Diaphragm Metering Pumps for Cooling Silicon Sensors at the CERN Research Center for Particle Physics

Marc Geiselhart

With approximately 9,600 magnets and a circumference of 26.659 km, the Large Hadron Collider (LHC) is the largest and most sophisticated accelerator operated by the CERN research institute, so far (Figure 1). When the LHC started operations, it marked a turning point in the field of particle physics, as it may help unlock answers to fundamental questions, such as the origin of matter. The Large Hadron Collider beauty (LHCb) experiment, the A Toroidal LHC ApparatuS (ATLAS) experiment, and the Compact Muon Solenoid (CMS) experiment are three of the four experiments currently installed at LHC. In order to achieve precise measurements, silicon detectors are built in close vicinity to the interaction point of all experiments. Carbon dioxide cooling plants cool the innermost layers of the silicon detectors down to temperatures as low as -40 °C. Two diaphragm metering pumps from Lewa GmbH have been used for the LHCb experiment since 2007. They ensure a uniform flow rate, which is essential for continuous and uniform cooling and disturbance-free operation. Two similar systems operated in redundancy guarantee from the beginning of 2015 the thermal management of the IBL sub-detector of the TALS experiment. For the CMS pixel detector upgrade, to be installed in 2016, a new CO₂ cooling system featuring a remote head Lewa metering pump has been built and commissioned. Unlike standard pumps, remote-head pumps can convey the highly compressed CO₂ without heat input.

The first cooling system equipped with Lewa pumps was developed and produced by the National Institute for Subatomic Physics Nikhef in Amsterdam for the Large Hadron Collider beauty (LHCb) experiment. The aim of this experiment is to answer the question of why the universe is comprised primarily of matter and not antimatter. One of the things researchers will look at is the B meson, which contains an elementary particle known as a b quark, also known as a beauty quark, from which the name LHCb is derived. In order to obtain such particles, the LHC must accelerate protons to near the speed of light and induce them into collision. The particles obtained in this way are recorded using special instruments and then analyzed with the assistance of computer programs.

Oil-free CO₂ cooling of detectors for precise results

The LHCb detectors are unlike other recording systems at the LHC, since detection occurs in only one direction. The first sub-detector, called the VeLo (for Vertex Locator) is located directly at the collision point. Others are arranged one after the other along a distance of 20 meters. Among other things, the VeLo is used to precisely determine the location of decays and for particle reconstruction. In order to reach the highest possible precision, the entire system must be under vacuum. Furthermore, to prevent severe radiation damage on silicon sensors, two carbon dioxide loops cool each half of the VeLo detector to about -25 °C (Figure 2). Silicon detectors subject to the strong radiation levels of the LHC are subject to two kinds of damages: displacements in the crystalline structure due to Non Ionizing Energy Loss, and accumulation of positive charge in superficial layers due to Ionizing Energy Loss. The most relevant effects of these combined radiation-induced damages are a sharp increase of the voltage required for the sensor depletion, an increase of the leakage current (hence of the signal-to-noise ratio), and a sensitive decrease of the breakdown voltage. While huge R&D efforts are dedicated to new generations of ever more radiation-resistant detectors, it is known that operation at temperatures well below 0 °C greatly mitigates these damaging effects.

CERN chose diaphragm metering pumps from Lewa for a number of reasons, especially because no oil can be tolerated in the detector cooling circuit, because oil can start to solidify under the influence of radiation and may then cause a blockage in the thin cooling lines. At least for CO₂, a compression cycle was impossible as no oil-free compressor for CO₂ exists on the market. Therefore it is only possible to adopt a pumped loop operated by an oil-free pump. Rotary oil-free pumps require lubrication by the circulating refrigerant fluid, but CO₂ is a very poor lubricant.

So a membrane pump was the best choice for long term reliability. Furthermore the Lewa pumps are known for their ability to deliver the completely uniform flow rate that is necessary for continuous, stable, two-phase cooling. This approach to cooling removes heat by exploiting the phase change of CO₂ from liquid to vapor. It has the benefit of using significantly less coolant and much smaller pipes than in single-phase cooling. In other respects, handling the coolant is not so easy: “Liquid
temperatures can be as low as -50 °C, which is within the critical range because CO₂ begins to solidify at -57 °C. We are currently working within a range of +20 to -40 °C for testing purposes. In most cases the temperature is around -30 °C,” according to Mr. Postema. However, for the specific case of the ATLAS IBL detector an operational range extended down to -40 °C was required: in this case a two-stage primary chiller was adopted, with carefully in-house designed controls in order to provide the pump with the correct sub-cooling level even at these low temperatures. By taking all this into consideration, the robust membrane pumps were the best choice for long term reliability.

**Remote head design keeps critical conditions at bay**

A different detector at the LHC, known as the Compact Muon Solenoid (CMS) experiment (Figure 3), is involved in the discovery of the Higgs boson, the search for evidence of super symmetries, and the study of what happens when heavy ions collide. The tracker used in this experiment contains 25,000 silicon sensors, each of which must be cooled individually. A major advantage of CO₂ cooling becomes apparent in this situation: due to the high level of compression, the volume of vaporized CO₂ remains very low, allowing the use of very thin tubing with a diameter of just 2 mm. As a result, very little material is needed despite having several hundred cooling tubes.

From 2015, the collision energy in the LHC, operated at 7 TeV during its first run, shall be increased to 13 TeV and subsequently to as high as 14 TeV. With the increased number of collisions to be recorded, a more powerful silicon detector will be installed in 2016. For this, a new CO₂ cooling system, recently commissioned, will be put in operation. This system will have a total dissipated power of 15 kW, much higher than the LHCb and the ATLAS ones (of the order of 2 kW, Figure 4). For the new plant engineers have chosen Lewa LDE-1 diaphragm metering pumps with a remote head design. The pump head has a cooling jacket and is constructed of 1.4571 type stainless steel. The displacement movement is transferred by way of a liquid column, also known as the hydraulic rod, contained in the connection line. The plunger puts the rod into an oscillating motion, which is forwarded to the valve head. The check valve responds to pressure and alternates between open and closed, inducing a unidirectional, pulsating flow of the fluid in the valve head.

In this way, the remote head design ensures that the displacement system stays out of the critical range in order to protect the system and the surrounding environment. It also prevents warming of the CO₂ or cooling of the oil, which would result in the formation of gas bubbles and cessation of pumping action, a common problem with standard pumps. “In two-phase cooling, the CO₂ must be close to its boiling point, as it tends to vaporize at warmer parts of the pump. That’s why the low heat input into the fluid is important. This in particular means that diaphragm metering pumps with remote head design can bring substantial advantages to the plant performance,” according to Marc Geiselhart, managing director at the Swiss Lewa subsidiary.

**Initial tests successful**

Since the failure of a pump during an experiment would be very costly in terms of time and money, additional specific features help ensure reliability. For example, the two-layer PTFE diaphragm prevents contamination of the CO₂ in case one layer of the diaphragm becomes damaged. In addition, an integrated pressure switch triggers immediate shutdown of the pump in the event of leakage. If requirements change, the flow rate can be regulated by remote stroke adjustment via two check valves.

The prototype for the new 15 kW system has already been installed and has successfully passed its initial test. The system is ten times larger than the one that uses Lewa standard pumps. The two CMS systems have also been fully assembled and are under commissioning. They will run redundantly in the actual experiment. In a subsequent scale-up, even more powerful pumps will be required, but engineers are currently waiting on results from the most recent experiment.
About CERN
The European Organization for Nuclear Research (CERN), founded in 1954, is dedicated to fundamental physics research. With approximately 2500 employees from 21 member states, it is the world’s largest particle physics research center. Currently more than 11,000 guest researchers from more than 100 countries conduct experiments in this large research center located in the Swiss canton of Geneva as well as in the French Département de l’Ain. Over the years, CERN built several particle accelerators, which accelerate particles to nearly the speed of light and induce them to collide. The Organization established its first particle accelerator, the Synchrocyclotron (SC), in 1957. The Large Hadron Collider came into operation in 2008 and is currently the most important accelerator at CERN. By examining the trajectory of the particles, the results of decay, and the interactions between the particles, researchers can draw conclusions about the nature of matter and the origins of the universe. Due to the enormous technical effort required to create and operate the systems, CERN is operated and financed internationally.

47th Annual Meeting on Nuclear Technology (AMNT 2016)
Key Topic | Enhanced Safety & Operation Excellence

The following report summarises the presentations of the Focus Session “Radiation Protection” presented at the AMNT 2016, Hamburg, 10 to 12 May. The other Focus, Topical and Technical Sessions have been covered in further issues of atw or will be covered in future issues.

Key Topic | Enhanced Safety & Operation Excellence
Focus Session: Radiation Protection
Angelika Bohnstedt and Erik Baumann

Protection against ionizing radiation is an important item in various fields of activities: operation of nuclear power plants, decommissioning, waste treatment and disposal, health care, etc. Talking about radiation safety culture is not limited to daily life in nuclear power plants. It is a matter present everywhere where people deal with radioactive sources or substances. Safety can always be improved. Regulations are required. Individuals and organizations performing activities with radioactive materials have to establish a secure surrounding for workers and members of the public as well as the environment. The role of radiation protection professionals and their scientific and professional societies (KTG, FS, IRPA etc.) is to promote a positive radiation safety culture in and around the workplace.

Thus the Focus Session Radiation Protection: Ionizing Radiation and Protection against it – a Matter of daily Radiation Safety Culture at the AMNT 2016 put the emphasis to the high importance of radiation safety culture as part of the overall safety culture. The presentations were about radiation protection issues as a task of occupational safety – required regulations and guidelines, the industry dealing with naturally occurring radioactive materials and natural background sources, the adaption for dismantling, the use of radiation in cancer treatment and the belonging protection aspects, and furthermore the consequences of Fukushima.

About 40 to 50 participants had the opportunity to listen to appealing presentations and use the time in between not only for interesting questions, but also in active discussions with colleagues from Germany and abroad. Thereby the session was a motivating exchange of information and knowledge.

The first presentation The Goal of Radiation Protection – Changes when implementing the guideline 2013/59 Euratom compared to established radiation protection goals was held by Dr M. Horn (TÜV Rheinland Industrie Service GmbH). The presentation gave an overview about the history of Limit Values in radiation protection starting 1951 and leading via ALARA (As Low As Reasonable Achievable) principle, biological effectiveness (RBW) and tolerance dose to the ICRP (International Commission on Radiological Protection) recommendations No 6 in 1955. The further development was shown and how the ICRP has been refined in the following decades based on increasing knowledge about scientific basis and about the detrimental health effects after exposure to ionizing radiation. Ms. Horn explained the different steps towards the last update of the ICRP recommendation 103 in 2007 introducing limit values for the lens of the eye and for skin.

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