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# COMMISSIONING OF THE CMS CRYOGENIC SYSTEM AFTER FINAL INSTALLATION IN THE UNDERGROUND CAVERN

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**Abstract**

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# COMMISSIONING OF THE CMS CRYOGENIC SYSTEM AFTER FINAL INSTALLATION IN THE UNDERGROUND CAVERN

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## ABSTRACT

After having served for the surface tests of the Compact Muon Solenoid (CMS) magnet, the cold box and ancillaries of the CMS helium refrigerator have been dismantled, moved and re-installed in the USC55 cavern in 2007. The full re-commissioning in the cavern has been followed by several tests of the refrigerator to confirm its nominal performance before it was used for the magnet and detector tests in 2008. During these tests the safety modes of the refrigeration system have been tested and improved. After a nine-year project both, the magnet and the refrigeration system are now ready for the CMS operation.

**KEYWORDS:** Helium,Thermosiphon,Magnet

## INTRODUCTION

CMS is one of the four experiments at CERN that have been constructed to study proton-proton collisions generated by the large hadrons collider (LHC). An important component of the CMS detector is the superconducting magnet that provides a magnetic field of 3.8 T [1]. The CMS superconducting solenoid magnet measures 12.5 m in length, 6 m in diameter and weighs 230 t. It is cooled-down and operated at 4.5 K by a thermosiphon cooling system that is fed from a dedicated helium refrigerator. The design of the CMS refrigeration system is explained in [2].

The following chapters describe first the work of disassembly and transfer of the components, and then the commissioning and performance tests carried out after the installation as well as the experience that has been gained during the first magnet and detector tests.

## REMOVAL, RE-ASSEMBLY AND COMMISSIONING

After the completion of the surface tests in December 2006 [3] the cold box and all its ancillaries have been dismantled, transferred and re-installed in the CMS underground caverns in point 5.

### Cryogenic Helium Transfer Line

Due to a different layout, the transfer line used on the surface could not been re-used for the underground installation. The new underground transfer line is assembled of three straight sectors of about 11 m long that connect cold box and intermediate cryostat through a 18-m long and 1.2 m diameter passage in the pillar wall between the service cavern and the experimental cavern (FIGURE 1).

For the installation inside the passage, it has been equipped with rails on which the transfer line is suspended by the means of trolleys. Two of the three transfer line sectors have already been installed in 2005 and parked inside the passage. The installation position inside the passage is shown in FIGURE 2. The lower part of the passage was at a later stage occupied by the fore-vacuum duct as well as by auxiliary pipes and cables. On the side of the experimental cavern, the transfer line passes through a crane rail at a few metres from the passage outlet and 17 m above the cavern floor. It has been quite a challenge to position the cut-out and reinforcement on the rail (FIGURE 3) precisely without the final connection point on the detector in place. This task was mastered with the assistance of the survey team who materialized the connection point in the empty cavern.

The third sector of the transfer line was only installed in March 2007, once the cold box and the detector were in place in order to allow the positioning of both elements.

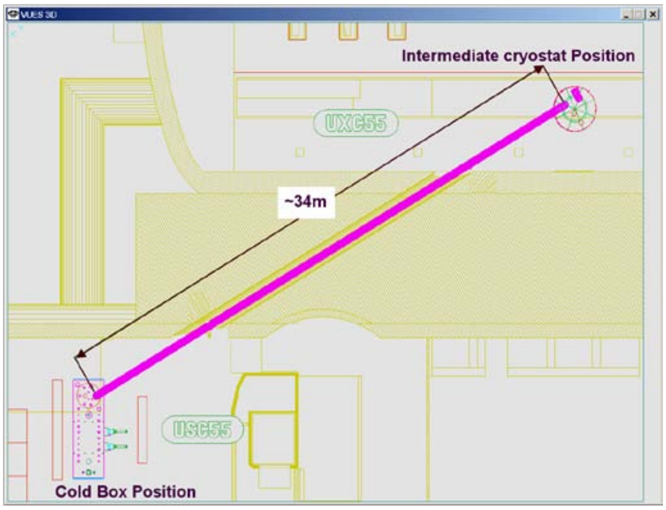
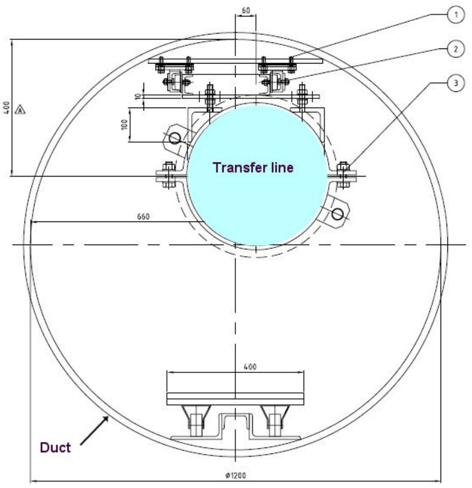



**FIGURE 1**. Helium transfer line through the pillar wall and its handling tool



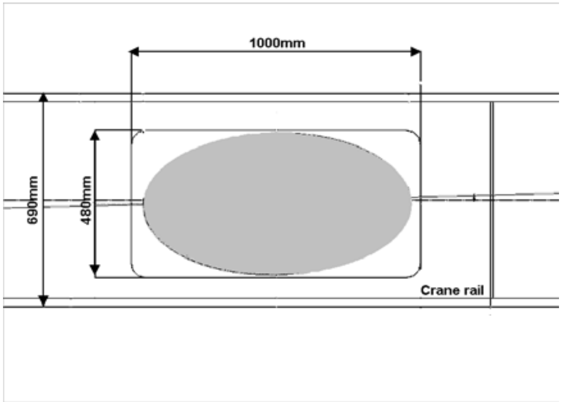




**FIGURE 2**. Helium transfer line position in the duct. **FIGURE 3**. Rail cut-out

Being subjected to the constraints bound by civil engineering, but also with the limitations of the crane in the USC55 cavern, the cold box was the second component requiring particular attention and preparation. Although the dimensional limits of the cold box had been respected during its design and manufacturing in 2002 and had been re-established by dismantling turbines, valve actuators, valves, instrumentation and more before the transport (FIGURE 4), it was still a rather difficult task to pass, on the way to the cavern installation point, through a narrow passage of 2000 mm in width and 2900 mm in height with an object that measured only a few mm less in width and 2760 mm in height. For this task a low profile heavy load trolley was specially designed and built (FIGURE 5).

After the cold box had been re-machined to the maximal allowable sizes early 2007, the transport and handling was carried out in February, 2007. Having been extracted from its temporary location in the SHL51 by means of a crane through an opening in the roof, the cold box was fixed to its rolling equipment before its transport down to the cavern floor. In the cavern the cold box was then towed by a tractor (FIGURE 6) up to the underpass where the two end flanges were removed in order to reduce the weight as much as possible for the next operation. The next obstacle was the lifting height limitation of the cavern crane which did not allow a standard hitching by the crane hook. It was therefore necessary to use an additional wagon equipped with a chain hoist on the crane gantry (FIGURE 7). This non-standard procedure had to be approved by the crane manufacturer and tested with a dummy load of 1.5 times the weight of the cold box beforehand.

**FIGURE 4**. Cold box before lifting

**FIGURE 5**. Cold box heavy load trolley

**FIGURE 6**. Cold box towing by tractor

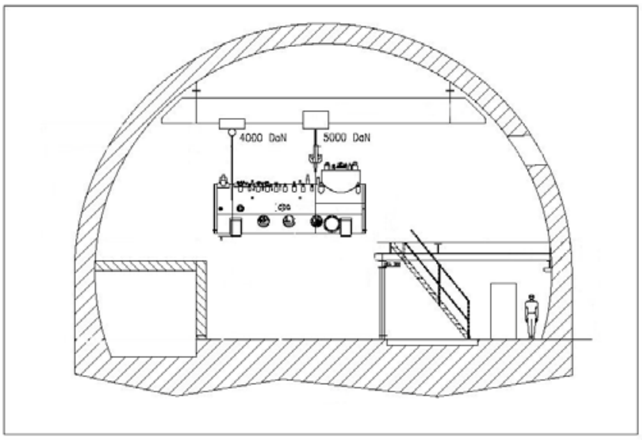



**FIGURE 7**. Lifting principle in USC55

In this way the cold box was placed on the support frame that had already been installed in advance. In order to allow the horizontal positioning at a later stage, the support frame has been placed on PTFE coasters.

Once in position, all the ancillaries were re-installed, pipes were re-welded, instruments were re-wired and the ensemble was thoroughly tested, including pressure tests, signal tests as well as instrument calibrations. The complete re-installation and testing has been achieved by July, 2007.

## PERFORMANCE TEST

Before the cool-down of the CMS magnet, various tests have been carried out in order to validate the performance of the cryogenic plant. A first test was performed with the cold box alone and with the third turbine stopped. A heat load was simulated with a heater in the phase separator of the cold box and the result was compared with an identical test performed on the surface. In a second test the third turbine was used and the heating power was simulated in the intermediate cryostat. In addition the liquefaction load was simulated by evaporating a flow of liquid helium with the atmospheric heater next to the cold box. In this test the shield of the transfer line and the intermediate cryostat could not be used which meant an additional heat load on the 4.5 K cooling loop. The results are listed in TABLE 1.

**TABLE 1**. Cold box tests results summary

| Performance Tests | Asked | Realized | Comment |
|---|---|---|---|
| Test of isothermal refrigeration capacity at 4.45K | By using Phase Sep heater with a level of 50 % | 421 W at 4.5K duration = 13 h | Identical test performed at surface 476W |
| Test of the capacity of the cryogenic system to measure the refrigeration capacity of the cryogenic system in the intermediate cryostat by means of electrical heaters | Steady-state run of 200 hours with intermediate cryostat heater 800W (without shielding of the intermediate cryostat) | 871 W at 4.5K 4 g/s of liquefaction capacity duration = 4 h | Test interruption due to trip CERN side (Compressor of air instrument and water pump fault) |

## COOLING OF THE CMS MAGNET AND PROBLEMS ENCOUNTERED

On February 11th, 2008, the first cool-down of the CMS magnet in the cavern has been started. The first phase of the cool-down is ensured by liquid nitrogen pre-cooling that provides refrigeration power of up to 30 kW. This first phase took about 2 weeks. Once the temperature of 100 K was reached at the outlet of the pre-cooler, two of the three turbines have been started for the second phase of the cool-down. Normally from 100 K it would take another 10 days to reach the nominal operation temperature of 4.5 K. However, due to an increasing temperature difference at the warm end of the first heat exchanger the refrigeration power decreased (FIGURE 8) and the cool-down could not be completed. The cold box had to be stopped on July 7th, to regenerate the heat exchanger at 70°C as humidity was suspected at the source of the problem. After restart, the cool-down was then completed in less than 3 days. However two additional regenerations were needed to restore completely the initial performance. We believe that the problem was due to desorbing humidity from the 300-m long helium pipes between the compressor station and the cold box in spite of a thorough purge of these lines before the start of the refrigerator.

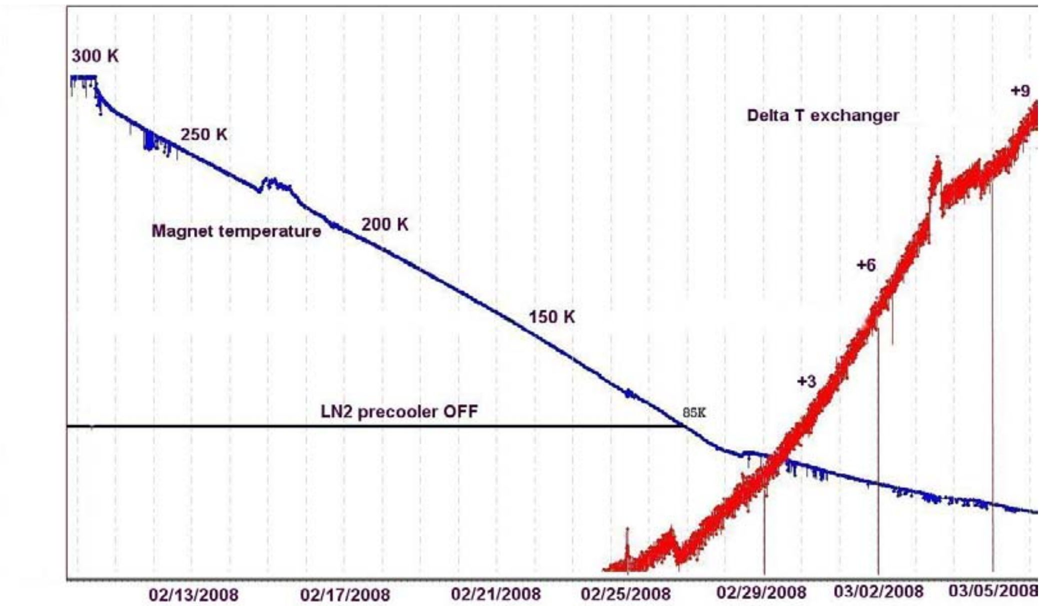



**FIGURE 8**. Magnet cool-down. Curves of the temperature and the delta T on the first heat exchanger

The only other notable problem which appeared during the nearly six operation months after the cool-down and before the magnet tests was an excessive leakage of the shaft seal on the first-stage compressor. Its leak rate increased from 8 ml/hour to 22 ml/h within a period of a few weeks. Unfortunately the first spare shaft seal turned out to leak even more. The leak rate of 40 ml/h did not even decrease after a run of 100 hours so that another replacement was carried out a few days later. The second spare shaft seal leaked about 160 ml/h and upon its removal a design incompatibility was recognized. It was therefore decided to refit the springs of the original shaft seal on the first spare shaft seal to ensure the same pressing. Furthermore utmost care was applied in respecting the tightening torques. This time the leak rate settled to 4 ml/h and has remained stable.

## CMS MAGNET AND DETECTOR TESTS

The campaign of magnet tests in the cavern began on August 25$^{th}$, 2008, 3 months after the cool-down. It consisted of several charging cycles to different current levels that were terminated by slow or fast discharges of the magnet. During the first fast discharge from 3 kA the effect of the eddy currents resulting from the elevated current derivative (dI/dt) resulted in sub-cooling of the cold box and thus stopping the turbines. To solve this problem, the pressure control valve in the return line to the cold box was programmed in such way that it remains blocked if the current derivative increases above 3 A/s. The surplus of return gas is guided via the cold box bypass to the atmospheric heater and back to the compressors. This operation mode has been successfully tested during the next fast discharge from 4.6 kA and allows a gain of time by finishing slow discharges with a fast discharge in the range where there is no risk to the magnet.

Other safety measures are implemented for full fast discharges from high current levels which generate a very high heat load and thus a large amount of cold gas. The aim of these safety measures is to protect the cold box and to avoid the compressors from stopping. The first safety measure is a complete shut-off of the magnet circuits at the level of the phase separator which ensures the containment of the rapid pressure rise within the magnet and phase separator. In complement to this safety measure the turbines are stopped and the helium is gradually released to the compressors in order to recuperate a maximum of helium gas. Once the pressure in the magnet is again below 1.4 bar, the turbines are restarted and the magnet is automatically reconnected to the refrigerator. These safety measures have been tested on August 30$^{th}$, 2008, during a fast discharge from 15 kA. During this test the pressure in the magnet phase separator reached 11.8 bar (FIGURE 9). However, during this first test, an event which had not been envisaged was the sudden evaporation of the residual liquid during the cryoplant re-connection. The consequence was an excessive flow towards the compressors that generated a total trip of the compressor sets. To avoid this problem, it was decided to open the valve connecting the phase separator with the magnet during the pressure recovery phase to drain away possible residual liquid in the magnet before the re-connection.

On October 10$^{th}$, a ramp up and ramp down cycle was performed without dumping the current. No effects of this cycle have been seen on the refrigerator. It followed a 3 week detector test with the magnet operated at 18.2 kA (3.8 T) interrupted only on two occasions by service failures. The end of this extended run was used to validate the emergency cooling mode of the refrigerator by voluntarily stopping the cold box. In the emergency mode the magnet is supplied from the 5000 l liquid helium filled intermediate cryostat that is installed on the detector while the magnet current is ramped down. This cooling mode uses three regulation loops that are backed-up by hardware PID-controllers in case the refrigerator PLC fails. One regulation loop maintains the pressure in the intermediate cryostat at 1.4 bar by the means of a heater, another loop controls the phase separator inlet valve and maintains the level in the phase separator of the magnet at 40 % and finally a third regulation loop regulates the pressure in the phase separator at 1.25 bar thus guaranteeing a pressure drop of 150 mbar between the intermediate cryostat and the phase separator. It is noted that all the elements of these three regulation loops are powered by an uninterruptible power supply (UPS) to bridge eventual power outages. The average heating power necessary for the preservation of the pressure at 1.4 bar in the intermediate cryostat was measured to 60 W at 4.5 K.

The final test was a fast discharge of the magnet from the nominal 18.2 kA (3.8 T). The cold box and compressor protections worked fine this time, however, the pressure in the magnet phase separator increased above the setting of the safety valves and led to a blow-down of about 90 kg into the cavern (FIGURE 10). In order to avoid any helium pollution of the detector the ventilation was immediately set to full speed and extraction mode.

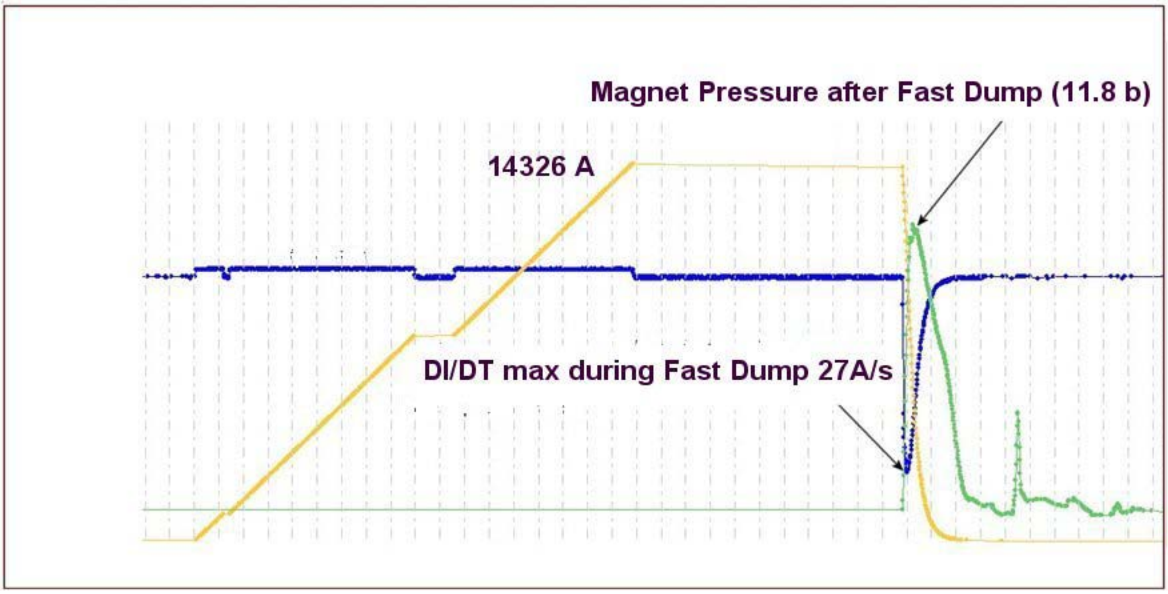



**FIGURE 9**. Increasing pressure trend in the magnet during the fast dump at 3 T

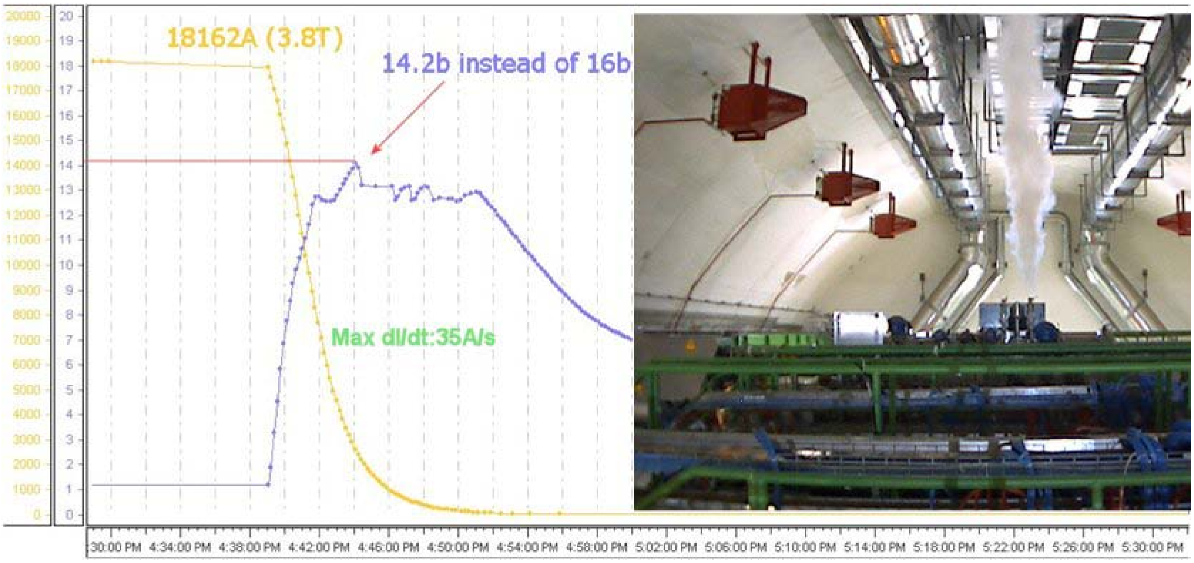



**FIGURE 10**. Increasing pressure trend in the magnet during the fast dump at 3.8 T

## CONCLUSION

The complete project of the CMS helium refrigeration plant including design, manufacturing, surface installation, performance testing magnet, removal and last but not least final installation and magnet tests in the underground cavern has lasted for over ten years. Following its successful commissioning, the CMS cryogenic system is now operated by the cryogenic operation team which shall ensure its availability for LHC physics in the coming years.

## AKNOWLEDGEMENTS

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