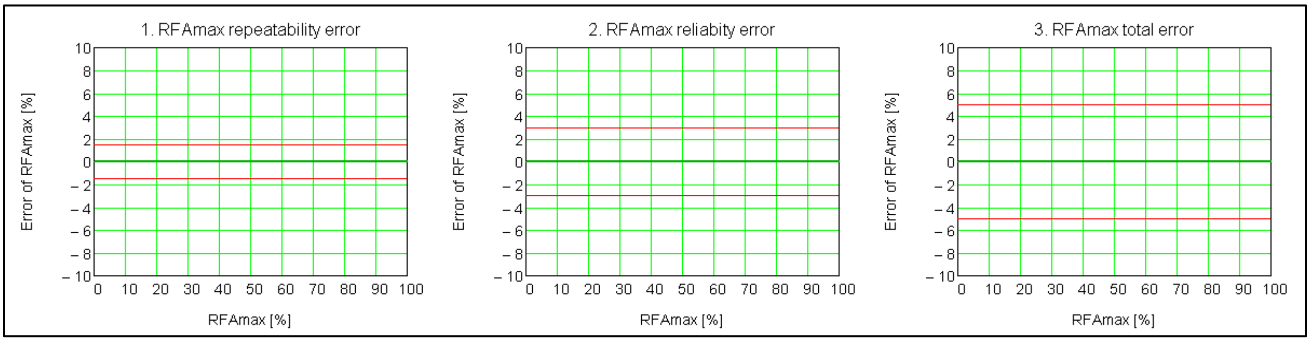
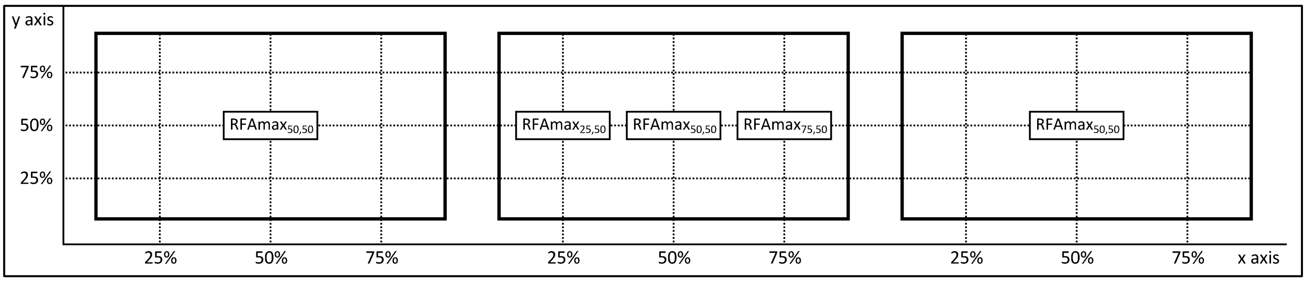
1. The test reading must be repeatable under identical conditions with a permitted maximum tolerance of ± 1.5% *RFAmax* value.

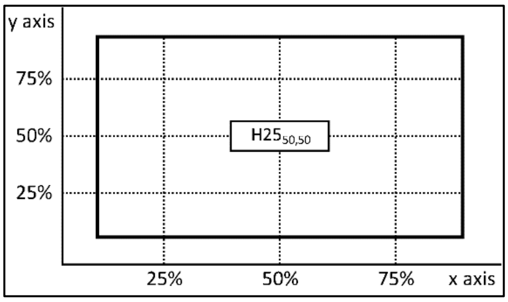
2. The test reading in 3 different positions on the plate, as shown in graph below, must not vary by more than ±3% *RFAmax* value (reliability).

3. The maximum permitted *RFAmax* value total error is 5%.





4. The maximum permitted *H25* value error is 8% above 300 daN and ±24 daN below.



5. The test reading must be repeatable under identical conditions with a permitted maximum tolerance of ± 3°-for the *φmin* value above 30° and with the linearly increasing tolerance of ± 6° at *φmin=0*°.

6. For the different positions of the tyre on the test platform, a test reading must not vary by more than ± 4.5°-for the *φmin* value above 30° and with the linearly increasing tolerance of ± 9° at *φmin=0*°. 5[11] positions on the platform.

7. The maximum permitted minimum phase shift error is 7.5° for the *φmin* value above 30° and with the linearly increasing tolerance of ± 15° at *φmin=0*°.

[11] *Results of three out of five positions have already been obtained when testing RFAMax =>. Two more positions only are to be tested here.*

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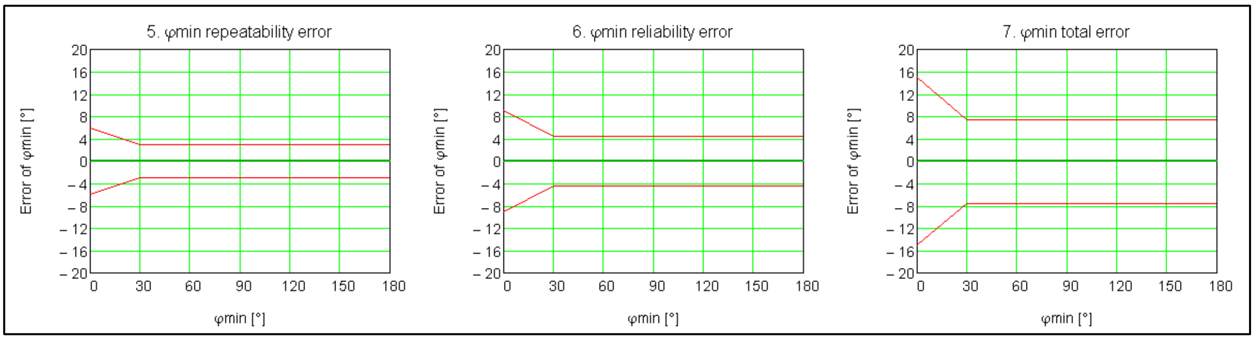

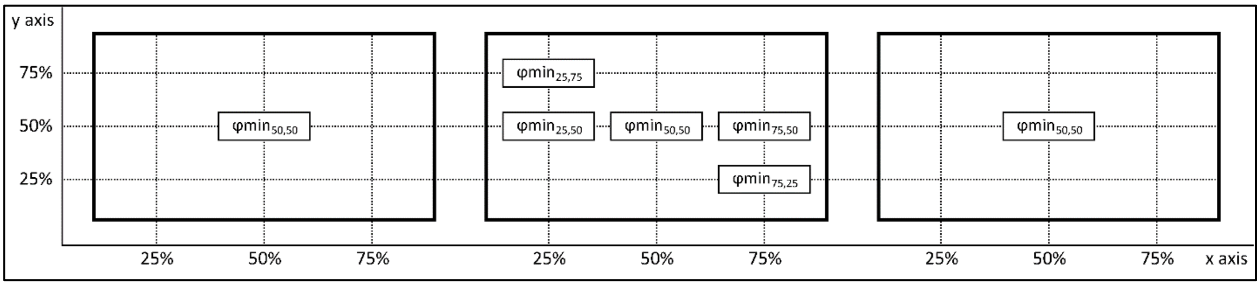

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6.2 Device for the centralization and display of measurement results

Devices for centralization, display and printing are outside the scope of this standard, however the values which are displayed, printed, sent out, stored or managed in any way by the centralization device must conform with the value generated by the suspension tester and must show the appropriate measurement units.

6.2.1 Test results

The following parameters shall be made available by the suspension tester to be used for the vehicle inspection according to the existing applicable procedure.

At the end of the test (test of one axle):

- $Fst_{i,j}$ static weight for each wheel
- $AFst_{i,j}$ static weight for each axle
- $DRFAmax_i$ value of the maximum relative force unbalance for each axle
- $i\varphi min_{i,j}$ Integer value of the Minimum phase shift for each wheel, it is calculated from the measured Minimum phase shift φmin rounded down *(35 has to be always green)*
- $Di\varphi min_i$ value of the Minimum phase shift unbalance for each axlecalculated from the $i\varphi min$ values, standard rounding
- $rig_{i,j}$ rigidity of the tyre for each wheel

6.2.2 Testing procedure – basic demands

- Wheel must be positioned centrally on the plate during the test.
- Vehicle shall be driven onto the bench in as straight a line as possible
- Don’t apply either the parking or service brakes during the suspension test
- If the wheel weight exceeds the maximum allowed weight, the testing device shall not allow a test to be performed.

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7 Recommendations for the Type Approval of the equipment

Authorities willing to mandate the use of equipment designed and manufactured to this specification can follow the procedure described hereafter to ensure that the tester conforms to this specification.

Type approval procedure for the suspension tester, that follow this specification, checks all important aspects of the suspension tester software, hardware and mechanical aspects, as well as the test procedure and accuracy of the tester.

Recommendations:

Start with the check described in paragraph 7.11, peak to peak amplitude statically and dynamically.

If this check is OK, continue with the weight check.

If the weight check is also OK and the tester manufacturer confirms their compliance with all other points, check of the reproducibility and reliability (6.1.4) of the *φmin* and *RFAmax* can be done.

If the above tests are all acceptable, then the rest of the points have to be checked.

Q0: Documentation

Q1: Dimension

Q2: Weight

Q3: Simulation + computation

Q4: Dynamic calibration

Q5: Repeatability

Q6: Manufacturer statement of conformity

Q7: Functional test

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7.1 Environmental conditions

In absence of particular specifications, the tests are performed at 20º +- 5º

7.2 Equipment needed for suspension tester approval

For the suspension tester to be assessed by national/European notified bodies, there is likely to be a requirement for a reference test tool. This may be developed by the notified bodies themselves according to this specification and using the recommended sensor specification described below.

The correct functioning of any reference system can be verified using a simulator / signal generator as offered by EGEA.

7.2.1 Loadcell with accessories

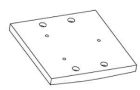
7.2.1.1 Loadcell - weight or vertical (static or dynamic) force measurement tool

The loadcell must comply, as a minimum, with the following specification[12]:

Range (kg):	1000	
Nonlinearity (% of range, end point method):	0.05	
Hysteresis (% of range):	0.02	
Non-repeatability (% of range):	0.02	
Temperature Effects:		
Zero Drift (% of range per °C):	0.0015	
Span Drift (% of reading per °C):	0.0015	
The maximum allowable extraneous loads are as follows:		
Maximum Side Force	800	lbs
Maximum Moment	800	lb-in
Maximum Torque	800	lb-in
The maximum error due to the extraneous loads would be 0.1% of the range or 2 lbs.		
The listed maximum allowable extraneous loads would be as applied singularly or individually.		
If different loads are applied simultaneously, then the total combined load must not be more than 100% of the allowable maximum extraneous load. (For this case, mathematical sum of all three extraneous loads must be < 800 lbs).		

7.2.1.2 Mounted duralumin round support of the tire (diameter, weight)

7.2.1.3 Interface shaped or flat board between loadcell and V-type or flat measuring plate



[12] Example of the loadcell that fulfils such specification is for instance loadcell S.Himmelstein and company, type 2540(2-3)

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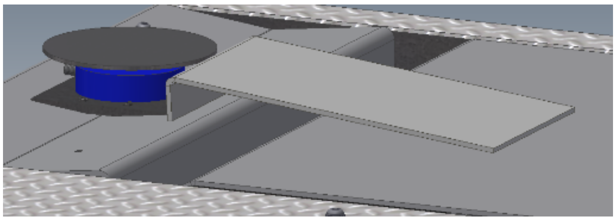
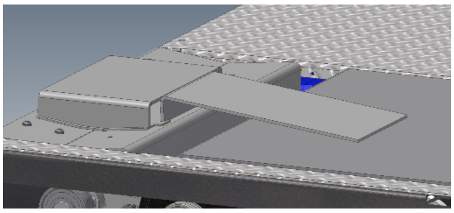
7.2.1.4 Drive on and off ramps for the loadcell and the dummy loadcell

Left picture below shows only drive on ramp to the loadcell. Right picture below shows drive on ramp to the dummy loadcell (placed below the wheel that is not under test), that has to be the same height as the measuring loadcell.





7.2.1.5 Measuring amplifier

The measuring amplifier must comply, as a minimum, with the following specifications[13]:

		Remark
Input signal	~2 mV/V	according the used loadcell
Bridge excitation	according the used loadcell	
Bridge resistance	according the used loadcell	
Cut-off frequency	300 Hz	-3 dB, using 3 pole filter
Linearity	<0.02% f.s	
Temp.coefficient, amplification	<0.2% f.s	
Temp.coefficient, zero-setting	<0.15% f.s	

7.2.2 Length measurement tool (laser for dynamic measurement) with accessories

7.2.2.1 Laser with the amplifier unit

The laser with the amplifier unit must comply, as a minimum, with the following specifications[14]:

[13] Example of the measuring amplifier that fulfils such specification is for instance HKM Messtechnik MV 2.0 DC amplifier.

[14] Example of the laser with the amplifier unit that fulfils such specification is for instance SICK OD-Max sensor OD30-05T1 with the amplifier unit AOD-P1.

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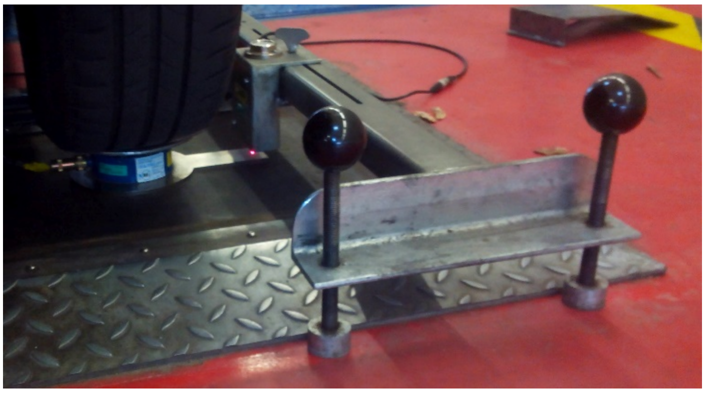
Measuring range	30±5 mm
Resolution[1)]	1 µm
Reproducibility[2)]	3 µm
Accuracy	10 µm[3)]
Temperature drift	± 0.05 % from 10 mm/°C
Measuring frequency	10 kHz
Response time[3)]	0.5 ms
Output rate	10 kHz
1) Averaging: 256/4096; Object: 90% remission; Distance: middle distance	
2) With constant environmental conditions; Averaging: 256/1096 (OD25) measurements; Object: 90% remission	
3) Without averaging and manually selected sensitivity	

7.2.2.2 Laser holder




7.2.3 Measurement system and evaluation software

The calibration kit has to be a complete calibration set that comprises both the software and measuring hardware needed[15].


15 As an example of the measuring hardware could be either Tedia UDAQ-1408A measuring module, NI USB-6001 or NI USB-6210

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7.2.4 Weight measurement tool (given parameters)

This tool is supplied by the test equipment manufacturer to test the vertical force according to paragraph 6.1.2.3

7.2.5 Signal generator to simulate sensor signals with known phase shift values.

7.2.5.1 Guidelines for the signal generator usage

The signal generator replaces the sensors (strain gauge, top position) input, therefore it has to simulate Raw Force signal *Fr(t)* together with the default zero *TOPp* signals.

To be able to operate correctly (correctly calculate *Fp(t) ->F(t)*), it has to receive also the m_p value used in the tester's software as the default value for the suspension tester platform. As mentioned in the previous sentence, dynamic calibration array (pictures on the points 3.20 and 3.9) has to use either zero or default values for this purpose.

The signal generator has to work as a replacement for the vehicle driving onto the suspension tester platform – it has to simulate the wheel weight together with its dynamic properties and correct sensitivity (generators mV or mA output is possible to recalculate to forces [N] used by the system).

The signal generator has as to be connected directly (replacing sensor inputs to the DAQ board).

The signal generator has as to be used in the calibration mode that allows manual start only.

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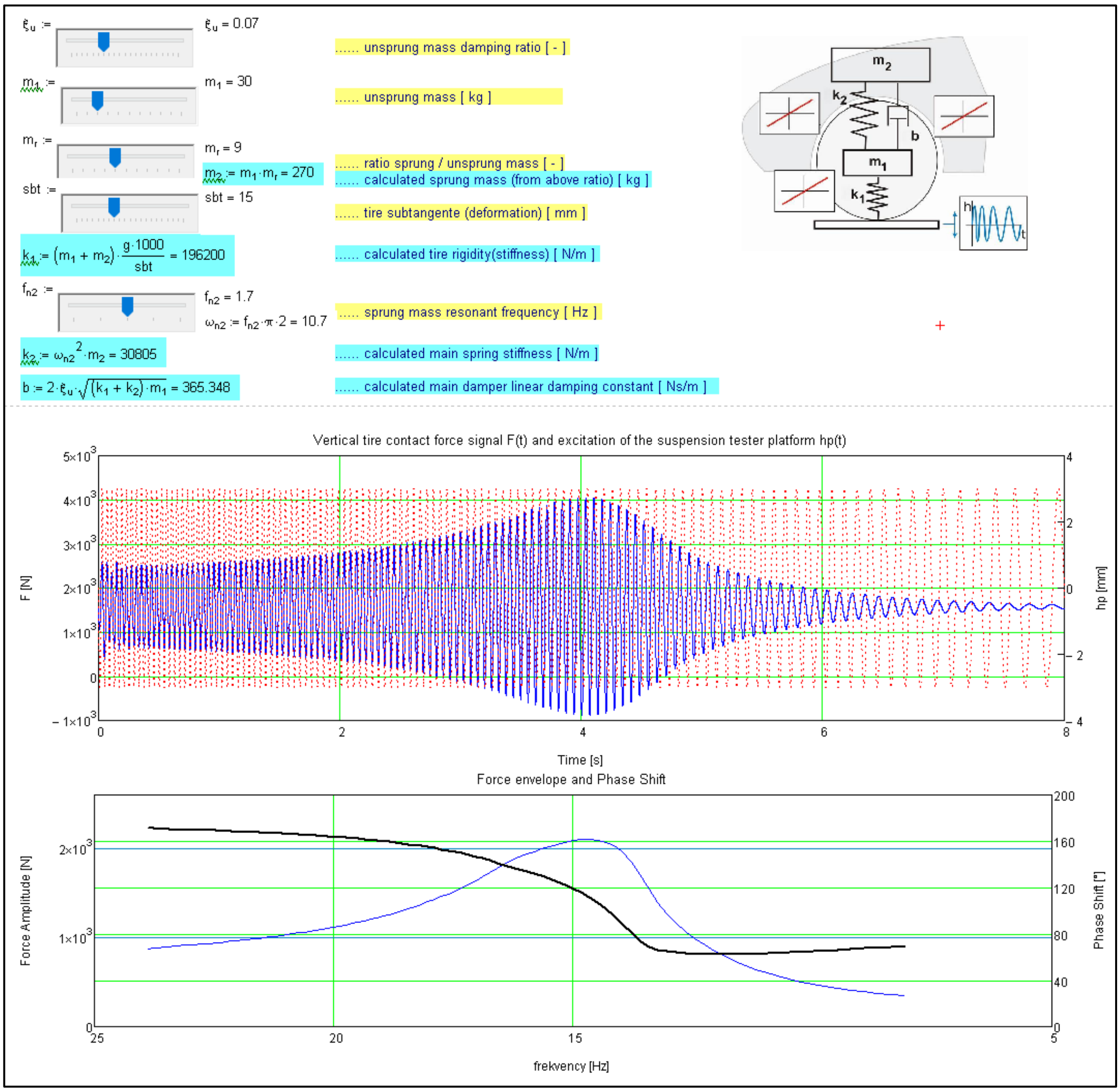
Recommendation: use something like ¼ car simulator from the next picture:



7.3 Prerequisites

For the suspension tester type approval procedure, it will be possible to adjust up or down calculated values:

1. of the calculated Minimum phase shift before it is saved to the *φmin* result (*φmin* = *φmin*+*φminCorr*$_j$), for each tester side independently (to perform range check that *φmin* is 0..180- paragraph 3.22, parameter *φminCorr* = 0 °).

2. of the measured static weight before it is saved to the *Fst* (*Fst* = *Fst* + *FstCorr*) result (check correct operation against *RFstFMax*, …, paragraph 3.21, parameter *FstCorr* = 0 N)

It must be possible to register the signal of the force over time, during one of the verification checks on the proper functioning of the device.

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For the periodic inspection and the tester type approval procedures, it is possible that device under test / evaluation method could have a systematic error, which must be evaluated and corrected before type approval testing is conducted[16].

- According to the paragraph 5.3, the device has a special calibration mode - are all demands from paragraph 5.3 fulfilled?
- Was the dynamic calibration performed correctly and is the result also correct?
- Calibrated masses or a calibrated mechanical tool are used to apply a known force to the middle of the measuring plates, with the possibility to increase or decrease force gradually.
- When a test is conducted in the special Calibration mode or the test is done only on a single wheel/axle, there must be a manufacturer's statement that it is calculated the same way during the standard test or for any other axle or wheel.
- Default Test Vehicle (further DTV) with demanded parameters (5.1 – rear axle weight around 500 kg, *FAmax ~ 0.8*Fst* (natively).
- Any Vehicle (further VEH), that is either the DTV, one of five vehicles from the next point or any other vehicle specified by the tester manufacturer that is best suited to perform the given approval tasks.
    1. For the final test of measurement error to have ready another 5 vehicles (further 5VEH) inside following segments: A (VEH1)
    2. B (VEH2)
    3. C (VEH3)
    4. D (VEH4)
    5. F (VEH5)

7.4 (3.15) *Fmin* and *Fmax*

Check using signal generator or VEH, table or graph → Q3, Q7

7.5 (3.16)*F(t)* signal underflow and overflow

Based on the graph view of the *F(t)* signal check correct reaction on *FUnderLimPerc* (*FUnder* flag set) and *FOverLim* (*FOver* flag set), any wheel of VEH, change levels of both parameters. Check that the conditions of all 4 flags are set correctly.

Check using signal generator or VEH, table or graph → Q3, Q7

7.6 (3.17)*FAmax* and *fres*

Similarly to paragraph 7.5, check that for all 4 cases FAmax and fres are calculated correctly.
Check using signal generator or VEH, table or graph → Q3,Q7

---

[16] *Whilst performing a first series of total error tests using DTV it is found that average error of DTV on the Minimum phase shift is for instance -5 degrees. If the device and the software is OK it was found that this average error remains similar also during total error tests with VEH1-VEH5. This systematic error strongly restricts the results uncertainty on one side (it is only 2.5 points) when the other side of the error range is 12.5 points. That's why the systematic error should be corrected at the beginning.*

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7.7 (3.19) *H25*

Check whether *H25* is calculated ~10 periods on 25 Hz – manuf. statement & code? → Q6

7.8 (3.21) Phase shift *φ*

Using the phase shift graph and phase shift table (par. 5.3) check correct phase shift detection on *RFstFMin*, *RFstFMax* using 7.3 *FstCorr*.

Check using signal generator or VEH, table or graph → Q3,Q7

7.9 (3.22) Minimum phase shift *φmin*

Check correct minimum phase shift detection <0..180) using 7.3 $\varphi minCorr_j$ independently for L+R.

Check *φmin* in *DeltaF* from the *fres*, changing *DeltaF*.

Check using signal generator or VEH, table or graph → Q3,Q7

7.10 (5.1) Horizontal vibrating tolerance

Manufacturer proof (drawing).
Q6: Manufacturer statement of conformity

7.11 (5.1) Static Peak to peak amplitude

Laser or dial gauge. Empty platform.
Q1: Dimension

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7.12 (5.1) Dynamic peak to peak amplitude

Rear axle of the DTV and Laser positioned beside the wheel and securely mounted and aligned, independently of the suspension tetser, so as to be able to measure the vertical movement of the wheel.

Q1: Dimension

Stroke Test, L = Left platform	**platform positions:**
Vehicle:	Default Test Vehicle
Registration:	XXX-888
Date/Time:	5/7/2018 14:00

Stroke Test, R = Right platform	platform positions:
Vehicle:	Default Test Vehicle
Registration:	XXX-888
Date/Time:	5/7/2018 14:00

Check:		
	$h_{PSmeas,x,50}$	-5.7 mm < hPSmeas,x,50 < +6.3 mm
	$h_{PSmeas,50,50}$	-0.2 mm < hPSmeas,Left,50,50-hPSmeas,Right,50,50 < +0.2 mm

STATIC TEST

platform position	25,50		50,50		75,50		50,25		50,75	
	$h_{PSmeas,25,50}$		$h_{PSmeas,50,50}$		$h_{PSmeas,75,50}$		$h_{PSmeas,50,25}$		$h_{PSmeas,50,70}$	
#	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
0	-2.89	3.18	-2.96	3.24	-3.07	3.23	-2.72	2.99	-3.14	3.18
1	-3.12	3.12	-2.87	3.17	-2.92	2.95	-2.81	2.90	-3.14	3.38
2	-2.96	2.99	-2.95	3.08	-3.00	3.01	-2.78	2.86	-3.26	3.25
3	-3.11	3.10	-3.07	2.96	-3.11	2.98	-2.84	2.81	-3.32	3.14
µ	-3.06	3.07	-2.96	3.07	-3.01	2.98	-2.81	2.86	-3.24	3.26
$h_{PSmeas,Right}$	6.13		6.04		5.99		5.67		6.50	
$h_{PSmeas,Left}$			6.13							
L-R			0.10							

Check:		
	$h_{PDmeas,x,y}$	-0.3 mm < hPSmeas,x,y-hPDmeas,x,y < +0.3 mm
	$h_{PDmeas,50,50}$	-0.3 mm < hPDmin,Left,50,50-hPDmin,Right,50,50 < +0.3 mm
		-0.3 mm < hPDmax,Left,50,50-hPDmax,Right,50,50 < +0.3 mm

DYNAMIC TEST

platform position	25,50		50,50		75,50		50,25		50,75	
	$h_{PDmeas,25,50}$		$h_{PDmeas,50,50}$		$h_{PDmeas,75,50}$		$h_{PDmeas,50,25}$		$h_{PDmeas,50,70}$	
#	Min.Stroke	Max.Stroke	Min	Max	Min	Max	Min	Max	Min	Max
0	5.88	6.19	5.98	6.15	5.99	6.25	5.46	5.90	6.35	6.68
1	5.94	6.00	6.05	6.19	5.82	6.15	5.58	5.94	6.25	6.61
2	5.97	6.12	5.78	6.11	5.92	5.99	5.60	5.74	6.23	6.56
3	5.83	5.95	5.77	6.21	5.93	6.13	5.37	5.93	6.19	6.58
4	5.94	5.98	5.84	5.99	5.86	6.16	5.36	5.92	6.30	6.67
5	5.86	6.15	5.98	6.05	5.78	5.97	5.48	5.86	6.41	6.55
μ_{Right}	5.91	6.03	5.87	6.17	5.89	6.09	5.51	5.87	6.22	6.58
$h_{PSmeas}-\mu$	0.22	0.11	0.17	-0.13	0.10	-0.09	0.15	-0.20	0.27	-0.09
μ_{Left}			5.82	6.09						
$\mu_L - \mu_R$			-0.04	-0.08						

7.13 (5.3) Internally calculated and used objects (values, graphs, tables)

Check whether all described values are calculated, displayed and can be printed or saved (*Fmin..Drig*).

Check using signal generator or VEH, table or graph → Q3,Q7

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7.14 (5.4) Frequency variation function

Check maximum frequency ~25 Hz
Flywheel parameters. Manufacturer statement.
ΔT25 check on ~150kg, ~500 kg and the maximum range wheel weight

Freq. variation function – check with the DTV + VEH5 and look at the Freq over time (index) graph, print it and draw lines from demands – frequency linearity, check 18-6 Hz > 7.5 second.
Q7: VEH of requested parameters, frequency curve could also be calculated by the EGEA software if this is required (see point 7.2)

7.15 (5.5) Minimum phase shift φmin absolute criteria

Recommended VEH or DTV, rear, overinflate and use *φminCalCorr* (7.3) to go below the limit
Check using signal generator or VEH, → Q3, Q7

7.16 Relative criteria of the *φmin* and *FAmax*

Recommended VEH or DTV, rear and use *φminCorr* (7.3) to check relative criteria for the *φmin*, overinflate and underinflate tyres to reach desired effect.
Check using signal generator or VEH, → Q3 , Q7

7.17 (6.1.2.2) Weight fluctuation before/after the test

Check if it works correctly – it is necessary that the suspension tester manufacturer to specify this action
Q7- Functional test

7.18 (6.1.2.3) Vertical force measurement

Check as normally checked for instance on the roller brake tester. This is a procedure that every vehicle inspector is familiar with. Conduct a series of 5 measurements @ [0,0] plate position, a series of 3 measurements @ [0.25, 0] and [0.75,0]], check for the hysteresis not only on the full scale, but also between 150-300, 150-500, 300-800kg.

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Q2: Weight

Total Error Weight, Left

platform position 50, 50

Vehicle:	None
Registration:	
Date/Time:	12/16/2017 11:16

Check: Weight -2 % < Δ(μR-μB)[%] < +2 %, Bench > 3000 N
-60 N < Δ(μR-μB)[N] < +60 N , Bench <= 3000 N

		Preload				Load 1				Load 2				Load 3			
#	Nominal Force [N]	Ref [N]	Bench [N]	Δ(R-B) [N]	Δ(R-B) [%]	Ref [N]	Bench [N]	Δ(R-B) [N]	Δ(R-B) [%]	Ref [N]	Bench [N]	Δ(R-B) [N]	Δ(R-B) [%]	Ref [N]	Bench [N]	Δ(R-B) [N]	Δ(R-B) [%]
0	0	0	0			0	0			0	0			0	0		
1	1500	1500	1515	**-15**	**-1.0**	1501	1516	**-15**	**-1.0**	1501	1520	**-19**	**-1.3**	1500	1520	**-20**	**-1.4**
2	3500	3500	3540	**-41**	**-1.2**	3500	3535	**-35**	**-1.0**	3499	3535	**-35**	**-1.0**	3501	3539	**-38**	**-1.1**
3	7000	7001	7042	**-42**	**-0.6**	7001	7045	**-44**	**-0.6**	7000	7043	**-43**	**-0.6**	7001	7048	**-47**	**-0.7**
4	10000	10000	10052	**-52**	**-0.5**	10001	10051	**-51**	**-0.5**	10000	10051	**-50**	**-0.5**	10000	10048	**-48**	**-0.5**
5	7000	7000	7027	**-27**	**-0.4**	7001	7023	**-23**	**-0.3**	7000	7028	**-28**	**-0.4**	6999	7023	**-24**	**-0.3**
6	3500	3500	3500	**0**	**0.0**	3500	3497	**4**	**0.1**	3499	3497	**2**	**0.1**	3499	3495	**5**	**0.1**
7	1500	1501	1499	**2**	**0.1**	1500	1498	**2**	**0.1**	1501	1500	**1**	**0.0**	1500	1500	**0**	**0.0**
8	0	0	0	**0**		0	-1	**1**		1	2	**-1**		0	2	**-3**	

		Average of Load 1 .. Load 3			
#	Nominal Force [N]	μRef [N]	μBench [N]	Δ(μR-μB) [N]	Δ(μR-μB) [%]
0	0	0.0	0.0		
1	1500	1500.4	1518.8	-18.3	**-1.2**
2	3500	3500.0	3536.3	**-36.2**	-1.0
3	7000	7000.5	7045.0	**-44.5**	-0.6
4	10000	10000.3	10050.0	**-49.7**	-0.5
5	7000	6999.9	7024.6	**-24.7**	-0.4
6	3500	3499.6	3496.1	**3.5**	0.1
7	1500	1500.3	1499.3	0.9	**0.1**
8	0	0.1	0.7	-0.6	

7.19 (6.1.3) Measurements to be carried out

Check that measurements to be carried out, displayed, reported, sent out or printed as described in the user manual, comply with the requirements of this standard.

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7.20 (6.1.4) Repeatability, reliability and total error of *φmin RFAmax*

Unless specified otherwise, all measurements use the DTV Front and Rear, both sides (Left and Right).

All tables below have been prepared with constant limit values, errors aren't increasing with a value below *φmin=30°*.

- Points 1. & 5.: 1 non-evaluated pre-test + 15 measurements, 5-20 sec delay, car stays on the same place of the measuring plate. The calibration set is not used at this stage.
  Don't use µ (average value), instead calculate the linear regression of values over time (or measurement order number). All measured values have to be ±err from this line.

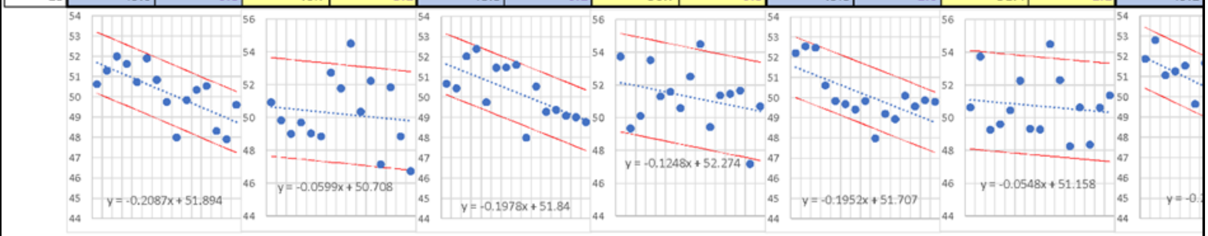
Q7: Functional test

Repeatability test platform position 50, 50

Vehicle: Default Test Vehicle
Registration: XXX-888
Date/Time: 12/15/2017 10:41

Check:		
	RFAMmax	-1.5 % < T-B < +1.5 %, T = TrendLine
	φmin	-3 % < T-B < +3 %, T = TrendLine

	FL = Front Left wheel				RL = Rear Left wheel				FR = Front Right wheel				
	RFAmax		φmin		RFAmax		φmin		RFAmax		φmin		RFA
#	Bench	Δ(T-B)	Bench	Δ(T-B)	Bench	Δ(T-B)	Bench	Δ(T-B)	Bench	Δ(T-B)	Bench	Δ(T-B)	Bench
0	53.5		53.5		53.5		53.5		53.5		53.5		53.5
1	50.6	1.0	50.9	-0.3	50.7	1.0	53.7	-1.6	52.2	-0.7	50.6	0.5	51.9
2	51.3	0.2	49.8	0.8	50.4	1.0	49.4	2.7	52.6	-1.2	53.7	-2.7	52.8
3	52.0	-0.7	49.0	1.5	52.0	-0.8	50.1	1.8	52.5	-1.4	49.3	1.7	51.1
4	51.6	-0.6	49.7	0.8	52.4	-1.3	53.5	-1.7	50.6	0.3	49.6	1.3	51.3
5	50.7	0.1	49.0	1.4	49.8	1.1	51.3	0.3	49.8	0.9	50.5	0.4	51.5
6	51.9	-1.3	48.9	1.5	51.5	-0.8	51.6	-0.1	49.7	0.9	52.3	-1.4	49.6
7	50.8	-0.4	52.7	-2.4	51.5	-1.0	50.6	0.8	49.4	0.9	49.3	1.4	51.7
8	49.8	0.5	51.8	-1.5	51.6	-1.3	52.5	-1.3	49.8	0.3	49.3	1.4	50.0
9	48.0	2.0	54.5	-4.3	48.0	2.1	54.5	-3.3	48.0	2.0	54.5	-3.8	48.0
10	49.8	0.0	50.3	-0.2	50.5	-0.7	49.4	1.6	49.2	0.5	52.3	-1.7	50.0
11	50.3	-0.8	52.2	-2.2	49.3	0.4	51.4	-0.5	49.0	0.6	48.3	2.3	49.8
12	50.5	-1.2	47.1	2.8	49.4	0.1	51.5	-0.7	50.1	-0.7	50.7	-0.2	48.7
13	48.3	0.9	51.8	-1.9	49.1	0.2	51.7	-1.0	49.6	-0.4	48.4	2.1	48.8
14	47.9	1.1	48.8	1.0	49.0	0.1	47.2	3.3	49.9	-0.9	50.6	-0.2	50.1
15	49.6	-0.8	46.7	3.1	48.8	0.1	50.7	-0.3	49.8	-1.0	51.4	-1.1	49.1



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- Points 2. & 6.: Only one axle. 1 non-evaluated pre-test +5 measurements at 3 (*RFAmax*. + *φmin*) different positions, 5-20 sec delay, with the wheel being placed both at the edge and at the middle position of the boundary of the testing area specified in the user manual (see exact demand in paragraph 6.1.4.). The calibration set is not used at this stage. Evaluations will be done independently for all wheels of the DTV, below sample protocol based only on the Front Left wheel.
  Q7: Functional test

Reliability test, FL = Front Left platform positions: RFAmax φmin

Vehicle: Default Test Vehicle
Registration: XXX-888
Date/Time: 7/1/2018 10:12

Main Check:	RFAmax	-3 % < µRFA_x1,y1-µRFA_x2,y2 < +3 %
	φmin	-4.5 % < µφmin_x1,y1-µφmin_x2,y2) < +4.5 %
Secondary Check:	RFAmax	-1.5 % < µ-B < +1.5 %,
(Repeatability)	φmin	-3 % < µ-B < +3 %

Difference of ANY!!! 2 averages

	platform position 25,50				platform position 50,50				platform position 75,50			
	RFAmax		φmin		RFAmax		φmin		RFAmax		φmin	
#	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)
0	53.5		53.5		53.5		53.5		53.5		53.5	
1	56.4	-0.9	46.4	0.2	51.7	0.2	53.4	-1.4	53.1	-0.7	52.0	-1.1
2	55.7	-0.1	47.7	-1.0	52.5	-0.6	52.0	0.0	52.8	-0.4	50.3	0.5
3	56.3	-0.8	48.5	-1.9	51.8	0.1	52.8	-0.8	52.3	0.0	49.4	1.5
4	54.7	0.8	45.1	1.5	52.0	-0.1	49.4	2.7	52.4	-0.1	50.3	0.6
5	54.5	1.0	45.5	1.2	51.5	0.4	52.6	-0.5	51.3	1.1	52.4	-1.5
	$\mu_{RFA\_25,50}$		$\mu_{\varphi min\_25,50}$		$\mu_{RFA\_50,50}$		$\mu_{\varphi min\_50,50}$		$\mu_{RFA\_75,50}$		$\mu_{\varphi min\_75,50}$	
	55.5		**46.6**		**51.9**		**52.0**		**52.4**		**50.9**	

Secondary checks in Δ(µ-B) columns

	platform position 25,75				platform position 75,25			
	RFAmax		φmin		RFAmax		φmin	
#	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)
0	53.5		53.5		53.5		53.5	
1	52.5		53.6	-7.0	52.0		52.1	-1.2
2	52.9		53.2	-6.6	52.4		51.0	-0.1
3	50.6		49.6	-3.0	50.4		49.5	1.4
4	50.5		51.9	-5.2	51.5		53.0	-2.1
5	50.9		52.5	-5.8	52.2		49.0	1.9
			$\mu_{\varphi min\_25,75}$				$\mu_{\varphi min\_75,25}$	
			52.2				**50.9**	

Main Check:

-3 % < µRFA_x1,y1-µRFA_x2,y2 < +3 %

$\mu_{RFA\_25,50}$	$\mu_{RFA\_50,50}$	$\mu_{RFA\_75,50}$
	3.6	3.1
		-0.5

-4.5 % < µφmin_x1,y1-µφmin_x2,y2) < +4.5 %

$\mu_{\varphi min\_25,50}$	$\mu_{\varphi min\_50,50}$	$\mu_{\varphi min\_75,50}$	$\mu_{\varphi min\_25,75}$	$\mu_{\varphi min\_75,25}$
	-5.4	-4.2	-5.5	-4.3
		1.2	-0.1	1.1
			-1.3	0.0
				1.3

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- WITH THE CALIBRATION SET.

DTV and 4 VEH, described in the prerequisites, for both axles, both sides.
Points 3. & 4. & 7. – 1 non-evaluated pre-test + 5 measurements on each wheel, 5-20 sec delay, car stays on the same place of the measuring plate (middle, 50,50).
Error evaluation (example based on R*FAmax* value):

- For each series of 5 measurements apply point 1. or 5.(repeatability) using simple average, not linear regression.

- All measured values from each series have to be within the specified tolerance = ± 5% from the reference.

- All the µ values from all measurements of all five vehicles have to be ± $^{2}/_{3}$ of the specified tolerance (only systematic error is allowed, not fully random error)

Q7: Functional test

Total Error Test platform position 50, 50 • (•)

Vehicle:	DTV, next vehicle VEH1, ..., VEH5
Registration:	XXX-888
Date/Time:	5/7/2018 16:45

Main Check:	RFAma	-5 % < Δ(R-B) < +5 %
	φmin	-7.5 % < Δ(R-B) < +7.5 %
	RFAma	max(µ(R-B), DTV,5VEH)-min(µ(R-B), DTV,5VEH)<6.7 %
	φmin	max(µ(R-B), DTV,5VEH)-min(µ(R-B), DTV,5VEH)<10 %
Secondary Check:	RFAma	-1.5 % < µ-B < +1.5 %,
	φmin	-3 % < µ-B < +3 %

DTV

	FL = Front Left wheel								RL = Rear Left wheel							
	RFAmax				φmin				RFAmax				φmin			
#	Ref	Bench	Δ(R-B)	Δ(µ-B)	Ref	Bench	Δ(R-B)	Δ(µ-B)	Ref	Bench	Δ(R-B)	Δ(µ-B)	Ref	Bench	Δ(R-B)	Δ(µ-B)
0	52	53.5			52	53.5			52	53.5			52	53.5		
1	52.4	53.8	-1.4	-0.6	52.9	48.8	4.1	3.6	52.2	54.3	-2.1	-3.1	52.8	49.9	2.9	0.0
2	52.8	53.9	-1.1	-0.7	52.5	50.4	2.1	2.0	51.2	50.2	1.0	1.0	52.0	47.9	4.1	2.0
3	51.7	52.3	-0.6	0.9	52.7	55.0	-2.3	-2.6	51.5	49.7	1.8	1.4	51.3	55.3	-4.0	-5.3
4	51.1	53.2	-2.0	0.1	51.5	53.5	-2.0	-1.1	51.3	50.1	1.2	1.1	50.9	49.8	1.1	0.2
5	52.0	52.9	-0.8	0.3	51.9	54.3	-2.4	-1.9	51.5	51.5	0.0	-0.4	51.1	46.9	4.3	3.1
		µB	µ(R-B)			µB	µ(R-B)			µB	µ(R-B)			µB	µ(R-B)	
		53.2	-1.2			52.4	-0.1			51.2	0.4			49.9	1.7	

	FR = Front Right wheel								FR = Front Right wheel							
	RFAmax				φmin				RFAmax				φmin			
#	Ref	Bench	Δ(R-B)	Δ(µ-B)	Ref	Bench	Δ(R-B)	Δ(µ-B)	Ref	Bench	Δ(R-B)	Δ(µ-B)	Ref	Bench	Δ(R-B)	Δ(µ-B)
0	52	53.5			52	53.5			52	53.5			52	53.5		
1	52.3	49.4	2.9	1.8	51.5	50.7	0.8	-0.4	52.2	50.3	1.9	0.4	52.1	46.3	5.9	5.2
2	52.2	49.4	2.8	1.7	53.0	49.8	3.2	0.6	52.5	49.6	2.9	1.1	51.6	54.4	-2.8	-2.9
3	51.3	51.7	-0.4	-0.5	52.4	47.6	4.8	2.8	52.9	53.7	-0.8	-3.1	52.0	49.6	2.4	1.9
4	52.9	52.5	0.4	-1.3	51.6	47.8	3.8	2.6	51.8	50.7	1.1	0.0	52.4	51.1	1.2	0.4
5	51.4	52.8	-1.4	-1.6	50.9	55.9	-5.0	-5.6	52.4	49.1	3.3	1.6	51.3	56.0	-4.7	-4.5
		µB	µ(R-B)			µB	µ(R-B)			µB	µ(R-B)			µB	µ(R-B)	
		51.2	0.9			50.4	1.5			50.7	1.7			51.5	0.4	

	FL RFAmax µB	µ(R-B)	FL φmin µB	µ(R-B)	RL RFAmax µB	µ(R-B)	RL φmin µB	µ(R-B)	FR RFAmax µB	µ(R-B)	FR φmin µB	µ(R-B)	FR RFAmax µB	µ(R-B)	FR φmin µB	µ(R-B)
VEH1	50.9	1.0	53.2	-1.2	52.5	-0.2	52.2	-0.5	51.2	0.5	50.4	1.6	53.1	-1.3	52.3	-0.6
...																
VEH5	52.6	-0.4	53.0	-1.3	51.5	0.4	51.8	0.2	52.0	0.1	52.6	-0.5	53.4	-1.4	47.9	4.0

	FL RFAmax	FL φmin	RL RFAmax	RL φmin	FR RFAmax	FR φmin	FR RFAmax	FR φmin
max(µ(R-B), DTV,5VEH)	1.0	-0.1	0.4	1.7	0.9	1.6	1.7	4.0
min(µ(R-B), DTV,5VEH)	-1.2	-1.3	-0.2	-0.5	0.1	-0.5	-1.4	-0.6
max-min	2.2	1.2	0.6	2.2	0.7	2.1	3.1	4.6

Total Error H25 platform position 50, 50 •

Vehicle:	Default Test Vehicle
Registration:	XXX-888
Date/Time:	12/16/2017 9:32

Check:	H25	-8 % < Δ(R-B)[%] < +8 %, Bench > 3000 N
		-240 N < Δ(R-B)[N] < +240 N , Bench <= 3000 N

	FL = Front Left wheel				RL = Rear Left wheel				FR = Front Right wheel				FR = Front Right wheel			
	RFAmax				RFAmax				RFAmax				RFAmax			
#	Ref [N]	Bench [N]	Δ(R-B) [N]	Δ(R-B) [%]	Ref [N]	Bench [N]	Δ(R-B) [N]	Δ(R-B) [%]	Ref [N]	Bench [N]	Δ(R-B) [N]	Δ(R-B) [%]	Ref [N]	Bench [N]	Δ(R-B) [N]	Δ(R-B) [%]
0	3300	3400			1750	1850			3000	3150			1700	1830		
1	3302	3395	-94	-2.8	1749	1847	-98	-5.6	2999	3151	-152	-5.1	1700	1831	-132	-7.8
2	3301	3404	-103	-3.1	1751	1847	-96	-5.5	3000	3148	-148	-4.9	1701	1825	-124	-7.3
3	3300	3400	-100	-3.0	1750	1849	-99	-5.7	2999	3153	-154	-5.1	1699	1826	-127	-7.5
4	3301	3396	-95	-2.9	1750	1854	-104	-6.0	2998	3147	-148	-4.9	1699	1826	-127	-7.4
5	3300	3401	-101	-3.1	1751	1847	-96	-5.5	3000	3152	-152	-5.1	1699	1835	-136	-8.0

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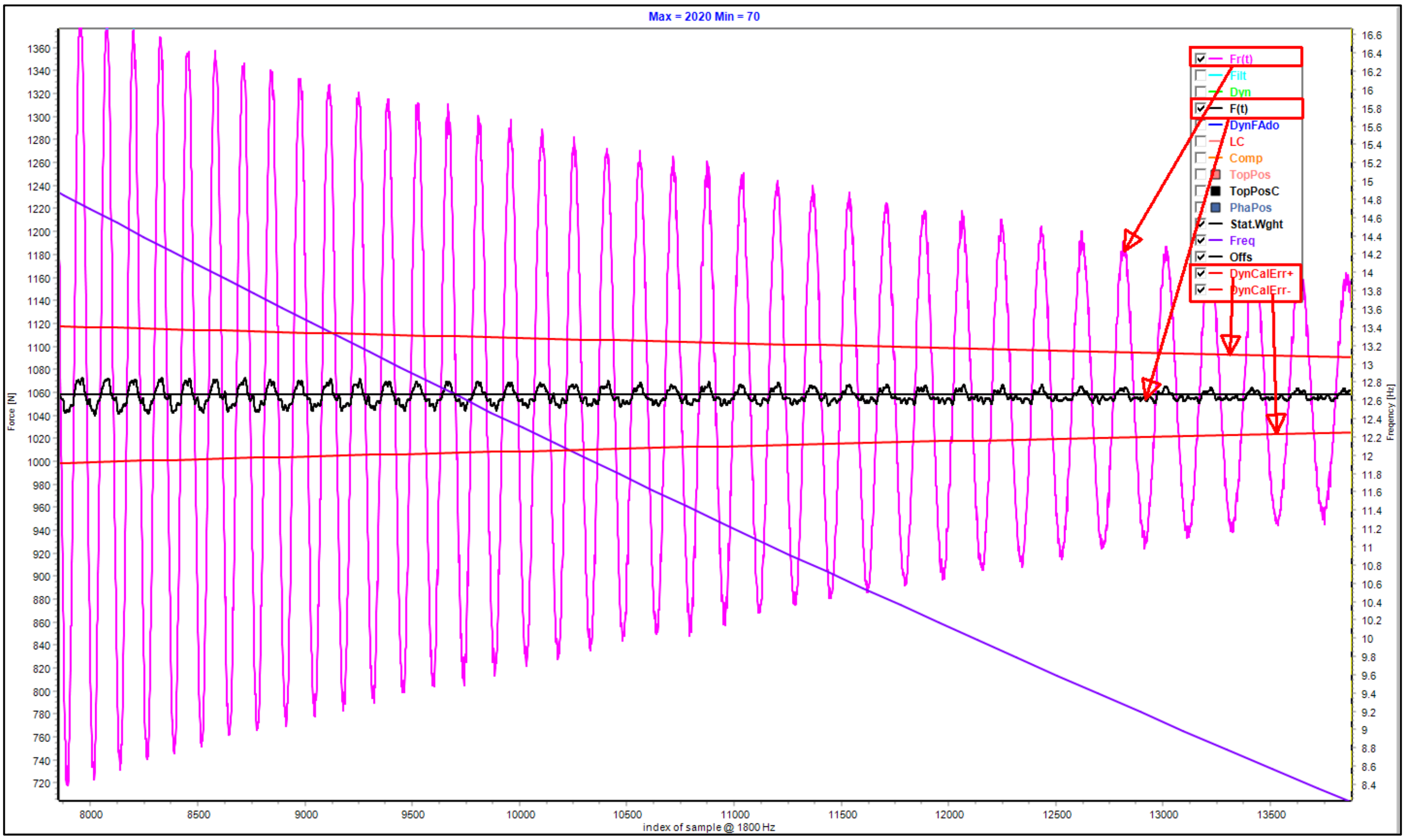
7.21 Total Error – defective damper

Probably using the rear axle of a DTV, where it is possible to release the bottom of the damper from the suspension (e.g. the axle or the wishbone), and then perform a test of this single wheel using the previous table.

Check using signal generator or VEH, table or graph → Q3, Q7

7.22 (3.10) Dynamic calibration

Check whether dynamic calibration is working (intentionally mis-positioned sensor, added weight to the measuring platform)



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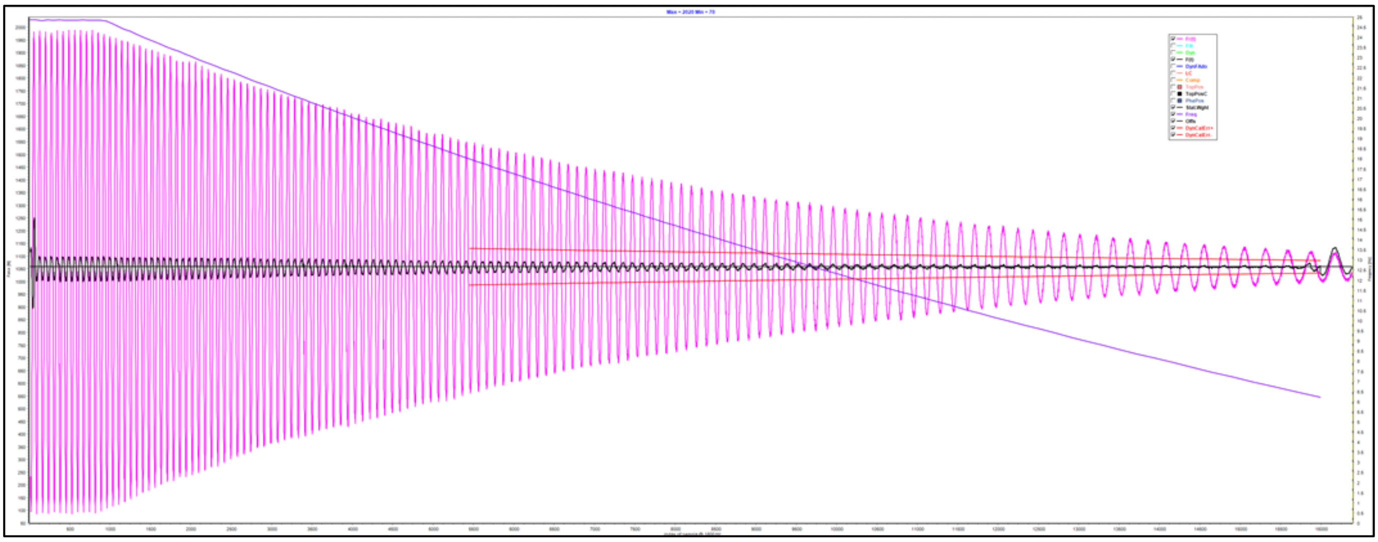

Q4: Dynamic calibration

7.23 (6.2.1) Displayed parameters

Check that *iφmin* and *Diφmin* are calculated correctly.

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8 Recommendation for the periodical calibration

The periodical calibration equipment has to comply with the requirements of the standard ISO 17025.

Periodical traceable calibration of test devices has to be ensured. Therefore, the direct measurements must fulfill the following at the periodic calibration:

- Suspension tester has to be equipped with special calibration mode, that allows repeated tests of each vehicle wheel independently with manual start up and control
- In this calibration mode all demands from the paragraph 5.3 have to be met
- All parameters have to be displayed and subsequently printed and/or saved electronically.
- At the time of the first installation, measure the platforms static peak to peak amplitude according to the paragraph 5.1, together with the L/R difference, with the vehicle positioned in the middle of the platform (50,50)[17]
- Vertical force (*Fst*) error according to 6.1.2.3
- Dynamic calibration according to point 3.10 and dynamic verification using special test mode that allows the start of a test without a vehicle on the platforms. Depending on the construction of the suspension tester, if the dynamic zero check (with no load on the plate) can't be done, the tester manufacturer shall propose and validate an alternative equivalent method.
- Test of repeatability and reliability according to point 6.1.4, *RFAmax*, *φmin*, simplified from approval procedure, table below[18].

Calibration simplified Repeatability and Reliability test, FL = Front Left

platform positions: RFAmax φmin

Vehicle: Default Test Vehicle
Registration: XXX-888
Date/Time: 7/1/2018 10:25

Reliability	RFAmax	-3 % < µRFA_x1,y1-µRFA_x2,y2 < +3 %
	φmin	-4.5 % < µφmin_x1,y1-µφmin_x2,y2) < +4.5 %
Repeatability	RFAmax	-1.5 % < µ-B < +1.5 %,
	φmin	-3 % < µ-B < +3 %

	platform position 25,75				platform position 50,50				platform position 75,25			
	RFAmax		φmin		RFAmax		φmin		RFAmax		φmin	
#	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)	Bench	Δ(µ-B)
0			53.5		53.5		53.5				53.5	
1			45.1	1.0	51.2	-0.3	50.2	2.2			51.4	0.5
2			47.8	-1.7	51.1	-0.2	53.3	-0.8			50.8	1.1
3			45.4	0.7	50.2	0.6	52.8	-0.4			53.5	-1.6
4					51.9	-1.1	53.1	-0.7				
5					49.8	1.0	52.7	-0.3				
			$\mu_{\varphi min\_25,75}$		$\mu_{RFA\_50,50}$		$\mu_{\varphi min\_50,50}$				$\mu_{\varphi min\_75,25}$	
			46.1		**50.8**		**52.4**				**51.9**	

Reliability φmin

-4.5 % < µφmin_x1,y1-µφmin_x2,y2) < +4.5 %

$\mu_{\varphi min\_25,75}$	$\mu_{\varphi min\_50,50}$	$\mu_{\varphi min\_75,25}$
	-6.3	-5.8
		0.5

[17] Simple dial gauge on the arm

[18] 4+6+4 tests /wheel

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9 Abbreviations, symbols and parameters

Symbol	Designation	Class	Numeric type	Value	Unit	Decimal places (min)
$AC_{\varphi min}$	Parameter for acceptance of the absolute criterion of the minimum phase shift	parameter	float	35,0	°	1
$AFst_{i,j}$	Static weight for each axle	Calculated	float		daN	1
a_{rig}	Parameter to calculate tyre rigidity	parameter	float	0,57100	-	5
b_{rig}	Parameter to calculate tyre rigidity	parameter	float	46,0	-	1
CalcTOPp(i)	Calculated top position of the i^{th} period of the suspension tester platform	Calculated	float, int		s, -	
$DRFAmax_i$	Imbalance of the maximum force amplitude for each axle	Calculated	float		%	
$D\varphi min_i$	Imbalance of the minimum phase shifts for each axle	Calculated	float		%	
$Di\varphi min_i$	Imbalance of the minimum phase shifts for each axle, calculated from iφmin, standard rounding	Calculated	float		%	
DeltaF	Frequency below the Minimum adhesion frequency where Minimum phase shift has to be detected	parameter	float	5,0	Hz	1
Drig	The imbalance of the tyre rigidity	Calculated	float		%	
$DVal_i$	General form to calculate imbalance of the $Val_{i,1}$, $Val_{i,2}$	Calculated	float		%	
DynCalErr	parameter to calculate frequency dependent force of the dynamic calibration error	parameter	float	4	N/Hz	1
ep	amplitude of the platform excitation	parameter	float	3,00	mm	2
f	the frequency calculated from the *TOPp* sequence	Calculated	float		Hz	
FAmax	Maximum amplitude of the F(t) signal	Calculated	int		N	
Fdn	Intersection of the decreasing part of the i_{th} period of the F(t) signal and Fst	Calculated	float, int		s, -	
Fdynmax	Maximum amplitude of the *F(t)* signal	Calculated	int		N	

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Fdynmin	Minimum amplitude of the *F(t)* signal	Calculated	int		N	
Fdynx	Extreme amplitude of the *F(t)* signal	Calculated	int		N	
Fmin	Minimum value of the F(t) signal	Calculated	int		N	
Fmax	Maximum value of the F(t) signal	Calculated	int		N	
$fn, fn_{i,j}$	Minimum adhesion frequency	Calculated	float		Hz	
Fover	This parameter is set when the F(t) signal overflows	Calculated	boolean			
FOverLim	Above this value parts of the upper periods of the F(t) are cut off	parameter	int, system dependent		N	
Fp(t)	Dynamic force signal of the suspension tester platform	Calculated	int		N	
fres	Resonant frequency of the F(t) signal	Calculated	float		Hz	
Funder	This parameter is set when the F(t) signal underflows	Calculated	boolean		boolean	
FUnderLim	Below this value parts of the lower periods of the F(t) are cut off	parameter	int		N	
FUnderLimPerc	Parameter to determine FUnderLim	parameter	float	1	N	1
Fup	Intersection of the increasing part of the i_{th} period of the F(t) signal and Fst	Calculated	float, int		s, -	
F(t)	Vertical tyre contact force signal	Calculated	int		N	
Fp(t)	Dynamic force signal of the suspension tester platform	Calculated	int		N	
Fr(t)	Raw force signal	Measured	int		N	
Fst_i	Vertical force of an axle	Calculated	int		N	
$Fst, Fst_{i,j}$	Vertical force of a wheel	Measured	int		N	
FstCorr	Fst modification	parameter	int	0	N	
$f\varphi_{min}$	Frequency on which the Minimum phase shift was determined	Calculated	float		°	
H25	Static amplitude *H25* of the *F(t)* signal	Calculated	int		N	
hp(t)	Excitation of the suspension tester platform	physically generated	float		mm	

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$h_{PDmax,x,y}$	*P*latforms *D*ynamically measured *max*imum peak to peak amplitude	Measured	float		mm	
$h_{PDmin,x,y}$	*P*latforms *D*ynamically measured *min*imum peak to peak amplitude	Measured	float		mm	
$h_{PSmeas,x,y}$	*P*latforms *S*tatically *meas*ured peak to peak amplitude	Measured	float		mm	
MaxCalcFreq	Frequency to which certain data are evaluated	parameter	float	18	Hz	1
maxF(i)	Maximum of the i^{th} period of the *F(t)* signal	Calculated	int		s, -	
maxFp(i)	Maximum of the i^{th} period of the *Fp(t)* signal	Calculated	int		N	
MinCalcFreq	Frequency from which certain data are evaluated	parameter	float	6	Hz	1
minF(i)	Minimum of the i^{th} period of the *F(t)* signal	Calculated	int		s, -	
Period(i)	i^{th} period of *Fp(t)* signal, surrounded by *ST(i)* and *ST(i+1)*	Calculated	float, float		s, -	
RC_{RFAmax}	Parameter for acceptance of asymmetry of the relative dynamic force amplitude values	parameter	float	30,0	%	1
RCrig	Parameter for acceptance of asymmetry of the tyre rigidity	parameter	float	35,0	%	1
$RC_{\varphi min}$	Parameter for acceptance of asymmetry of the minimum phase shift values	parameter	float	30,0	%	1
RFAmax	Relative (to the Static weight Fst) maximum amplitude of the F(t) signal	Calculated	float		%	
rig, $rig_{i,j}$	Non-rolling rigidity of the tyre	Calculated	int		N/mm	
rigHiLim	Above this limit rigidity warning Yellow	parameter	int	400	N/mm	
rigLoLim	Below this limit rigidity warning Yellow	parameter	int	160	N/mm	
RFstFMax	Range related from the top force measurement to the static weight	parameter	float	25,0	%	1
RFstFMin	Range related from the bottom force measurement to the static weight	parameter	float	25,0	%	1
Fref(i)	Reference position of the i^{th} period of the vertical tyre contact force signal	Calculated	float, int		s, -	
ST(i)	Sensor Trigger of the i^{th} period of the *Fp(t)*	Measured	float, int		s, -	
StatWLim	Difference ot the Fst before and after the wheel test	parameter	int	25	daN	

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Fst_{hi}	parameter establishing whether phase shift for given period of F(t) signal could be calculated	Calculated	int		N	
Fst_{lo}	parameter establishing whether phase shift for given period of F(t) signal could be calculated	Calculated	int		N	
TOPp(i)	Top position of the i^{th} period of the suspension tester platform	Calculated	float, int		s, -	
ΔF(i)	Peak to peak amplitude of the i^{th} period of the *F(t)* signal	Calculated	int		N	
ΔPeriod(i)	Delay between *CalcTOP(i)* and *TST(i)*	Calculated	float, int		s, -	
$ΔT_{25}$	Minimum duration before measurement starts on 25 Hz	Calculated	float		ms	
ΔTfLinErr	Error from the linearity of frequency decrease	parameter	float	2,0	Hz	1
ΔTfMaxSlope	Error from the linearity of monotone frequency decrease	parameter	float	3	Hz/s	1
ΔTmeas	Minimum duration of measurement	parameter	float	7.5	s	1
φ	Phase shift	Calculated	float		°	
$φ_{min}$	Minimum phase shift	Calculated	float		°	
$iφ_{min}$	Minimum phase shift, rounded down	Calculated	float		°	
φminCorr	φmin modification	parameter	int	0	°	
$φ_{max}$	Phase shift at 18 Hz	Calculated	float		°	

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ANNEX 1

Design Example

General

Terminology and filter used by the implementation are based on the article J.F. Kaiser and W.A. Reed, 'Data smoothing using low-pass filters', Review of Scientific Instruments, Volume 48, Issue 11, pp. 1447-1457 (1977), Method 1 – Nearly equal ripple approximation filter.

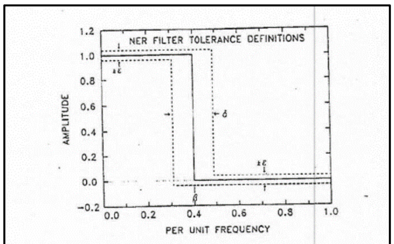

FIG. 2. Definitions of β, δ, and ε used in design of nearly equal ripple (NER) filter.

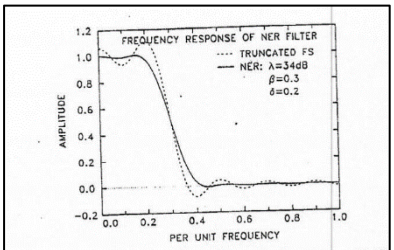

FIG. 3. Frequency response characteristics of an NER filter with 10 pairs of terms and a Fourier series truncated after 10 pairs of terms.

F(t), *Fp(t)*, relative force maximum amplitude

Whole signal, $\varepsilon = 0.01$, pass band *0-50* Hz, stop band *130* Hz up[19].

Phase shift processing

There are more influences (nonlinearities, impacts, ...) that are present on a real vehicle during the test that can corrupt phase signal against those known from the theory based on the ¼ car model.

Proposed phase signal processing will correct most of these influences.

Filter for the F(t) signal – raw phase shift $\varphi_r(i)$ calculation

For each frequency step f_{step} of 1 Hz in the frequency range 18 – 5 Hz create unique filter according [10]using following parameters:
PassMulPh = 2, StopMulPh = 4 (parameters)
f_{step} = *18, 17, ... 6* (this is not a real parameter, it is software constant)
ε = 0.01 (EpsPh parameter)
for each f_{step}, pass band = $0 - f_{step}$ * *PassMulPh* Hz
for each f_{step}, stop band = f_{step} * *StopMulPh* Hz up

Apply this filter to the F(t) signal (= FILTER PHASE from paragraph 3.21) and calculate the raw phase shift $\varphi_r(i)$ sequence.

[19] This is recommendation, it's mechanical design dependent

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Raw phase shift $\varphi_r(i)$ processing

Introduce parameters:
MinPhLim = -20
MaxPhaseLim=180
WLIncr = True (Wavelength Increasing)
TLtoWL=2 (samples, @1800 Hz).Length of the waveform determined from the Top(ST) differs maximum of 2 samples (assuming here sampling rate of 1800 Hz) from the real Waveform Length.

Certain part of the $\varphi_r(i)$ sequence was reduced due to conditions described in paragraph 3.22
From the raw phase shift $\varphi_r(i)$ signal remove all members, that don't fulfill above parameters, create processed phase shift $\varphi_p(i)$ signal.

Result phase shift $\varphi(j,\omega)$ signal

Resample/resize $\varphi_p(i)$ signal to become equidistant in the frequency range, equidistant frequency step equal *0.1* Hz.
Iteratively apply Gaussian filter (parameter *GsFltOrd = 20*) and using variance of $\Delta\varphi(j)$(filtered and equidistant data) replace incorrect elements by better approximations.

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