Modelling of thermal load and electric fields in microfocus X-ray tubes

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X-RAY WorX GmbH

Innovative Microfocus X-ray Tubes - Made in Germany

Outlook

- X-RAY WorX
- Fields of business
- Microfocus X-Ray technology
- Comsol application by X-Ray WorX:
  - Optimization of thermal load on HV-Insulators (ht & sm)
  - Optimization of thermal load on the target (ht & sm)
  - Optimization of aperture diameter and filament position incl. particle tracing (es & pt)
  - Optimization of the geometry of the cathode chamber and cathode assembly (es)
- Summary

X-RAY WorX

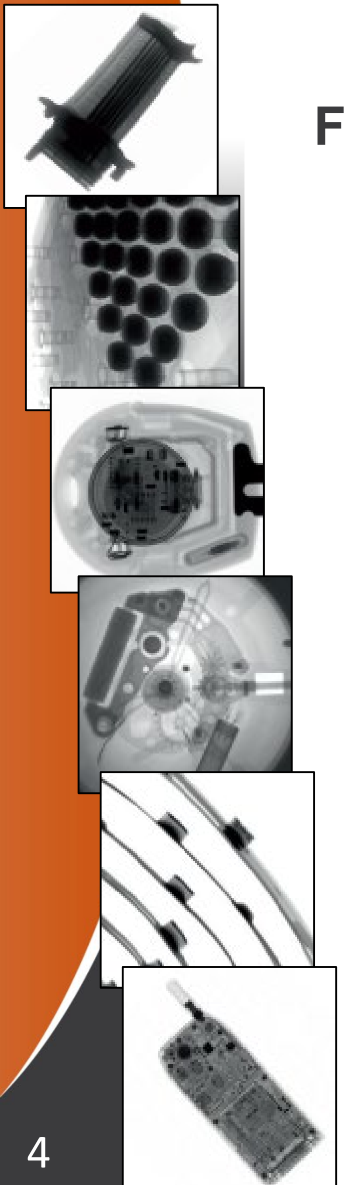
We are one of the leading global suppliers of high resolution microfocus tubes for non-destructive testing, computed tomography, and metrology in industry and science.

- In cooperation with our partners, we offer worldwide sales and services for microfocus X-ray solutions.
- It is our goal to continuously improve and enhance microfocus technology in terms of resolution, focal spot stability, power, and ease of use.

Since January 2021 X-RAY WorX is part of the Swedish Indutrade group

www.x-ray-worx.com

Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V.



Fields of business

Development and production of microfocus X-ray tubes

High resolution X-ray tubes

High power X-ray tubes

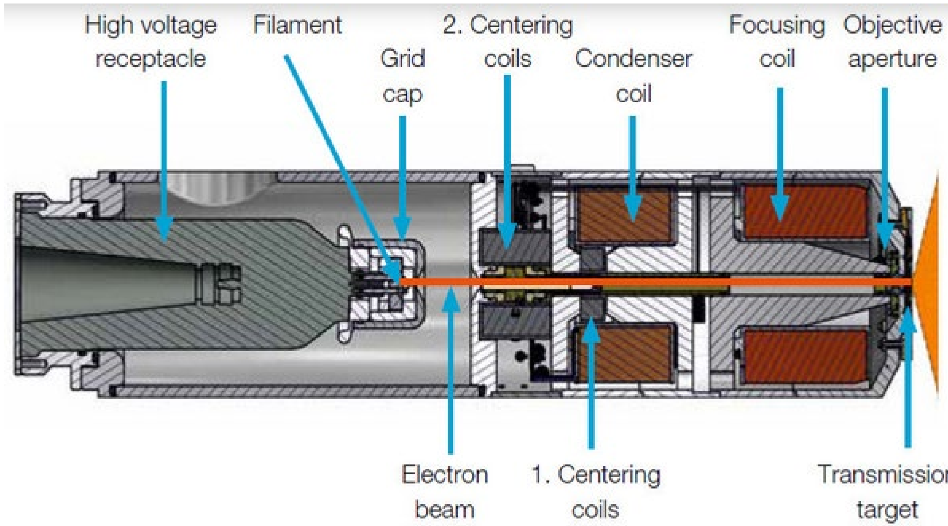
Dual head X-ray tubes

Rod anode X-ray tubes

We are continuously working on improvement of availability, reduction of focal spot movement, efficient cooling systems, higher filament lifetime, improvement of resolution and stability, automation, and maintainability.

Microfocus X-Ray technology

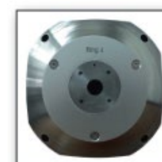
Microfocus transmission tubes – double stage



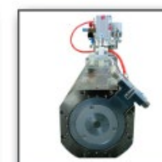
THE Plus	TCHE Plus	TCNF Plus
Up to 300kV	Up to 240kV	Up to 240kV
2µm – 15µm JIMA	0.9µm – 15µm JIMA	0.5µm – 15µm JIMA
External cooling	External cooling	Internal cooling
Diamond target	Diamond target	Diamond target
Target cooling	Target cooling	Target cooling
50W target power	50W target power	50W target power

Product image

Microfocus X-ray tube XWT-160-TCNF Plus



Target with scale

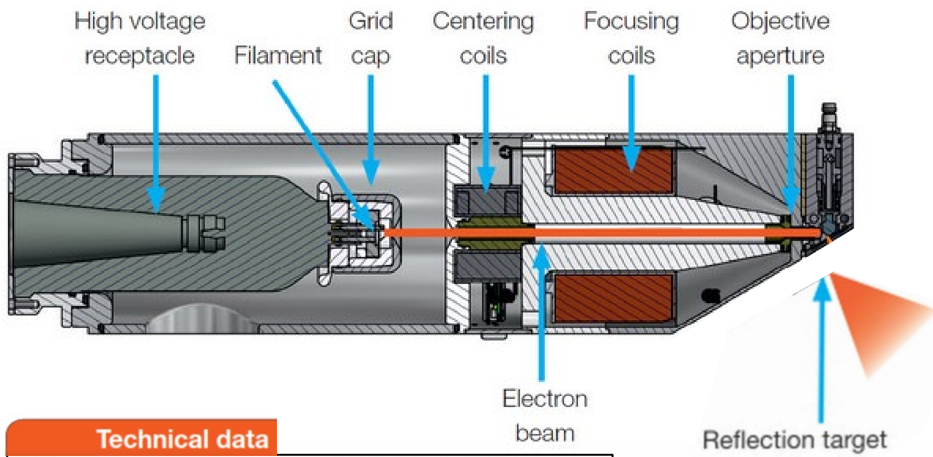


XWT-190-TCNF Plus with 50 W target power

JIMA resolution 0.5 µm

Microfocus X-Ray technology

Microfocus reflection tubes



Technical data

Data	Product line *CT Plus*		
Max. voltage (kV)	225	240	300
Min. voltage (kV)	20	20	50
Max. current (mA)	3.0	3.0	3.0
Min. current (mA)	0.05	0.05	0.05
Max. power, emission (Watt)	500	500	500
Max. power, target (Watt)	450	450	450
JIMA resolution (µm)	4.0	4.0	4.0
Tube type	Reflection		
Target type	*High Power*		
Target material	Tungsten		

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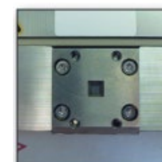
Superior Microfocus Technology

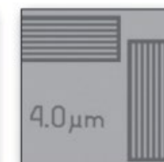
Product image

Microfocus X-ray tube XWT-300-CT Plus



XWT-300-CT Plus with new collimator

XWT-300-CT Plus with new cooling circuit



JIMA resolution 4.0 µm: 225kV - 300kV tubes

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Comsol application bei X-Ray WorX

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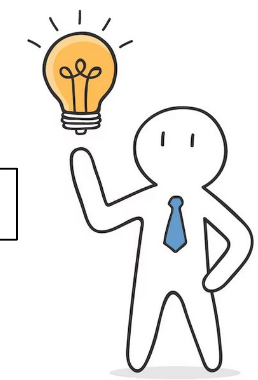
Our technical challenges

- More X-ray power: thermal load on the target (anode)
- Dielectric strength (proper materials, geometry, polishing, vacuum conditions
- Filament lifetime: geometry, temperature, filament current, vacuum conditions
- Smaller focal spot: electron optics and thermal load on the target surface
- Smaller & lighter modules
- Long-term thermal stability (cooling and e-optics performance)

Comsol Multiphysics

- Heat transfer
- AC/DC
- Particle tracing module
- Material library
- LiveLink™ for Inventor®
- Design module
- Structural Mechanics (optionally)

→ Physical modelling
↓↑
Design / technical solution
↓
Prototyping
↓
Experimental tests → Implementation



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Optimization of the thermal load on HV-Insulators

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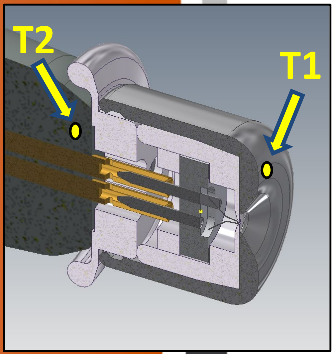
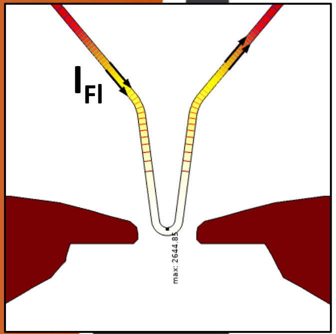
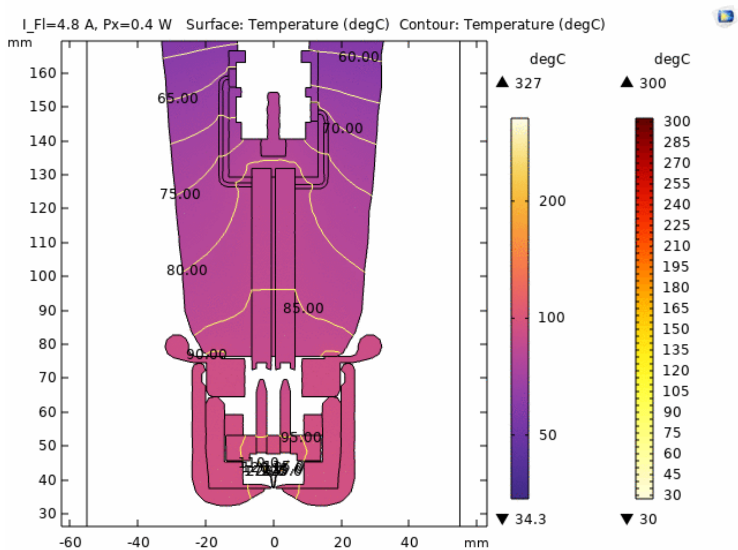
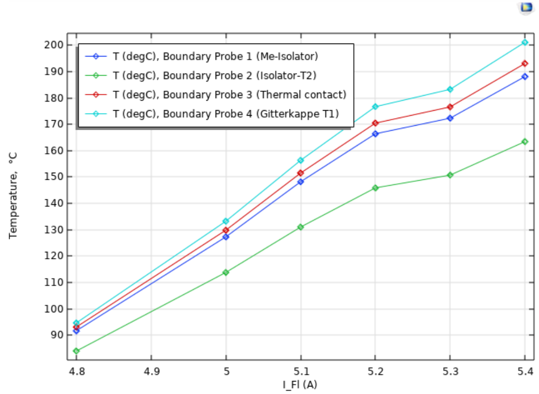
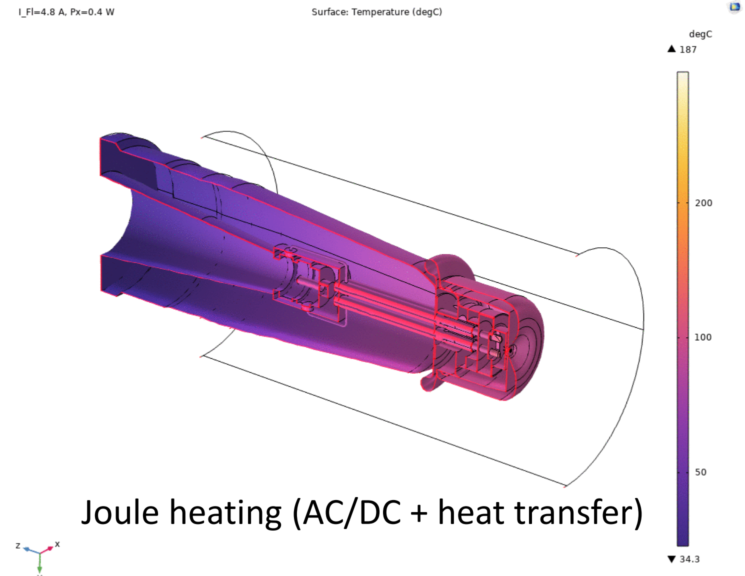


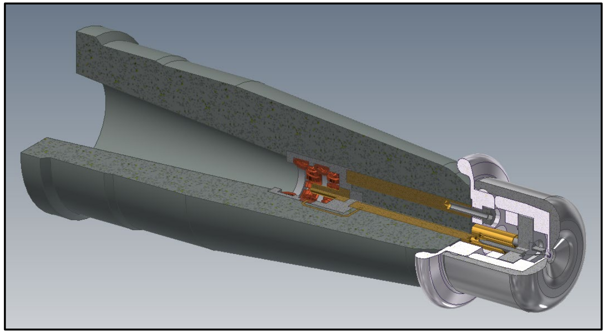




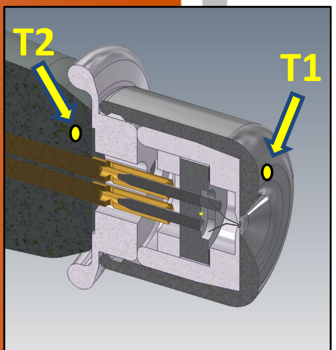


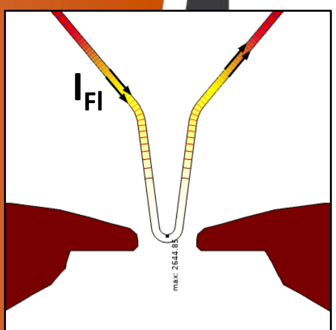


Joule heating (AC/DC + heat transfer)



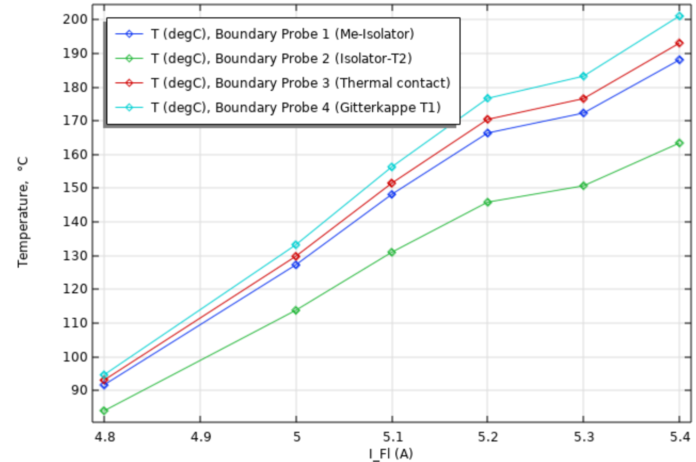
Heat transfer: experiment and modelling





Experimental data

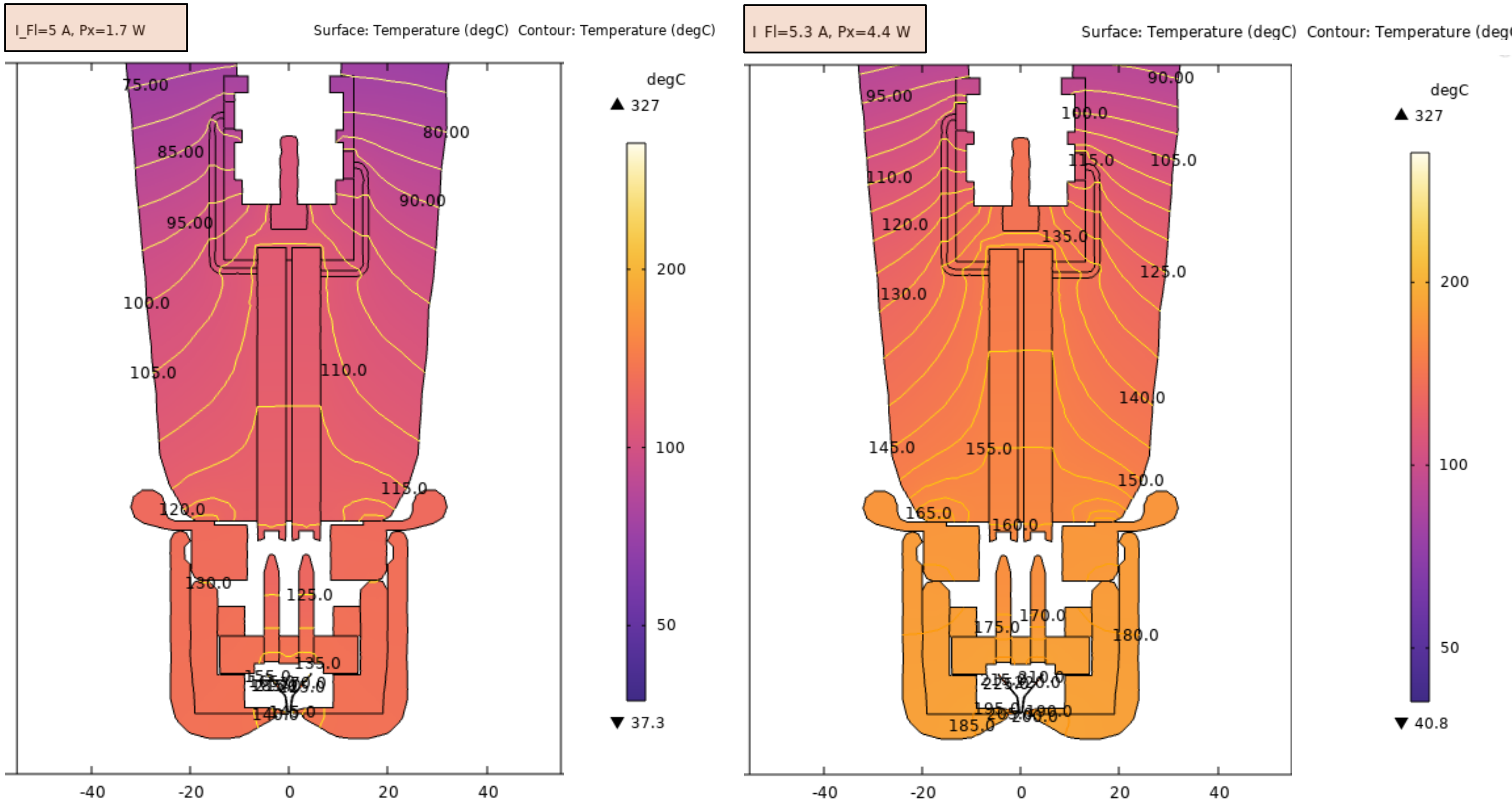
I_Fl (A)	T1 (Gitterkappe)	T2 (Isolator)
0	28,7	28,8
4,8	94,4	78,6
5,0	132,3	108
5,1	156	127,8
5,2	176,3	143
5,3	183,6	152,8
5,4	201,4	166,1



Simulation data (Boundary Probes)

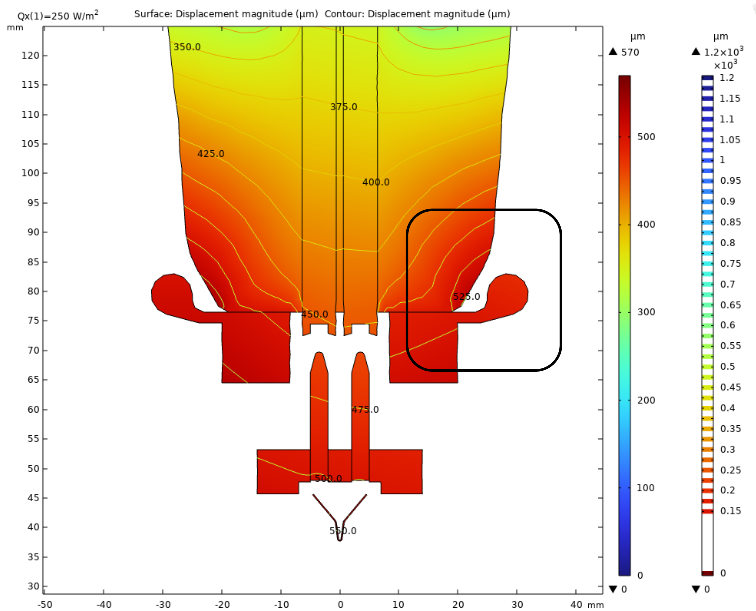
I_Fl (A)	Px (W)	T (degC) T1 (Gitterkappe)	T (degC) (Thermal contact)	T (degC) (Me-Isol)	T (degC) T2 (Isolator)
4.8	0.4	94.613	93.046	91.631	83.934
5.0	1.7	133.24	129.84	127.29	113.79
5.1	2.9	156.36	151.53	148.22	131.02
5.2	4.1	176.73	170.48	166.44	145.91
5.3	4.4	183.31	176.65	172.36	150.75
5.4	5.6	201.19	193.14	188.15	163.47

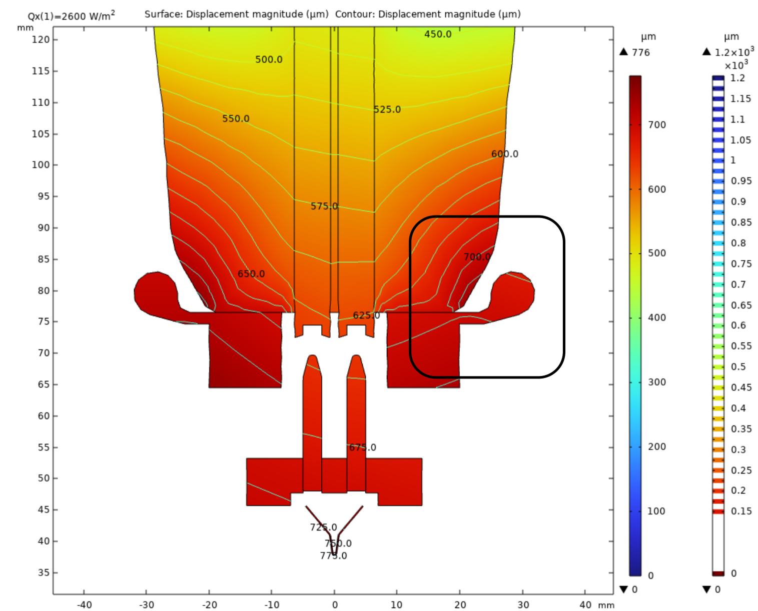
Modelling results (heat transfer)

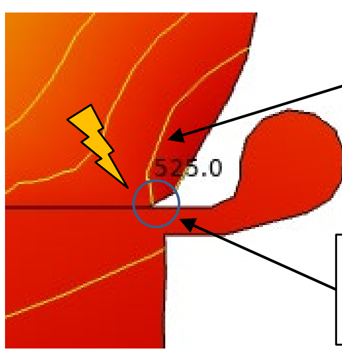


FEM: Temperature field / thermal expansion → design optimization

Modelling results (thermal expansion)

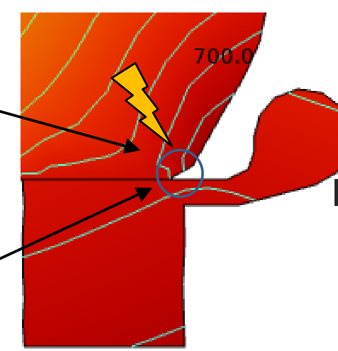






Thermal stress and strong deformation!?

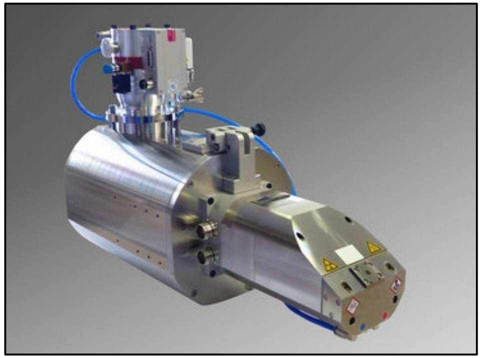
I_{FI}= 5.0A, (T_2=108 ˚C)



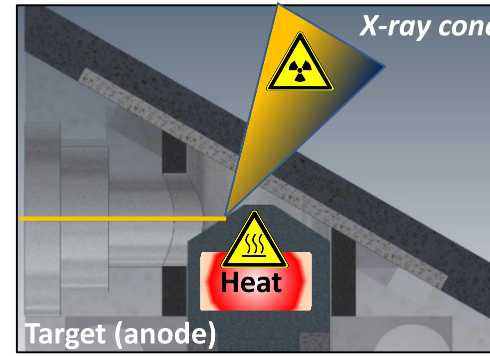
I_{FI}= 5.3A, (T_2=153 ˚C)

„Triple point“: HV breakdown / surface flashover

Optimization of thermal load on the target

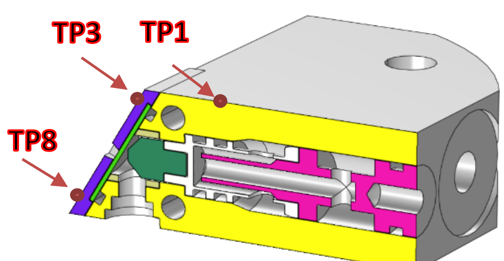


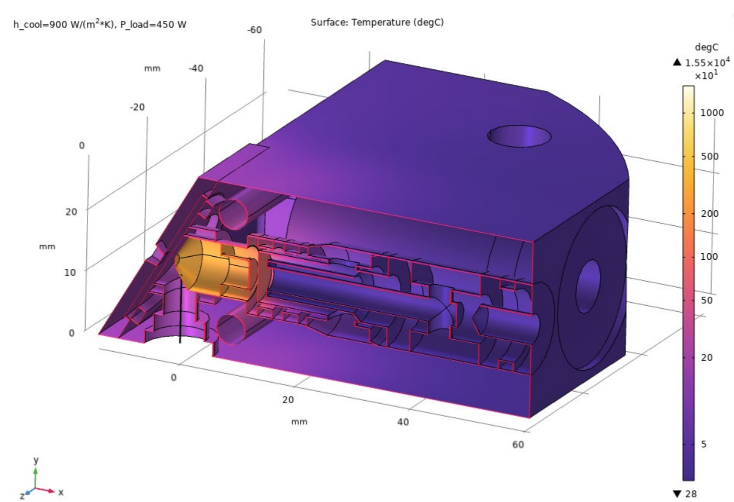
		Voltage [kV]						
		60	100	150	190	225	240	300
Target power [W]	50	60	60	60	55	40	40	40
	100	110	105	100	85	80	75	75
	150	140	175	145	125	125	125	125
	200		250	190	170	170	170	170
	250		340	235	235	225	225	225
	300			300	300	285	285	285
	350			370	370	340	340	340
	400			450	450	400	400	400
	450				500	450	450	400



Topics:

- Heat distribution within the Target (anode)
- Thermal expansion within the target-assembly
- Heat distribution within the tube housing
- Extreme temperatures at the target surface
- Active cooling





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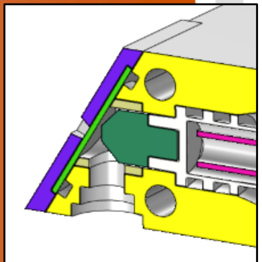
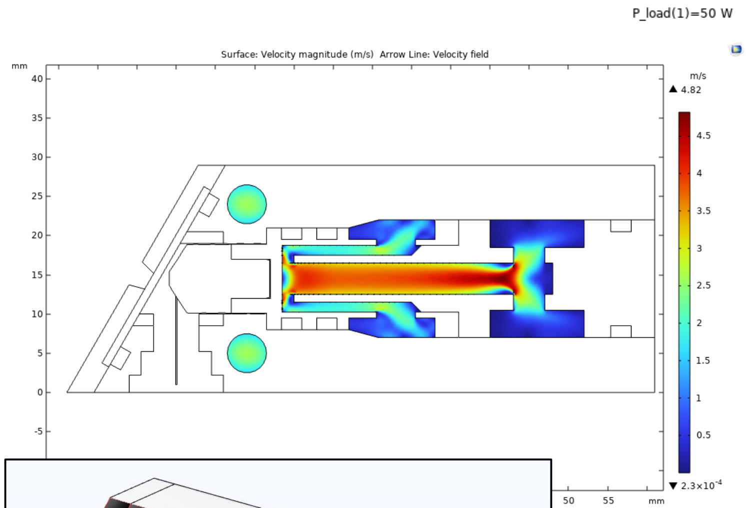
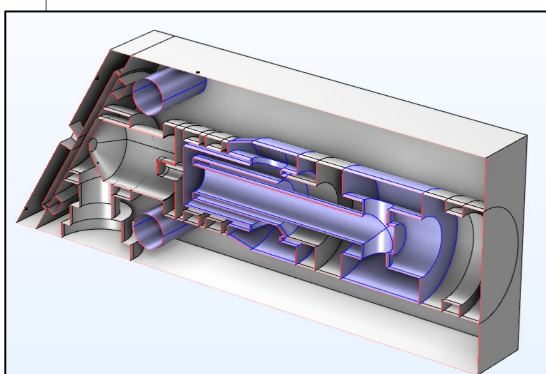
Our approach: nonisothermalflow and heat transfer (One-way coupling approach)

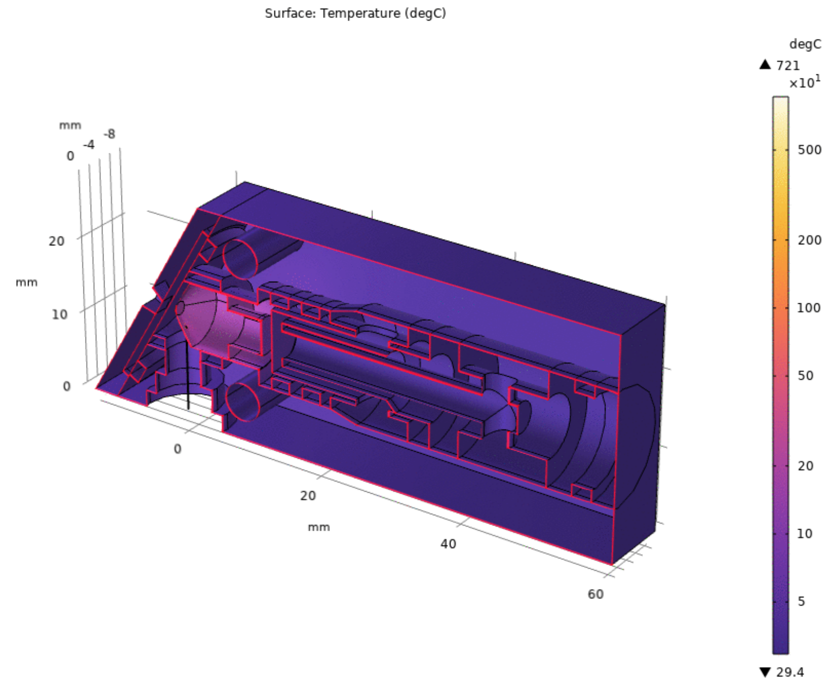


1) Nonisothermal Flow





2) Heat Transfer



Surface probes are used to monitor temperatures; experimental data is available for reference

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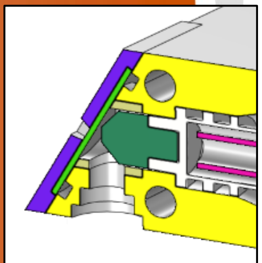
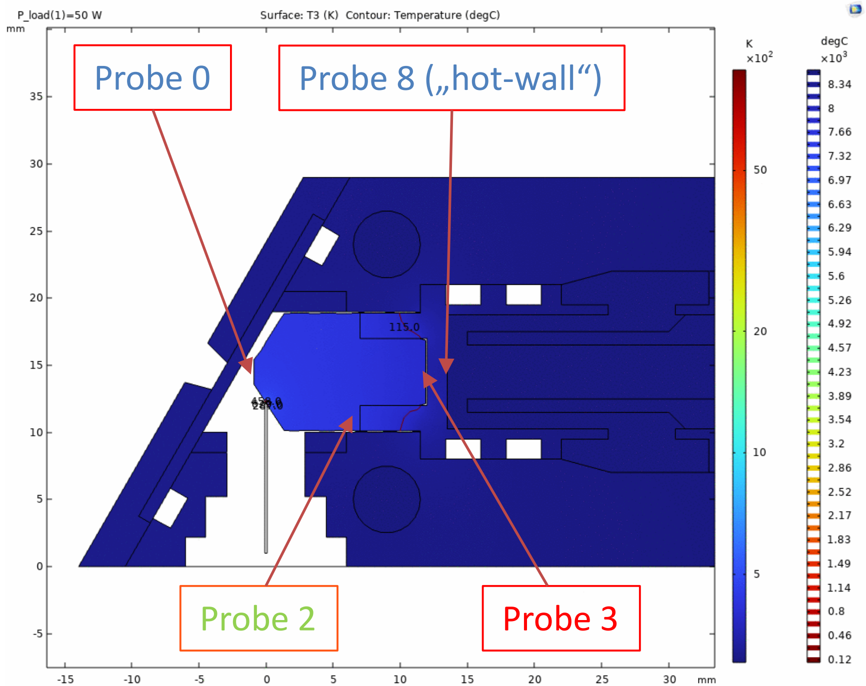
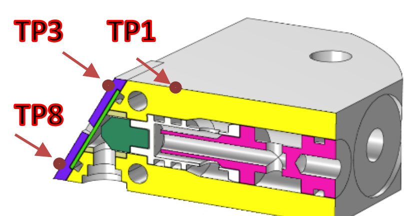
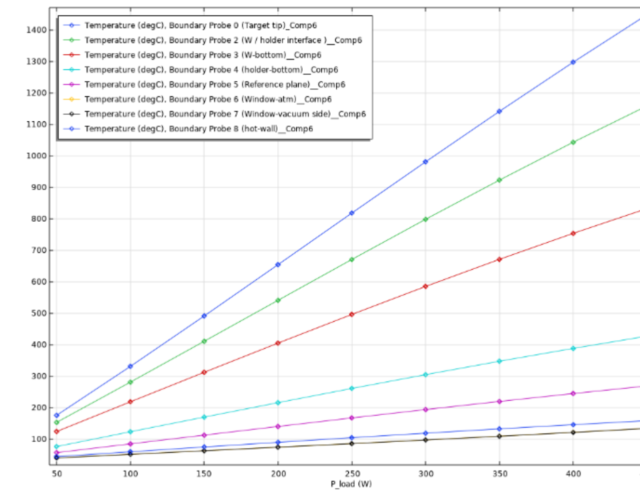
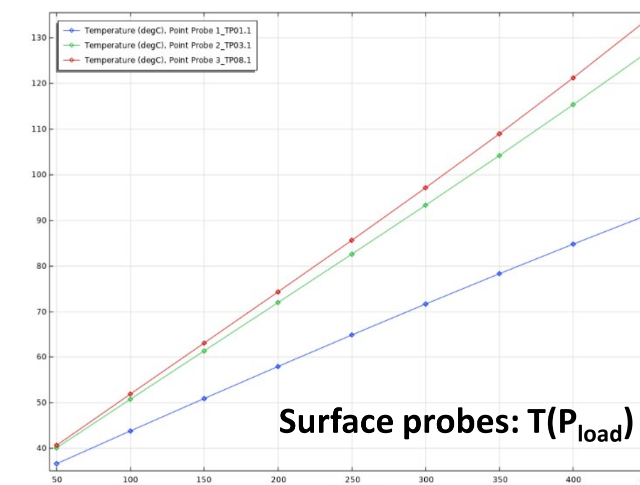
Modelling results (heat transfer)



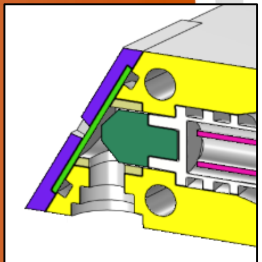


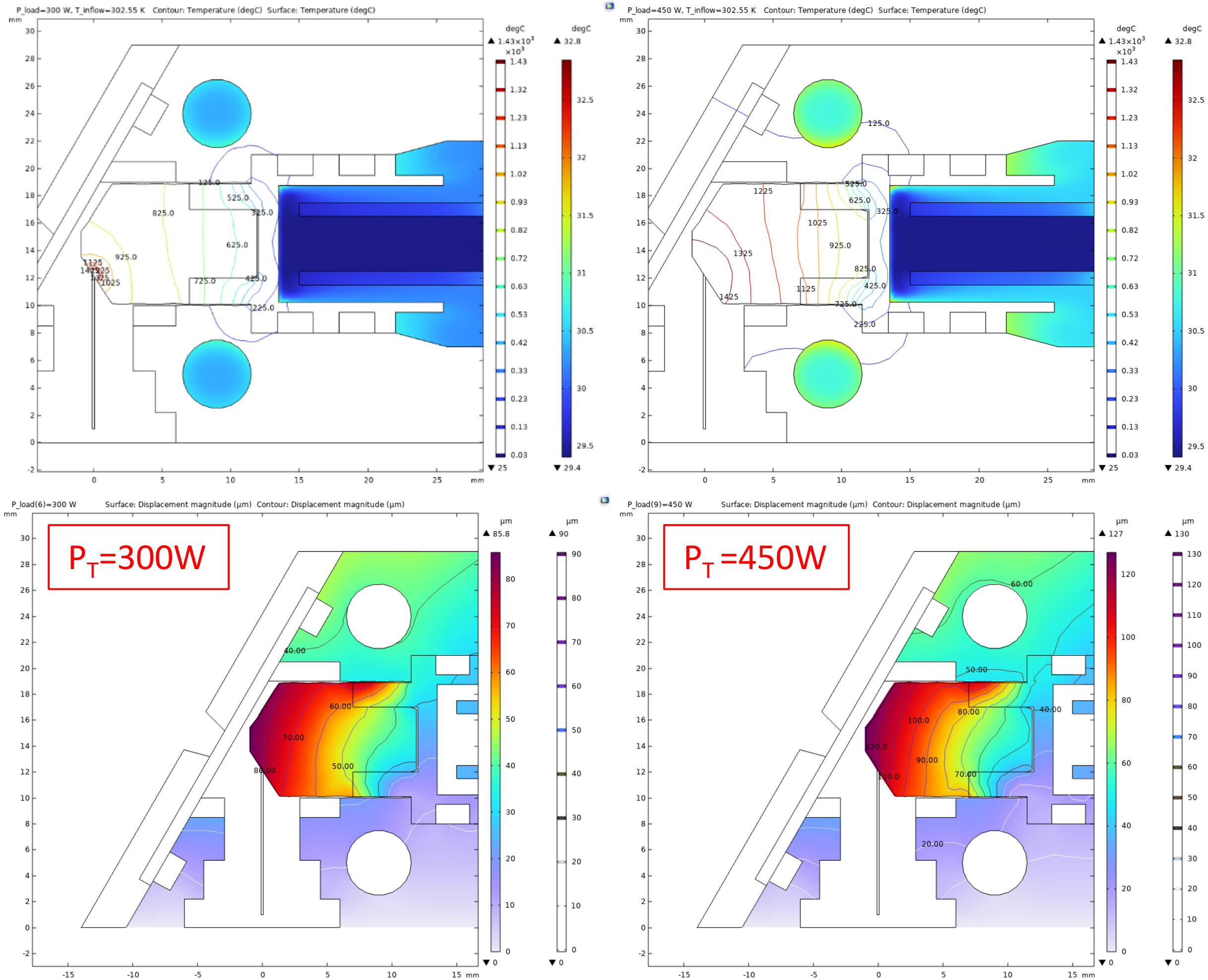






Modelling results (heat transfer and thermal expansion)





Target assembly: design optimization

14/11/2023

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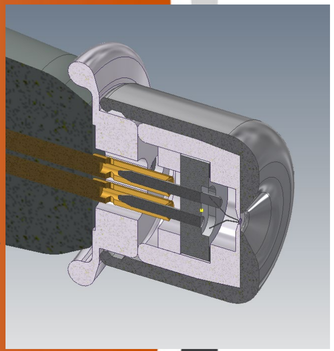
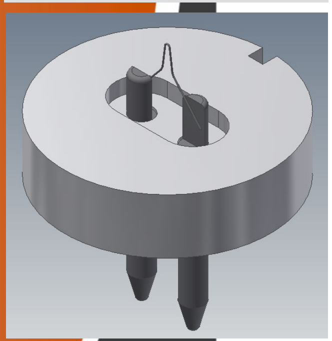
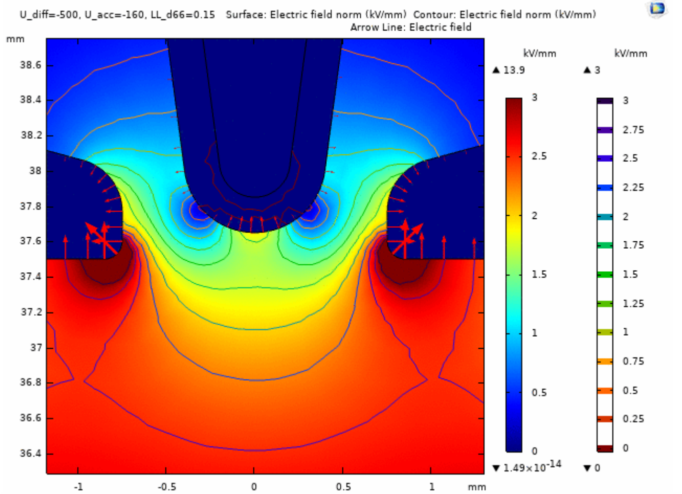
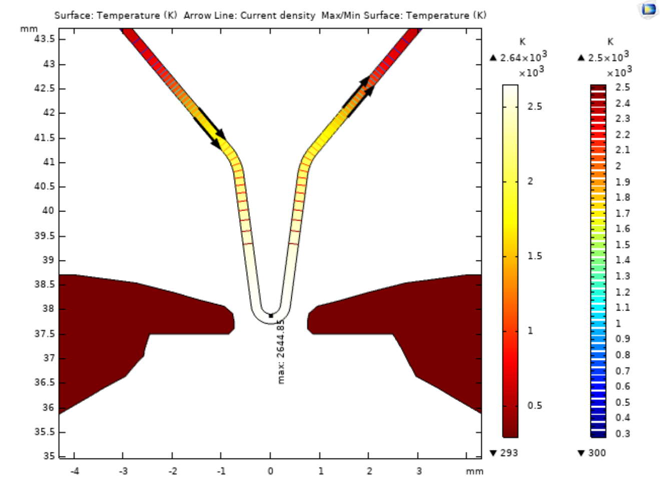
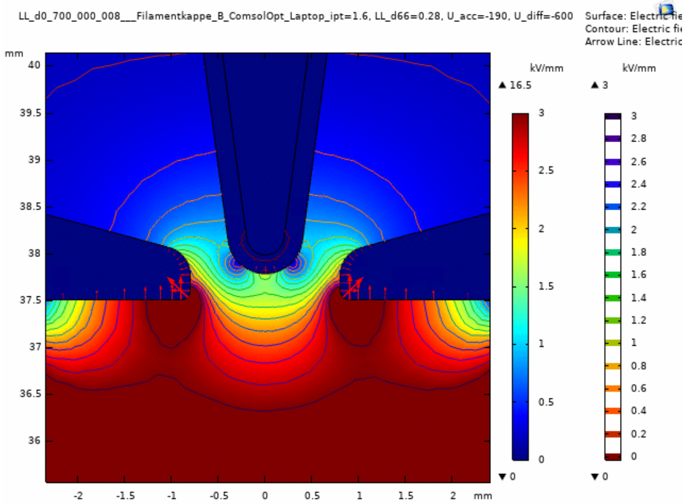
Optimization of aperture diameter and filament position, particle tracing

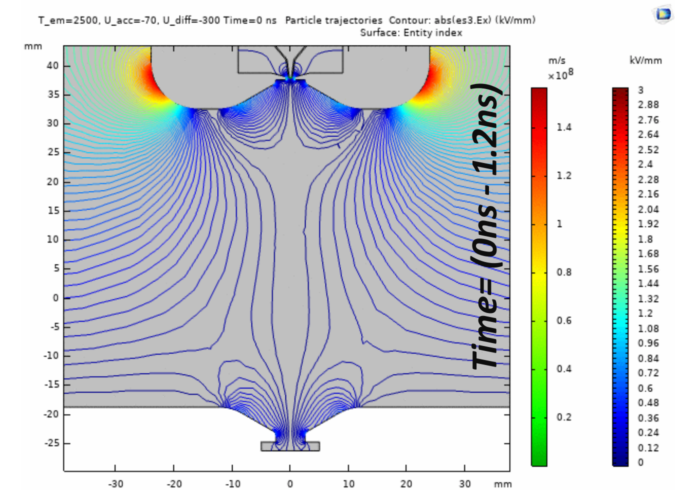












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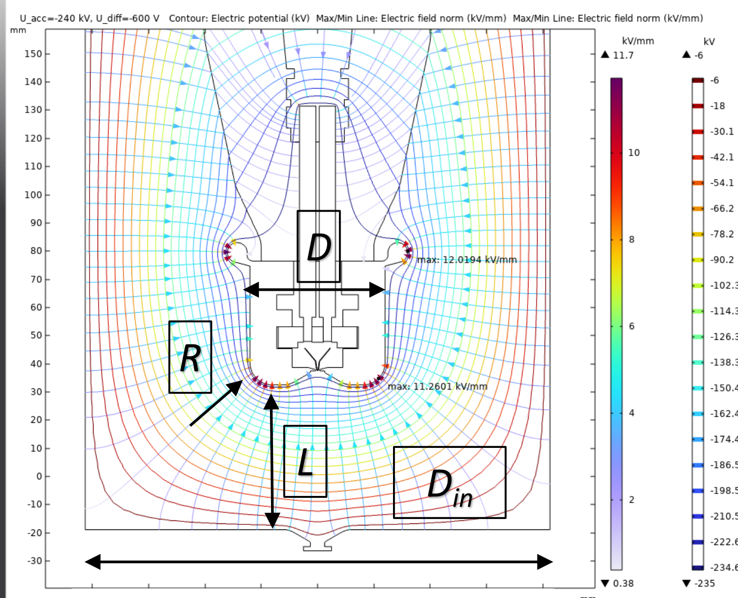
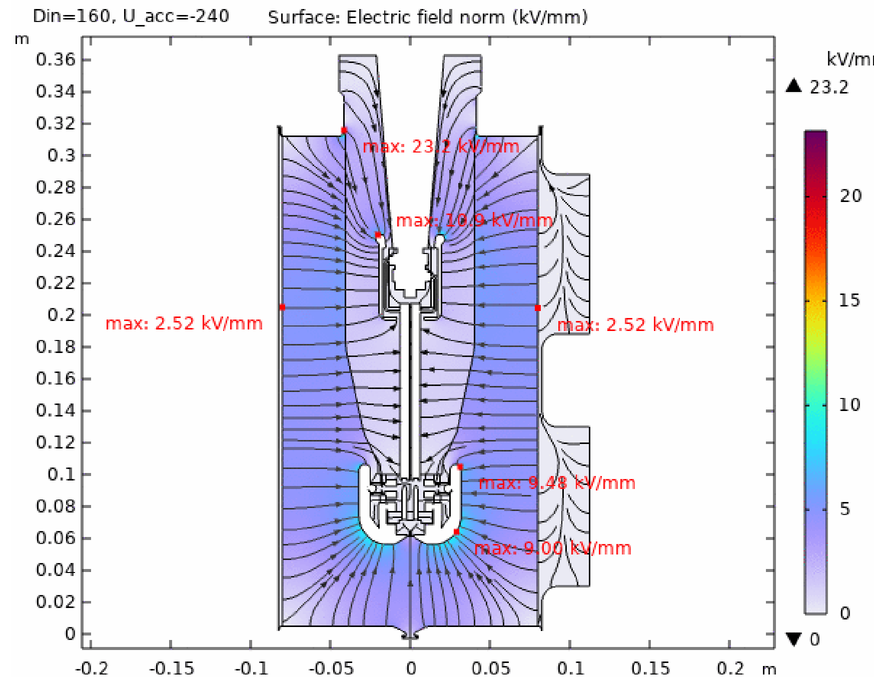
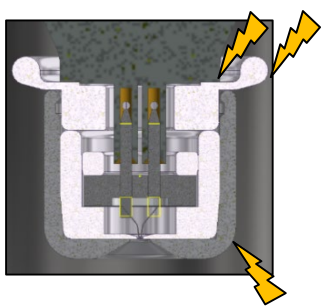
Optimization of the geometry of the cathode chamber and cathode assembly







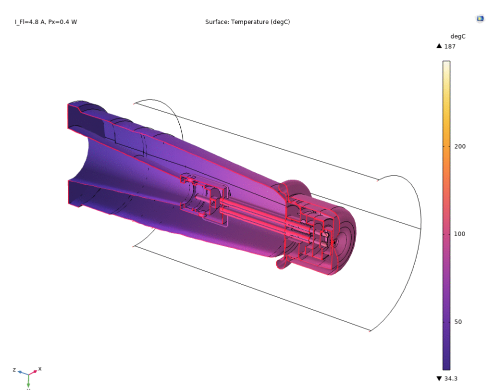
Minimization of local electrical field
(electrostatic, dielectric strength)

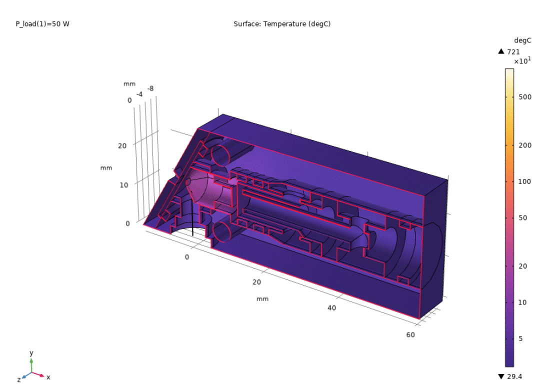
„Triple point“: very strong enhancement of the electric field
may take place due to the thermal expansion

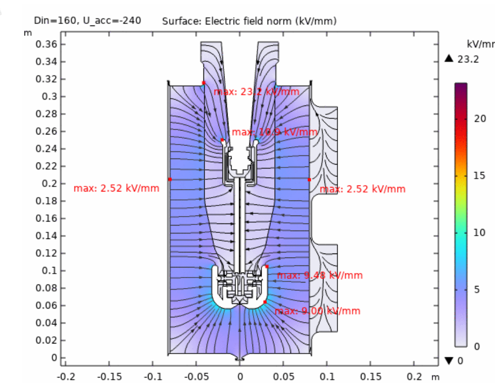
Summary

Comsol application by X-Ray WorX incl.:

- Optimization of the thermal load on HV-Insulators and the target
- Optimization of aperture diameter and filament position, filament current and particle tracing
- Optimization of the geometry of the cathode chamber and cathode assembly







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Thank you

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Abstract

Modelling Of Thermal Load And Electric Fields In Microfocus X-ray Tubes

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Abstract

The thermal load on the system components is one of the technical problems in the development of microfocus X-ray tubes. To improve their stability in long-term use, it is important to understand the physical phenomena and their influence on the system stability and filament lifetime.

To improve our X-Ray WorX products, we apply Comsol Multiphysics software to optimize the thermal load on the insulators as well as the target used to generate the X-rays. Joule heating mechanism, used to facilitate thermionic emission from the filament, generate a lot of heat that must be dissipated by the cathode assembly and insulator. The insulators in particular can cause problems from a dielectric and mechanical point of view, since they experience relatively high temperatures and thermal expansion under thermal load in the presence of strong electric fields. The decisive factors here are the vacuum conditions, the temperature distribution, the dielectric insulation strength by high-voltage application of up to 300 kV and the mechanical construction. We apply FEM to address the issue of thermal management and dielectric strength and to optimize the mechanical design of our cathode assembly and insulator.