




TGF von keramischen Wärmedämmschichten

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H.-P. Bossmann

Bad Neuenahr, 3./4. 12. 2015



TGF von keramischen Wärmedämmschichten

Gliederung

- Definitionen und Zielsetzungen
- Probe, Probenhalter und Kühlung
- Brenner und Zündung
- Pyrometer und Hubtisch
- Prüfstand
- Überwachung und Speicherung
- Steuerung und Messungen
- Zusammenfassung

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Zielsetzungen für Entwicklungsprojekt

- Prüfung von TBC-beschichteten Proben (Entwicklung)
- Prüfung von TBC-beschichteten Proben (Fertigung)
- Prüfung von TBC-beschichteten Proben (ex-service)
- TBC-Oberflächen-Temperatur bis 1250°C
- TBC-Substrat-Temperatur 600-900°C
- Steady state Haltezeiten bis 30 Minuten
- Soviel Proben wie möglich

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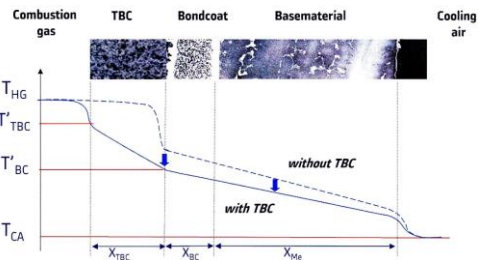
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Definitionen



innengekühlte Laufschaufel aus Nickel-Basis-Legierung (Feinguss)

TGF thermal gradient fatigue
Ermüdungsbeanspruchung durch thermische Gradienten

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Definitionen



innengekühlte Gasturbinen-Leitschaufel mit Filmkühlung (ex-service)

ohne Kühlung kein
Temperaturgradient
und keine TBC-
Temperaturen >1000°C !!

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Gliederung

- Definitionen und Zielsetzungen
- Probe, Probenhalter und Kühlung

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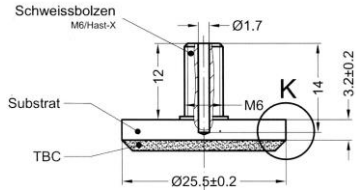
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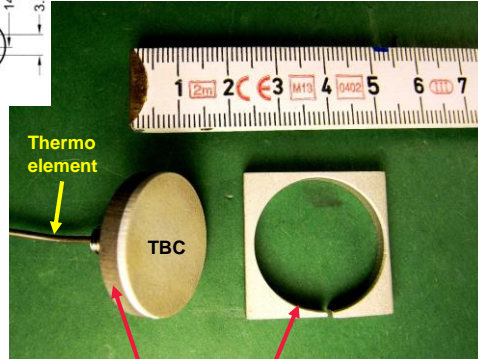
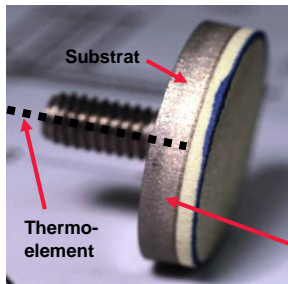
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burner rig Probe



Probenvorbereitung



Wasserstrahlschnitt

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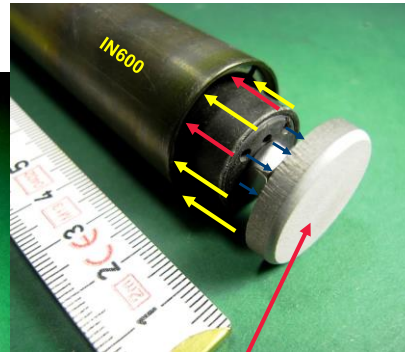
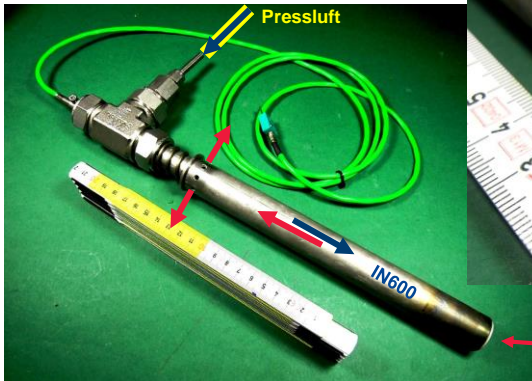


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Probenhalter

individuell temperaturgeregelte
Pressluftkühlung durch
10 Proportionalventile



TBC-Probe

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Gliederung

- Definitionen und Zielsetzungen
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- Brenner und Zündung

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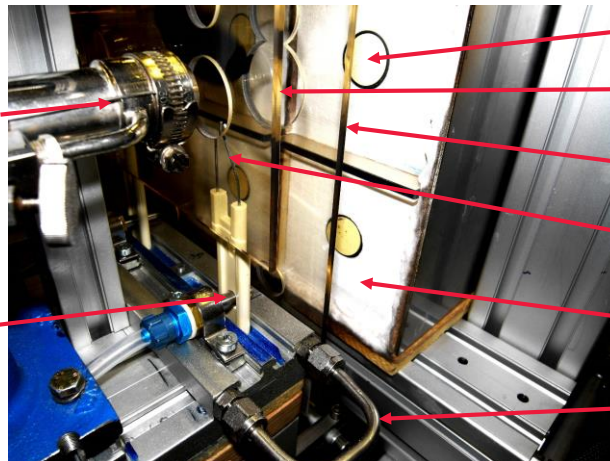


Brenner

(Leistung, Abstand, Brennfleck, Regelbarkeit)

ESL-
Brenner
(Erdgas,
Sauer-
stoff,
Luft)

TBC-
Front-
kühlung
(nur bei
Bedarf)



Probe

Glas-
keramik

Quarzglas

HS-Zünd-
elektrode

Front-
platte

Wasser-
kühlung

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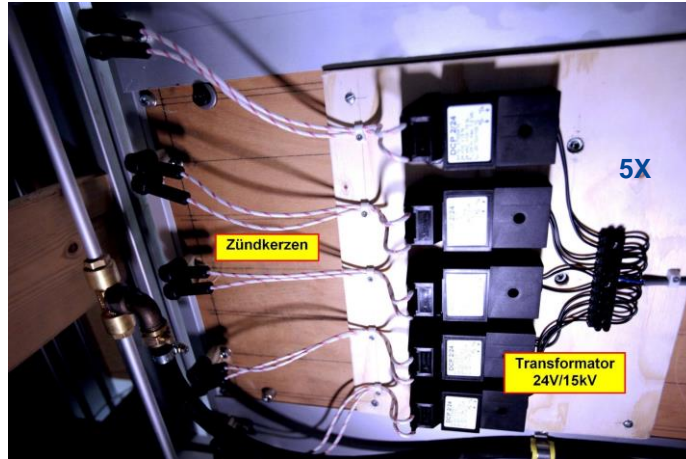
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Hochspannungszündung (Funkenstrecke, Pilotflamme)



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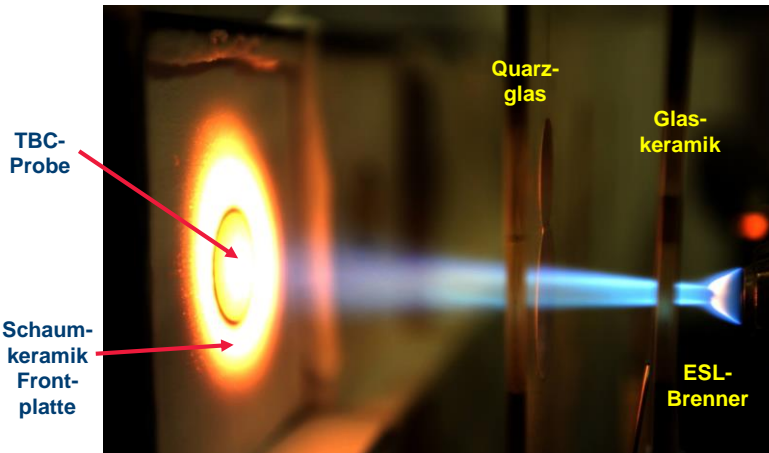
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ESL-Brenner (max. 20 kW) Erdgas – Sauerstoff - (Press-) Luft



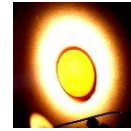
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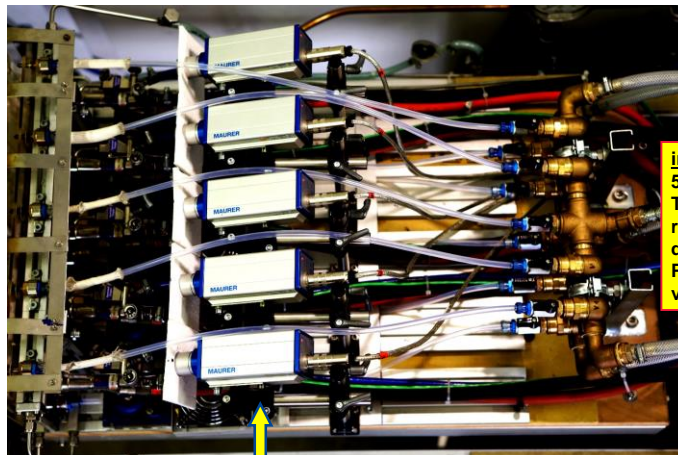
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Pyrometer (langwellig 8-9 μm)



**individuelle
5-fach TBC-
Temperatur-
regelungen
durch 5 O₂-
Proportional-
ventile**

5X

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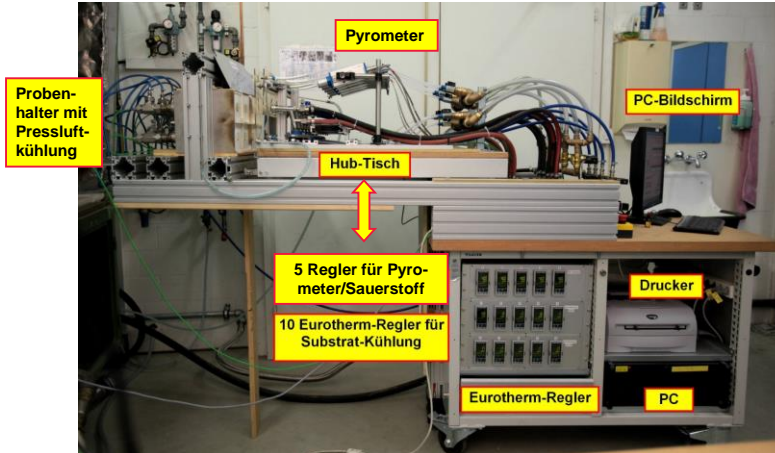
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Hubtisch (Schrittmotor)



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- Prüfstand

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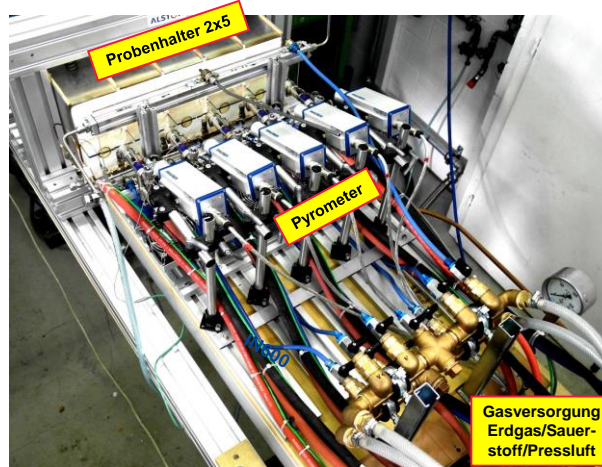
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Prüfstand



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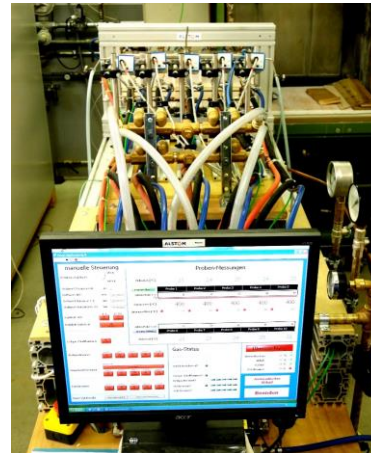


Prüfstand

im Betrieb



Steuerung



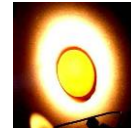
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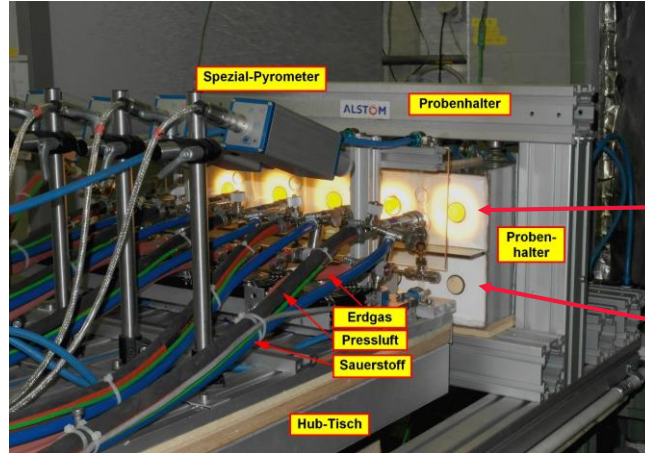




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Prüfstand (Betriebszustand)



Hubtisch
oben
d.h.

obere
Reihe 1-5
heizen

untere
Reihe 6-10
kühlen

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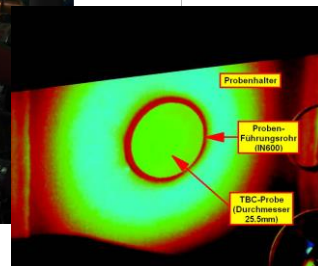
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Prüfstand



5 Proben
pro Reihe
Brennfleck =
Proben-
durchmesser



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- Überwachung und Speicherung

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Überwachung

Prüfstand- und Brennertemperaturen

- + Kühlwasser Alu-Profil
- + Kabine
- + Abgas
- + Kamin
- + Brennerkopf (5x)
- + Pyrometer (3x)
- + Frontplatten (6x)

Probentemperaturen

- + Max. Temperatur Substrat (10x)
- + Aufheizgeschwindigkeit Substrat (10x)
- + Aufheizgeschwindigkeit TBC (10x)

zur

Brennerüberwachung und
TBC-Versagensanalyse

Konstantleistung 5x20 kW

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Speicherung

Steuerprogramm (auf Befehl)

- + Ist-Zeit und ges. Laufzeit
- + Individuelle Zyklenzahlen (10x)
- + Substrat-Temperaturen (10x)
- + TBC-Temperaturen (10x)
- + Substrat-Solltemperatur
- + TBC-Solltemperatur
- + Aufheizgradient Substrat (10x)
- + Operator-Kommentare

Operator (on demand alle 3s)

- + Ist-Zeit und ges. Laufzeit
- + Individuelle Zyklenzahlen (10x)
- + Substrat-Temperaturen (10x)
- + TBC-Temperaturen (10x)
- + TBC-Solltemperatur

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- Steuerung und Messungen

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LabView gesteuerter manueller Ablauf

Soll-Werte (indicated by a yellow arrow pointing to the left column)

Handsteuerung aller Ventile (indicated by red arrows pointing to the valve control buttons)

Proben-Messungen (indicated by a blue arrow pointing to the measurement tables)

1 ÷ 5 (indicated by a blue arrow pointing to the first measurement row)

6 ÷ 10 (indicated by a blue arrow pointing to the second measurement row)

Überwachung (indicated by a blue arrow pointing to the monitoring panel)

Zustandstabelle:

Substrat oben [°C]	25	25	25	25	24
Pyrometer [°C]	400	400	400	400	400
Brennerkammer [°C]	26	29	27	26	29
Substrat unten [°C]	24	25	25	24	24

Überwachung:

- Frontprofil < 90 °C
- Abluft < 100 °C
- Kabine < 150 °C
- Kühlwasser < 70 °C

Gas-Status:

- Kühlluft TBC 1-5?
- Kühlluft TBC 6-10?
- Kühlluft Substrat?
- Kühlluft Brenner?
- Pilotgas?
- Zündung?
- Erdgas Brenner?
- O2 Brenner?
- Luft Brenner?

Buttons: Start-Zykluswahl, Zyklus abbrechen, Zum automatischen Ablauf, Programm Beenden

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TGF von keramischen Wärmedämmschichten



LabView gesteuerter automatischer Ablauf

Befehls-Liste (indicated by a yellow arrow pointing to the left panel)

Sollwerte TBC (indicated by a red arrow pointing to the 'aktueller Sollwert' field)

Messwerte (indicated by a red arrow pointing to the measurement tables)

stufenweises Anheben auf TBC-Sollwert (indicated by a red arrow pointing to the 'aktueller Sollwert' field)

Brenner- und TBC-Überwachung (indicated by a red arrow pointing to the monitoring panel)

Zustandstabelle:

Substrat oben [°C]	395	394	393	393	394
Pyrometer [°C]	1119	1173	1191	1172	1118
Substrat unten [°C]	561	578	552	607	574

Überwachung:

- Frontprofil < 90 °C
- Abluft < 100 °C
- Kabine < 150 °C
- Kühlwasser < 70 °C

Ventilsteuerung:

- Brenner aktiv/halten?
- Einzelbrenner aktiv?
- Brenner Test ok?
- Kühlluft TBC 1-5?
- Kühlluft TBC 6-10?
- Kühlluft Substrat?
- Kühlluft Brenner?
- Pilotgas?
- Zündung?
- Gas Brenner?
- O2 Brenner?
- Luft Brenner?

Buttons: Start, Abbrechen, Speichern als AUS, Zurück zu manueller Steuerung

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LabView gesteuerter automatischer Ablauf 1200/800 °C



Program Ablaufsteuerung

Befehls-Liste

Befehl	Par. 1	Par. 2
64 Speichern	5	1160
65 Substrat TBC	5	1180
66 Speichern	5	1180
67 Substrat TBC	5	1180
68 Speichern	1	200
69 Überwachung	12	1200
70 Substrat TBC	0	1100
71 Speichern	0	1100
72 Substrat TBC	0	1100
73 Speichern	0	1100
74 Halbozeit	0	1
75 "Schleife-Ende"	0	0
76 Überwachung	0	0
77 Substrat TBC	0	1100
78 Enthalpe/Endgas Brenner	0	1
79 Enthalpe/Endgas Brenner	0	2
80 Enthalpe/Endgas Brenner	0	3
81 Enthalpe/Endgas Brenner	0	4
82 Enthalpe/Endgas Brenner	0	5
83 Halbozeit	1	1
84 Speichern	0	1
85 Enthalpe/ Sauerstoff Brenner	0	1
86 Enthalpe/ Sauerstoff Brenner	0	2
87 Enthalpe/ Sauerstoff Brenner	0	3
88 Enthalpe/ Sauerstoff Brenner	0	4
89 Enthalpe/ Sauerstoff Brenner	0	5
90 Halbozeit	1	1
91 Enthalpe/ Produkt Brenner	0	1
92 Enthalpe/ Produkt Brenner	0	2
93 Enthalpe/ Produkt Brenner	0	3
94 Enthalpe/ Produkt Brenner	0	4
95 Enthalpe/ Produkt Brenner	0	5

Program neu laden, editieren

Platz zur Datenspeicherung auswählen:

Dateiname (ohne Endung):

Kommentar (nächste Speicherung bei Befehl):

Start Pause Beenden Speichern als AUS

Proben-Temperaturen

Substrat [°C]: 800 802 801 801 801

Pyrometer [°C]: 1199 1201 1200 1202 1200

Brennerdüse [°C]: 102 130 124 114 109

Zyklus oben: 4 4 4 4 4

Zyklus unten: 4 4 4 4 4

Substrat [°C]: 393 393 389 398 392

Haltezeit: 43

Ventilsteuerung: Brenner ausschalten, Einzelbrenner aktiv?

Überwachung: aktiviert

Frontprofil < 90: 28 °C

Abluft < 100: 25 °C

Kabine < 150: 26 °C

Kühlwasser < 70: 26 °C

Zurück zu manueller Steuerung

Proben
oben 1 ÷ 5 heizen
unten 6 ÷ 10 kühlen
Prüfstandüberwachung

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LabView gesteuerter automatischer Ablauf



Program Ablaufsteuerung

Befehls-Liste

Befehl	Par. 1	Par. 2
137 Speichern	5	1160
138 Substrat TBC	5	1180
139 Speichern	5	1180
140 Substrat TBC	5	1180
141 Speichern	1	200
142 Überwachung	12	1200
143 Substrat TBC	0	1100
144 Speichern	0	1100
145 Substrat TBC	0	1100
146 Speichern	0	1100
147 Halbozeit	0	1
148 "Schleife-Ende"	0	0
149 Überwachung	0	0
150 Enthalpe/Endgas Brenner	0	1
151 Enthalpe/Endgas Brenner	0	2
152 Enthalpe/Endgas Brenner	0	3
153 Enthalpe/Endgas Brenner	0	4
154 Enthalpe/Endgas Brenner	0	5
155 Enthalpe/Endgas Brenner	0	6
156 Enthalpe/Endgas Brenner	0	7
157 Halbozeit	1	1
158 Enthalpe/ Sauerstoff Brenner	0	1
159 Enthalpe/ Sauerstoff Brenner	0	2
160 Enthalpe/ Sauerstoff Brenner	0	3
161 Enthalpe/ Sauerstoff Brenner	0	4
162 Enthalpe/ Sauerstoff Brenner	0	5
163 Halbozeit	1	1
164 Enthalpe/ Produkt Brenner	0	1
165 Enthalpe/ Produkt Brenner	0	2
166 Enthalpe/ Produkt Brenner	0	3
167 Enthalpe/ Produkt Brenner	0	4
168 Enthalpe/ Produkt Brenner	0	5

Program neu laden, editieren

Platz zur Datenspeicherung auswählen:

Dateiname (ohne Endung):

Kommentar (nächste Speicherung bei Befehl):

Start Pause Beenden Speichern als AUS

Proben-Temperaturen

Substrat [°C]: 400 400 400 400 400

Pyrometer [°C]: 1203 1199 1200 1200 1200

Brennerdüse [°C]: 100 130 131 123 138

Zyklus oben: 3 3 3 3 3

Zyklus unten: 2 2 2 2 2

Substrat [°C]: 800 800 800 800 800

Haltezeit: 32

Ventilsteuerung: Brenner ausschalten, Einzelbrenner aktiv?

Überwachung: aktiviert

Frontprofil < 90: 32 °C

Abluft < 100: 30 °C

Kabine < 150: 33 °C

Kühlwasser < 70: 28 °C

Zurück zu manueller Steuerung

Proben
oben 1 ÷ 5 kühlen
unten 6 ÷ 10 heizen

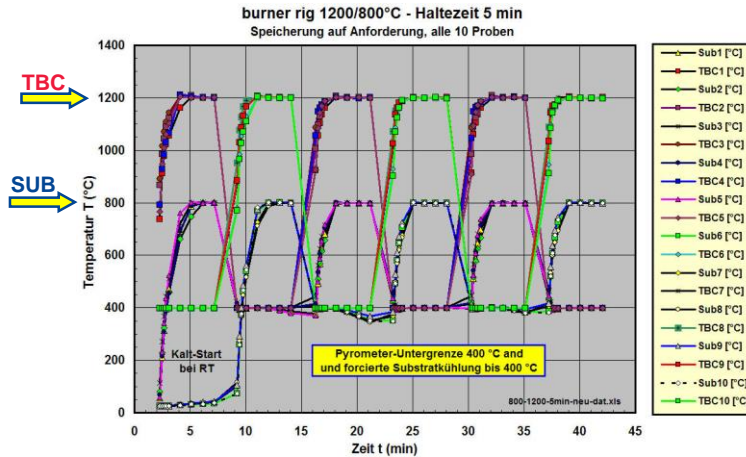
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TGF von keramischen Wärmedämmschichten

Messungen



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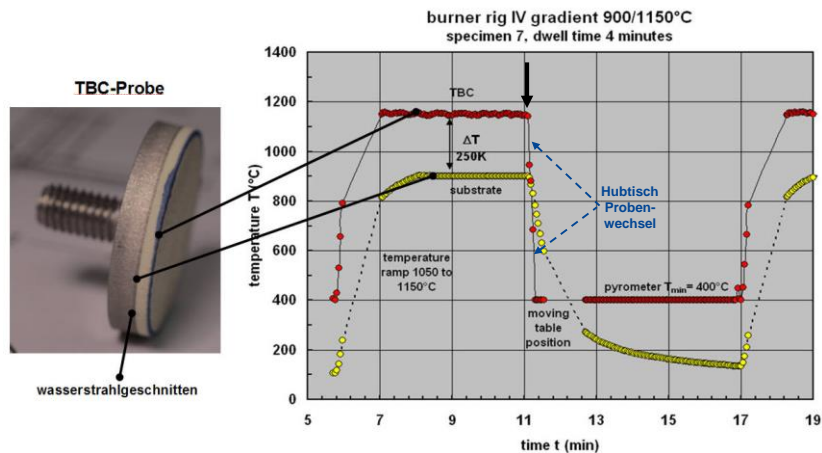
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Messungen



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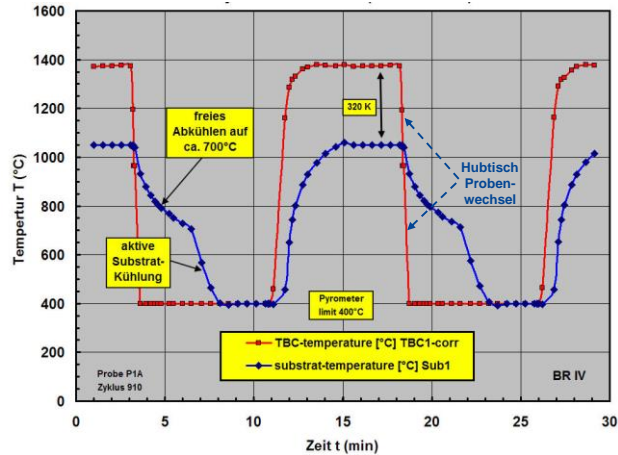
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Messungen
1370/1050 °C 5 min Haltezeit



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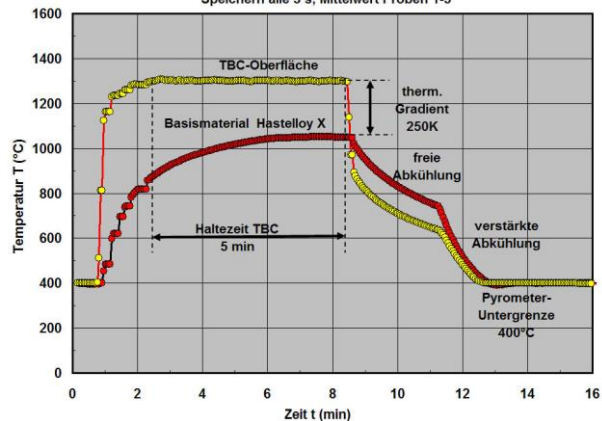


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Messungen

burner rig 1300/1050°C
Speichern alle 3 s, Mittelwert Proben 1-5



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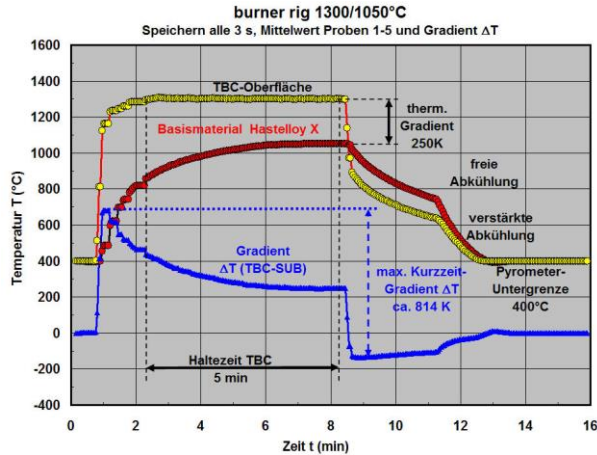
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Messungen



Kalt-Start

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Gliederung

- Definitionen und Zielsetzungen
- Probe, Probenhalter und Kühlung
- Brenner und Zündung
- Pyrometer und Hubtisch
- Prüfstand
- Überwachung und Speicherung
- Steuerung und Messungen
- Zusammenfassung

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Zusammenfassung



Prüfstand - **IST**- Parameter

Probendurchmesser	25.5mm
Probenzahl	1 bis 10
Heizung TBC	Erdgas/Luft/Sauerstoff
Kühlung Substrat	Pressluft
Maximaltemperatur TBC	1500°C
Temperatur Substrat	600-1100°C
Haltezeit	beliebig
Steuerung	LabView

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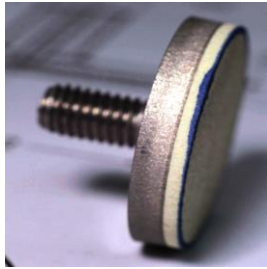
THERMAL FATIGUE TESTING of TBC's with controlled temperature gradient and dwell time

**Tobias Stärk Compositing/Film &
Animation/ Graphic Design**

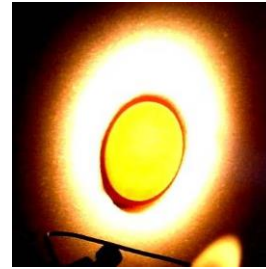
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burner rig
Entwicklung



Thermal gradient
fatigue von
keramischen
Wärmedämmschichten

Danke

Thank you



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Wärmedämmschichten



Fragen und Anregungen

an:

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Beratung, Messungen, Präsentationen, eigene Anlage



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