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Dynamic verification of material testing machines using applied samples

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Deutscher Kalibrierdienst (DKD)

Since its foundation in 1977, the DKD has brought together calibration laboratories of industrial enterprises, research institutes, technical authorities, inspection and testing institutes. On 3 May 2011, the DKD was reestablished as a *technical body* of PTB and the accredited laboratories.
This body is known as *Deutscher Kalibrierdienst* (DKD – *German Calibration Service*) and is under the direction of PTB. The guidelines and guides elaborated by DKD represent the state of the art in the respective technical areas of expertise and can be used by the *Deutsche Akkreditierungsstelle GmbH* (the German accreditation body – DAkkS) for the accreditation of calibration laboratories.
The accredited calibration laboratories are now accredited and supervised by DAkkS as legal successor of the DKD. They carry out calibrations of measuring instruments and measuring standards for the measurands and measuring ranges defined during accreditation. The calibration certificates issued by these laboratories prove the traceability to national standards as required by the family of standards DIN EN ISO 9000 and DIN EN ISO/IEC 17025.

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Foreword

DKD guidelines are application documents that meet the requirements of DIN EN ISO/IEC 17025. The guidelines contain a description of technical, process-related and organizational procedures used by accredited calibration laboratories as a model for defining internal processes and regulations. DKD guidelines may become an essential component of the quality management manuals of calibration laboratories. The implementation of the guidelines promotes equal treatment of the equipment to be calibrated in the various calibration laboratories and improves the continuity and verifiability of the work of the calibration laboratories.

The DKD guidelines should not impede the further development of calibration procedures and processes. Deviations from guidelines as well as new procedures are permitted in agreement with the accreditation body if there are technical reasons to support this action.

Calibrations by accredited laboratories provide the user with the security of reliable measuring results, increase the confidence of customers, enhance competitiveness in the national and international markets, and serve as metrological basis for the monitoring of measuring and test equipment within the framework of quality assurance measures.

This guideline has been drawn up by the DKD Technical Committees *Force and Acceleration* and *Materials Testing Machines* and approved by the Board of DKD.

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1 Introduction

1.1 *Definition of dynamic forces*

A dynamic force is the product of mass and acceleration, with mass or acceleration varying over time. The calibration of dynamic forces makes it possible to determine the frequency-dependent (dynamic) properties of the force measurement application.

1.2 *Purpose and scope of application*

This document serves as a guideline for the dynamic verification of materials testing machines using applied samples. The dynamic verification helps to gain knowledge regarding the dynamic behaviour of the material testing machine and substantiates the results obtained by the testing of materials. Given that the applied samples in this guideline are used without further traceability, the procedure described does not constitute a calibration (as opposed to [1] or [2]) but an additional verification of the dynamic properties.

In the verification procedure it is assumed – as a matter of principle – that the dynamic forces exerted and displayed by the testing machine correspond to the dynamic forces acting on the sample [3]. Mass inertia of the specimen holders should only have a negligible influence. As a rule, the materials testing machine must be equipped with dynamic compensation in which the force signal is corrected by means of acceleration measurement.

As a proof of traceability, the materials testing machine must always also be statically calibrated according to DIN EN ISO 7500.

1.3 *Basic principle of the verification process*

The first step is to calibrate the materials testing machine according to DIN EN ISO 7500-1 to establish traceability of the statically exerted force to the national standard. The static calibration must be carried out prior to the dynamic verification.

The second step is to install an applied specimen in the materials testing machine and adjust its display under static load so that it corresponds to the force display of the materials testing machine ([4] and [5]).

The third step comprises the dynamic loading of the applied sample as well as checking the conformity between the display of the test machine and that of the applied sample. The corresponding measured values must be recorded and evaluated to be included in the result of the dynamic verification.

As a fourth step, the conformity between the display of the applied specimen and the force display of the materials testing machine is checked once again by renewed static loading.

2 Symbols

Abbreviations/ symbols	Unit	Explanation
$F_{\mathrm{P\ max},n}$	N	Force indication of the applied sample at the upper vertex (maximum) of the stress cycle n
$F_{\mathrm{P\ min},n}$	N	Force indication of the applied sample at the lower vertex (minimum) of the stress cycle n
$F_{\mathrm{WPM\ max},n}$	N	Force indication of the materials testing machine at the upper vertex (maximum) of the stress cycle n
$F_{\mathrm{WPM\ min},n}$	N	Force indication of the materials testing machine at the lower vertex (minimum) of the stress cycle n
$\Delta F_{\mathrm{max},n}$	N	Difference between the indications of the materials testing machine and the applied sample at the upper vertex (maximum) of the stress cycle n
$\Delta F_{\mathrm{min},n}$	N	Difference between the indications of the materials testing machine and the applied sample at the lower vertex (maximum) of the stress cycle n
n	1	Counter of stress cycles
$q_{\mathrm{max},n}$	%	Relative deviation at the upper vertex (maximum) of the stress cycle n
$q_{\mathrm{min},n}$	%	Relative deviation at the lower vertex (minimum) of the stress cycle n
$S_{\mathrm{P},n}$	N	Stress range of the cycle n

3 Preparatory measures

3.1 Preparation of the materials testing machine

The materials testing machine must be fully equipped for the materials testing. To ensure a correct test set-up, preliminary tests should be carried out using an applied sample whose design corresponds to the test specimen of the subsequent materials test.

The following should be noted:

1. The test conditions (ambient conditions, parameters of the testing machine, etc.) should be the same as for the subsequent materials test.
2. Bending due to misalignment must be ruled out:
   a. In the case of round specimens, which are easy to centre due to their design, the clamping device must be aligned in such a way that the force flow is centred in the specimen axis.
   b. Flat specimens and components whose mounting position cannot be exactly reproduced prove more problematic in the verification process. The use of installation aids is recommended here to increase the reproducibility of the test procedure.
3. Information regarding the specimen shape and clamping device can be found in the respective standard for material testing.

3.2 Preparation of the applied sample, preliminary tests

An applied sample showing the same dimensions and material density as the samples to be tested should be used. An ideal solution would be to use one of the specimens to be tested and apply strain gages onto that specimen in a suitable position.

Note: Depending on the desired load level, it may be necessary to choose an applied sample of bigger dimensions or to manufacture it from a more solid material. Materials whose elastic modulus depends on the strain rate are not suited to be used as applied specimen.

It must be ensured that the zero signal of the installed and unloaded applied sample (display of the testing machine = 0 kN) corresponds approximately to the zero signal in the disassembled state. If this is not the case, this indicates an incorrect alignment of the materials testing machine. The following procedure is recommended for the reproducible installation of an applied sample:

1. Install the applied sample in the materials testing machine and clamp it (see Figure 1).
2. Preload the materials testing machine and applied sample with the desired dynamic forces.
3. Statically approach the maximum force value (upper peak value of the dynamic load) and hold it for at least 30 seconds.
4. Remove the load from the applied sample and release the clamping on one side.
5. After at least 30 seconds, readjust the force display of the materials testing machine and the applied sample to zero.
6. Re-clamp the applied sample.
7. Approach force value zero on the display of the materials testing machine. The display of the applied sample should correspond to the zero display after adjustment in the unloaded state. Deviations from zero possibly indicate the presence of disturbance quantities and must be recorded.

8. Set the display of the applied sample to zero.
9. Statically preload the applied sample: statically approach the maximum force value (upper peak value of the dynamic load), hold it for at least 30 seconds and unload it (display of the testing machine = 0 kN). If necessary, reset the display of the applied sample to zero; the difference to the previous zero must be recorded.

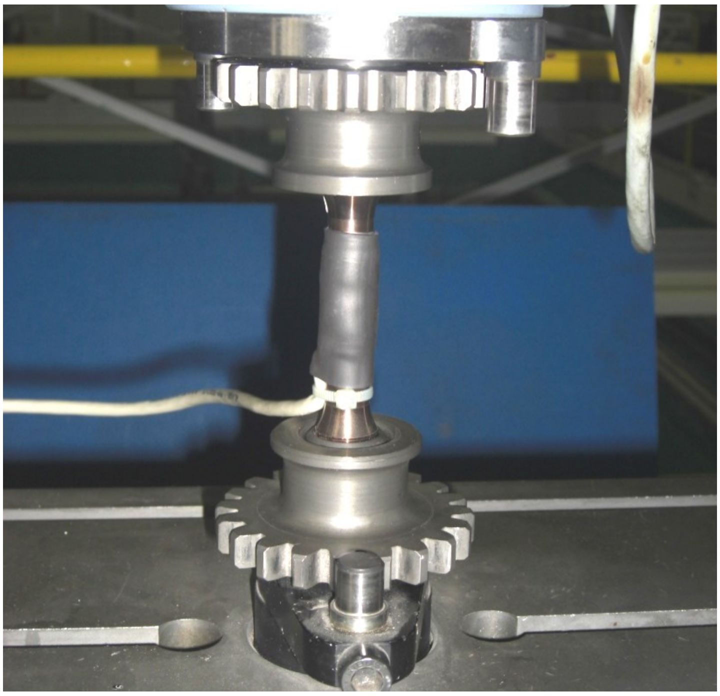

Figure 1: Built-in applied round specimen including clamping tool

4 Display adjustment of the applied sample under static load

Due to the system, relative linearity deviations of several 10^{-3} are to be expected for the applied samples. For adjustment purposes, it is therefore necessary to first determine the desired forces (force range) for the dynamic verification. If the dynamic verification is to be carried out for only a few force values lying close to each other, the display adjustment of the applied sample may be carried out using a linear factor. If the dynamic verification shall cover a larger value range, the display adjustment should be non-linear, e.g. by using a cubic function.

The maximum values (upper peak values of the dynamic test) and minimum values (lower peak values of the dynamic test) to be tested are to be statically approached at least three times in alternating sequence from unloaded condition (display of the testing machine = 0 kN); the indicated values of the applied sample are to be documented in order to determine the adjustment parameters for adaptation to the machine display.

After completing the adjustment, it is necessary to check the matching of the displays. For this purpose, the following force values must be approached three times each:

- maximum value
- maximum value + 5 % of the stress range
- maximum value - 5 % of the stress range
- minimum value
- minimum value + 5 % of the stress range
- minimum value - 5 % of the stress range

As to the approached forces, the display deviation of the applied sample (mean value of the three loads) and the repeatability should correspond to the values determined during the static calibration according to DIN EN ISO 7500-1. The display deviation and repeatability must be recorded.

To verify the accuracy of the determined factors, a quasi-static test with very low accelerations (i.e. low vibration frequencies and small force amplitudes) can be carried out prior to the dynamic test – provided that the machine can do this.

After the adjustment, the applied sample may not be released from the clamping device as the previously carried out adjustment can no longer be guaranteed due to the influence of a renewed clamping.

5 Recording of the measurement values

In addition to the display values of the materials testing machine and the applied specimen, the exact time of recording of the measured values must also be registered. In addition, the raw signals should preferably be recorded in "mV/V" or "V" so that they can be used for the subsequent plausibility check.

At least 50 cycles should be used for recording.

5.1 Sampling rate

To be able to determine the peaks of the acting dynamic forces with adequate accuracy, an adequate sampling rate is required. It should be noted that the signal noise increases when using a low-pass filter with a correspondingly higher cut-off frequency for signal filtering.

In case of a periodic sinusoidal loading, at least 80 sample points should be recorded per cycle.

With a periodic triangular function, the course of the force at the vertex changes much faster than with a sinusoidal function (see Figure 2, or Figure 3 to Figure 5). Therefore, the sampling rate should be higher. The acceleration at the vertex theoretically goes to infinity, and practically the apex of the triangle is rounded. For a triangular force curve, approximately 200 pairs of values should be recorded per cycle to limit amplitude deviations (see Figure 4 and Figure 5).

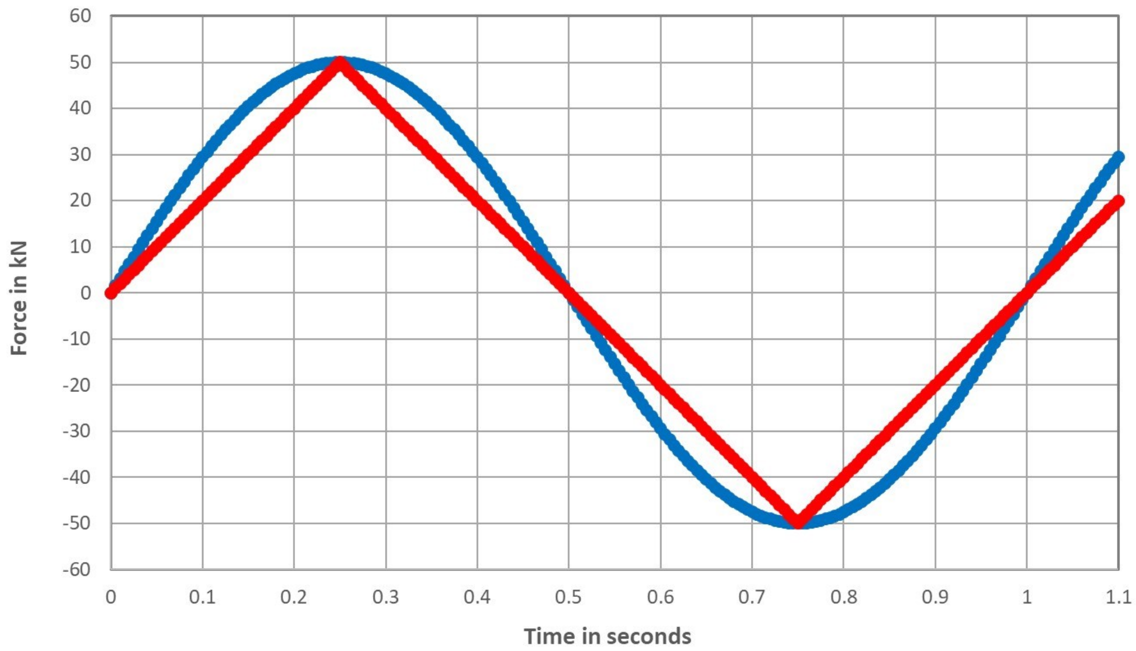

Figure 2: Signal curve for sinusoidal and triangular loads

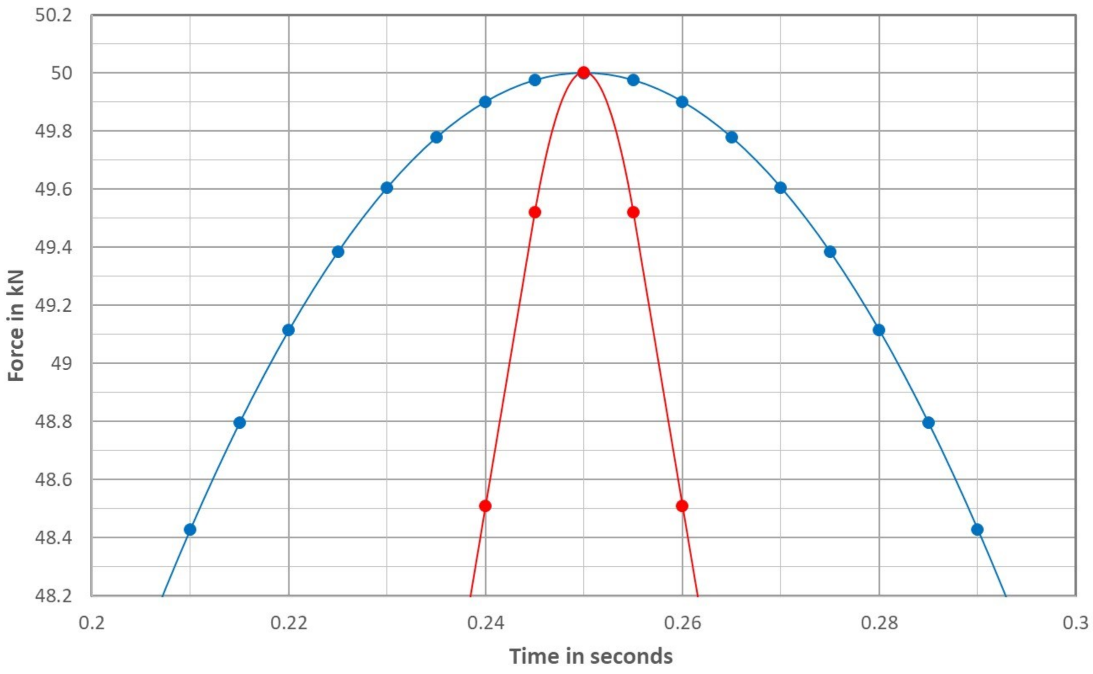

Figure 3: Sampling of a sinusoidal and a triangular oscillation, 200 sampling points per cycle, signal peaks rounded, data point on vertex

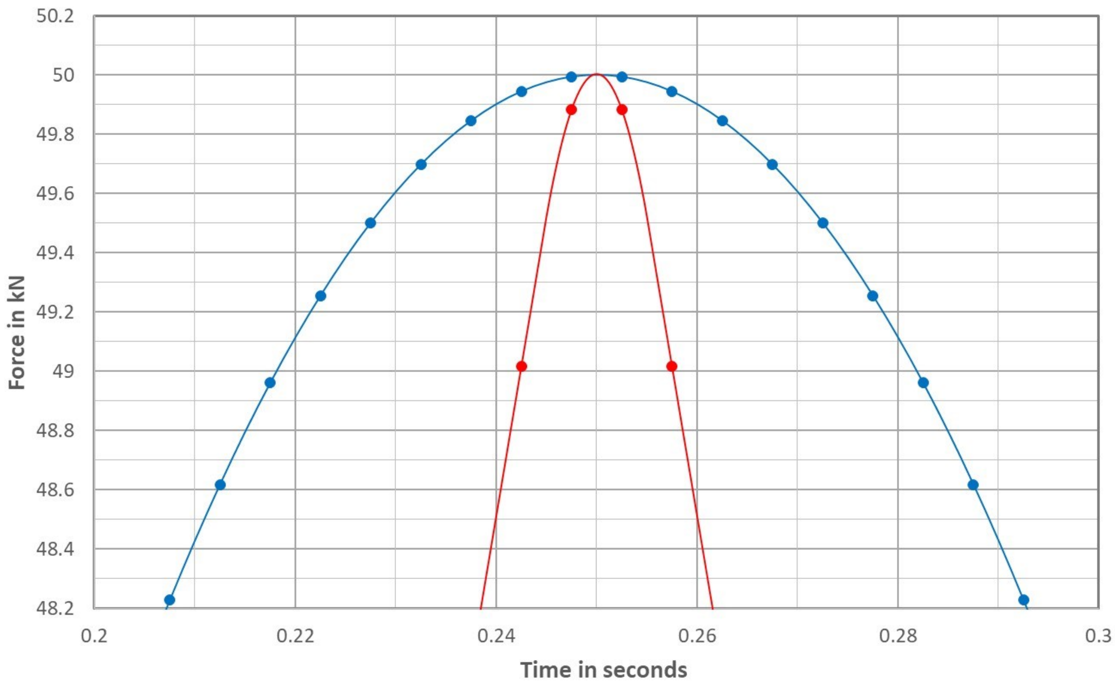

Figure 4: Sampling of a sinusoidal and triangular oscillation with 200 sampling points per cycle

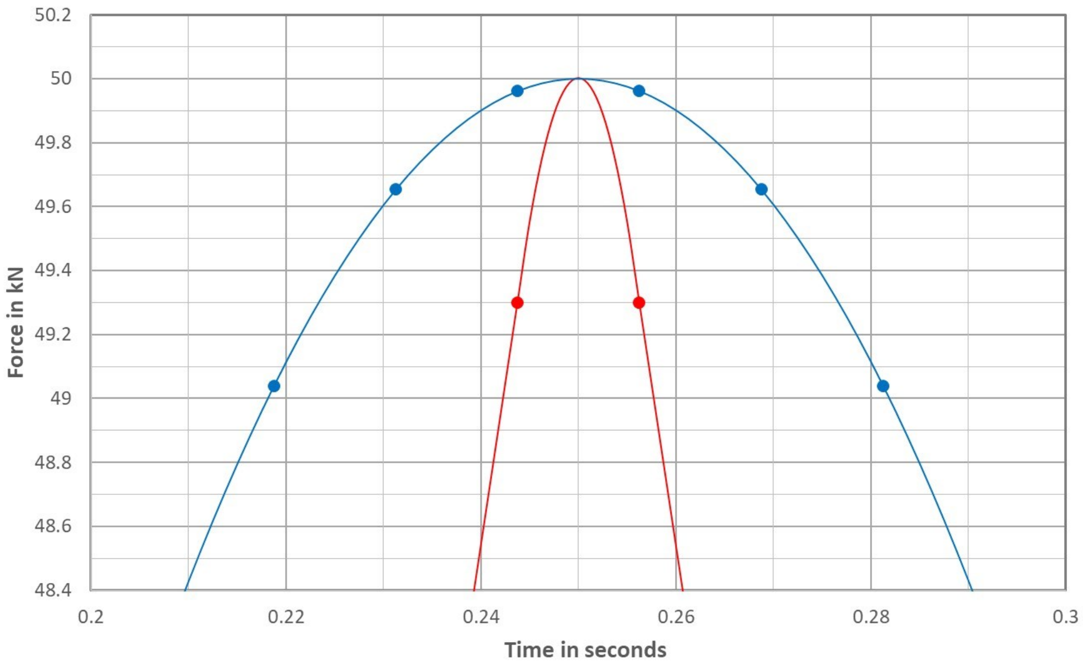

Figure 5: Sampling of a sinusoidal and triangular oscillation with 80 sampling points per cycle

5.2 *Filter technology*

Filters are used to remove unwanted high-frequency noise components from the measurement signals. The cut-off frequency of the low-pass filters used should be about 10 % to 15 % of the sampling rate.

> Example:
> Periodic sinusoidal load with 70 Hz,
> 80 samples per cycle
> → Sampling rate = 70 Hz · 80 = 5,6 kHz
> → Cut-off frequency of the low pass filter ≥ 560 Hz

The same low-pass filter (filter cut-off frequency, filter type, filter order) is to be used on all measuring amplifiers involved (displays of the materials testing machine and the applied sample); this is to ensure equal noise bandwidths of the filtered measuring signals as well as comparability of the measured peaks.

Given that most types of measuring amplifier have their own pre-set filter frequencies, it may be necessary to alter the desired low-pass filter frequency (10 % to 15 % of the sampling rate) and use the nearest identical filter frequency for both measuring channels. This should preferably be done in the direction of higher filter limiting frequencies.

Figure 6 and Figure 7 show examples of how the signal noise can be changed by varying the filter settings.

Note: During the sampling of the measuring signal, it must be ensured that the data acquisition system uses an anti-aliasing filter which filters out frequency components above half the sampling rate.

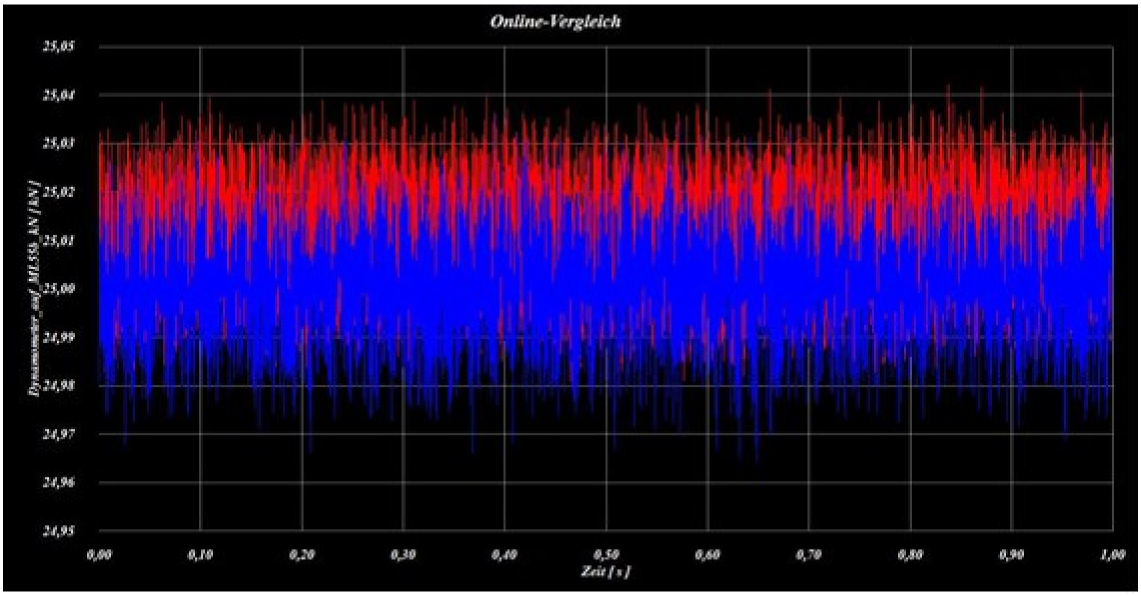

Figure 6: Filter BU 2 kHz and 1,5 kHz

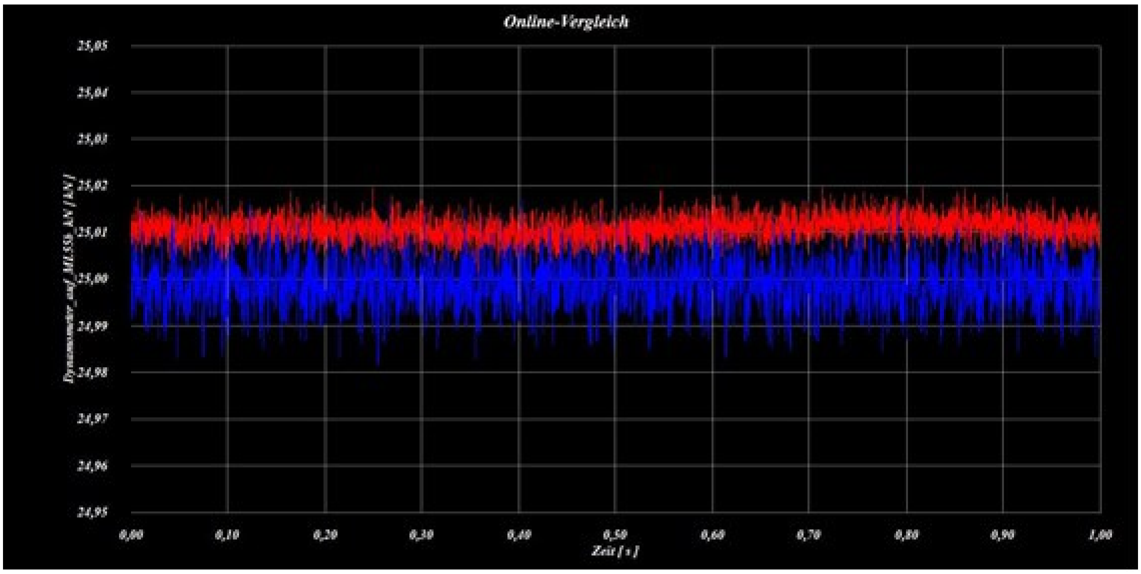

Figure 7: Filter BU 1 kHz

5.3 Synchronisation

A later synchronisation of the indicated values of the material testing machine and the applied specimen is only possible in case of a recognisable event which is recorded by both recording devices. This could be, for example:

- the beginning of the test
- the end of the test
- a trigger signal
- an irregularity in the measurement curve

5.4 Use of analogue outputs

In the case of material testing machines whose measuring amplifier has an analogue force output, it is recommended to use this output. The advantage of recording the measurement values via the analogue output is – depending on the measuring equipment – that the values can be recorded almost simultaneously, and synchronisation becomes easier. The disadvantage here is that there is no verification of the digital recording device of the materials testing machine.

The analogue force output of the materials testing machine must be adjusted according to the display of the materials testing machine. The conformity must be checked.

5.5 Working with static displays

In the case of materials testing machines that do not dynamically record the measurement values and that do not possess an analogue signal, the static values indicated on the machine display may be used for calculation – provided the values are constant values. In many cases, only the mean value and the vibration amplitude are displayed on fatigue testing machines.

Alternatively, the set value of the function generator can also be used as the actual value. The precondition for this is that the materials testing machine can approach the values set in the function generator without deviations.

6 Determination of the display deviation under dynamic load

6.1 Synchronisation of the measured values

It must be ensured that the measurement values of the materials testing machine and the applied specimen that are to be compared exactly belong together. For this purpose, the recorded measurement values must be synchronised. The time base of the measurement data of the applied specimen is shifted such that its first peak coincides with the first peak of the materials testing machine.

6.2 Determination of peak values

Since the sampling of the measurement values does not necessarily take place exactly at the vertex, the peak values for each individual cycle are to be calculated from the measurement values in an appropriate manner. In doing so, the sensitivity of the filter used must be adapted to the signal width and the fluctuations of the control loop.

6.3 Determination of deviations

First, the stress range (SP) for each individual cycle (index n, at least 50 cycles should be used) is calculated as follows from the measured values of the applied sample:

$$S_{\mathrm{P},n} = F_{\mathrm{P\,max},n} - F_{\mathrm{P\,min},n} \tag{1}$$

Subsequently, the display deviations of the materials testing machine and the applied specimen are to be determined for each individual cycle at the upper peak values (maxima) and lower peak values (minima) as follows:

$$\begin{aligned} \Delta F_{\mathrm{max},n} &= F_{\mathrm{WPM\,max},n} - F_{\mathrm{P\,max},n} \\ \Delta F_{\mathrm{min},n} &= F_{\mathrm{WPM\,min},n} - F_{\mathrm{P\,min},n} \end{aligned} \tag{2}$$

The relative deviations in relation to the stress range are calculated as follows for each individual cycle:

$$\begin{aligned} q_{\mathrm{max},n} &= \frac{\Delta F_{\mathrm{max},n}}{S_{\mathrm{P},n}} \cdot 100\ \% \\ q_{\mathrm{min},n} &= \frac{\Delta F_{\mathrm{min},n}}{S_{\mathrm{P},n}} \cdot 100\ \% \end{aligned} \tag{3}$$

The relative deviations of the individual cycles should be visualised in a diagram. The maximum relative deviations that have been determined for the upper and lower peak values are to be indicated as numerical values.

6.4 Plausibility check

The number of determined peaks, which must be the same for both displays (of material testing machine and applied sample), is the main point of the plausibility check. The number of maxima as well the number of minima must be equal, and the number of maxima may only differ by one from the number of minima.

The time stamps of the extracted maximum and minimum values should be compared. The time difference of successive peaks should be approximately half a period and the dispersion should be small.

When using constants for testing, as described in section "5.5 Working with static displays", the quality of the test must be assessed by calculating the standard deviation of the maxima and minima. The standard deviation must be indicated.

6.5 Other verification points

In addition, the following criteria should be checked with the aid of the graphical representation of the measured values:

- Has the desired frequency been reached?
- Has the desired amplitude been reached?
- Does it contain all peak values?
- How do the peak values (maxima and minima) develop with an increasing number of oscillations? If the peak values increase with increasing duration of the oscillation, the settling process of the materials testing machine may not yet be completed.
- How do the relative deviations develop with an increasing number of oscillations? If the relative deviations change with increasing duration of the oscillation, the settling process of the materials testing machine may not yet be completed.

7 Calibration certificate

A calibration certificate of the static calibration according to DIN EN ISO 7500-1 is to be issued. This calibration certificate is supplemented by information regarding the dynamic verification of the materials testing machine:

> *"A dynamic verification of the materials testing machine was additionally performed according to DKD-R 3-10 Sheet 3:08/2019 by using an applied specimen. The measurement uncertainty of the static calibration according to DIN EN ISO 7500-1 does not contain any contributions from the dynamic verification."*

In addition, it is necessary to list the test parameters and results, such as:

- determined maximum relative deviations
- graphical representation of the relative deviations of the individual stress cycles
- type and size of applied sample (e.g. round sample, diameter, length)
- exact designation of the gripping tool used
- type of periodic forces (sine, triangle, …)
- verified force levels (e.g. 50 kN, …)
- frequencies used

8 Bibliography

[1] ISO 4965-1: Metallic materials - Dynamic force calibration for uniaxial fatigue testing - Part 1: Testing systems.
[2] ISO 4965-2: Metallic materials - Dynamic force calibration for uniaxial fatigue testing - Part 2: Dynamic calibration device (DCD) instrumentation.
[3] Sawla, A.: Measurement of dynamic forces and compensations of errors in fatigue testing, Proceedings of the 12th IMEKO World Congress “Measurement and Progress”, Beijing, China. Vol.2 (1991), 403-408.
[4] ASTM E467: Standard Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System.
[5] Häuser, Ch.: Verfahren zur dynamischen Verifizierung von Prüfmaschinen; Presentation to the DKD Technical Committee for Materials Testing Machines, 2015.

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