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**Plastics — Validation of force-time  
curves obtained from high-speed  
tensile tests**

*Plastiques — Validation des courbes force-temps obtenues à partir  
d'essais de traction à grande vitesse*

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## Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

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This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

The method described in this document provides criteria for the validation of measurement curves obtained from high-speed tensile tests.

Force, time, travel and strain measurement systems of high-speed tensile equipment are usually calibrated in static mode. Dynamic effects, occurring at such tests, need to be addressed and limits or ranges of use for the obtained assessment parameters need to be set in order to allow the validation of the obtained measurement curves.

This document contains a method to measure the spectrum of the natural mechanical frequencies of the force transducer and grip arrangement, considering that these frequencies are the most important limiting factor for the range of use of a high-speed tensile test equipment.

In addition, there are further parameters which may play a role for the dynamic quality of the measurement curves, such as the data acquisition frequency, or oscillations generated in the machine frame. These parameters should be carefully supervised, and measures need to be taken if such problems occur in a significant way.

In case direct travel or strain measurement is used to generate stress-strain curves or to determine nominal or local strain rates, further parameters, such as the synchronization between force, time and strain channels, need to be supervised.

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# Plastics — Validation of force-time curves obtained from high-speed tensile tests

## 1 Scope

This document specifies procedures for validation of high-speed tensile test data. It specifies a method to determine the spectrum of the natural oscillation frequencies of the force transducer and grip configuration of the high-speed tensile test equipment.

The lowest significant frequency is used for the validation. This validation procedure only applies to force measurement systems used in high-speed tensile testing machines showing a level of resonance influence that could be critical to the obtained result. Once the relevant frequencies of the system and the anticipated strain for the given material are known, this method allows to calculate the theoretical maximum allowed test speed too.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

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

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

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

### 3.1

#### **unloaded region**

time domain prior to the application of the load by the striker

Note 1 to entry: See [Figure 1](#).

### 3.2

#### **striking peak**

first force peak generated by the striker hitting the grip

Note 1 to entry: See [Figure 1](#).

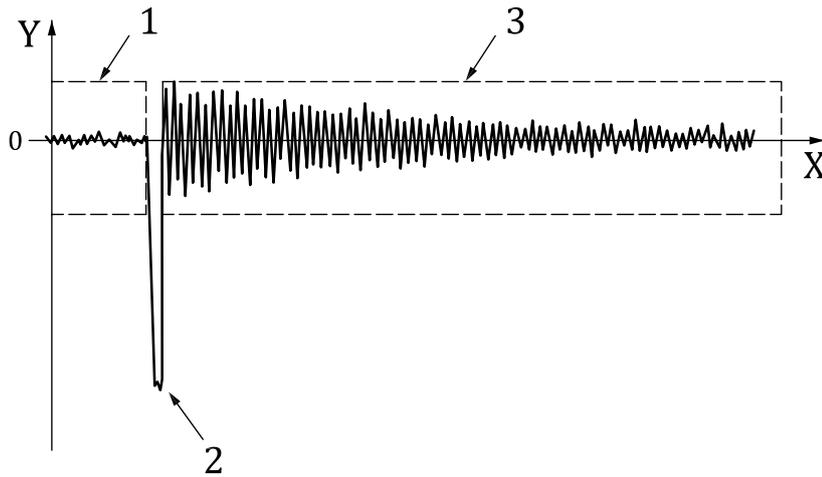
### 3.3

#### **residual oscillations region**

oscillations triggered by the striker

Note 1 to entry: It represents the force on the time domain after the strike of the striker.

Note 2 to entry: See [Figure 1](#).



**Key**

- X time (ms)
- Y force (N)
- 1 unloaded region
- 2 striking peak
- 3 residual oscillations region

**Figure 1 — Typical force-time signal during the impact test**

**3.4 maximum force within the residual oscillations**

$F_{r,max}$

maximum force – intended as absolute value – present in the residual oscillations, excluding the striking peak

Note 1 to entry: It is expressed in Newtons (N).

**3.5 maximum force in the unloaded state**

$F_{u,max}$

maximum absolute force value in the unloaded region

Note 1 to entry: It is expressed in Newtons (N).

**3.6 natural oscillation spectrum**

frequency spectrum obtained as a result of a Fast Fourier Transform Analysis of the residual oscillations region, normalized to the largest amplitude present

**3.7 frequency**

$f$

frequency of a relevant peak in the natural frequency spectrum

Note 1 to entry: It is expressed in kilohertz (kHz).

**3.8 normalized intensity of the frequency**

$I$

normalized intensity of frequency peak in the natural oscillation spectrum

### 3.9 lowest relevant frequency

 $f_{\text{low}}$ 

frequency of the first relevant peak in the natural oscillation spectrum

Note 1 to entry: It is expressed in kilohertz (kHz).

### 3.10 event time

 $t_e$ 

time from the start point of the force-time curve without unloaded region to the point of the relevant event to be measured

Note 1 to entry: The relevant event is either the yield point, or the break point or any other defined point.

Note 2 to entry: It is expressed in milliseconds (ms).

### 3.11 threshold number of waves in the event

 $w_{N,\text{th}}$ 

minimum number of waves of the relevant lowest frequency within the event time

### 3.12 gripping distance

 $L$ 

initial length of the part of the specimen between the grips

Note 1 to entry: It is expressed in millimetres (mm).

Note 2 to entry: See [Annex A](#).

### 3.13 grip displacement

 $\Delta L$ 

displacement of the grip pulled to tensile direction of specimens from the beginning of the test

Note 1 to entry: It is expressed in millimetres (mm).

Note 2 to entry: Most of the loading mechanics of the high-speed tensile test device have the one side pulled and the other end fixed, as shown in [Annex A](#).

### 3.14 nominal strain

 $\varepsilon_t$ 

grip displacement divided by the initial gripping distance

Note 1 to entry: It is expressed as a dimensionless ratio, or as a percentage (%).

### 3.15 nominal test speed

 $v$ 

rate of separation of the gripping jaws

Note 1 to entry: It is expressed in metres per second (m/s).

### 3.16 maximum force

 $F_{\text{max}}$ 

maximum force observed in the whole force-time curve during the high-speed tensile test

Note 1 to entry: See [Figure 2](#).

Note 2 to entry: It is expressed in Newtons (N).

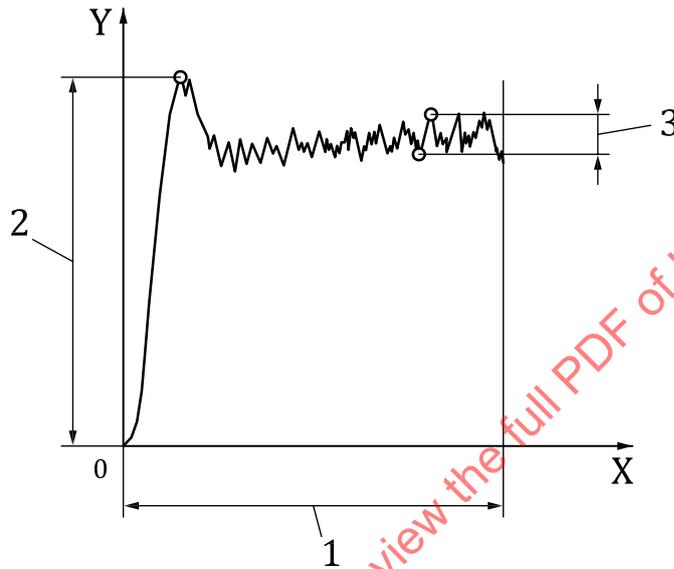
**3.17 maximum amplitude of oscillations**

$$\Delta F_{a,max}$$

largest peak-to-peak amplitude of oscillations, observed over a small portion of the curve during the high-speed tensile test, ignoring single spikes of electronic noise

Note 1 to entry: See [Figure 2](#).

Note 2 to entry: It is expressed in Newtons (N).



**Key**

- X time (ms)
- Y force (N)
- 1  $t_e$  event time (ms)
- 2  $F_{max}$  maximum force (N)
- 3  $\Delta F_{a,max}$  maximum amplitude of oscillations (N)

**Figure 2 – Typical force-time curve during tensile test at high speed**

**4 Principle**

The principle of this document is based on the following two acceptance criteria:

- 1) The measurement of the natural oscillations of grip and force transducer configuration (see [6.1](#))

The natural oscillation frequencies of the force transducer and grip arrangement in the testing instrument are measured after a defined impact. These frequencies are analysed by means of a Fast Fourier Transform (FFT) and presented by their intensity over the relevant frequency range. The highest intensity observed is used to calculate a normalized intensity. The lowest frequency of a relevant normalized intensity will be used to establish the validation criterion.

- 2) The maximum allowed intensity (see [6.2](#))

The intensity of oscillations superimposed on the force – time curve is calculated by the ratio between the oscillation amplitude and the maximum force observed during the test.

## 5 Measurement of the natural oscillation spectrum of the grip and force transducer configuration

### 5.1 Measurement of natural oscillation frequencies

#### 5.1.1 Set-up of the high-speed tensile equipment

The force transducer and the grip shall be well tightened and installed according to the equipment manufacturer's advice. If the jaw faces of the grips cannot be tightened without clamping a test specimen, as it may be the case when using wedge-type grips, use a small part of a rigid test specimen to ensure the jaw faces to be in a fixed and tightened situation.

#### 5.1.2 Set-up of the striker

Use the striker capable of creating a defined single centric impact to the grip in the direction of the machine axis. It is recommended to use a tool that allows variation of the impact intensity and to adjust the striking position.

NOTE 1 A typical device of the striker and its striking position is shown in [Annex B](#).

The mass and the impact speed of the striker shall be such to ensure that the maximum force within the residual oscillations  $F_{r,max}$  is higher than 10 % of the full-scale value of the selected force measurement range and greater than 200 N.

NOTE 2 Preliminary tests to achieve these conditions are detailed in [5.1.3](#).

The impact force shall not exceed the capacity of the force transducer.

The direction of stroke shall coincide with the machine axis and be centric to it to within  $\pm 5$  mm.

If it is not possible to create a centric impact due to the design of the grip, perform the impact at the closest possible position providing the least lateral oscillations and report the striking position with the results.

NOTE 3 Influence of the striking position on the natural oscillation spectrum is shown in [Annex C](#).

#### 5.1.3 Measurement procedure

Carry out preliminary impacts to adjust the impact speed of the striker in a way to ensure that the maximum force within the residual oscillations  $F_{r,max}$  :

- is higher than 10 % of the full-scale value of the selected force measurement range;
- is at least 200 N;
- is at least 3 times higher than the maximum force in the unloaded state  $F_{u,max}$ .

Adjust the zero-point of the force measurement system.

Adjust the sampling rate in such way to be at least twice the natural oscillation frequency to be analysed. A minimum sampling rate of 100 kHz is recommended.

Select the suitable range of the amplifier.

Measure the force resulting from the natural frequency oscillation over a time between 5 ms and 12 ms, in order to have enough measurement points for the FFT evaluation.

Perform three measurement strikes in accordance with the defined conditions and record the force-time data in the unloaded state and after the impact for each impact.

Note the amplifier range, the cut-off frequency and the data acquisition frequency being used.

Determine  $F_{r,max}$  and  $F_{u,max}$ , and ensure that the required relationship is achieved.

**5.2 Determination of the natural oscillation spectrum**

Use FFT to acquire the amplitude spectrum from the force-time curve acquired from the impact test.

Determine the length of the time-window to be used in the calculations of FFT.

In the case of acquiring the amplitude spectrum, data from 1,5 cycles after the force peak during impact test shall be used.

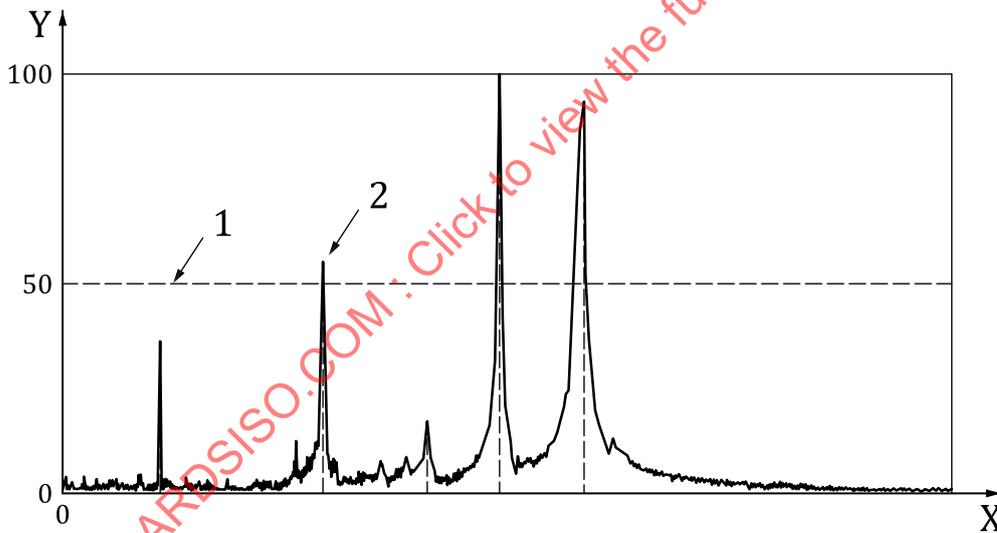
Select the appropriate window function and record the window function used.

Compare the frequency spectra obtained from the three measurements and check if the peaks occur at about the same frequencies and with similar intensities. If not, check for any loose parts and for the correct introduction of the impact strike and repeat the measurement.

The natural oscillation spectrum shall be plotted as the normalized intensity of the amplitude spectrum as a function of the frequency (see [Figure 3](#)). The spectrum to be reported is an average value, obtained from the spectrum results of each impact test.

Select the lowest frequency in the natural oscillation spectrum showing a normalized intensity of 50 % or more. This is the lowest relevant frequency  $f_{low}$  which is to be used for the validation (see [Figure 3](#)).

NOTE [Annex B](#) indicates example of measurements of the natural oscillation spectrum of a testing machine.



- Key**
- X frequency (kHz)
  - Y normalized intensity (%)
  - 1 normalized intensity of 50 %
  - 2 lowest relevant frequency ( $f_{low}$ ), expressed in kilohertz (kHz)

**Figure 3 — Typical natural oscillation spectrum of the impact test**

## 6 Validation

### 6.1 Minimum event time

It is considered, that a resonant force measurement system of a known lowest relevant natural frequency,  $f_{low}$ , can only produce sufficiently reliable force measurement data, if the number of oscillation waves occurring during the event of measurement is high enough.

The threshold number of waves up to the relevant event to be measured,  $w_{N,th}$  is defined to be 9.

NOTE 1 This value has been evaluated through an interlaboratory test performed by experts in ISO TC 61/SC 2 at the time of the preparation of the document. Ten laboratories have been involved, testing 4 materials at 3 different test speeds.

Validate the measured force-time curve by the time elapsed up to the relevant event, as shown in [Formula \(1\)](#):

$$t_e \geq \frac{w_{N,th}}{f_{low}} \quad (1)$$

where

$t_e$  is the minimum event time (ms);

$w_{N,th}$  is the threshold number of waves in the event;

$f_{low}$  is the lowest relevant frequency (kHz).

If the event time associated to the relevant point under evaluation in the experimental curve is lower than the minimum event time  $t_e$  calculated from [Formula \(1\)](#), then the result shall be discarded because it is not acceptable. On the contrary, if the event time associated to the relevant point in the experimental curve is equal to or greater than the minimum event time  $t_e$  calculated from [Formula \(1\)](#), then the result is acceptable.

The maximum allowed nominal test speed  $v$ , leading to a valid test, can be estimated if the nominal strain at the relevant event is known. See [Formula \(2\)](#):

$$v \leq \frac{f_{low} \cdot L}{w_{N,th}} \varepsilon_t \quad (2)$$

where

$v$  is the nominal test speed (m/s);

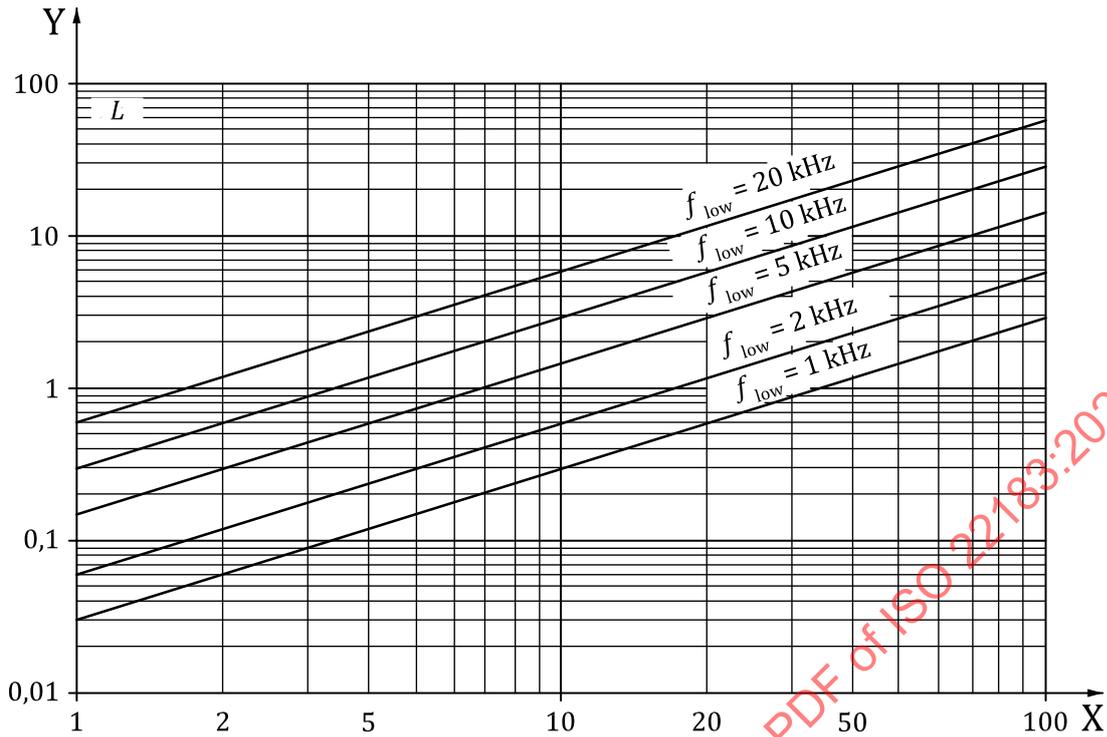
$L$  is the gripping distance (mm);

$f_{low}$  is the lowest relevant frequency (kHz);

$\varepsilon_t$  is the nominal strain at the relevant event expressed as a dimensionless ratio;

$w_{N,th}$  is the threshold number of waves in the event.

NOTE 2 For the relation between the nominal test speed and the nominal strain, see [Annex D](#).



**Key**

X	nominal strain ( $\epsilon_t$ ) at the relevant event, expressed as a dimensionless ratio (%)
Y	nominal test speed ( $v$ ), expressed in metres per second (m/s)
$f_{low}$	lowest relevant frequency (kHz)
L	gripping distance (mm)

**Figure 4 — Example for graphical evaluation of the allowed maximum nominal test speed for different lowest relevant frequency,  $f_{low}$**

A graphical determination of the allowed maximum nominal test speed is shown in [Figure 4](#) for a type 3 specimen, according to ISO 8256, using gripping distance of  $L = 30$  mm. The lines indicate the maximum nominal test speed for different examples of lowest relevant natural frequencies over a range of expected nominal strain at the relevant point to be measured.

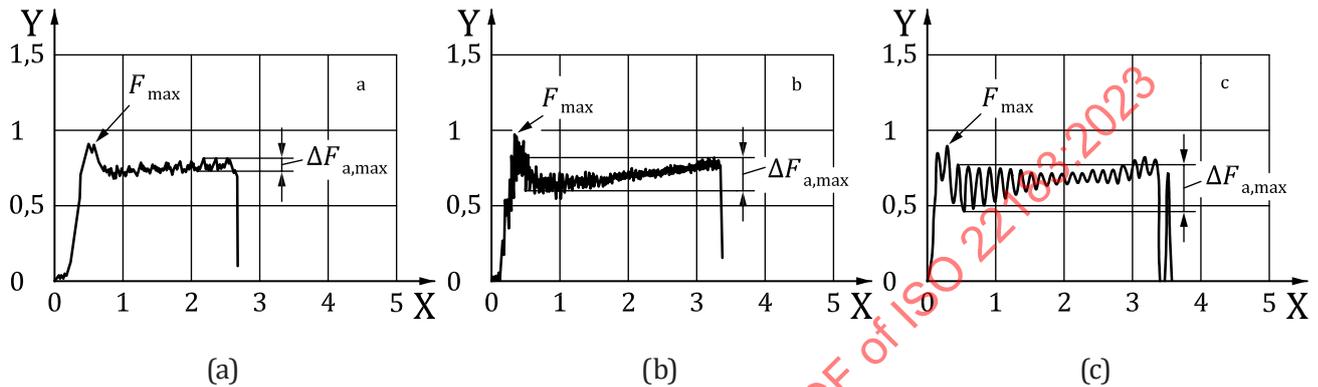
### 6.2 Maximum allowed intensity

The intensity of oscillations which are superposing the actual tensile material test force-time curves forms the second validation criterion. In the relevant range of the force time curve, the amplitude of such oscillations shall not exceed 0,25 of the maximum force, i.e. the maximum allowed intensity using [Formula \(3\)](#), (see [Figure 5](#)). If the maximum intensity ratio calculated from [Formula \(3\)](#) is greater than 0,25 then the result shall be discarded because it is not acceptable (see an example in [Figure 5](#)). On the contrary, if maximum intensity ratio is equal to or lower than 0,25, then the result is acceptable (see an example in [Figure 5](#)).

$$\frac{\Delta F_{a,max}}{F_{max}} \leq 0,25 \tag{3}$$

where

- $F_{\max}$  is the maximum force in the event (N);
- $\Delta F_{a,\max}$  is the maximum amplitude of oscillations in the event (N);
- $\Delta F_{a,\max} / F_{\max}$  is the maximum intensity expressed as a dimensionless ratio.



#### Key

X time (ms)

Y force (N)

$F_{\max}$  maximum force (N)

$\Delta F_{a,\max}$  maximum amplitude of oscillations (N)

a  $\Delta F_{a,\max} / F_{\max} = 0,10 \leq 0,25$  Acceptable

b  $\Delta F_{a,\max} / F_{\max} = 0,23 \leq 0,25$  Acceptable

c  $\Delta F_{a,\max} / F_{\max} = 0,32 > 0,25$  Not acceptable

**Figure 5 — Examples of acceptable and not acceptable oscillation intensity for a given tensile test at high speed**

## 7 Test report

The test report shall include the following information.

### 7.1 Test report for the determination of the relevant natural frequency by FFT analysis:

- a reference to this document, i.e. ISO 22183:2023;
- the type of testing machine used and its identification, including the description of the type of grips used (wedge, screw, etc.);
- the designation, capacity and the type of the force transducer and the mass of the grip connected to it;
- the selected full-scale value of range of the force measurement system;
- the characteristics of force signal filtering, if applied;
- the designation of the striker;

- g) the readings for  $F_{r,max}$  and  $F_{u,max}$ ;
- h) the sampling rate used of the force transducer. Report any deviation from the suggested value of 100 kHz;
- i) the number of data points used for the FFT analysis (512, 1024, 2048 or 4096 points);
- j) a graph showing the measured spectrum of the natural oscillations;
- k) the lowest relevant natural frequency,  $f_{low}$ .

**7.2** Test and validation report for the high-speed tensile test:

- a) a reference to this document, i.e. ISO 22183:2023;
- b) the type of testing machine used and its identification;
- c) the capacity of the force transducer and the type, designation and mass of the connected grip;
- d) the selected full-scale value of range of the force measurement system;
- e) the characteristics of force signal filtering, if applied;
- f) the material being tested;
- g) the specimen shape or type and dimensions;
- h) the nominal speed;
- i) the conditioning applied to the specimen;
- j) any unusual observation;
- k) the date of test;
- l) the results and force-time curves;
- m) the result of the validation.

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## Annex A (informative)

### Configuration of the high-speed testing machine

#### A.1 General

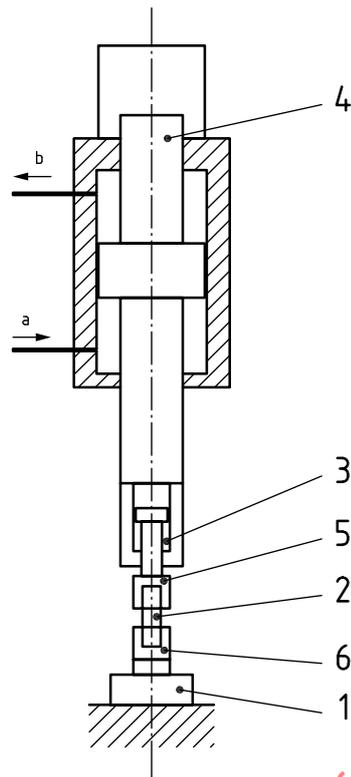
Different types of machines are available to perform high-speed tensile tests. Servo-hydraulic high-speed testing machines are most widely used in such applications as they provide a broad speed range from near-to-static up to high strain rates. Typically ranging from 0,001 m/s up to 20 m/s, covering the whole range of test speeds required by the method.

Instrumented drop weight and pendulum impact machines, as well as rotational equipment can be used to perform high speeds testing only. Typically, these types of machines cover a range of impact speeds from about 1 m/s up to 10 m/s, in some cases up to 20 m/s.

Electro-dynamic machines are also available and may be used in a certain range of test speeds.

Schematic views of a load system for a typical hydraulic testing machine and a drop-weight system are shown in [Figure A.1](#) and [Figure A.2](#), respectively.

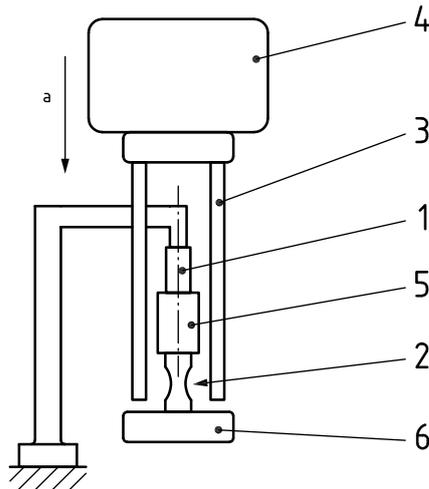
A highly rigid and heavy machine frame ensures that no relevant oscillations interfere into the quality of the measurement. It is recommended to use a mechanism able to minimize the initial acceleration time required to bring the specimen from zero to the nominal test speed. Servo-hydraulic systems are usually equipped with a lost motion bar (see [Figure A.1](#)) that allows the piston to accelerate up to the test speed before impacting the specimen. In a drop-weight system this behaviour is guaranteed by the drop height the falling mass – given by the striker and any additional mass – travels before impacting the specimen.



**Key**

- 1 force transducer
- 2 test specimen
- 3 lost motion bar
- 4 piston
- 5 upper grip, pulled
- 6 lower grip, fixed
- a Oil in.
- b Oil out.

**Figure A.1 — Schematic view of load system for the hydraulic testing machine**

**Key**

- 1 force transducer
- 2 test specimen
- 3 striker
- 4 impact additional mass
- 5 upper grip fixed
- 6 lower grips (crosshead) pulled
- a Drop direction.

**Figure A.2 — Schematic view of load system for the drop weight system**

## A.2 Test speeds

The testing machine is designed to operate at the nominal test speed.

Servo-hydraulic systems allow to accelerate the piston at the nominal test speed by means of a lost motion bar connected to one of the grip, typically the upper grip to be pulled. The test specimen is then elongated along its major longitudinal axis at an almost constant test speed until it fractures. Servo-hydraulic systems are typically capable to keep the speed constant during the whole tensile test thanks to the open/closed loop actuator control.

Drop-weight systems on the contrary use an impact mass released from an imposed height to reach the nominal test speed. Once the specimen is impacted the speed can vary depending on the energy absorbed. To avoid results which cannot be compared, the decrease of the speed during the test with a drop-weight system shall not be greater than 20 % (see ISO 6603-2).

## A.3 Grips

In order to increase the natural oscillation spectrum frequency, a lightweight and highly rigid grip might be used.

The system shall generally be stiff enough in both axial and lateral direction, to reduce undesired resonance effects in the acquired data. The initial distance between the lower and upper grip defines the gripping distance.

#### A.4 Force transducer

The measurement system shall be able to record forces with an accuracy equal to or within  $\pm 2\%$  of the maximum force occurred during the test. Calibration of the force measurement system may be performed statically (for example, by imposing known loads on the force transducer) or dynamically, see ISO 7500-1.

In order to increase the natural oscillation spectrum frequency, a highly rigid force transducer should be used.

The force transducer should be mounted on the fixed side and not on the accelerated side to avoid inertial forces during acceleration.

#### A.5 Recording of data

The data acquisition frequency needed for the recording of force signal should be higher than 100 kHz.

For the bandwidth of the amplifier train (direct current or carrier frequency amplifier) the lower bandwidth limit is 0 Hz, and the upper bandwidth limit shall be at least 100 kHz, combined with a sampling frequency of at least 100 kHz.

It is a common practice, in the testing of very brittle materials, to carry out low-pass filtering on the recorded force-time diagram or parts of it, although the accuracy of the measurements is thereby reduced. If post-test filtering is used, the type of filter and its essential characteristics are reported in the test report (see [Clause 7](#)).

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## Annex B (informative)

### Example for the measurement of natural oscillation frequencies

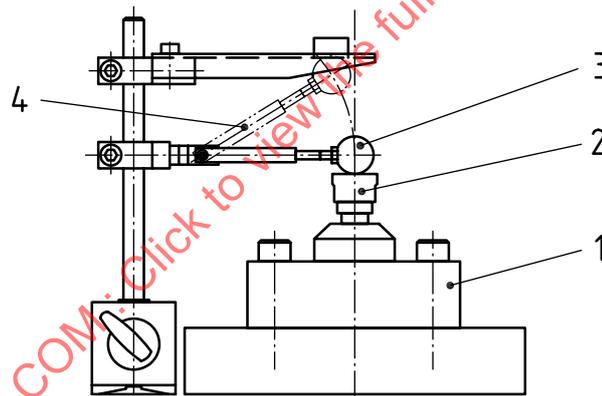
#### B.1 Impact test

The measurements were made using a high-speed tensile testing machine with a mechanism with the fixed side at the bottom and the movable side at the top. The strain gauged force transducer was well fixed on the testing machine. A wedge type grip was used. The grip was secured after gripping a bit of the test specimen to ensure no looseness. Adjustments were made so that a bit of the test specimen did not protrude out from the gripping jaws.

As shown in [Figure B.1](#), the centre of the top end-face of the grip was struck from above using a striker which had a mechanism for performing strikes with good repeatability.

The force-time curve was acquired after adjusting the drop height accordingly.

The measurements were performed three times.



#### Key

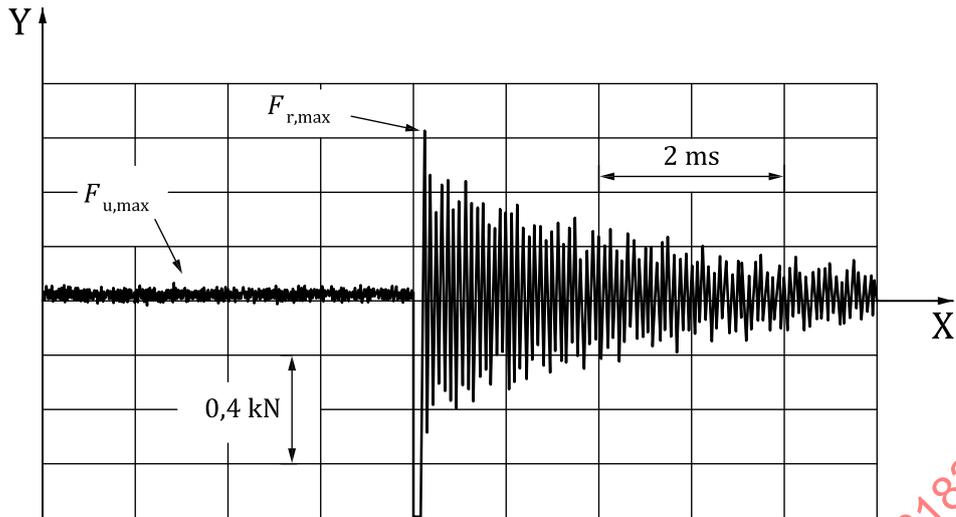
- 1 force transducer
- 2 grip
- 3 striker
- 4 arm

Figure B.1 — Schematics of example of a striker

#### B.2 Results

##### B.2.1 Force-time signals

A representative example of a force-time curve before and after impact test is shown in [Figure B.2](#). The values of  $F_{u,max}$  and  $F_{r,max}$  on each measurement in three tests are given in [Table B.1](#), according to procedure given in [5.1](#).



**Key**

X time ( ms )

Y force (N)

$F_{u,max}$  maximum absolute force value in the unloaded region (N)

$F_{r,max}$  maximum force within the residual oscillations (N)

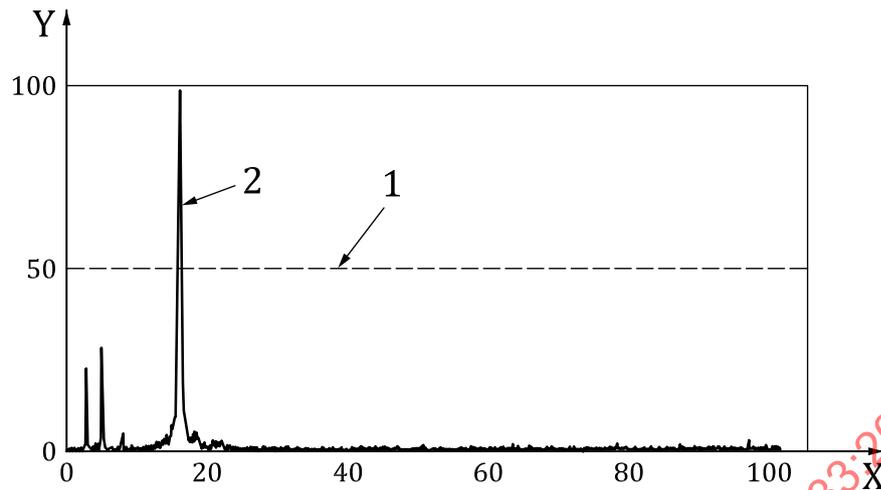
**Figure B.2 — Force-time signal before and after impact test**

**Table B.1 — Measurement results of  $F_{u,max}$  and  $F_{r,max}$**

Number of measurements	$F_{u,max}$ (kN)	$F_{r,max}$ (kN)
1st	0,08	0,61
2nd	0,08	0,57
3rd	0,09	0,50

**B.2.2 Determination of the lowest relevant frequency,  $f_{low}$**

The validation frequency of  $f_{low}$  is determined as shown in [Table B.3](#) after the selection of the lowest frequency in the natural oscillation spectrum showing a normalized intensity of 50 % or more.

**Key**

X frequency (kHz)

Y normalized intensity (%)

1 normalized intensity of 50 %

2 lowest relevant frequency ( $f_{low}$ ), expressed in kilohertz (kHz)**Figure B.3 — Natural oscillation spectrum measured****Table B.2 — Frequencies of the natural oscillation spectrum,  $f$  and their normalized intensity,  $I$** 

$f$ (kHz)	$I$ (%)
2,9	23
5,0	29
16,1	100

**Table B.3 — Lowest relevant frequency,  $f_{low}$** 

$f_{low}$ (kHz)	16,1
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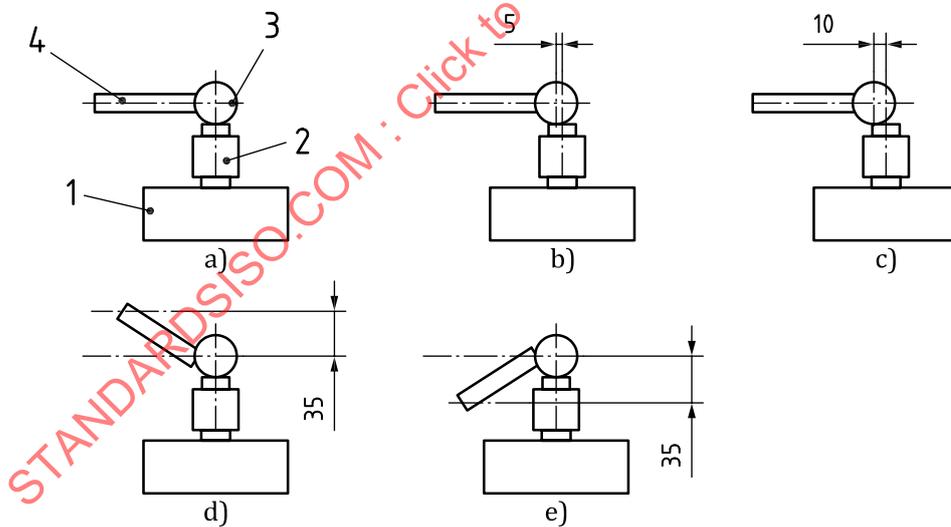
## Annex C (informative)

### Influence of a set position on the natural oscillation spectrum

#### C.1 Set position of striker

Influence of the impact position on the measurement results were examined from the correct position up to several misalignments, like different hitting axis and different horizontal positions of the arm, as shown in a), b), c), d) and e) of [Figure C.1](#).

- a) The striking position is the centre of the tip of the gripping jaws. The drop height is with the arm in a horizontal position when the strike is made.
- b) The drop height is with the arm in a horizontal position when the strike is made and the striking position is out of 5 mm to the side from the centre of the tip of the gripping jaws.
- c) The drop height is with the arm in a horizontal position when the strike is made and the striking position is out of 10 mm to the side from the centre of the tip of the gripping jaws.
- d) The striking position is the centre of the tip of the gripping jaws. The strike was made with the centre of a rotation of arm positioned 35 mm above the horizontal.
- e) The striking position is the centre of the tip of the gripping jaws. The strike was made with the centre of a rotation of arm positioned 35 mm below the horizontal.



**Key**

- 1 force transducer
- 2 grip
- 3 striker
- 4 arm

**Figure C.1 — Set position of striker performed**