CRASHWORTHINESS and Test Strategies for High Strain Rate Testing

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CRASHWORTHINESS and Test Strategies for High Strain Rate Testing

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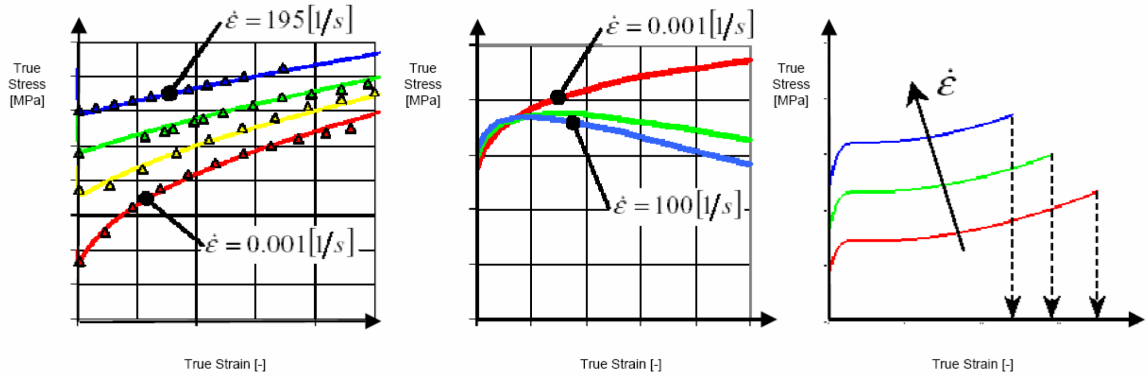
Influence of strain rate on mechanical properties of engineering materials

Steel **Aluminium Alloy** **Plastics**



- Increase in yield stress with increasing strain rates

- Adiabatic heating effects at higher strain rates can cause stress softening

- Increase in yield stress with increasing strain rates.
- Tendency for reduced fracture strain

Strain Rate Effect

Material models

Descriptive

Predictive

- **Johnson-Cook Model**

$$\sigma = (A + B\varepsilon^n)[1 + C\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}](1 - T^{*m})$$

A, B, C, m, n : Material constants

$$T^* = \frac{T - T_{room}}{T_{melt} - T_{room}} \qquad \dot{\varepsilon}_0 = 1/sec$$

- **Cowper-Symonds Model**

$$\sigma = \sigma_0(\varepsilon)[1 + (\frac{\dot{\varepsilon}}{D})^{\frac{1}{p}}]$$

$$\sigma_0(\varepsilon) = k(\varepsilon_{yp} + \bar{\varepsilon})^n$$

σ_0 : Static stress
D, p : Material constants

Simulation

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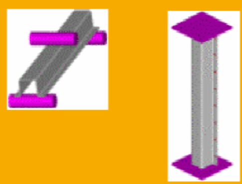
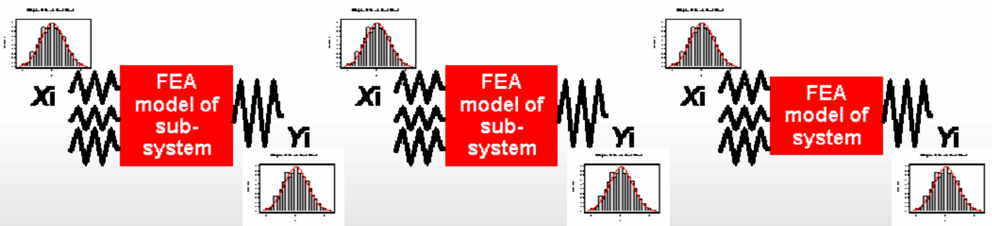
Typical Framework for the Materials Verification Process

Validate material input data to FEA



Validate material data in components & sub-assemblies

Validate material data in full vehicle assembly



Simulation [Wood, Warwick Uni, 2005]

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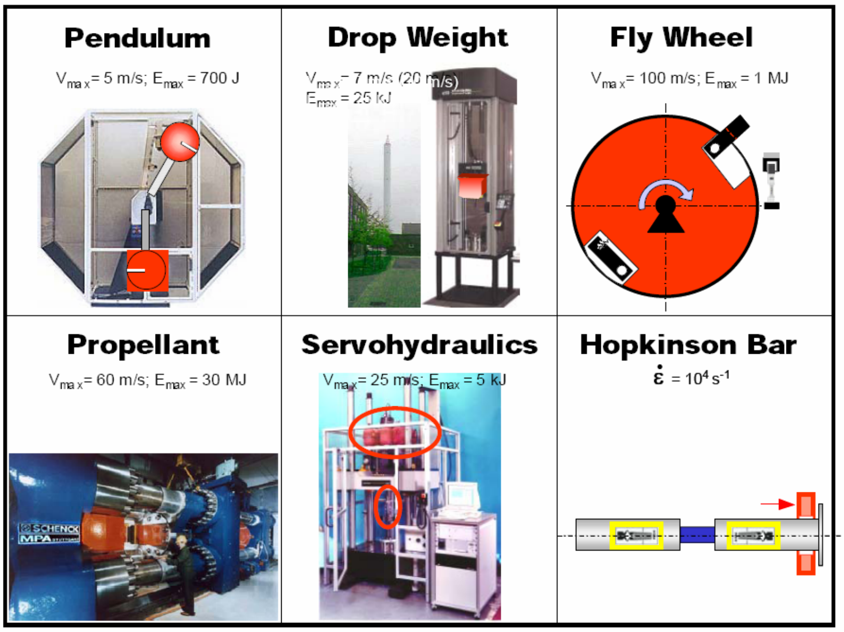
Impact Test Facilities



High Strain Rate Test

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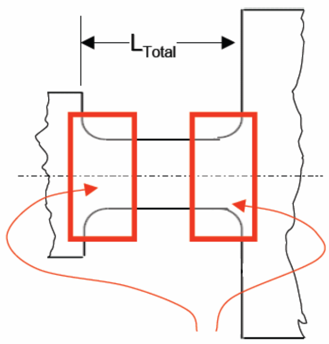
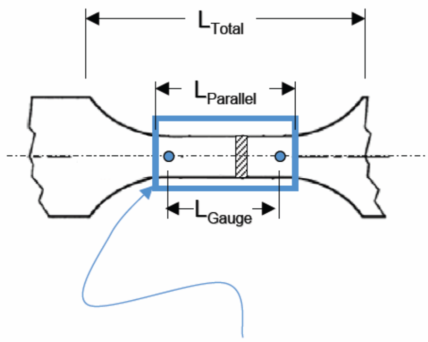
Consequences of specimen geometries



Inhomogeneous stress distributions
Material constraint > 1 !!



Homogeneous stress distributions

Hopkinson Bar, Drop Tower	Servohydraulics

Servohydraulic - Specimen

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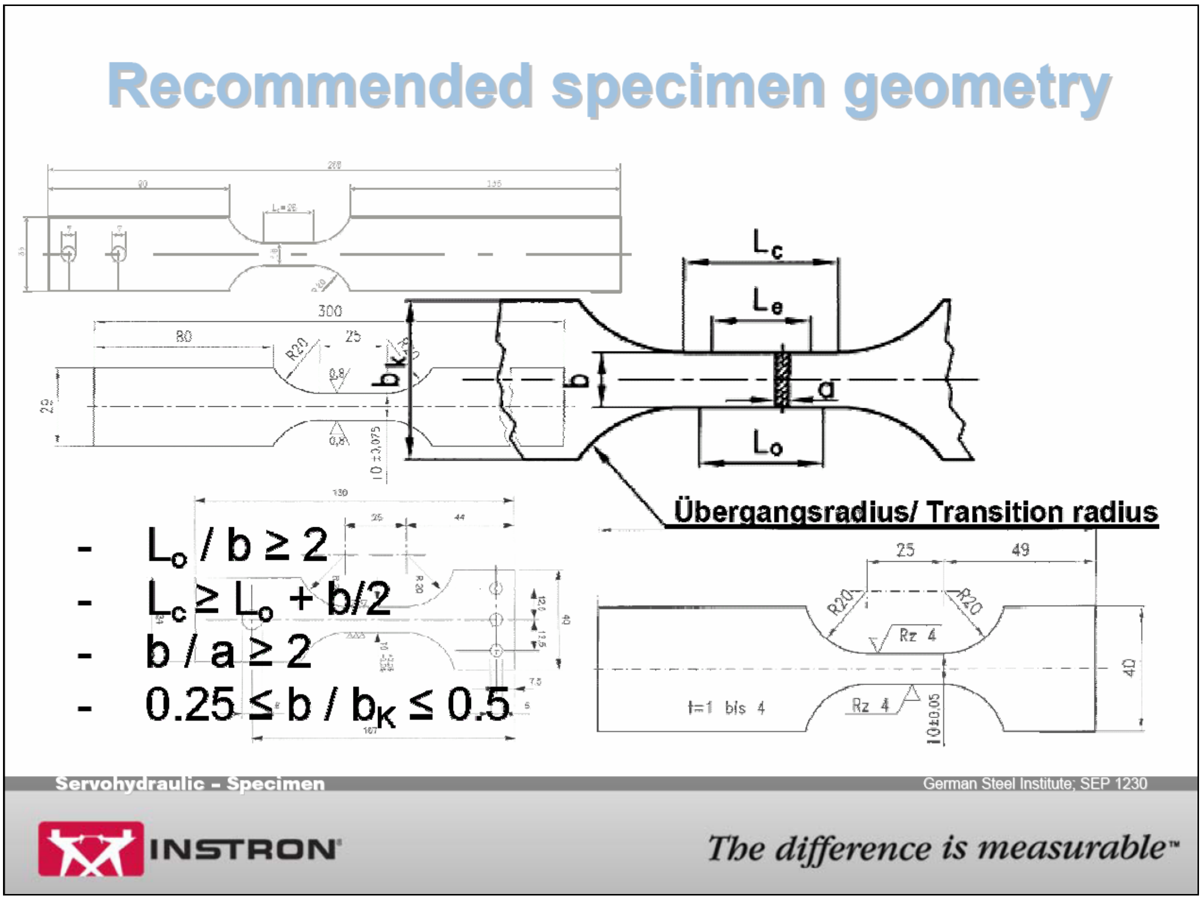
Recommended specimen geometry
Lc
Le
b
a
Lo
bK
300
80
25
R20
Übergangsradius/ Transition radius
- Lo / b ≥ 2
- Lc ≥ Lo + b/2
- b / a ≥ 2
- 0.25 ≤ b / bK ≤ 0.5
25
49
R20
R20
Rz 4
Rz 4
t=1 bis 4
40
10±0,05
Servohydraulic - Specimen
German Steel Institute; SEP 1230
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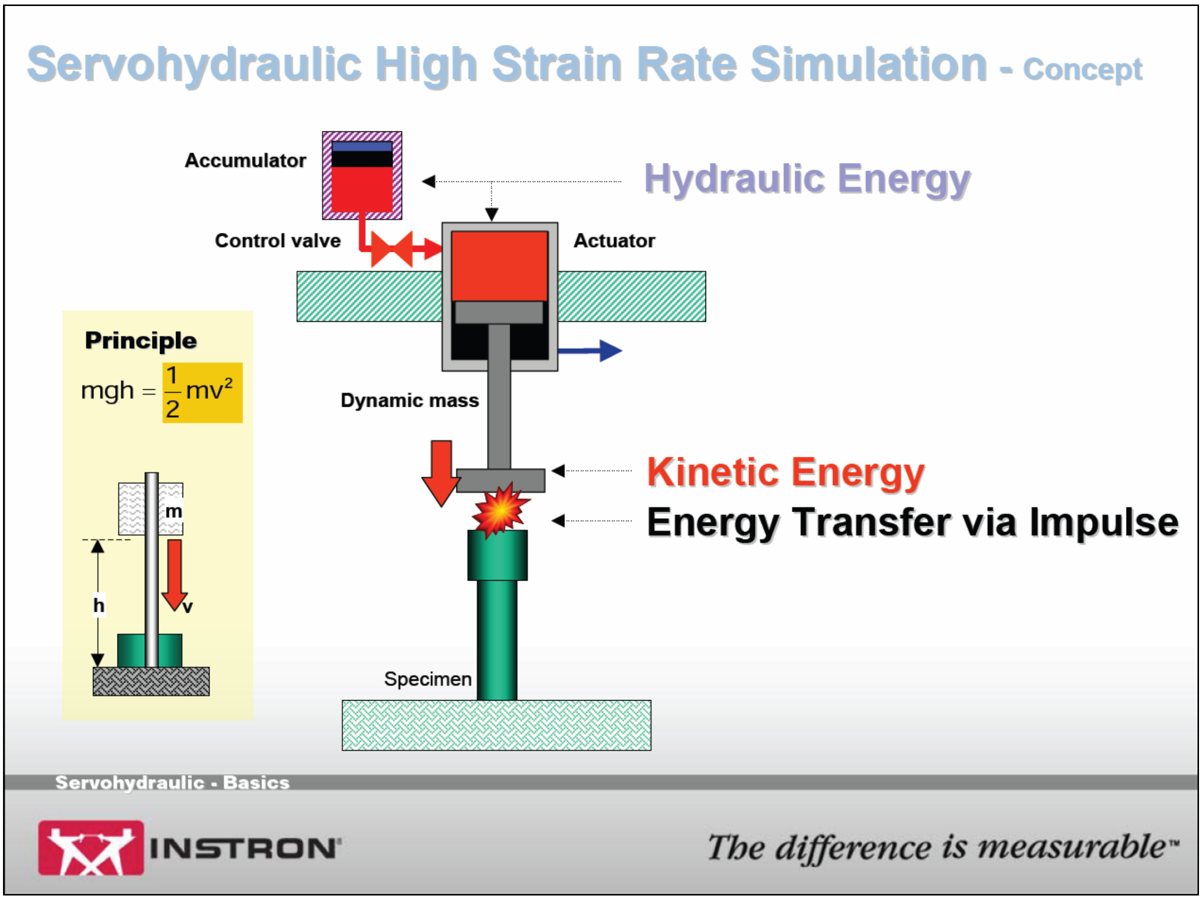
Servohydraulic High Strain Rate Simulation - Concept
Accumulator
Hydraulic Energy
Control valve
Actuator
Principle
mgh = 1/2 mv²
m
h
v
Dynamic mass
Kinetic Energy
Energy Transfer via Impulse
Specimen
Servohydraulic - Basics
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Load Frames

VHS25/25-20
VHS40/50-20
VHS65/80-20/{25}

VHS65/80-20/{25}
VHS160/100-20

Servohydraulic - Loading Unit

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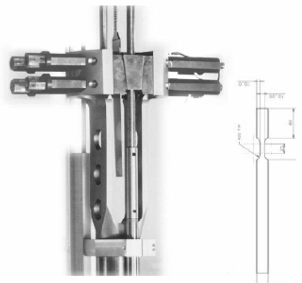
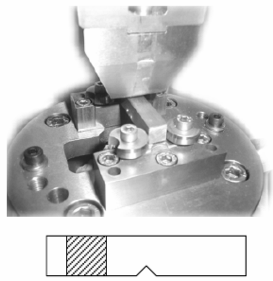
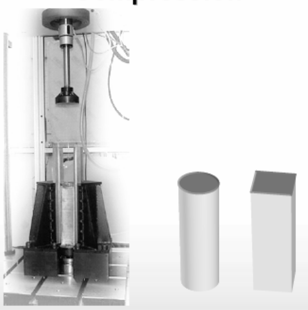
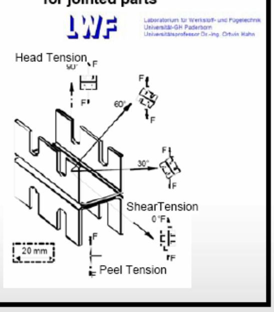
Tension	3 Pt Bending	Puncture
		
Compression	**Shear**	**Mixed Mode Test** for jointed parts
		

Servohydraulic - Test Accessories

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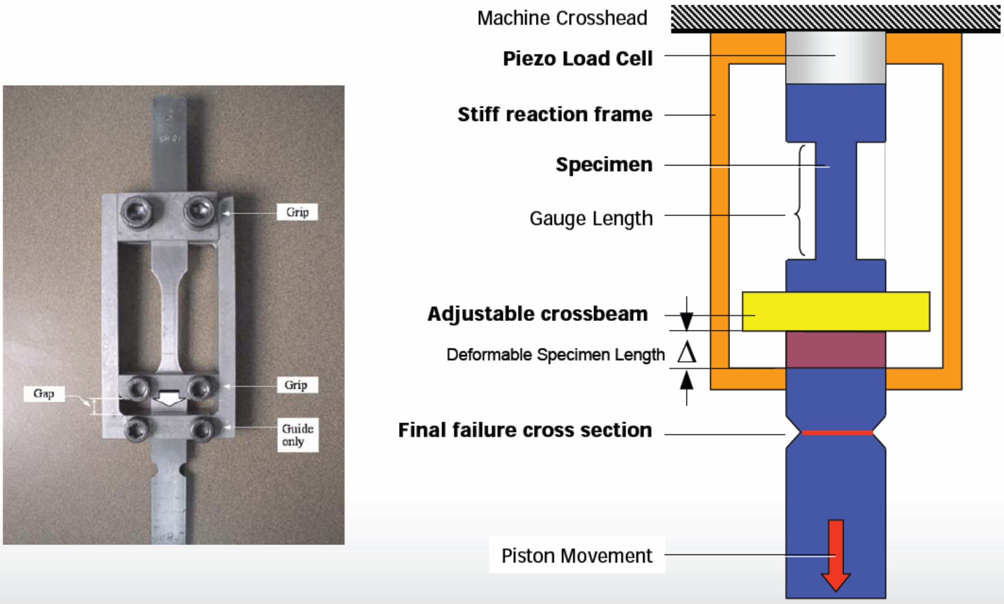
Possible Test Set-up for a blocked High Strain Rate Tension Tests

Influence of impact preloading on mechanical behaviour – residual strength



Servohydraulic – Special Tests [Chai et al., 2002]

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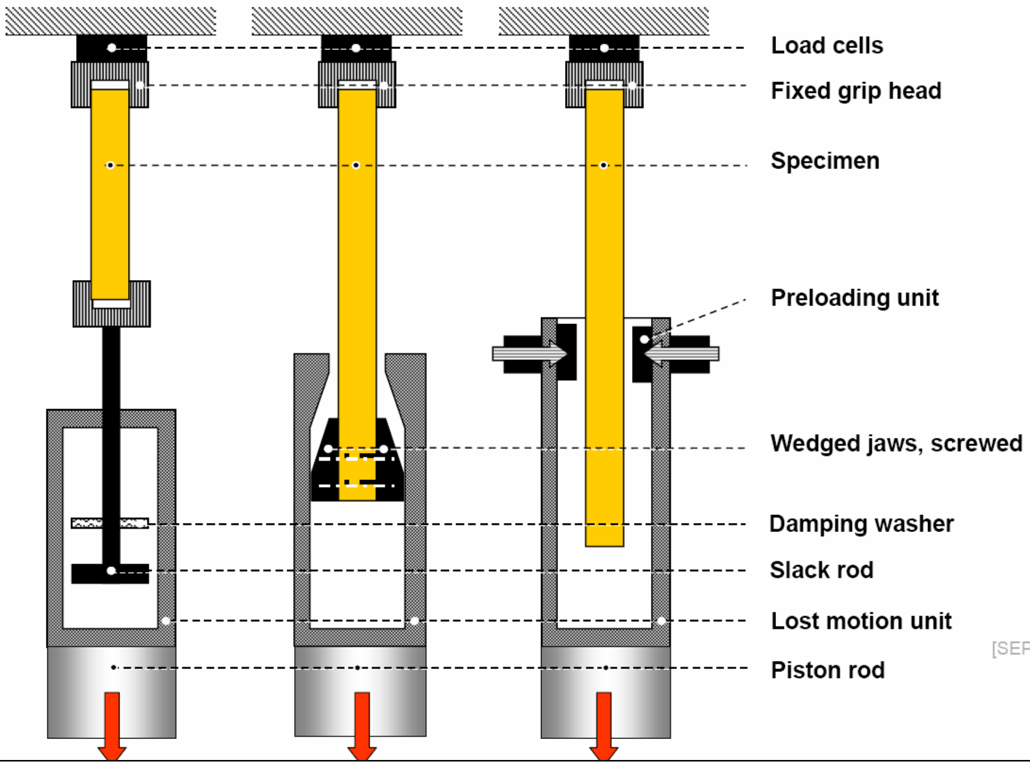
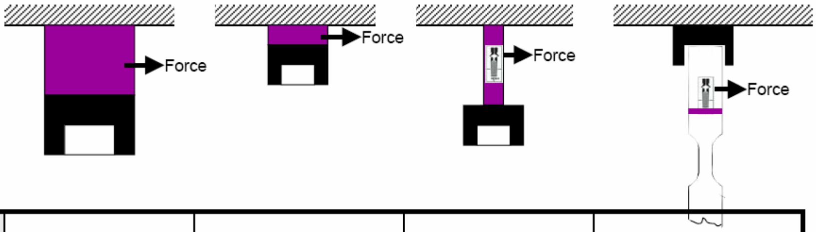
Acceleration and Clamping Methods



[SEP1230, 2006]

Load Measurement Method



Load Measurement Method	Conventional load cell	Piezo-electric load washer	Special compact load measurement element	Instrumented specimen
Upper strain rate limit [s^{-1}]	10^{1}	10^{2}	$5x10^{2}$	10^{3}
Lower strain rate limit [s^{-1}]	None	10^{0}	None	None
Note:	Oscillation of measured load may be large at low strain rate already	Beyond the upper limit major oscillations may be superposed on the mechanical load signal		Strain gauge should be attached at a place that is free from plastic defor-mation during loading

Servohydraulic - Force

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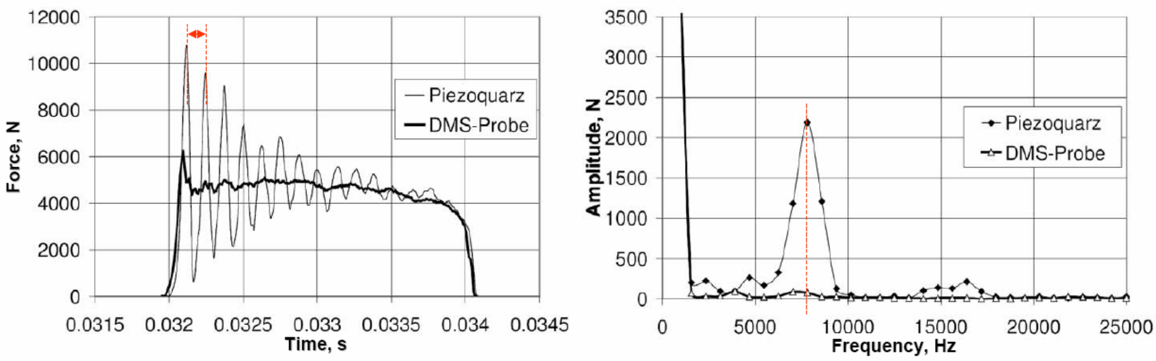
FFT-Analysis of Load Signal



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Servohydraulic - Force

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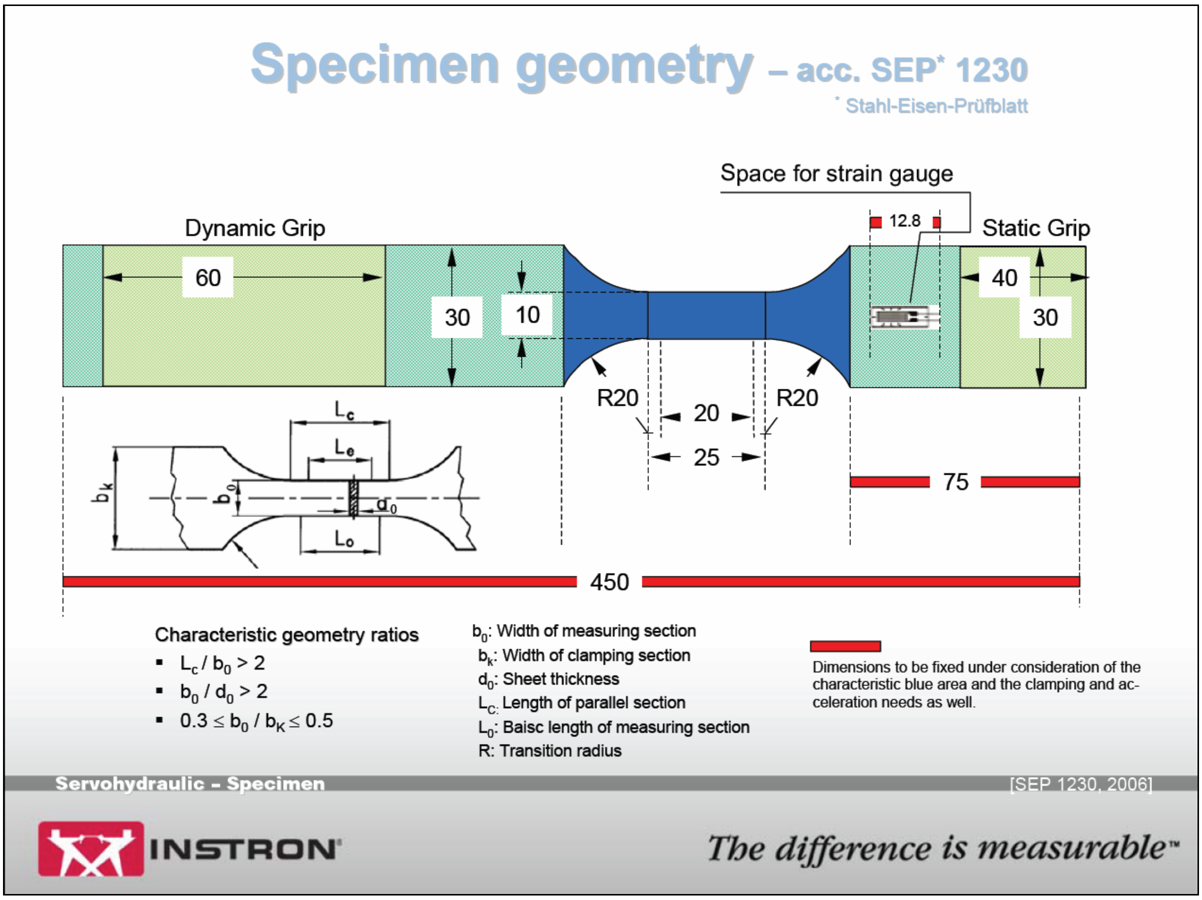
Specimen geometry – acc. SEP* 1230
* Stahl-Eisen-Prüfblatt
Space for strain gauge
Dynamic Grip
Static Grip
12.8
60
30
10
40
30
R20
R20
20
25
75
450
Lc
Le
bk
b0
d0
Lo
Characteristic geometry ratios
Lc / b0 > 2
b0 / d0 > 2
0.3 ≤ b0 / bK ≤ 0.5
b0: Width of measuring section
bk: Width of clamping section
d0: Sheet thickness
Lc: Length of parallel section
L0: Baisc length of measuring section
R: Transition radius
Dimensions to be fixed under consideration of the characteristic blue area and the clamping and acceleration needs as well.
Servohydraulic – Specimen
[SEP 1230, 2006]
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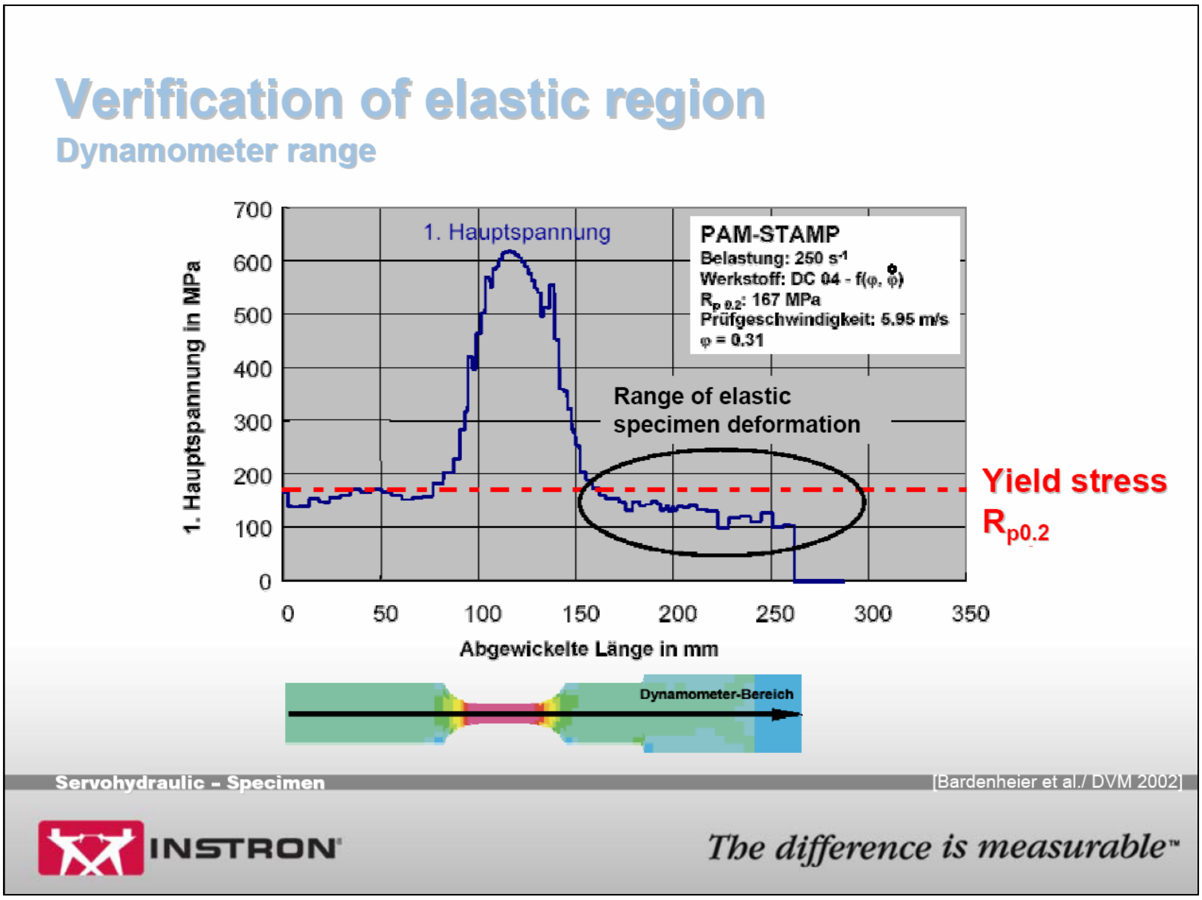
Verification of elastic region
Dynamometer range
1. Hauptspannung
PAM-STAMP
Belastung: 250 s-1
Werkstoff: DC 04 - f(φ, φ̇)
Rp 0.2: 167 MPa
Prüfgeschwindigkeit: 5.95 m/s
φ = 0.31
Range of elastic specimen deformation
Yield stress Rp0.2
1. Hauptspannung in MPa
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
350
Abgewickelte Länge in mm
Dynamometer-Bereich
Servohydraulic – Specimen
[Bardenheier et al./ DVM 2002]
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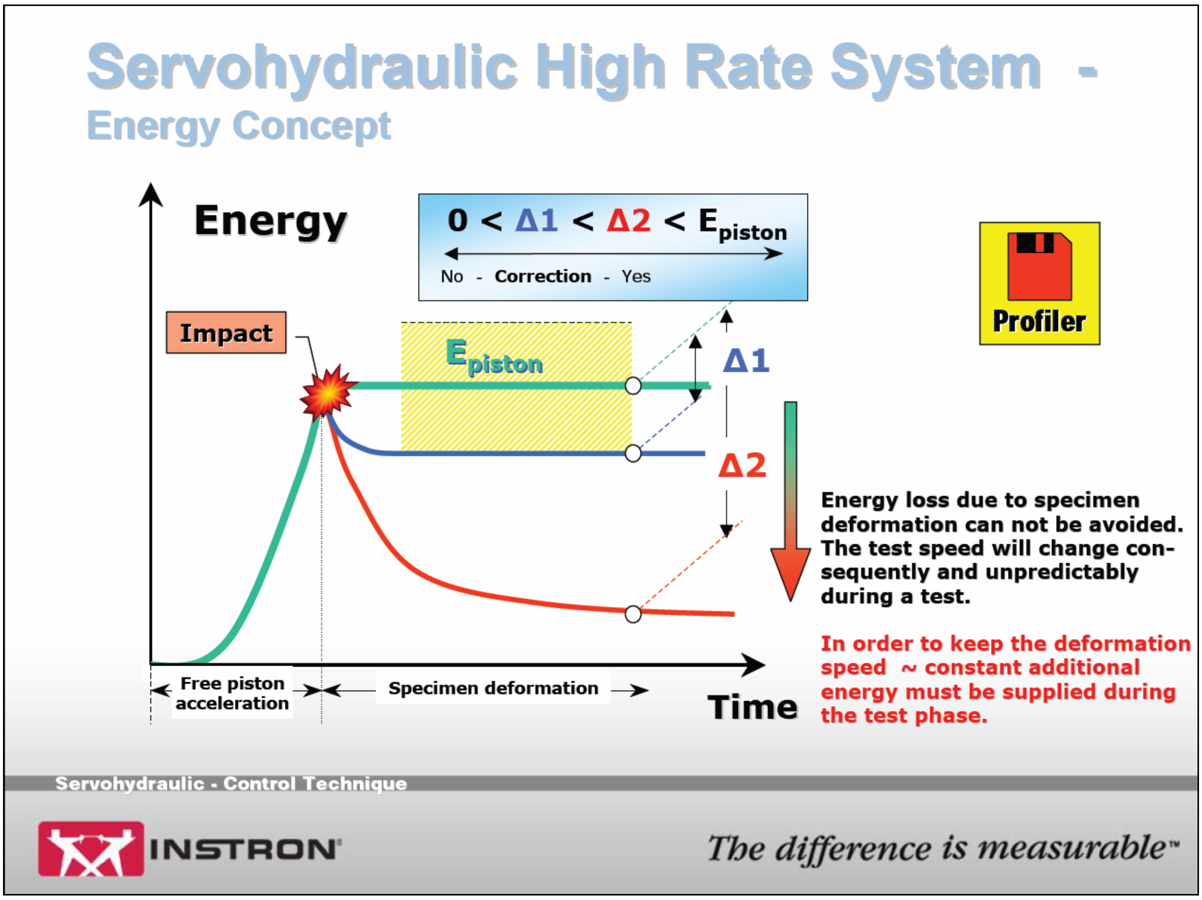
Servohydraulic High Rate System -
Energy Concept
Energy
0 < Δ1 < Δ2 < E piston
No - Correction - Yes
Profiler
Impact
E piston
Δ1
Δ2
Energy loss due to specimen deformation can not be avoided. The test speed will change consequently and unpredictably during a test.
In order to keep the deformation speed ~ constant additional energy must be supplied during the test phase.
Free piston acceleration
Specimen deformation
Time
Servohydraulic - Control Technique
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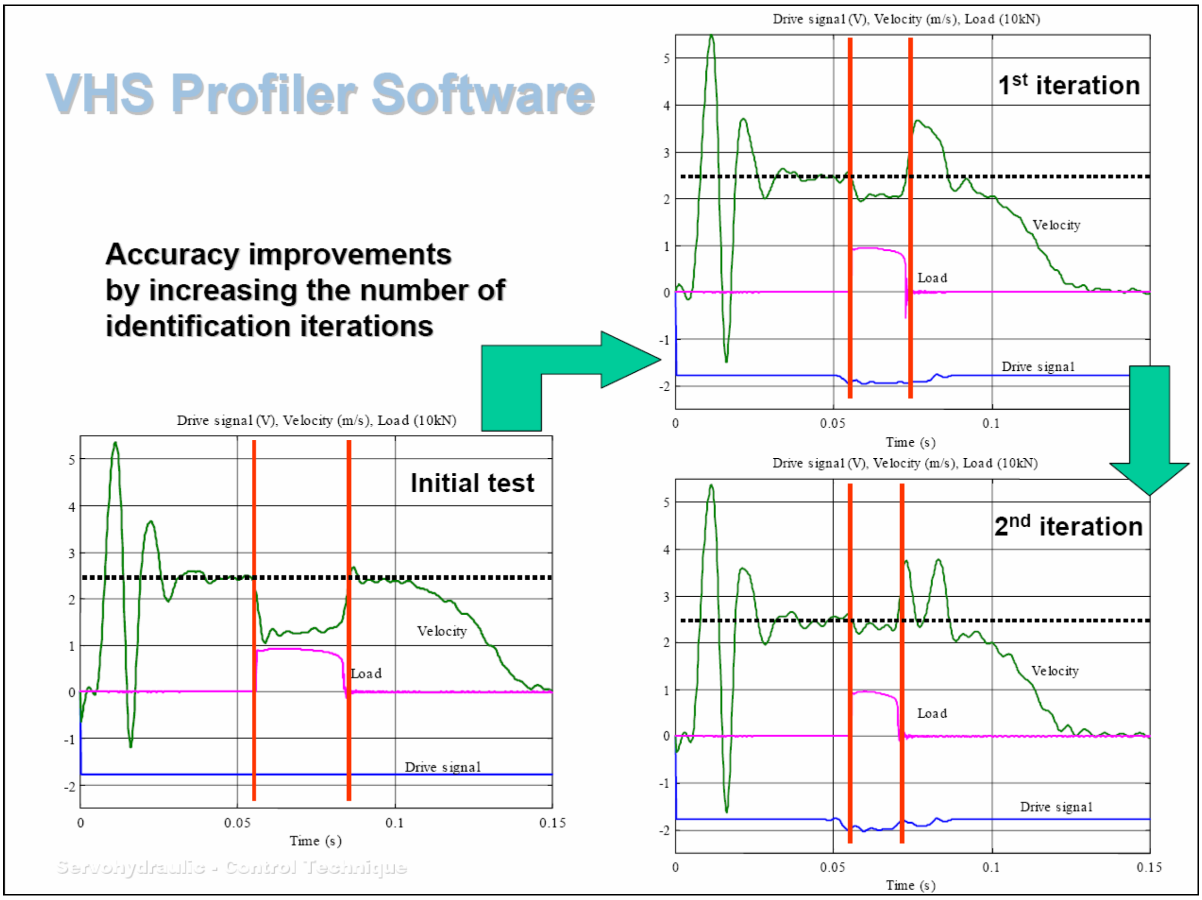
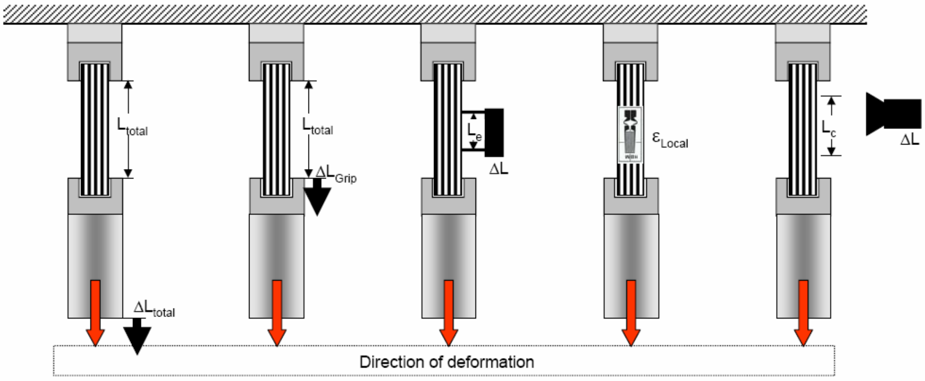

VHS Profiler Software
Accuracy improvements by increasing the number of identification iterations
Initial test
1st iteration
2nd iteration
Drive signal (V), Velocity (m/s), Load (10kN)
Velocity
Load
Drive signal
Time (s)
Servohydraulic - Control Technique

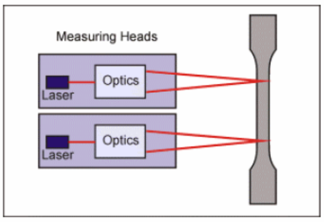
Displacement / Strain Measurements



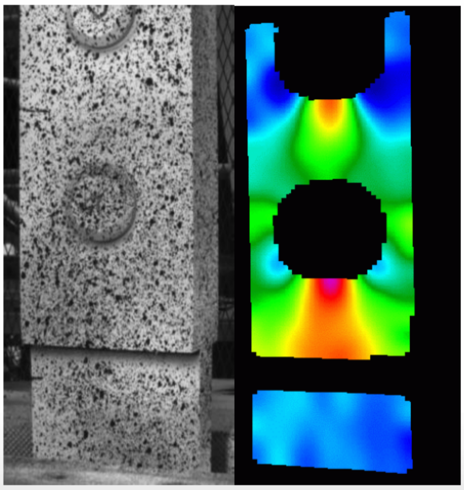
Method	Actuator Piston or Crosshead Movement	Griphead Displacement	Conventional Extensometer	Strain Gauge	Non-contact Extensometer
Displacement / Strain Measurement	Conventional displacement transducer	Laser, Optical device	Clip-on Extensometer	Strain gauges for high strains	Laser-Doppler, High-Speed Camera
Upper strain rate limit $[s^{-1}]$	None	None	10^0	None	None
Note:	Not recommended ! Signal contains machine deformations as well. Poor resolution	Reference gauge length is L_{total}	Due to inertia effects limited to quasi-static deformations only	Strain measure-ments are limited by the max. strain measurable	Lower strain rate limit for Laser-Doppler is ~ 1 s^{-1}; ref. to L_0= 25mm

HR - Extensometry

Integral strain



Local strain



Servohydraulic - Strain Measurement

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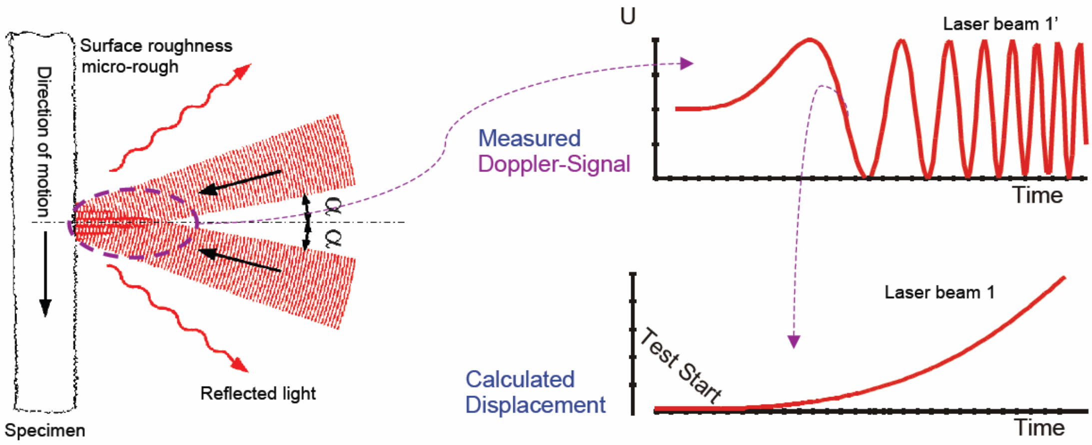
Interference fringe pattern on a moving surface



Servohydraulic - Strain Measurement

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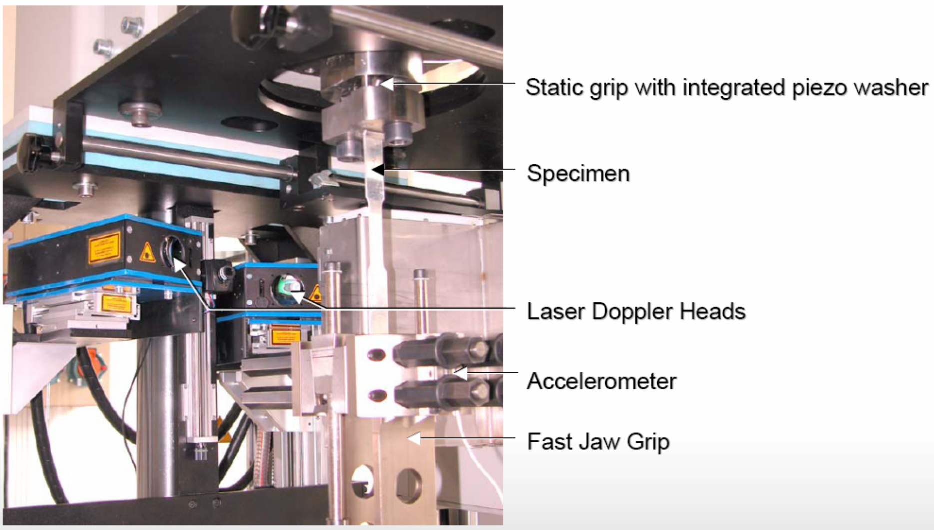
Test Setup with Laser Doppler Extensometer



Servohydraulic - Strain Measurement

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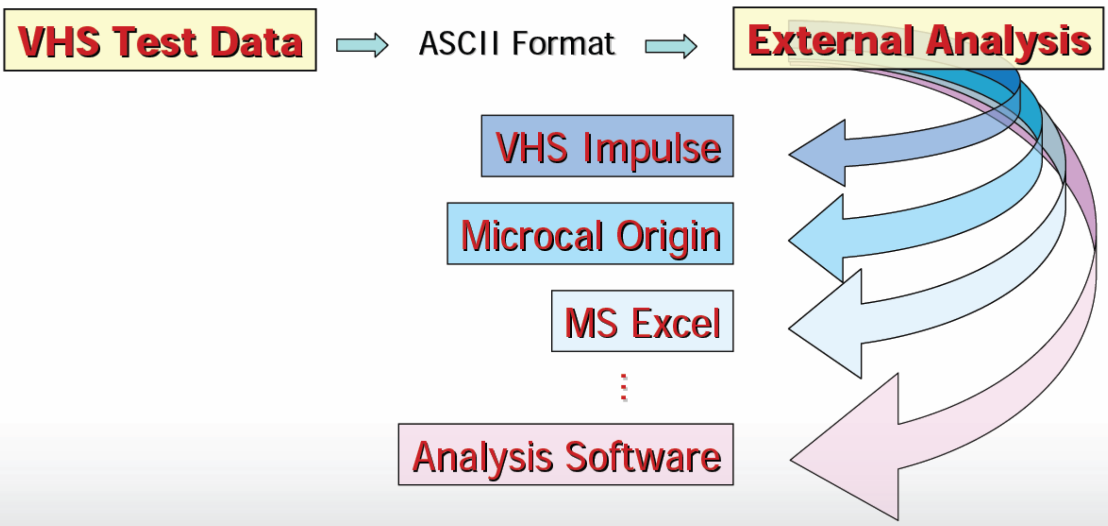
Export of Test Data



Servohydraulic - Data Analysis

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Strain Rate Definitions

- Nominal strain rate $\dot{\varepsilon}_{nominal} = \frac{v_{impact}}{L_0}$
- Mean technical strain rate $\dot{\varepsilon}_{mean} = \frac{A}{t_f}$
- Technical strain rate $\dot{\varepsilon}(t) = \frac{d\varepsilon(t)}{dt}$
- Technical plastic strain rate $\dot{\varepsilon}_{pl} = \text{Average}\{\dot{\varepsilon}(t_{Rp1})\ldots\dot{\varepsilon}(t_{Rm})\}$

A	Strain to fracture
L_0	Gauge length
t_f	Time to fracture
v_{impact}	Impact speed
$\dot{\varepsilon}(t_{Rp1})$	Strain rate @ R_{p1}
$\dot{\varepsilon}(t_{Rm})$	Strain rate @ R_m

Nach Boehme, W. – IWM, Freiburg

Servohydraulic - Data Analysis

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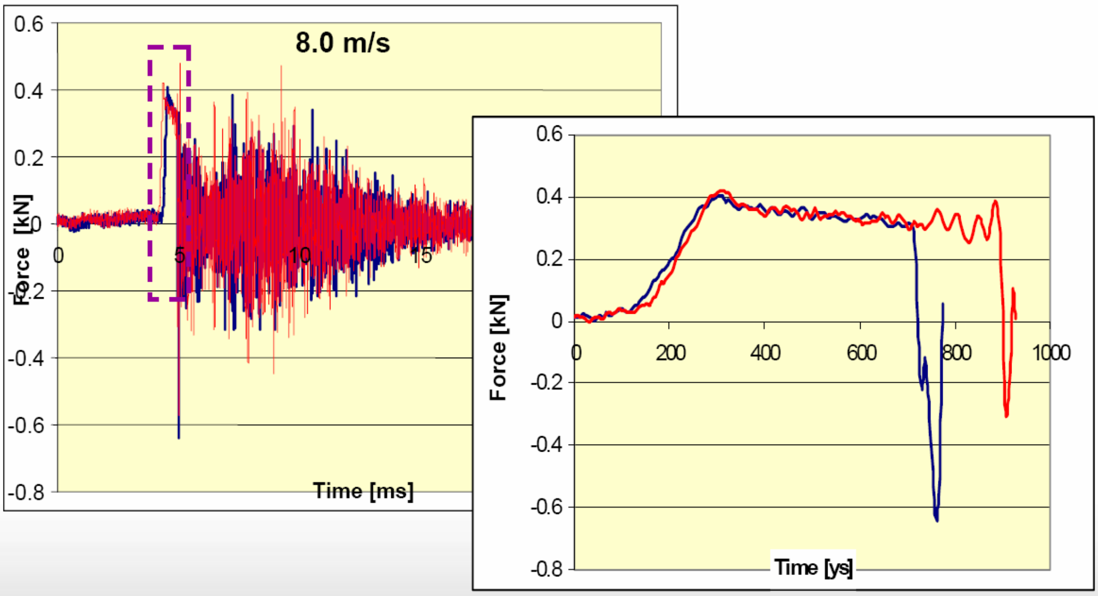
Data Analysis



Servohydraulic - Data Analysis

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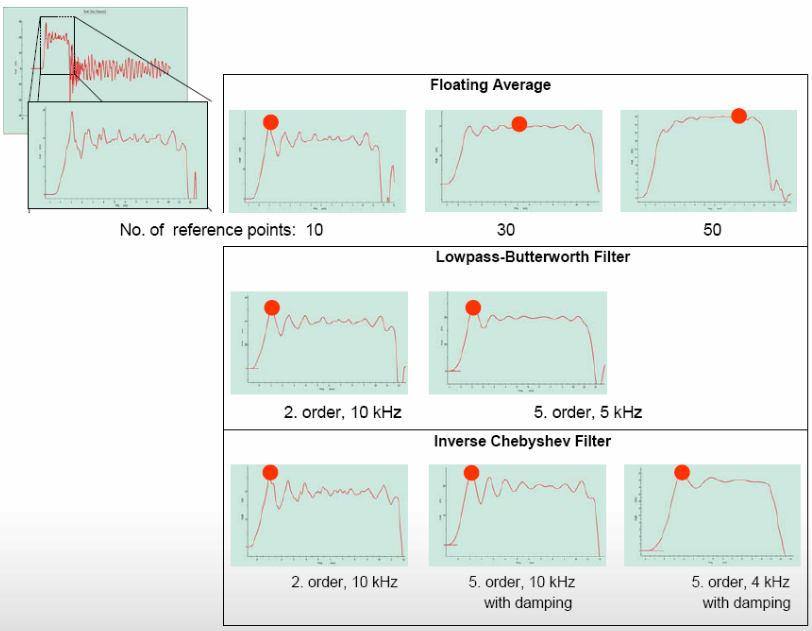
Influence of analysis parameters



Servohydraulic - Data Analysis

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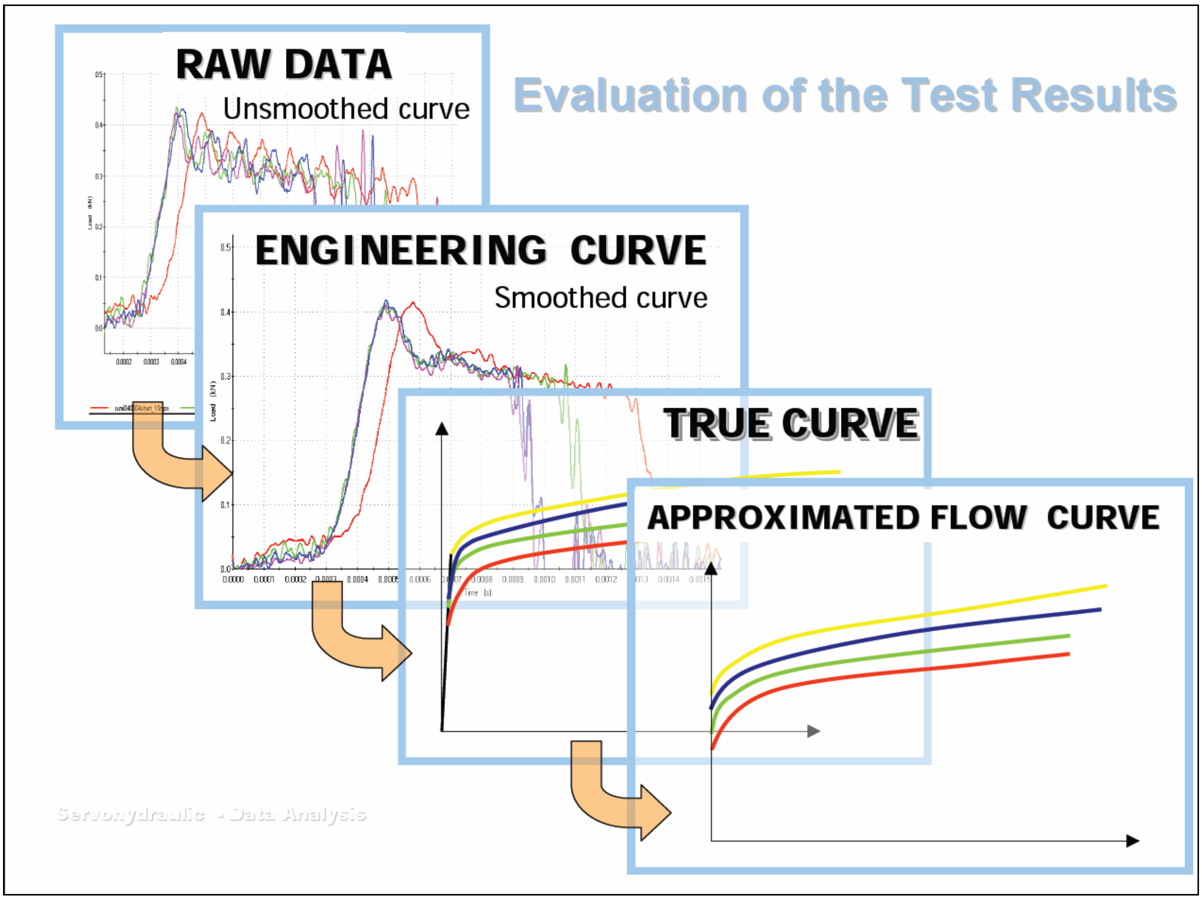
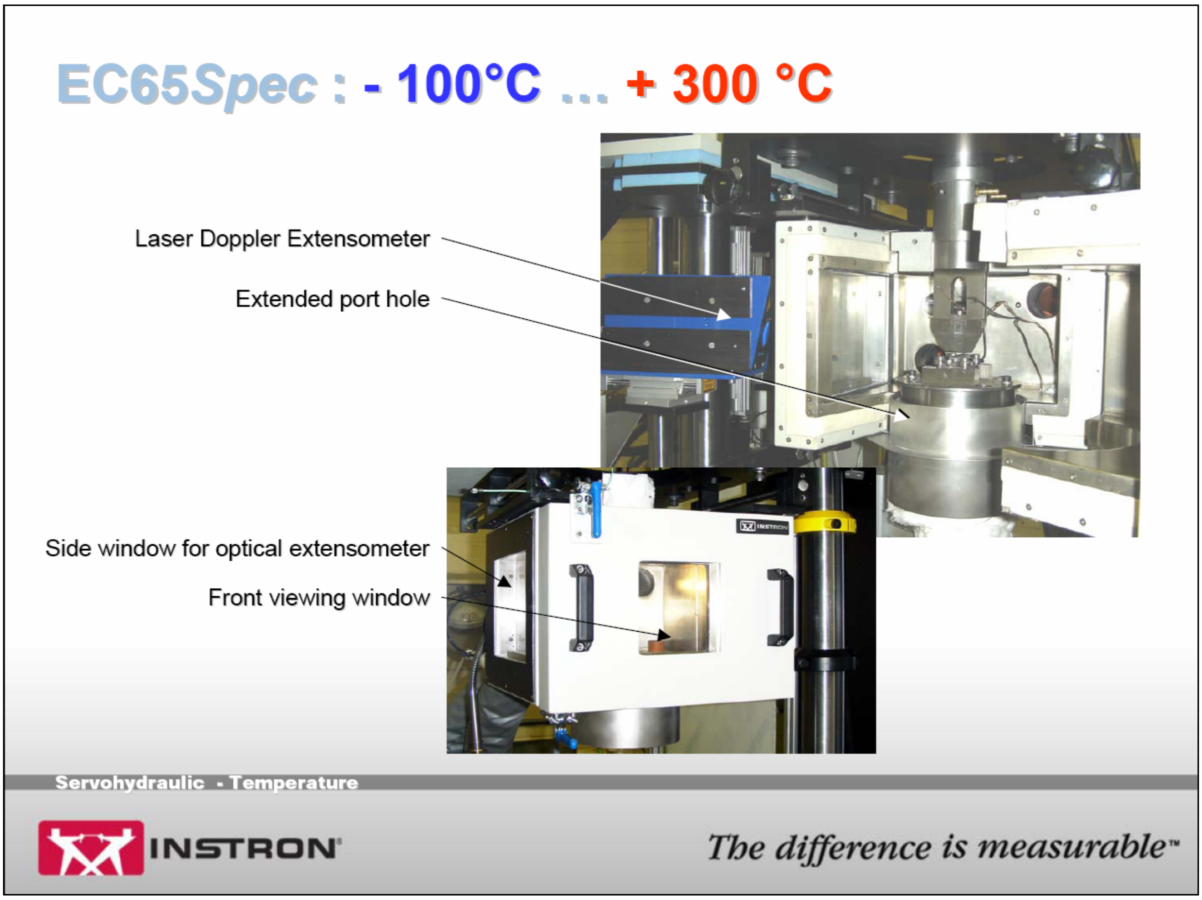

Evaluation of the Test Results
RAW DATA
Unsmoothed curve
ENGINEERING CURVE
Smoothed curve
TRUE CURVE
APPROXIMATED FLOW CURVE
Servohydraulic - Data Analysis


EC65Spec : - 100°C ... + 300 °C
Laser Doppler Extensometer
Extended port hole
Side window for optical extensometer
Front viewing window
Servohydraulic - Temperature
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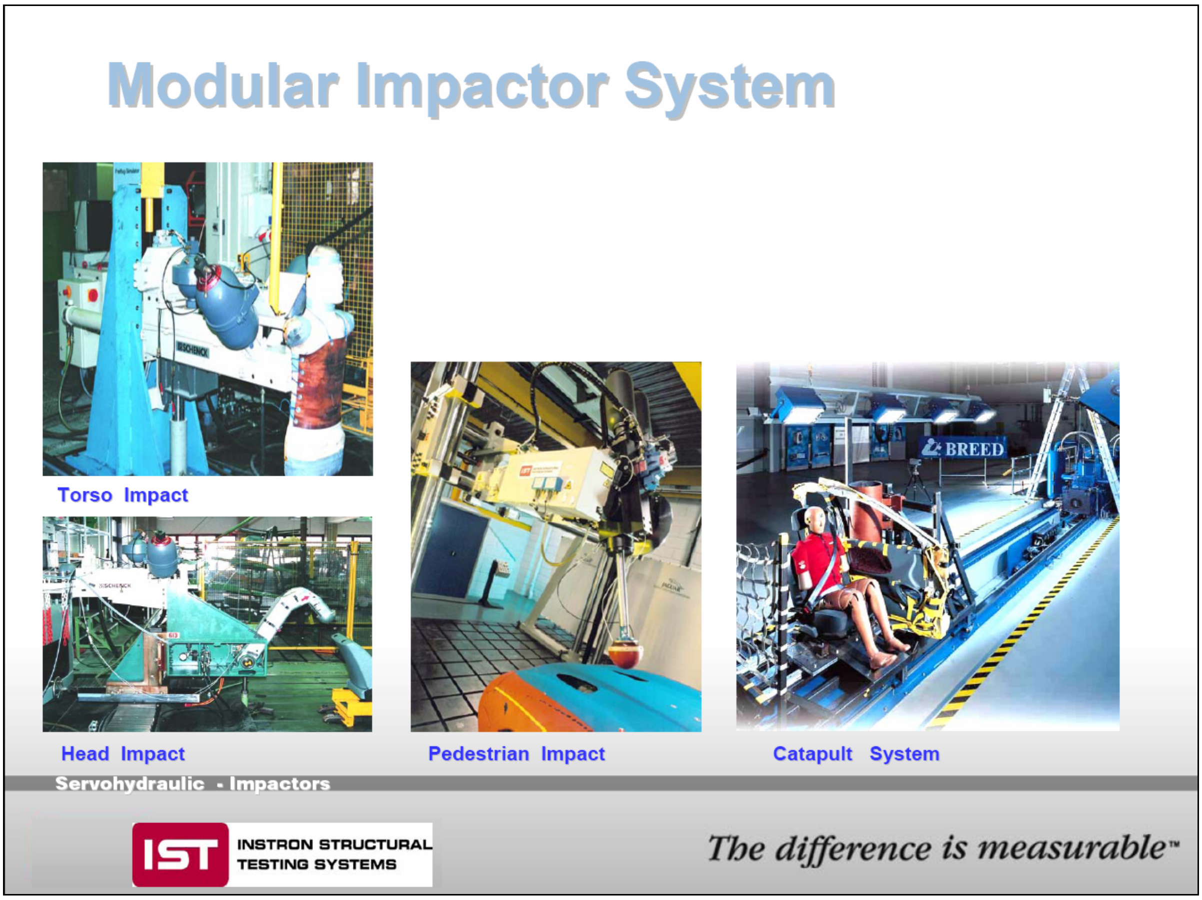
Modular Impactor System
Torso Impact
Head Impact
Pedestrian Impact
Catapult System
BREED
Servohydraulic - Impactors
IST INSTRUCTURAL TESTING SYSTEMS
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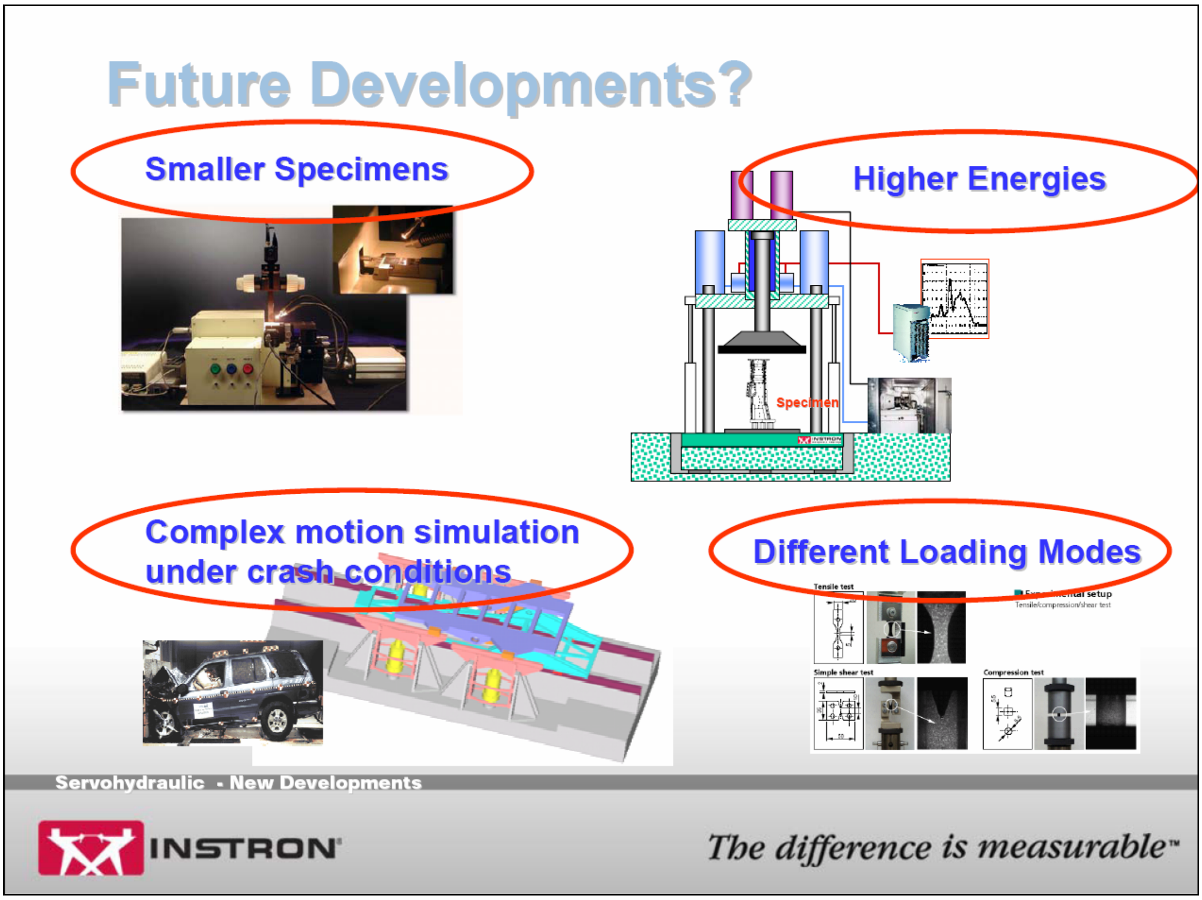
Future Developments?
Smaller Specimens
Higher Energies
Specimen
Complex motion simulation
under crash conditions
Different Loading Modes
Tensile test
Simple shear test
Compression test
Servohydraulic - New Developments
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