Engineering Aspects of the e-Driven and Undulator Driven Positron Targets for the ILC.

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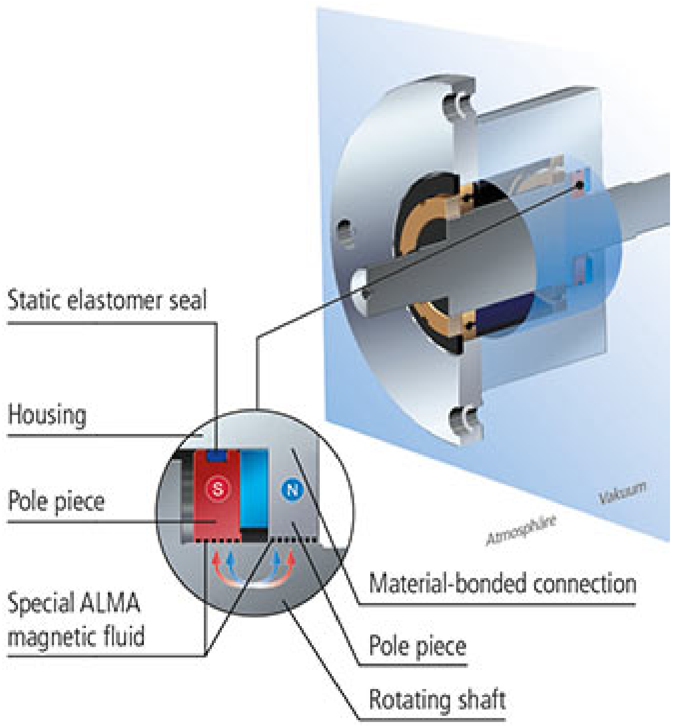
1. Considerations on the engineering aspects of the e-driven target.

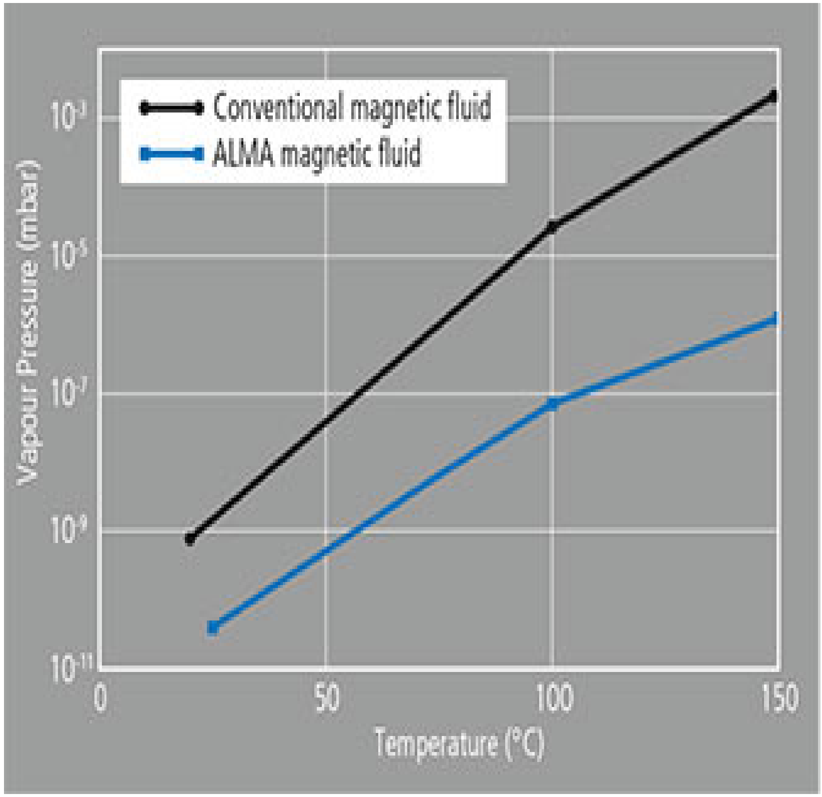
- Target wheel with 50 cm diameter and W-target, 14 mm thick.
- Deposited average power 35 kW!
- Rotation velocity ~ 5 m/s, 200 rpm.
- Cooling by water at 50 C.
- Requires penetration of the rotation axis through the vacuum tank.
- Requires Ferro Fluid Rotating Seal.

The ferro fluid rotating seal

- RIGAKU seal: critical issues are the oil, heating and cooling and temporary degradation of the vacuum and lifetime.
- Ferro-tec seal, similar problems.
- ALMA-seal: not yet evaluated.

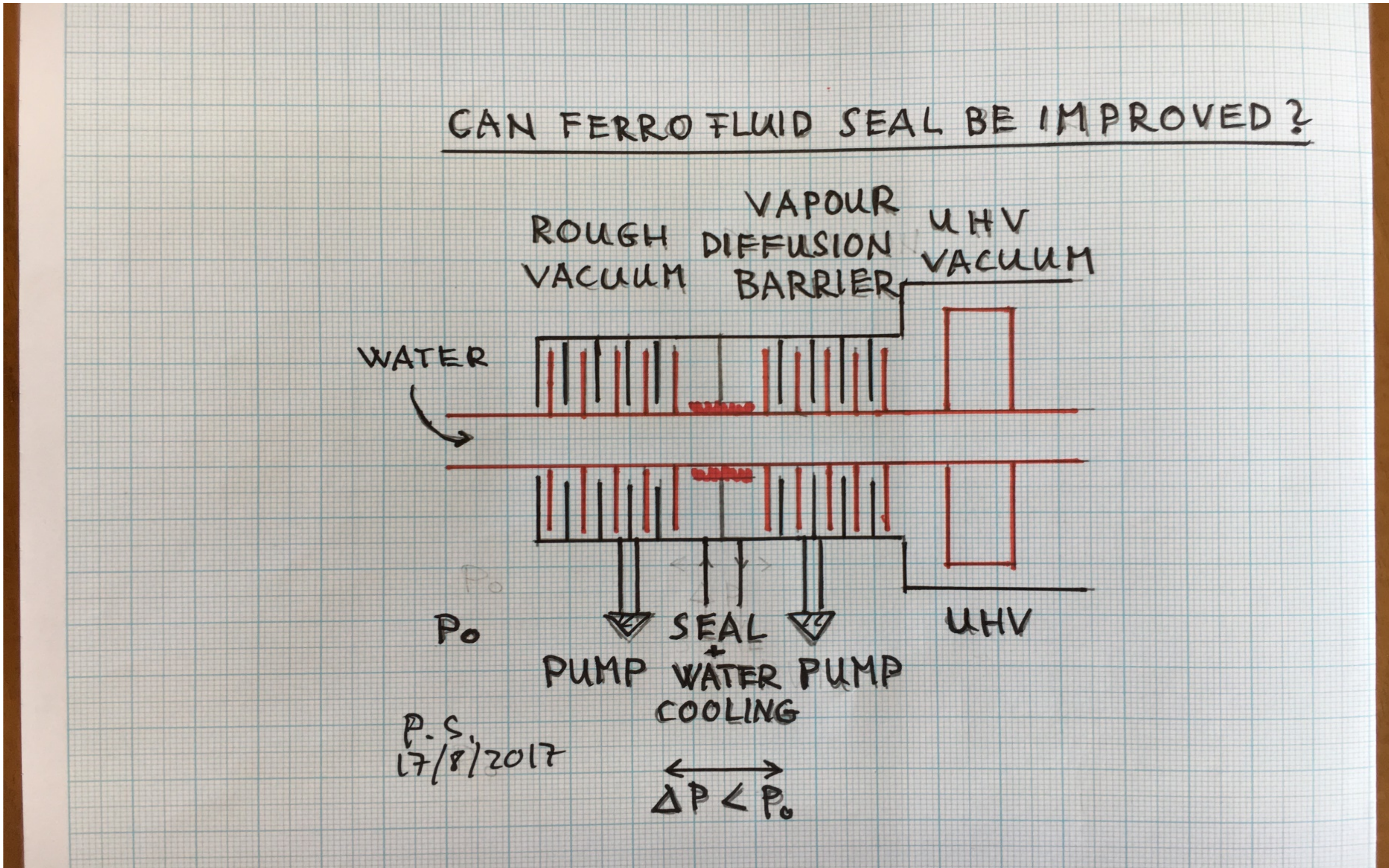
- Doc of ALMA: www.alma-driving.de





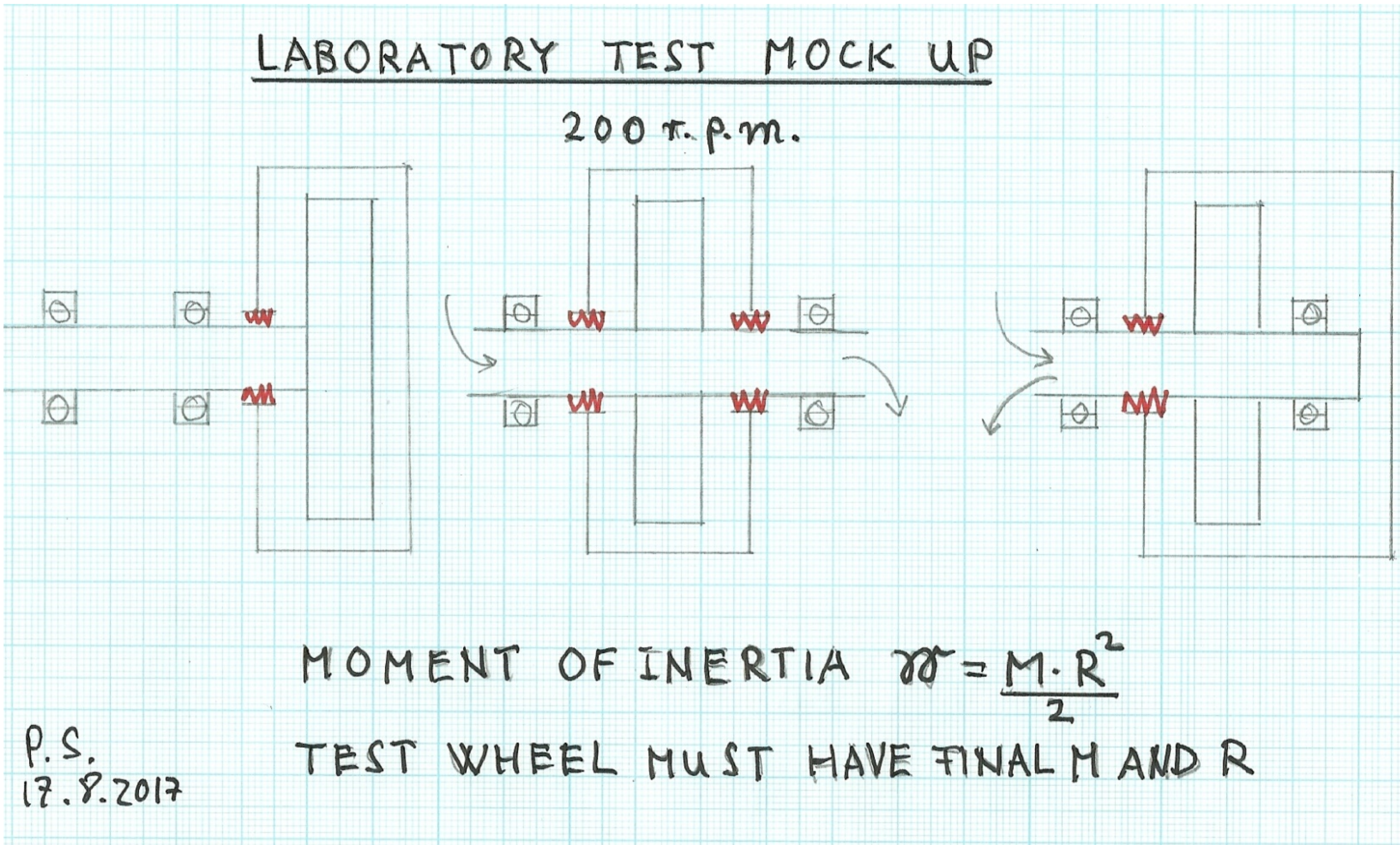
- Problems of ferro fluid seals: pressure difference across the seal is 1 atm!
- Heating of the seal, needs good water cooling.
- Diffusion into the vacuum of air through the seal and outgassing of oil vapour.
- Use best possible oil with low viscosity and low vapour pressure. Protect it from radiation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

Improve ferro fluid seal by better cooling and differential pumping.



- Use vacuum buffers, baffles, with differential pumping upstream and downstream of the rotating seal.
- Alternative: use two or a series of ferro fluid seals with intermediate pumping.

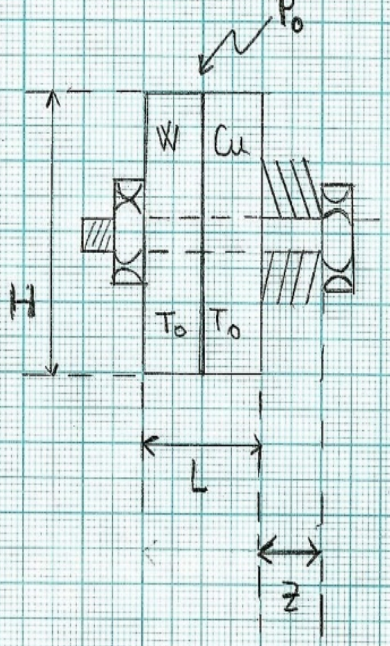
Laboratory test of the ferro fluid seals

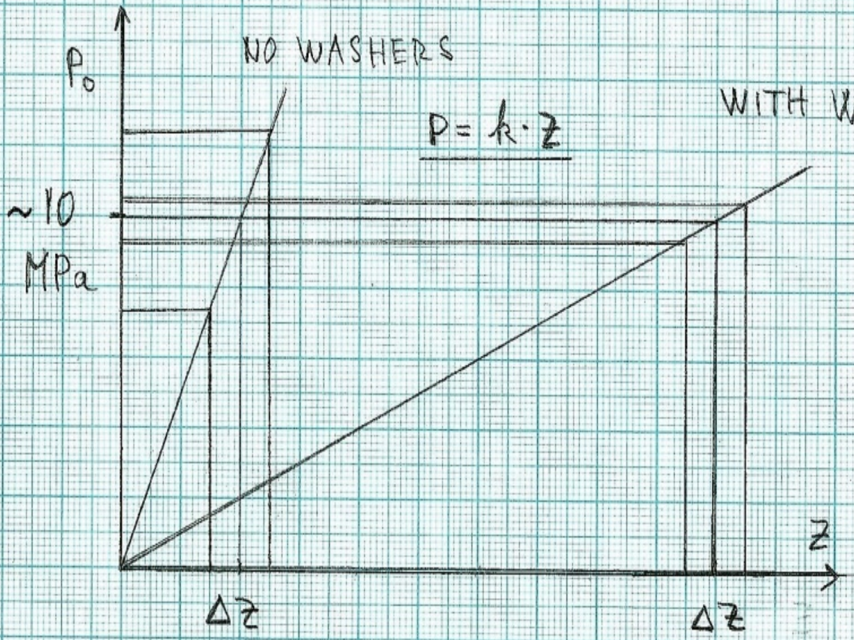


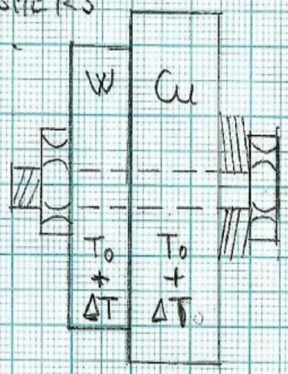
Thermal contact between the W-target and the water cooled wheel.

- 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







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

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

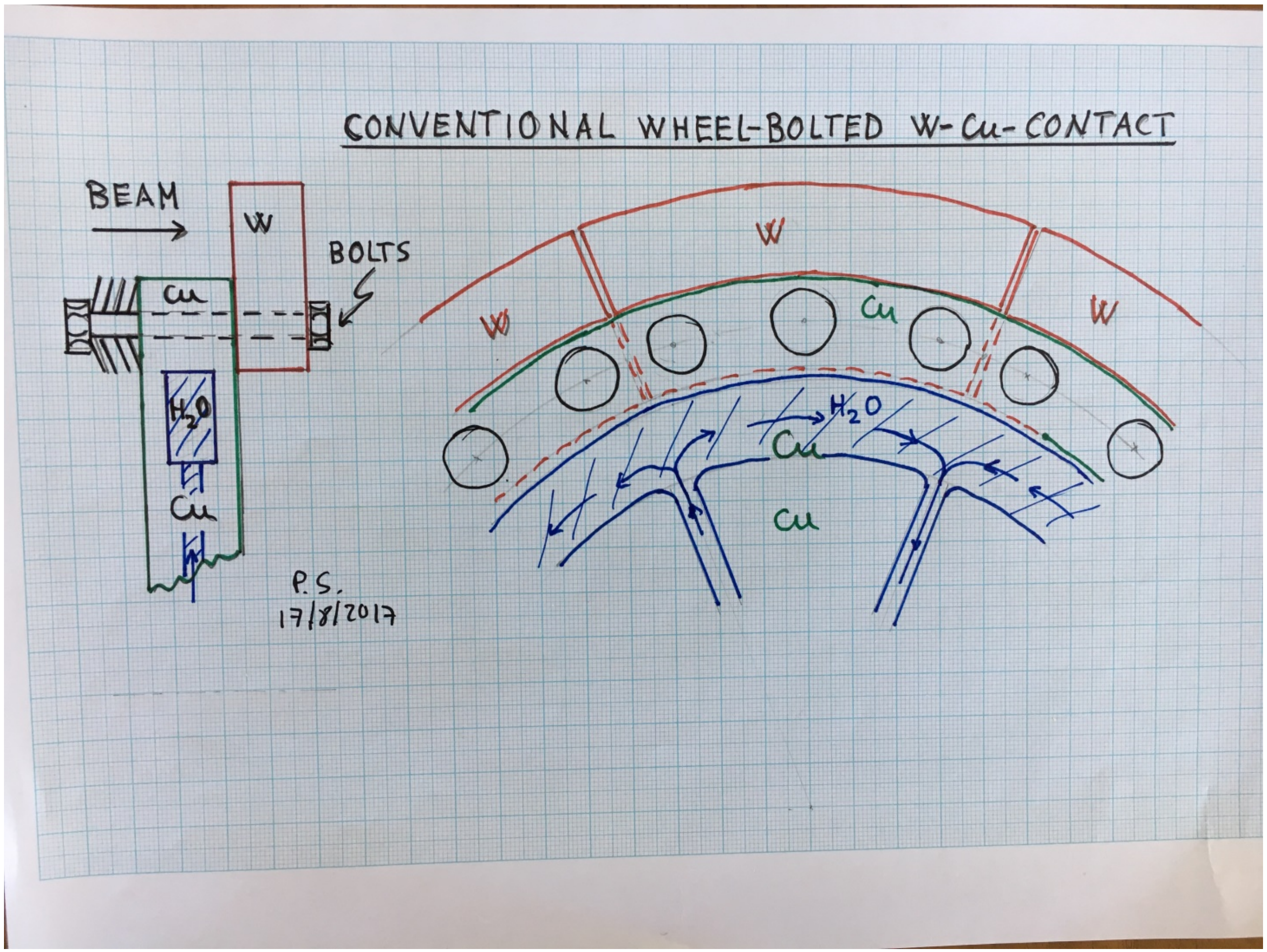
$$P = P_0 \pm \bar{\alpha} \cdot \Delta T \cdot L \cdot k$$

$$\sigma_H = \mu P$$

$$\mu \leq 0.3$$

P.S.
17.8.2017

Design is modeled by Song Jin-IHEP



Comments

- 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 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 conferences).
- The stresses at the W-Cu interface are critical.
- The thermal contact can fail due to pulsed heating and fatigue at this location.
- 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.
- These stresses are ~ 150 Mpa or possibly above (Courtesy Song Jin).

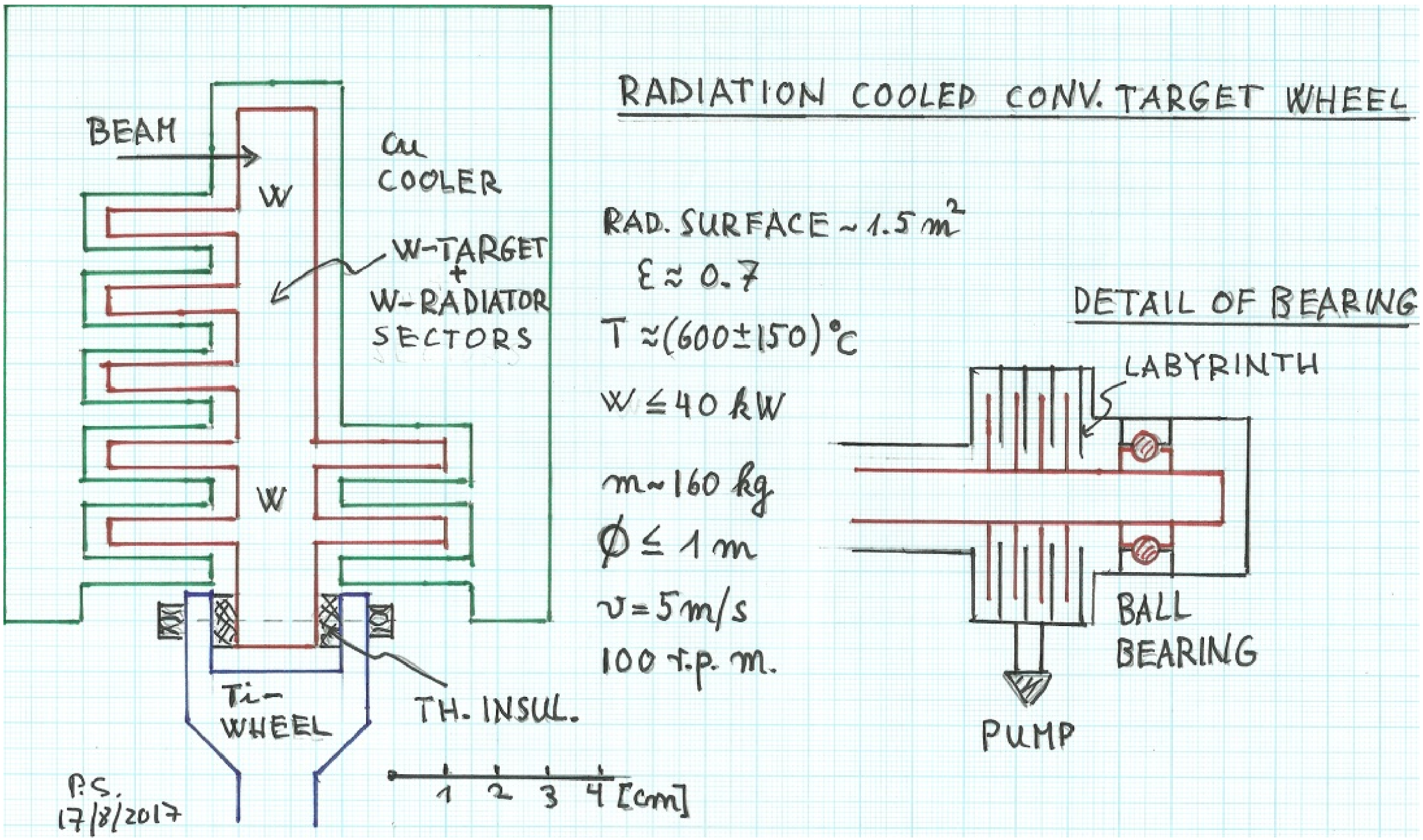
Stresses at the W-Cu interface with bolted contact.

- 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.

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 mass 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.

But the design is not trivial

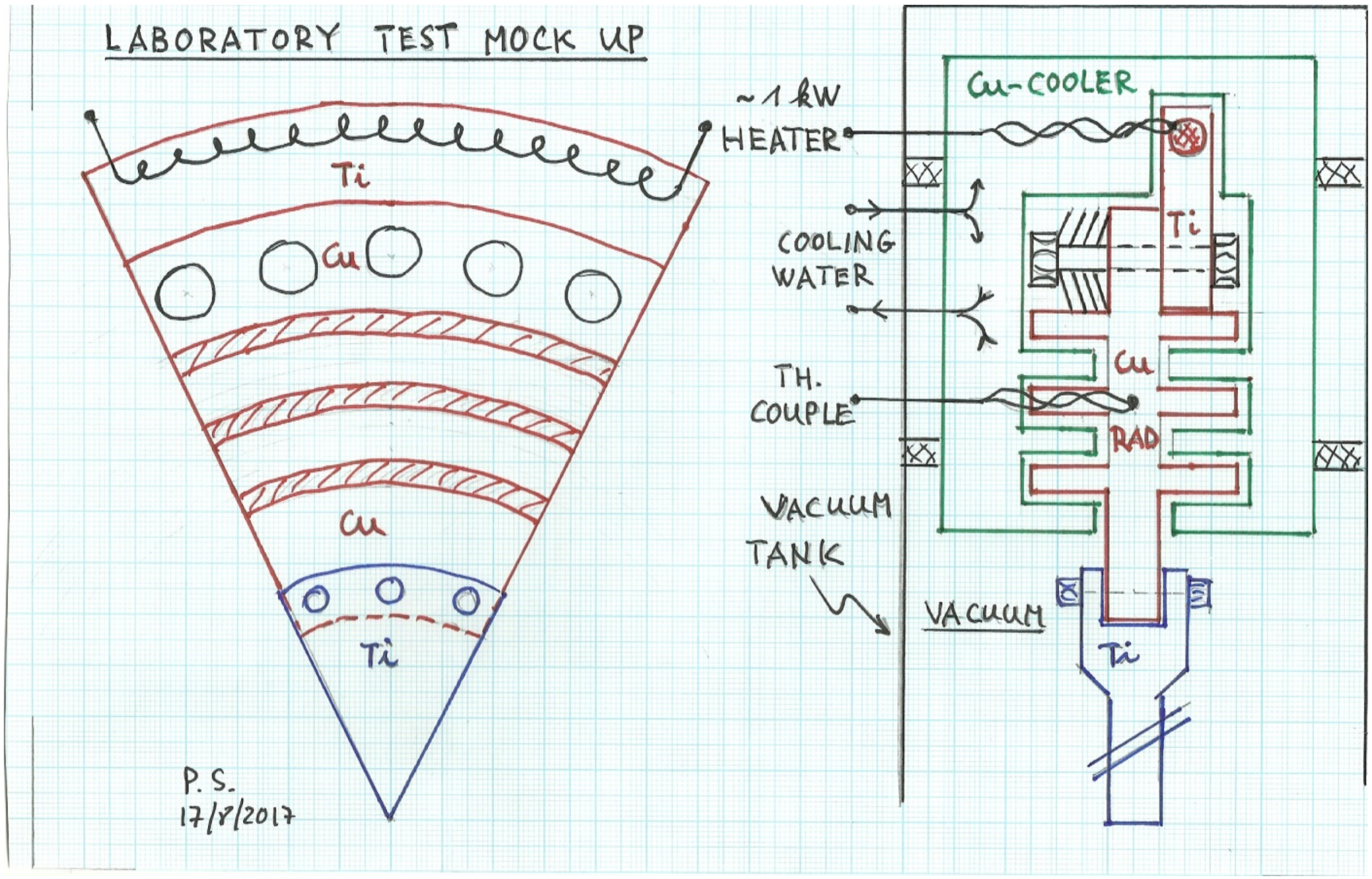


- Manufacture of the W sectors, no problem.
- The W-sectors are fixed to a full Ti-wheel.
- Due to the high weight of the wheel, magnetic bearings may no longer be possible.
- Use “standard” ball bearings for vacuum application, possibly with MoS_2 lubrication and labyrinth baffles and differential pumping.
- Manufacturer: nsk/Japan: Bearings for vacuum environments.
- www.nsk.com/products/spacea/vacuum/#tab2.

2. Engineering aspects of the undulator driven target.

- Validate the cooling of the target by radiation in a simple mock up in the laboratory.

Laboratory mock up for the validation of the cooling by radiation.



What can be learnt 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?

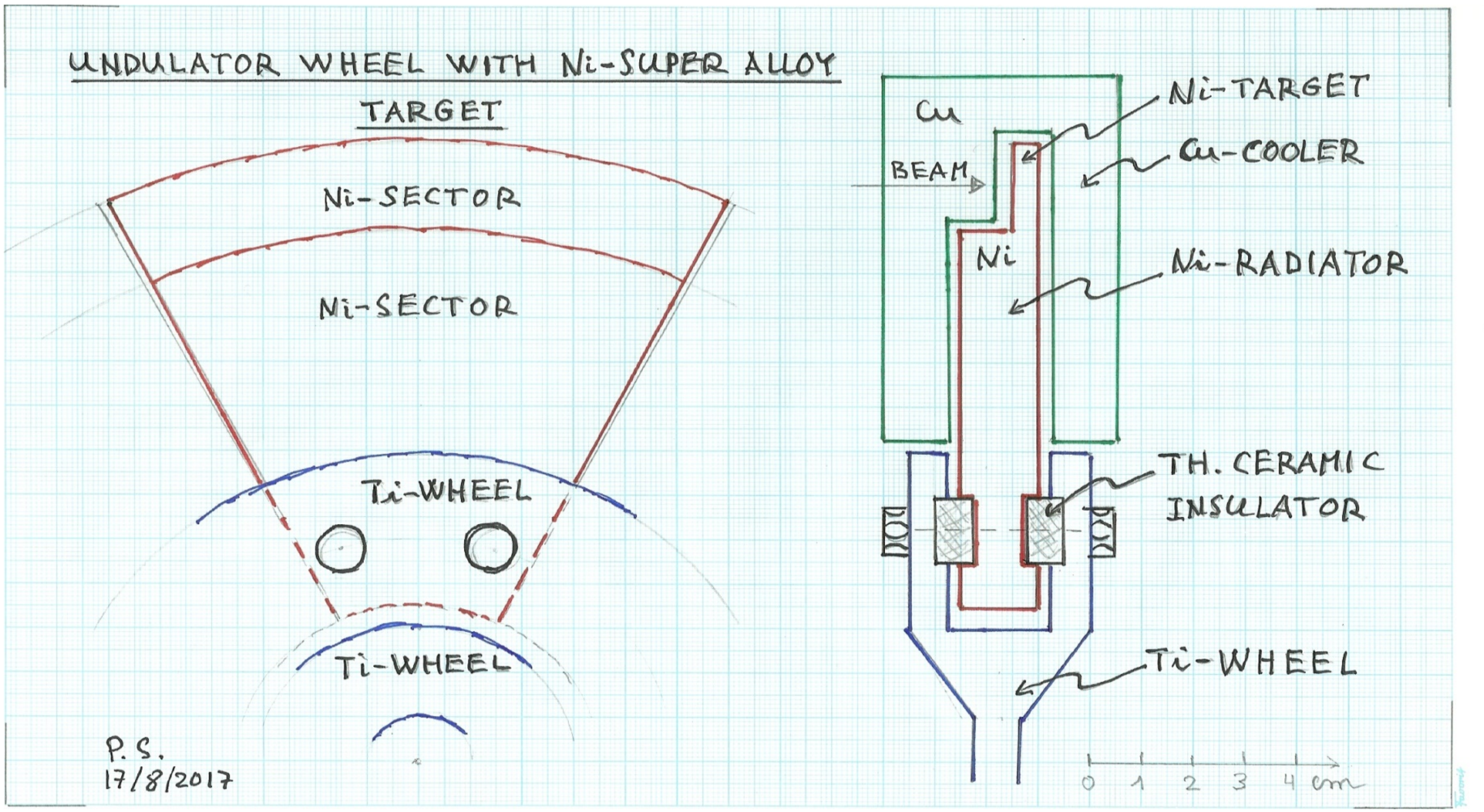
Replace the Cu-Radiators by High Temperature Ni-Alloys.

- Among other things, the large weight of >100 kg of the Cu-radiators, to be 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.

- All this is very preliminary, however conservative.
- By accepting somewhat higher temperatures, the average radiated power can be increased.
- There is room for improvements and optimisation.
- Optimum target thickness, e+ yield, PEDD and dpa by FLUKA and temperatures and thermal stresses due to the pulsed heating with ANSYS have to be studied.

- 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 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.

3. Summary and Conclusion.

- The e-driven 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 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, however, at the cost of somewhat higher average temperatures in the target.
- Relying on the SLAC experience, the pulsed heating and thermal shock stresses should provide sufficient lifetime (Courtesy Omori-san).

An e-driven W-wheel, cooled by radiation: A Plan “B”?

- Cooling by radiation, without water in the wheel, does not need ferro fluid seals.
- To provide sufficient radiating surface, the increased weight may be too high for magnetic bearings.
- Therefore, conventional ball bearings at 100 rpm and adapted to UHV application, should be investigated.

Comments on the Undulator driven 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 not yet been assessed, in particular in view of the weight of > 100 kg of the wheel.
- Trading higher average temperatures in the target-radiator unit against lower radiation surface, and thus lower weight, could be an option.
- With high temperature Ni-alloys, used at 700 C or above, for the target-radiator unit, a weight of about 50 kg may be possible.

Global Conclusion.

- The issues raised and the additional improvements and venues proposed, should give confidence that both the e- and the undulator driven targets can be built and operated with sufficient lifetime.
- It needs however now adequate manpower, funding and time, to validate the proposals.
- There may even be enough margin to use 2600 bunches and 500 GeV center of mass energy.

History: A MW positron wheel was re-invented in 1988. Ref: EPAC, Rome.

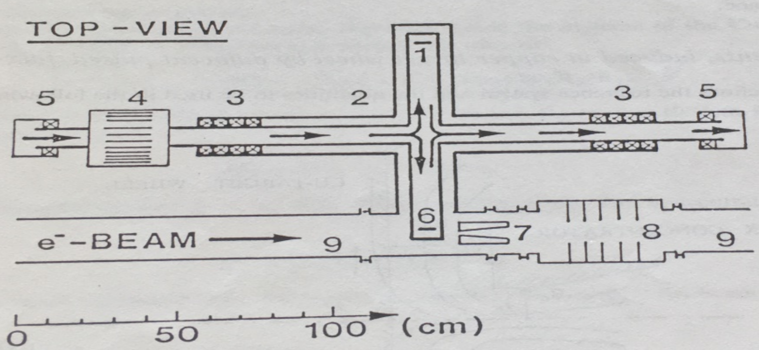
of removing the heat. Before, however, advocating realistically such devices, substantial technological developments have to be undertaken.

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

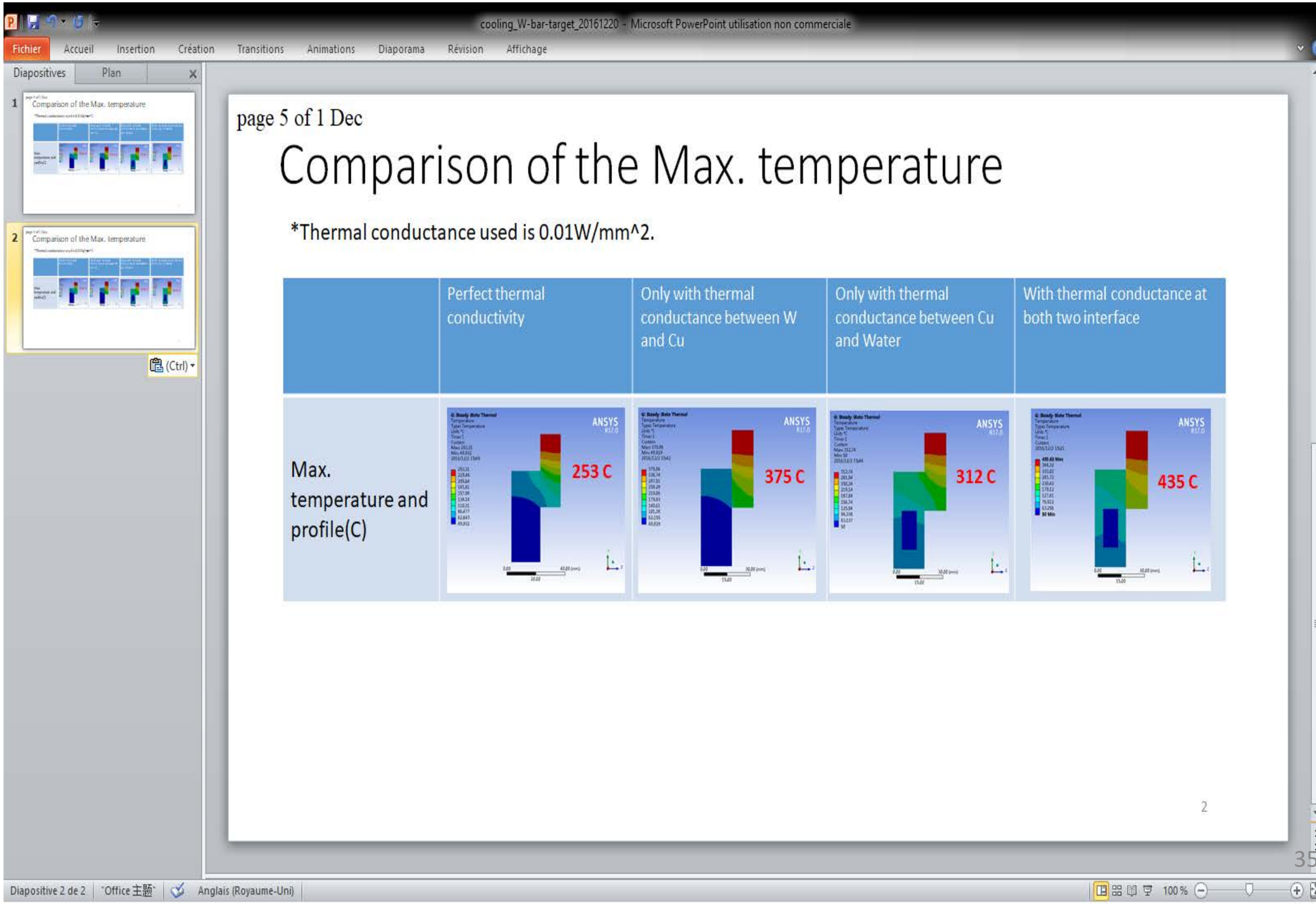
The beamline runs horizontally alongside the axis of the wheel (see top view) which, after displacement of the top shield, makes access with an overhead crane from above easier. To prevent access to the immediate vicinity of the target wheel, all systems must be devised as plug-in systems which are installed 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.

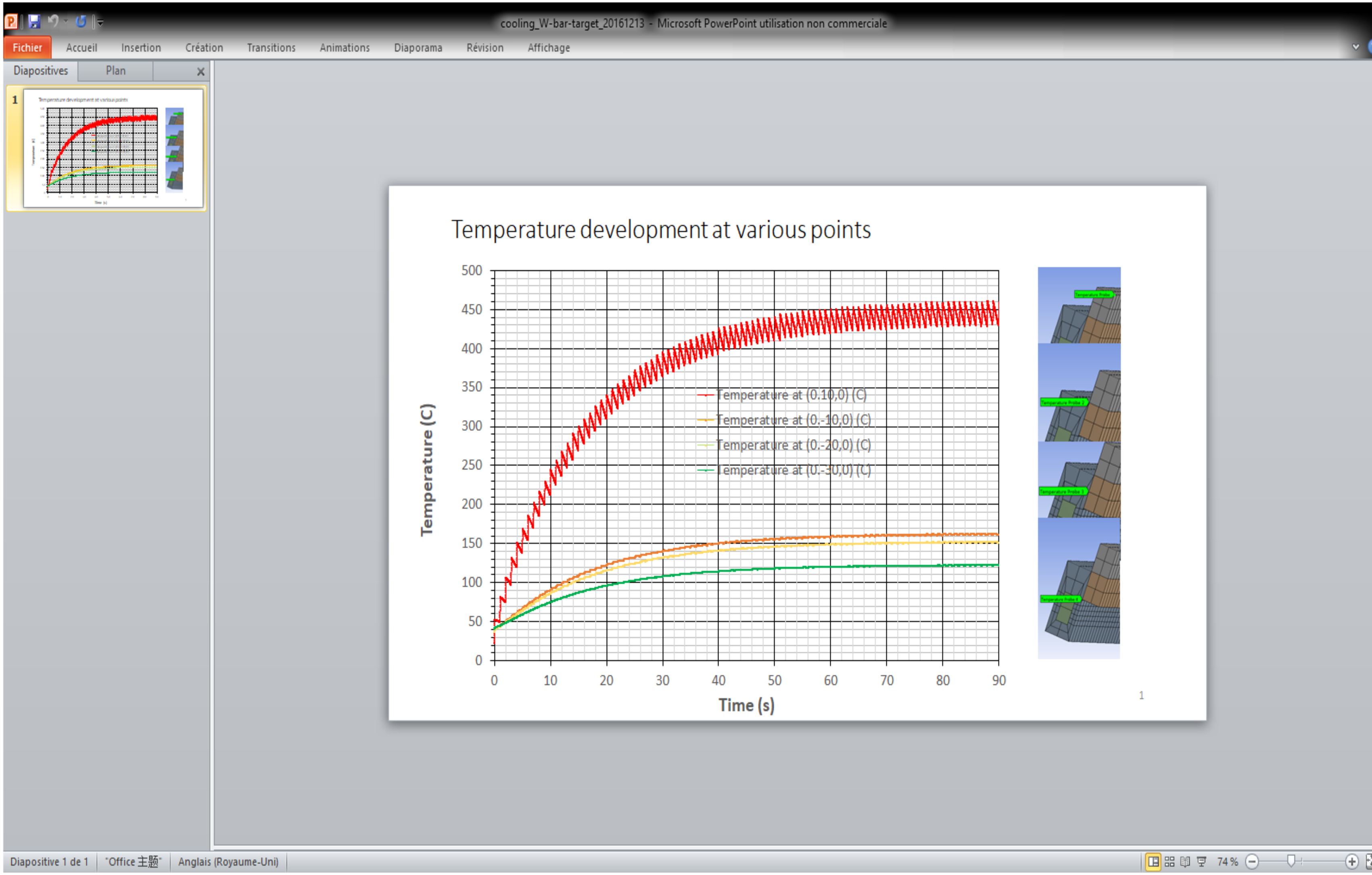


KEY: 1: Target Wheel. 2: Vaccum Tank. 3: Rotating Vacuum Feedthrough. 4: Motor. 5: Rotating Water Feed-through. 6: Tungsten Target. 7: Solenoid. 8: Acceleration Stage. 9: Beam Transport Pipe. 10: Mobile Top Shield. 11: Cooling Water In/Outlet. 12: Electrical Supply. 13: Overhead Crane.

Thank you for your attention.

Back ups, Courtesy Song Jin.

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