# Turbo-molecular pumps in magnetic fields

## (*Visit to Karlsruhe Institute of Technology*)

Vishal Francis, Tom Weston 17/10/2012

- Motivation
- Rotor heating
- Shielding
- Experimental setup
- How can MICE benefit?

# Motivation

- To discuss published paper with Joachim Wolf
- See experimental setup
- Meet Alexander Jansen, Ph.D “Modelling rotor temperature (TMP), in magnetic fields.

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## Model of the rotor temperature of turbo-molecular pumps in magnetic fields

Robin Größle[a], Norbert Kernert[b], Sebastian Riegel[a], Joachim Wolf[a,*]

[a] Karlsruhe Institute of Technology, IEKP, Postfach 3640, 76021 Karlsruhe, Germany
[b] Karlsruhe Institute of Technology, IK, Postfach 3640, 76021 Karlsruhe, Germany

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A B S T R A C T

The KATRIN neutrino experiment operates about 20 turbo-molecular pumps (TMP) in the vicinity of super-conducting magnets, pumping out tritium gas from the electron beam-line of the experiment. In a dedicated test setup with Helmholtz coils systematic studies have been conducted, investigating the rotor temperature and stability of operation of TMPs at full speed as a function of gas load, magnetic field strength and direction of the field. The temperature of the magnetically levitated spinning rotor was measured in vacuum with an infra-red pyrometer. A simple model has been developed, which describes quantitatively the temporal progression of the rotor temperature as a function of gas flow and field strength of an external static magnetic field. The model requires 5 pump-specific parameters, characterising the heating effects of eddy currents and gas friction and cooling by radiation loss and convection. When designing a vacuum system with TMPs in a critical environment (e.g. magnetic beam-line, fusion reactor), the model can be used to predict the maximum temperature of the rotor, to ensure a safe operation of the pump.



### 1. Introduction

Stringent vacuum requirements in particle physics experiments in combination with strong magnetic fields pose a challenge for the design of new vacuum systems. Magnetic fields induce eddy currents in the fast spinning rotors of turbo-molecular pumps (TMP), which can lead to an overheating of the rotor. Few measurements and even less theoretical models [1–5] are available, which describe the heating of a rotor and can aid in the design of an optimized vacuum system. Therefore, a simple model has been developed [6] to describe the temporal evolution of the rotor temperature under varying operating conditions with easy to measure parameters. The model allows predictions of the rise time of the temperature and of the final equilibrium temperature of the rotor for different parameters like magnetic field, gas flow, motor current and housing temperature of the pump.

Initially these investigations were motivated by the requirements of the KATRIN experiment, currently under construction at the Karlsruhe Institute of Technology (KIT) [7], where about 20 TMPs will be operated close to super-conducting magnets (3.6 T and 5.6 T) of the electron beam-line. These TMPs have magnetic bearings. Therefore, the rotors lose heat mainly via radiation. The manufacturer recommends for long-term safe operation a rotor temperature below 90 °C. Higher temperatures can reduce the lifetime of the pump. At temperatures above 120 °C thermal expansion can lead to a rotor crash when the expansion of the hot rotor exceeds the small gap to the colder stator blades, which are connected to the housing of the pump. Since the model allows slow variations (compared to the rotation frequency of the rotor) of the parameters over time, it can also be used to simulate the effect of pulsed magnetic fields, as they can occur, for instance, in nuclear fusion experiments.

After first tests with an existing set of Helmholtz coils [6] a new, improved setup has been designed with larger coils, providing a homogeneous magnetic field (±1%) even for large TMPs. Here we report on first results with a *Leybold MAG W 2200®* pump from the JET nuclear fusion facility (Culham/UK), and the parameters are used to simulate the rotor temperature in a pulsed magnetic field.

### 2. Model of the rotor temperature

The time dependence of the rotor temperature $T_R$ can be obtained by integrating the differential equation of the power balance:

$$m_R \cdot c \cdot \frac{dT_R(t)}{dt} = \sum_i P_i(t) = m_R \cdot c \cdot \sum_i k_i \cdot f_i(t) \qquad (1)$$

* Corresponding author. Tel.: +49 721 608 25532; fax: +49 721 608 29108.
*E-mail address:* Joachim.wolf@kit.edu (J. Wolf).

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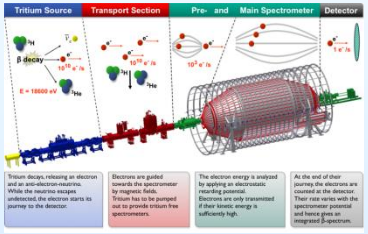
# Work at KIT

Sheet from J. Wolf presentation

- **KATRIN:**
  - differential pumping sections (2 - 18mT) → shielding
  - spectrometer (save distance of TMPs ?)




- **Nuclear fusion plant (JET, ITER, …)**
  - pulsed mag. field (>> 5 mT)
- **Operation of TMPs in magnetic fields**
  - magnetic fields induce eddy currents in the rotor
    - ➢ rotor temperature ?
    - ➢ overheating leads to destruction of the pump !
  - stable operation:
    - ➢ rotation frequency ?
    - ➢ magnetic bearing ?
  - influence of the direction of the field ?
  - effect of shielding ?

# Rotor Heating

## Motivation

KIT Karlsruhe Institute of Technology

- **Rotor temperature ?**
  - can not be measured directly (e.g. PT 100)
    - IR pyrometer (difficult during normal operation of TMP)
    - temperature dependent $\mu_r$, …
  - heating:
    - friction (high gas load)
    - hot gas (high gas load)
    - magnetic field (eddy currents)
    - radiation
  - cooling:
    - radiation
    - heat conductance / convection (high gas load)
  - influence of housing temperature ?
  - influence of external cooling (water cooling) ?

IR-Pyrometer



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# Empirical model of the TMP rotor heating

- **aim of the model:**
  - understanding of major contributions to the ***heat balance of a rotor***
  - characterize these contributions with ***few empirical parameters***
  - ***predict the temperature*** of a rotor for different external conditions
- **basic ingredients of the model:**
  - eddy currents **(heating of the rotor)**
  - motor and magnetic bearing effects **(heating, no-load power)**
  - gas flow **(heating and cooling)**
  - radiation loss **(cooling)**
- **available data:**
  - **rotor temperature** (IR-pyrometer)
  - **magnetic field** (Hall sensor, coil current)
  - **temperature of the pump housing** (PT100)
  - **TMP motor current and temperature** (controller)
  - **gas flow, pressure**



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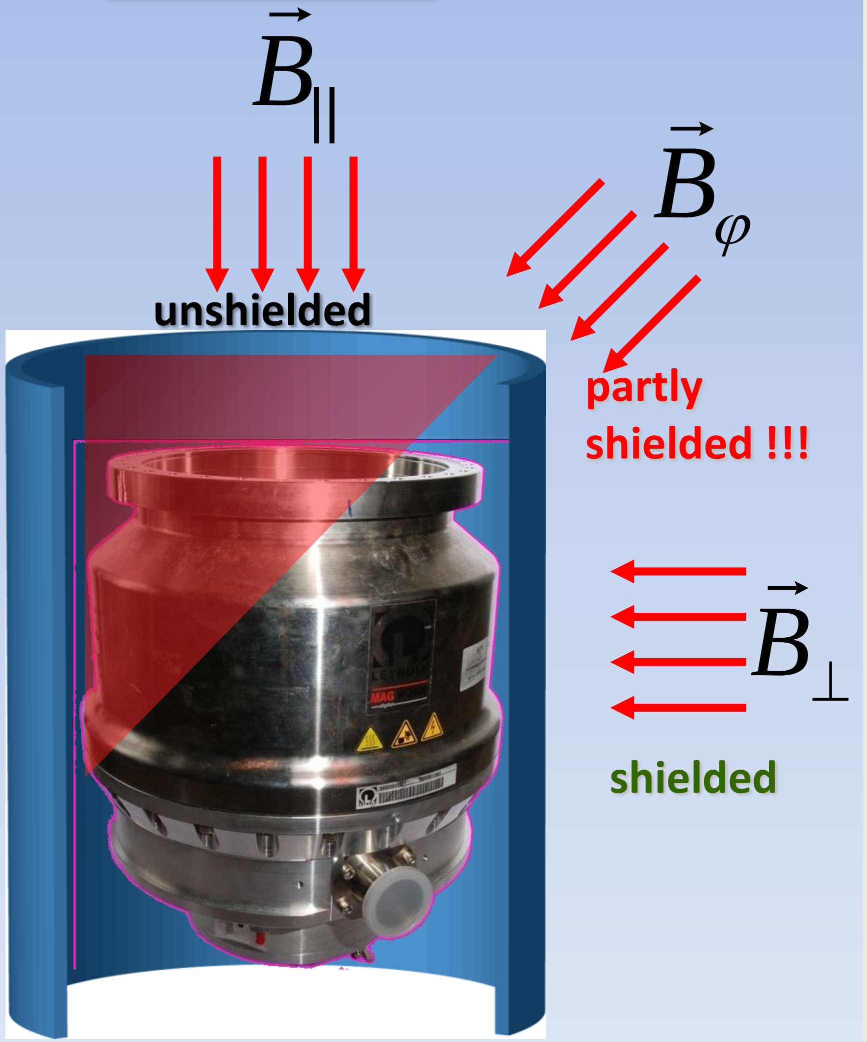
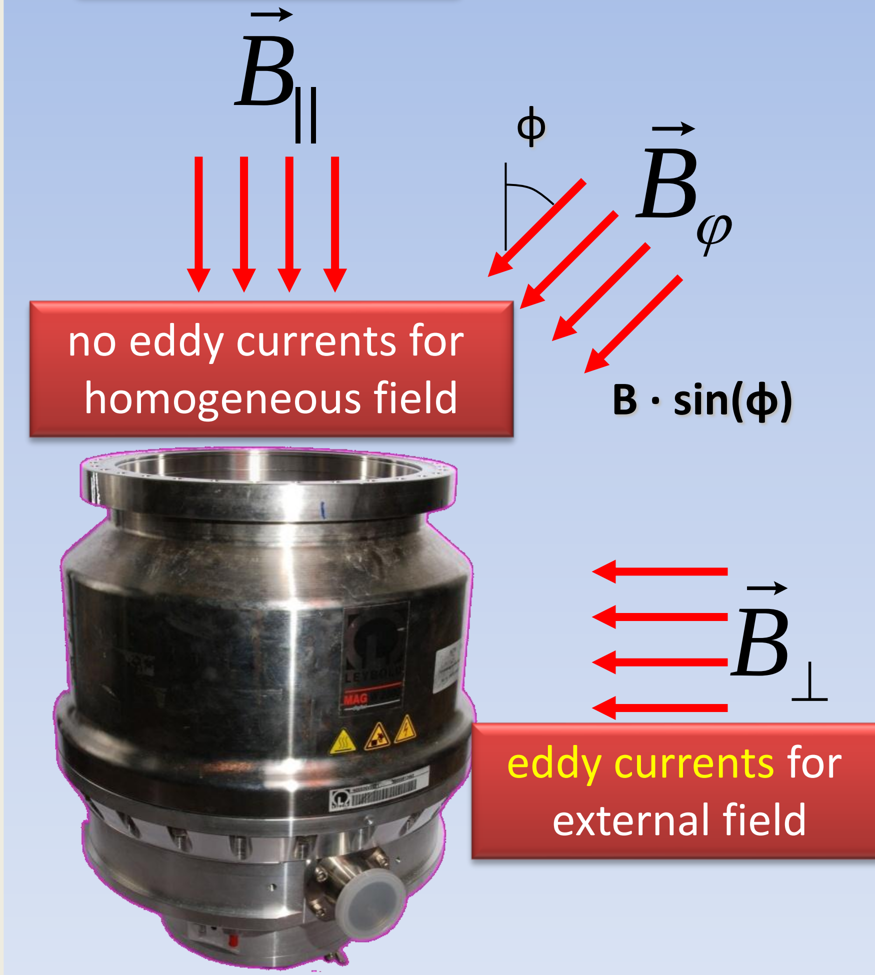
# SHIELDING

**Reduction of the field by shielding**

## shielding




## unshielded



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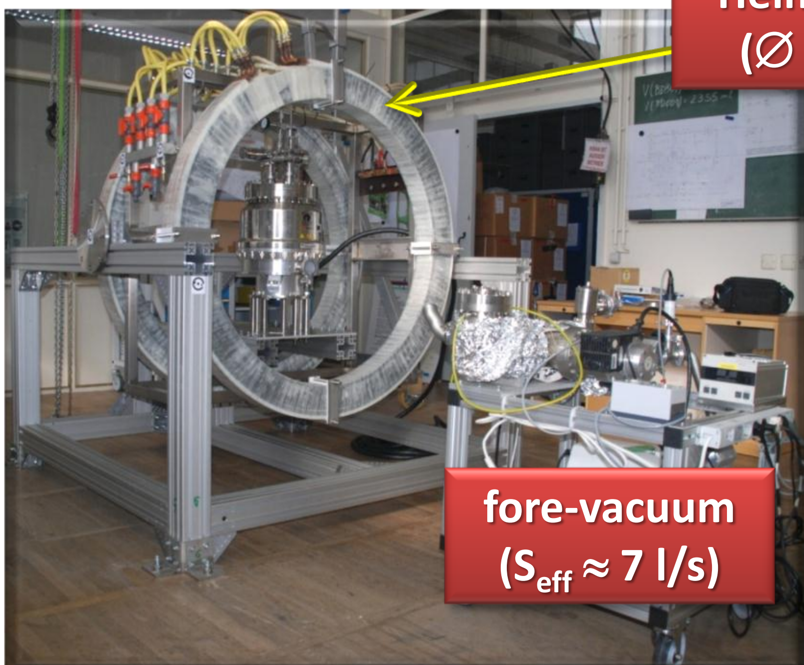
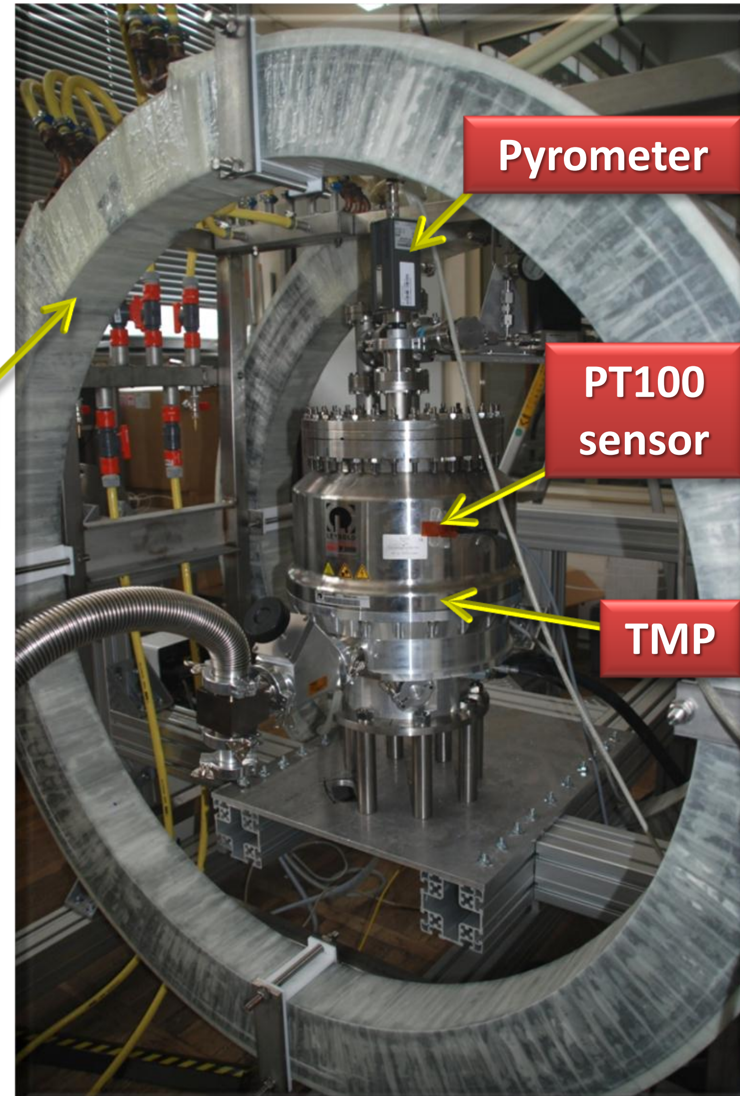
# Experimental setup

- rotor temperature
- stability of the magnetic bearing
- rotation frequency



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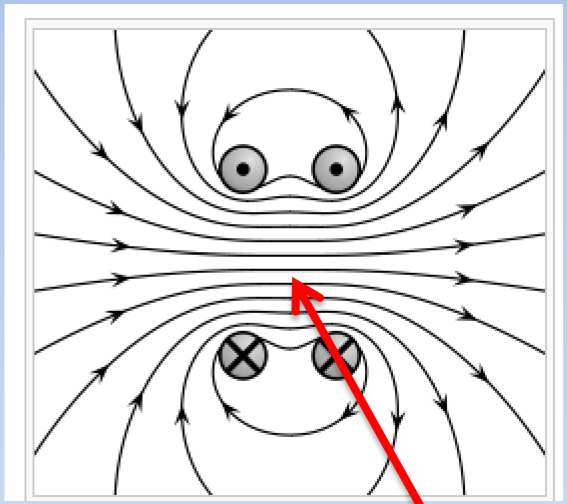
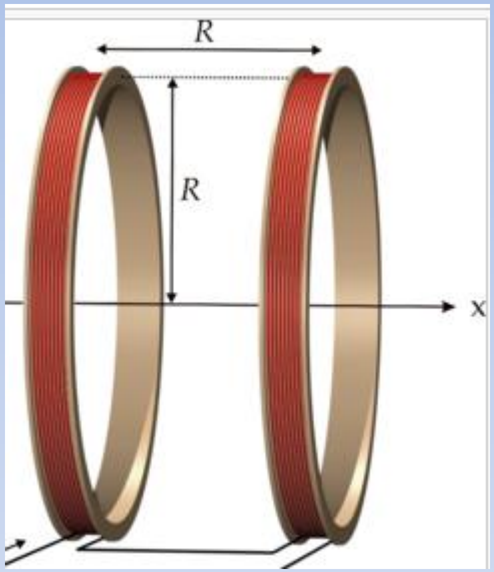
# Reminder



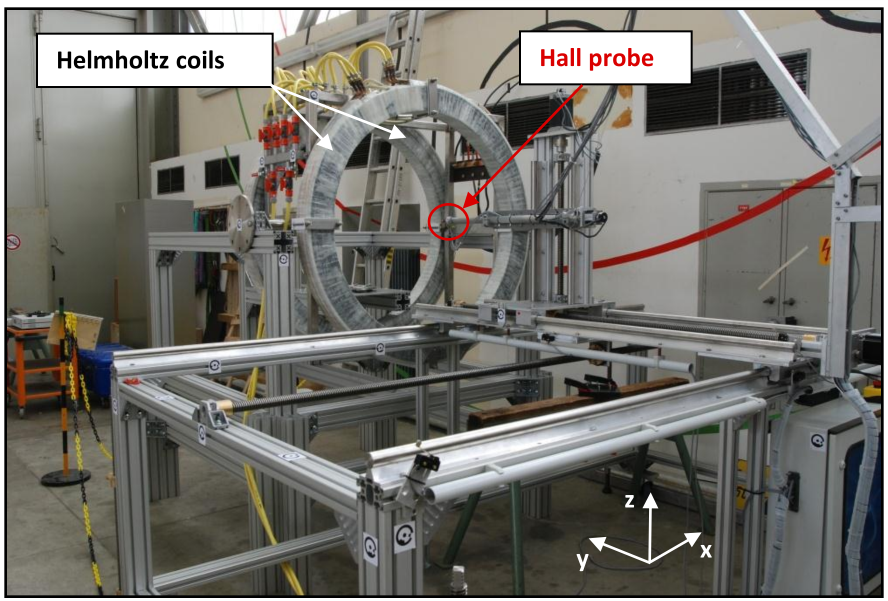


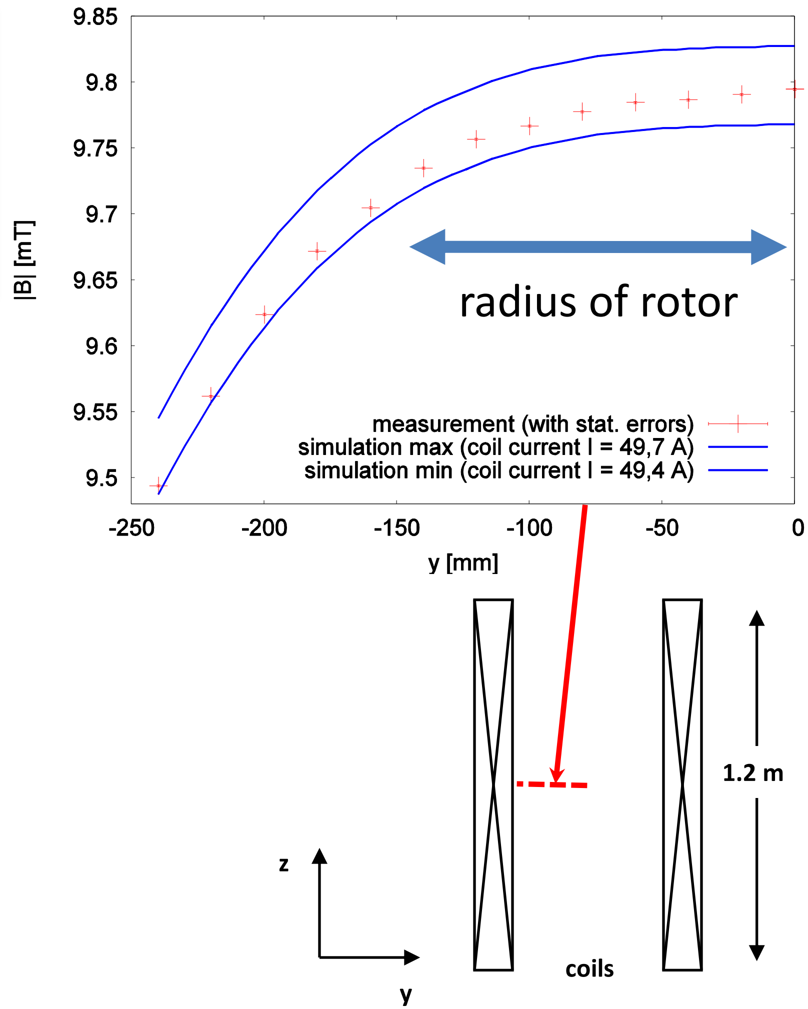

Region of uniform magnetic field where TMP will sit

# Helmholtz coils

- Helmholtz coils tested with 3D sensor
- Inner volume scanned
- Calibration with external Hall probe
- Test of homogeneity of B-field: ±1%

**thesis by Stefan Zepter**



# Test setup summary

- Coil diameter 1.2m,
- Field up to 200G long term, can test 500G short term.
- Test TMP - long term tests,
- Quick shielding test, using hall probes and shield set up,
- Quick electronic equipment test,

# How can this help MICE

- We can use the set up at KIT. *(We will have to request and send a proposal for costing).*
- We can do quick tests using staff and students at KIT *(helps their Ph.D).* Electronic items???, magnetic shields and control equipment etc.
- Long term TMP tests *(may need our staff to assist).*

# What next?

- Invite Joachim Wolf and Alexander Jansen to RAL

  *(To talk to MICE. A good source for consultation)*

- Do we make a test setup at RAL or use the facility at KIT?
- Other MICE groups converge and propose a "test wish list".