Preliminary design of a 1.8 K thermal conductivity test stand for HFM

Bruno Hashinokuti Iwamoto
E-mail: iwamoto.bruno@gmail.com
Supervisor: Torsten Koettig
Central Cryogenic Laboratory, CERN

Abstract

This document presents the work developed at the Central Cryogenic Laboratory (Cryolab) during the 2023 Summer Students Programme, which focused mainly on the preliminary design of a 1.8 K thermal conductivity test stand for the HFM programme. The main goals of the 1.8 K test stand and its relationship with the HFM programme will be introduced, followed by the description of the system and each component's design process. The system's instrumentation diagram will be presented and the next steps will be discussed. Finally, the description of other works developed at Cryolab during the programme will be commented.

Keywords
High-field magnets; Cryogenic test stand; Thermal conductivity; Cryostat.

1 Introduction

The development of high-field magnets (HFM) with superior performance than those present in the LHC is essential to meet the demand of future projects such as the High-Luminosity LHC (HL-LHC), the Future Circular Collider (FCC-hh) and the Super proton-proton Collider (SppC), which require magnetic fields up to 16 T. Since the lead times for the development of high-field magnets have a typical duration of a decade, the HFM R&D programme aims to develop new solutions for the future machines, focusing on two main goals. The first is being able to develop Nb_3Sn magnets through industrial manufacturing processes with a cost effective solution and robust design. The second is to improve and develop HTS conductor technology to demonstrate the suitability of state-of-the-art HTS conductors for accelerator magnets [1].

Therefore, in order to achieve the aforementioned goals, additional test and manufacturing infrastructure and facilities for HFM are needed, many of them requiring large investments. Regarding the test infrastructures, many additional demands were mapped including a 1.8 K vertical test stand for measuring thermal properties which is the focus of this report.

2 System description

The new test stand is being developed to run various experiments from 1.8 K to higher temperatures around 30 K to measure the thermal conductivity and diffusivity of materials of interest for magnet development, such as insulation materials or impregnation resins. Among the many possible applications, the first experiment to be carried out will be the measurement of thermal conductivity of oxygen-free high conductivity copper (OFHC) samples to validate the test stand's measurement system itself. Before introducing the system's 3D model, it is necessary to present the system features and project requirements already defined by the Cryolab group. The layout of the new test stand should be similar to the other stands already in use at Cryolab.

The test stand will use a two-stage pulse-tube cryocooler model Sumitomo RP-082B2 for the cooling system. On each cold stage region, a copper flange will be attached to support a cooper thermal shield and also to be used as a heat sink for the capillary tubes. Right below the second stage, a gas gap heat switch (GGHS) will be installed to allow the user to switch the cooling source between the cryocooler and the helium circuit. Because the cryocooler itself has the cooling power of only 1.0 W at 4.2 K, it is necessary to include a helium circuit - consisting of a helium pot, a capillary tube for helium inlet, a Joule-Thomson (JT) valve, and a pumping line - to provide additional cooling capacity and extend the temperature range to below 3 K, which the cryocooler cannot reach on its own. The system's internal configuration is represented in Figure 1. Given that, a list describing the status of each component and the actions needed to start the construction of the test stand is summarized in Table 1.

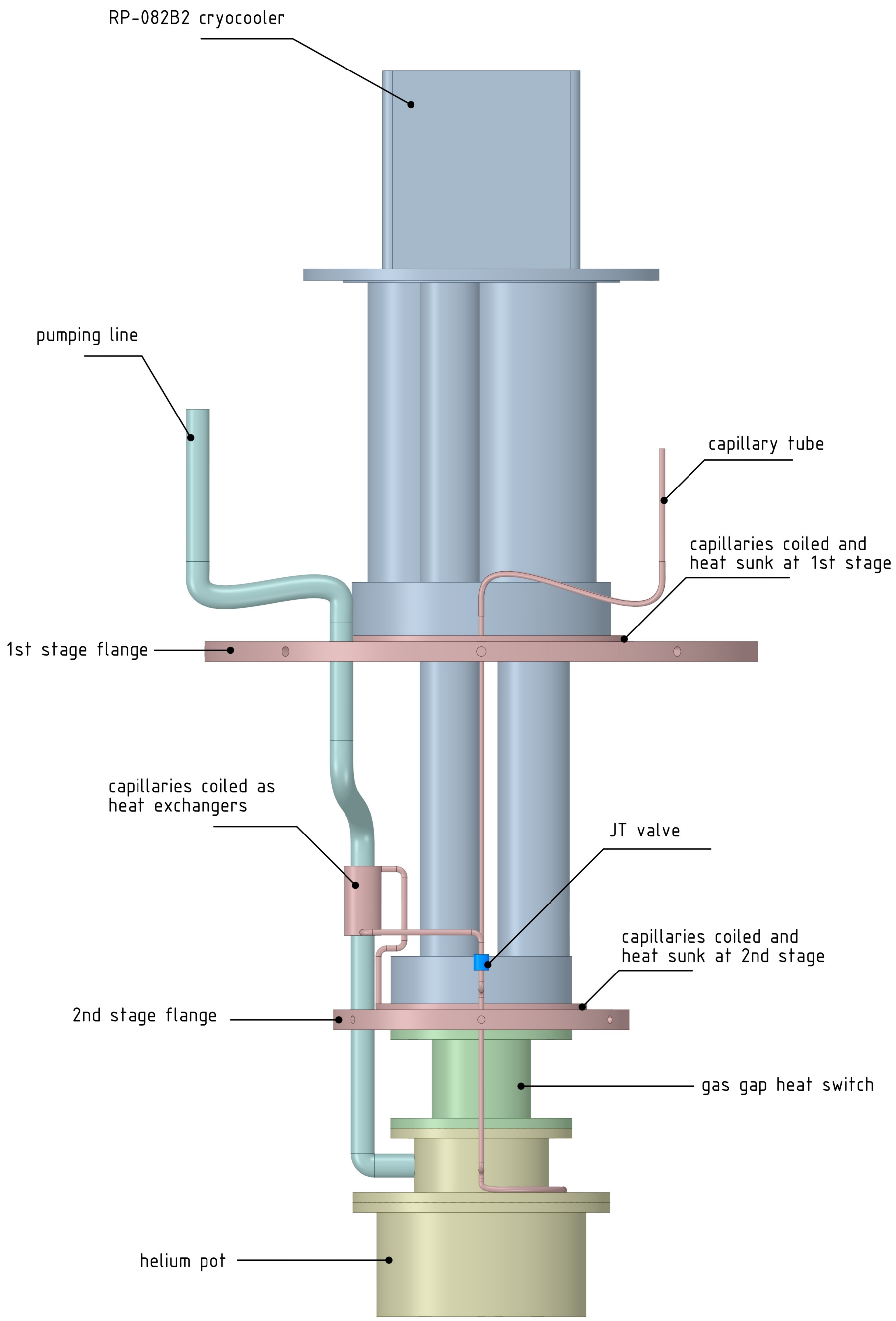


Figure 1: Representation of the internal components of the test stand

Table 1: Task list for the preliminary design of the 1.8 K thermal conductivity test stand

Item	Description	Action
Cryocooler RP-082B2	Pulse tube cryocooler already acquired by Cryolab	3D modeling (for model representation only)
Vacuum chamber and flanges	Vacuum chamber already available for assembly	3D modeling (for model representation only)
Copper flange for thermal shield on 1st stage	Interface for both thermal shield and coiled capillaries	3D modeling and manufacturing drawing
Copper flange for thermal shield on 2nd stage	Interface for both thermal shield and coiled capillaries	3D modeling and manufacturing drawing
Thermal shield 1st stage	Copper sheet already rolled in the desired diameter	Design and sizing assisting
Thermal shield 2nd stage	Copper sheet already rolled in the desired diameter	Design and sizing assisting
1.8 K helium pot	Simple design using a KF50 extension with a brazed Cu bottom/top	3D modeling and manufacturing drawing
Copper capillary lines for helium	Copper capillaries will be coiled and heat sunk at the same flange as thermal shield	3D modeling
Pumping line for the helium pot	Helium pressure line connected to helium pot	3D modeling
Sensor holder	Temperature sensor holder for the experiment	3D modeling and manufacturing drawing

2.1 Cryocooler and vacuum system

As mentioned before, the cryocooler and the vacuum chambers were already provided by the Cryolab and they are ready for assembly. The cryocooler is a Sumitomo RP-082B2 pulse-tube cryocooler with a capacity map as shown in Figure 2. The vacuum chamber is made of stainless steel and is about 407 mm in external diameter and 906 mm in height. The flange to fix the cryocooler to the chamber was already provided by the Cryolab. Figure 3 shows the external view of the system and Figure 4 shows the cryocooler mounted to the top flange and to the structural frame which is going to support the entire system.

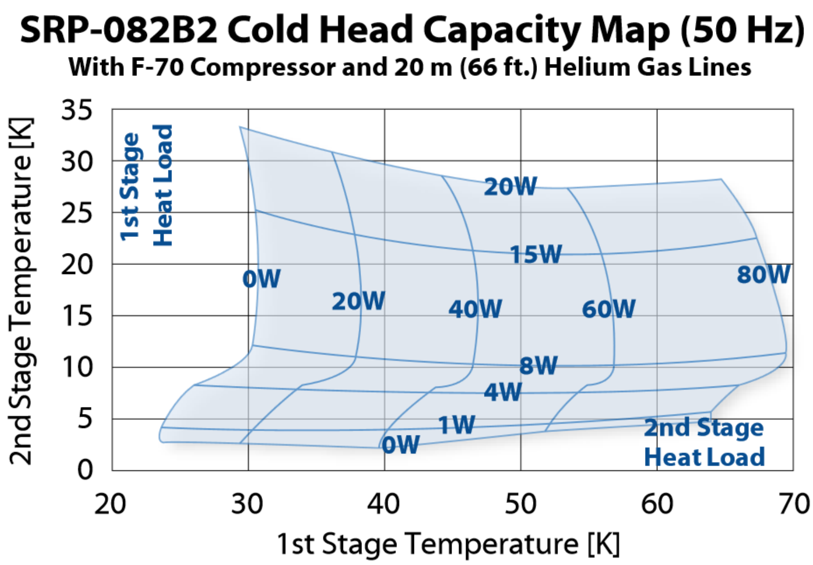
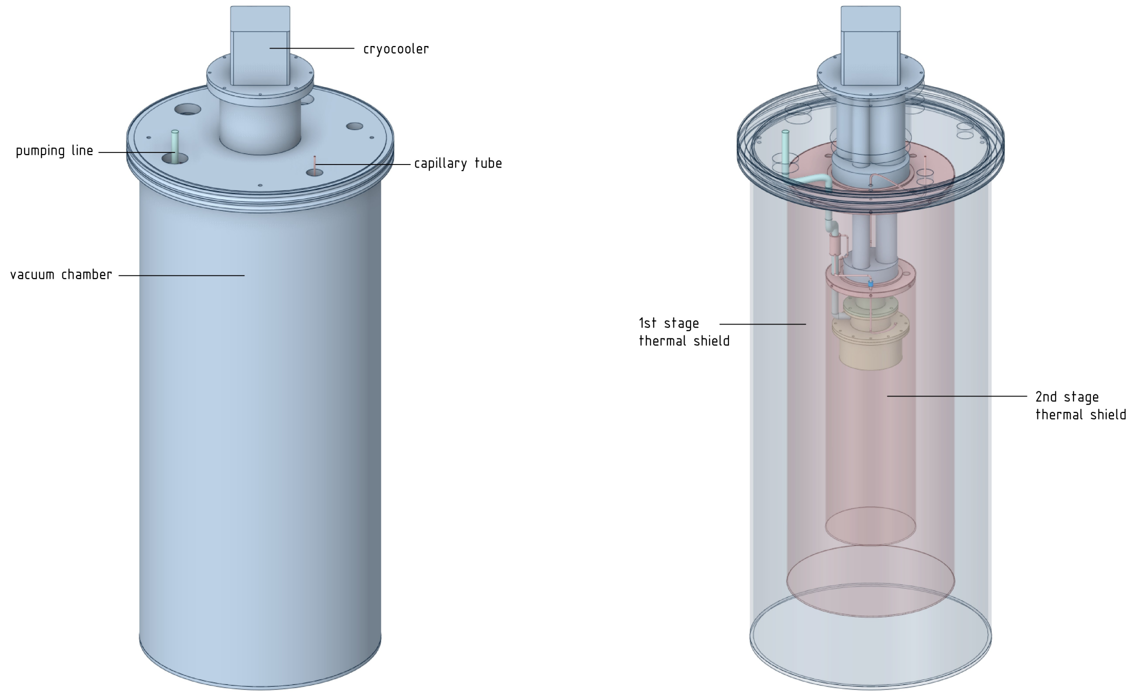


Figure 2: RP-082B2 capacity map [2]



(a) Cryocooler mounted on the vacuum chamber (b) View with transparent components

Figure 3: External view of the test stand on the 3D model

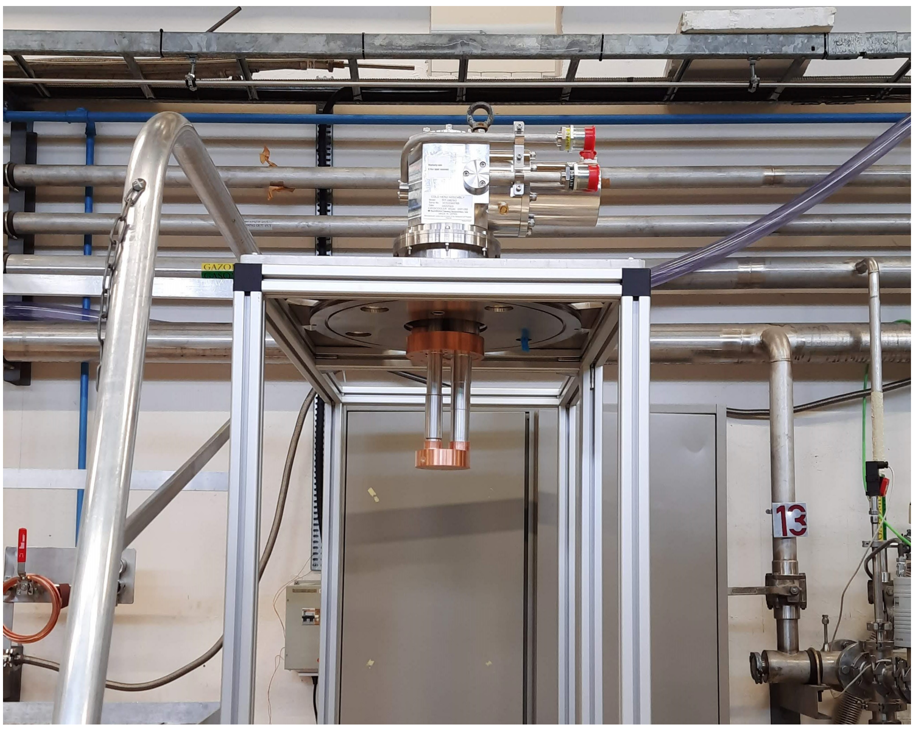
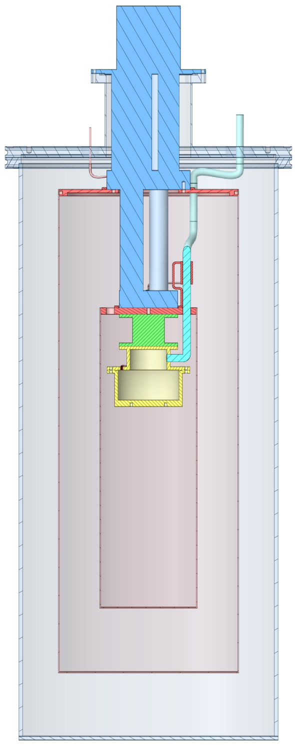


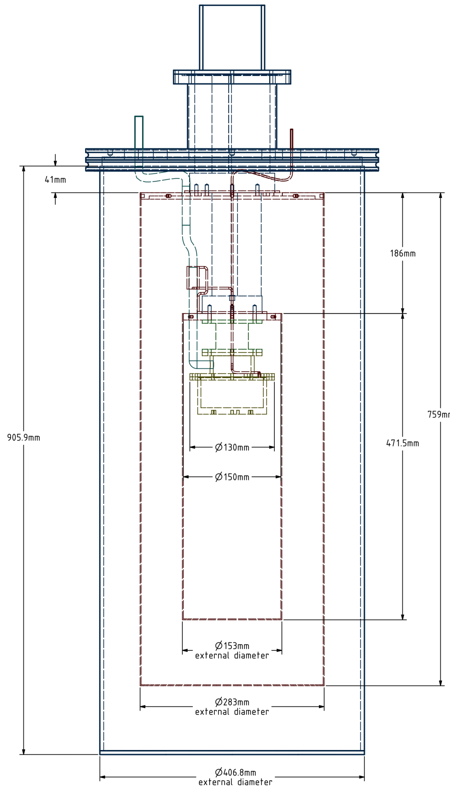
Figure 4: Cryocooler and flange mounted on the frame

2.2 Copper flanges and thermal shields

The diameter of the 1st and 2nd stage copper thermal shields were already defined by the Cryolab group and the 1 mm copper sheet was already rolled to make the side of the cylindrical shield for the 1st stage. Then, the 3D models and technical drawings were made to figure out how long the thermal shields should be and how much space would be available internally, especially as the shields will be covered by multilayer insulation (MLI) blankets and space for this application must be considered. Figure 5a and Figure 5b show a section view of the system and some dimensions of the cryostat. The two copper flanges to be fixed on each cryocooler cold stage to hold the thermal shields and provide surface contact area to heat sink the capillaries were designed and they are ready to be manufactured.



(a) Section view of the 3D model



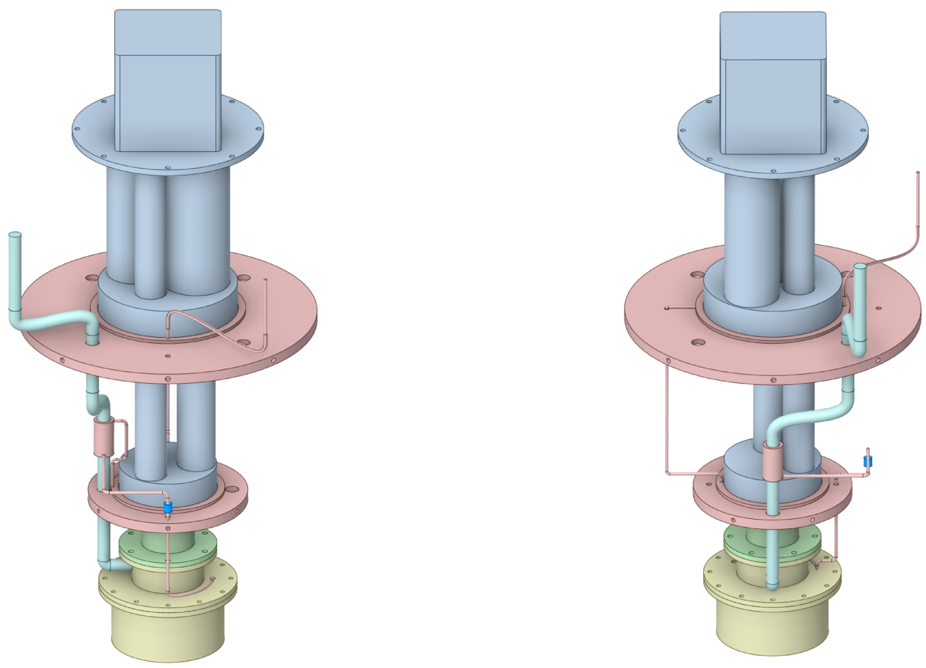
(b) System's dimensions

Figure 5: Section view of the cryostat

2.3 Helium circuit and GGHS

As introduced before, the helium circuit consists of a copper pot to store helium mounted between the GGHS and the experiment platform connected with an inlet helium capillary line and a pumping line. In this system, helium gas first comes from the warm side at an absolute pressure of 1.0 bar through the copper capillary tube and it is precooled at the first stage and second stages as the capillaries are coiled on the copper flanges. The helium then exchanges heat with the pumping line flow as the capillary is coiled 10 times around the pumping line tube, acting as a counter flow heat exchanger. It then passes through a Joule-Thomson valve where the gas is expanded and reaches a saturation pressure of 16.38 mbar before entering and condensing in the pot. At the bottom surface of the helium pot, threaded holes are designed to hold the experiment platform. Figure 6a and Figure 6b show perspective views of the model for better understanding.

As the helium circuit is designed to provide additional cooling power that the cryocooler is not able to reach, the GGHS is needed to thermally decouple the pot and the sample from the cryocooler's second stage when lower temperatures are desired. This means that when it is turned on the switch fills its interior with helium gas, which causes it to present high thermal conductance, making the cooling power come from the cryocooler. When the GGHS is turned off no gas is inside the switch, which causes it to present poor thermal conductance, and then all the cooling power comes from the helium circuit. The GGHS was already available to be mounted on the system and the helium pot's technical drawings were done.



(a) View A (b) View B

Figure 6: Perspective view of internal components

3 Instrumentation diagram

An instrumentation diagram was made in order to provide a good understanding about the general layout of the electrical components inside the test stand. It aims to explain how the sets of transducers and heaters are going to be distributed on the instrumentation feedthroughs and in which regions the instruments are going to be heat sunk. The diagram also gives information about the wires' length and properties. Figure 7 is a 2D sketch showing where the transducers and heaters are going to be mounted and Figure 8 shows the instrumentation diagram.

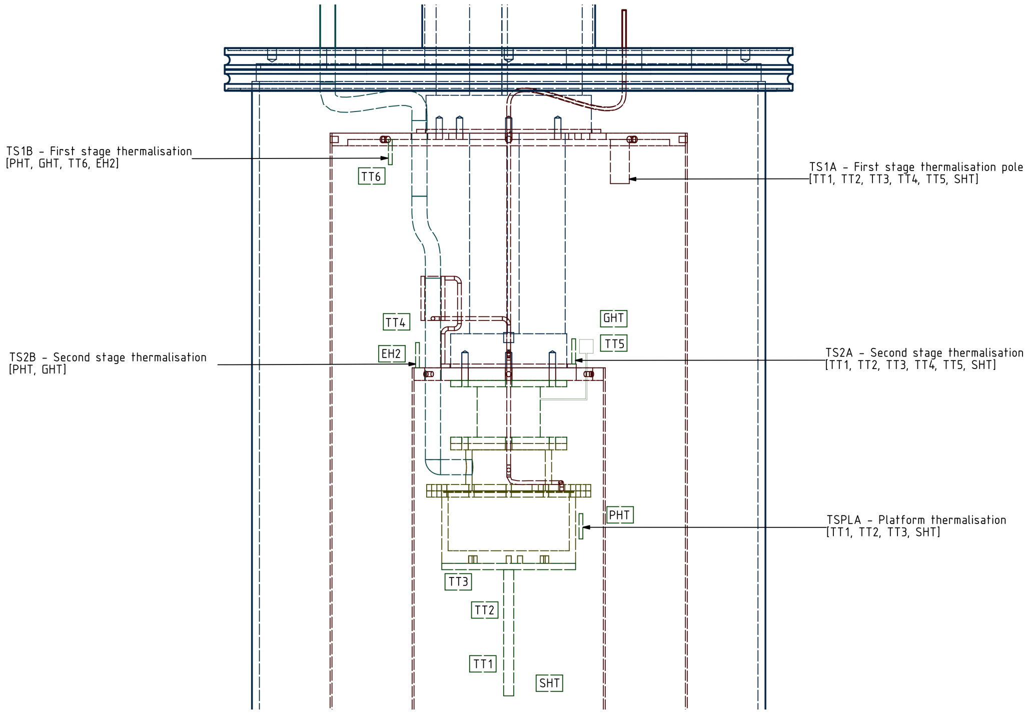


Figure 7: Transducers and heaters layout

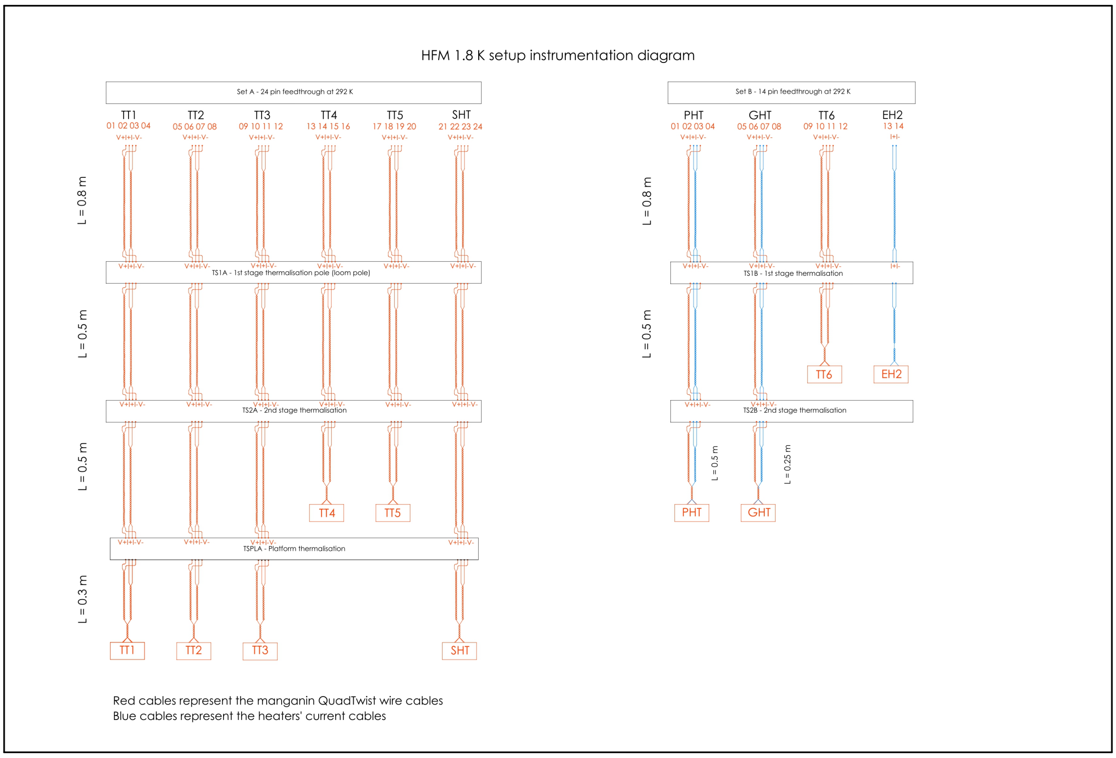


Figure 8: Instrumentation diagram

4 Final comments

Working on the development of the 1.8 K thermal conductivity test stand and accompanying many other experiments at the Central Cryogenic Laboratory was of great importance mainly due to the expertise related to experimental techniques in cryogenics acquired. The activities carried out during this period not only provided the opportunity to get in touch with the latest technologies on cryogenics but also provided a greater understanding about the state-of-the art related to the development of cryogenic systems and superconducting materials at CERN. Moreover, the knowledge acquired during the internship and shared with the Brazilian Center for Research in Energy and Materials (CNPEM) has already been useful since there are similar projects ongoing at CNPEM. Knowledge about cryostat design, cryocoolers, sensors and wires mounting, and MLI blankets installation will be useful to make progress on the development of cryostats for superconducting coil testing at CNPEM. Finally, the next steps to finish the 1.8 K thermal conductivity test stand project are the components manufacturing and final assembly.

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