The undulator based ILC positron source activities at ANL
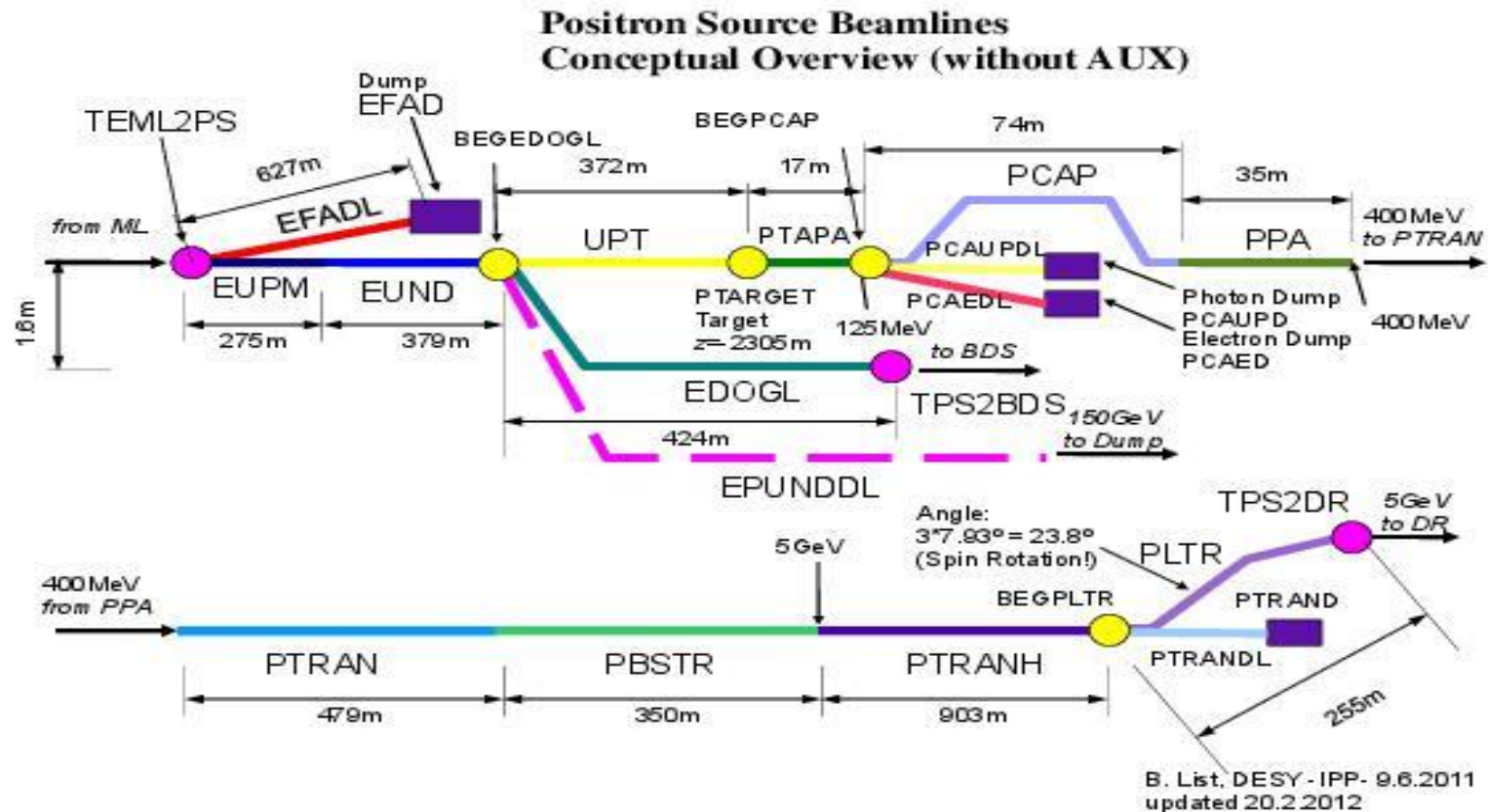
Wei Gai

ANL/Tsinghua University

AWLC 15, KEK

Beamline Lattice

- New lattice design has been done to comply with the new layouts as follow.

Existing (unsolved) Issues for Undulator based source

- Beam dynamics, (OK)
- Undulator (OK? Or @95%)
- Target (heating and shocks)
  - Good? No issues? No critical problems (97%), there is rooms for further improvements.
- Target support vacuum chamber, test at LLNL.
  - Life time of the vacuum seal (short time survival, but long term > a few weeks with vacuum spikes, no clear path forward at this point), no radiation damaging testing yet. , and
  - Cooling water impact on wheel dynamics (simulation should be done).
  - Rotating Seal leak tests at KEK planned.
  - New ideas: Non-contact (differenetial pumping), support, radiation cooling. Many others (later in the talk).
- OMD, (OK)
- Accelerator (NC)
  - SLAC test showed 14 MV/m.
- Interfacing with damping ring (OK)

Positron Source Spinning Wheel Target

- Prototype has been built and tested for eddy current issue.

- Vacuum seal test of supporting shaft was not very successful. The current prototype is not robust enough for production system.

- Still need to demonstrate full wheel with cooling channel.

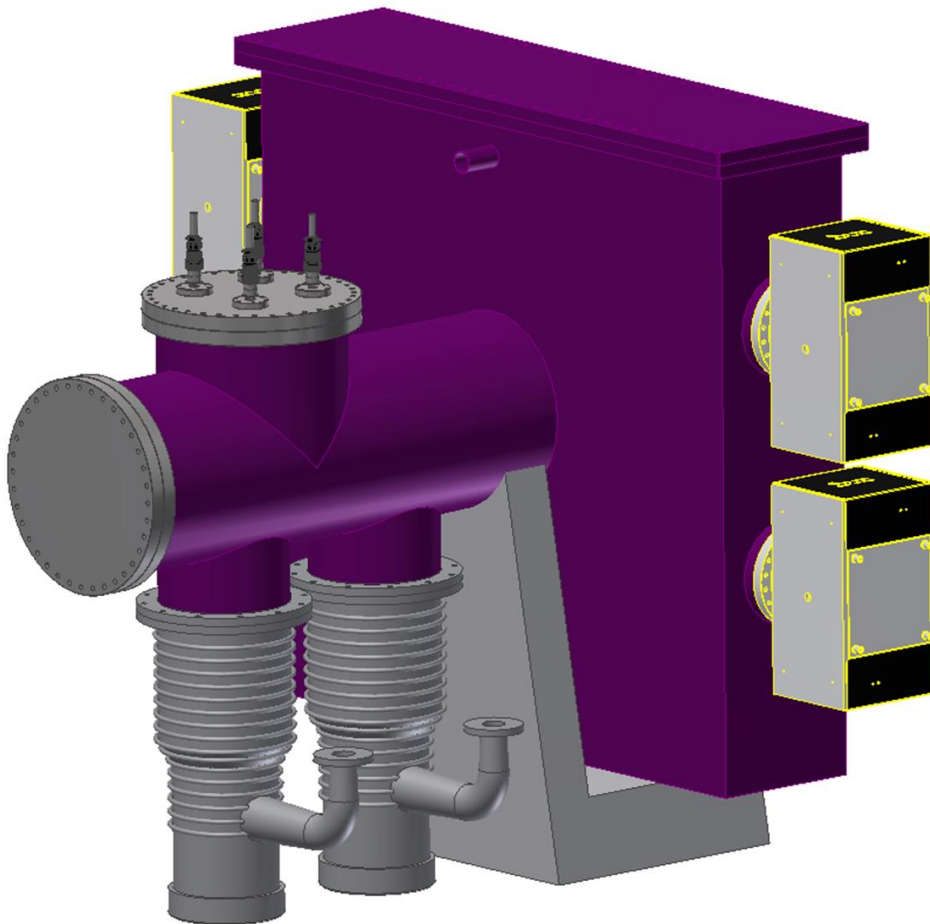- Not funded for further test and demonstration.

Major Concerns on positron sources

- Issues on moving forward on the current LLNL test.
  - Approaches are still viable?
  - Funding
  - Technical support
- Alternative target design for undulator sources
  - Other type of targets
    - Radiative cooling,
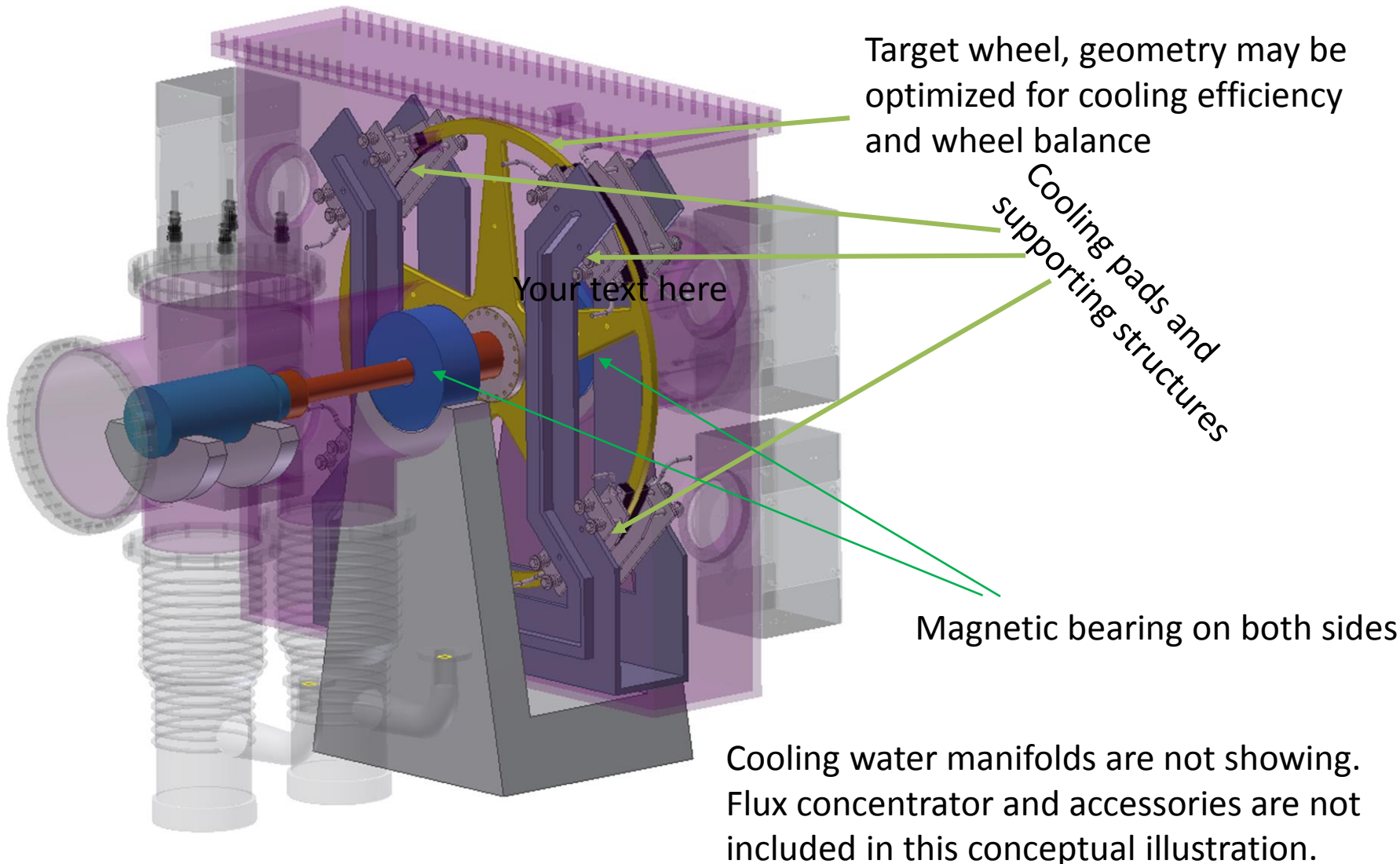   - Sliding cooling
    - ….

Remedies and benefits

- Eliminate the need of rotating vacuum seal by putting the whole target system in vacuum chamber.

- Eliminate the need of rotating water union and the complicated cooling channels in target wheel by using conduction cooling from spring loaded cooling pads

- The eliminating of rotating vacuum seal problem will enable us to support the shaft on both ends without concerning the vacuum.

- The eliminating of cooling channels in target wheel will simplify the target wheel design process and allows more freedom on optimization.
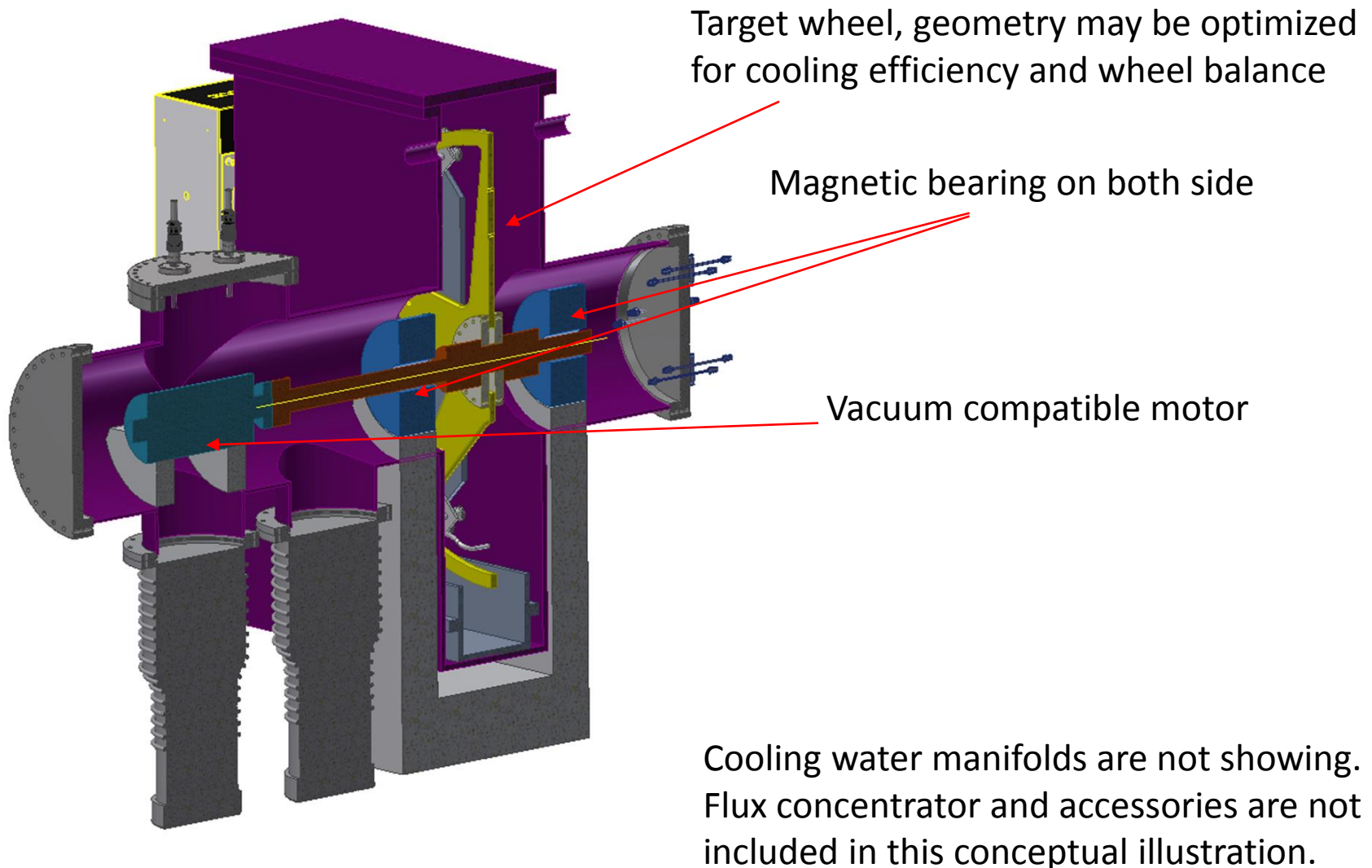
Looking from outside,
-A vacuum chamber without external drive except electrical and cooling water feed-throughs
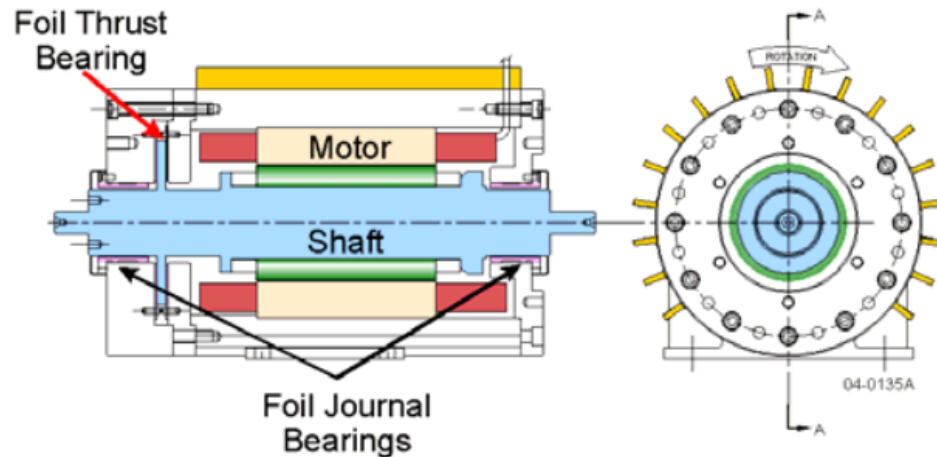
Inside the chamber

Target wheel, geometry may be optimized for cooling efficiency and wheel balance

Cooling pads and supporting structures

Your text here

Magnetic bearing on both sides

Cooling water manifolds are not showing. Flux concentrator and accessories are not included in this conceptual illustration.

Cross section view

Target wheel, geometry may be optimized for cooling efficiency and wheel balance

Magnetic bearing on both side

Vacuum compatible motor

Cooling water manifolds are not showing. Flux concentrator and accessories are not included in this conceptual illustration.

Vacuum compatible electrical motor

MiTi® Oil-Free, High-Speed Motor Drive
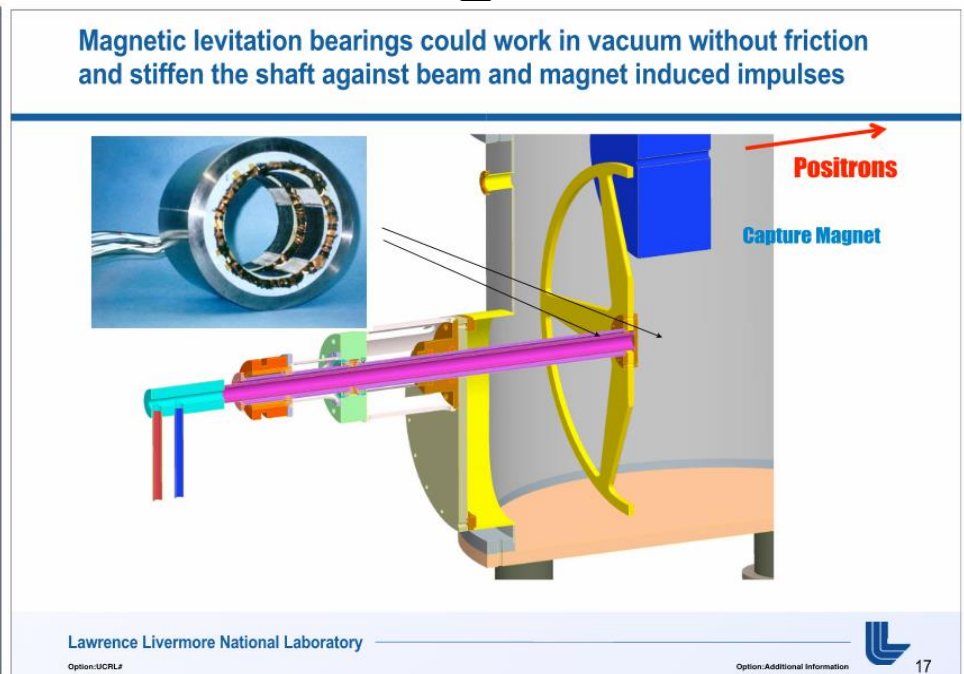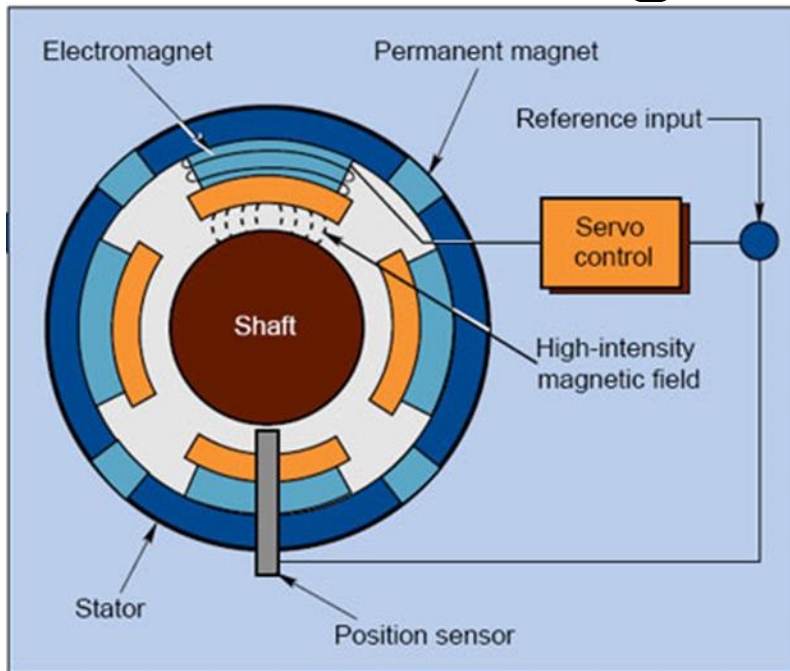
Foil Thrust Bearing

Motor

Shaft

Foil Journal Bearings

ROTATION

04-0135A

One needs to remember that magnetic motor does not require lubrication itself as long as bearings are lubricated correctly. We consider a motor drive that is oil free and maintenance free.

Through the web search, we found the MiTi®'s 32 kW, 60,000 rpm Oil-Free, High-Speed Motor.

Magnetic bearing

Magnetic levitation bearings could work in vacuum without friction and stiffen the shaft against beam and magnet induced impulses

Lawrence Livermore National Laboratory

The principle of magnetic bearing is simple, it has been used extensively in aerospace industry.

Active bearing basics. Electromagnetic fields support moving parts without contact; servo control system stabilizes suspended element by increasing supporting force in direction opposite that of any displacement, to restore correct position.

Conduction cooling using spring loaded cooling pads
- the game changer
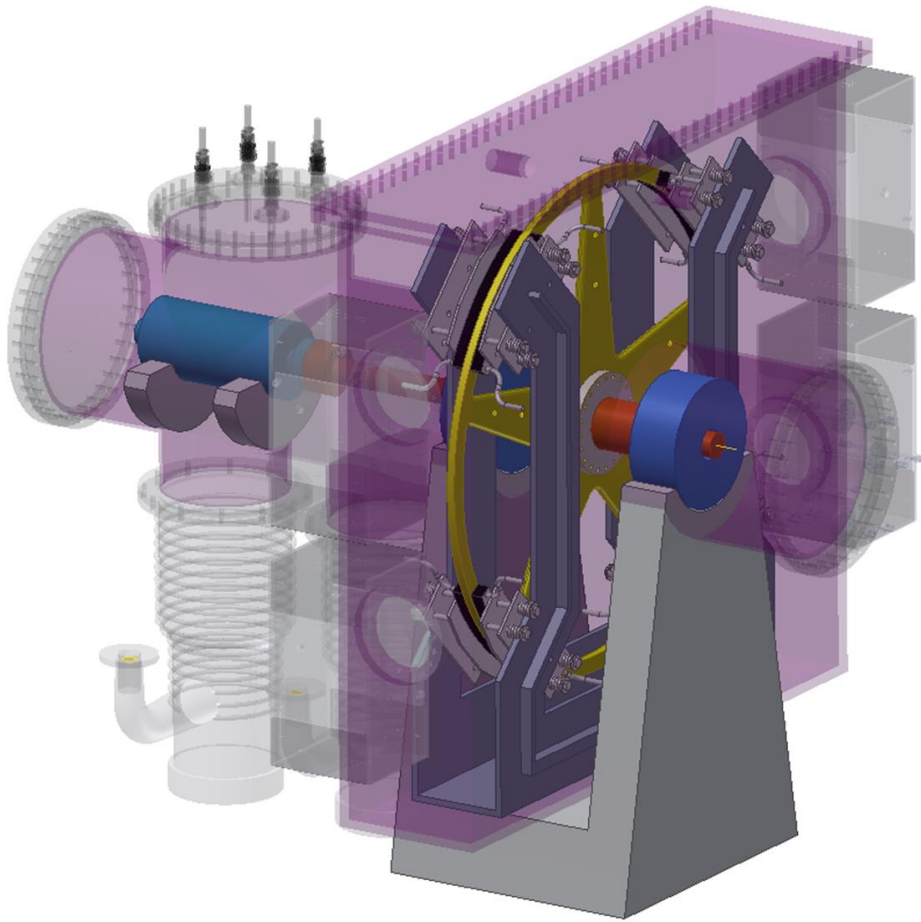
- By using the spring loaded cooling pads in close contact with the target rim, we can easily remove the power deposited in target.

- As we removed the need of cooling water channel inside the target wheel, we eliminated the need of feeding cooling water in the shaft and thus eliminated the need of rotating vacuum seal altogether and make it possible to have the target system enclosed completely inside a vacuum chamber with only electrical connections and stationary cooling water feed through.

Summary of the scheme: The friction between target wheel and cooling pad

- The friction between target wheel and cooling pad would be a problem if there is not a vacuum compatible lubricant as the target wheel is in constant contact with the cooling pads.

- The friction problem will be solved by coating the wheel and cooling pads with a solid film of Tungsten Disulfide (WS2).

- WS2 is a magic material, which has following properties: Tungsten Disulfide (WS2) or Tungsten Disulphide is an extremely slick, dry film lubricant coating. WS2 has an extremely low coefficient of friction of 0.03 -- lower than that of Teflon, Graphite, or Molybdenum Disulfide (MoS2). The film is remarkably durable compared to many other lubricant materials and can withstand tremendously high loads of over 300,000 psi! WS2 has unsurpassed performance properties for lubricity, non-stick, low drag, wear life, and load rating.

- WS2 has an electrical conductivity in the order of 10^{-3} (ohm.cm)$^{-1}$ [1]. With a half micron coating, the electrical/thermal resistance introduced by the coating will be negligible

[1]. P. A. Chate, D. J. Sathe and P. P. Hankare, Electrical, optical and morphological properties of chemically deposited nanostructured tungsten disulfide thin films. Appl Nanosci (2013) 3:19–23, DOI 10.1007/s13204-012-0073-0

Proposed Parameters

- The ILC target rim has area of > 1000 cm^2 and will be coated with WS2.

- The cooling pad will be spring loaded and also coated with WS2.

- The contacting area is assumed to be $300 cm^2$ with a contact pressure of $1N/cm^2$ (1.45psi). The heat generated by the friction is estimated to be 3kW.

- If Tungsten(173 W/m/K) is used for the cooling pads, then the temperature at the surface of target will be estimated at about 38 K above ambient for 20kW power removal.

- The cooling pad will have cooling channel inside and connected with cooling water manifolds. As the cooling pad is stationary, a vacuum compatible cooling water manifold should be easily implemented.

R&D issues and Risks

- R&D issues:
  - Design a vacuum chamber that can house 1 meter wheel with cooling system implemented on the outer wall and pads.
  - Purchase a vacuum compatible motor capable of 10 kW, and 4000 rpm.
  - A set of magnetic bearing to support the shaft with TI wheel. Or use the WS2 coating if ball bearings are used.
  - Gain experience on WS2 coating.
- Risks: Based the data we find, we could not identify any major risk associate with the design. However, we would like to prototype the system on the full scale to gain the experiences on
  - Lifetime of the WS2 coating;
  - Vacuum compatible motor selections;
  - Heat removal from a high vacuum chamber;
  - Stabilization of wheel with magnetic bearing/WS2 coated bearing;
  - Eliminate any unwarranted concerns on the undulator based source

Report on initial sliding cooling test at Institute of Modern Physics, China
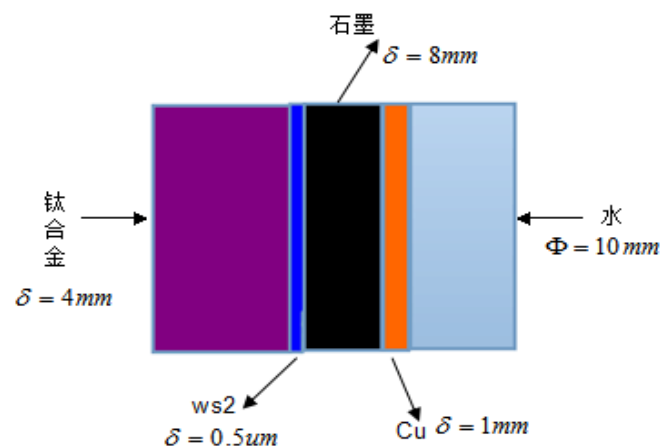
摩擦冷却实验报告

By XM Zhang, ZM Zhang and Wei Gai

ML2联轴器　　　　　Y100L-2电机

Φ400

270

741

436.50

镀　涂

摩擦冷却装置
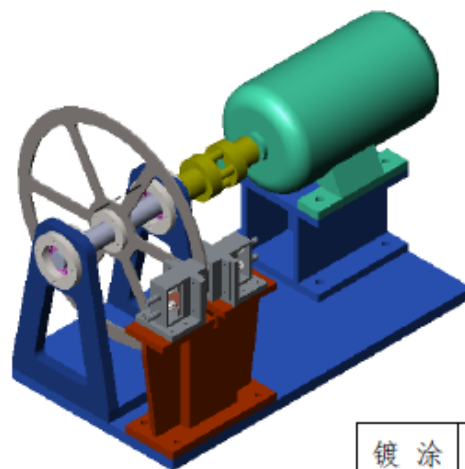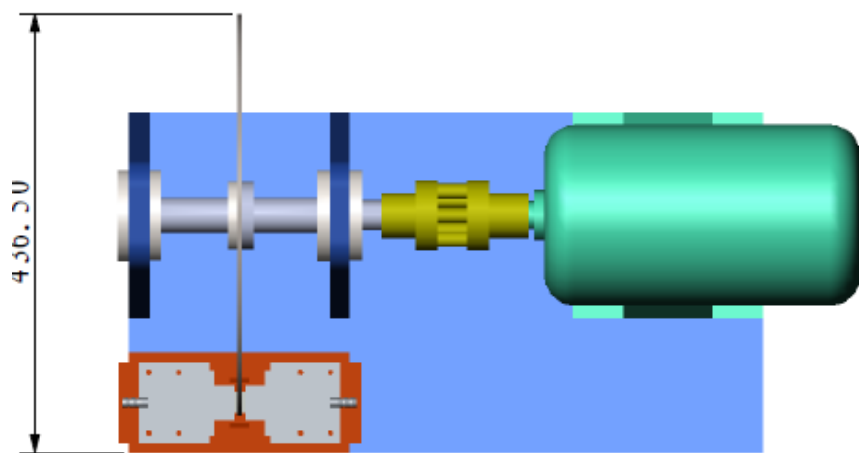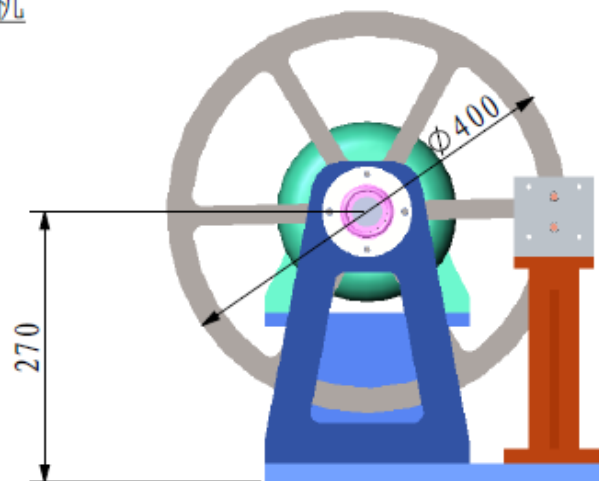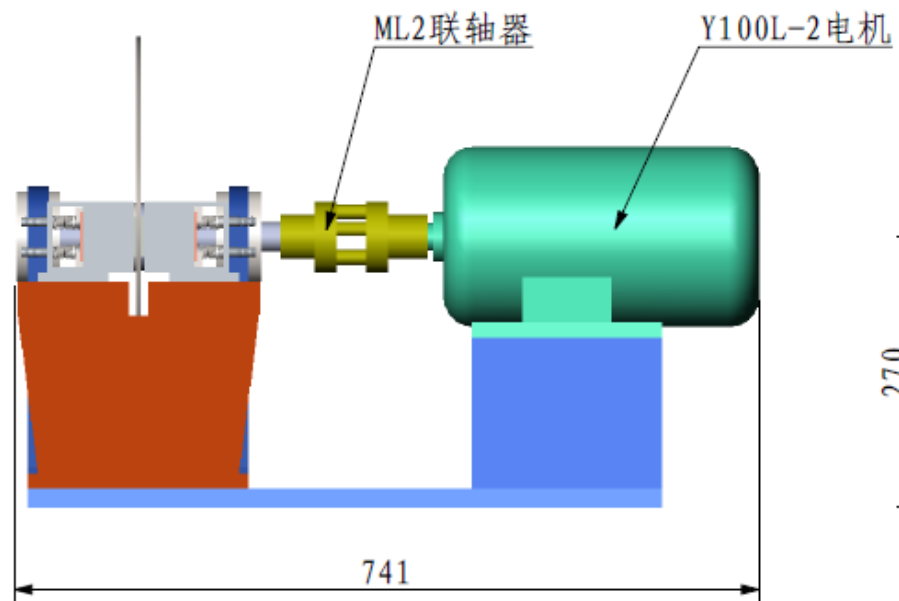
DC

（1）理论计算（多层平壁的稳态热传导）
Heat transfer modeling of multi-layered system

石墨 $\delta = 8mm$

钛合金 $\delta = 4mm$

水 $\Phi = 10\,mm$

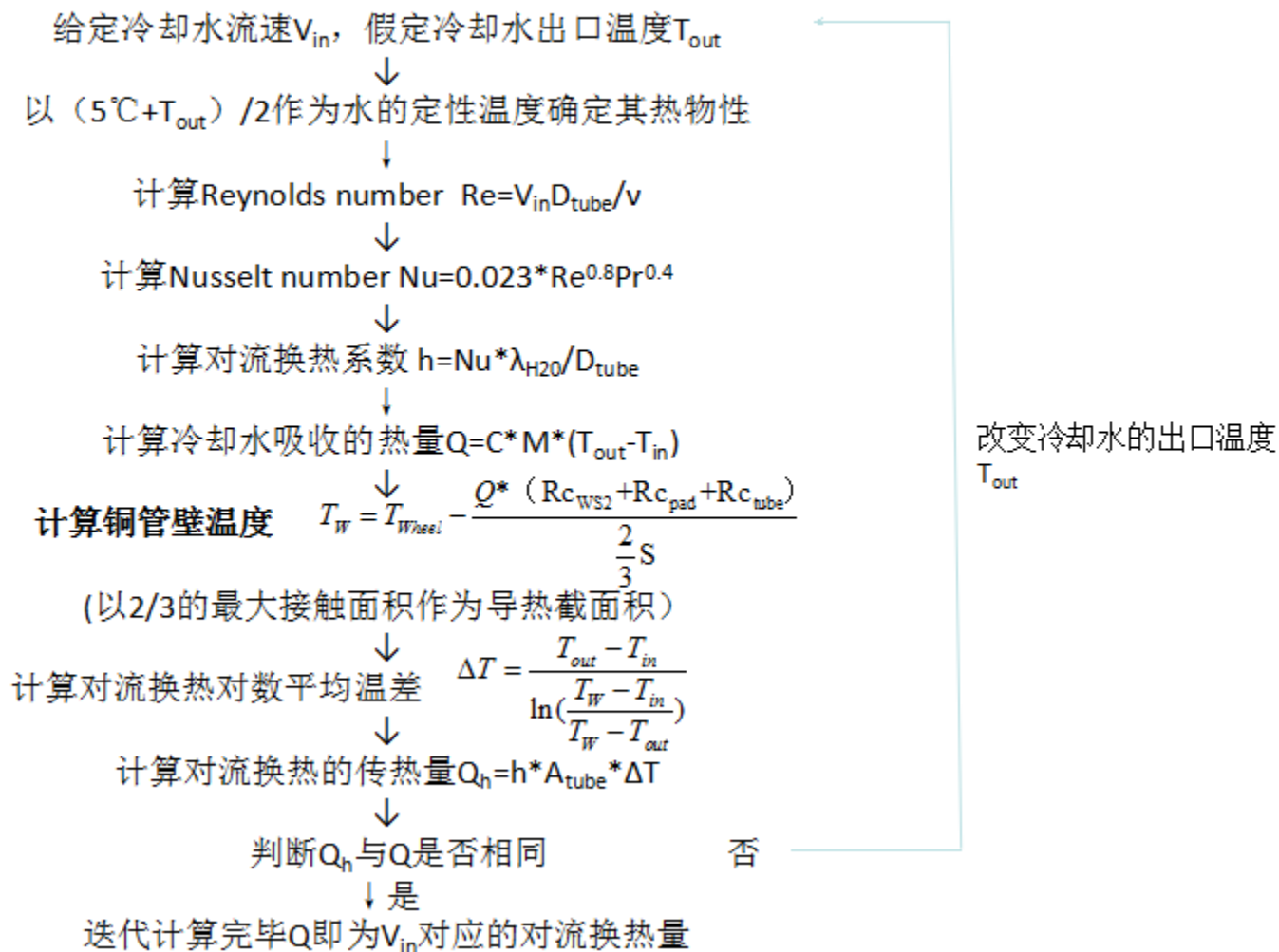ws2 $\delta = 0.5um$

Cu $\delta = 1mm$

在稳定状态下，通过各层的热流量均等于Q，

$$Q = \frac{\Delta t_1}{\dfrac{b_1}{\lambda_1 A_1}} = \frac{\Delta t_2}{\dfrac{b_2}{\lambda_2 A_2}} = \frac{\Delta t_3}{\dfrac{b_3}{\lambda_3 A_3}}$$
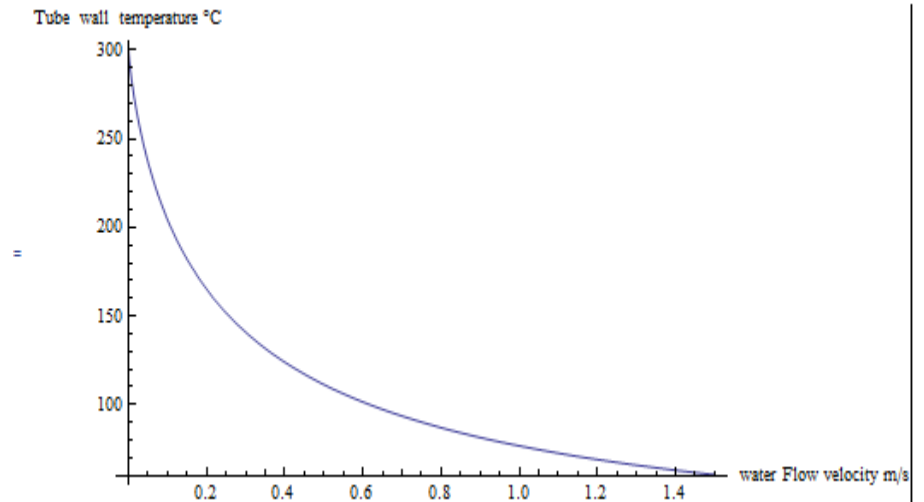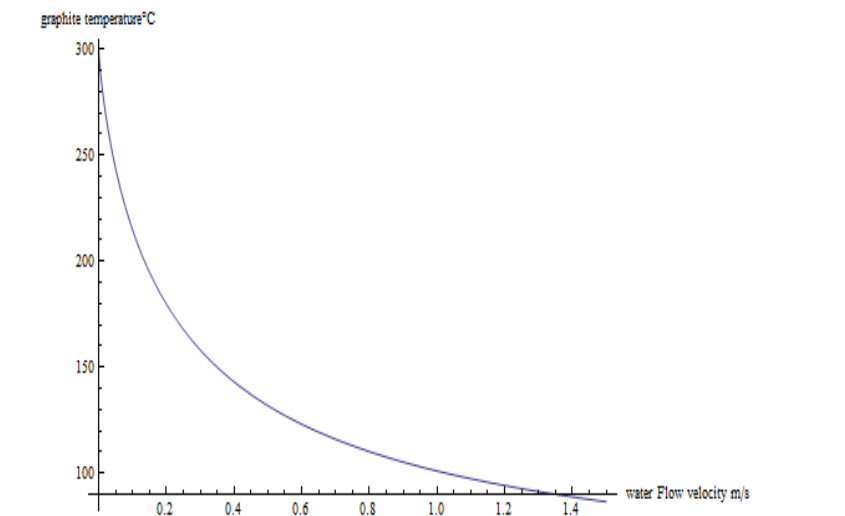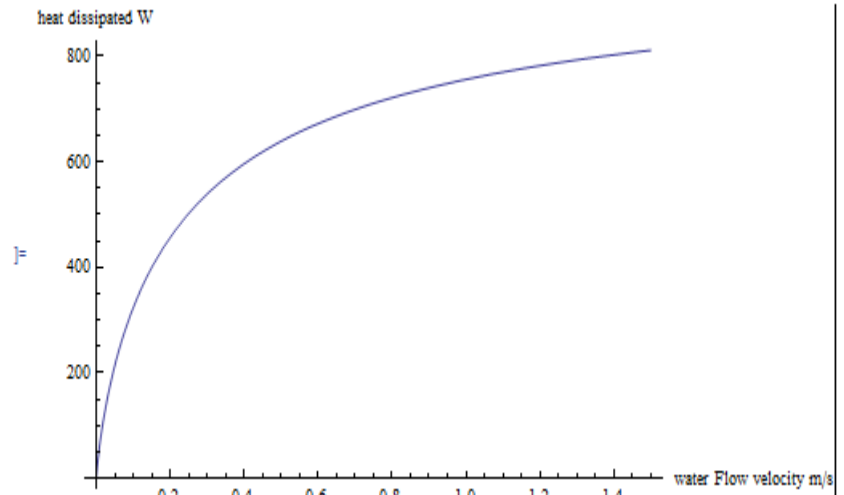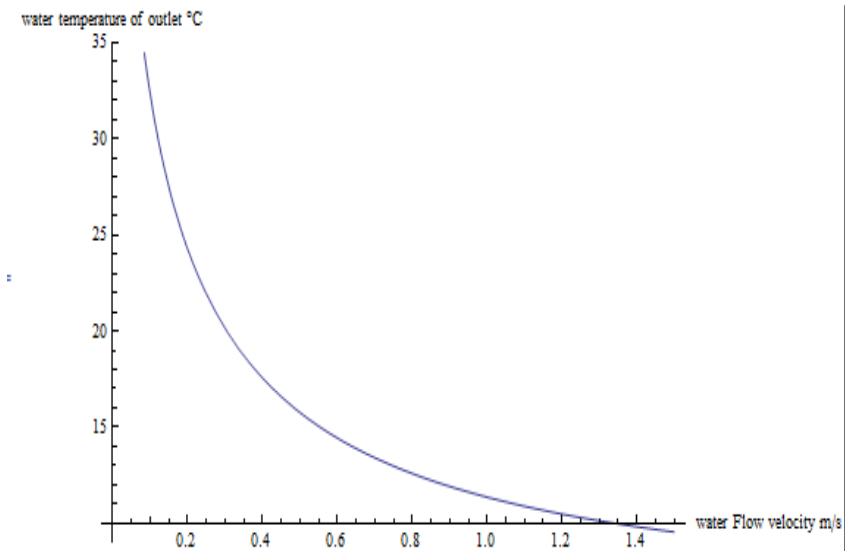
$$Q = \frac{\Delta t_1 + \Delta t_2 + \Delta t_3}{\dfrac{b_1}{\lambda_1 A_1} + \dfrac{b_2}{\lambda_2 A_2} + \dfrac{b_3}{\lambda_3 A_3}} = \frac{\sum \Delta t}{\sum R}$$

$$= \frac{t_1 - t_{n+1}}{\displaystyle\sum_{i=1}^{n} R_i}$$
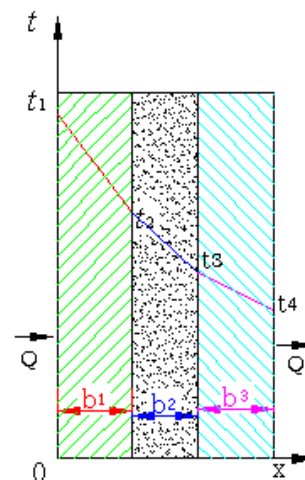
计算流程：根据热力学的Q吸=Q放（忽略热辐射和对流，只考虑热传导）来建立方程。

给定冷却水流速V_{in}，假定冷却水出口温度T_{out}

↓

以（5℃+T_{out}）/2作为水的定性温度确定其热物性

↓

计算Reynolds number Re=$V_{in}D_{tube}$/v

↓

计算Nusselt number Nu=0.023*$Re^{0.8}Pr^{0.4}$

↓

计算对流换热系数 h=Nu*λ_{H20}/D_{tube}

↓

计算冷却水吸收的热量Q=C*M*(T_{out}-T_{in})

↓

计算铜管壁温度 $T_W = T_{Wheel} - \dfrac{Q*（Rc_{WS2}+Rc_{pad}+Rc_{tube}）}{\frac{2}{3}S}$

(以2/3的最大接触面积作为导热截面积)

↓ $\Delta T = \dfrac{T_{out}-T_{in}}{\ln(\dfrac{T_W-T_{in}}{T_W-T_{out}})}$

计算对流换热对数平均温差

↓

计算对流换热的传热量Q_h=h*A_{tube}*ΔT

↓

判断Q_h与Q是否相同   否

↓ 是

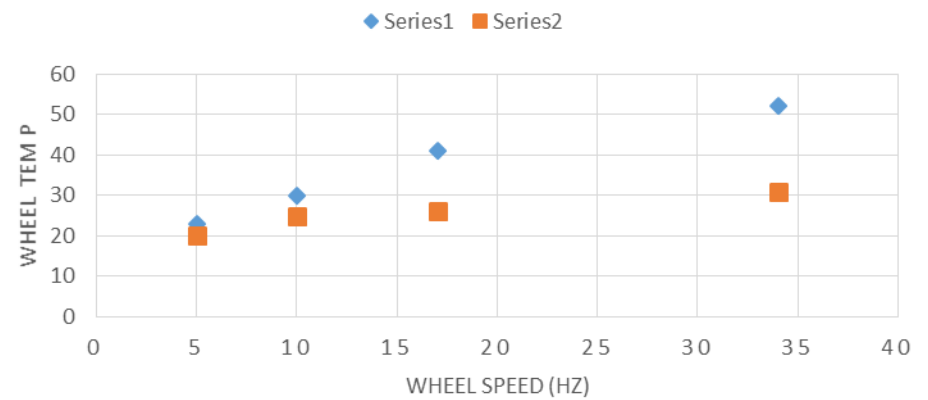迭代计算完毕Q即为V_{in}对应的对流换热量

改变冷却水的出口温度
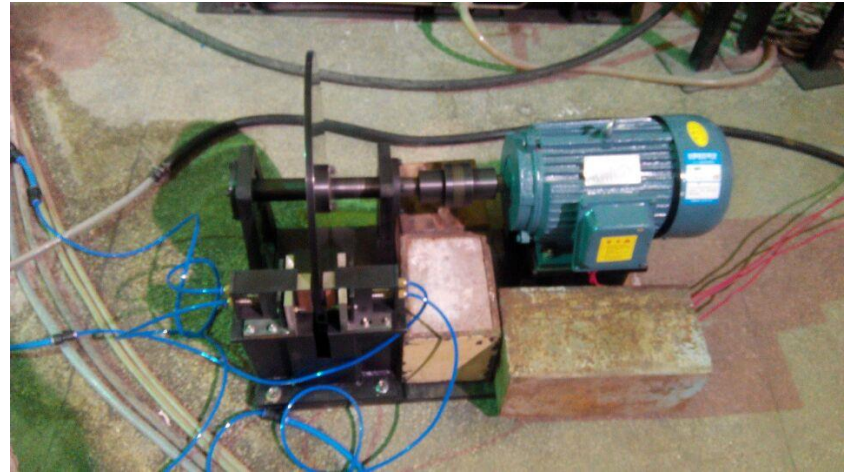T_{out}

理论的计算（mathmatica 300degree）

MEASURED WHEEL TEM WITH AND WITHOUT WATER FLOW.

（2）Experiment Set-up

Initial Analysis:

（1）上面的图形表示：转靶不同频率下通水与不通水之间靶的温度、石墨的温度、铜块的温度的对比图。比较而言，通水的确可以带走热量。
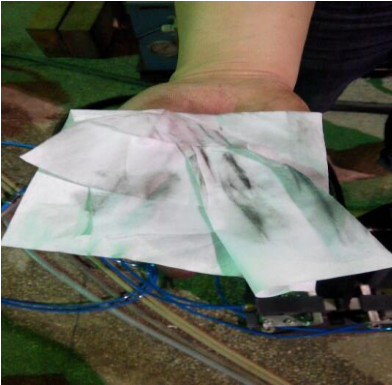
（2）根据材料的属性，大概有37%摩擦产生的热作用于转靶。63%作用于石墨，根据具体情况，

17HZ(10min)下，摩擦力产热14kJ,摩擦力的功率22w

34HZ(10min)下，摩擦力产热22KJ，摩擦力的功率36w

摩擦力做功，相对比较小。

（3）Next Step, fully instrumented/quantitative tests

1） External heat
2） Apply MoS2
3） Instrument temperature sensors everywhere.

Future Plan (or recommendations)

- At IMP
  - More quantitative tests of components, investigate critical engineering issues.
  - External heat sources (10 kW) and a full wheel (1 meter) at 2000 rpm.
  - Investigate mechanics of the sliding contacts,

- At ANL (working with Tribology Group)
  - Support the IMP tests,
  - An optimized design for ILC parameters, including advanced surface coating techniques,
  - Design and test vacuum compatible components,
  - Construct a realistic target that can operate continuously for years.

- Working with good engineering team, I am optimistic and confident.

- One more thing……

Undulator based positron source can be adapted for FCC and CEPC

~ 50 km of main ring and booster

Injection into booster ring at 6 GeV, (Tang made direction right)

Stacking as in CLIC design and with some damping damping

4 meter Helical undulators
Either in booster or Main ring

Target, capturing for positron and acceleration 6 GeV for both electron and positron