RUHR-UNIVERSITÄT BOCHUM

Chair of Drive Technology | Prof. Dr.-Ing. Manuel Oehler

Testing the tooth root fatigue strength of gears using resonance testing machines

60th anniversary of RUMUL Russenberger Prüfmaschinen AG

Alexander Thomas M. Sc.

LEHRSTUHL FÜR ANTRIEBSTECHNIK

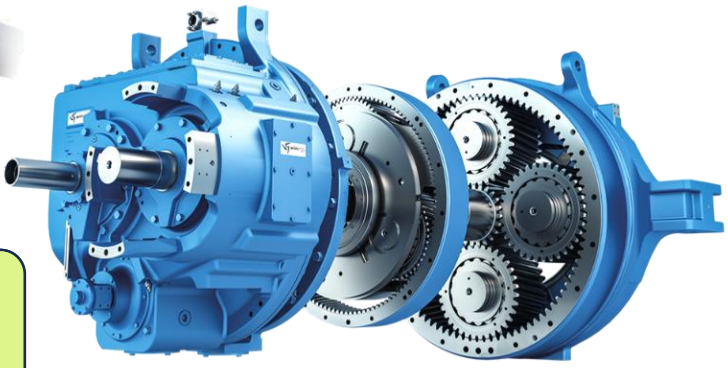
Chair of Drive Technology (ante)

Research on Gears – but why?

Industrial Applications

- Gearboxes convert torque and rotational speed within the drivetrain


Goal 2030:
~ 10-15 % reduction in
kerosene consumption

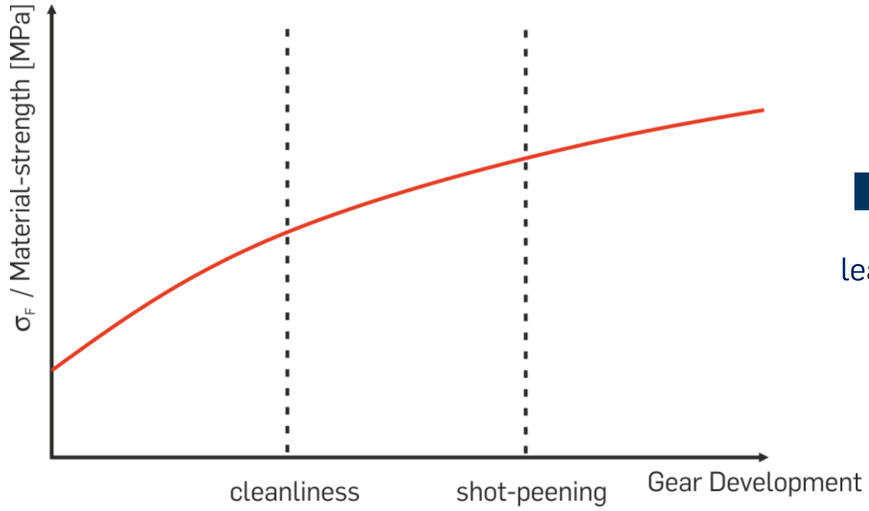


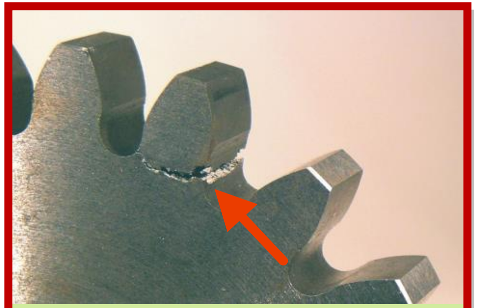

Goal: 2030
> 20 MW power in
Off-shore applications

Research on Gears – but why?

Increase the tooth root strength

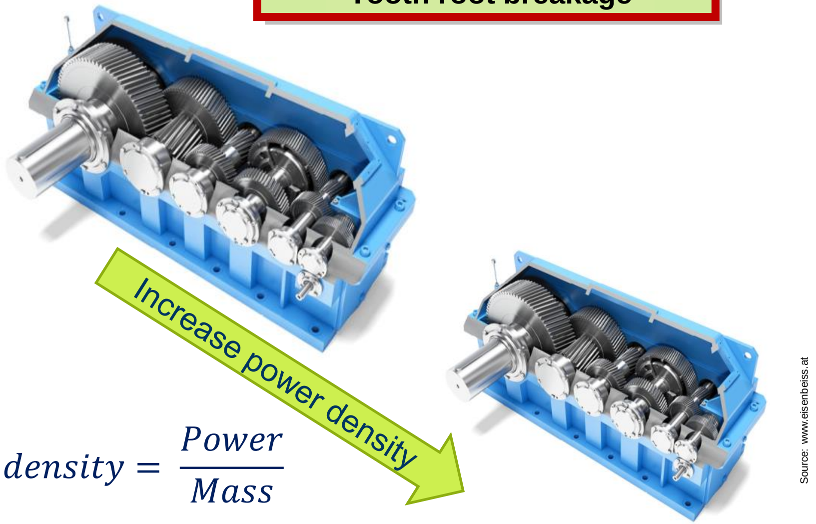
- to increase power density for gearboxes
- to increase the service life of gearboxes





Tooth root breakage

leads to..

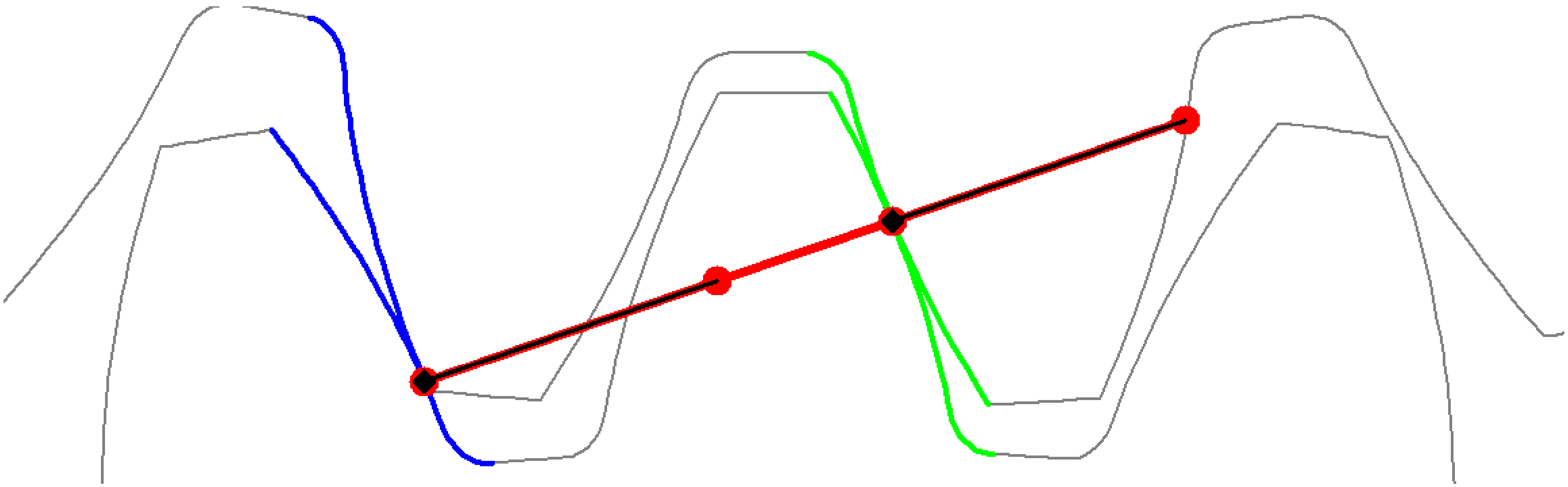


$$power\ density = \frac{Power}{Mass}$$

RUHR UNIVERSITÄT BOCHUM RUB

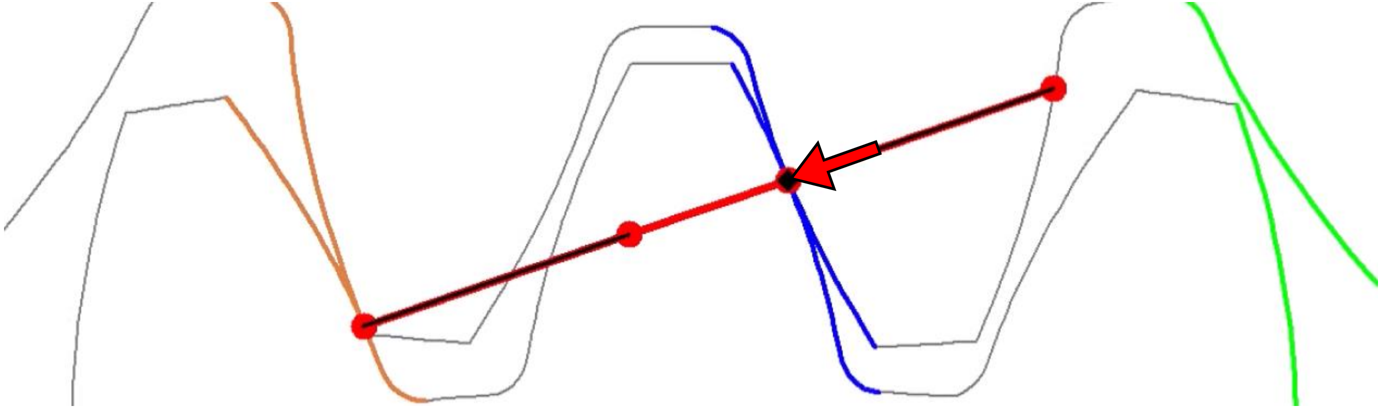
Tooth root stress

- Meshing of involute gears – origin of tooth root stresses



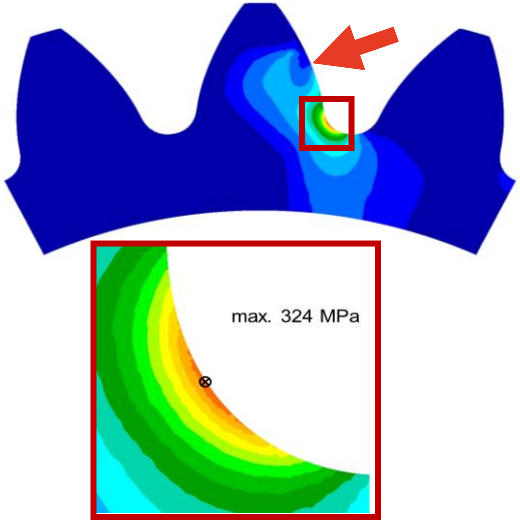
Tooth root stress

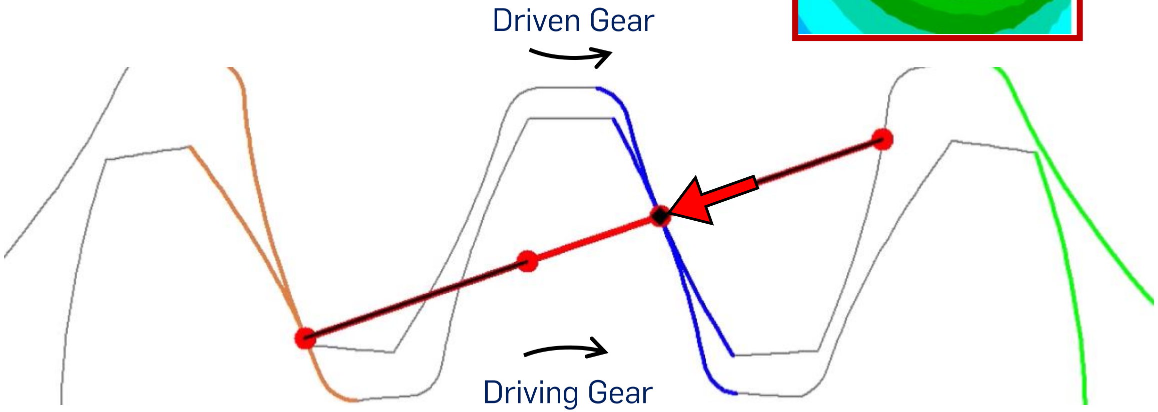
- Several stress types in the tooth root summing up to a multistate stress
  - Tensile/compressive stress
  - Bending stress
  - Shear stress

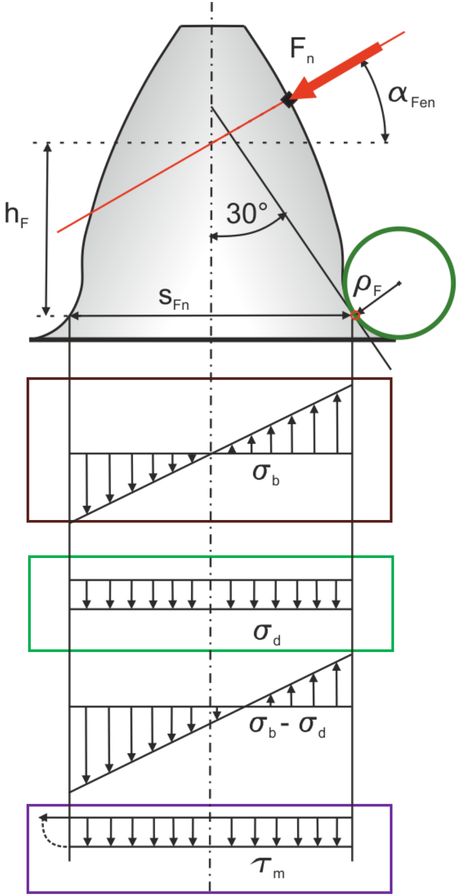


Tooth root stress

- Several stress types in the tooth root summing up to a multistate stress
  - Tensile/compressive stress
  - Bending stress
  - Shear stress







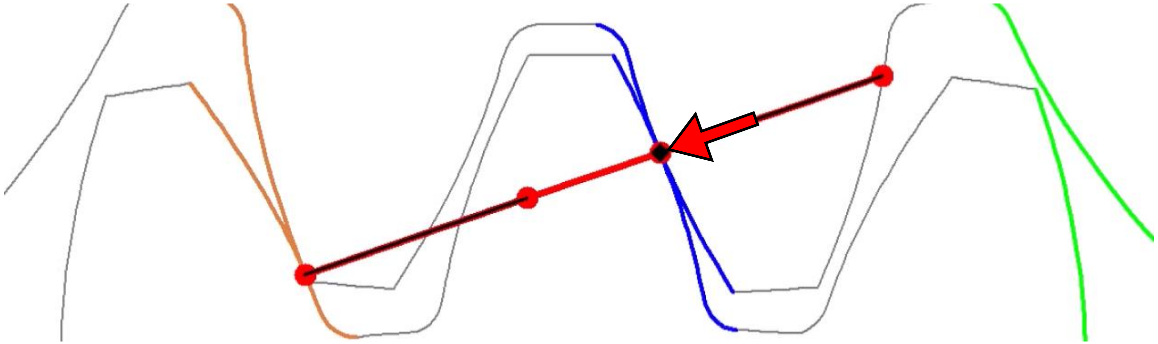
Tooth root stress

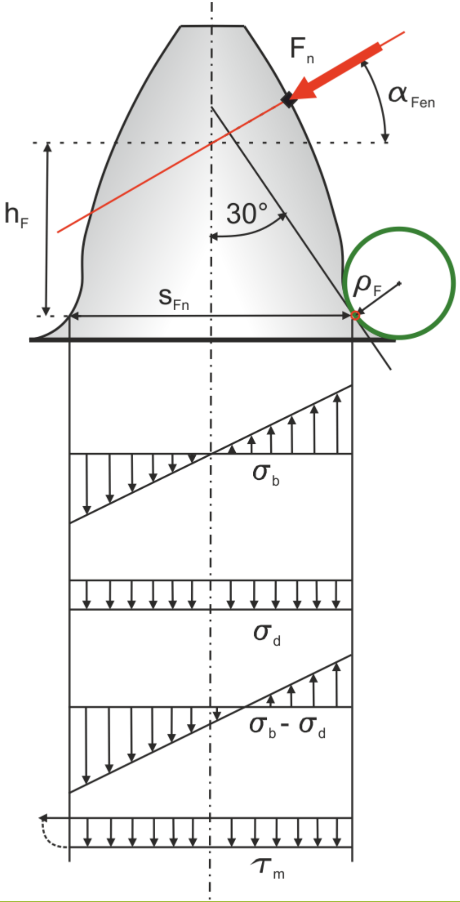
- Calculation of the tooth root bending strength σ_F acc. to ISO 6336-3

$$\underbrace{Y_F \cdot Y_S \cdot Y_\beta}_{\text{Geometry}} \cdot \underbrace{\frac{F_n \cdot \cos(\alpha_n)}{b \cdot m_n}}_{\text{Load (Tooth bending stress)}} \cdot \underbrace{K_A \cdot K_V \cdot K_{F\alpha} \cdot K_{F\beta}}_{\text{Application}} < \underbrace{\sigma_F \cdot Y_{ST} \cdot Y_{NT} \cdot Y_{\delta\, rel\, T} \cdot Y_{R\, rel\, T} \cdot Y_X}_{\text{Material}}$$

Geometry | Load (Tooth bending stress) | Application | Material

Why is the tooth root bending strength σ_F for the gear design that important?



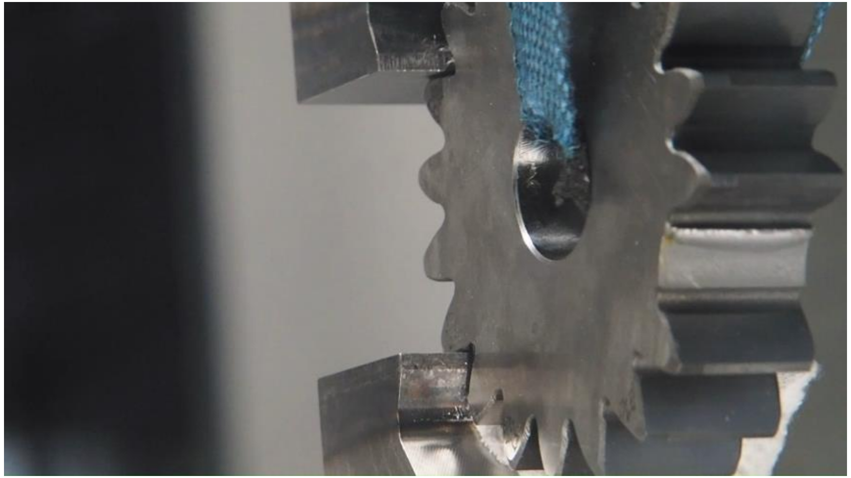


RUHR UNIVERSITÄT BOCHUM RUB

Tooth root fatigue strength

Significance of the tooth root bending strength

- Failure of the tooth root of a gear = fatigue damage type
- Gears have to sustain high number of load cycles ($> 10^6$)



How can the tooth root bending strength be tested?

Tooth root fatigue strength

Fatigue strength testing

- Fatigue life analysis: design of components that can withstand a given external load for a specific time

Running test

Pulsator test

Tooth root fatigue strength

Fatigue strength testing

- Fatigue life analysis: design of components that can withstand a given external load for a specific time

Running test

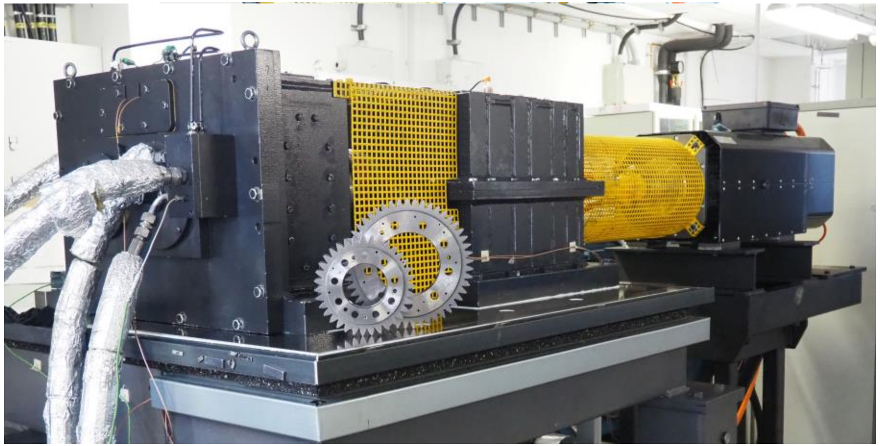
Pulsator test

Tooth root fatigue strength

Fatigue strength testing

- Fatigue life analysis: design of components that can withstand a given external load for a specific time

Running test



Pulsator test

Tooth root fatigue strength

Fatigue strength testing

- Fatigue life analysis: design of components that can withstand a given external load for a specific time

Running test

$$N = 6 \cdot 10^6$$

$$n_{Pulsator} = 100\ Hz$$

$$n_{running} = 1500\ rpm = 25\ Hz$$

$$t_{Pulsator} = 16.6\ H$$

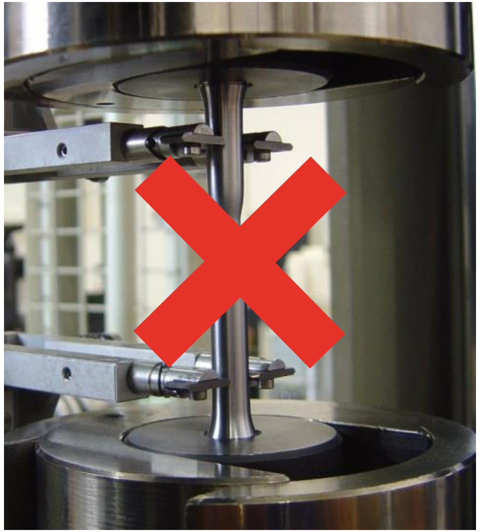
$$t_{running} = 66.6\ H$$

Pulsator test

Tooth root fatigue strength

Fatigue strength testing

- Fatigue life analysis: design of components that can withstand a given external load for a specific time

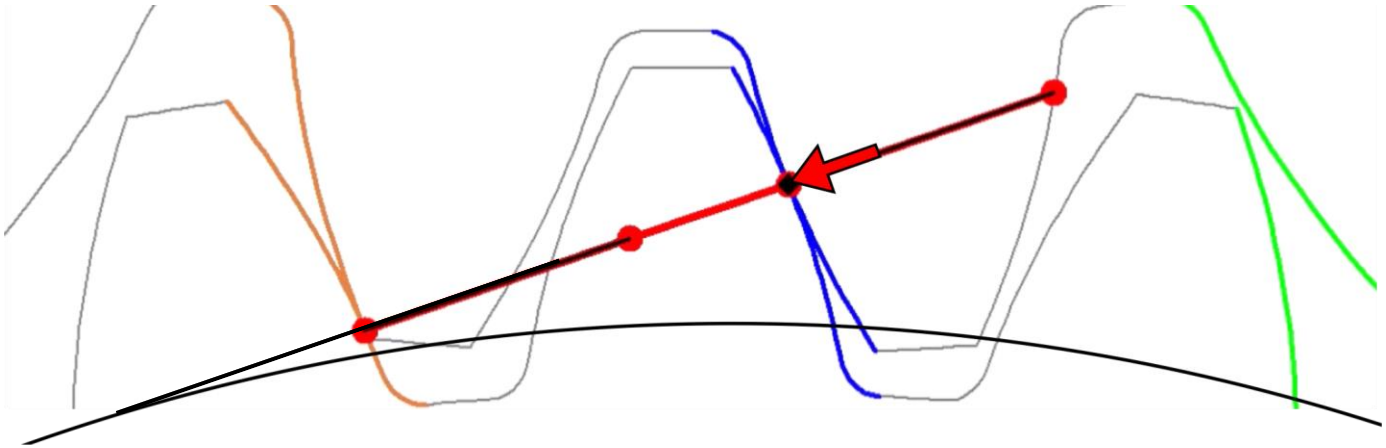


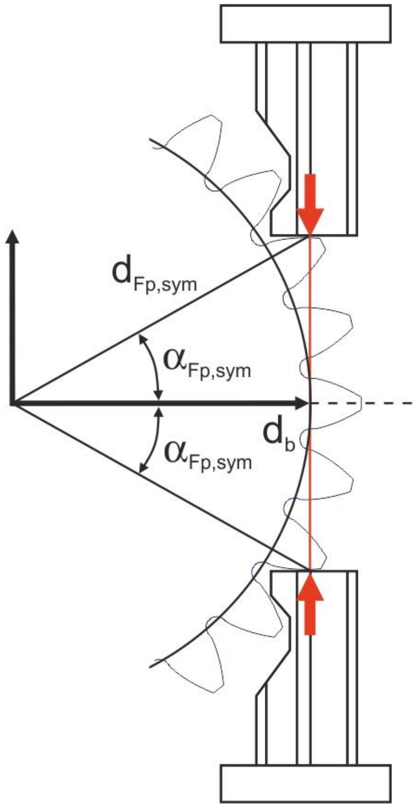
Is it possible to mount a gear into a pulsator machine?

Tooth root fatigue strength

Involute Function

- How can we clamp a curved body like a gear wheel under a resonance machine with uniaxial force application?

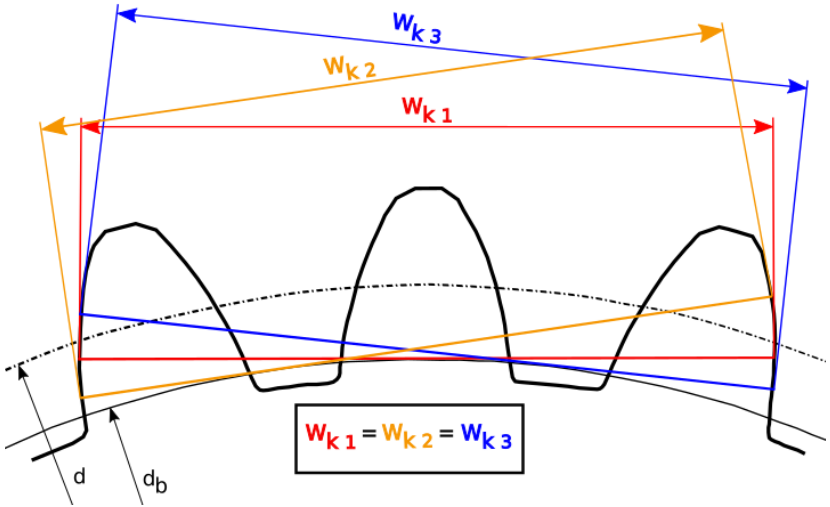


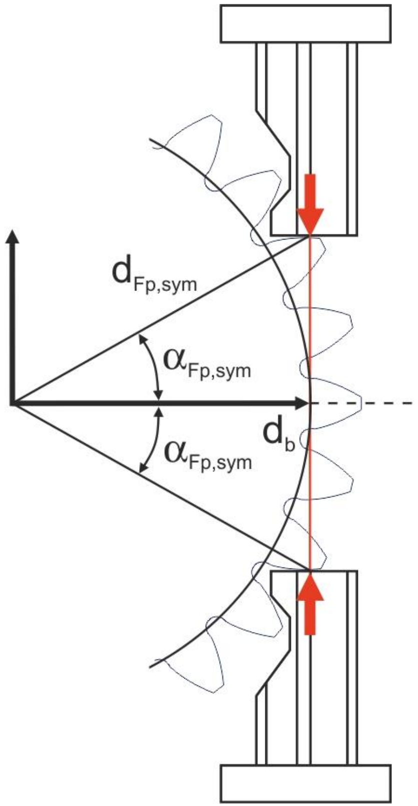


Tooth root fatigue strength

Involute Function

- How can we clamp a curved body like a gear wheel under a resonance machine with uniaxial force application?





Tooth root fatigue strength

Determination of the tooth root load carrying capacity

- S/N-Curve:
    - Correlation between load and number of load cycles

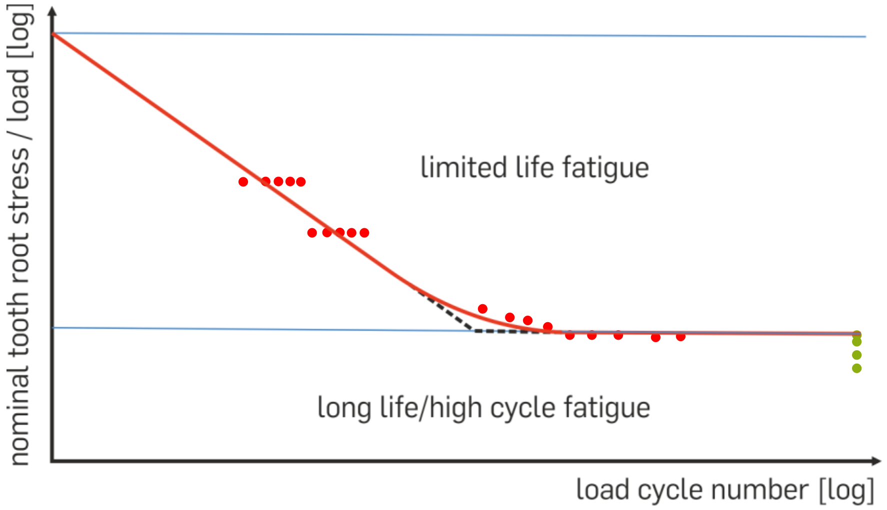
Procedure:

1. Determination of long life/high cycle fatigue

    Staircase - Method

2. Determination of limited life fatigue

    Horizon - Method

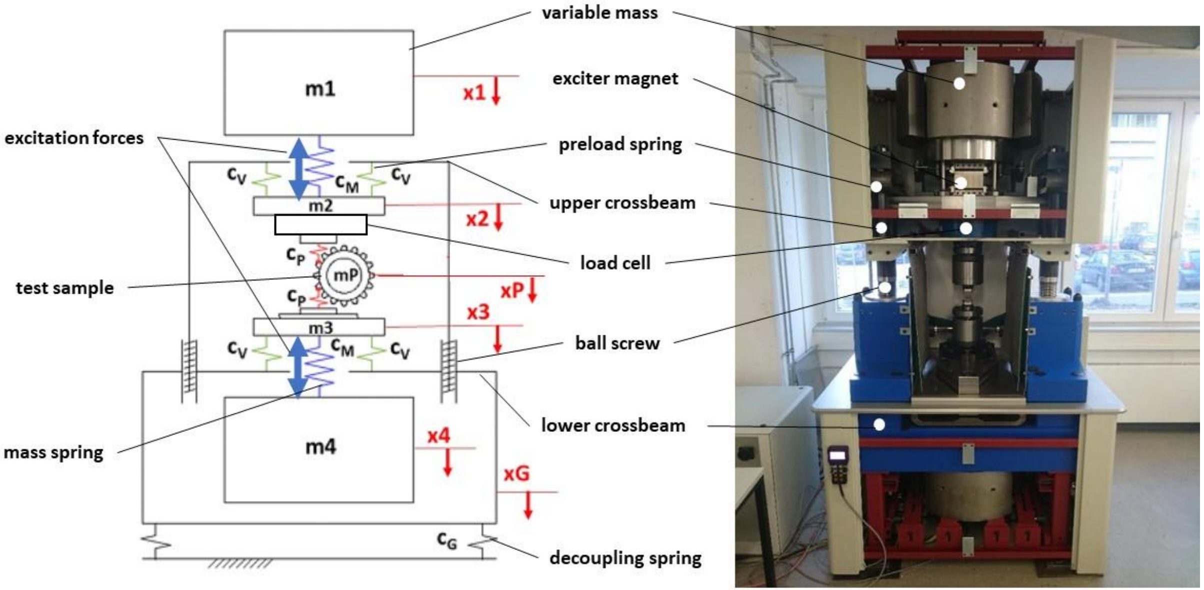


Test rig

Rumul VIBROFORTE 500

Electro-magnetically excited high-load resonance pulsator

- Test frequency $f_p = 50 - 160$ Hz
- Max. force $F_{max} = 500$ kN
- Stat. force $F_{stat} = +/- 500$ kN
- Dyn. force $F_{dyn} = +/- 250$ kN
- Max. stroke $s_{max} = +/- 2$ mm



RUHR UNIVERSITÄT BOCHUM

Variety of test specimens

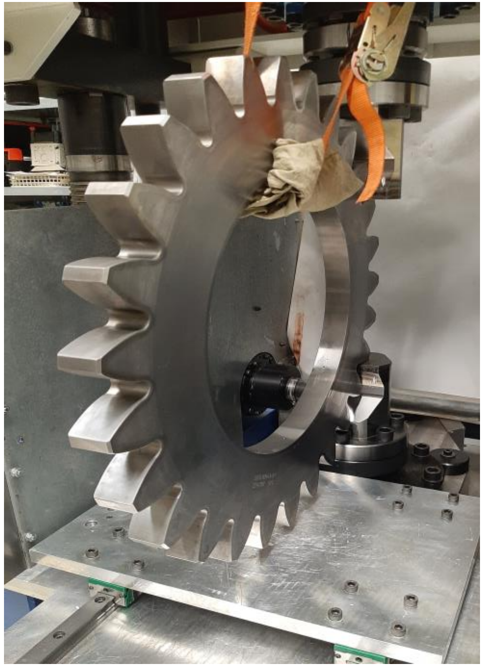
$d_a < 100\ \text{mm}$

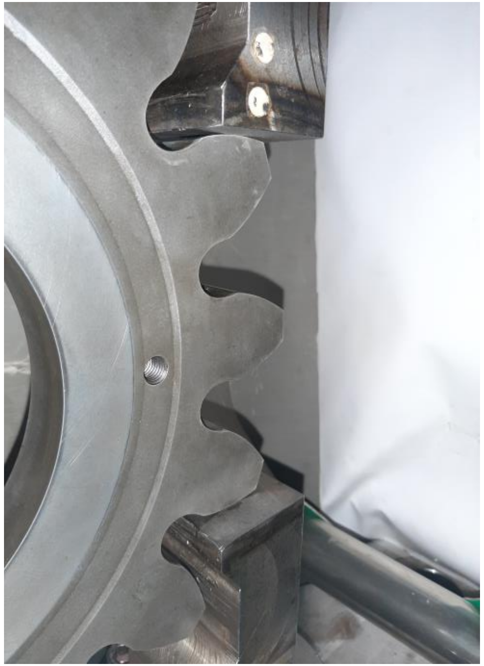
Specimen true to scale

$100\ \text{mm} < d_a < 500\ \text{mm}$

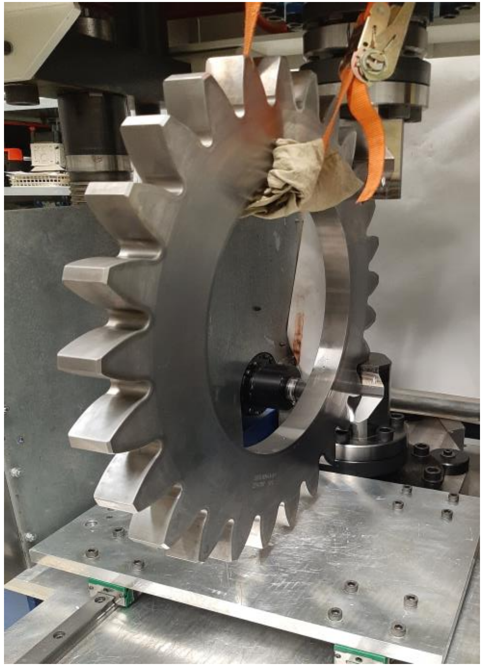
$d_a > 500\ \text{mm}$

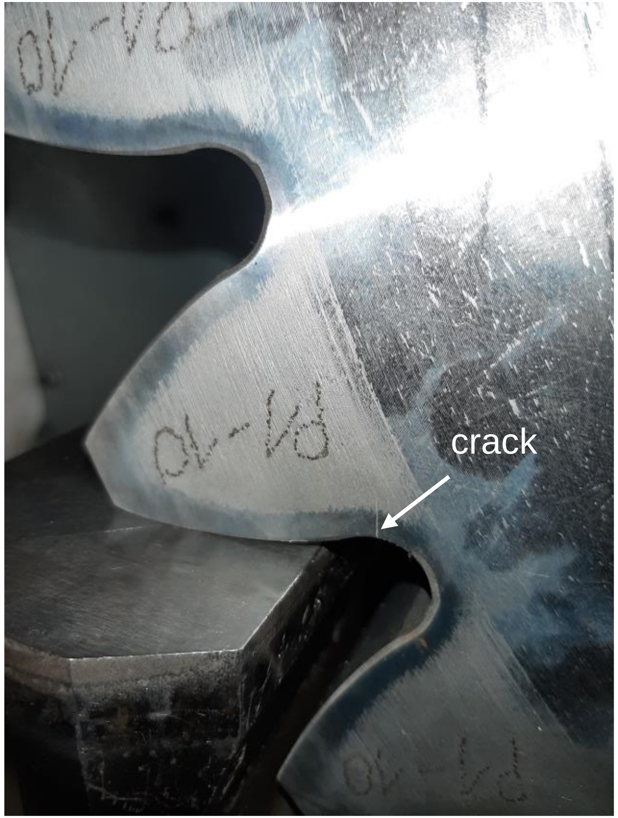
Test examples



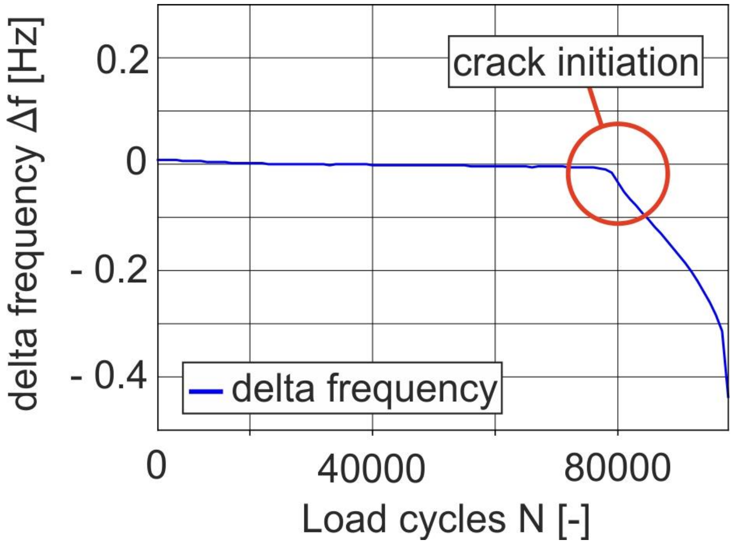


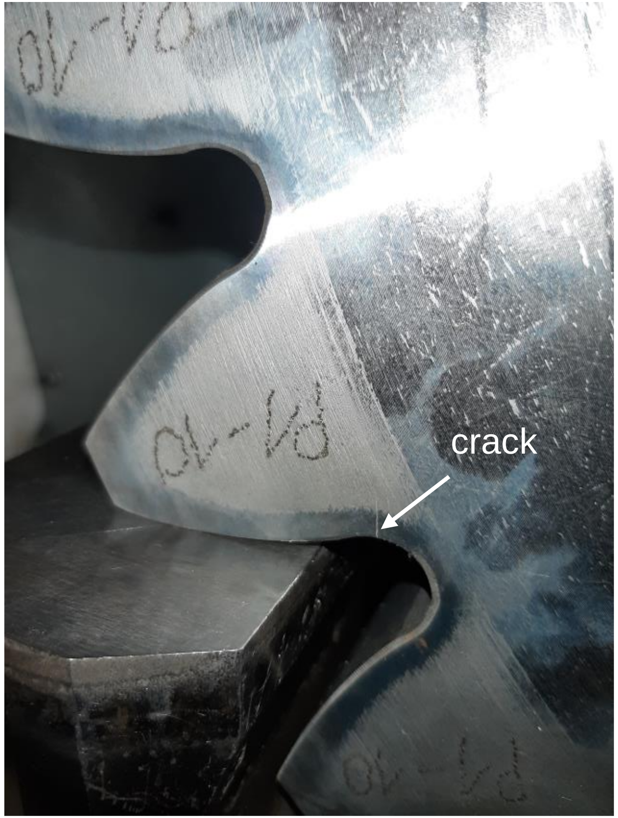
Test examples





Test examples

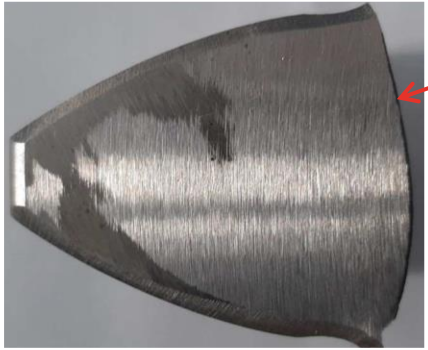


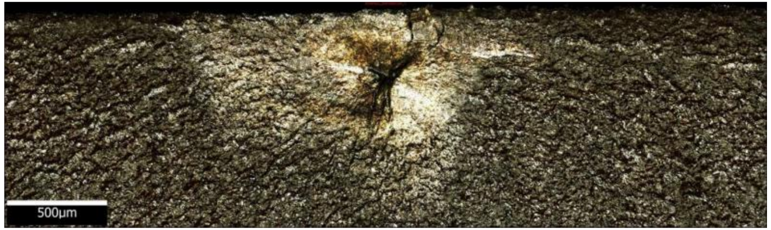


Crack and fracture surface investigation

- Crack: Localization of the crack in the tooth root fillet
- Surface:
  - Heat treatment
  - Crack starting point/propagation
  - Material condition: e.g. ductility

Fracture surface



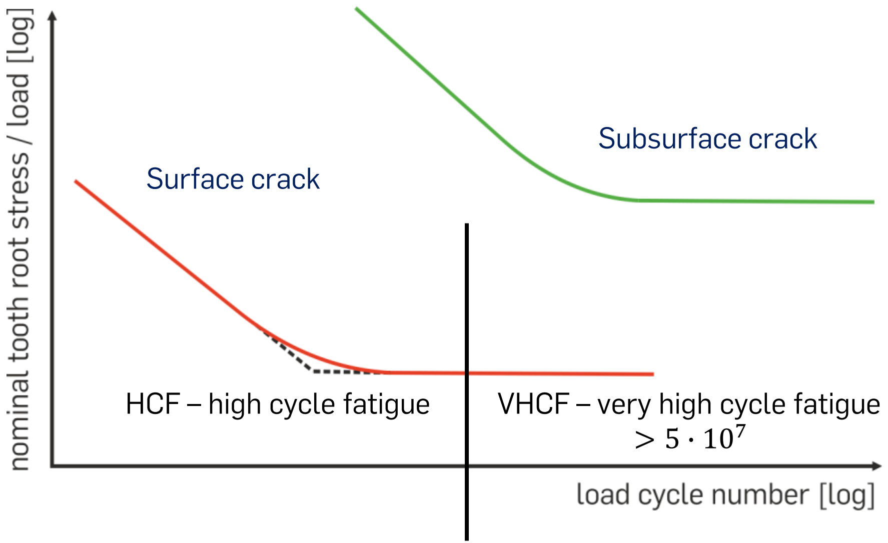


Outlook – Research on Gears

Research in the very high cycle fatigue

- allows the investigation of failure due to subsurface cracks
- provides higher in depth material knowledge
- allows a design for higher power density for longer time

How can we test the tooth root fatigue strength of gears for such high number of load cycles?



Outlook – Research on Gears

HCF – High cycle fatigue

$$N = 6 \cdot 10^6$$

$$n_{Pulsator} = 100\ Hz$$
$$n_{running} = 1500\ rpm = 25\ Hz$$

$$t_{Pulsator} = 16.6\ H$$
$$t_{running} = 66.6\ H$$

VHCF – Very high cycle fatigue

$$N = 5 \cdot 10^7$$

$$n_{Pulsator} = 100\ Hz$$
$$n_{running} = 1500\ rpm = 25\ Hz$$

$$t_{Pulsator} = 138.8\ H = 5.79\ days$$
$$t_{running} = 555.6\ H = 23.15\ days$$

How can we test the tooth root fatigue strength of gears for such high number of load cycles?

Outlook – Research on Gears

GIGAFORTE 50

Die GIGAFORTE 50 wurde speziell für Versuche im VHCF Bereich entwickelt. Mit einer Prüffrequenz von 1000 Hz können Versuche mit mehr als 100 Millionen Lastwechsel in kurzer Zeit gefahren werden. Es können Standardproben und kleine Bauteile kraft- oder dehnungsgeregelt zyklisch belastet werden.

Technische Daten

Max. Scheitelwert der Kraft	50 kN Zug/Druck
Max. Schwingbreite der Kraft	50 kN (+/- 25 kN)
Max. statische Kraft	+/- 50 kN
Dynamischer Weg	0,2 mm (+/- 0,1 mm)
Prüffrequenz	ca. 1000 Hz *(+/- ca. 3 % abhängig von der Probensteifigkeit)*

GIGAFORTE 50

$$N = 5 \cdot 10^7$$

$$n_{Gigaforte} = 1000\ Hz$$

$$t_{Gigaforte} = 13.8\ H = 0.58\ days$$

$$t_{Pulsator} = 138.8\ H = 5.79\ days$$

$$t_{running} = 555.6\ H = 23.15\ days$$

Thank you for your attention

A. Thomas

alexander.thomas-z4j@rub.de

+49 234 32 26286

www.rub.de/ifa