The Hexagon Metrology laser trackers inspect the construction of the huge magnets of a nuclear fusion reactor

by Levio Valetti

A miniature sun on the earth, capable of generating an astonishing amount of energy. Clean, safe, controllable energy, essential to guarantee supply for the exponential, overwhelming growth of the energy requirement on our planet. A nuclear reaction process powered by a raw material that is absolutely common, inexpensive and easily available: the hydrogen of sea water. The almost complete absence of risks in controlling this reaction, as well as the negligible production of waste harmful for the environment, and human and animal life.
The making of a toroidal magnet like the one for ITER requires the application of extremely advanced and complex technologies.

All this and much more is the synthesis of energy generation through nuclear fusion, the physical phenomenon that powers the Sun. Observed by generations of scholars and reproduced on a very small scale in the 1930s, this is now becoming a reality due to advancements in physics and technologies. The actual feasibility will be technically and scientifically demonstrated in the next few years thanks to a large research project financed by the European Union, China, India, Japan, Korea, Russia and United States, that will result in the construction of a huge experimental reactor in Cadarache, in southern France. ITER, as the project and reactor is called, will be completed and started up in 2020. It will have to prove itself capable of producing for at least 30 minutes a quantity of energy ten times higher than that needed to power it: 500 MW output against 50 MW of actual consumption. The anticipated success of the experiment will be the driving force behind the continuation of a second project, known as DEMO, which is already underway. In the following 15-20 years, the continuation of a second project, known as DEMO, is expected to lead to the accomplishment of the first real industrial plant for the generation of electricity from nuclear fusion.

As one of the various possible solutions to accomplish a nuclear fusion system, ITER is based on the magnetic confinement of the reaction. The core of the fusion is plasma, a state of matter that in the ITER reactor is achieved when it is heated up at temperatures higher than 150 million °C. The movement of the pairs of plasma atoms as they come together up to their fusion is made possible by a massive thrust from a magnetic field. When the fusion of atomic particles has been achieved into a single nucleus, the latter takes on a mass lower than the sum of the original particles, leading to the emission of huge quantities of energy. After the reaction, the magnetic system continues to operate, confining the plasma in a space that enables the use of this heat energy and limits the forces acting on the containment room wall.

In La Spezia, overlooking the Ligurian Sea, between Liguria and Tuscany, is the headquarters of ASG Superconductors, one of the Italian companies in charge of manufacturing some of the main components of ITER. At its facilities in Genoa and La Spezia, ASG manufactures magnets of all sizes – superconductive and traditional magnets, used to make innovative magnetic resonance machines, and machines for the controlled bombardment of tumour cells, for experimental high-energy physics. It has supplied part of the magnets forming the Large Hadron Collider (LHC), the particle accelerator at CERN in Geneva, as well as for nuclear fusion.

Alberto Barutti and Bruno Caserza are the quality manager of ASG and the general manager of the La Spezia facility respectively.

“The making of a toroidal magnet like the one for ITER,” explains Barutti, “requires the application of extremely advanced and complex technologies. The coil sizes are huge and the magnetic field required is so big that to produce it in compliance with the overall system efficiency, superconductive materials have to be used, which is one of our areas of expertise. So we have set up a plant here in La Spezia focused only on the construction of the coils that will form the reactor confinement magnet. All stages of the construction and inspection of the gigantic components take place in this plant and each individual operation is inspected by extremely strict quality and dimensional checks. Every component manufactured is unique and will prove its performance and actual operation only when the reactor is fully assembled and put into service. As a result, no mistakes can be afforded. Everything must be perfectly compliant to the theoretical specifications to avoid the failure of an experiment unique in its importance, and the costs incurred.”

The various components of the magnet include 18 main D-shaped windings (Winding Pack), which are about 13 m long and over 8 m wide. Every winding is formed in turn of 7 double windings, known as ‘double pancakes’, that are sandwiched together to form the Winding Pack. The conductor that the coils are made from is a frame formed of a central conduit in which the cooling liquid helium will flow (at a temperature close to absolute zero to allow superconductivity), a concentric matrix of copper conductors in which superconductive filaments are embedded, and finally a metallic containment coating. The conductor has an external diameter of about 40 mm and is supplied in huge coils of 750 m each.

The reactor in its final assembly (Tokamak), the toroidal magnet, and one of the windings produced by ASG Superconductors.
“After passing strict acceptance tests, including testing in a vacuum chamber,” Barutti continues, “the first operation consists of unwinding the conductor from the transport coil, straightening it, washing it, and then sanding the surface of the outer coating with special equipment. The last stage of the forming system – the most important and complex one – makes the conductor bends so as to produce the two turns of each coil, the upper and lower one, in the air without using jigs. In this stage, the material is not superconductive yet and can be handled, bent and formed at will. As the coils are going to change their shape after the subsequent heat treatment required to achieve cable superconductivity, strict inspection for shape and overall length is essential from this stage. We must achieve the exact original shape that only after deformation as a result of this heat treatment will become the intended shape. And all this with tolerances that are really demanding for the details that have not been machined. In this process stage, we use a Leica Absolute Tracker AT901 with a Leica T-Scan laser scanner. The 22 turns of the double winding have to meet tolerances in the order of few tenths of a millimetre on the 3D form error, and the total length of the turn has tolerances of few parts per million throughout the full length, which is also the most complex size to be measured.”

“Thanks to special procedures developed in cooperation with Hexagon Metrology technicians during the equipment installation,” Caserza explains, “with the laser scanner we detect the geometry of each turn at completion of bending and before proceeding with the next one, we examine the full length and shape in order to make any compensations that might be necessary on the next one, and achieve the correct shape and length. We then make a full check of the shape of the winding obtained.”

Once the bending stage has been completed, the double winding is ready for heat treatment. A 28-day heat treatment cycle involving various stages and
temperatures in a special atmosphere-controlled oven, will give the material superconductivity characteristics. From now on, in all subsequent processing stages, the big winding needs to be handled with extra care. The superconductive material becomes extremely fragile after crystallisation and any mechanical strain on it might cause breaks and impair its performance.

Caserza continues, “The heat treatment has been designed to keep winding deformation under control, but it is still necessary to check the actual shape of every winding before going on with the next part of the process. We also have to make very precise adjustments to the mountings that keep the windings’ shape to prepare them for the subsequent assembly stages. We use a second Leica Absolute Tracker AT901 laser tracker along with a Leica T-Probe contact sensor for this task. A guided inspection procedure allows the operators to make the necessary corrections to the relative positions of the turns, based on the deviations detected with an accuracy of a few hundredths of a millimetre.”

The dimensional inspection of the double winding after heat treatment.

The housing of the double winding and the closing of the “pancake”.

The subsequent assembly stages include the fitting of the windings into a special housing, insulation and sealing of the housing itself with special covers that will be welded with a robotised system. A third Leica Absolute Tracker AT901 laser tracker is used for calibration of the fixture to support the individual pancakes inside the welding station. Once the covers have been welded and after accurate dimensional inspections in a vacuum chamber and electrical inspections, every pancake is carefully wrapped in an insulating coating. Subsequently, it is filled with a resin using a vacuum impregnation process. The last step before delivery is the stacking of the seven components and the final insulation of the assembly. After the second impregnation and the final tests, at last the huge D-shaped winding is ready to leave for its final destination.

“Our process,” Barutti continues, “is closely dependent in every phase on dimensional and form inspections that we perform with equipment and procedures supplied by Hexagon Metrology, and set up in close cooperation with their technicians. Hexagon Metrology did not just provide us with hardware and software, they also developed programs and procedures dedicated to our specific application, which has unique characteristics and therefore required a deep expertise synergy to achieve the final objective. I’d like to point out that it’s through their availability that we are accomplishing as the first one an equipment that will take the laser tracker technology even in an old-style environment like the one of magnetic measurements. Thanks to these new technologies, the final release of manufactured coils will take advantage of a dramatic reduction in processing time, a significant simplification of the activity, as well as an added value for data quality.

Reference Websites

ASG Superconductors: www.as-g.it
ITER Project: www.iter.org
Reactor Assembly (Tokamak): www.nbi.dk/video/159

Alberto Barutti takes his leave with a last comment on the activities performed with Hexagon Metrology: “At the time of the preliminary analysis and design of the equipment, we have carefully assessed various options for the dimensional control of our components. Our past positive experiences directed us towards the solutions offered by Hexagon Metrology. So we also had the opportunity to experience a close cooperation with their technicians. Hexagon Metrology did not just provide us with hardware and software, they also developed programs and procedures dedicated to our specific application, which has unique characteristics and therefore required a deep expertise synergy to achieve the final objective. I’d like to point out that it’s through their availability that we are accomplishing as the first one an equipment that will take the laser tracker technology even in an old-style environment like the one of magnetic measurements. Thanks to these new technologies, the final release of manufactured coils will take advantage of a dramatic reduction in processing time, a significant simplification of the activity, as well as an added value for data quality.”

Reference Websites

ASG Superconductors: www.as-g.it
ITER Project: www.iter.org
Reactor Assembly (Tokamak): www.nbi.dk/video/159
Hexagon Metrology offers a comprehensive range of products and services for all industrial metrology applications in sectors such as automotive, aerospace, energy and medical. We support our customers with actionable measurement information along the complete life cycle of a product – from development and design to production, assembly and final inspection.

With more than 20 production facilities and 70 Precision Centers for service and demonstrations, and a network of over 100 distribution partners on five continents, we empower our customers to fully control their manufacturing processes, enhancing the quality of products and increasing efficiency in manufacturing plants around the world.

For more information, visit www.hexagonmetrology.com

Hexagon is a leading global provider of information technologies that drive productivity and quality across industrial and geospatial applications. Hexagon's solutions integrate sensors, software, domain knowledge and customer workflows into intelligent information ecosystems that deliver actionable information. They are used in a broad range of vital industries.

Hexagon (Nasdaq Stockholm: HEXA B) has more than 15,000 employees in 46 countries and net sales of approximately 2.6bn EUR.

Learn more at www.hexagon.com