Material Related Design Criteria

and Test Methods

for Components Driven by R744 as Refrigerant

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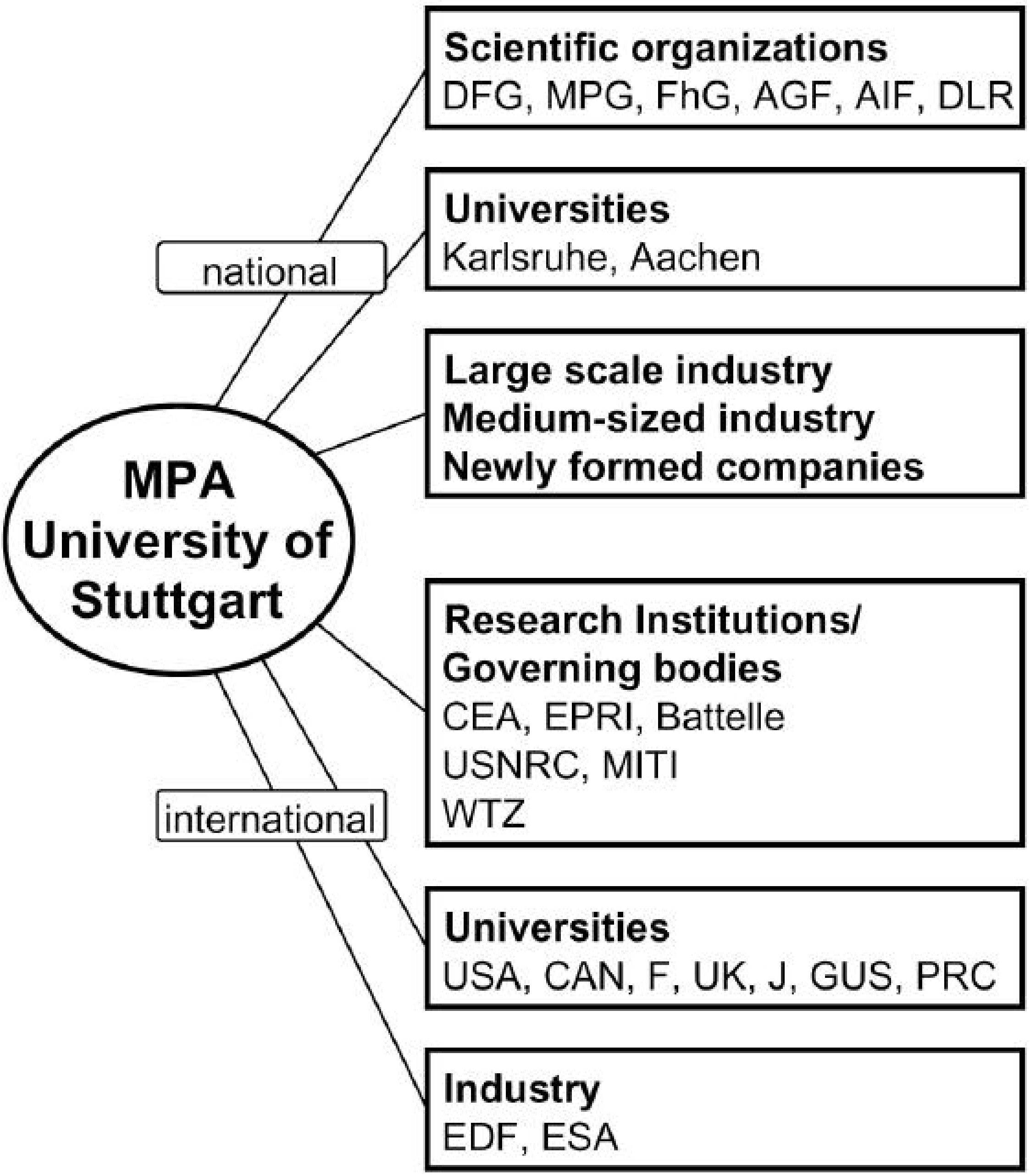
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See notes overleaf

1st issue

MPA Stuttgart : Contratcs with Foreign Institutions

Content

- **State of the European Standards**
- **State-of-the-Art**

- **Postulation of Operational Loading for Pressurized Components of AC Systems Driven by R744**
- **Material Specific Aspects**
- **Proposal for Component Tests**
- **Conclusion**

State of the European Standards Concerning Air Conditioning of Automobiles

Relevant European Standards

- **PED:** **Pressure Equipment Directive**
  ? of overriding importance

- **prEN 13445:** **Unfired pressure vessels**
  ? materials: steels and spheroidal graphite cast iron

- **prEN 378:** **Refrigerating systems and heat pumps**
  ? Safety and environmental requirements

- **prEN 12693:** **Refrigerating systems and heat pumps**
  ? Refrigerant compressors

- **prEN (182025):** **Pressure equipment for refrigerating systems and heat pumps**
  ? basis: prEN 13445
  ? materials: steels, spheroidal cast iron, Al, Cu
  ? pressure: limited by 6.4 MPa

Extracts from Relevant European Standards Concerning Air Conditioning of Automobiles

General	
automotive air conditioning systems are classified as mobile systems	they are subjected to the Pressure Equipment Directive

Methods of Design	
Design by Formula (DBF) Design by Analysis (DBA)	Design by Experiments
ß	ß
quasistatic if less than 500 cycles fatigue if more than 500 cycles	only if the strength of the components cannot be determined by DBF or DBA

Extracts from Relevant European Standards Concerning Air Conditioning of Automobiles

Experimental Methods	
1 Strain Gage Test	<u>criteria</u>: $R_{p/T} / R_{m/T} \leq 0.625$ <u>remark</u>: the maximum allowable pressure is defined by the pressure at the beginning of the yielding of the component
2 Burst Test	<u>criteria</u>: no part of the component shall become detached, no splinters shall be projected, rupture may not initiate in welds <u>burst</u>: five times the maximum allowable pressure → pressure vessel <u>pressure</u>: three times the maximum allowable pressure → compressor

Some Comparisons between ASME Pressure and Vessel Code and European Standards

		ASME Code	European Standards
Methods of Design	Design by Formula (DBF)	approx. adequate	
	Design by Analysis (DBA)	approx. adequate	
	Design by Experiments	see below	
Experimental Methods	Strain Gage Test	approx. adequate	
	Burst Test	approx. adequate	
	Fatigue Test	yes	no

Some Conclusions from Relevant European Standards Concerning Air Conditioning of Automobiles

1 Up to now there is <u>no European Standard</u> available covering components made of aluminium or copper materials and pressurized by more than 6.4 MPa

2 Design by formula and analysis is standardized for steel materials even in case of fatigue loading of the component <u>but</u> no experimental method is standardized to cover fatigue loading of the components exception: components made of spheroidal graphite cast iron

3 <u>Creep effects</u> of aluminium and copper materials at temperatures above 100°C (212°F) are not considered

The standardized burst test and strain gage test are quasistatic test methods. They don’t describe fatigue loading (pressure cycles of the AC system).

State-of-the-Art Air Conditioning Systems Driven by R134a

Design Conditions for Components "HP-Side"

pressure: 3 MPa
temperature: 125°C (257°F)
} considering extreme hot "ON"-conditions

proof of integrity: e.g. burst test → T = 125°C (257°F), p ≥ 9 MPa

Design Conditions for Components "LP-Side"

pressure: 1.5 MPa
temperature: 80°C (176°F)
} considering extreme hot "OFF"-conditions

proof of integrity: e.g. burst test → T = 80°C (176°F), p ≥ 3 MPa

Component Materials

aluminium alloys mainly

Experiences

well established over many years

State-of-the-Art Air Conditioning Systems Driven by R744

Design Conditions Assumed for Components "HP-Side"

pressure: 16 MPa
temperature: 180°C (356°F)

} considering extreme hot "ON"-conditions

proof of integrity, e.g.:

① burst test:
$p \geq 3 * 16\,\text{MPa} = 48\,\text{MPa}$ (compressor)
$p \geq 5 * 16\,\text{MPa} = 80\,\text{MPa}$ (pressure vessel)
} 180°C (356°F)

(acc. to European Standards)

② fatigue test: still to be defined / standardized

Design Conditions Assumed for Components "LP-Side"

pressure: 11 MPa
temperature: 80°C (176°F)

} considering extreme hot "OFF"-conditions

proof of integrity, e.g.:

① burst test:
$p \geq 3 * 11\,\text{MPa} = 33\,\text{MPa}$ (compressor)
$p \geq 5 * 11\,\text{MPa} = 55\,\text{MPa}$ (pressure vessel)
} 80°C (176°F)

(acc. to European Standards)

② fatigue test: still to be defined / standardized

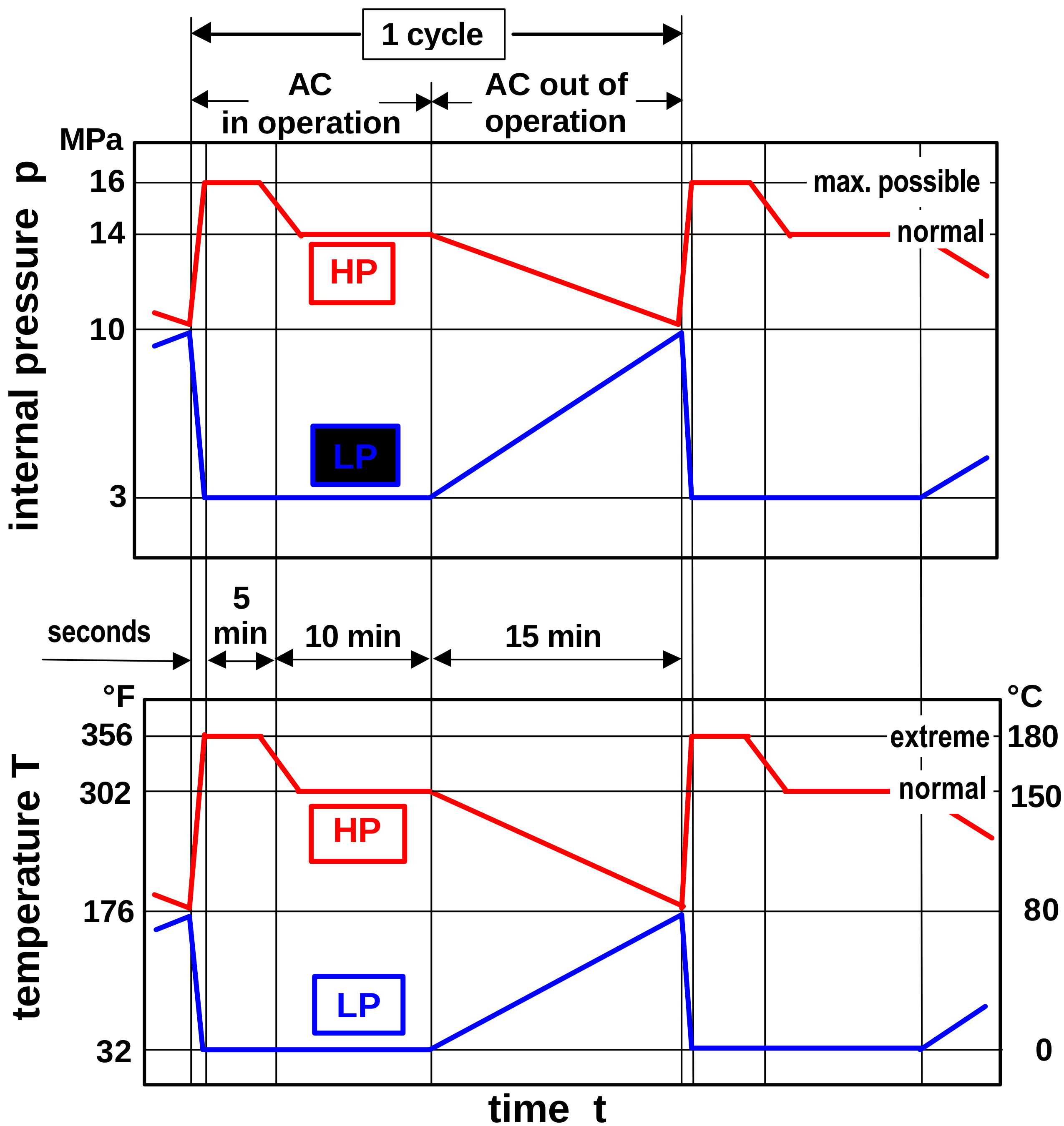
Experiences: prototype tests

- **State of the European Standards**
- **State-of-the-Art**
- **Postulation of Operational Loading for Pressurized Components of AC Systems Driven by R744**
- **Material Specific Aspects**
- **Proposal for Component Tests**
- **Conclusion**

Operational Pressure and Thermal Loading

Ride Postulation: **City cruising at extreme hot conditions**
24 cycles a day for 15 years lifetime
15 minutes “ON“ / 15 minutes “OFF“

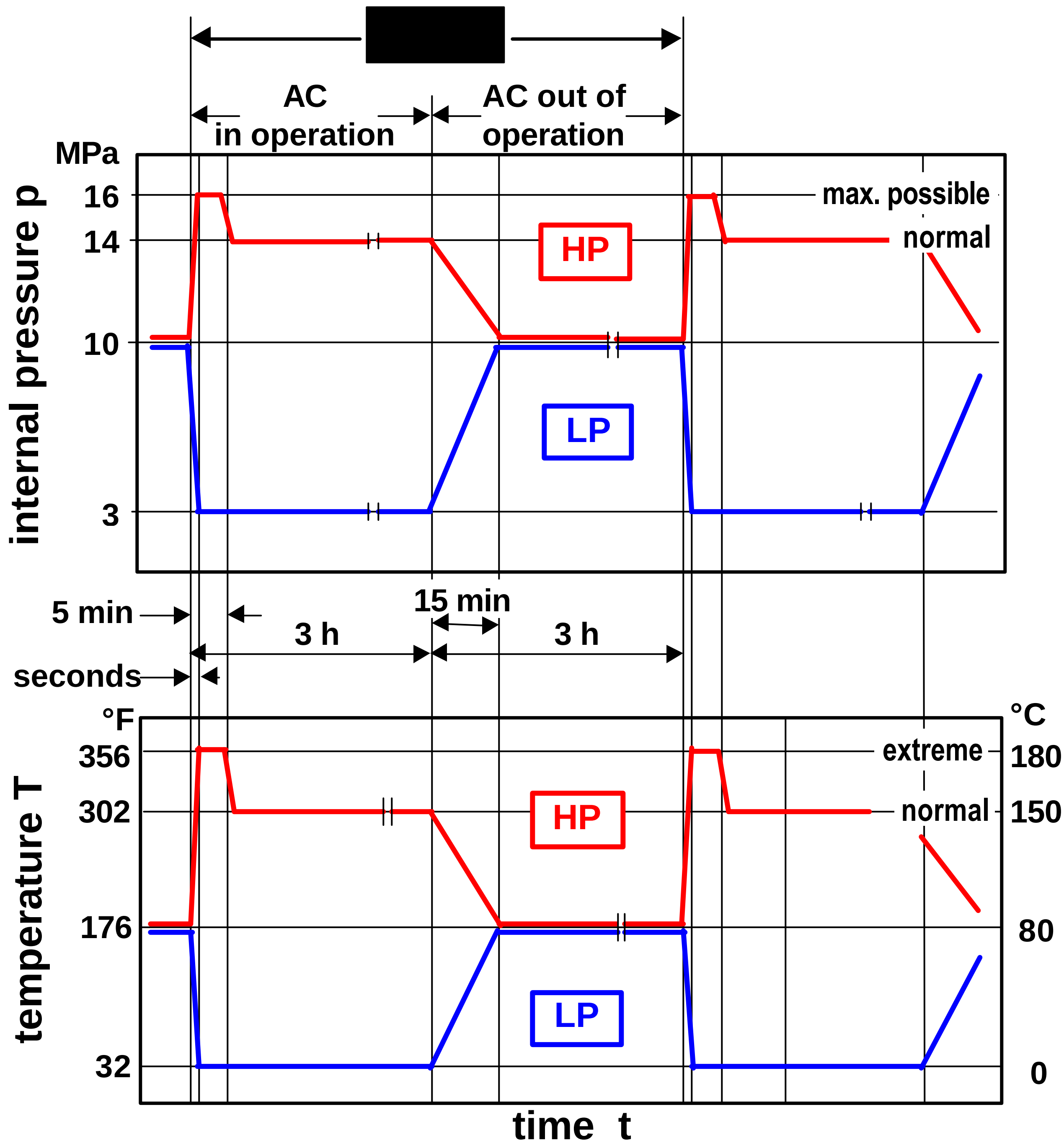
Objective: **Definition of test parameters for fatigue tests**



Operational Pressure and Thermal Loading

Ride Postulation: <u>On road cruising at extreme hot conditions</u>
2 cycles a day for 15 years lifetime
3 hours “ON“ / 3 hours “OFF“

Objective: Definition of test parameters for fatigue tests



Design Criteria for Components of “HP-Side“

RIDE POSTULATION

- City cruising at extreme hot temperatures for 15 years lifetime
- 24 cycles a day (15 minutes “ON“, 15 minutes “OFF“)

COMPONENT LOADING

Highest pressure and thermal loading under “ON“-conditions (city cruising)

description	summation	results
cyclic pressure	$p_{max} - p_{min}$ = 16 MPa - 10 MPa	$p_{max} - p_{min}$ = 6 MPa
number of cycles	N = 24 cycles a day * 365 days * 15 years	N = 131 000 cycles
time t_H (Holding period) under constant [1)] p = 16 MPa T = 180°C (356 °F)	S t_H = 5min * 24 cycles a day * 365 days * 15 years	S t_H = 11 000 h

[1)] Example: phase of the first 5 minutes after start up

Design Criteria for Components of “LP-Side“

RIDE POSTULATION

- On road cruising at extreme hot temperatures for 15 years lifetime
- 2 cycles a day (3 hours “ON“ / 3 hours “OFF“)

COMPONENT LOADING

Highest pressure and thermal loading under “OFF“-conditions (on road cruising)

description	summation	results
cyclic pressure	p_{max} - p_{min} = 10 MPa - 3 MPa	p_{max} - p_{min} = 7 MPa
number of cycles	N = 2 cycles a day * 365 days * 15 years	N = 11 000 cycles
time t_H (Holding period) under constant p = 10 MPa T = 80°C (176 °F) [1)]	S t_H = 3 hours * 2 cycles a day * 365 days * 15 years	S t_H = 33 000 h

[1)] 3 hours “OFF“-conditions per cycle

- **State of the European Standards**
- **State-of-the-Art**
- **Postulation of Operational Loading**

- **Material Specific Aspects**

- **Proposal for Component Tests**
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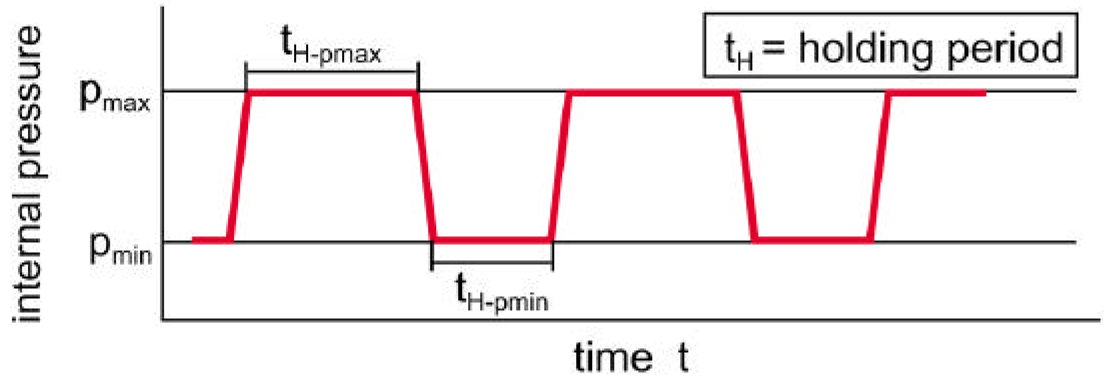
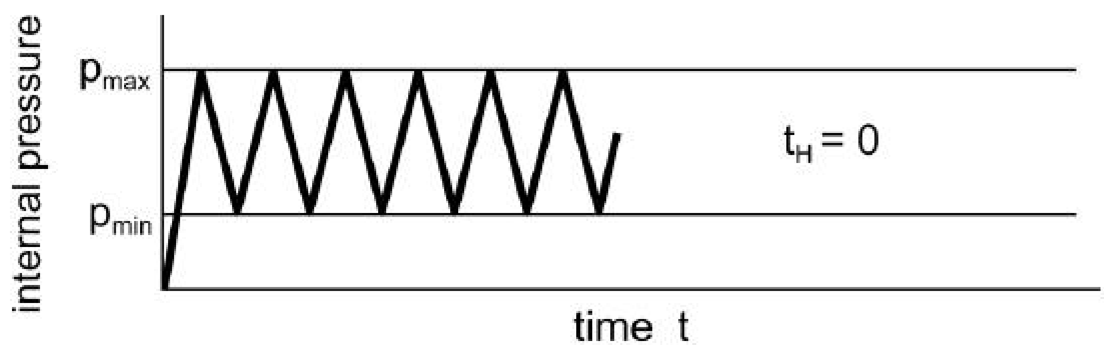
Idealization of Component Loading

Idealization *(schematic)*

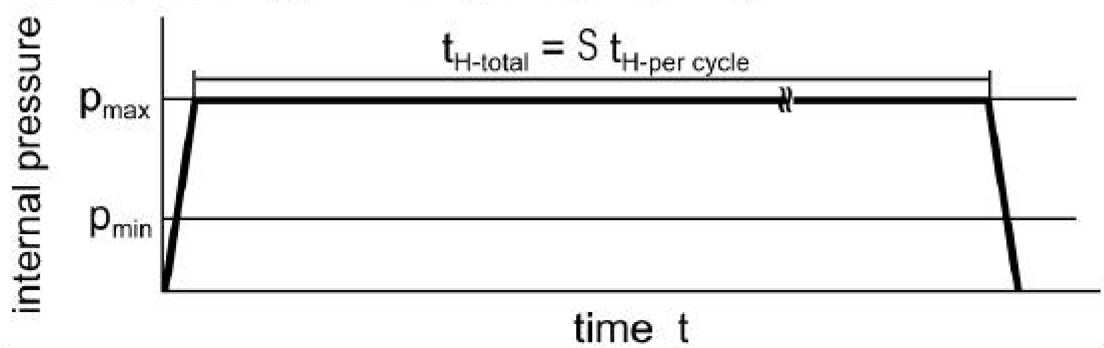


Superposition of

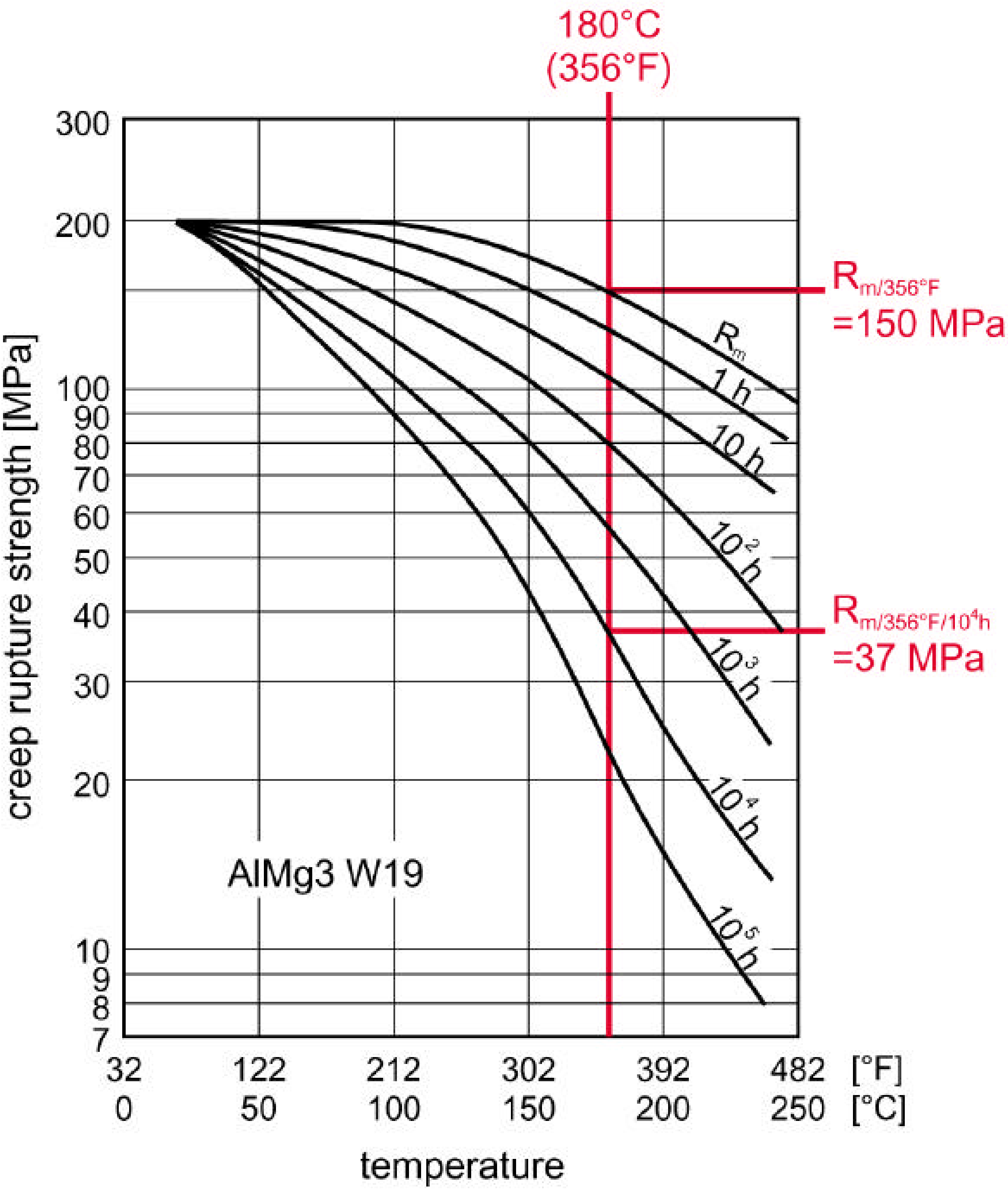
1 fatigue loading ***(failure by fatigue crack growth)***



2 creep loading ***(failure by creep rupture)***



Example of the Creep Behaviour of Aluminium Alloys



MPA Philosophy

Concerning the Design of Components for Automotive Refrigerant Systems

- The burst test doesn't describe the loading of the components in an operation-related manner

- An alternative test method is recommended covering the following objectives
  - Consideration of the fatigue as well as the creep behaviour of materials
  - Consideration of the requirements concerning product liability
  - Introduction in existing standards for automotive systems

- **State of the European Standards**
- **State-of-the-Art**
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- **Material Specific Aspects**

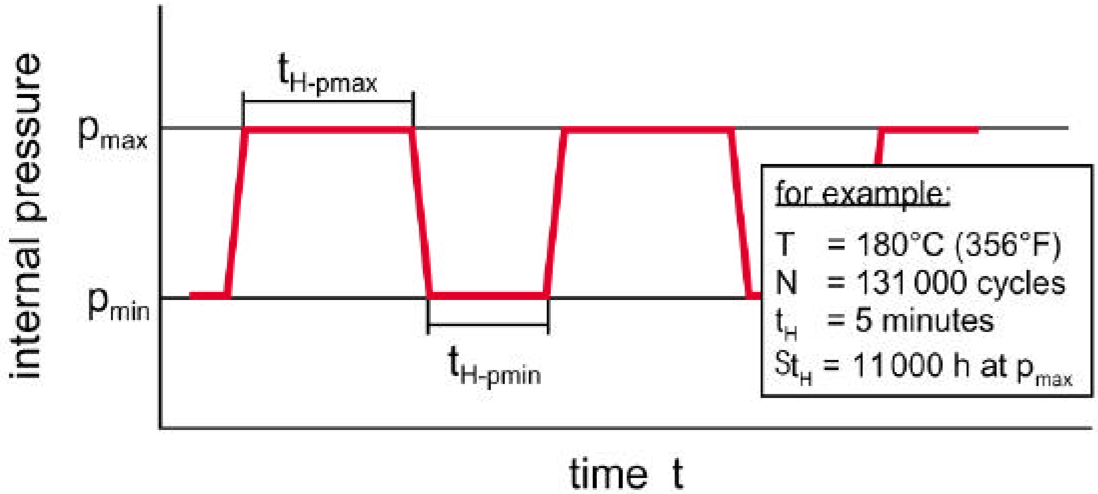
• Proposal for Component Tests

- **Conclusion**

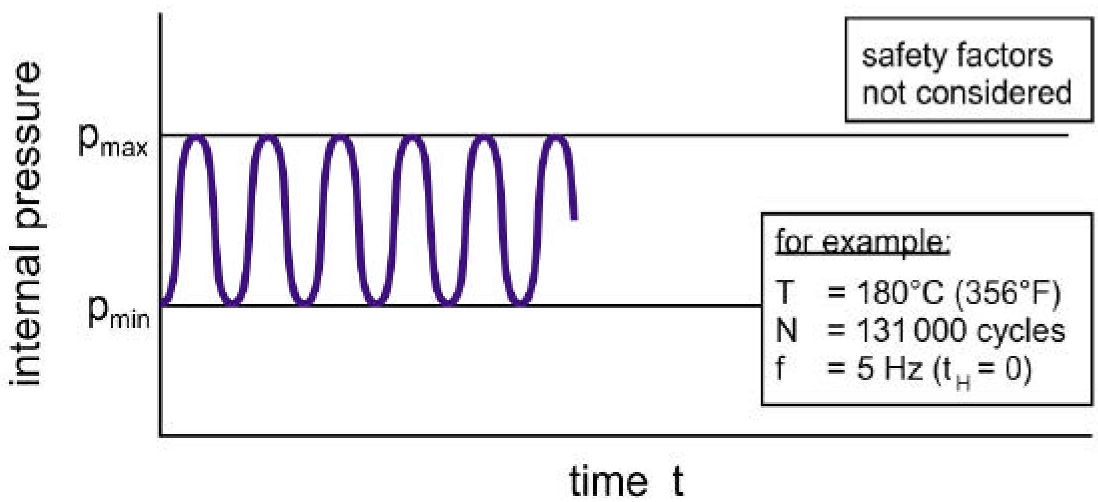
Proposal for Component Tests
Component Material: ~~Steel~~

Basis: No creep effects of the material have to be considered in the range of temperatures up to about 300°C (572 °F)

Idealization of the operational loading *(schematic)*



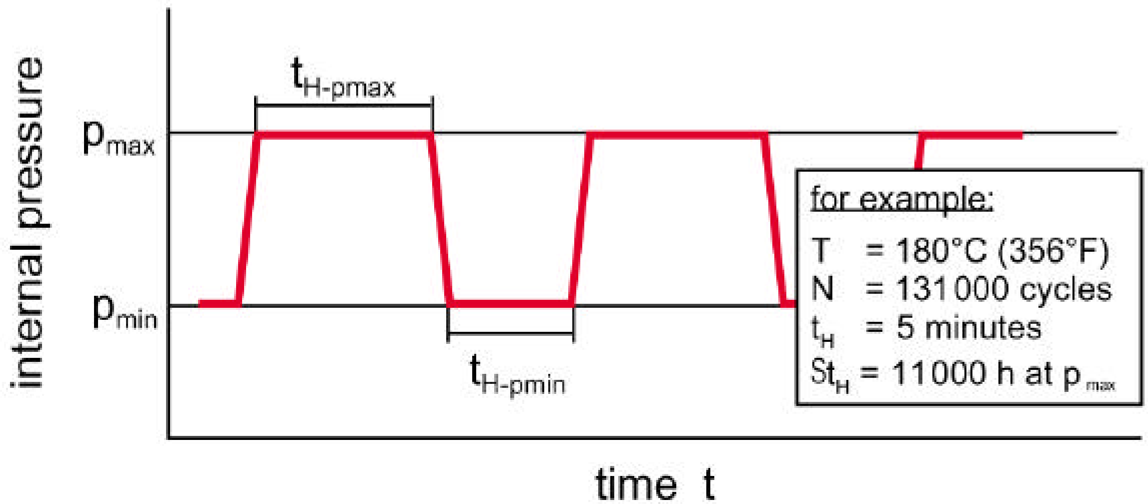
Component test
(cyclic internal pressure, sinusoidal or triangular)



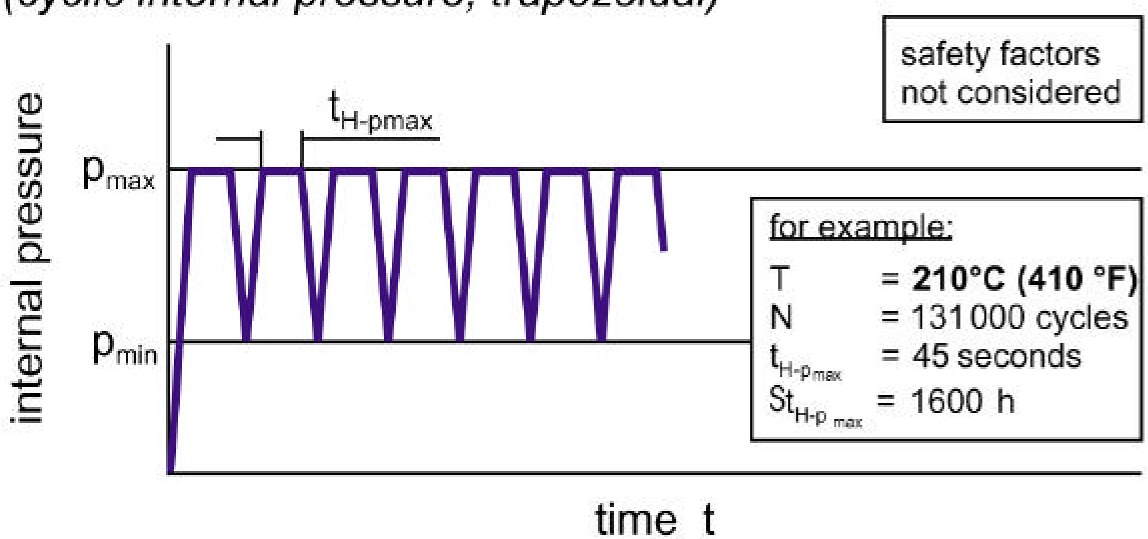
Proposal for Component Tests
Component Material: ~~Aluminium Alloys~~

<u>Basis:</u> Creep-fatigue effects of the Material have to be considered at temperatures above about 50°C (122 °F)

Idealization of the operational loading *(schematic)*

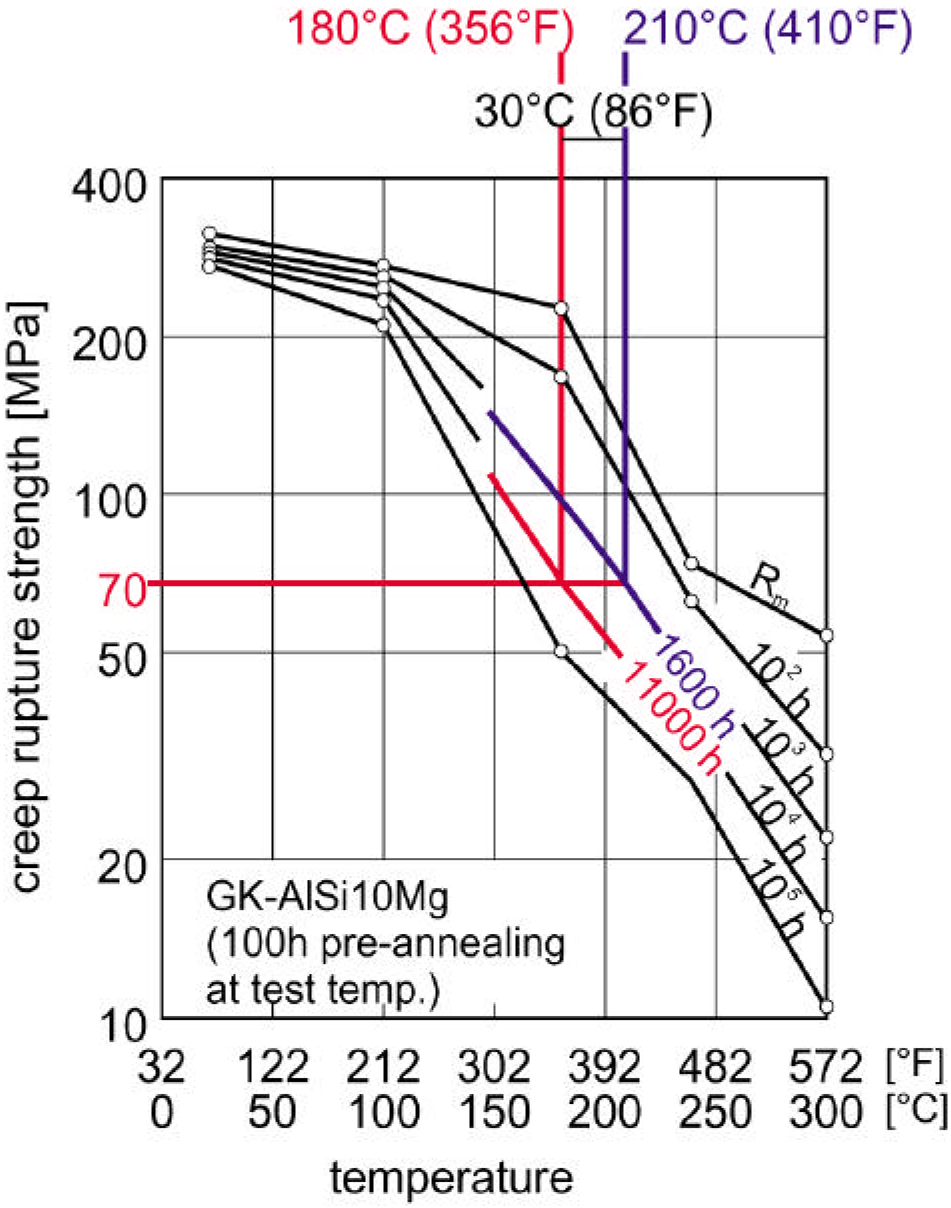


Component test
(cyclic internal pressure, trapezoidal)



Creep Test: Reduction of Holding Time up to Rupture by Raising the Test Temperature

Example: Cast Aluminium Alloy (stress 70 MPa)
Reduction of Holding Time from 11000 h to 1600 h



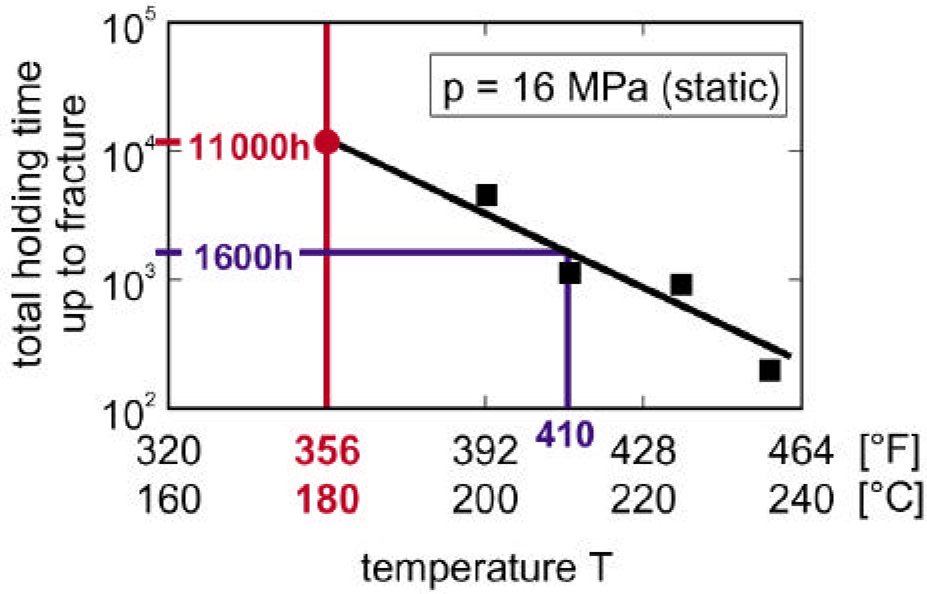
Creep Tests with Components under Static Internal Pressure in Case of Missing Creep Rupture Values

Objective: Assessment of elevated temperatures for the cyclic internal pressure tests

Idealized Operation Conditions (e.g.):

T	= 180°C (356 °F)
p_{max} - p_{min}	= 16 MPa - 10 MPa
N	= 131 000 cycles for 15 years lifetime
t_H	= 5 minutes *(holding time at p_{max})*
Σ t_H	= 11 000 h vor 15 years lifetime

Creep Tests under Static Internal Pressure (schematic)



Parameters Derived for the Cyclic Internal Pressure Tests

T	= 210°C (410 °F)
p_{max} - p_{min}	= 16 MPa - 10 MPa
N	= 131 000 cycles (safety factor not considered)
t_H	= 45 seconds *(holding time at p_{max})*
Σ t_H	= 1 600 h *(duration of the test)*

Proposal for Component Tests

Final Burst Test

Objective	determination of the safety margin against fracture
Requirement	to be carried out with the component of the fatigue test respectively creep-fatigue test burst pressure $p \geq 1.5 * $ maximum allowable pressure test temperature T = design temperature of the component
Example	burst pressure $p \geq 1.5 * 16$ MPa = 24 MPa test temperature T = 356°F

CONCLUSION

1. The European Standards do not cover all automotive specific aspects of the pressure equipment for refrigerating systems and heat pumps

2. An operation orientated method is recommended as supplementation to the existing standards and to guarantee product liability

3. This method should consider the fatigue as well as creep loading

4. The creep-fatigue test with additional burst test is to be regarded as an operation orientated scientific method and in this way implies a practical supplementation to existing standards as well as aspects of product liability

5. It is intended to verify the proposed creep-fatigue test by a research project

6. Independent of the design method the operational loading of the components has to be assumed as precise as possible