Electron Driven and Undulator Driven Positron Targets for the ILC. R+D Path and Goals.

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LCWS Strasbourg

23-27 October 2017

Contents

1.1 R+D Path for the Conventional Target.

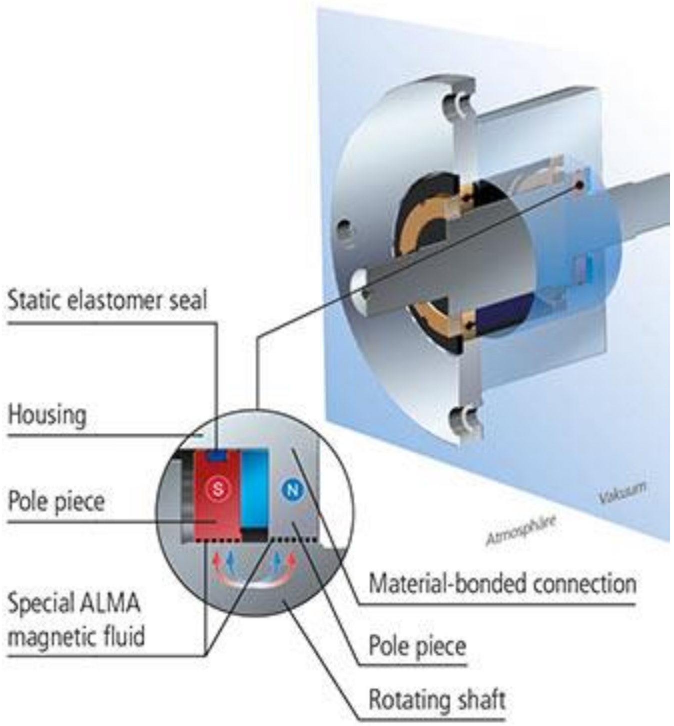
- Basic parameters:
- Target wheel with 50 cm diameter and a W-target with 14 mm thickness.
- Rotation velocity ~ 5 m/s, 200 rpm.
- W-target mounted on a water cooled Cu-wheel.
- Requires penetration of the rotating axis into the vacuum tank.
- Requires Ferro Fluid rotating seal.

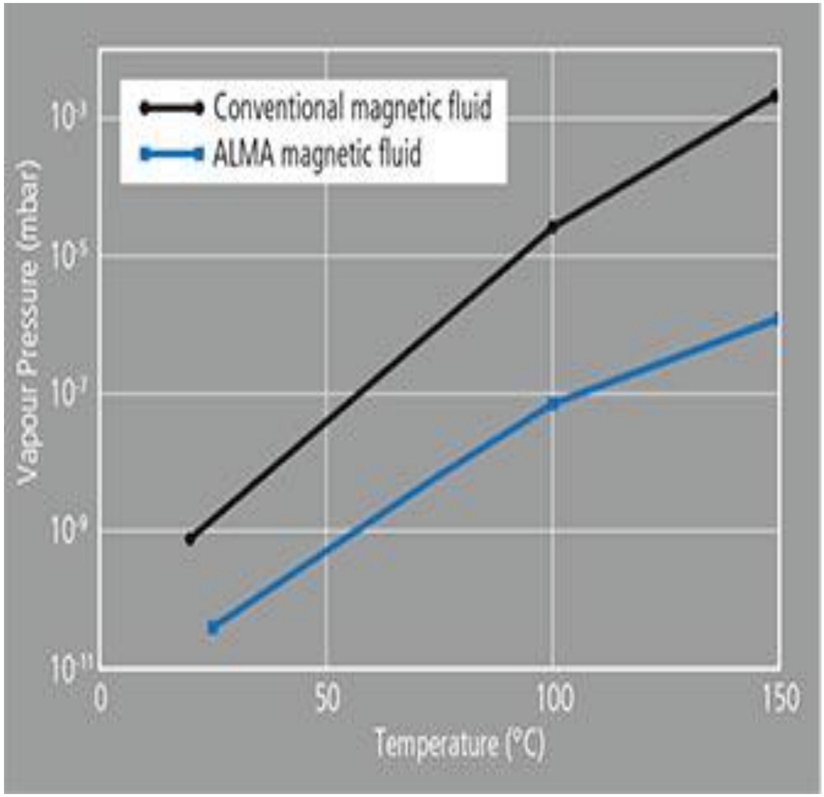
Possible R+D for the ferro fluid rotating seal

- RIGAKU seal: critical issues are the oil, heating and cooling and temporary degradation of the vacuum and lifetime (Ref. Omori-san).
- Check enclosed air pockets and mechanical loads.
- Ferro-tec seal, similar problems?
- ALMA-seal: not yet evaluated.

Doc of ALMA: www.alma-driving.de

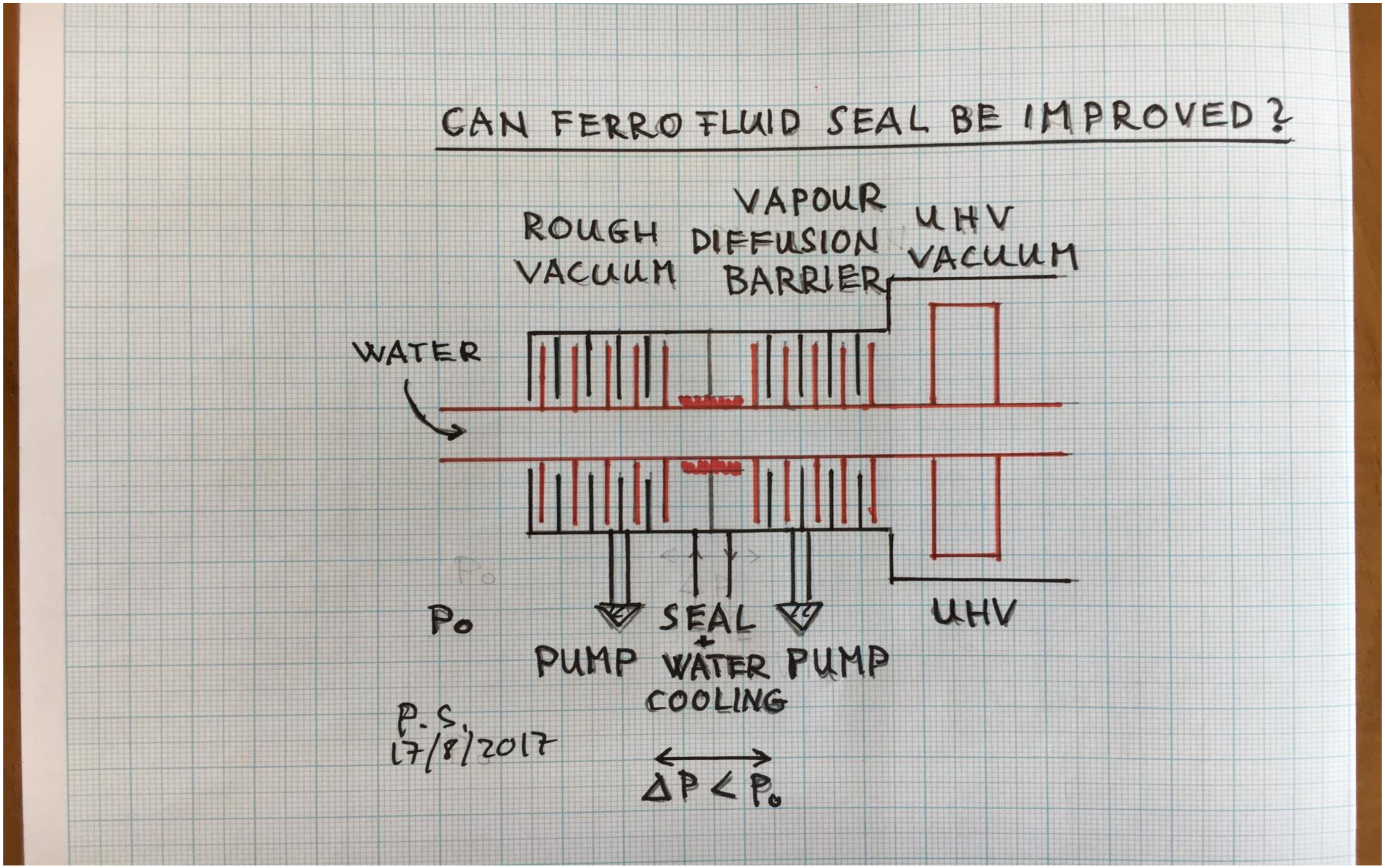
- 10 -7 mbar =10-5 Pa



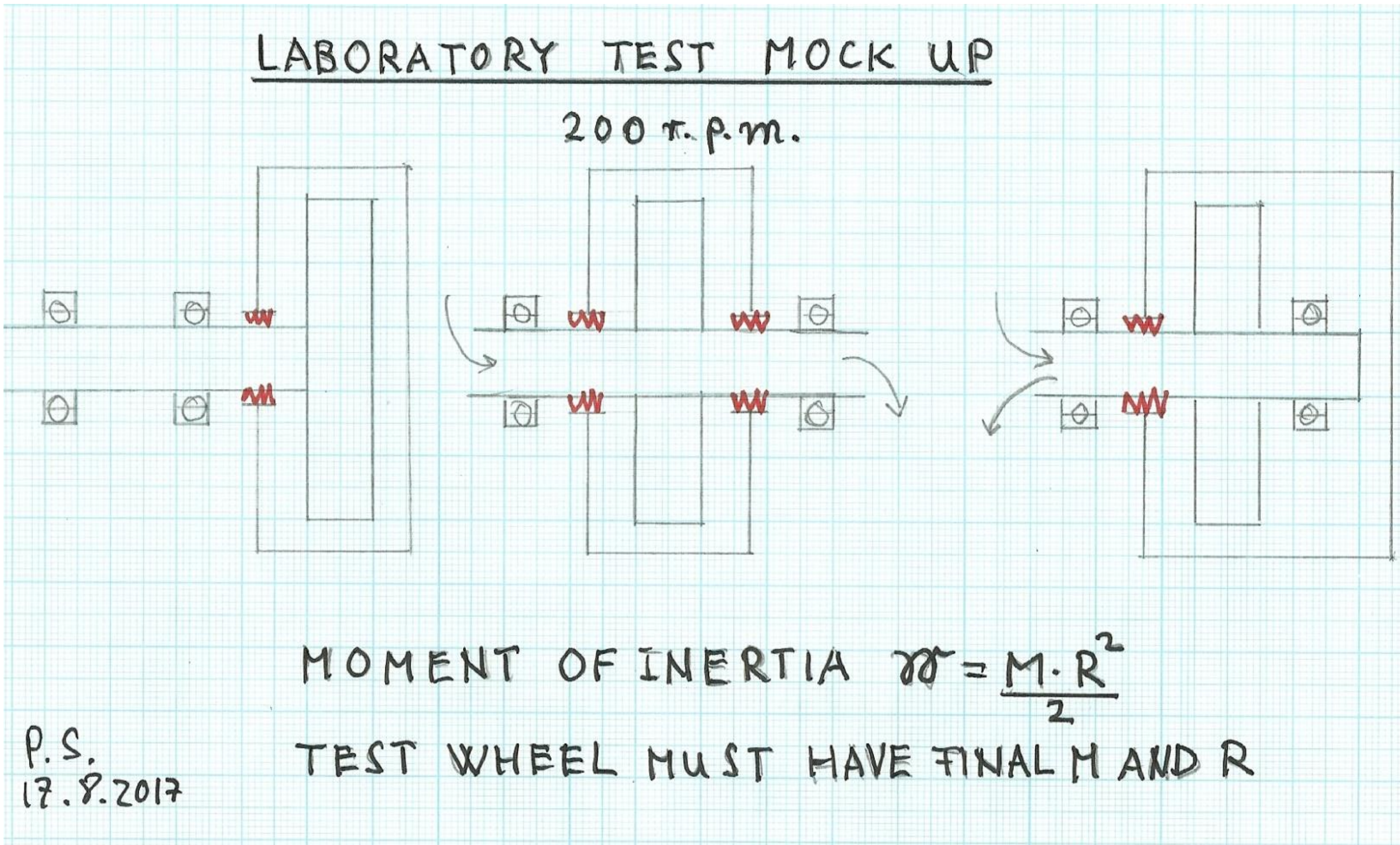


- Problems of ferro fluid seals: pressure difference across the seal is 1 atm!
- Heating of the seal, needs good water cooling.
- Diffusion of air into the vacuum through the seal and outgassing of oil.
- Use best possible oil with low viscosity and low vapour pressure. Protect it from radiation damage by adding adequate shielding.

Investigate adding Labyrinth seals with differential pumping.



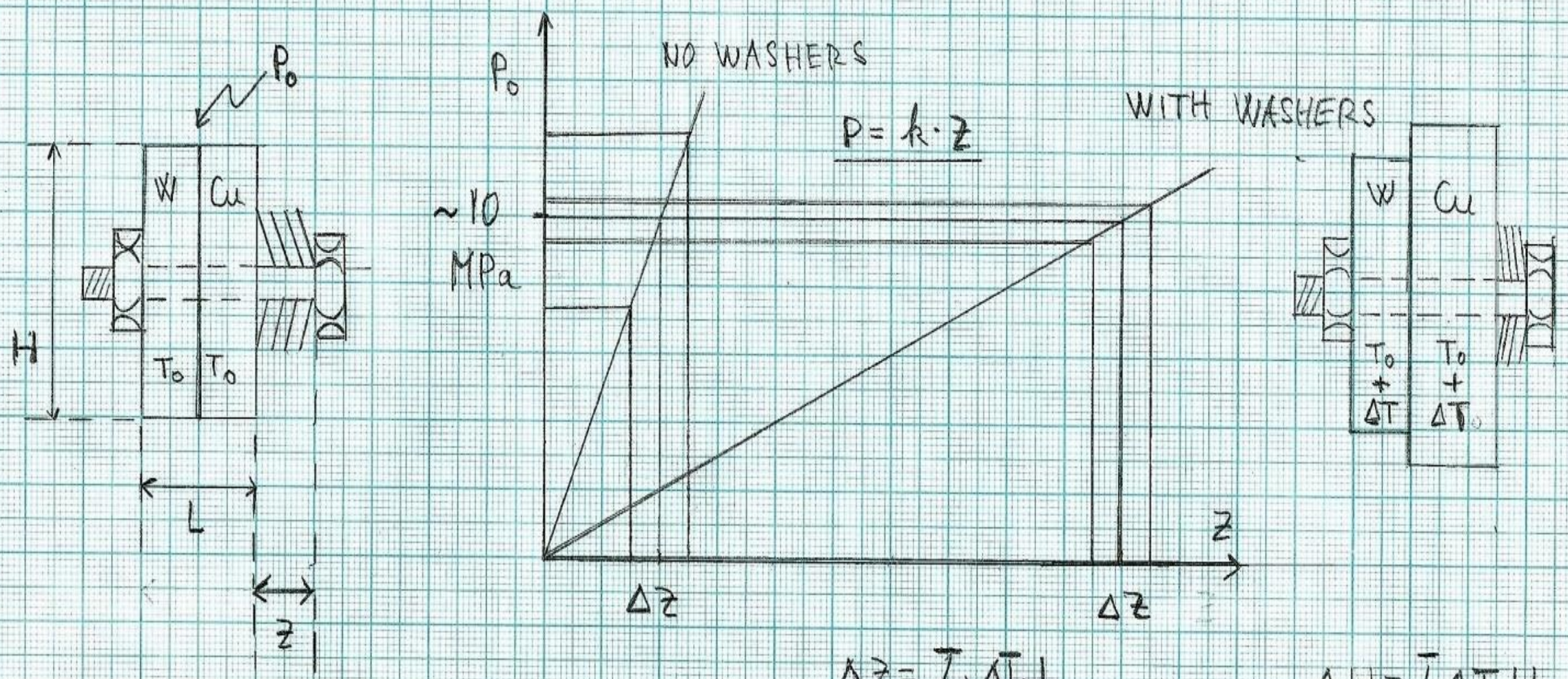
Laboratory test of the ferro fluid seals with realistic geometry and supports



Thermal contact between the W-target and the water cooled Cu-wheel.

- Diffusion-, explosion-, friction-bonding, brazing: the W and Cu part have different thermal expansion coefficients and different temperatures. This could lead to stresses during fabrication and fatigue during operation. Procedures have to be validated!
- Thermal contact by pressure between W and Cu via bolts. Trivial to validate in the laboratory under vacuum.

THERMAL CONTACT WITH BOLTS + SPRING WASHERS



$$\Delta z = \bar{\alpha} \cdot \Delta T \cdot L$$

$$\Delta H = \bar{\alpha} \Delta T H$$

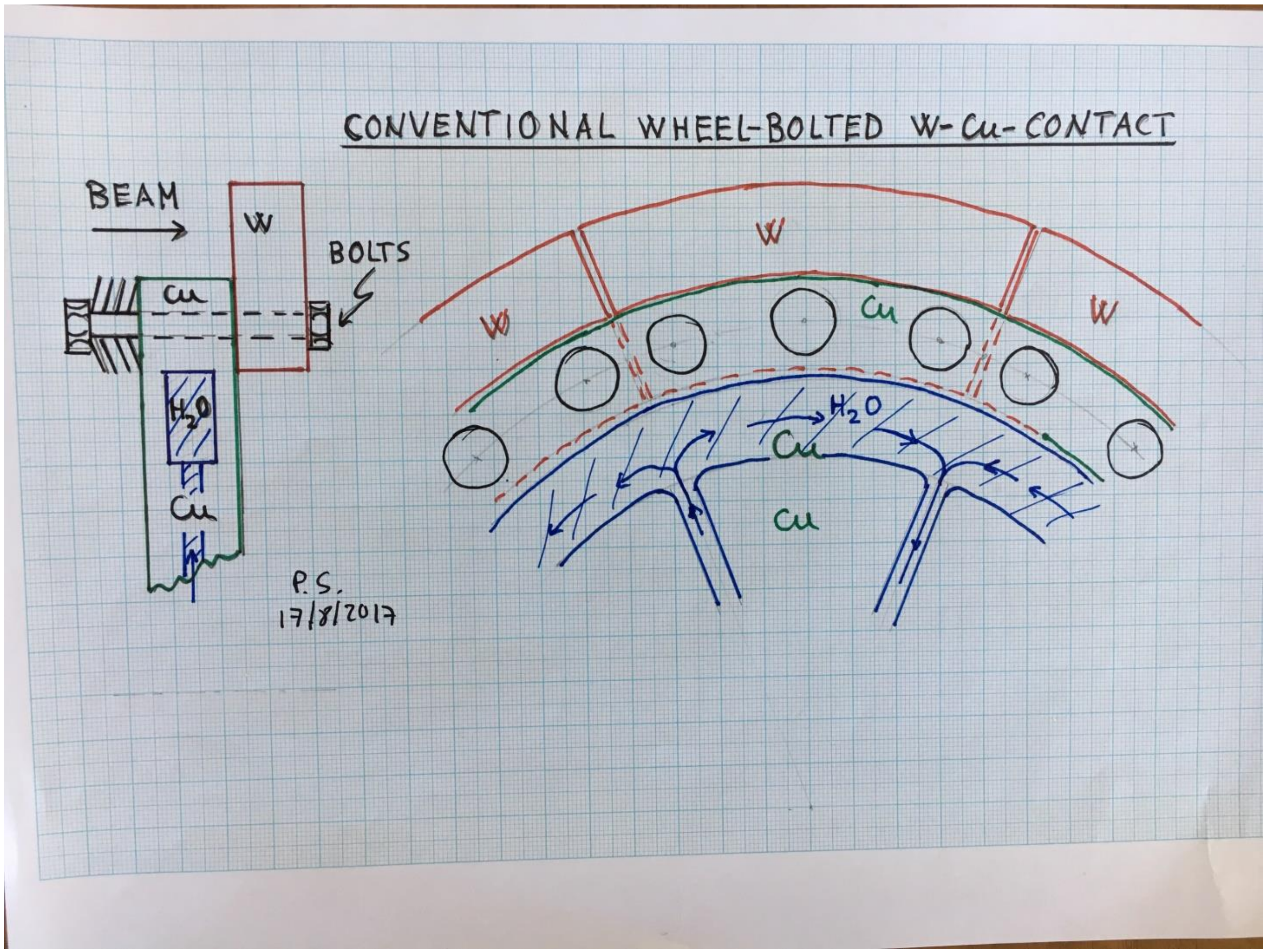
$$P = P_0 \pm \bar{\alpha} \cdot \Delta T \cdot L \cdot k$$

$$\sigma_H = \mu P$$

$$\mu \leq 0.3$$

P.S.
17.8.2017

Design is modeled by Song Jin-IHEP



Design of the Wheel.

- The W-target is made of sectors. Much easier and cheaper to manufacture.
- The water cooled Cu-wheel is a full, monolithic disk.
- The thermal W-Cu contact is made by pressure of about 10 MPa via bolts.
- The heat path from the W-target to the water cooling had however to be increased to provide the space for the bolts.

- The estimated thermal resistance at the bolted W-Cu interface is 2.0 W/cm^2 K for vacuum and at a pressure of about 10 MPa.
- The thermal resistance at the Cu-water interface is also about 2.0 W/cm^2 K for turbulent flow.
- The time average peak temperature in the W-target is 354 C for 35 kW average power.
- The temperature rise/pulse will increase this temperature by about 100 K (Courtesy Song Jin).

Thermal Stresses

- The thermal stresses inside the W-target have been discussed previously (see Presentations by Omori-san and Song Jin in earlier POSIPOL workshops).
- The stresses at the W-Cu interface are critical.
- For intermetallic contacts by bonding or brazing of the W-Cu interface, stresses will occur due to temperature gradients and different thermal expansion coefficients of W and Cu. Thermal contact can fail due to fatigue.
- These stresses are ~ 150 MPa or possibly above (Courtesy Song Jin, tbc).

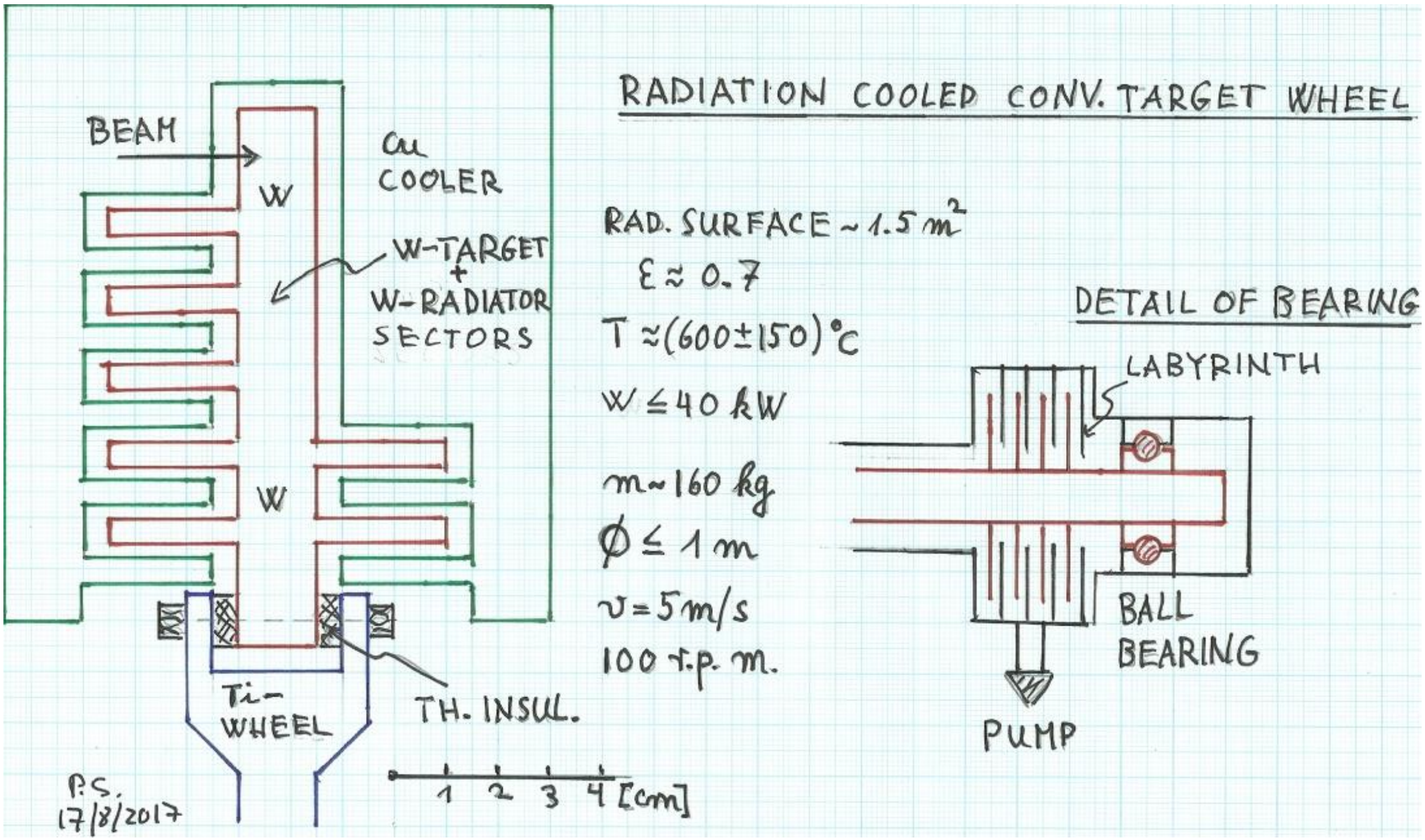
Stresses at the W-Cu interface with bolted contact.

- At a pressure of 10 MPa, a friction coefficient between the smooth W and Cu surfaces of at most 30% is a very safe value.
- Thus friction stresses of at most 3 MPa can occur.
- Therefore the mating W and Cu parts can expand thermally freely and independently in lateral direction, parallel to the interface.
- Due to the spring loaded bolts, axial thermal expansion of the Cu and the W-parts is not prevented, with only little change in contact pressure.

1.2 A Fall Back Solution: A Radiation Cooled Conventional Target.

- With the reduced average beam power, cooling by radiation could be an option.
- Avoids water cooling and ferro fluid seal.
- 4 $dT/T= dW/W=-dF/F=-dM/M=-d\varepsilon/\varepsilon$.
- For 10% increase in T, the power can be increased by 40%, or the radiating surface, the weight and the emissivity can be reduced by 40%.
- Each target/radiator sector around the wheel is made of one single piece of W, no thermal contact problem (brazing, bolts) between target and radiator.

Design Parameters for <35 kW.



- Manufacture of the W sectors, no problem.
- The W-sectors are fixed to a Ti-carrier wheel.
- Due to the high weight of the wheel, magnetic bearings may no longer be possible.
- Investigate “standard” ball bearings for vacuum application, possibly with MoS2 lubrication and labyrinth baffles and differential pumping for 100 rpm.
- Manufacturer: nsk/Japan: Bearings for vacuum environments.
- www.nsk.com/products/spacea/vacuum/#tab2.

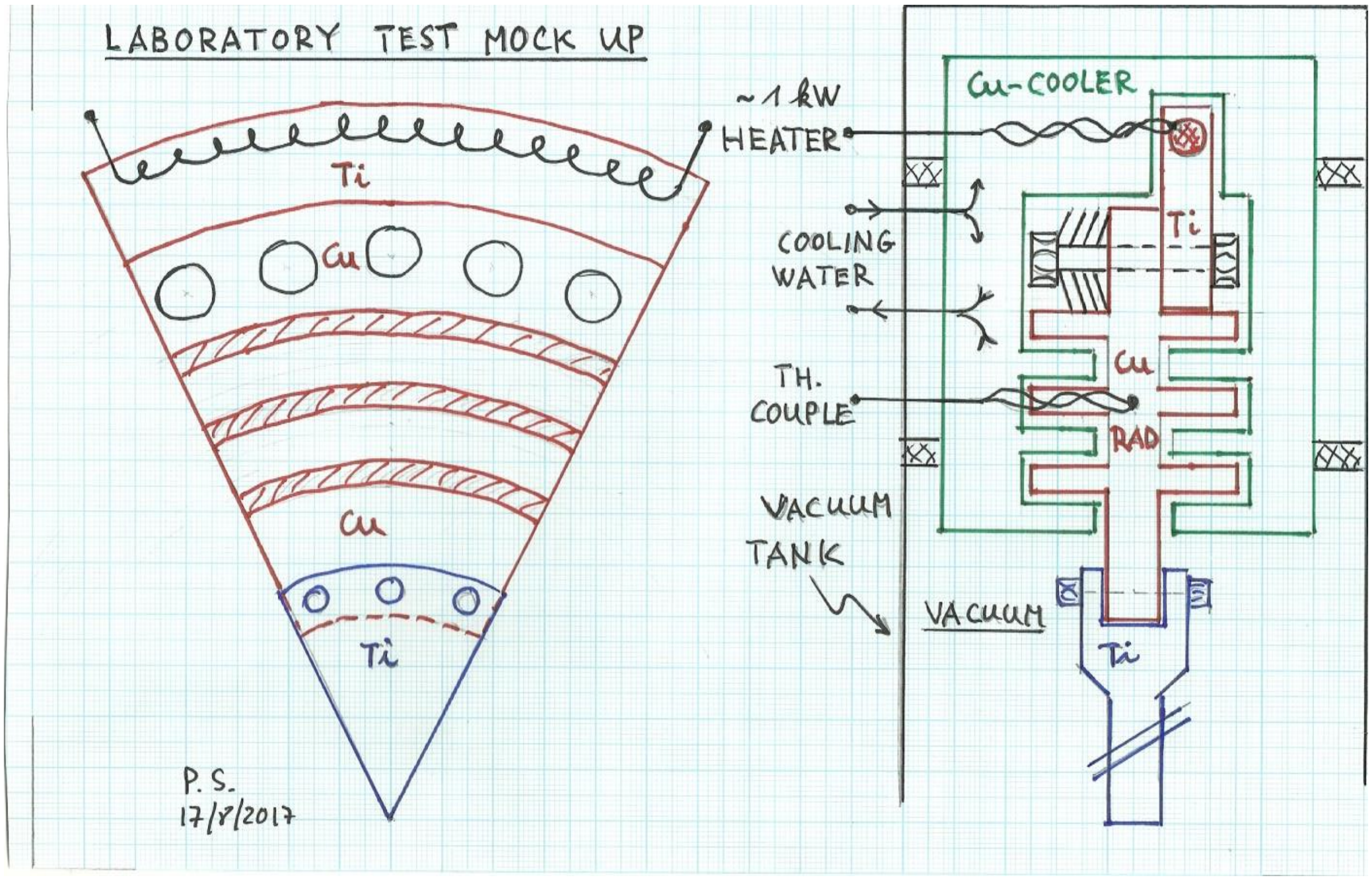
1.3 Validation of the Design in a Lab Test Mock Up.

- Build a sector of say 10% of the total wheel (piece of cake), heat the W with a 3.5 kW electrical heater and apply a bolted contact to the water cooled wheel.
- Place this non rotating unit into a vacuum tank and study the temperatures.
- Similarly, the cooling by radiation can be studied in this mock up.
- In a separate mock up, validate the performance of a magnetic bearing and a “standard”, high load ball bearing for UHV application at 100-200 rpm.

2. R+D Path for the Undulator Target.

- 2.1 The basic Design.
- Wheel of 1 m diameter, rotating at 2000 rpm.
- Cooled by radiating the average power of 2-4 kW from the Ti-target and from attached Cu-radiators, into stationary, water cooled heat sinks, the coolers.
- Rotating magnetic bearings inside the vacuum, carry the weight of the wheel of > 100 kg.

2.2 Validation of the Design in a Lab Test Mock Up.



What do we need?

- A vacuum tank with enough inside volume and a generous access flange.
- Vacuum pumps for rough (?) and UHV (?).
- Feed through for cooling water, power for the heater, instrumentation, vacuum gauge, thermocouples.

What can we learn from this test?

- Temperatures vrs. average power.
- Influence of the size of the radiating surface and its emissivity on the temperature.
- Influence of the bolted pressure on the temperature.
- Study the effects of the pulsed beam.
- Instead of a continuous heating with 1 kW, use a heater every 7 s with 7 kW, but only over 1 s.
- To dissipate the same average power, but with short 1 ms pulses, will be hard to do?
- The centrifugal loads and the magnetic bearings have to be studied in a «real mock up» with a real size, rotating wheel.

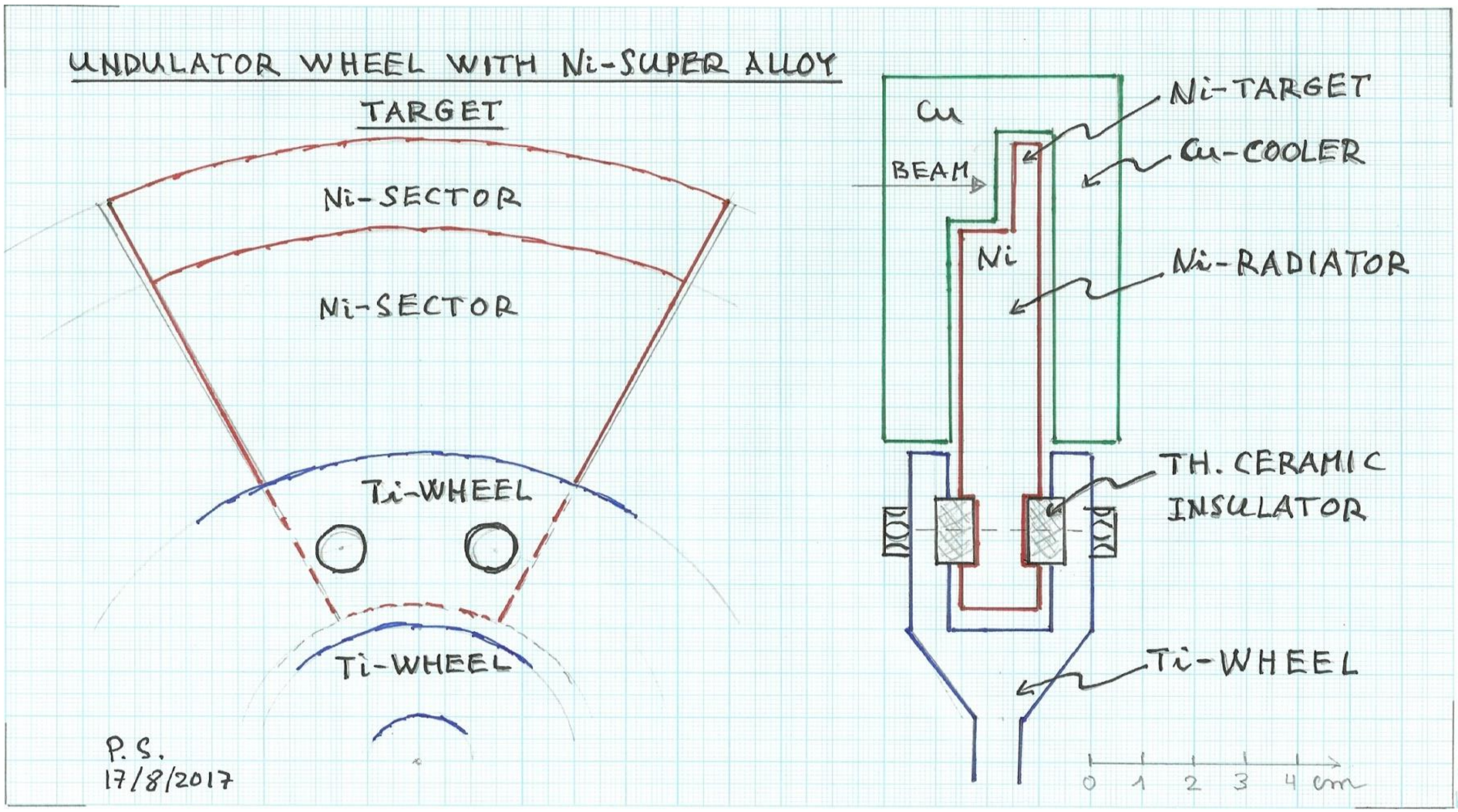
2.3 Option: Replace the Cu-Radiators by High Temperature Ni-Alloys.

- Among other things, the large weight of >100 kg of the Cu-radiators, limited to about 300 C, has to be carried by the magnetic bearings.
- By allowing temperatures above 700 C for the radiators, the radiating surface and thus the weight can be reduced.
- Investigate Nickel-Base Superalloys, like Inconel, Hastelloy,…., used for turbines, rocket motors,… above 700-800 C.

Typical parameters for these alloys between 700-1000 C.

- Density: 9 g/cm^3.
- Th. Conductivity: 20-26 W/m K.
- Specific Heat: 0.4 J/ g K.
- Th. Expansion coefficient: 18 10^-6 1/K.
- Young's modulus: 15 10^4 MPa.
- Yield strength: 350-550 MPa.
- Target thickness for Xo=0.2-0.4: 3-5 mm.

Mechanical Layout



Comments

- The power radiated from the actual thin target part is ignored. Kept as redundancy for the power from the Flux Concentrator,….
- Power radiated only from the thick part: 2 kW.
- Emissivity: 0.7, consider W-C-coating.
- Average radial temperature along the radiator 350 +/- 50 C.
- Time average peak temperature in the target: 500 C.
- ΔT/pulse has still to be added.

- As suggested in the drawing, the weight of the target-radiator part is about 30 kg.
- The weight of the carrier Ti-wheel is below 25 kg.
- The target-radiator unit is made in sectors and can thermally expand freely.
- The Ti-carrier wheel is thermally decoupled from the hot Ni-radiator unit and has only to retain the centrifugal forces from the radiators.
- Therefore, the time and space varying temperatures and deformations in the radiator unit around the wheel should not lead to large imbalances of the wheel.

Things to be studied.

- FLUKA: Check the e+ yield of the Ni-alloy against target thickness, PEDD, dpa, total average power.
- ANSYS: Optimize the radiator thickness with respect to temperature and weight.
- Check the thermal stresses.
- Also, this version of the Ni-target wheel can be tested in the same Lab Mock Up, used for the sectors of the Ti-wheel and for the conventional W-wheel.

3. Summary for the Conventional Target Wheel.

- As presented by Omori-san some months ago, the R+D and optimisation of the rotating ferro fluid seal is still under way.
- Possible ways to improve performance, reliability and lifetime of the seals can be envisaged.
- A failsafe thermal contact between the W-target and the water cooled Cu-wheel is proposed.
- This can be validated in a simple Lab Mock Up.
- Relying on the SLAC experience, the pulsed heating and thermal shock stresses should provide sufficient lifetime (Courtesy Omori-san).

e-driven W-wheel, cooled by radiation: A Fall Back Solution

- Cooling by radiation, without water in the wheel, avoids ferro fluid seals.
- To provide sufficient radiating surface, the increased weight may be too high for magnetic bearings (tbc).
- Therefore, conventional ball bearings at ~100 rpm and adapted to UHV application (Labyrinth plus differential pumping), should be investigated.
- Radiation cooling can be validated in a simple Lab Mock Up.

4. Summary for the Undulator Wheel.

- The validation and optimisation of the cooling by radiation can be investigated in a simple mock up in the laboratory.
- The use of magnetic bearings has to be assessed in a separate study, in particular in view of the weight of > 100 kg of the wheel.
- Option: Replacing the Ti-target material by high Z Ni-alloys, could lead to higher e+ yield.
- Higher temperatures at the radiators allows to reduce the radiating surface, and thus the weight of the wheel to about 50 kg.
- The thermal loads and stresses in the Ni-alloy have to be assessed.

5. Planning and Resources.

- CONVENTIONAL WHEEL:
- a) Rotating seal validated by 2018 (tbc).
- b) Cooling test in the Lab mock up, 2018-2019.
- c) Results in 2019-2020.
- d) Design of final wheel 2020.
- e) Fabrication and Lab tests of the final wheel in 2020-2022.

If ferro fluid seals a) not validated:

- Pursue the Radiation Cooled, Conventional Wheel.
- Schedule: b)-e), as above.

- Human resources till 2020: 1 Physicist, 1 engineer/designer, lab technicians.
- R+D budget for hardware and tests till 2020: 300 k$ (excluding tests of rotating seal).

- UNDULATOR WHEEL:
- a) Cooling test in the Lab mock up, 2018-2019.
- b) Results in 2019-2020.
- c) ANSYS studies of the dynamics of the wheel, under mechanical, thermal and magnetically induced loads in 2018-2020.
- d) Validation of magnetic bearings and drive in 2018-2020.
- e) Design of final wheel 2021.
- f) Fabrication and Lab tests of the final wheel in 2022-2024.

- Human resources till 2021: 2 physicists, 1 engineer/designer, lab technicians.
- R+D budget till 2021 for ANSYS studies, lab tests and magnetic bearings: 500-600 k$.

History: A MW positron wheel was re-invented 30 years ago. Ref: First EPAC 1988 in Rome.

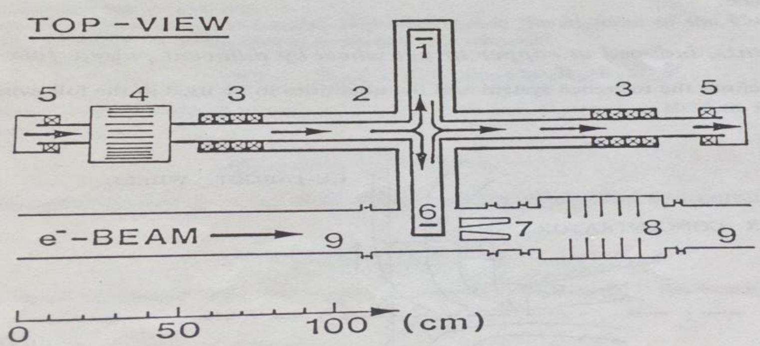
of removing the heat. Before, however, advocating realistically such devices, substantial technological developments have to be undertaken.

When considering the technical aspects of the target structure, we have ignored the possible constraints imposed by the downstream e^+ acceleration stage. Moreover, static or pulsed magnetic fields from solenoids, used as the first collecting elements adjacent to the target, might interact strongly with any fast moving metallic target support structure or rapidly flowing liquid metal stream. Therefore in the design of the e^+ collection system one has to consider carefully the eddy currents and the resulting additional power dissipation and forces which might be induced in the target structure. This can, however, only be done once the characteristics of the e^+ collection system are known.

5. APPENDIX

5.1 Principal layout of the positron target station

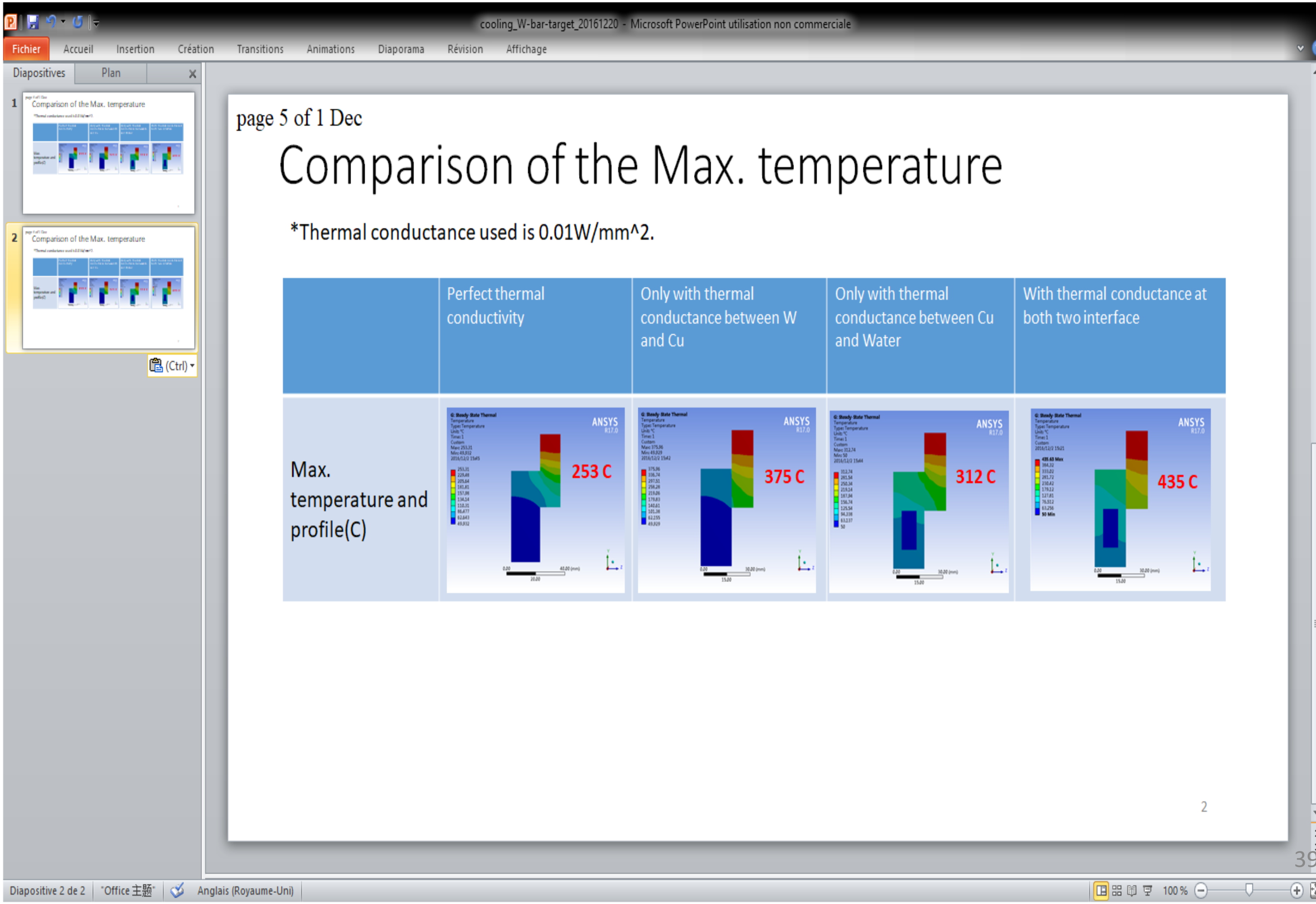
The beamline runs horizontally alongside the axis of the wheel (see top view) which, after displacement of the top shield, makes access with an overhead crane from above easier. To prevent access to the immediate vicinity of the target wheel, all systems must be devised as plug-in systems which are installed and removed by the crane. This will be fitted with dedicated tools for special tasks, (e.g. opening of vacuum flanges). All further manipulations and repairs on radioactive components take place in the adjacent "Hot Cell". Local shields inside the target vault to protect critical components (e.g. the rotating feed-throughs or the motor) are not shown.

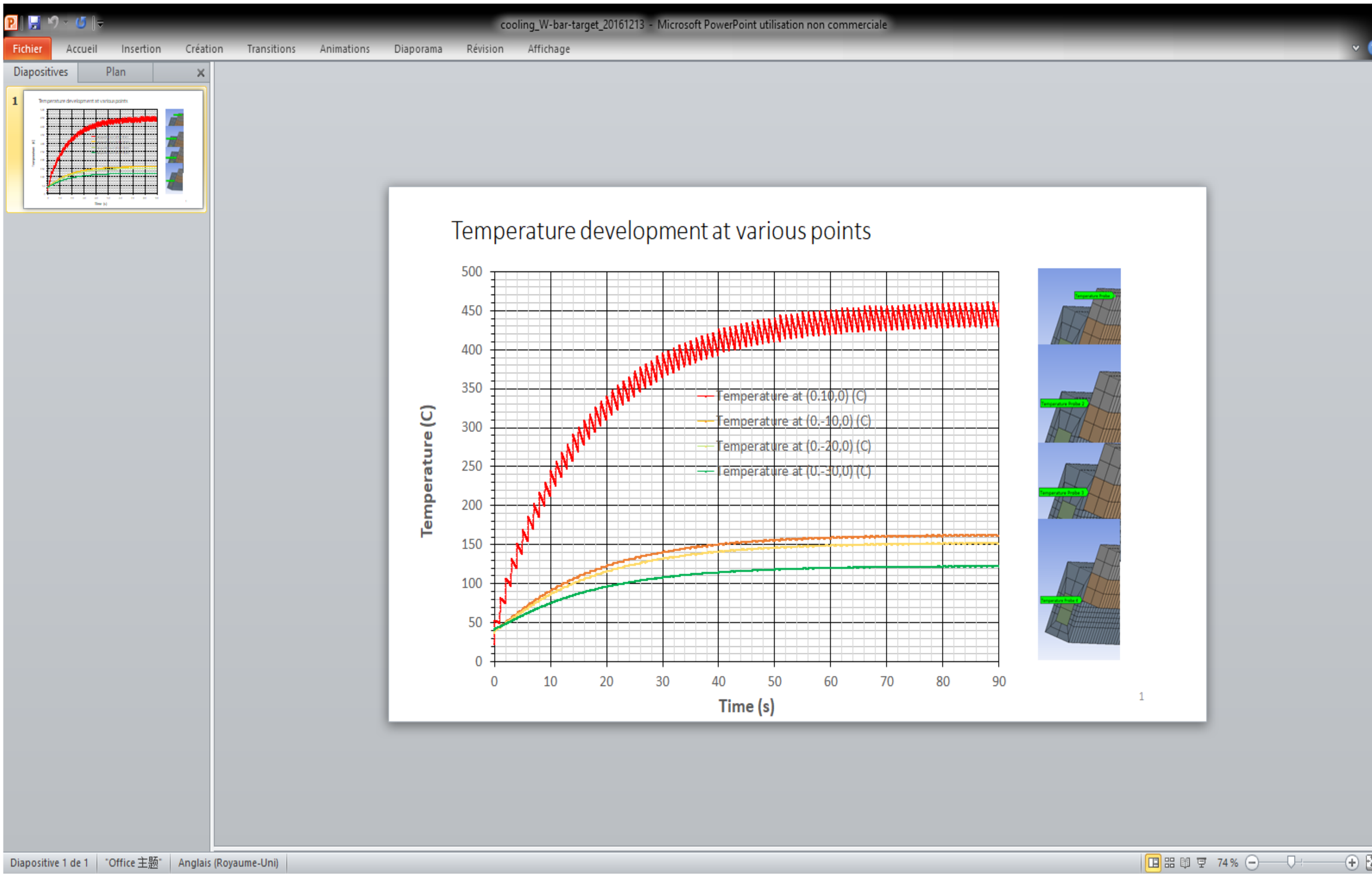


KEY: 1: Target Wheel. 2: Vaccum Tank. 3: Rotating Vacuum Feedthrough. 4: Motor. 5: Rotating Water Feed-through. 6: Tungsten Target. 7: Solenoid. 8: Acceleration Stage. 9: Beam Transport Pipe. 10: Mobile Top Shield. 11: Cooling Water In/Outlet. 12: Electrical Supply. 13: Overhead Crane.

Thank you for your attention.

Back ups, Courtesy Song Jin.

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