Temperature measurement in LCF- and TMF testing

Einladungsvortrag, Darmstadt, 16./17.02.2000

The Practicalities of Thermo-Mechanical Fatigue Testing in the New Millenium
Held at
Instron Wolpert, Landwehrstr. 55, 64293 Darmstadt, Germany on 16/17 February 2000
Organised by the
HTMT High-Temperature Mechanical Testing Committee (ESIS TC11)

Scope: Erfahrungsaustausch Hochtemperaturprüfung metallischer Werkstoffe, insbesondere auf den Gebieten LCF (low cycle fatigue) und TMF (thermomechanical fatigue), und Vorbereitung einer europäischen TMF-Norm, in Anlehnung an die ISO-Norm und der Bearbeitung in der working group WG9, s. **Beilage 1**
Gut besuchte Veranstaltung von Teilnehmern aus der Industrie, von Prüfanstalten, Forschungsstellen, Universitäten und Prüfmaschinenherstellern mit 17 Vorträgen am ersten Tag, gefolgt von einem workshop zur Diskussion und Fixierung von Prüfmodalitäten bei der TMF-Prüfung mit dem Ziel eine europ. Prüfanweisung zu erstellen: ISO/TC164/SC5/WG9 Thermomechanical Fatigue Testing Method Working Document 01/18/00
Kurzfassungen aller Vorträge und Posters, s. **Beilage 2**
TMF Test Description & Data Base Structure, s. **Beilage 3**
Gliederung des Einladungsvortrags Temperature measurement and control in LCF- and TMF-testing, K. Stärk, ALSTOM/Baden, s. **Beilage 4**
Folienkopien des Vortrages, s. **Beilage 5**

Alle Vorträge sind im (dicken) Tagungsband
The Practicalities of Thermo-Mechanical Fatigue Testing in the New Millenium
enthalten, der in der GTWM.T Ressort-Bibliothek abgelegt ist und ggf. ausgeliehen werden kann.

FAZIT:

- Es gibt etwa 25 Prüfstellen in Europa, die TMF-Prüfungen mehr schlecht als recht durchführen können.
- Jedes Labor hat seine spezifischen Einrichtungen und meist selbst geschriebene Steuer- und Auswertesoftware. Eine anerkannte Software eines Prüfmaschinenherstellers gibt es nicht.
- Die Flugturbinenhersteller legen seit einigen Jahren nach TMF-Daten aus. Der Rest versucht mit TMF den Betriebszyklus zu simmulieren bzw. nahe zu kommen, weiss aber eigentlich nicht recht, was er mit den mühsam gewonnenen Daten anfangen soll!
- In der Auslegung von Komponenten werden ggf. LCF- und TMF-Daten verwendet. Eine anerkannte Ueberführung von LCF-Ergebnissen in TMF-Ergebnisse oder umgekehrt existiert nicht.

Beilage 1

HIGH TEMPERATURE TESTING SYMPOSIUM

at

MATERIALS WEEK 2000

25-28 Sept. 2000, International Congress Centre, Munich

in conjunction with MATERIALICA

SCOPE

Recent developments in microprocessor and measurement sensor technology have led to significant advances in high temperature testing practices. These have enabled materials engineers: *i)* to undertake complex tests that were previously not feasible and *ii)* to perform conventional tests more efficiently, with greater precision and with output possibilities which were formerly impractical to achieve. These technical developments have been complemented by an increase in the experience exchange between national experts due to greater collaboration, for example, in the preparation of international testing standards and codes of practice.

Papers are invited to cover the state-of-the-art relating to:

- *MEASUREMENT TECHNIQUES AND ASSOCIATED UNCERTAINTIES*
- *TESTING PRACTICES*
- *DATA GATHERING AND ANALYSIS METHODS*

↳ now available for the determination and characterisation of creep-rupture, low cycle fatigue, creep-fatigue, thermal-mechanical fatigue, and high temperature fracture properties

↳ for parent, welded and coated materials.

The scope of the symposium encompasses the testing of uniaxial, multi-axial, fracture mechanics and feature-specimen/component-type testpieces.

Abstracts should be submitted via. the **www.materialsweek.org** web page by 15th May 2000.

Alternatively, they may be submitted to:

Dr Peter Paul Schepp, Program Co-ordinator materialsweek@dgm.de

Prof. Christina Berger, Topic Co-ordinator berger@mpa-ifw.tu-darmstadt.de

Dr Stuart Holdsworth, Symposium Chairman stuart.holdsworth@energy.alstom.com

Beilage 2

The Practicalities of Thermo-Mechanical fatigue Testing in the New Millenium

Organised by the HIGH-TEMPERATURE MECHANICAL TESTING COMMITTEE (ESIS TC11)

February 16-17, 2000.
Venue: Instron Wolpert, Landwehrstrasse 55, 64293 Darmstadt

ABSTRACTS

High Temperature Mechanical Testing Committee

Beilage 2

The Practicalities of Thermo-Mechanical fatigue Testing in the New Millenium

Temperature measurement in LCF- and TMF testing

K.F. Stärk
ABB Alstom Power Ltd., Baden/CH

Temperature measurement in LCF- and TMF testing seems to be the simplest part of the equipment and it needs the most of experience and care.
Most of the labs use for this specific measurement what they have for other needs. The correct measurement of a changing temperature in a TMF specimen with a high temperature rate is a demanding task.
In reality, most of the components have a relative low temperature rate. Due to short testing durations and typical thermal shock situations, the labs prefer high temperature rates up to 20K/s or more. TMF as a component simulation has to avoid all unknown influence of the temperatur to the strain control of the specimen.
In general a temperature gradient over the thickness of the specimen or over the wall thickness of a hollow specimen is not allowed.
This overview presentation shows the possibilities of temperature measurement, the applications, some mistakes and experiences in TMF or LCF testing:

- methods and principles
- heating and cooling
- examples for errors, limitations and solutions
- resolution, reproducibility and accuracy

Temperature measurement and control in LCF- and TMF-testing

Dr.-Ing. K.F. Stärk, ABB Alstom Power Ltd., Baden/CH

1. Heating methods and principles

- resistant heat chamber for LCF
- direct resistant heating for LCF/TMF
- IR radiation heating for LCF/TMF
- induction heating for LCF/TMF (1, 2 or 3 coils)
- indirect induction heating with a susceptor
  - for metallic materials (low temperature, Al, Cu)
  - for nonmetallic materials (ceramics, polymers)

2. Cooling methods for TMF

- natural cooling
- outside air pressure cooling
- outside and inside air pressure cooling

  sharp cooling is not recommended due to temperature gradient across the specimen or wall thickness

3. Measurement methods and principles

- Thermocouples and application
  - NiCr-Ni type K up to 1000°C
  - PtRh-Pt type S up to 1400°C
  - response time
  - long term stability
  - long term behaviour
  - use only PtRh-Pt thermocouples
  - use <u>one</u> calibrated heat of thermocouple wires
  - use <u>no</u> sheathed thermocouples for TMF
- Pyrometer and surface properties
  - single color pyrometer
  - two-color pyrometer
  - response time
  - long term stability
  - long term behaviour
  - calibration with thermocouples
  - use pre-oxidized specimens

4. LCF testing at constant temperature

- - distribution over the gauge length = f(t)
- - possibilities to change the distribution

5. TMF testing in the temperature range RT to 1100°C

- - distribution over the gauge length =f(t)
- - possibilities to change the distribution

6. The deception of digital temperature devices = DFM

- resolution is → what you see
- reproducibility is → what you believe to have
- accuracy is → what you want to have

I call it the ***DFM***, the **digital Fata Morgana**

7. General hints and recommendations:

- you will believe what you want to see
- you will get what you want to have
- have doubts about your measurements
- make cross checks with other principles
- make cross checks with other labs

A short summary in German:

"Wer misst, misst Mist"

During a test, the specimen temperature shall be measured and controlled using thermocouples and/or pyrometers. For thermocouples, direct contact between the thermocouple and the specimen is implied and shall be achieved without affecting the test results (e.g. crack initiation at the point of contact of the thermocouple shall be avoided). Commonly used methods of the couple attachment are: resistance spot welding (outside the useful zone), fixing by binding or pressure.

Tableau de correspondance entre nouveau et anciens codes de couleurs des câbles d'extension, de compensation et de prolongation
Overview of the old and new colour standards of the extension, compensation and prolongation cables
Übersicht der alten und neuen Farbstandards der Thermo-, Ausgleichs- und Anschlußleitungen

THERMOCOAX				Avant janvier 1994 - *Before January 1994 - Vor Januar 1994*					1994
	+/-	°C MINI	°C MAXI	THERMOCOAX	NF	DIN	BS	ANSI	NN*
K	NiCr / NiAl	- 200°C	+ 1 000°C	–					
J	Fe / CuNi	- 40°C	+ 750°C	–		–			
L	Fe / CuNi	- 40°C	+ 750°C	–	–		–	–	–
N	NiCrSi / NiSi	- 40°C	+ 1 300°C		–	–	–		
E	NiCr / CuNi	- 200°C	+ 900°C	–					
T	Cu / CuNi	- 200°C	+ 350°C	–					
S	Pt10%Rh/ Pt	0°C	+ 1 600°C	–					
R	Pt13%Rh/ Pt	0°C	+ 1 600°C	–					
B	Pt30%Rh/ Pt6%Rh	0°C	+ 1 700°C				–		
"C"	W5 / W26	0°C	+ 2 200°C		–	–	–	–	–
"D"	W3 / W25	0°C	+ 1 800°C		–	–	–	–	–

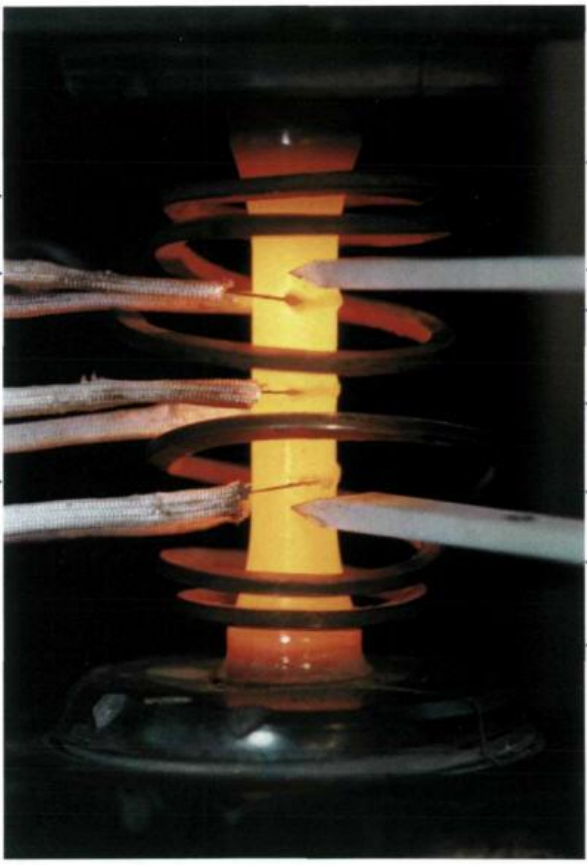
*)NN : Nouvelle Norme pour NF, DIN, BS et ANSI
New Standard for DIN, BS, NF and ANSI
Neue Norm für DIN, NF, BS und ANSI

●) fil magnétique
magnetic wire
magnetische Ader

THERMOCOAX

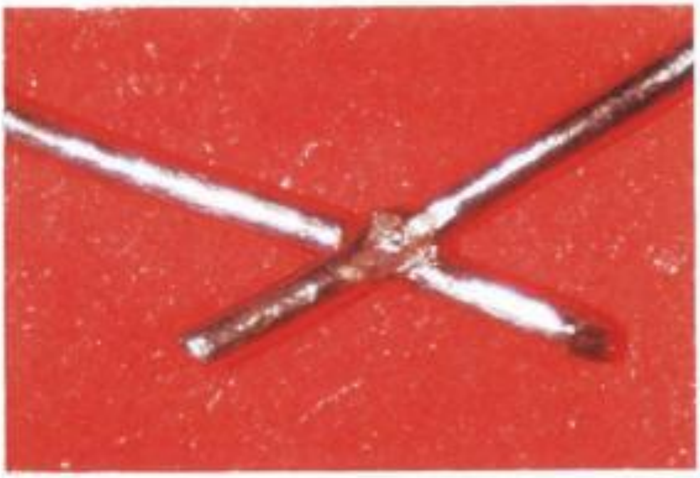
induction heating system about 150kHz (2x3kW)

ABB ALSTOM POWER



SX-LCF test at 950°C

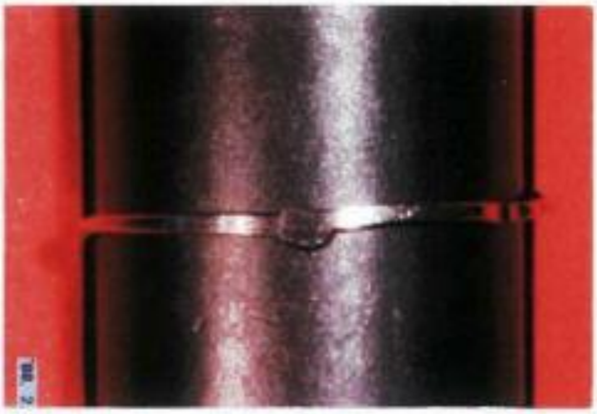
ABB ALSTOM POWER



step 1

capacitor
discharge
welding

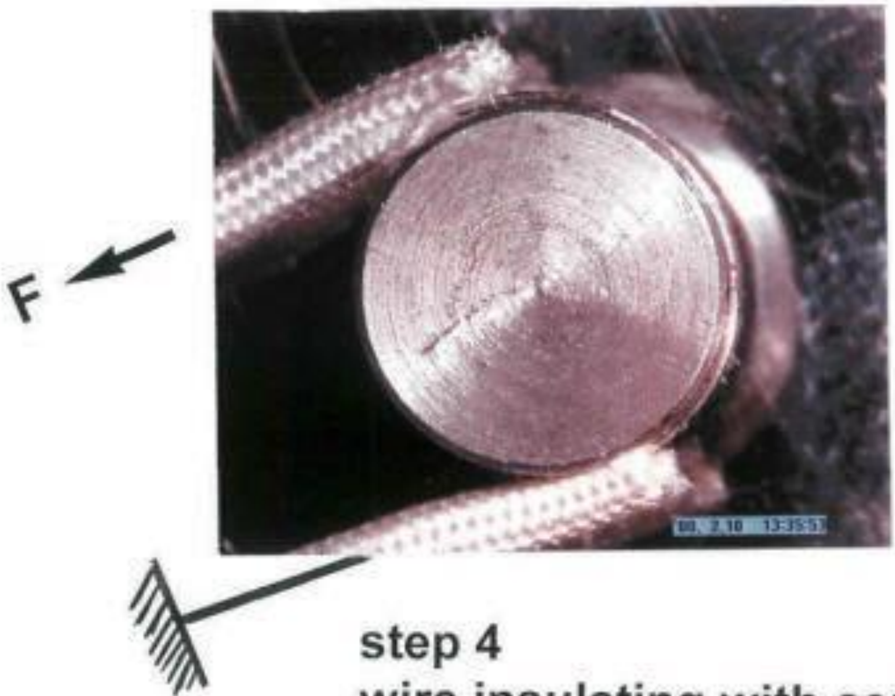
step 2
cutting



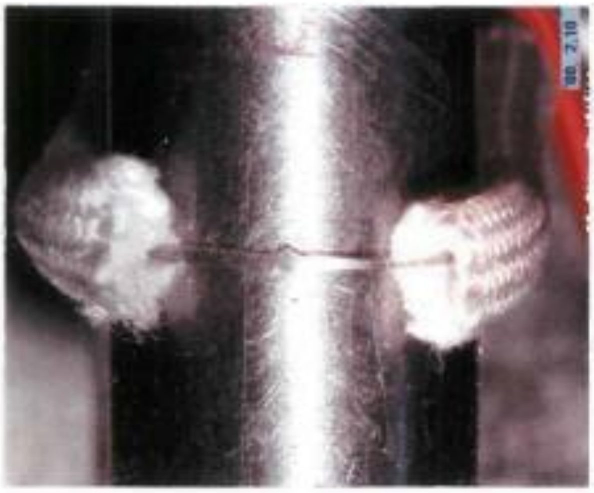
step 3
forging

production steps of PtRh-Pt type S
thermocouples ∅ 0.35mm
for tensile, LCF and TMF tests

ABB ALSTOM
POWER



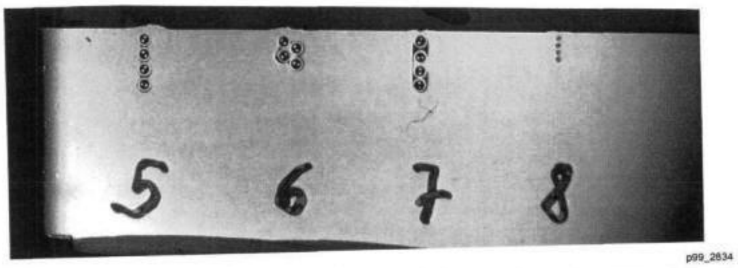
step 4
wire insulating with ceramic hose
and preloading



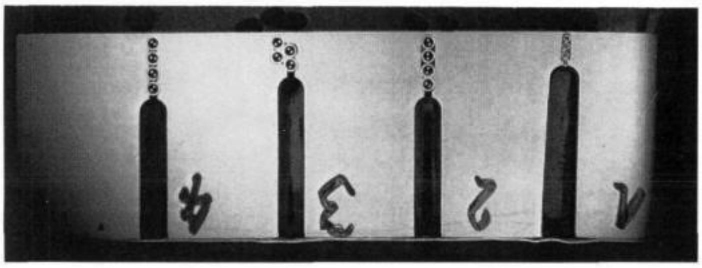
step 5 step 6
positioning and insulating
with ceramic glue

production steps of PtRh-Pt type S
thermocouples ∅ 0.35mm
for tensile, LCF and TMF tests

ABB ALSTOM
POWER



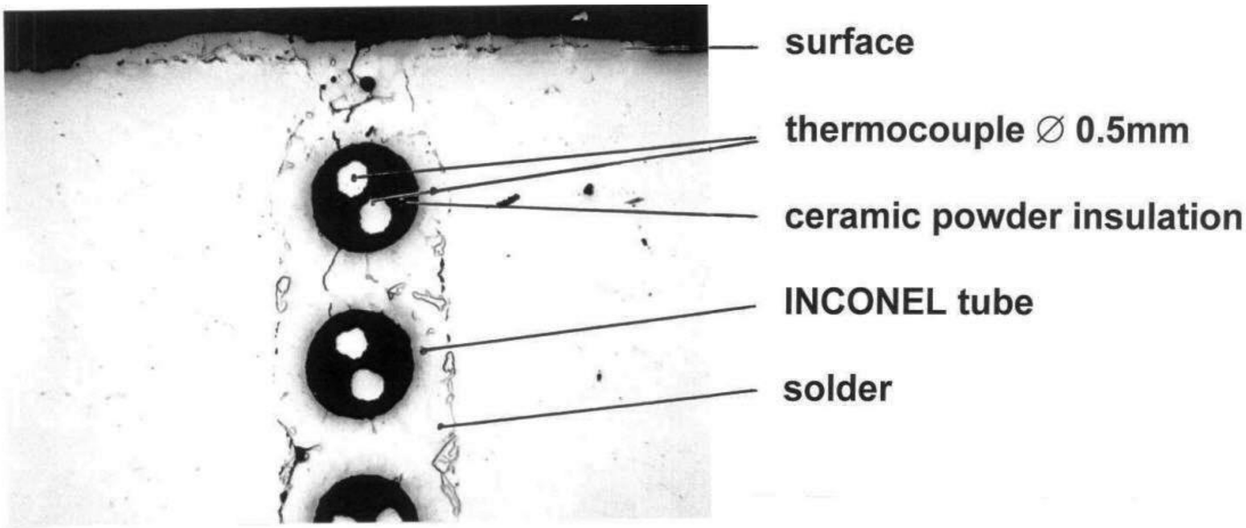
thermocouples with
∅ 0.5mm and ∅ 1.0mm
inserted in wire electro spark-eroded
channels and brazed from surface



wall thermocouples with
∅ 0.5mm and ∅ 1.0mm
inserted in wire electro spark-eroded
channels and brazed from back

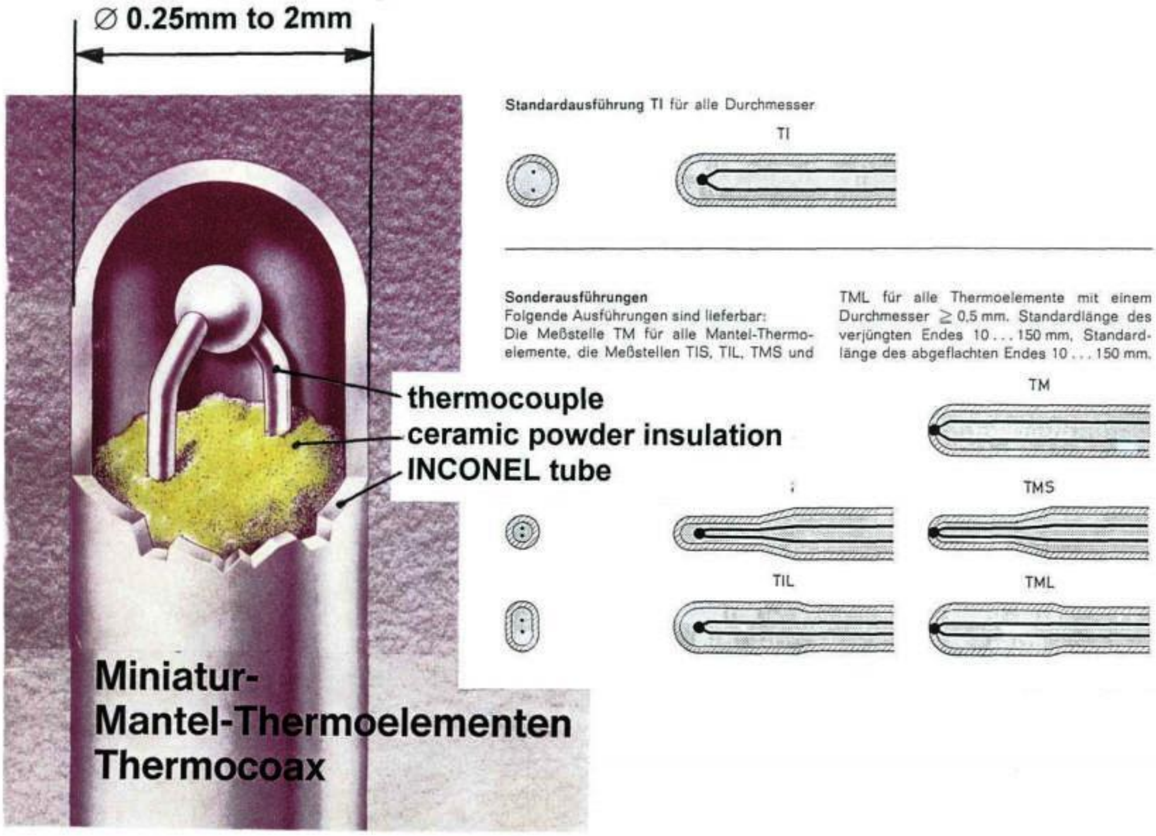
brazed sheathed thermocouples in a thin wall

ABB ALSTOM
POWER



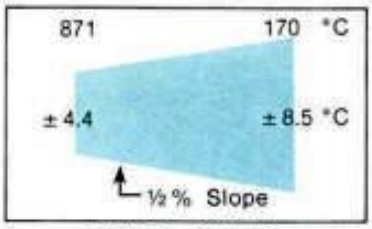
brazed sheathed thermocouples

ABB ALSTOM
POWER

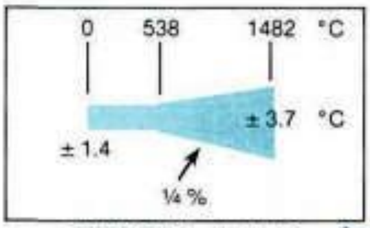


sheathed thermocouples

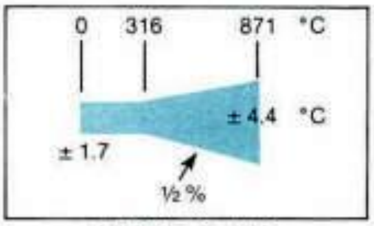
ABB ALSTOM
POWER



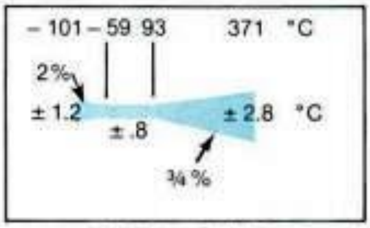
TYPE B 24 AWG



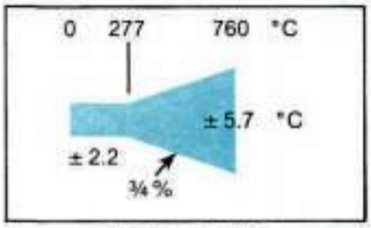
TYPES R,S 24 AWG



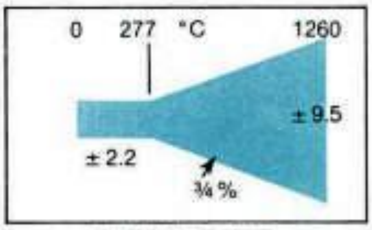
TYPE E 8 AWG



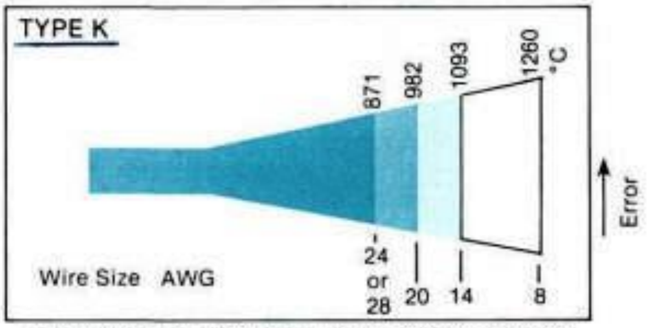
TYPE T 14 AWG



TYPE J 8 AWG



TYPE K 8 AWG



TEMPERATURE RANGE vs. WIRE SIZE vs. ERROR

AWG	DIA, MILS	DIA, mm
8	128	3.3
10	102	2.6
12	81	2.1
14	64	1.6
16	51	1.3
18	40	1
20	32	0.8
22	25	0.6
24	20	0.5
26	16	0.4
28	13	0.3

At high temperatures, small thermocouple wire is affected by diffusion, impurities, and inhomogeneity more so than large wire. The standard wire errors reflect this relationship.

Note that each NBS wire error specification carries with it a wire size. The noble metal thermocouples (B, R, and S) are specified with small (24 ga.) wire for obvious cost reasons.

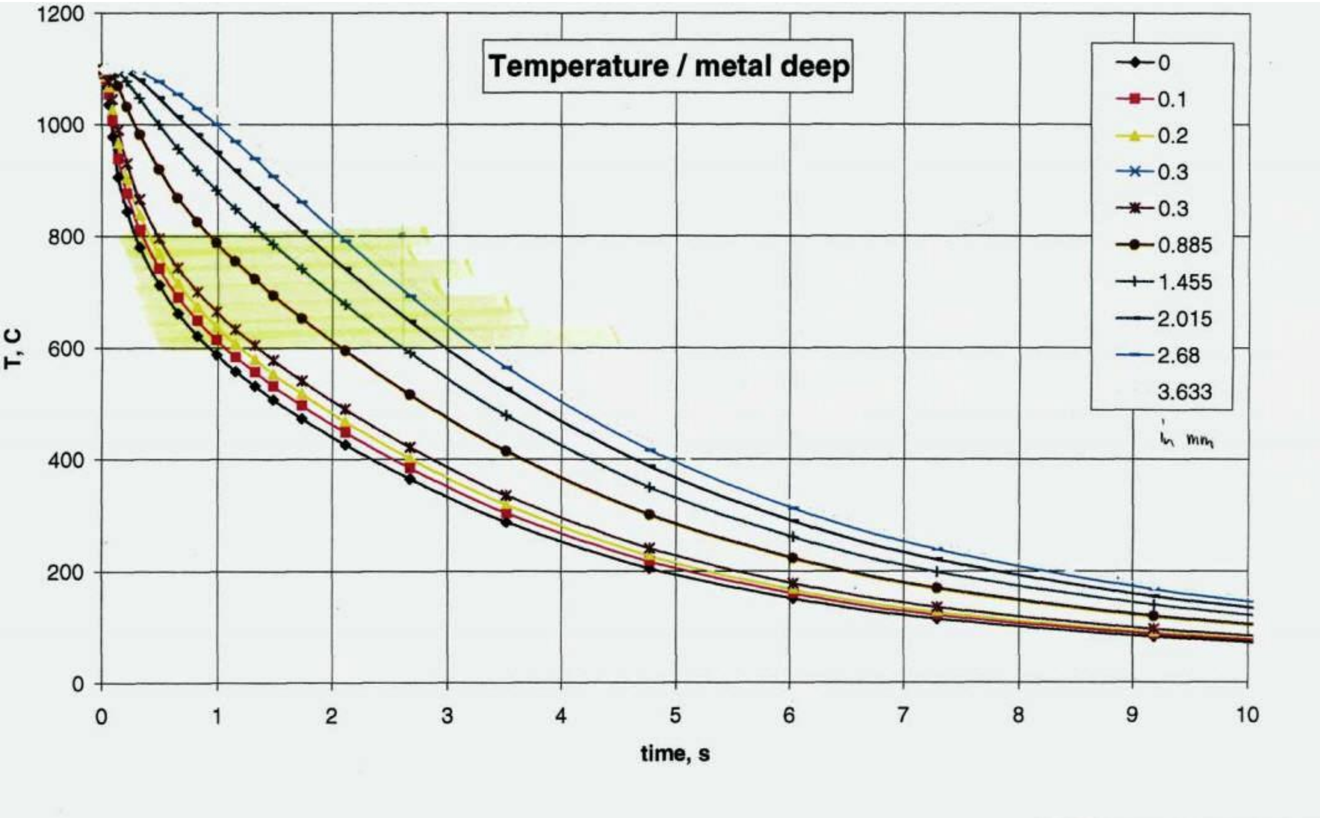


ABB ALSTOM POWER

	Thermopaare Teil 2: Grenzabweichungen der Thermospannungen (IEC 584-2 : 1982 + A1 : 1989) Deutsche Fassung EN 60584-2 : 1993	DIN EN 60584-2

Tabelle 1. **Klassen der Grenzabweichungen für Thermopaare** (Vergleichsstellen-Temperatur 0 °C) *)

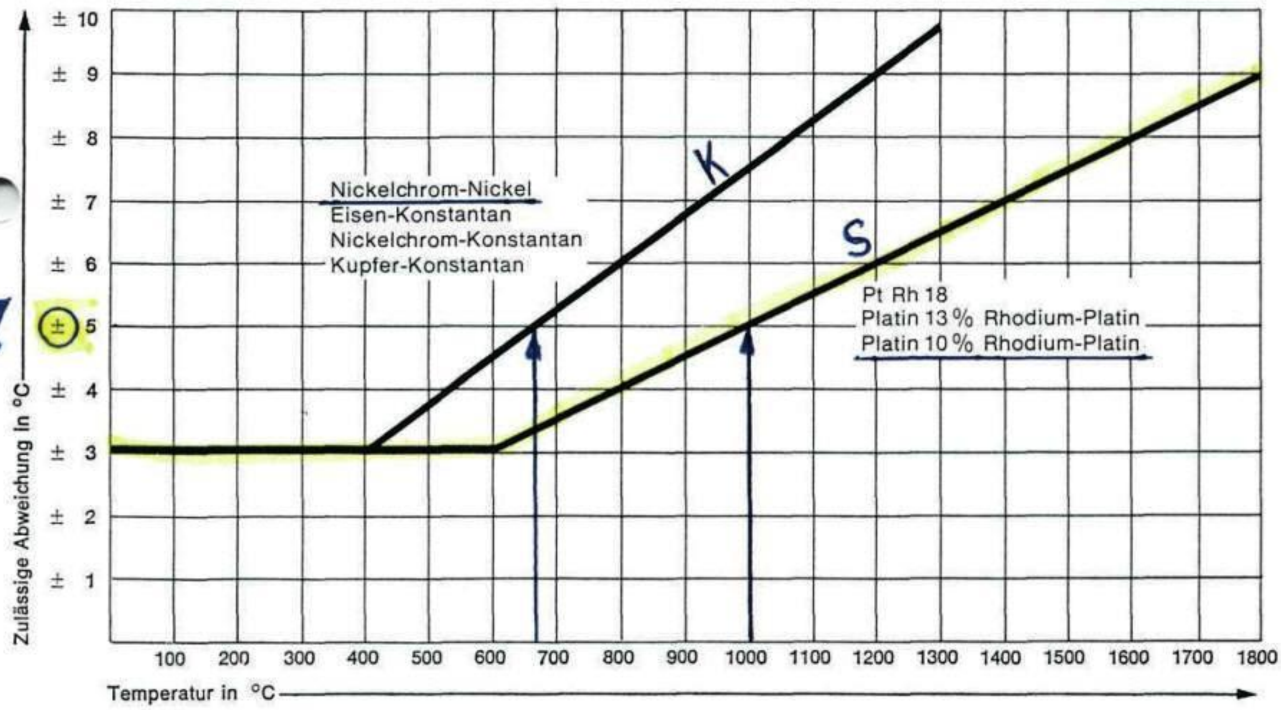
Typ	Klasse 1	Klasse 2	Klasse 3 1)
Typ K, Typ N			
Temperaturbereich	− 40 °C bis + 375 °C	− 40 °C bis + 333 °C	− 167 °C bis + 40 °C
Grenzabweichung	± 1,5 °C	± 2,5 °C	± 2,5 °C
Temperaturbereich	375 °C bis 1000 °C	333 °C bis 1200 °C	− 200 °C bis − 167 °C
Grenzabweichung	± 0,004 · |t|	± 0,0075 · |t|	± 0,015 · |t|
Typ R, Typ S			
Temperaturbereich	0 °C bis 1100 °C	0 °C bis 600 °C	–
Grenzabweichung	± 1 °C	± 1,5 °C	–
Temperaturbereich	1100 °C bis 1600 °C	600 °C bis 1600 °C	–
Grenzabweichung	± [1 + 0,003 (t − 1100)] °C	± 0,0025 · |t|	–

1) Thermopaare und Thermodrähte werden üblicherweise so geliefert, daß die Grenzabweichungen nach obenstehender Tabelle für den Temperaturbereich oberhalb − 40 °C eingehalten werden. Die Abweichungen für Thermopaare des gleichen Materials können bei Temperaturen unterhalb von − 40 °C größer sein als die in Klasse 3 festgelegten Grenzabweichungen. Wenn Thermopaare benötigt werden, die die Grenzabweichungen nach den Klassen 1, 2 und/oder 3 einhalten sollen, muß dies vom Besteller angegeben werden, wobei üblicherweise eine spezielle Selektion des Materials notwendig ist.

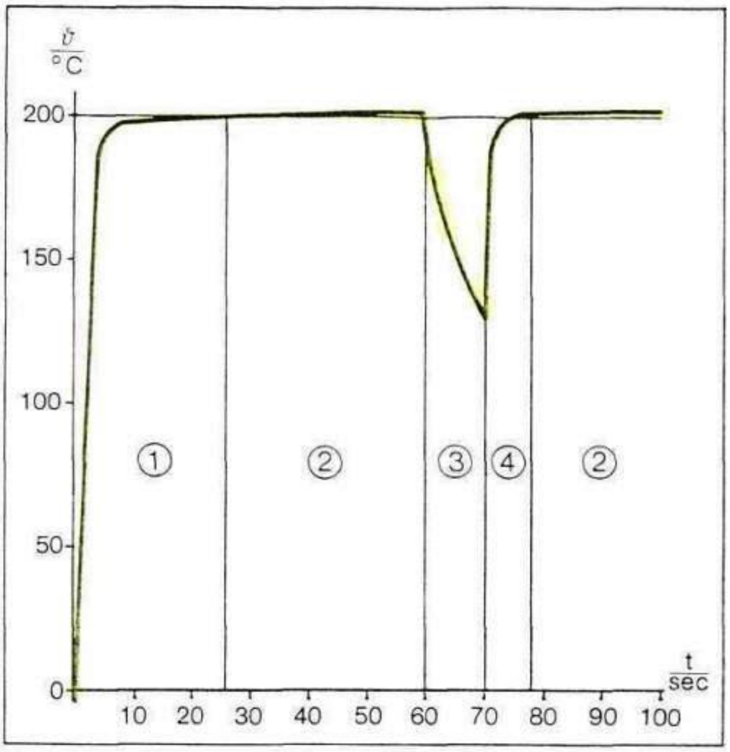
Toleranzen

Diese Deutsche Norm DIN EN 60584-2

beinhaltet unverändert DIN IEC 584-2, **Ausgabe Juni 1992.**



Aufheizkurve von Oberflächen-Fühlern gemessen an einer beheizten Referenzplatte.



1. Fühler an Platte gedrückt Aufheizvorgang bis auf 1° C (= 0,5%) vom Endwert
2. Fühler an Platte gedrückt Beharrungstemperatur
3. Fühler von Platte entfernt Abkühlvorgang
4. Fühler wieder an Platte gedrückt Aufheizvorgang bis auf 1° C (= 0,5%) vom Endwert

example for response time of a thermocoule contact sensor

Genauigkeit:
T Serie: ± 0,75% vom Meßbereichsendwert oder ± 2°C ± 1 Digit*
60 Serie: ± 1% vom Meßbereichsendwert oder ± 3°C ± 1 Digit*
*Es gilt der jeweils größere Wert
Alle anderen Serien ± 1% vom Meßbereichsendwert oder ± 1 Digit

Reproduzierbarkeit:
± 0.3% vom Meßbereichsendwert
± 1 Digit

Wiederholgenauigkeit:
0.3% vom Meßbereichsendwert ± 1°C.

Emissionsfaktoreinstellbereich:
Einstellbar von 0.1 bis 1 für alle Serien, außer OR Serie.

- **accuracy:**
± 10K for 1000°C

- **reproducibility**
± 4K for 1000°C
- **repeatability**
± 4K for 1000°C
"you can get what you want"

example for a data sheet for a pyrometer

ABB ALSTOM POWER