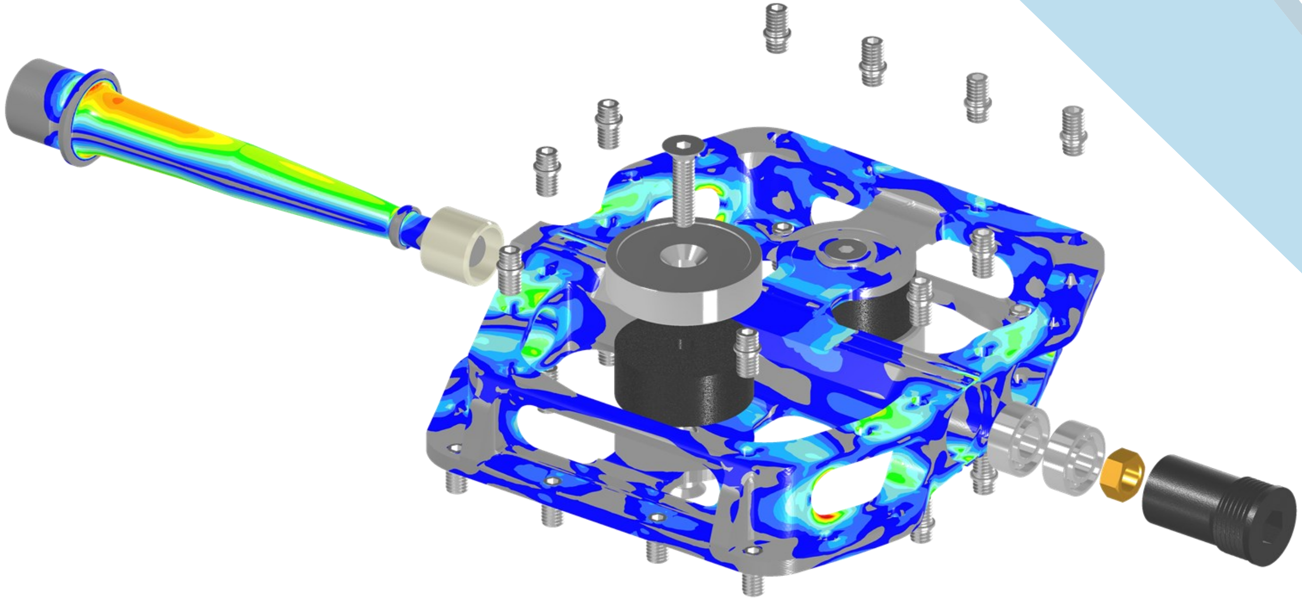
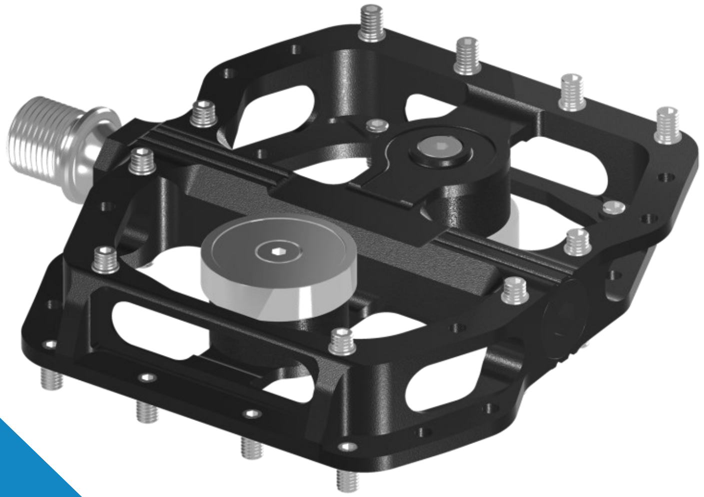
magnetic safety bike pedals
magped
ENDURO2



Design, FEM strength analysis and testing of an innovative mountain bike pedal with magnetic locking mechanism



12th SAXSIM 2023, TU Chemnitz

Rev. 1.1 | 07.03.2023

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Strukturrsimulation
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Table of Contents

Strukturcommitted Strukursimulation

1. Introduction

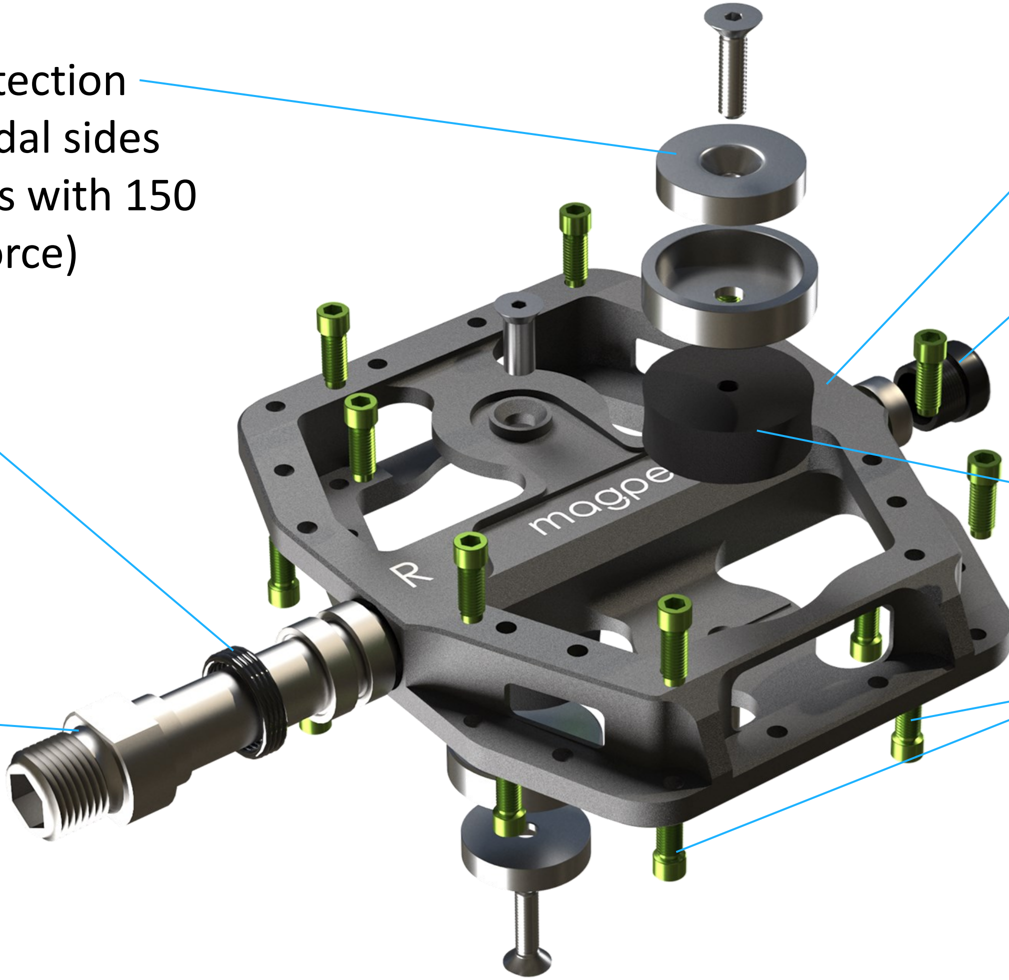
1.1 Short presentation of the predecessor mountain bike pedal model

Design and design characteristics of the predecessor mountain bike pedal “Enduro1” by magped GmbH

magnets in steel protection chamber on both pedal sides (two magnet versions with 150 or 200 N magnetic force)

elastomer sealing

steel axis (simply supported by sliding bushing and ball bearing)



aluminum pedal body

aluminum end cap for bearing fixation

elastomer foam elements for flexible magnet fixation (patented)

steel or aluminum bolts/pins (can be individually mounted/configured)

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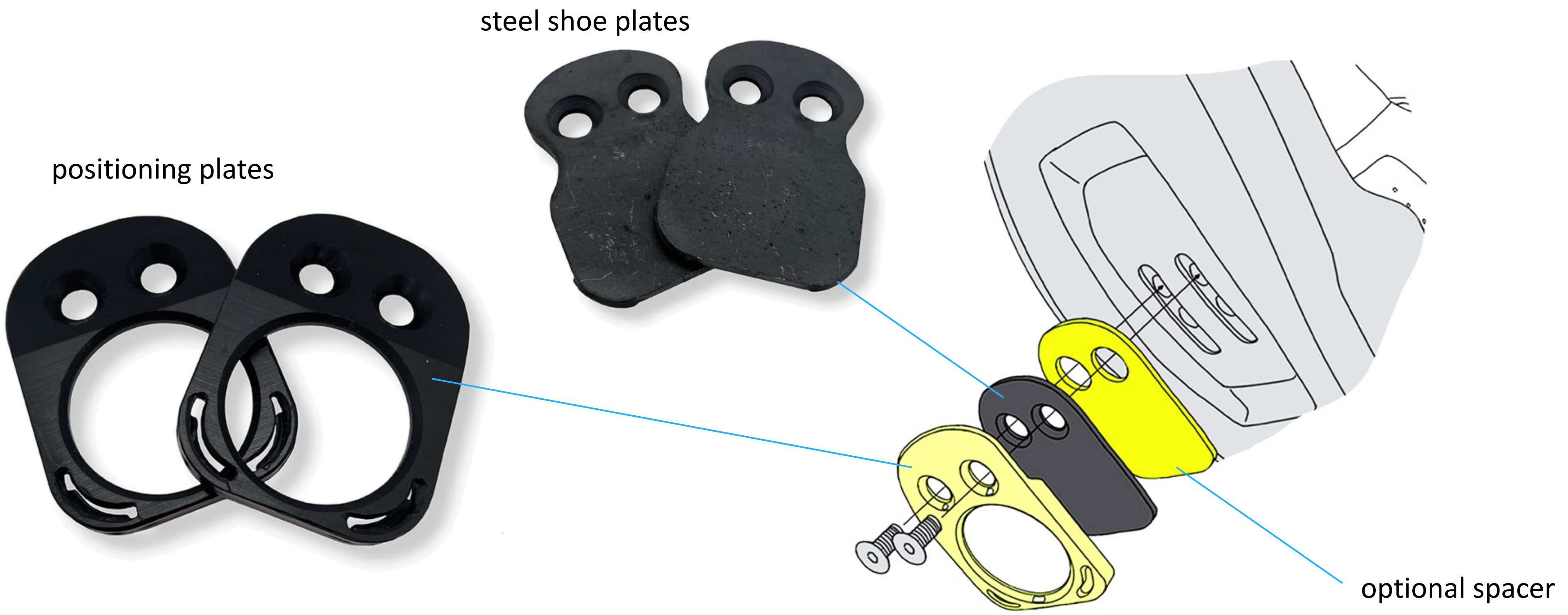
1. Introduction

1.1 Short presentation of the predecessor mountain bike pedal model

The shoe side…

- The magped magnetic system is compatible with shoes designed for the standard Shimano SPD system



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1. Introduction

1.2 Manufacturer product range

Different pedals with the patented magnetic locking mechanism & accessories

SPORT2

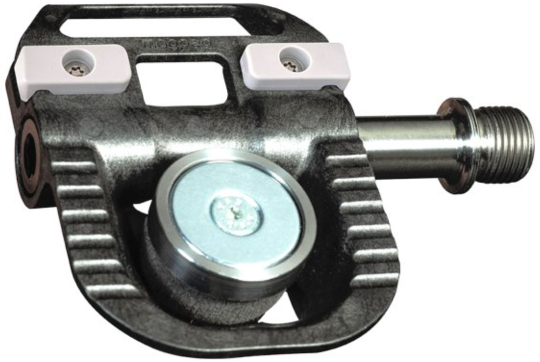
- entrance model
- steel axis and aluminum body
- mass 420 / 440 / 458 g (depending on magnet type 100 – 150 – 200 N)

ULTRA2

- universal model
- titanium axis and magnesium body
- mass 320 / 338 g

ROAD

- for road/racing bikes
- titanium axis and aluminum body
- mass 270 g



GRAVEL

- for gravel bikes
- titanium axis and xCarbon body (carbon fiber reinforced plastics)
- mass 212 g

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1. Introduction

1.3 Company presentation

magped GmbH

- Small company founded 2018 and located in Aldrans, Austria
- Team consists of just 4 persons
- Pedals and pedal prototypes are developed and manufactured in Austria
- Serial production of CNC milled pedals and axes as well as their preassembly are carried out in Asia; final completion with magnets and QA is done in Austria
- Pedals with Polyketon/Carbon bodies (approx. 30 % of the products) are completely produced and assembled in Austria, as well as small parts, shoe plates etc.
- For more details, see www.magped.com

Harald Himmler

Paul Wessiak

Hias Peer

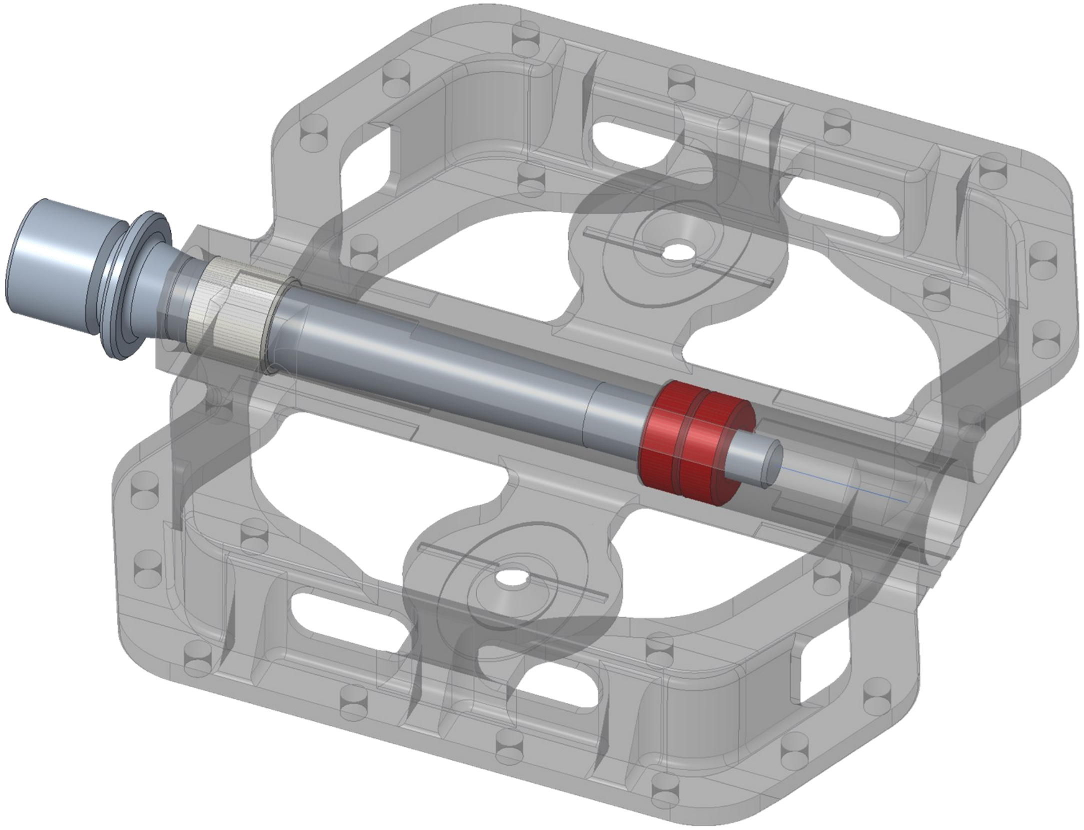
Katja Wessiak-Offenstein

1. Introduction

1.4 Development objectives and initial design draft of the successor pedal model “Enduro2”

Development objectives

- Significant mass savings: Enduro1 pedal mass is 578 g per pedal pair with strongest (200 N) magnets (4x) incl. pins; this was often criticized in product tests
  - ➢ Enduro2 target mass shall be significantly less than 0.5 kg even with biggest magnet type!
- Increased reliability and robustness *despite mass savings:*
  - ➢ FEM analysis and optimization becomes important part of product development!
- Triple instead of double bearing support for pedal axis
- Widened (broader) pedal body for better grip/comfort
- Typical “magped” design: Enduro2 design must be clearly visible as further development of the Enduro1 product design
  - ➢ The initial design draft at the start of the Enduro2 development project is shown on the right



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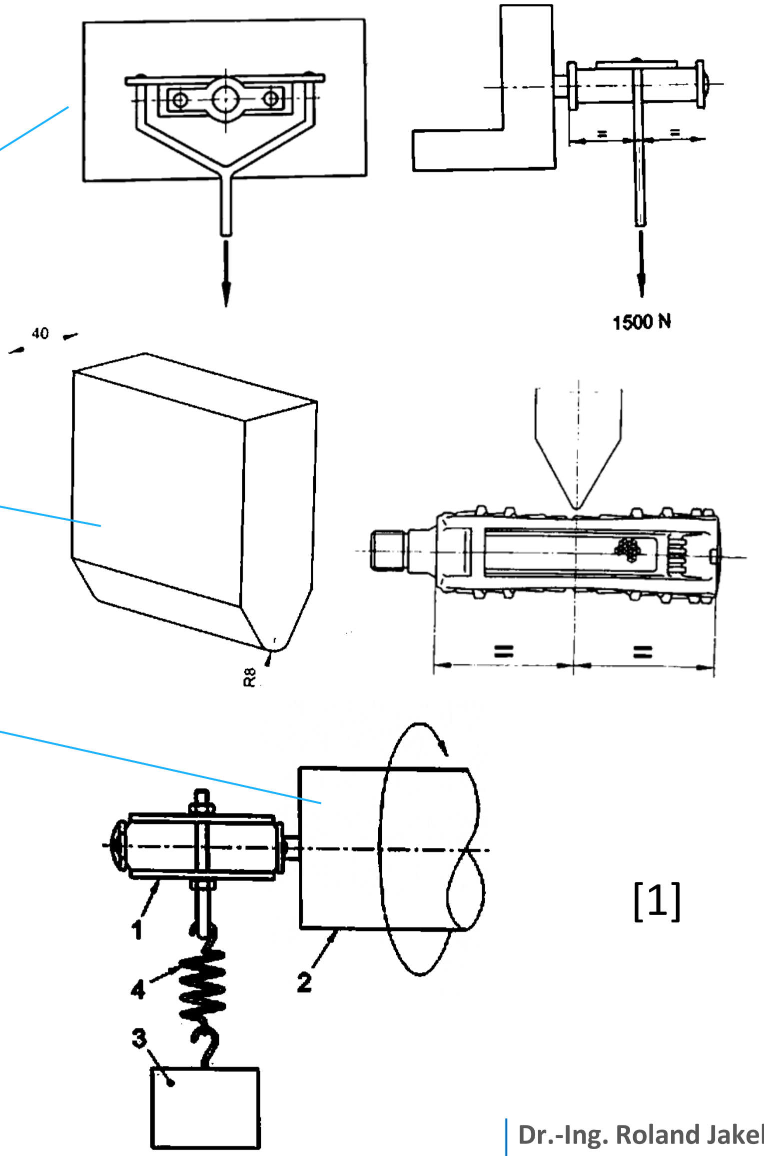
2. Determination of the load cases for design & optimization

2.1 Load cases acc. to DIN EN ISO 4210

Loads for bicycle pedals

- DIN EN ISO 4210 gives load values for testing
- The following tests are specified for bike pedals [1]
    1. Static test with 1500 N centrally applied load for 1 min
    2. Impact test with a drop mass of 15 kg, drop height 400 mm, central impact on the pedal
    3. Dynamic testing:
        - Pedal (1) is bolted with its axis to a rotating test shaft (2)
        - A mass (3) of 90 kg (for mountain bikes) is fixed with a tensile spring (4) to the pedal center
        - 100000 rotations at a max. speed of 100 rpm have to be applied
        - pedals with two sides have to be turned over after 50000 rotations



[1]

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2. Determination of the load cases for design & optimization

2.2 Chosen load cases and qualification test program

Uncertainties

- DIN EN ISO 4210 does not define further load cases for the pedal body itself, perhaps because just the axis is really safety-critical (axis rupture may lead to severe accident, whereas a deformed pedal body can simply be replaced)
- The dynamic load of 90 kg/100.000 cycles for mountain bikes acc. to ISO 4210 can be regarded as a minimum requirement: Higher loads are preferred to obtain a more robust design for downhill biking
- A big uncertainty are special load cases and abuse especially in severe downhill applications; e.g. crash of the pedal body against a rock during pedaling

Finally chosen load levels, cases for numerical optimization and final qualification testing

- It was decided to design the pedal axis fatigue endurable for 100 kg (981 N) central load using the material data for bending fatigue strength
- Final product qualification test: 125 kg (1226 N) for 100000 cycles (instead of just 90 kg ISO 4210 load)
- Drop test acc. to EN ISO 4210, but drop height 720 mm instead of 400 mm (same 15 kg mass)
- Static test of 1500 N (is totally uncritical and no design driver!)
- In addition, a small pre-series of pedals is tested by mountain bikers in hard downhill applications

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3. Strength analysis and weight optimization of the pedal axis

3.1 Pre-optimization steps

Material selection

- For the pedal axis, a CrMo-steel with the following characteristic strength data is foreseen:
  - Yield strength 800 MPa
  - Ultimate strength 1000 MPa
  - Bending fatigue limit 480 MPa (464 MPa with taking into account the technological size factor[2])

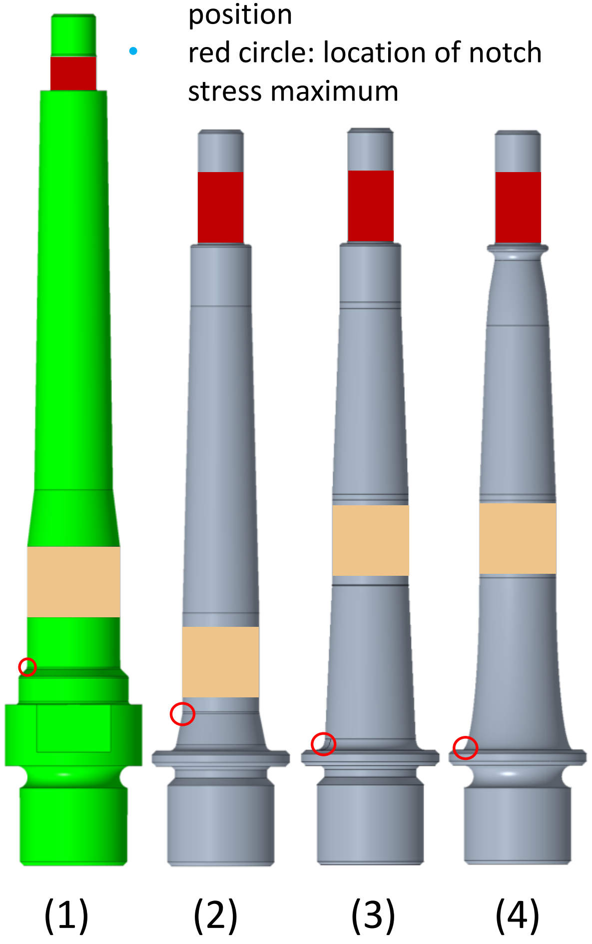
Determination of the „reference stress state“ of the old Enduro1 pedal axis (1)

- Comparison with the existing and well known Enduro1 pedal, of which approx. 40000 have been sold
  - For the reference load of 100 kg, the max. notch stress is 580 MPa, so this old axis design is not fatigue endurable for the new self-defined load level for improved robustness
  - However, this axis successfully surpasses the ISO 4210 dynamic loading test (100000 cycles / 90 kg)

Pre-optimization steps

- The initial Enduro2 design draft (2) with shorter axis had a max. notch stress of 755 MPa
- The next main design step (3) with shifted bearing location (allowing thicker cross sections in the high-loaded cone area and notch transition) offered a max. notch stress of 570 MPa and therefore was already slightly better than the initial Enduro1 design
- Further shape optimization (4) led to decreasing the max. notch stress to 463 MPa, so the design goal of fatigue endurability for 100 kg load was met for the first time

- red: ball bearing positions (double bearing for Enduro2)
- light brown: sliding bearing position
- red circle: location of notch stress maximum



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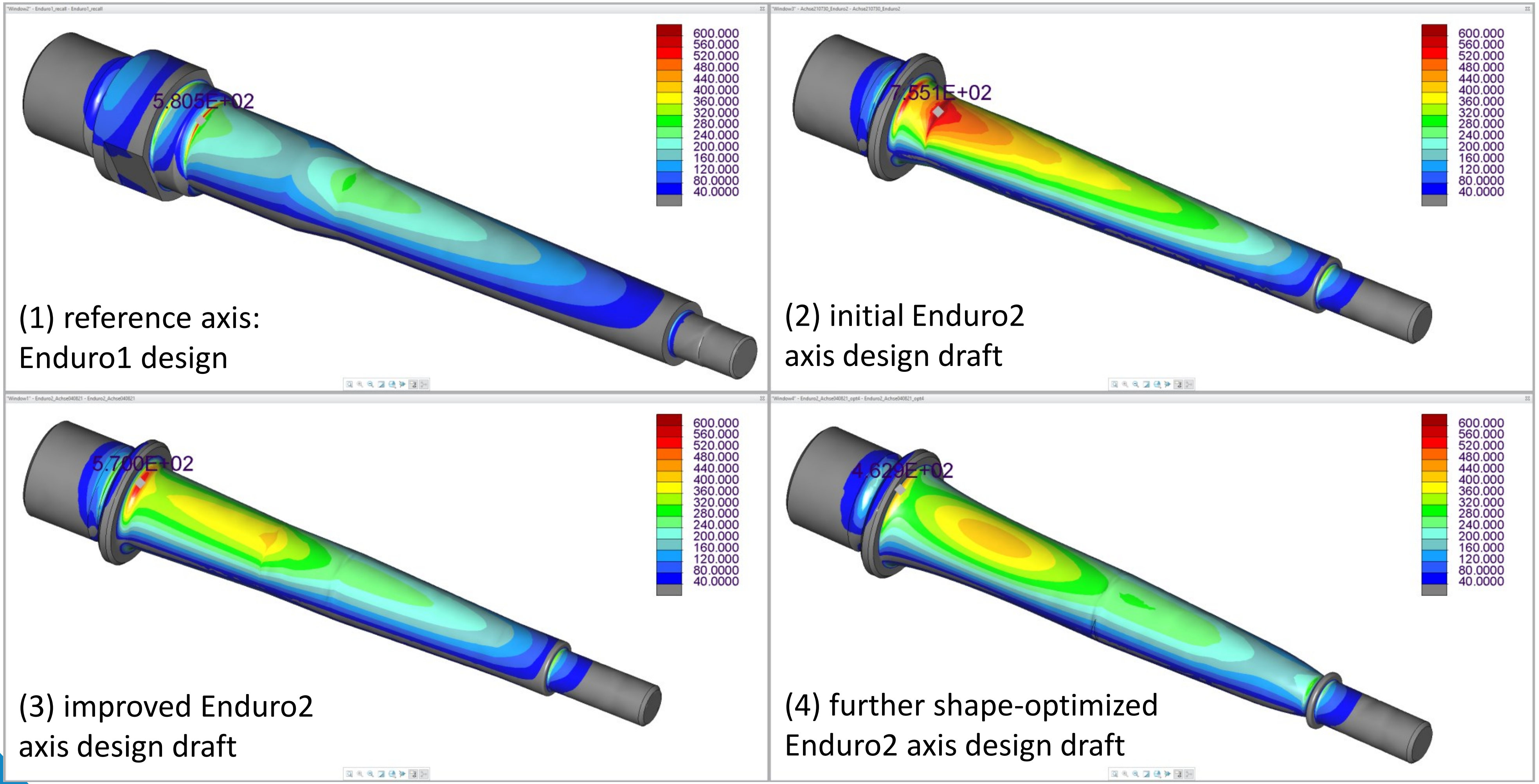
3. Strength analysis and weight optimization of the pedal axis

3.1 Pre-optimization steps

Stress states for 100 kg load (fatigue endurance limit: 464 MPa)



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3. Strength analysis and weight optimization of the pedal axis

3.2 Optimized shape

Theoretical consideration of the pedal axis

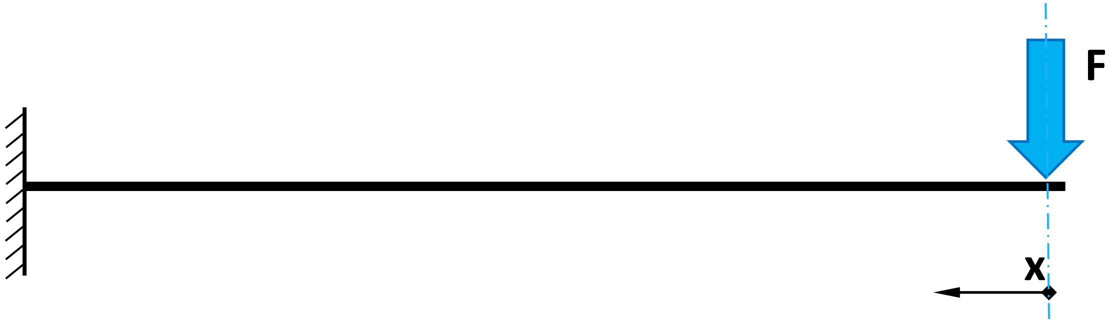
- Simplified, the pedal axis is a free cantilever beam with circular cross section
- For obtaining minimum mass and optimum material utilization, the edge fiber tension of the axis should always be constant
- If we neglect stress from the lateral force and take into account just stress from the bending moment, this leads to the following equation for the edge fiber tension with w_b = bending moment of resistance of a circular cross section:

$$\sigma_b(x) = \frac{M_b(x)}{w_b(x)} = \frac{F \cdot x}{\frac{\pi d(x)^3}{32}}$$

- With the requirement $\sigma_b(x) = \sigma_{bmax} = const$ for the edge fiber, we obtain for the function "axis diameter d vs. length x" the following expression:

$$\frac{\pi d(x)^3}{32} \sigma_{bmax} = F \cdot x$$

$$\Leftrightarrow d(x) = \sqrt[3]{\frac{32 \cdot F \cdot x}{\pi \cdot \sigma_{bmax}}}$$



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3. Strength analysis and weight optimization of the pedal axis

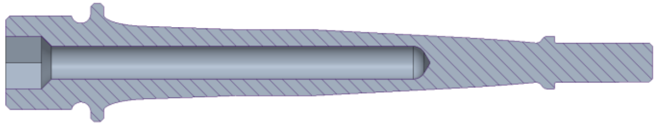
3.2 Optimized shape

Optimized design description

- The axis was now elongated by 3 mm (for reduction of ball bearing force) and further shape optimized in various iterations: For 100 kg load, the notch stress could finally be decreased from 463 MPa to 417 MPa!
- Zone 1: Approximation of the root-function (diameter vs. length) of a beam with constant outer fiber stress obtained by stepwise radius and cone sections
- Zone 2: Special non-circular cross-section transition from conic shaft to bolted flange end (tilted ellipse)

Obtained mass reduction

- Enduro 1 axis mass: 85 grams (reference)
- Enduro 2 axis mass: 57 g without / 49 g with optional drill hole (mass saving 33 % without / 42 % with drill hole)



User tips for shape / notch stress optimization

- Presentations of 6th and 7th SAXSIM [3], [4]

[3]


AEROSPACE, DEFENCE & RAILWAYS

Systematic Analysis and Comparison of Stress Minimizing Notch Shapes

– Obtaining a stress concentration factor of K_t = 1 without using a FEM-code –

Isabelle Ciomber, Dr. Roland Jakel

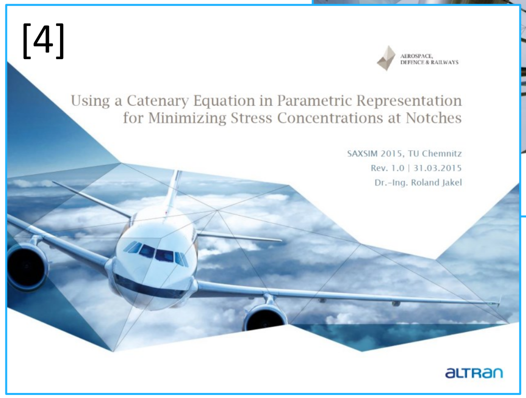
Altran GmbH & Co. KG

6th SAXSIM, TU Chemnitz

Rev. 1.0 | April 1st, 2014

altran

[4]


AEROSPACE, DEFENCE & RAILWAYS

Using a Catenary Equation in Parametric Representation for Minimizing Stress Concentrations at Notches

SAXSIM 2015, TU Chemnitz

Rev. 1.0 | 31.03.2015

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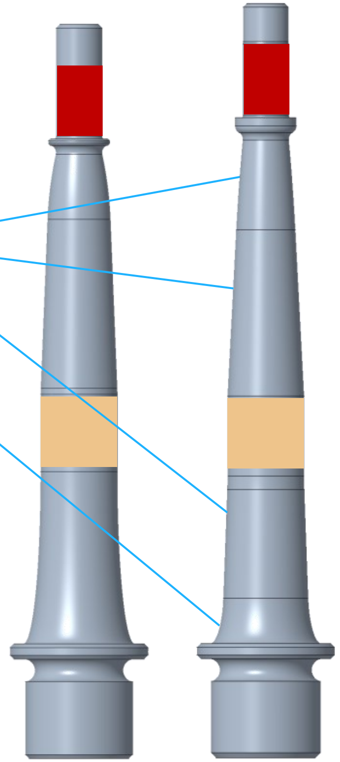
altran



(4) → final design

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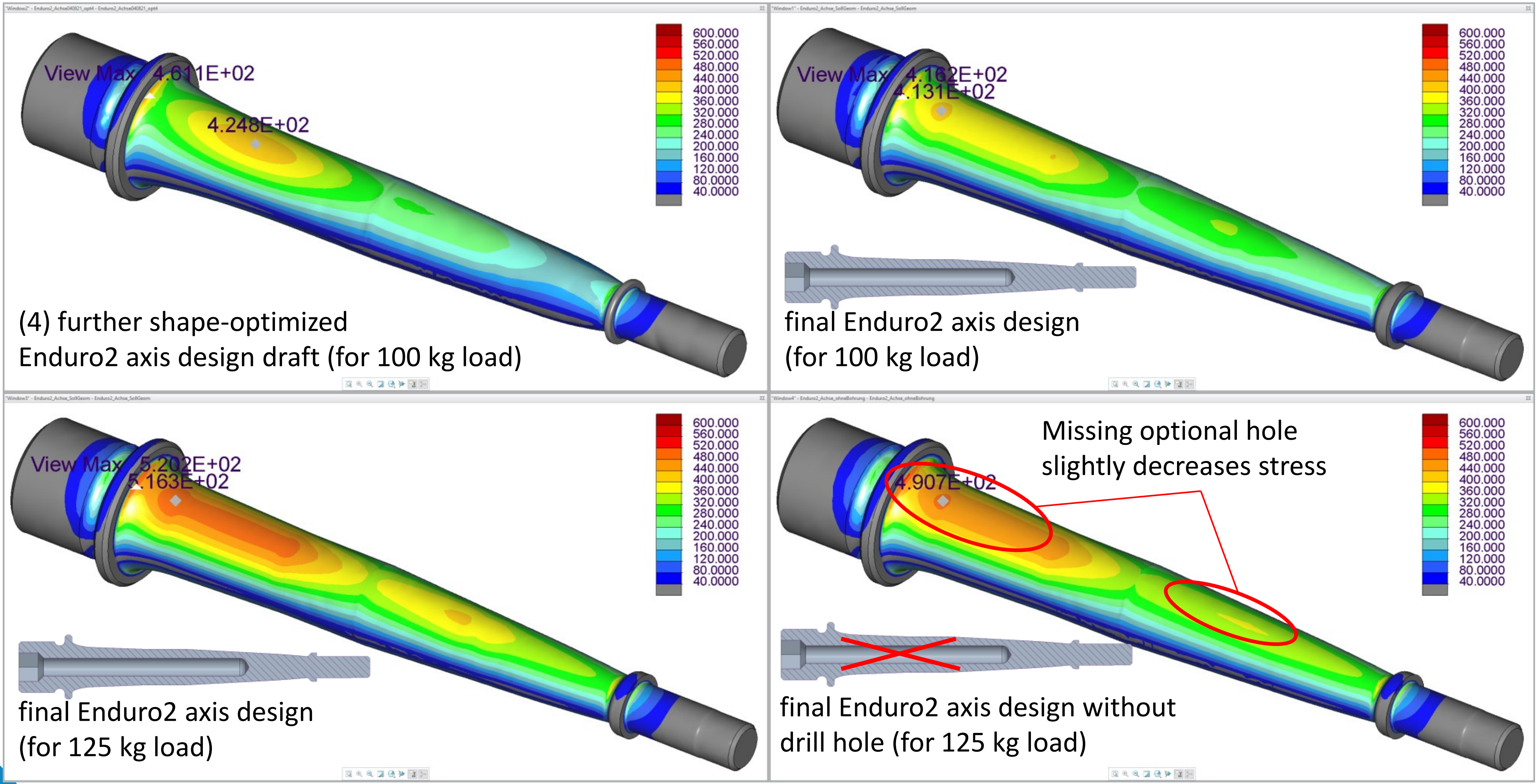
3. Strength analysis and weight optimization of the pedal axis

3.2 Optimized shape

Stress states for 100 kg/125 kg load (fatigue endurance limit: 464 MPa)



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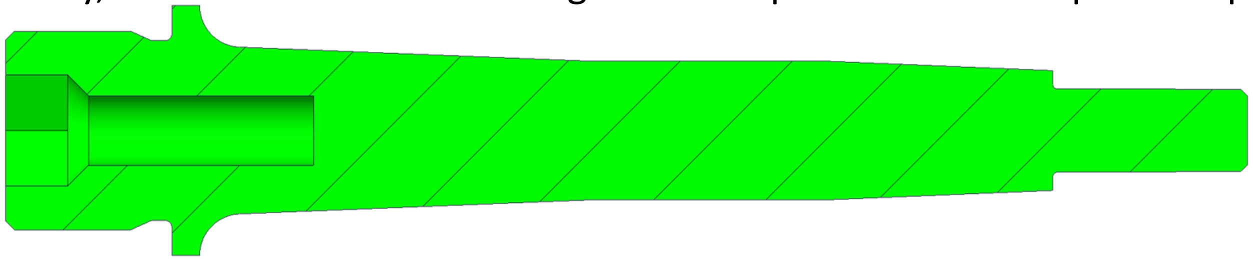
3. Strength analysis and weight optimization of the pedal axis

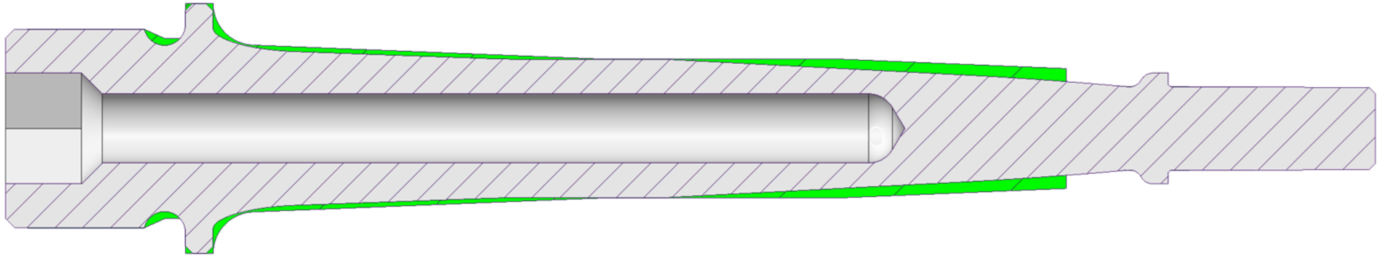
3.3 Comparison with the axis of a competitor

Shape Comparison

- Finally, the new Enduro2 axis design was compared with a competitor's product which is known for its extreme robustness:



- The cross sections in direct comparison look as follows (grey: Enduro2; green: competitor)



- Note: The mass of the competitor's axis is identical to the Enduro2 axis design *without* optional hole!

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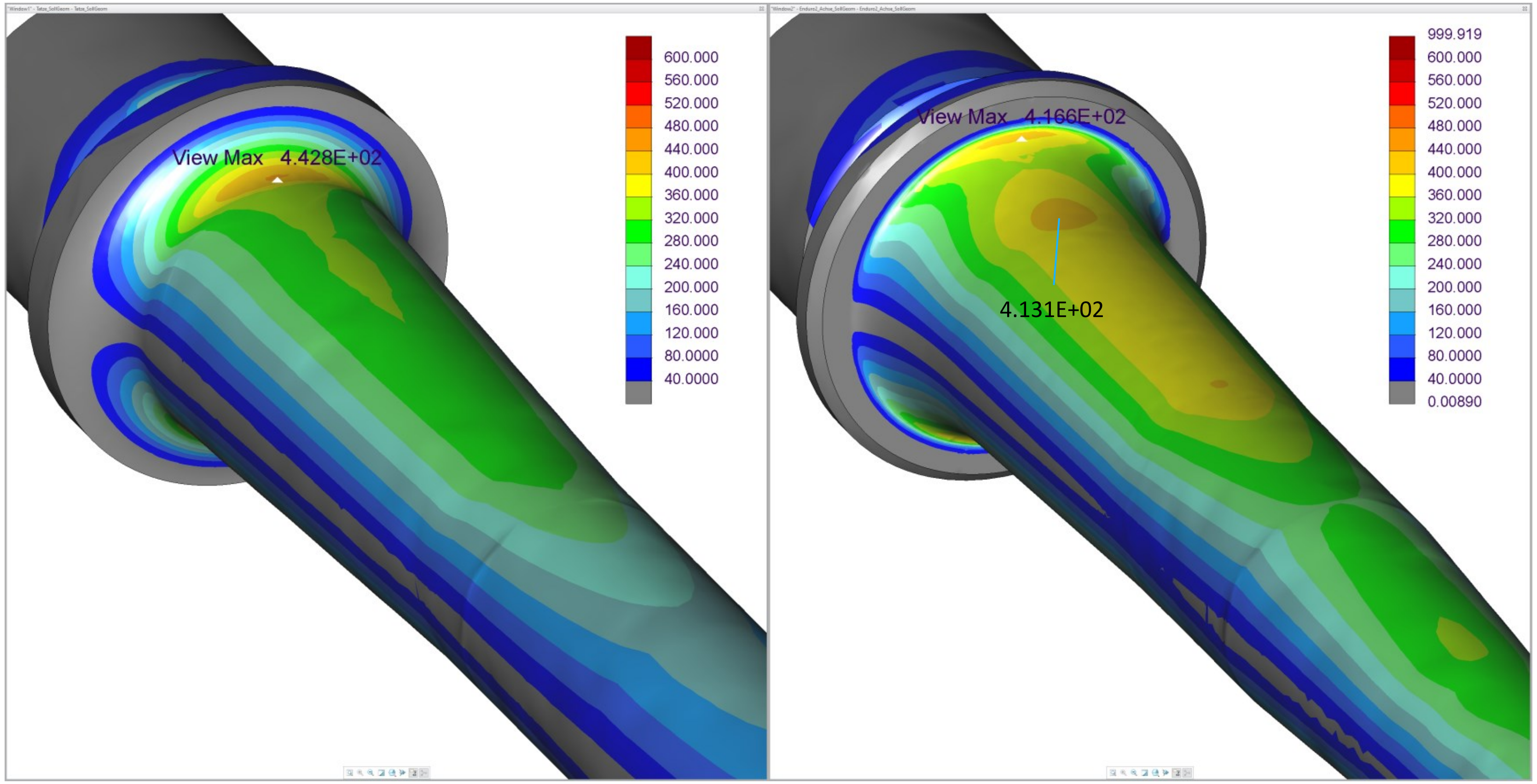
3. Strength analysis and weight optimization of the pedal axis

3.3 Comparison with the axis of a competitor

Stress states for 100 kg load

- Left: Competitor 443 MPa / right: Enduro2 axis 417 MPa



4. Strength analysis and weight optimization of the pedal body

4.1 Introduction

Challenges in pedal body design

- One of the biggest problems in load estimation for the pedal body is that the accurate load introduction points and load distribution over these points are not really known
- They depend on various factors like footwear of the biker, shoe sole shape, adjustment of the magnet and shoe plates, magnet size, individual pin configuration on the pedal body, pedaling habits of the biker,…
- Furthermore, in mountain bike applications, there is a high risk of misuse: E.g., the pedal might hit a rock during pedaling in heavy terrain – the resulting impact points & load levels can't be determined exactly
- Therefore, it is practically impossible to cover all possible load states!

Advantages in pedal body analysis

- Unlike the pedal axis, the pedal body is much less safety critical: Plastic deformation or (local) rupture usually does not lead to catastrophic failure, and deformations or cracks can be found relatively easy by visual inspection!
- Therefore higher stresses compared to the yield limit of the used material can be accepted

Material choice

- An aluminum material with the following strength data is chosen:
  - Tensile strength 260 MPa, yield strength 240 MPa, fatigue endurance limit for bending 95 MPa

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4. Strength analysis and weight optimization of the pedal body

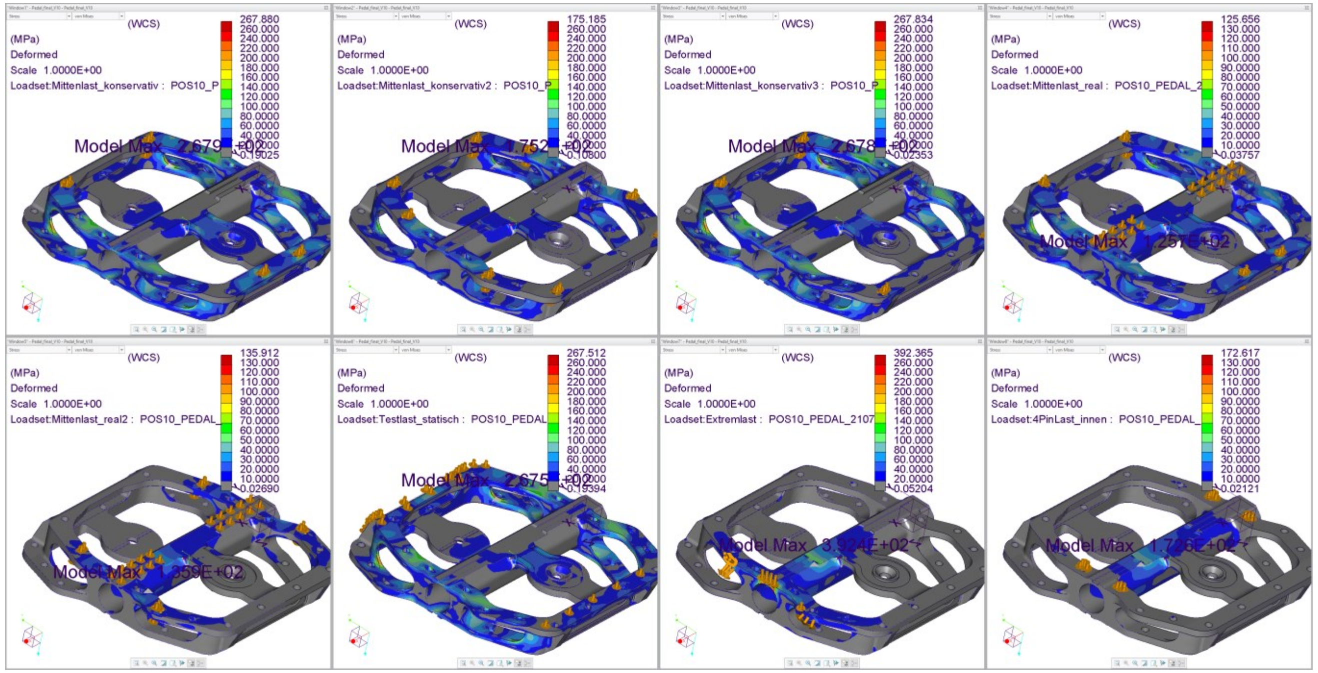
4.2 Load cases and analysis approach

Various load cases computed

- Different assumptions for load introduction locations for central 100 kg cyclic load (boundary condition: no torque on axis!)
- Extreme load case if the biker introduces the 100 kg load at the outer edge of the pedal (max. bending moment)
- One tensile load case (200 N tensile force pulling the magnet upwards, balanced by 119 N on two end pins downwards)
- One static load case (1500 N)

Max. target stress levels

- For the nominal, centric load cases, local stresses should not be higher than approx. 130 MPa (note: Pedaling is no alternating load, but predominantly pulsating → fatigue endurance limit for cyclic bending is conservative and may be surpassed!)
- For rare, special loads, very locally the yield limit (240 MPa) may be exceeded



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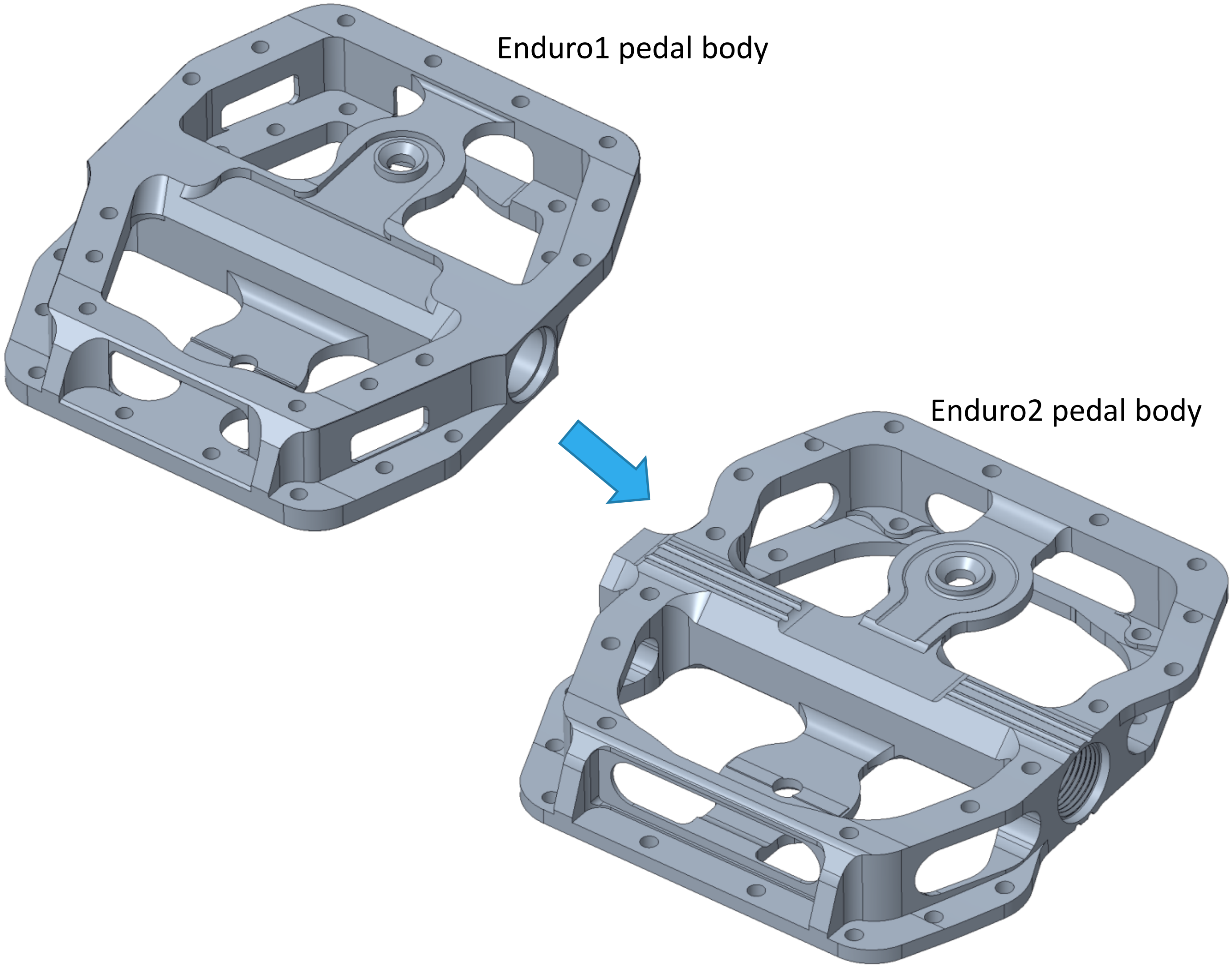
4. Strength analysis and weight optimization of the pedal body

4.3 Result

Remarks

- The new pedal body is not designed for maximum light weight, since this would make the pedal too sensitive against misuse cases!
- Therefore, a design has been chosen in several iterations that is a good compromise between strength, weight and pleasing design



Design comparison and mass savings Enduro1 / Enduro2 pedal bodies

- Enduro1 pedal body: 107 g
- Enduro2 pedal body: 85 g
- Mass saving 22 g = 21 %

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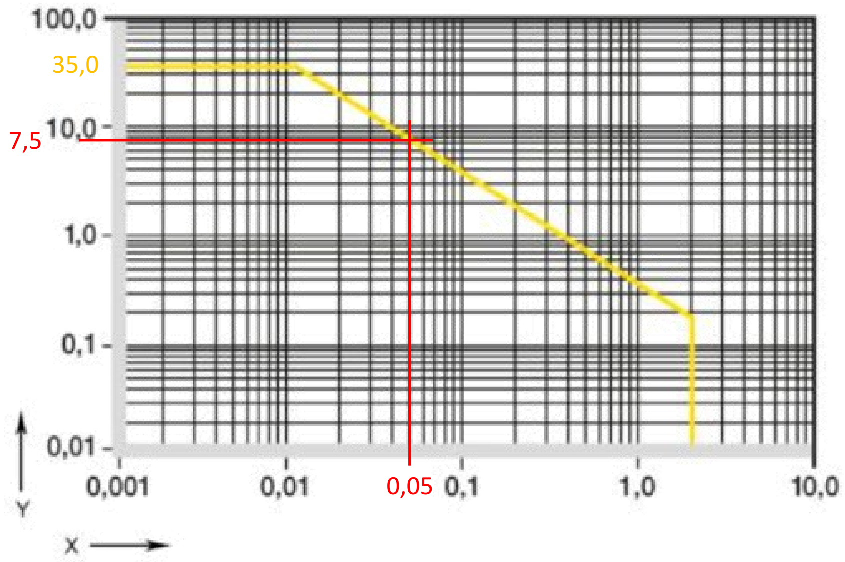
5. Bearing design and analysis

5.1 Sliding bearing layout

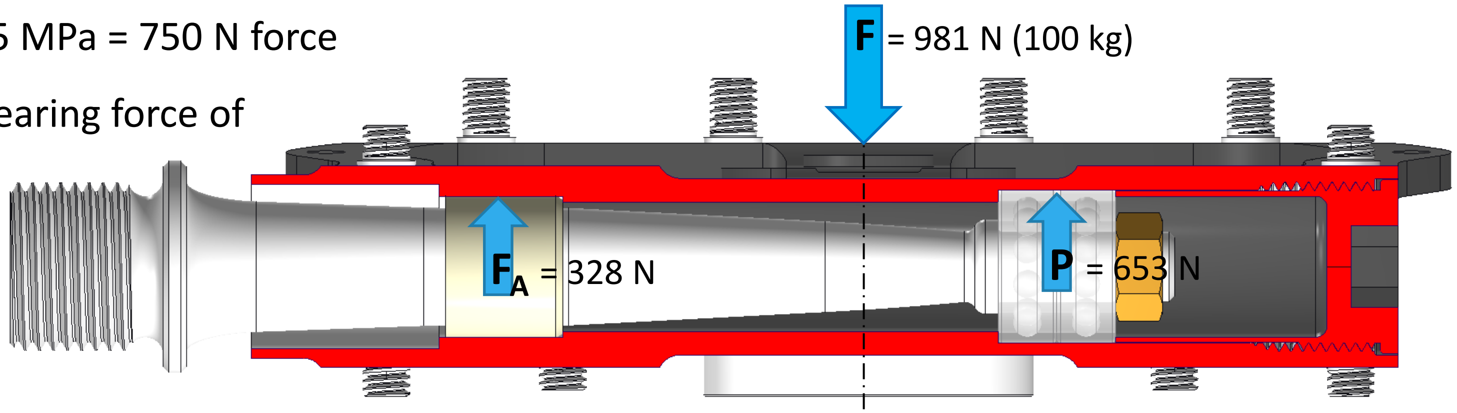


Bearing type

- The new design uses a sliding bushing type “Igus JSM-1012-10“ (inner diameter 10 mm, length 10 mm) made of iglidur® J200 material
- For low speeds, the max. allowed average surface pressure is 35 MPa, so the bearing can withstand approx. 3500 N bearing force
- At 100 rpm max. cyclic ISO 4210 test speed, the circumferential velocity is:

$$v_u = \omega r = \frac{2\pi n}{60} r = 52 \frac{\mathrm{mm}}{\mathrm{s}} = 0.05\ \mathrm{m/s}$$

- This reduces the allowed pressure to ≈7.5 MPa = 750 N force
- This is still much more than the regular bearing force of F_A = 328 N for 100 kg loading
- Therefore, the sliding bearing is sufficiently designed for this load!



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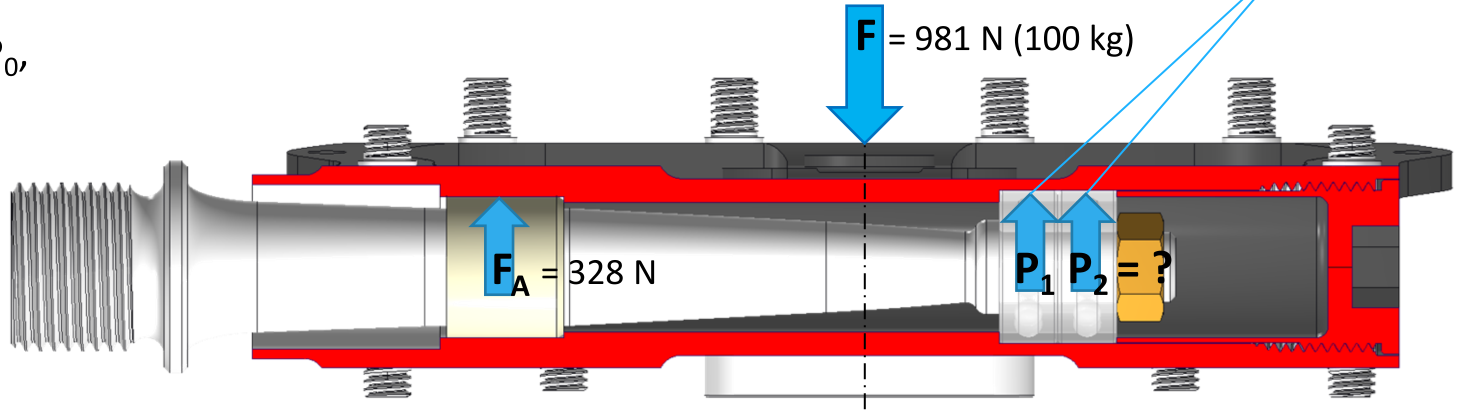
5. Bearing design and analysis

5.2 Ball bearing layout

Triple bearing support → a pair of identical ball bearings is used for the fixed bearing side!

- The new Enduro2 design uses two identical ball bearings type 686 ZZ (D = 13 mm, d = 6 mm, b = 5 mm: max. 45000 rpm…)
  - Static load rating C_0 = 440 N
  - Dynamic load rating C = 1080 N
- The assumption that each ball bearing carries approx. half of the force turned out to be very inaccurate
- Because of the triple bearing support, the system becomes statically over-determined and the flexibility of bearings and axis/pedal body has to be taken into account!
- Note: For the static safety factor $s_0 = C_0/P_0$, a value down to 0.5…0.4 can be allowed, if permanent ball deformation is acceptable!

2x ball bearing 686



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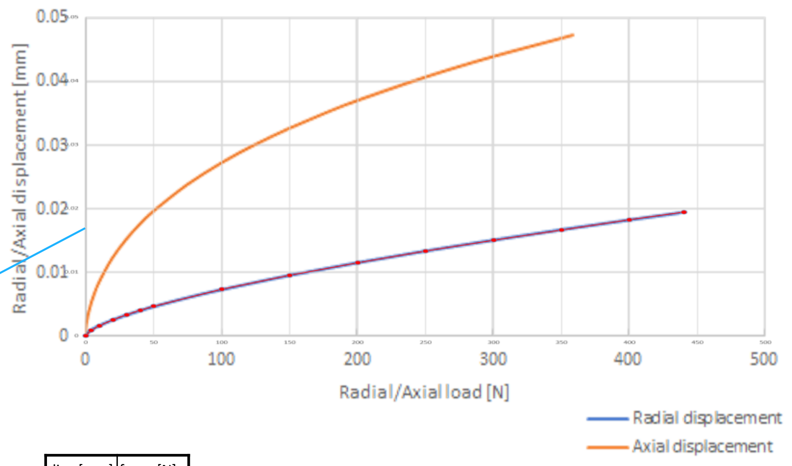
5. Bearing design and analysis

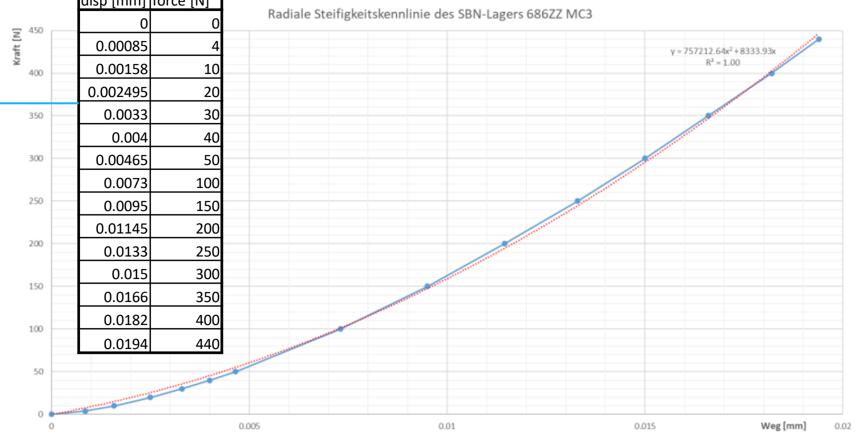
5.2 Ball bearing layout

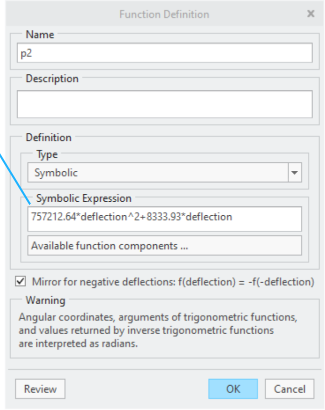
Computing the bearing loads of the over-determined system by FEM

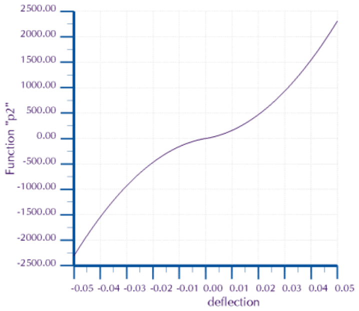
- The force-displacement-curves of the foreseen bearing type were provided as graphs by the bearing manufacturer SBN
- A numerical description of the radial displacement curve was derived by using EXCEL and a parabolic curve fit
- The resulting function was coded as symbolic expression for simple, nonlinear springs in Creo Simulate
- These springs are located at the two ball bearing positions and attached by weighted links to the bearing seat surfaces at the axis and the pedal body (for Creo Simulate model details, see next slide)
- Furthermore, for the sliding bushing, a gap of 0.1 mm is assumed between bushing and axis surface and nonlinear, friction-free contact is defined



disp [mm]	force [N]
0	0
0.00085	4
0.00158	10
0.002495	20
0.0033	30
0.004	40
0.00465	50
0.0073	100
0.0095	150
0.01145	200
0.0133	250
0.015	300
0.0166	350
0.0182	400
0.0194	440







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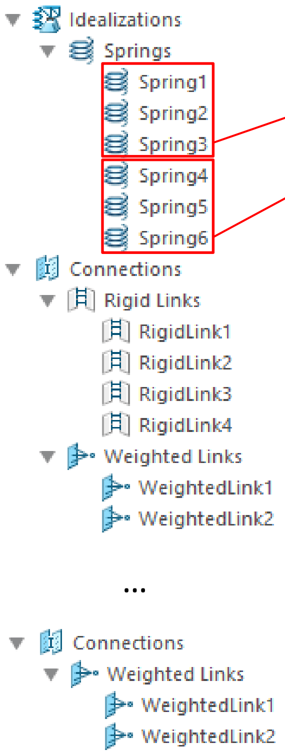
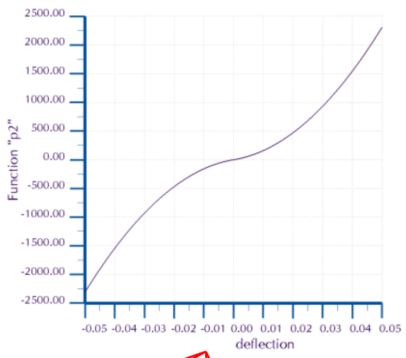
5. Bearing design and analysis

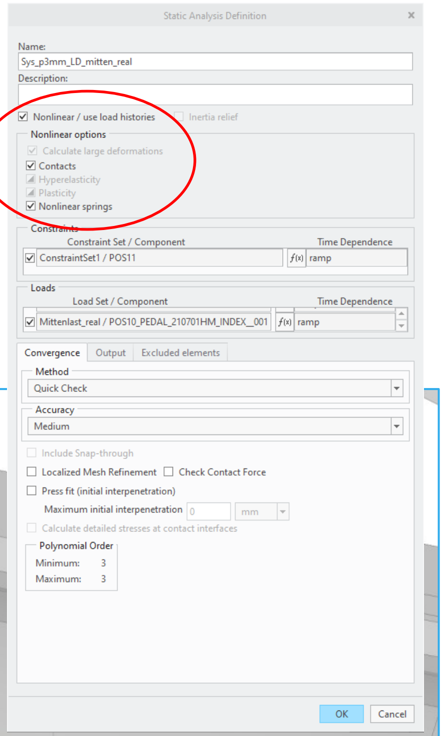
5.2 Ball bearing layout

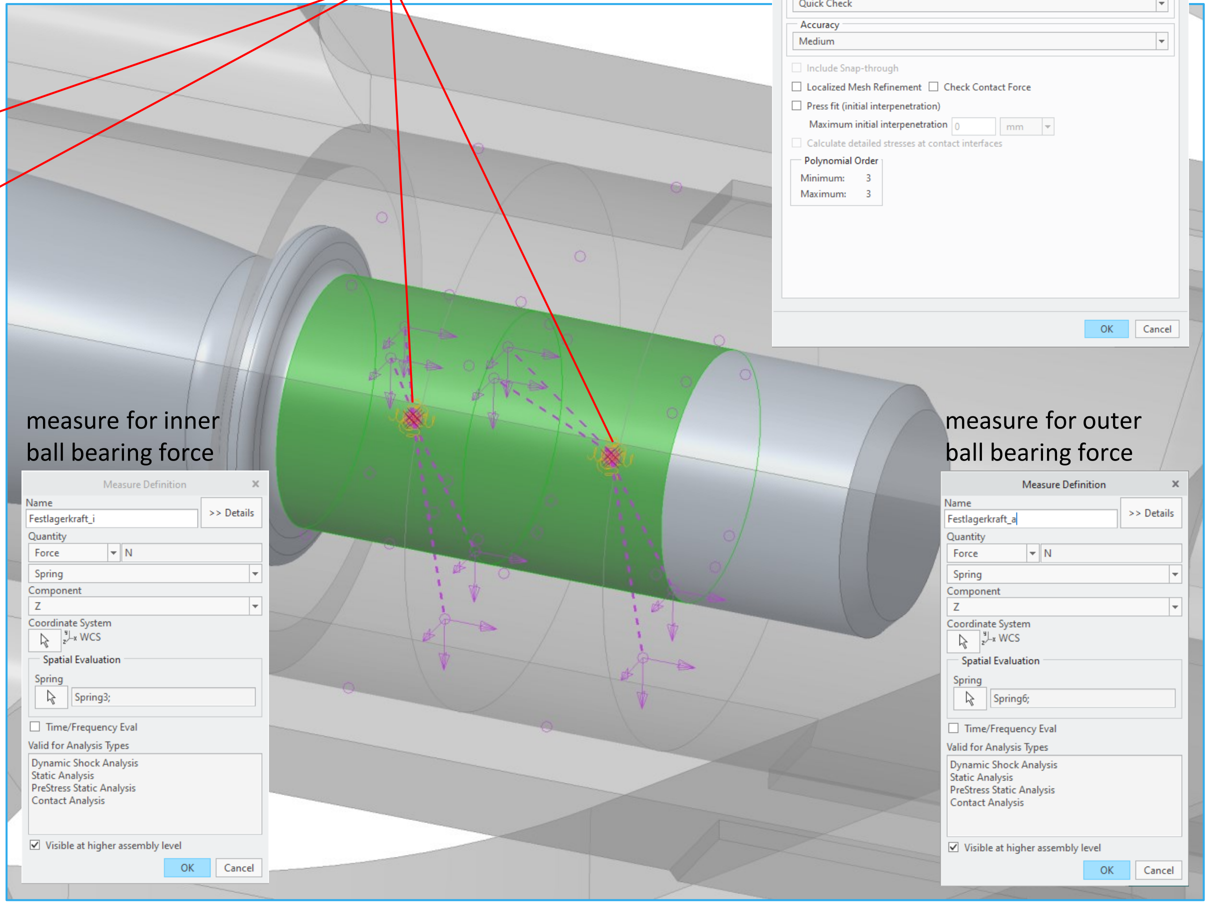
Creo Simulate model details for nonlinear bearing analysis

- Group of 3 perpendicular simple springs, respectively, for each ball bearing
- Only vertical springs defined with nonlinear force-deflection-curve
- Within each group, three spring end points connected by rigid links, respectively
- Each group of end points connected by in total 4 weighted links to the bearing seat surfaces at axis and pedal body
- Spring force measures for computing the radial (vertical) ball bearing forces
- Nonlinear static analysis with activated large displacements to activate nonlinear spring curves









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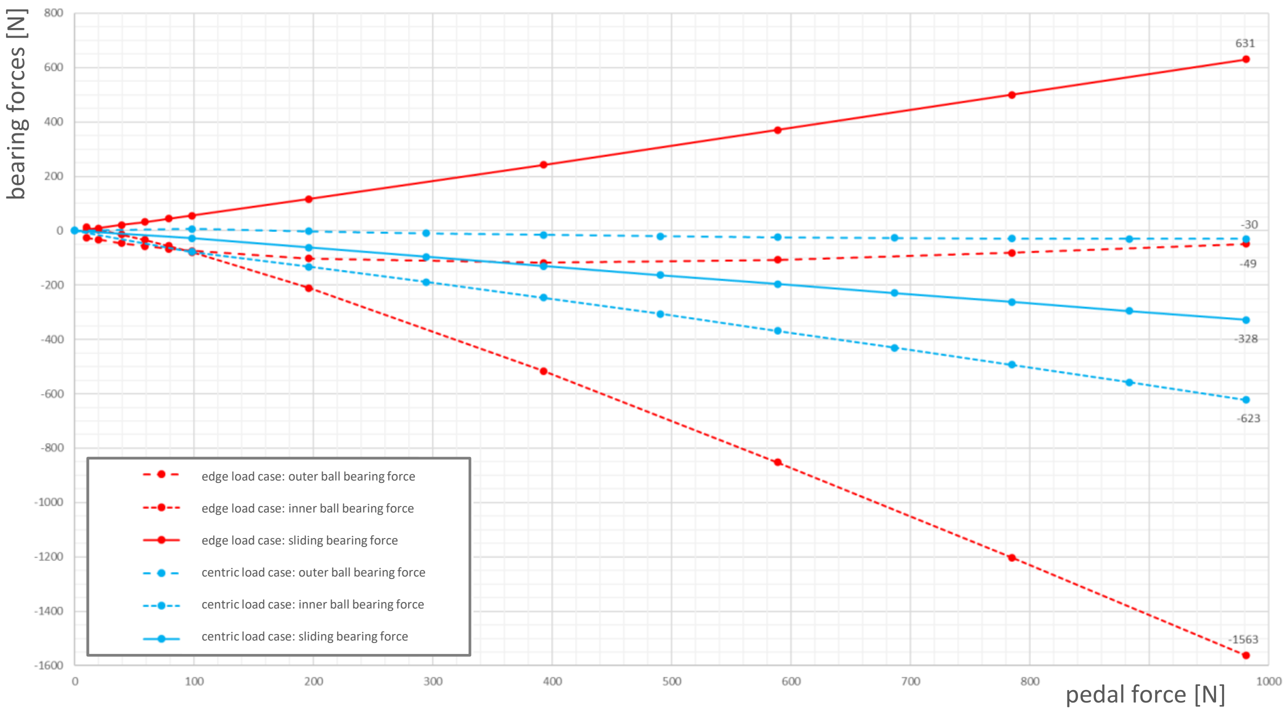
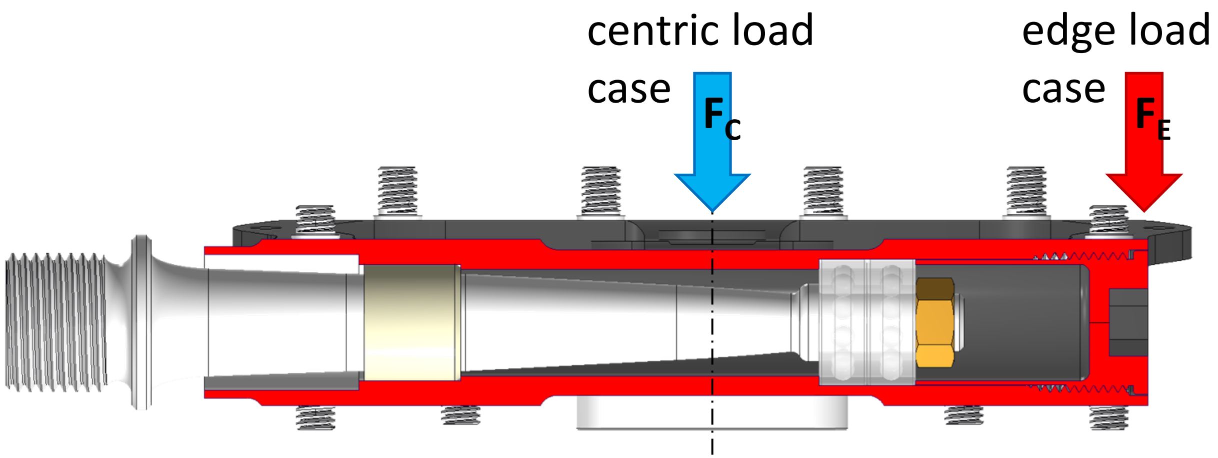
5. Bearing design and analysis

5.2 Ball bearing layout

Results of the nonlinear analysis

- Two load cases: 100 kg centric and 100 kg edge load
- For centric loading (blue), the individual ball bearing load vs. pedal load curves are approx. straight lines
- For edge loading (red lines), a clear nonlinear behavior of the ball bearing loads is observed
- Surprisingly, in both cases nearly <u>the full load is carried by the inner bearing</u>, so it cannot be assumed that the radial ball bearing force is evenly distributed over the pair of bearings!
- Taking this into account, it would have been sufficient to use just one ball bearing in the design
- However, the pair of ball bearings was kept to obtain
  - more safety against loss of pedal if one bearing totally fails,
  - more robustness against plastic deformation of the rolling element for certain misuse cases (stone impact)





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5. Bearing design and analysis

5.2 Ball bearing layout

Ball bearing life span – dynamic loads

- For the centric pedal load of 100 kg (981 N), the load at the inner ball bearing becomes 623 N
- Acc. to the table on the right side, C/P = 1.73 < 3; such a high load usually is to be prevented
- However, for 10 % probability of failure, this bearing should be able to withstand

$$L_{10} = \left(\frac{C}{P}\right)^3 = \left(\frac{1080}{623}\right)^3 = 5.21\, million\ \ rounds$$

- Expressed in operating hours h at the max. ISO 4210 dynamic pedal test speed of 100 rpm, this is equivalent to a service life of

$$L_{10h} = \frac{10^6}{60n}\left(\frac{C}{P}\right)^3 = \frac{10^6}{60{\cdot}100}\left(\frac{1080}{623}\right)^3 = 868\ h = 36\ \mathrm{d}$$

➢ Note the ISO test just requires 100000 rounds at 90 kg pedal load!

➢ *We can estimate that also the dynamic pedal test load of 125 kg will not lead to ball bearing failure during the test!*

Recommendations for assessment of the dynamic loading state		Remarks
C/P > 15	low load	to be prevented because of increasing risk of roller sliding → high wear and shortened life span!
C/P < 15	medium load	
C/P < 6	high load	
C/P < 3	very high load	to be prevented even for low rotational speeds

Ball bearing – static loads

- For the centric pedal load of 100 kg, the static factor of safety becomes

$$s_0 = \frac{C_0}{P_0} = \frac{440}{623} = 0.7 > 0.5$$

- For the edge load case, we obtain

$$s_0 = \frac{C_0}{P} = \frac{440}{1563} = 0.28 < 0.5$$

➢ *It becomes clear that the ball bearing life span is significantly determined by infrequent high loads (abuse, edge load…) that lead to plastic deformation of the rolling elements!*

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6. Product testing

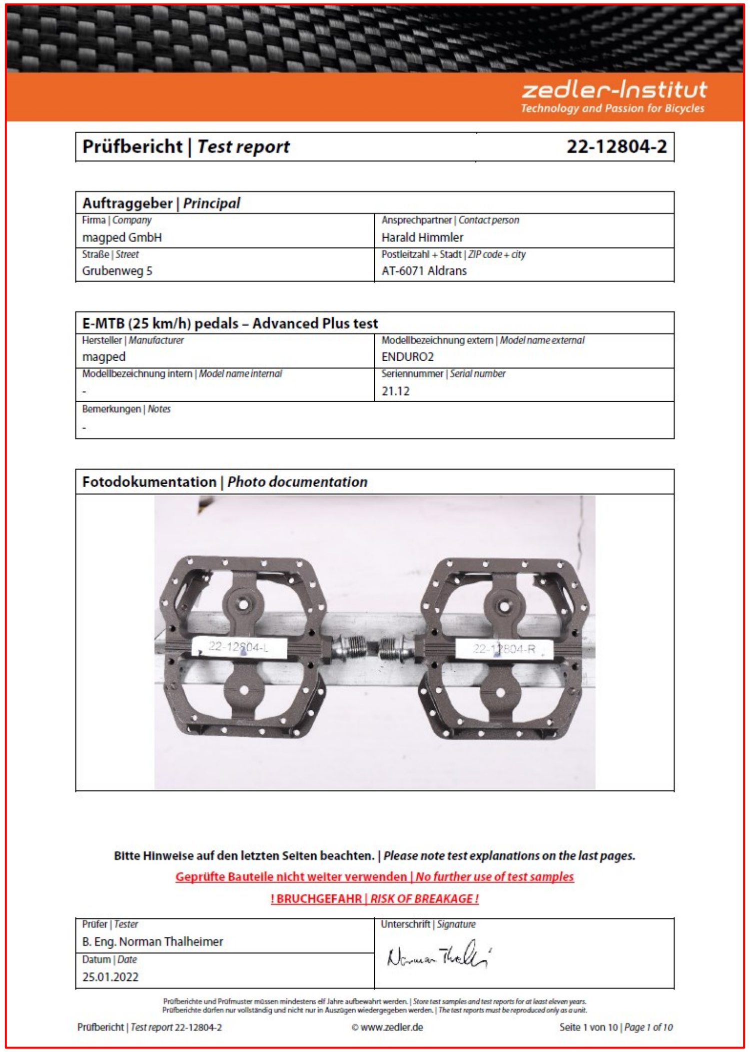
6.1 Test program

Commissioned test institute

- Product tests have been performed at the German “zedler-Institut” for bicycle technology and security

Zedler “Advanced plus” test program for E-MTB (25 km/h) pedals

- The Advanced plus test is significantly harder compared to the DIN ISO 4210 test!
  - Static strength test acc. to DIN ISO 4210-2: *1500 N for 60 s*
- Alternating bending load on the shaft, but just static bending on the pedal body:
  - Dynamic durability test, first side of pedal: 125 kg for 50000 cycles (rounds)
  - Dynamic durability test, second side of pedal: 125 kg for 50000 cycles (rounds)
  - Two similar durability tests, but with 5 ° pedal inclination for more realistic conditions
- Pulsating bending load on the shaft <u>and</u> pedal body:
  - Fatigue test similar to crank assembly: 1800 N for 100000 cycles
- The following test creates high dynamic impact loads:
  - Impact test (falling mass): 15 kg mass from 720 mm height (ISO 4210 test just requires 400 mm!)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Prüfbericht | *Test report*	22-12804-2

Auftraggeber | *Principal*	
Firma | *Company*: magped GmbH	Ansprechpartner | *Contact person*: Harald Himmler
Straße | *Street*: Grubenweg 5	Postleitzahl + Stadt | *ZIP code + city*: AT-6071 Aldrans

E-MTB (25 km/h) pedals – Advanced Plus test	
Hersteller | *Manufacturer*: magped	Modellbezeichnung extern | *Model name external*: ENDURO2
Modellbezeichnung intern | *Model name internal*: -	Seriennummer | *Serial number*: 21.12
Bemerkungen | *Notes*: -	

Fotodokumentation | *Photo documentation*

Bitte Hinweise auf den letzten Seiten beachten. | *Please note test explanations on the last pages.*
Geprüfte Bauteile nicht weiter verwenden | *No further use of test samples*
! BRUCHGEFAHR | *RISK OF BREAKAGE* !

Prüfer | *Tester*	Unterschrift | *Signature*
B. Eng. Norman Thalheimer	
Datum | *Date*: 25.01.2022	

Prüfberichte und Prüfmuster müssen mindestens elf Jahre aufbewahrt werden. | *Store test samples and test reports for at least eleven years.*
Prüfberichte dürfen nur vollständig und nicht nur in Auszügen wiedergegeben werden. | *The test reports must be reproduced only as a unit.*

Prüfbericht | *Test report* 22-12804-2 © www.zedler.de Seite 1 von 10 | *Page 1 of 10*

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6. Product testing

6.1 Test program

General remarks on the Zedler test nomenclature

- The Zedler “Advanced Plus” test described on the previous slide is recommended for mountain bikes with 130 kg combined mass; details see below
- The Zedler “Advanced” test for pedals differs from the “Advanced Plus” test just by reducing the pedal dynamic load of 125 kg to 105 kg (note the DIN EN ISO 4210 test just requires 90 kg for mountain bikes!) → recommendation for mountain bikes with 110 kg combined mass

Testing procedure for the Enduro2 pedals

- Testing starts with the Advanced Plus load levels
- If a failure is observed, the next pedal is tested at the reduced “Advanced” load levels (i.e. 105 instead of 125 kg)
- In doing so, at least a recommendation for the lower combined mass class can be pronounced if the test is successful

Mountainbikes (MTB) | *Mountain bikes (MTB)*

Gemäß dem aktuellen Erkenntnisstand können für das Interpretieren der ergänzenden Prüfungen nach den Zedler-Institut Prüfstandards folgende Empfehlungen ausgesprochen werden:

Advanced	–> Freigabe für 110 kg Gesamtgewicht, Fahrrad, Gepäck, Fahrer und, falls freigegeben, Kindersitz und Anhänger. ASTM Fahrrad Kategorie 3/4/5
Advanced Plus	–> Freigabe für 130 kg Gesamtgewicht, Fahrrad, Gepäck, Fahrer und, falls freigegeben, Kindersitz und Anhänger. ASTM Fahrrad Kategorie 3/4/5
Advanced Plus XXL	–> Freigabe für 150 kg Gesamtgewicht, Fahrrad, Gepäck, Fahrer und, falls freigegeben, Kindersitz und Anhänger. ASTM Fahrrad Kategorie 3/4 |

According to the current scientific findings, the following recommendations can be pronounced as an interpretation of the complementary test methods according to the test standards of the Zedler-Institut:

Advanced	*–> Applicable for 110 kg combined mass of the bicycle, luggage, rider and, if permitted, child’s seat and trailer. ASTM bike category 3/4/5*
Advanced Plus	*–> Applicable for 130 kg combined mass of the bicycle, luggage, rider and, if permitted, child’s seat and trailer. ASTM bike category 3/4/5*
Advanced Plus XXL	*–> Applicable for 150 kg combined mass of the bicycle, luggage, rider and, if permitted, child’s seat and trailer. ASTM bike category 3/4*

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6. Product testing

6.2 Testing of the first test batch of pedals with hollow-bored axis

Background information

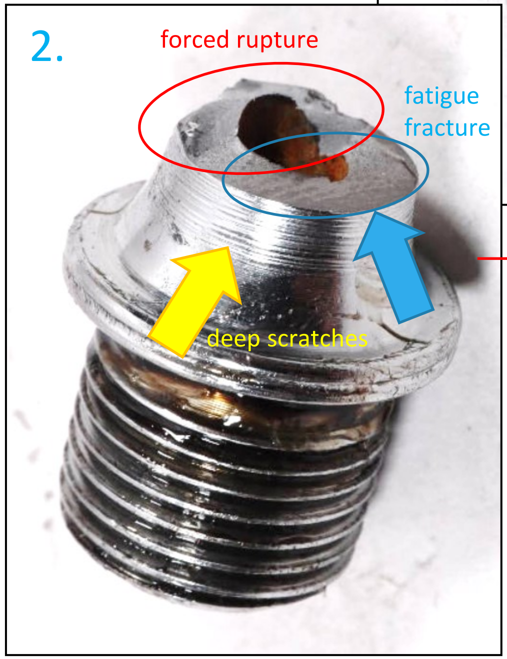
- For the first pre-series batch of 10 pedal pairs, 5 were manufactured with hollow-drilled axes for weight reduction, and five without these bore-holes
- Testing according to the Zedler test procedure was started with 2 pedal pairs using the hollow-bored axes (two right, two left)

Test results

- Two right pedal axes showed fatigue failure at the end of the bore hole under Advanced plus test load (125 kg) during durability testing of the second side, respectively, after nearly the complete number of test cycles (45052 cycles at vertical test, 46913 cycles at 5° inclination test; example failure shown in image 1)
- One left pedal axis showed fatigue failure under Advanced load (105 kg) at the elliptic transition at the end of vertical testing side 2 (after 49397 cycles, image 2)
- One left pedal passed all tests under "Advanced" load levels successfully

Cause of the fatigue failures: Manufacturing defects

1. Strong eccentric hole & R2-rounded transition at hole end was sharp (2x)
2. Insufficient surface finish: Deep scratches in high-stressed transition area (yellow arrow)



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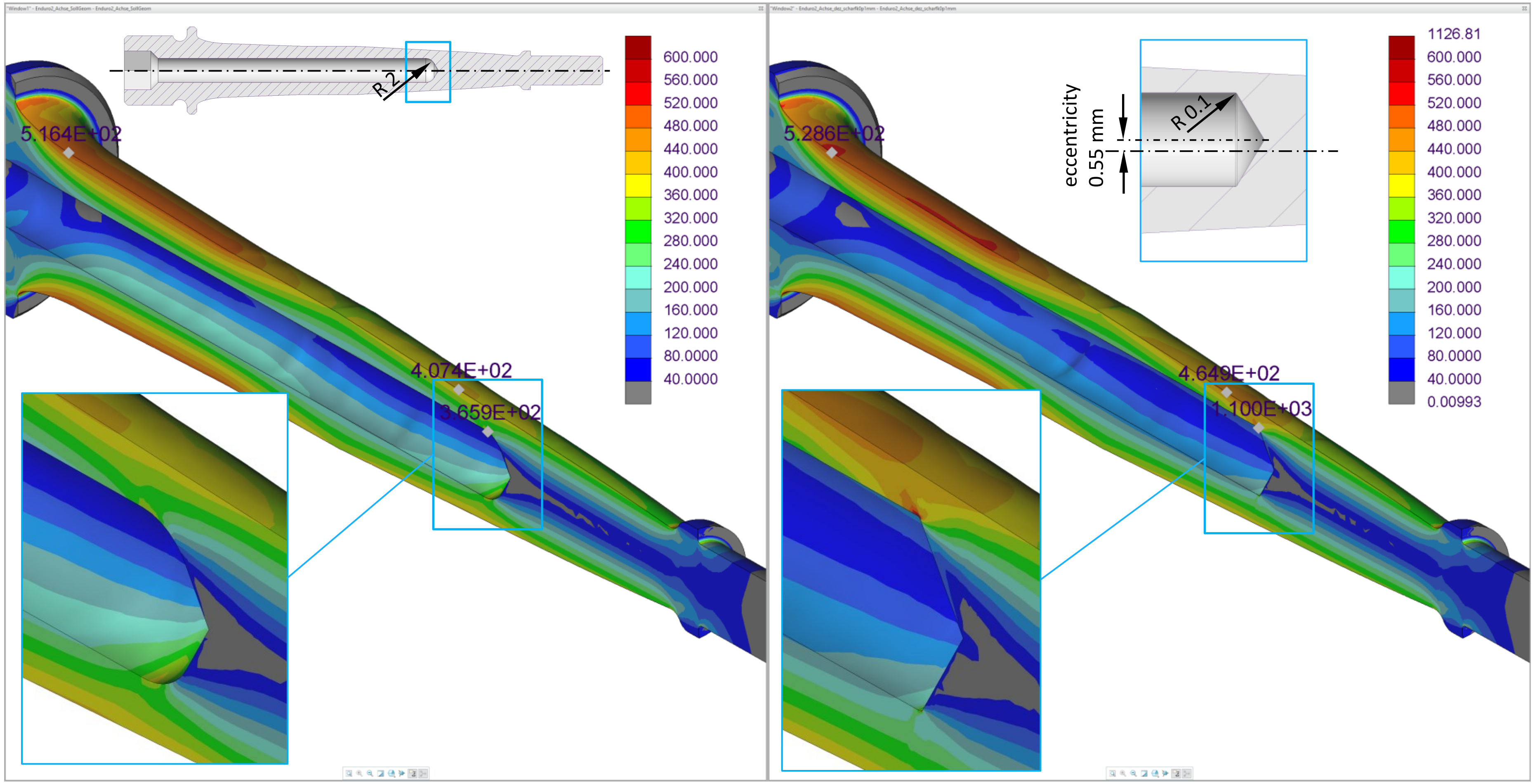
6.2 Testing of the first test batch of pedals with hollow-bored axis

Verification of stress levels at the locations of fatigue rupture

- Stress levels [MPa] at 125 kg load: Left: required geometry, right: bore hole with manufacturing defects



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6.3 Testing of the first test batch of pedals without hollow-bored axis

Test result

- All tests have been passed successfully for the “Advanced Plus” load levels (125 kg)

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Zedler-Institut Advanced Plus Prüfungen linkes Pedal |
Zedler-Institut Advanced Plus testing left pedal

ISO 4210-2 | 4.13.3 **Statische Festigkeitsprüfung #1 | *Static strength test #1***	Kraft | *Load*	Dauer | *Time*	Test Nr.	Ergebnis | *Result*
	1.500 N	60 sec	1	ok
Bemerkungen | *Notes* -				

Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung, erste Pedalseite #1 |** ***Dynamic durability test, first side of pedal #1***	Gewicht | *Weight*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	125 kg	50.000	2	ok
Bemerkungen | *Notes* -				

Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung, zweite Pedalseite #2 |** ***Dynamic durability test, second side of pedal #2***	Gewicht | *Weight*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	125 kg	50.000	3	ok
Bemerkungen | *Notes* -				

Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung,** **erste Pedalseite #3 |** ***Dynamic durability test, first side of pedal #3***	Winkel | *Angle*	Gewicht | *Weight*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	5°	125 kg	50.000	4	ok
Bemerkungen | *Notes* -					

Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung,** **zweite Pedalseite #4 |** ***Dynamic durability test, second side of pedal #4***	Winkel | *Angle*	Gewicht | *Weight*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	5°	125 kg	50.000	5	ok
Bemerkungen | *Notes* **At the end of the test bearing clearance, no cracks or fractures.**					

Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung analog Kurbeleinheit #1 |** **Fatigue test similar to crank assembly #1**	Kraft | *Load*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	1.800 N	100.000	6	ok
Bemerkungen | *Notes* -				

Zedler-Institut Advanced Plus **Stoßprüfung (fallende Masse) #1 |** **Impact test (falling mass) #1**	Höhe| *Height*	Gewicht | *Weight*	Anzahl | *Number*	Test Nr.	Ergebnis | *Result*
	720 mm	15 kg	1	7	ok
Bemerkungen | *Notes* **After impact 15 mm permanent deformation and fracture at pedal body, pedal did not separate.**					

Hinweis | *Note:*
Die Prüfreihenfolge wurde gegenüber der ISO-Norm abgeändert. Die Prüfaufbauten entsprechen der ISO 4210:2015. Bei der dynamischen Festigkeitsprüfung Stufe 2 wird die Pedalebene in Fahrtrichtung von hinten gesehen um 5° gegenüber der Waagerechten geneigt. |
The test sequence was changed from the ISO norm. Test setups correspond to ISO 4210:2015. During the dynamic durability test the pedal is inclined by 5° from its horizontal position in the direction of travel as viewed from behind.

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Zedler-Institut Advanced Plus Prüfungen rechtes Pedal |
Zedler-Institut Advanced Plus testing right pedal

ISO 4210-2 | 4.13.3 **Statische Festigkeitsprüfung #1 | *Static strength test #1***	Kraft | *Load*	Dauer | *Time*	Test Nr.	Ergebnis | *Result*
	1.500 N	60 sec	1	ok
Bemerkungen | *Notes* -				

Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung, erste Pedalseite #1 |** ***Dynamic durability test, first side of pedal #1***	Gewicht | *Weight*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	125 kg	50.000	2	ok
Bemerkungen | *Notes* -				

Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung, zweite Pedalseite #2 |** ***Dynamic durability test, second side of pedal #2***	Gewicht | *Weight*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	125 kg	50.000	3	ok
Bemerkungen | *Notes* -				

Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung,** **erste Pedalseite #3 |** ***Dynamic durability test, first side of pedal #3***	Winkel | *Angle*	Gewicht | *Weight*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	5°	125 kg	50.000	4	ok
Bemerkungen | *Notes* -					

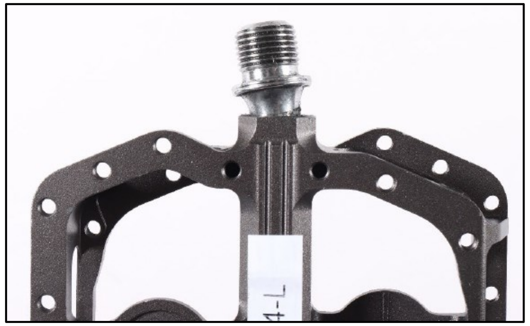
Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung,** **zweite Pedalseite #4 |** ***Dynamic durability test, second side of pedal #4***	Winkel | *Angle*	Gewicht | *Weight*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	5°	125 kg	50.000	5	ok
Bemerkungen | *Notes* **At the end of the test bearing clearance, no cracks or fractures.**					

Zedler-Institut Advanced Plus **Dynamische Festigkeitsprüfung analog Kurbeleinheit #1 |** **Fatigue test similar to crank assembly #1**	Kraft | *Load*	Zyklen | *Cycles*	Test Nr.	Ergebnis | *Result*
	1.800 N	100.000	6	ok
Bemerkungen | *Notes* **At the end of the test crack at pedal body. Axle was ok and no fractures.**				

Zedler-Institut Advanced Plus **Stoßprüfung (fallende Masse) #1 |** **Impact test (falling mass) #1**	Höhe| *Height*	Gewicht | *Weight*	Anzahl | *Number*	Test Nr.	Ergebnis | *Result*
	720 mm	15 kg	1	7	ok
Bemerkungen | *Notes* **After impact 13 mm permanent deformation and fracture at pedal body, pedal did not separate.**					

Hinweis | *Note:*
Die Prüfreihenfolge wurde gegenüber der ISO-Norm abgeändert. Die Prüfaufbauten entsprechen der ISO 4210:2015. Bei der dynamischen Festigkeitsprüfung Stufe 2 wird die Pedalebene in Fahrtrichtung von hinten gesehen um 5° gegenüber der Waagerechten geneigt. |
The test sequence was changed from the ISO norm. Test setups correspond to ISO 4210:2015. During the dynamic durability test the pedal is inclined by 5° from its horizontal position in the direction of travel as viewed from behind.

No axis rupture after severe impact tests, just expected plastic deformation!



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7. Realized mass savings

Enduro1 and Enduro2 on the balance

- Both equipped with the biggest magnets of 200 N
- For a pair of pedals:
  - Enduro1: 578 g
  - Enduro2: 468 g
    (mass without optional drill hole in the axis)
- Mass saving 110 g ≈ 20 % (the additional mass saving is caused by the much lighter new Enduro2 screw pins) - relative mass saving is higher with smaller magnets
- Development goal of a product mass < 500 g is successfully met!
- Higher mass saving is possible with an accurately manufactured, centric drill hole, but the preference is an easy visual inspection of the axis!

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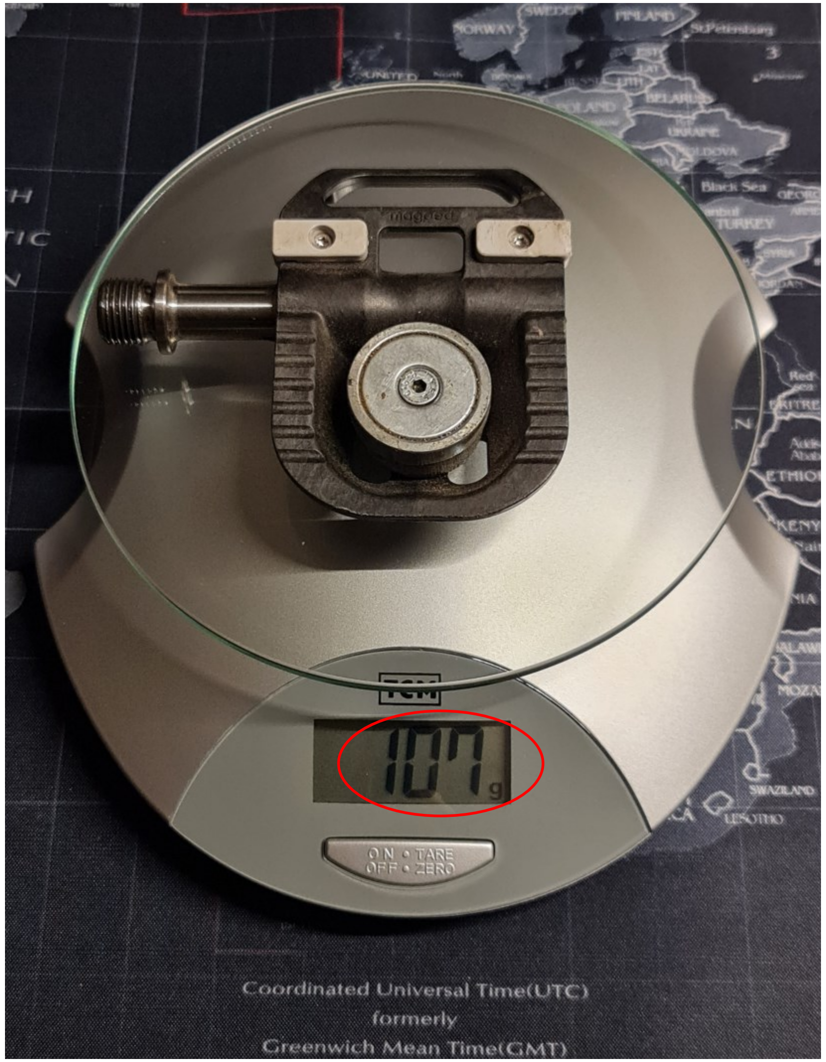
7. Realized mass savings

Other magped products on the balance

- For some bikers, even a pedal pair mass of 468 g might still seem to be high, but note the Enduro2 is a pedal which can also be used for hard downhill applications
- E.g. for the magped GRAVEL pedal, a much lower pedal pair mass of just 214 g is obtained
- This is caused by the following facts:
  - Just one 200 N magnet per pedal (only one-sided use)
  - Very light and small pedal body made of carbon reinforced plastics
  - Smaller and lighter titanium axis
  - Just 2 grey plastic blocks instead of several steel pins
- However, this is a pedal for gravel or cross country biking and not for mountain biking, which is subject to higher demands!



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8. Creation of marketing material for the final product

8.1 Still images

Use of the Creo Parametric built-in photorealistic rendering engine

- FEM stressed parts can be exported from the Creo Simulate post processor as VRML files and re-imported into the CAD
- High-resolution TIFF and JPEG images can be output from the Creo Parametric rendering engine

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8. Creation of marketing material for the final product

8.2 Photorealistic rendering containing FEM loading sequences

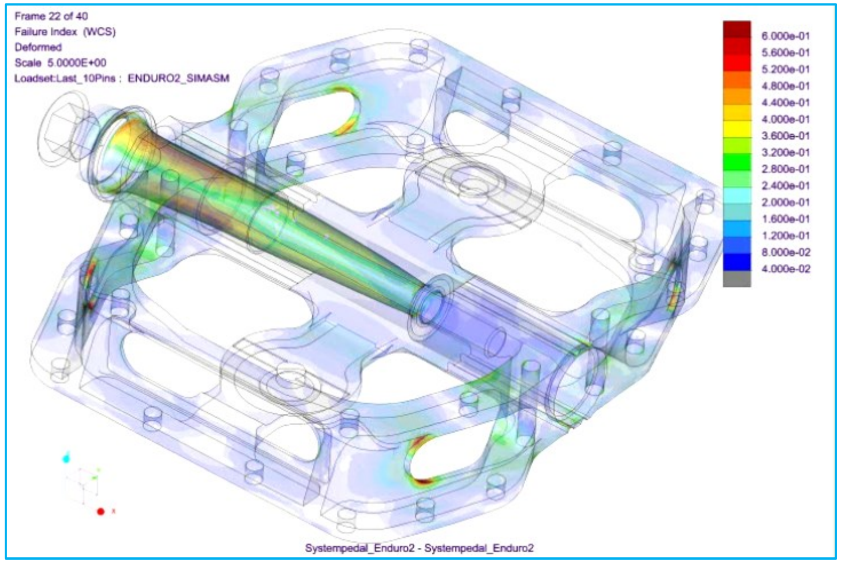
Limitation of the Creo Simulate post processor

- Unfortunately, the Creo Simulate PP can just output videos as low-resolution MPG- or AVI-files (max. 720 x 480 pixel)
- For obtaining better video quality, 3rd party software products have to be used (e.g. hypercam)

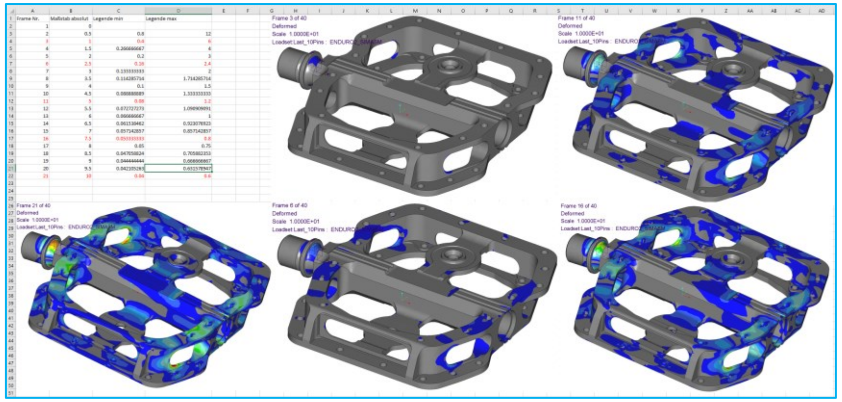
Chosen procedure for the FEM loading sequences of the magped image film

- A series of single VRML-files with individually adjusted legend scaling and deformation factors has been created by means of the Creo Simulate post processor
- These VRML-files have been read into a third-party software and merged into a movie sequence
- This also allows fly-by and even change of appearance (e.g. transparency)
- As an example, see the subsequent magped Enduro2 image film

Video generated by Creo Simulate (max. resolution of 720 x 480 pixel)



EXCEL with required magnification factors and legend scaling



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8. Creation of marketing material for the final product

8.2 Photorealistic rendering containing FEM loading sequences

magped image film for the Enduro2 pedal

- FEM animation starts at 00:27

magnetic safety bike pedals
magped

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Appendix

i. References

References

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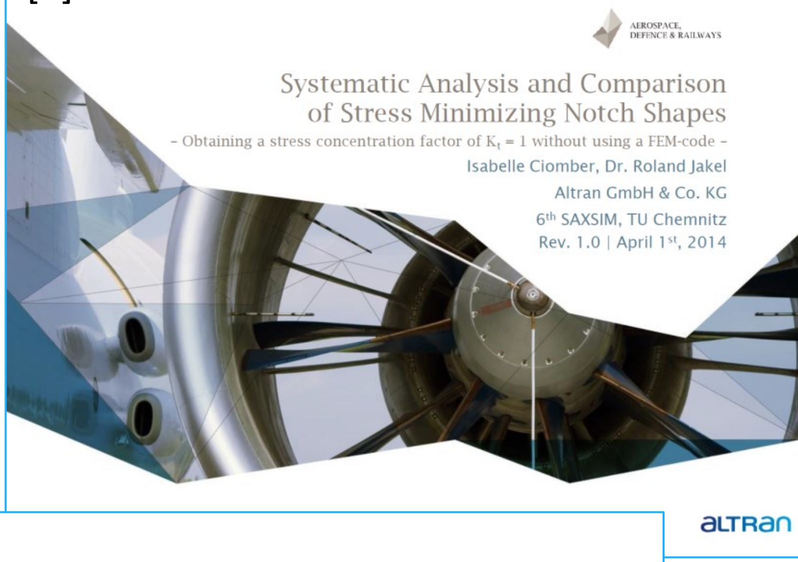
[4] R. Jakel: „Using a Catenary Equation in Parametric Representation for Minimizing Stress Concentrations at Notches“; presentation for the 7th SAXSIM; March 31st, 2015

[3]



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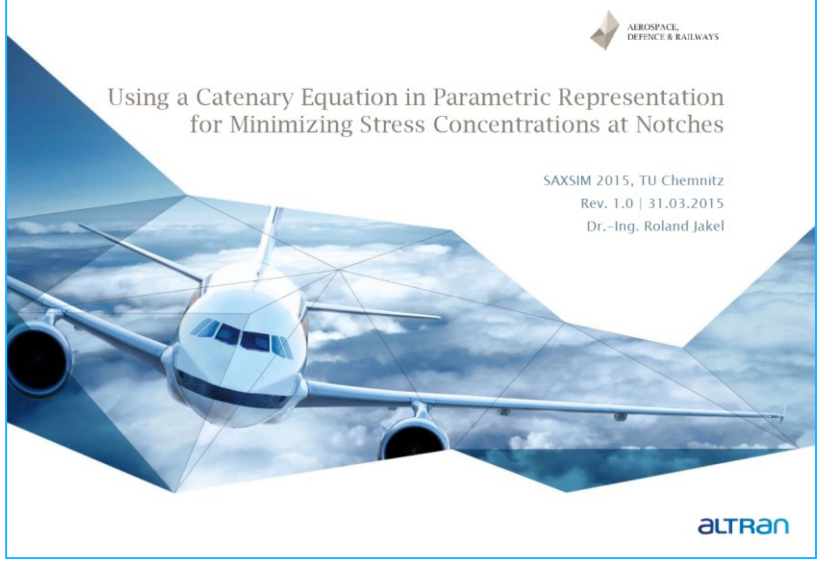

Appendix

ii. The author

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1990-1996: “Wissenschaftlicher Mitarbeiter” at the “Institut für Maschinenwesen der TU Clausthal“;
Ph.-D. in Engineering Science 1996 (design / computation of engineering ceramics)

1996-2001: Development Engineer at Daimler-Benz Aerospace AG, Space Infrastructure, Bremen, Germany

2001-2005: Consultant for structural simulation at DENC AG, Langenfeld (Design ENgineering Consultants)

2006-2012: Principal consultant for PTC simulation services at PTC Central Europe

2012-2019 (incl. predecessor companies): Advanced solution manager for structural simulation at Altran Germany

Since 2019: Freelancing consultant for structural simulation and product development

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