CERN-ACC-2014-0290

Johan.Bremer@cern.ch

Report

Liquid Hydrogen Target for the COMPASS Experiment

J. Bremer[1], N. Doshita[2], L. Dufay-Chanat[1], R. Geyer[3], G.K. Mallot[1], O. Pirotte[1], and B. Vullierme[1]

1 CERN
2 Yamagata University, Japan
3 LMU, Munich, Germany

Keywords: Liquid Hydrogen

Abstract

A liquid hydrogen target has been developed for the COMPASS experiment at CERN. The target has a diameter of 40 mm and a length of 2.5 meter, creating an active volume of about 3 liter of liquid hydrogen. The cylindrical part of the target wall is formed by a Kapton® foil strip, wound and glued to a thickness of 0.125 mm. The Kapton® foil is used to minimize the energy loss of the particles, scattered or created within the target volume, crossing the target boundary. The two end-caps enclosing the target volume have been fabricated from Mylar®. The system is cooled with a 30 W at 20 K cryocooler, delivering the cooling capacity for the cool-down as well as for the continuous operation of the system.

Presented at:

CEC/ICMC
Anchorage, Alaska
June, 2013

N°edms: 1262259

Liquid Hydrogen Target for the COMPASS Experiment

J. Bremer[1], N. Doshita[2], L. Dufay-Chanat[1], R. Geyer[3], G.K. Mallot[4], O. Pirotte[1], and B. Vullierme[1]

[1]*Technology Department, CERN, Geneva 23, CH-1211Switzerland*
[2]*Faculty of Science, Yamagata University, Kojirakawa 1-4-12, Yamagata, 990-8560, Japan*
[3]*Departement für Physik, LMU, Schellingstraße 4, D-80799 München*
[4]*Physics Department, CERN, Geneva 23, CH-1211Switzerland*

Abstract. A liquid hydrogen target has been developed for the COMPASS experiment at CERN. The target has a diameter of 40 mm and a length of 2.5 meter, creating an active volume of about 3 liter of liquid hydrogen. The cylindrical part of the target wall is formed by a Kapton® foil strip, wound and glued to a thickness of 0.125 mm. The Kapton® foil is used to minimize the energy loss of the particles, scattered or created within the target volume, crossing the target boundary. The two end-caps enclosing the target volume have been fabricated from Mylar®. The system is cooled with a 30 W at 20 K cryocooler, delivering the cooling capacity for the cool-down as well as for the continuous operation of the system.

INTRODUCTION

The nucleon is a highly complicated system of interacting quarks and gluons. QCD, the theory of strong interactions, cannot be solved for the small momentum transfers inside the nucleon and one has to rely on experimental determinations of the inner workings of the nucleon. Measured parton distribution functions describe the probability to find a quark of a certain flavour or a gluon carrying a certain fraction of the nucleon momentum (in the infinite momentum frame). To interpret for example the LHC measurements, the distribution of quark and gluons in the colliding protons must be very well known. However, the nucleon is not a 1-dimensional object and there are correlations e.g. between the transverse position of a quark/gluon inside a nucleon and its longitudinal momentum. Peripheral quarks are different from central ones. Therefore a 3-dimensional understanding of the nucleon structure must be developed. With the help of the novel theoretical concept of generalised parton distributions such a tomographic picture of the nucleon can be obtained, for example from deeply virtual Compton scattering measurements, where a virtual photon (e.g. from a muon) scatters from a nucleon leaving only the intact nucleon and a real photon in the final state.

Such measurements were proposed by the COMPASS Collaboration [1], which has studied the spin structure of the nucleon in deep inelastic scattering since 2002 at the CERN 160 GeV muon beam. A key element for the new measurements apart from the existing spectrometer [2] is the proton recoil detector Camera in which a 2.5 m long liquid hydrogen target with a light cryostat is located.

Since the measurement comprises a comparison of cross sections for scattering of positive and negative muons, the stability of the liquid hydrogen target is of utmost importance to guarantee stable luminosity. This paper describes the design, construction and performance of the long liquid hydrogen target, which was successfully operated during a two-month long run in autumn 2012.

THE TARGET CELL

The experimental constraints have asked for a liquid hydrogen target with a sensitive length of 2.5 meter and a diameter of 40 mm. To diminish the heat load to this target, it has been placed in a vacuum enclosure. The particles created or scattered in the liquid hydrogen volume shall be detected by the Camera detector situated around the hydrogen target set-up. To reduce the interaction between the particles mentioned above and the walls of the hydrogen target and its corresponding vacuum enclosure, the construction materials of these two items have to be selected carefully. For the target walls a Kapton® foil strip, wound and glued to a thickness of 0.125 mm, has been selected. This Kapton® tube has been cut to the correct length and has at one side been glued to a pre-formed Mylar® end-cap, while the other side (see Fig. 1) has been glued to a stainless-steel ring to which the liquid hydrogen entry, as well as the gaseous hydrogen return pipe have been connected. These pipes are also used for

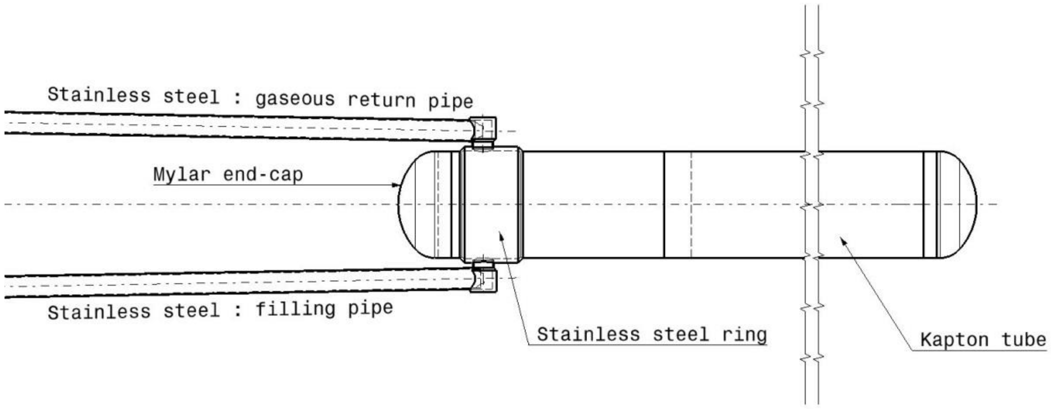

FIGURE 1. Hydrogen target lay-out

centering the Kapton® tube with respect to the beam line. The other side of the stainless-steel ring, the side from which the particles enter the hydrogen target, is also enclosed by a pre-formed Mylar® end-cap. In this way a sensitive liquid hydrogen volume of about 3.3 liter has been created.

During normal operation, the target volume has a maximal working pressure of 2 bar abs. To test the home made target for its operational function, a series of six targets have been produced from which two cells have been chosen randomly. To fulfill the safety requirements, these two cells had to resist to a pressure of at least 3 times the maximum working pressure. During the test, the lowest rupture pressure was measured to be 7.8 bar abs, well above the required minimal rupture pressure.

To assure that the Kapton® and Mylar® are materials well suited for use in the liquid hydrogen target construction, a test set-up has been developed to measure the permeability of these materials to gaseous helium down to temperatures of about 4.2 K. For this purpose, the target was installed in a stainless-steel vacuum chamber equipped with a leak detection system. The liquid filling connection of the target was, via a feed-through system, connected to a transfer line supplying liquid helium from a dewar 1.2 bar, while the gaseous return connection was connected to a helium recovery line at 1.05 bar in which a flow regulation valve had been included. The cool-down speed of the target is directly related to the setting of this regulation valve. The helium leak detector is during the complete cool-down process connected to the isolation vacuum measuring the instantaneous helium content in the vacuum space. The result of this measurement is given in Fig. 2, representing the clear decrease of the permeability of the target down to a temperature of about 120 K.

Seen the low permeability of helium gas through the target wall at temperatures below 120 K and seen that hydrogen gas should have a lower permeability than helium passing through the target wall, it was on the basis of this measurement decided to continue with the development of the Kapton® liquid-hydrogen target. It was however also foreseen that the vacuum insulation system had to be pumped continuously.

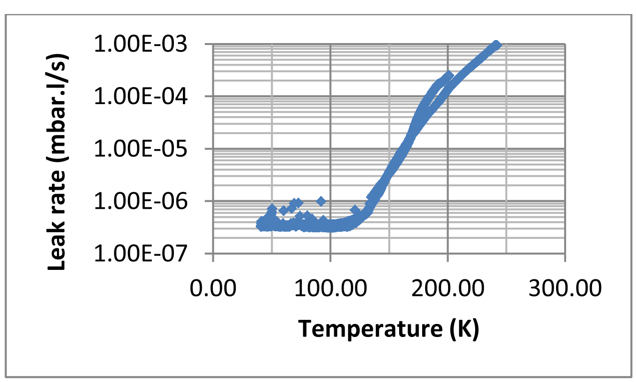

FIGURE 2. Measurement of helium leak rate of hydrogen target versus temperature

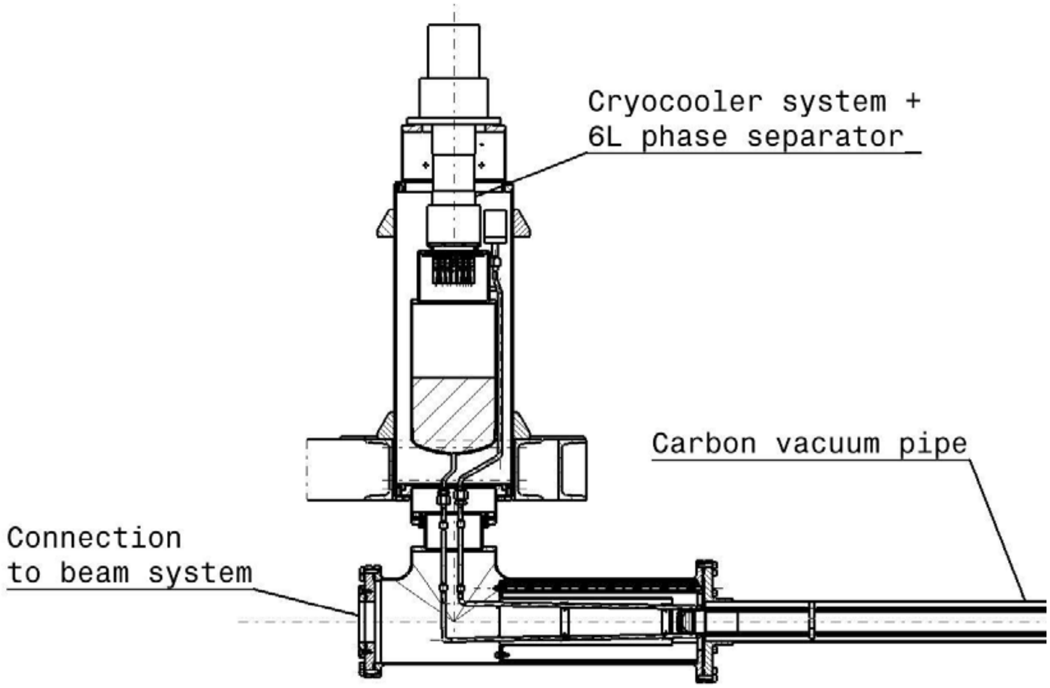

FIGURE 3. Vacuum enclosure and cryocooler installation

The liquid hydrogen target itself is placed in a 2.6 meter long cylindrical vacuum enclosure formed by a 1 mm thick Carbon Fiber Reinforced Plastics (CFRP) tube with a 8 cm diameter. At the beam outlet side, an end-cap is mounted to the tube. This end-cap is constructed from a 2 mm thick CFRP tube, closed by a 0.35 mm thick Mylar® foil. The beam entrance side of the tube (see Fig. 3) is connected, via a flange connection, to a stainless-steel T-piece. At the top of this T-piece, the cryogenic system used for the cooling of the liquid hydrogen target is installed, while the other leg of this T-piece, where the beam enters the experiment, is closed by a 0.175 mm thick Mylar® foil mounted between two flanges.

THE HYDROGEN TARGET COOLING SYSTEM

The cooling of the hydrogen target is based on a 30 W @ 20 K Sumitomo cryocooler system. The cold head of this cryocooler has been equipped with a copper heat exchanger. The complete system is then connected to a stainless-steel phase separator with a total volume of about 6 liter (see Fig. 3). The top of the phase separator is connected to the gas return line of the hydrogen target, while the bottom is connected to the target's liquid inlet line.

The phase separator is also directly connected to a 5000 liter gaseous hydrogen buffer volume (see Fig. 4). The pressure in the hydrogen system at the start of the cool down has been calculated such that in operational conditions the phase separator will be filled with one liter of liquid hydrogen, with the buffer volume at a pressure of 1.15 bar abs.

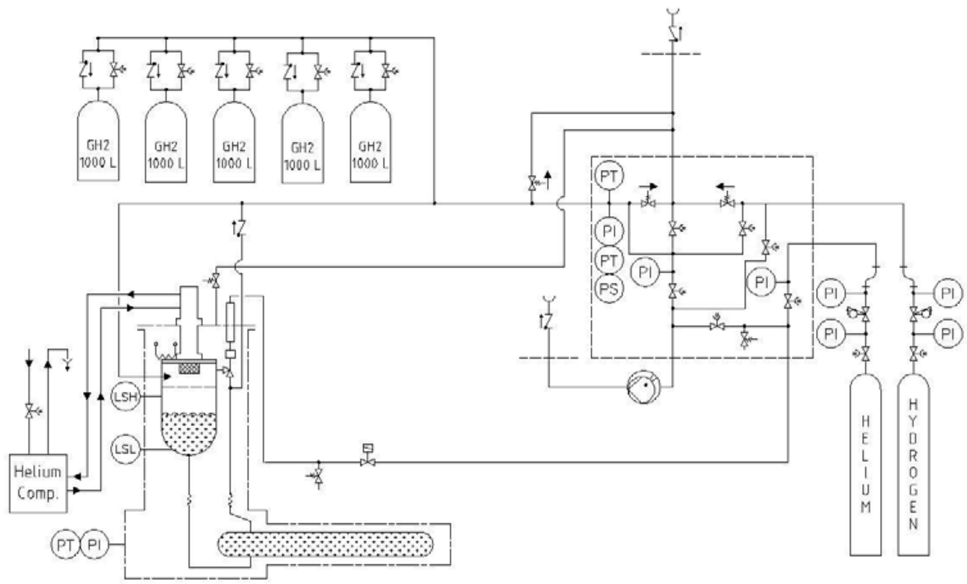

Figure 4. Piping and instrumentation diagram of the Compass hydrogen target system

COOL DOWN AND NORMAL OPERATION

The cool down of the target can be started once the target volume has been purged to eliminate air residuals. Given the shape and the construction material of the target, the target volume can only be pumped when the isolation vacuum space is under vacuum conditions. Four purges with helium gas were made, after which the system was purged twice more with hydrogen gas. This procedure was copied from earlier hydrogen target experiments having been operational at CERN. After the last purge, the complete system (buffer volume, phase separator, target and the interconnecting piping) was brought to a pressure of 1.95 bar abs of hydrogen gas.

Once the system had been purged the cryocooler was started without any regulation, running it at maximum power. Figure 5 gives the hydrogen pressure during cool down as a function of time. As shown, during the cool down of the phase separator and the target, the hydrogen pressure in the system was decreasing. Once liquid hydrogen starts to accumulate in the phase separator, the liquid is by gravity transported to the target volume, replacing the gaseous volume returning to the phase separator. Once the hydrogen pressure in the system arrives at 1.15 bar abs a hydrogen pressure regulation system was activated. This system regulates the electrical current though a heater placed on the cryocooler cold-head as a function of the hydrogen pressure.

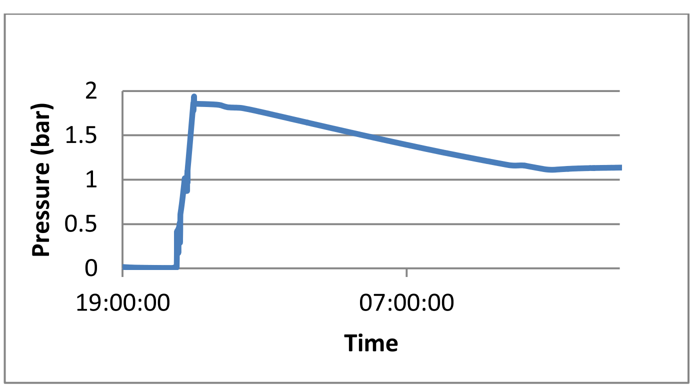

FIGURE 5. Hydrogen pressure during target cool down as measured in the phase separator

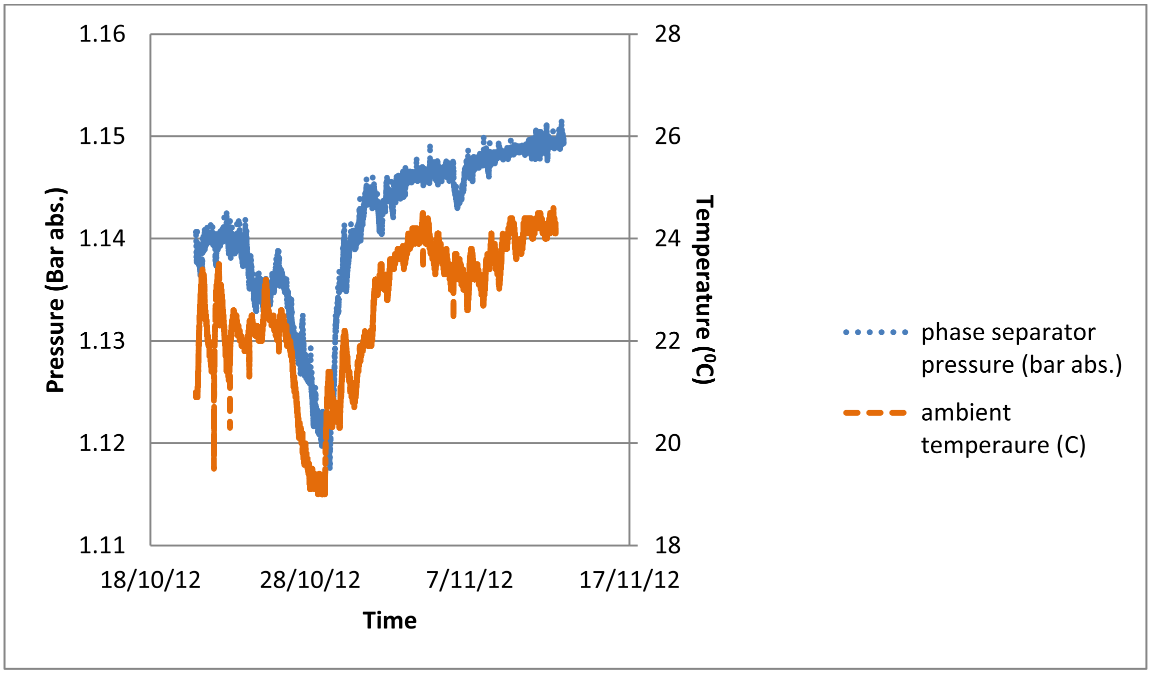

FIGURE 6. Hydrogen pressure during target cool-down as measured in the phase separator and ambient temperature of the experimental area

Once filled, the target cell has stayed operational during the 2-month beam period foreseen for the experiment. The buffer volume stayed connected to the target volume during this period to act as a damper for eventual short lasting pressure instabilities. During this period a severe temperature change outside of the building resulted in a non-negligible temperature variation in the experimental area. The pressure regulation system acting on the heater placed on the cryocooler cold-head, should of course have smoothened the effect of this ambient temperature on the pressure in the cryocooler volume. Since the detector data can be corrected for this temperature swing and since it was preferred not to waste any beam time, it was decided not to interfere in the tuning of this regulation to diminish the change of an eventual deterioration of the regulation system. The pressure regulations in the target cell volume measured over the 2-month beam time period and the corresponding ambient temperature are given in Fig. 6. This figure shows that within this period, the pressure difference between the extremities is about 300 mbar, corresponding to a temperature difference in the target volume of about 0.1 K. The experimental data taken over this period could be corrected for this variation.

The target cryogenic system has also been equipped with a valve in the gaseous hydrogen return tube, just before its connection to the phase separator. At the end of the beam-time period, a test was made closing this valve. In this case, the hydrogen vaporizing in the target cell cannot return to the phase separator, but pushes instead the liquid hydrogen out of the target towards the phase separator. After less than 10 minutes all the liquid hydrogen was driven out of the target cell. Using this technique, data could be taken for calibration purposes, with the beam going through the empty target cell. Once the valve in the gaseous return line was opened again, the target cell was quickly filled with liquid hydrogen flowing down from the phase separator, while the gaseous hydrogen present in the target returned to the phase separator to be re-condensed.

At the end of the experimental period, the cryocooler system was switched off and the vaporizing hydrogen from the target volume was returned into the buffer volume. The target volume emptied within several hours, while the warming up of the target itself took about 3 days.

CONCLUSIONS

A homemade liquid hydrogen target fabricated from Kapton® with Mylar® end-caps has been presented. The target has been cooled down and been operated at its nominal operation pressure of about 1.15 bar abs. The pressure stability over a 2-month running period can be estimated to about ± 150 mbar, corresponding to a temperature stability of ± 50 mK. The quick emptying scenario for the cold target, to be used for calibration periods, has been tested successfully.

ACKNOWLEDGMENTS

The authors would like to thank Christian Berthelier, Jean-Marc Debernard, Laurent Le Mao and Sebastien Prunet for their help and enthusiasm in the construction, testing and final installation of the target.

REFERENCES

1. COMPASS Collab., F. Gautheron et al., CERN-SPSC-2010-014, SPSC-P-340, 17 May 2010.
2. COMPASS Collab., P. Abbon et al., Instrum. Meth. A577 (2007) 455.