Product Information
Thermo-mechanical Fatigue Testing System – A Knowledge-Based Expert System for Solving Complex Test Requirements

Application
For the design and construction of thermal and simultaneously mechanical, cyclically loaded components, reliable characteristic values for the prediction of fatigue life and cyclic deformation behavior are required. Since these components are exposed to repeated temperature changes and are limited in their thermal expansion, they are subject to cyclically changing loads. The resulting constraints are caused by adjoining components or in the component itself by non-uniform temperature distributions or different expansion coefficients.

For reliable assumptions on fatigue life and for optimal and safe design of these components, precise characteristic values of the deformation behavior of the components used are required.

The testing system for thermo-mechanical fatigue testing meets all requirements of the European Code-of-Practice (CoP), and those of ASTM E 2368 and ISO 12111.

Advantages and features
Knowledge-based expert system – the optimal support for reliable testing
• Tailored TMF control system for real-time acquisition, processing, and evaluation of the measurement data
• Testing system based on the patented, zero-backlash, electromechanical Kappa SS-CF testing machine
• Induction heating system with adjustable heat output for different specimen materials
• Active compressed air cooling for accurate temperature control without overshooting
• Easy to handle and standard-compliant temperature control with ribbon thermocouples
• Development cooperation with KIT, the renowned Karlsruhe Institute of Technology
• Partnership with iew (Induktive Erwärmungsanlagen GmbH), the specialist in induction heating systems and their controls

Easy to handle for repeatable test results
• Workflow oriented operator assistance through automated testing with testXpert
• Easy test configuration
• Flexible and convenient evaluation options
• Stable environmental conditions, operator safety, and unhindered view of the specimen
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Knowledge-based expert system for optimal testing support
Reliably determining material behavior under cyclic thermal and mechanical load is an elaborate test task, which can however be made significantly easier with this knowledge-based expert system.

Depending on the damage mechanisms to be tested, temperature phasing and mechanical strain range are selected accordingly. The form of the curves can often be triangular or can be expanded with hold times, e.g. at maximum temperature. Furthermore, the strain and temperature can be applied at offset time intervals.

The most common types of tests are:
- IP (in phase)
- OP (out of phase)
- CD (clockwise diamond)
- CCD (counterclockwise diamond)

Thermo-mechanical fatigue tests are mainly strain-controlled, since the load acting on the component is caused by obstruction of the thermal strain. Stress-controlled tests are sometimes associated with non-uniform specimens, e.g. with notches, since here the elongation in the notch base cannot be measured.

In both cases, only the total elongation ($\varepsilon_t$) can be measured and controlled. It is composed of thermal elongation ($\varepsilon^{th}$) and mechanical elongation ($\varepsilon^{me}$): Formula $\varepsilon_t = \varepsilon^{th} + \varepsilon^{me}$.

In order to load the specimen with the desired mechanical strain in addition to the thermal strain, the thermal elongation with the defined temperature phase is measured in advance in a time-based manner and taken into account in the control of total expansion during the actual test.

Tailored TMF control system for real-time acquisition of the measurement data
- Real-time acquisition and processing of temperature, force and strain
- Determination and specification of the mechanical set value sequence for force and strain control
- Determination and specification of the thermal set value sequence for the automatically controlled heating and cooling cycles
- Precise control and synchronization of the mechanical and thermal cycles
- Real-time display of the test sequence for optimal monitoring of the test
- No separate calculations or external software support required
- testControl II, the proven measurement and control electronics from ZwickRoell, for high data acquisition rates and standard-compliant accuracy

Real-time acquisition and display of measurement data

- Temperature - Upper reversal point
- Temperature - Lower reversal point
- Mechanical strain - Upper reversal point
- Mechanical strain - Lower reversal point
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Precise control with patented electromechanical testing machine Kappa SS-CF

For testing with low frequency load cycles, the patented Kappa SS-CF electromechanical testing machine has proven itself time and again, over the years. The backlash-free zero crossing during cyclic tensile and compression loading allows for very precise control of the test force and test speed.

The precision planetary gear and servo motor are centrally located in the test axis and move synchronously with the crosshead. With the precise crosshead guidance and adjustable alignment fixture, standard-compliant axial alignment requirement to ISO 23788 and NADCAP can be ensured.

Excellent control behavior for force, stress and strain are possible with the high resolution motor encoder, the high resolution force channel and the corresponding extensometer.

Induction heating system for different specimen materials with adjustable capacity

- Induction heating system (10 kW) with individually adjustable heating capacity for testing materials with different electrical conductivity
- Specimen-specific inductors for optimal temperature distribution (axial, radial) for different test materials
- Active water cooling of the inductors for optimal heat induction on the specimen
- In accordance with CoP, the temperature deviation from the specified set value in the specimen measuring distance is <10K or < ±2% of the temperature difference
- Max. heating rates 25 K/s

Active compressed air cooling for accurate temperature control without overshooting

- With four symmetrically arranged flat spray nozzles, the cooling air is precisely aimed at the specimen surface.
- Proportional pressure control valves provide precise control of the air flow.
- The position of the cooling nozzles is adjustable. The position for future tests is reproducible.
- Depending on the specimen geometry, cooling rates of up to 25 K/s are possible.
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**Easy to handle and standard-compliant temperature control with ribbon thermocouples**
- Temperature measurement is carried out with standard-compliant ribbon thermocouples in the center of the specimen measurement travel:
  - \( \leq 850^\circ C \): Type K
  - \( > 850^\circ C \): Type S
- Easy to handle – especially when compared with welded thermocouples
- Easy and reliable attachment with adjustable spring pre-tensioning for dependable contact pressure
- Attached to 180° of the specimen circumference
- Up to three specimen thermocouples are possible

**Secure hold with the appropriate specimen grips**
- Hydraulic grips for typical cylindrical specimens with 6 mm specimen diameter and 15 mm shoulder end diameter
- Suitable for tensile/compression alternating load and backlash-free through zero forced operation or even fully reversed operation
- Water cooling for fast temperature stabilization along the specimen and for direct heat outflow from the specimen end

**Reliable strain measurement with contact-type extensometer**
- Specially constructed for use in high temperatures and designed to meet the strict requirements for strain-controlled tests to ISO 6892
- Automatic setting of the gauge length between individual tests
- Controllable contact force for repeatable positioning with the same force on subsequent specimens
- Meets the accuracy requirements of ASTM E83 class B2 and ISO 9513 in accuracy class 0.5
- With water cooling and class A silicon carbide ceramic sensors for use up to 1,600°C
- Quick connections for water cooling lines

**Stable environmental conditions and unhindered view of the specimen**
- The safety enclosure ensures optimal operator protection as well as stable environmental conditions, especially for sensitive strain measurements.
- The clear safety glass and open design of the cooling system provide an unhindered view of the specimen.

Water-cooled hydraulic grips for secure holding

Reliable strain measurement with contact-type extensometer
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Workflow oriented operator assistance through automated testing with testXpert

Testing system operation is designed to be purely intuitive. The user is guided through the various steps of a test, from preparing and running the test to analyzing results. According to CoP, the actual thermo-mechanical fatigue tests are preceded by the determination of the Young’s modulus and pre-cycles for control optimization. The system users are supported by special test programs, making separate calculations or external software a thing of the past. The temperature control deviation is determined by the difference between the temperature commands and the measured temperature (tolerance according to CoP ±5°C or ±1% of the temperature difference).

Step 1: Temperature control, stabilization

For accurate mechanical strain control, repeatable temperature cycles are essential. In order to produce the required thermal equilibrium, force-free pre-cycles are therefore carried out during force control in the first step.

Step 2: Determination of the thermal strain

In the next step, the thermal strain is determined dependent on the temperature. The force is regulated to zero and the thermal strain is measured.

Step 3: Zero-stress test verification

In this step, the accuracy of the thermal strain compensation is verified. Therefore, in this cycle the mechanical strain is held at zero (εme=0), which results in the correspondence of the total elongation with the thermal elongation (ε=εth). According to CoP, the resulting stresses are not allowed to exceed the following tolerances:

Max. values: < 5% of the stress difference of the TMF test

Mean value: < 2% of the stress difference of the TMF test

Step 4: Test process

The software carries out the current tests according to the selected test parameters.

Test data:

Material: Aluminum specimen
Specimen shape: Cylindrical
L: 10 mm
Test type: In phase
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Easy test configuration and traceable test results

- The intelligent setup assistant shows the user which test parameters must be configured and automatically checks all entries for plausibility.
- Freely selectable heating ramps, maximum and minimum temperatures, hold times, etc.
- Separate parameters for heating and cooling
- Various phase shifts
- Freely selectable number of pre-cycles
- Storage of test parameters for future tests
- Recording of testing system and system settings so you always have the answer to the question: "Who does what, when, why and who is responsible?"

Determination of the Young's modulus for verification of the correct test operation

According to the European Code-of-Practice, determination of the Young's modulus at room temperature, minimum temperature, maximum temperature, and at least one additional average temperature value, is recommended before every test. A subsequent comparison of the measured E-value with data from a reference database serves as verification of the correct control and measurement values of force, strain and temperature. If the measured values lie within the tolerance limit of max. 5%, the correct test operation is ensured.
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**Flexible and convenient evaluation options**

- Storage of all test cycles, with clear evaluation options and flexible export interface in NI TDMS file format for easy further use, e.g. in Excel
- Complete recording of up to 500 cycles with the software, individual or group presentation of the cycles
- Additional verification of all test data of the test performed in secure mode
- Easy export of data to all common evaluation/analysis platforms
- Comparison of individual test type cyclic stress-strain curves
- For the cycles recorded, the following results are available: Fmin, Fmax, Dmin and Dmax
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Technical data

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<td>Control frequency</td>
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<td>Requirements</td>
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<tr>
<td>Test load capacity</td>
<td>100 kN (tensile/compression)</td>
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<td>Crosshead travel</td>
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<td>Test speed range</td>
<td>0,001 mm/h to 250 mm/min</td>
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<td>Position transducer travel resolution</td>
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<td>Temperature control unit</td>
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<tr>
<td>Test temperatures</td>
<td>From RT to 1.600°C dependent on the specimen material (pre-tests required)</td>
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<td>Heating rate</td>
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<td>Cooling rate</td>
<td>Up to 25 K/s</td>
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<tr>
<td>Power rating of the induction heating system</td>
<td>10 kW</td>
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<td>Thermocouples</td>
<td>Up to 3 specimen thermocouples</td>
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<tr>
<td>≤ 850°C: Type K</td>
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<tr>
<td>&gt; 850°C: Type S</td>
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<tr>
<td>Specimen grips</td>
<td>Hydraulic, water cooled, clamping insert Ø 15 mm</td>
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<tr>
<td>Extensometer</td>
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<td>Initial gauge length</td>
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<td>Measurement range</td>
<td>+20 % / -10 %</td>
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<td>To ASTM E 83 class B2</td>
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<td>To ISO 9513 class 0.5</td>
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<tr>
<td>Max. operating temperature</td>
<td>1,200°C without water cooling</td>
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<tr>
<td></td>
<td>1,600°C with water cooling</td>
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<tr>
<td>Safety enclosure</td>
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<td>Software</td>
<td>Test program for determination of the Young's modulus</td>
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<td></td>
<td>Test program for the thermo-mechanical fatigue test</td>
</tr>
</tbody>
</table>

Option: Retrofitting to test frames from other manufacturers

We are certain that the Kappa SS-CF electromechanical testing machine provides the optimal foundation for precise control of the test force and test speed in thermo-mechanical fatigue testing. Nevertheless, we gladly accept the challenge to transform existing test frames with other manufacturers’ electronics and analog inputs and outputs into an almost equally reliable thermo-mechanical fatigue testing system.

All data at ambient temperature. We reserve the right to make technical changes in the course of ongoing development.