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Event Safety

CERN Accelerator School Course on Normal- and Superconducting Magnets in St. Pölten (AT) (19.11.-2.12.2023): Safety of Experiments

RÉSUMÉ :

The CERN Accelerator School Course on Normal- and Superconducting Magnets includes two laboratories in which students perform experiments on normal conducting and superconducting magnets. Associated hazards are cryogenic fluids and electricity.
This Safety File describes the hazards, risks and mitigation measures to be adopted.

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SUIVI DES MODIFICATIONS

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0.1	8.11.23	All	First draft after online discussion on 24. 10. 23 and information collection
0.2	10.11.23	All	Version for engineering check (CERN organisers and instructors)
0.3	15. 11. 23	All	Comments included, version for approval

Contents

1. Introduction

The CERN Accelerator School (CAS) organises a specialised course on Course on Normal- and Superconducting Magnets in St. Pölten, Austria 19. 11. to 2. 12. 2023. (https://indico.cern.ch/event/1227234/)

During the two-week course with 96 students and up to 24 instructors , hands-on sessions with demonstration experiments on high-temperature superconductors (HTS) and magnetic measurements will be held in two specially prepared rooms. The cryogenic fluid employed for the superconducting magnets is liquid nitrogen (lN_2).

This document lists the electrical, magnetic, cryogenic and oxygen deficiency hazards during the experiments and makes recommendations for mitigation.

2. Experiments: Location, Organisation, Equipment

The CAS takes place in Cityhotel D&C in St. Pölten.

2.1 High-Temperature Superconductors

2.1.1 Location

The "Waldviertel" conference room is reserved for the cryogenic experiments on HTS. The approximate size of the room is 12 m * 8.5 m * 4 m (Volume = 408 m^3), one of the long sides has windows with an estimated surface of 20 m^2.

At the beginning of the school, liaise with the Hotel reception to clarify evacuation paths from the meeting rooms and assembly points, and obtain an emergency telephone number (ambulance, fire brigade).

Obtain a small first-aid kit from the Hotel reception or a local pharmacy and add an ointment for burns (it will alos calm cold burns from lN2) and have it at hand in the laboratory.

2.1.2 Organisation

Five different experiments are set-up on one table each (see Annex 1). At each table, a group of five students performs the experiments during approximately one hour, then they change place with a different group. At least on instructor per table is always available to assist. It is assumed that all five experiments are active at the same time.

2.1.3 Equipment

2.1.3.1 Cryogenic Equipment

Small transport dewars with a capacity between 5 L and 10L will be used to transport lN_2 from the transport dewars stored in free air to the experiment tables. The lN2 will be poured into simple cryostats, open to air, by instructors. It is assumed that max. 50 L of lN_2 will be present in the room at the same time.

Table	Dewar Sizes	Quantity used	Responsible
1	4 * 2.5 L		CERN
2	1 L, 2.5 L		U Southampton
3	8 L, 4 L	< 10 L / day	CIEMAT
4	10 L	20 L / day	U Wien
5	Combination of the experiment from table 1-4		

2.1.3.2 Electrical Equipment

All electrical equipment is CE marked. Voltages are restricted to the Very Low Voltage range (Fr: TBT; U < 50 V)

Device	Make	Max range	Responsible
Current source	Keithley 2460	$I < 100$ mA, $U < 100$ V Voltage locked to < 50 V	CERN
Safety extra-low voltage (SELV) power supply	Delta Electronica SM15-400	$I < 400$ mA, $U < 15$ V	CERN
Power Supply	Agilent E3632A	$I < 4$ A, $U < 30$ V	U Southampton
Data Logger	Agilent 34970A	N. A.	U Southampton
Precision current source	Lakeshore 120	$I < 100$ mA, $U < 14$ V	U Wien

2.2 Magnetic Measurements

2.2.1 Location

A room is reserved in a Technical School in the vicinity of the Hotel for the experiment of magnets.

At the beginning of the Accelerator School classes, liaise with the Technical School management to clarify evacuation paths from the meeting rooms and assembly points, and obtain an emergency telephone number (ambulance, fire brigade)

Obtain a small first-aid kit from the Technical School management or a local pharmacy and have it at hand in the laboratory.

2.2.2 Organisation

Five tables with experiments are prepared, housing three different experimental scenarios. At each table, a group of five students performs the experiments during approximately one hour, then they change place with a different group. At least on instructor per table is always available to assist. It is assumed that all five experiments are active at the same time.

2.2.3 Equipment

2.2.3.1 Magnetic Equipment

Table	Magnet	Electrical characteristics	Magnetic Characteristics
1-3	Air-cooled quadrupole PXMQNAHNAP	I_{max} = 10 A R = 340 mΩ	L = 32 mH, E_{mag} = 1.6 J Max. pole tip field 73 mT
4	Air-cooled dipole PXMCCATWAP	I_{max} = 6 A	L = 4 mH, E_{mag} = 0.07 J Max pole tip field 6 mT
5	1 Halbach-type Linac 4 quadrupole with permanent magnets	N.A.	Pole peak field 230 mT
	Permanent magnets: NdFeB and SmCo	N. A.	Pole tip field > 100 mT.

2.2.3.2 Electrical Equipment

All electrical equipment is CE marked. Operational voltages are restricted to the Very Low Voltage range (Fr: TBT; U < 50 V). All equipment is supplied by and under responsibility of CERN.

Device	Make	Max range
3 Desktop Power supplies	TTi TSX1820P	I < 10 A, U < 20 V
Power Amplifier	Kepko 72 V 6 A	I < 6 A, U < 76 V
Power Amplifier	Kepko 36 V 6 A	I < 6 A, U < 36 V

3. Hazard Register and Simple Mitigation Methods

Hazard		Mitigation	Person responsible of the measure
Cryogenic Fluid: IN_2 (T = 77 K)		During the handling of IN_2, all participants wear suitable low-temperature gloves and safety goggles.	Amalia Ballarino
Oxygen Deficiency Hazard (ODH)		**Detailed assessment in section 4.1**	Amalia Ballarino
Transport and storage of IN_2		Two storage dewars (capacity 250 L) are stored outside but protected from rain. Instructors fill small transport dewars (capacity between 1 L and 10 L) from the storage dewars and carry them to the experimental room.	Amalia Ballarino
Electricity		**Detailed assessment in section 4.2**	Marco Buzio
Magnetic Fields		**Detailed Assessment in Section 4.3**	Marco Buzio
		Both experimental rooms are inaccessible to wearers of implanted medical devices. Place the corresponding sign on the doors.	Marco Buzio
Noxious chemical substances		**Soldering media:** Only instructors are permitted to solder, using a soldering station with local exhaust ventilation.	Marco Buzio
Trip and Fall		All electrical cables on the floor shall be secured with black-yellow tape	Amalia Ballarino/ Marco Buzio
Mechanical Hazards		All parts, components and samples foreseen to be manipulated by CAS students shall be free from sharp corners The low levels of torque and speed of the rotating coil system are not deemed to be a significant hazard. During operation, students shall be instructed to keep a min. distance of 1 m.	Marco Buzio

4. Risk Assessments for Particular Hazards

4.1 Oxygen Deficiency Hazard and Mitigation

The following estimates show that the average oxygen concentration in the room will not fall below 19 %.

The room "Waldviertel" will be reserved for experiments on HTS, using the cryogenic fluid liquid nitrogen (lN_2)., The room's volume V = 408 m^3. For all following estimates the general assumption is instantaneous mixing of evaporated gas with the air in the toom.

4.1.1 Screening estimate

For a conservative screening estimate, it is assumed that every table uses 10 L of lN_2 per experiment. At the beginning of each phase, **50 L lN_2** are present in the room. If they would evaporate at once, the resulting N_2 gas at room temperature would occupy 35 m^3, by displacing air. The remaining concentration of O_2, $c(O_2)$ is [1]:

$$c(\mathrm{O}_2) = 21\,\% \left(1 - \frac{35}{408}\right) = \mathbf{19.2}\,\%$$

This value is larger than 18 % and therefore acceptable.

4.1.2 Time-dependent Estimate (more accurate)

In reality, lN_2 will evaporate at a variable rate over the duration of one hour. The critical value of $c(O_2, t)$ is therefore time deponent. A more realistic estimate includes the evaporation rate of lN_2, and the natural air exchange in the room. A conservative approach is that all lN_2 will evaporate during the first 15 minutes when the superconductors are cooled down. The evaporation rate of lN_2 is 3.33 L/min, leading to an evaporated gas flow of ***R* = 2.33 m^3/min**. In a typical room, the air exchange rate is twice per hour, in the ***V* = 408 m^3**- room above, ***Q* = 13.6 m^3/min**. The time-dependent concentration of O_2 is [1]:

$$c(\mathrm{O}_2, t) = \frac{21\,\%}{Q + R} \left\{Q + R \cdot \exp\left(-\frac{Q + R}{V} t\right)\right\}$$

Entering the values for V, Q and R one obtains at ***t* = 15 minutes** a value of ***c*(O$_2$) = 19.6%.** This value is also in the safe range of oxygen concentration.

4.1.3 Mitigation Measures

The conclusion of the previous estimates is that there is no intrinsic oxygen deficiency hazard during the proposed experiments. The following mitigation measures are nevertheless mandatory to:

- Monitor local concentration of O_2 with portable ODH detector (three at representative locations in the room, for example on some of the working tables).

- Make a full air exchange every hour, when students change table, by opening all windows and the door of the room widely for 5 minutes.

4.2 Electrical Risk Assessment and Mitigation

All electrical devices (transformers, power converters, multimeters etc.) bear a CE-mark. The experiments use voltages U < 50 V, i.e. in the **very low voltage range** where the skin resistance protects from further harm.

Only instructors are allowed to connect or disconnect normal-conducting magnets from the power supplies, (see below under 4.3.1.)

To prevent an accidental disconnection of cables, they will be either of type Mammut screw connection, or they will be secured with a cable tie.

If metallic conductors are exposed, they shall be protected by Kapton tape.

4.3 Magnetic Risk Assessment and Mitigation

Magnets in both laboratories (HTS and Superconductivity, Magnetic Measurements) cause flux densities more than 0.5 mT. **Persons with implanted medical devices (e.g. pacemaker or insulin pump) must not enter the laboratories**. The standard warning sign will be posted on the doors to the laboratory rooms.

4.3.1 Electromagnets

The electromagnets store a small amount of electromagnetic energy (see table under 2.2.3.1.). This energy is released in case of an abrupt connection or disconnection of the magnet, and therefore, on the electrical terminals an induced voltage will appear. The energy and voltage are, however, not able to create an electrical arc in air.

The connection and disconnection of electromagnets shall only be performed.

- By instructors
- When the power supply of the respective magnet is in position *zero* or *off*.

4.3.2 Permanent Magnets

Projectile effect: the strong permanent magnets included in the setup may generate a peak field up to 400 mT generate and magnetic forces up to 100 kg (“aimant de la mort” [3]) and therefore do represent a risk of projectile effect, as well as pinching body parts and/or splintering when manipulated. Mitigating measures: a) the magnets shall be kept normally enclosed in a box such as that no significant magnetic force can be generated outside; b) the magnets generating more than 15 kg of force shall be operated only by trained CERN staff; c) the students shall receive appropriate training to operate smaller magnets, including the obligation to keep a minimum 0.5 m distance from other magnets, any steel part or electronic equipment, or potentially sensitive personal items (credit cards, mechanical watches etc)

5. References

[1] Thomas Otto, Safety for Particle Accelerators, Section 2.3. Springer Nature Switzerland, Cham 2021

[2] CERN General Safety Instruction: Non-Ionising Radiation, GSI-NIR-1

[3] Source: Supermagnete.fr

Annex 1 : Summary of High-Temperature Superconductor Experiments

	Table 1 (Prepared by CERN) Properties of Superconductors	Table 2 (Prepared by SOTON)	Table 3 (Prepared by CIEMAT)	Table 4 (Prepared by Un. of Vienna)
Magnets and cryostatic equipment	- REBCO Tape - REBCO Bulk - Permanent magnet - Permanent magnet in U-shaped configuration - LN2 4 containers 2.5 l each, total of 10 l. - Glass cryostat with vacuum insulation - Liquid nitrogen open cryostat (2 units)	- REBCO Tape - No magnets - LN2 containers 1 container 2.5 l and 1 container 1.0 l - Glass cryostat with vacuum insulation (from CERN) - Liquid nitrogen open cryostat (1 units from CERN)	- Laptop Computer - Software Quick Field Student version - 2 *HTS coils (manufactured & provided by CIEMAT) - 3* Polystyrene Boxes (Cryostat provided by CIEMAT) - 2* LN2 Dewar for filling the cryostat (8 & 4 liter, respectively) - Demonstration magnetic bearing kit (manufacturing & provided by CIEMAT)	- LN2 containers: 1 container of 10 l. To be refilled regularly. At least 20 l are needed each day. - REBCO bulk - Styrofoam box - HTS coil - Various permanent magnets - Varnish insulated copper wire -Teflon tape
Electrical Instrumentation	- Safety extra-low voltage (SELV) power supply (2 units): Delta Electronica SM15-400, 15 V, 400 A - Keithley 2460, 100 V, 1.05 A, the voltage will be limited to below 48 V and front panel locked Needed: 2 outlets 16 A three-phase - Cryogenic Pt sensors - Hall probe - Four minicomputers for DAQ Needed: 2 outlets 10 A monophase - Multimeters with shunt (2 units) - Nanovoltmeter (4 units) - Source measure unit (2 units) - Lakeshore 224 (2 units	- Agilent E3632A Power Supply, 30 V, 4A - Agilent 34970A Data Logger, no power output - A laptop computer Needed: 3 outlets 10 A monophase - Datalogger (1 unit) - Power supply (1 units) - laptop (1 unit)	- DC power supply (8V- 125 A) Needed: 1 socket 10A single-phase - Millivoltmeter - DC Amperemeter up to 125A - Thermometer (77K-300K) - Data logger - Laptop with Labview - Screen Needed: up to 3 sockets 5A single-phase	- Two miliampere current sources (Lakeshore 120 precision current sources: max 100 mA, max 14 V) - Lock-In-Amplifier - Voltmeter - Hall probe - Temperature sensor - Computer with USB ADC converter -Heating cartridge
Exercises and Measurements (Summary)	-**critical current of REBCO tape** at 77 K and in self-field - **anisotropy of critical current** of REBCO tape: use of U-shaped magnet at 77 K - **critical temperature** of REBCO tape - **Resistive transition** of REBCO tape and quench propagation - **Field-cooled** and **zero field-cooled** experiment with REBCO bulk and permanent magnet - **electrical resistivity** of selected materials (copper, stainless steel and REBCO tape) at room temperature and at 77 K	- **Resistive transition as a function of temperature** of REBCO tape and Bi2223 tape	- **The process of designing a HTS magnet** (pptx presentation) - **HTS Coil fabrication** (video presentation) - **Cooling down process** of the HTS coil controlled by thermometer - **V-I curve measuring** of the HTS coil at 77 K using voltage taps placed in the coils - **Optional: Operating a magnetic bearing demonstrator** based on a Field-cooled process*	- Inductive measurement of superconducting transition temperature - Flux transformer - Persistent mode operation, influence of joint resistance - Flux trapping in magnet - Flux pumping

Note: On a 5th table, some of the experiments of tables 1 – 4 will be repeatedly installed.