FUSION POWER IS THE SUN IN A BOTTLE

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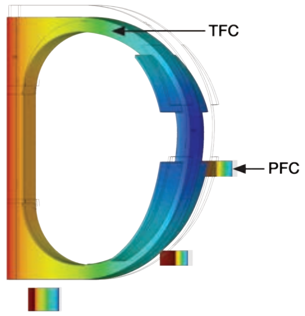
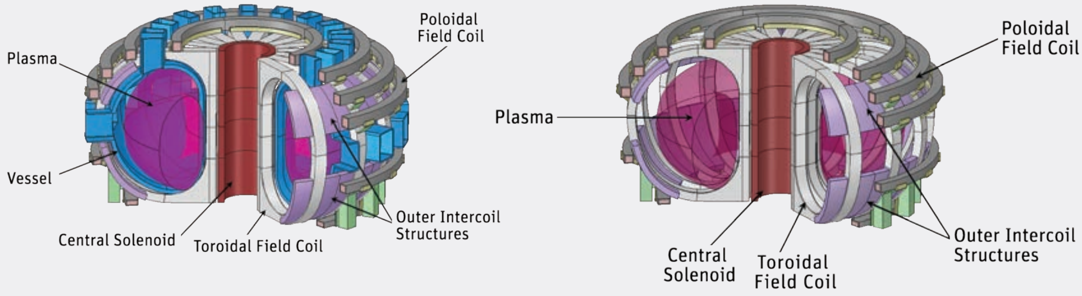
The sun and stars are powered by light atoms that fuse at extremely high temperatures and pressures. Reproducing this process on earth has the potential to provide a sustainable solution to the world's energy requirements, but this requires overcoming some very difficult technical challenges. Engineers at the Italian National Agency for New Technologies, Energy and Sustainable Economic Development are using ANSYS Mechanical and ANSYS SpaceClaim to optimize the design of critical structures in the Demonstration Power Station project, which will produce fusion power on the same scale as a modern electric power generation station.



Cooldown stresses on TFC and PFC

> **“The simulations performed by ENEA will help deliver a structurally sound and cost-competitive fusion power reactor to satisfy future world energy demands”**

Fusion power has the potential to be the ideal energy source. It runs on cheap and abundant hydrogen and creates little or no emissions or radioactive waste. It requires much less land mass than wind or solar power installations and produces power 24/7. But producing a self-sustaining fusion reaction requires that isotopes of hydrogen — deuterium and tritium — be heated to over 100 million C, at which point they become a plasma: an electrically charged gas that is common in space but rare on earth. At these temperatures deuterium and tritium fuse to form helium, a neutron and large amounts of energy. Sustaining such a high temperature requires that the plasma be contained by electromagnets that exert forces that are equivalent to three-quarters of the weight of an aircraft carrier. Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) engineers are using ANSYS Mechanical to design structures economically to contain the plasma.



Schematics of DEMO fusion reactor including plasma-containing vessel (left) and magnetic system only (right)

POTENTIAL SOLUTION TO GLOBAL ENERGY DEMANDS

In southern France, construction is half completed on the International Thermonuclear Experimental Reactor (ITER), which, when it begins operation in the 2040s, will be the world’s largest fusion reactor, the first fusion device to produce net energy and the first fusion device to maintain fusion for long periods of time. ANSYS Mechanical was used extensively by the groups designing ITER, particularly in the design of the structural supports for the electromagnets.

Meanwhile, design is proceeding on the next-generation Demonstration Power Station (DEMO) project, which is intended to generate energy at the level of a modern power plant and provide a prototype for a future generation of fusion power plants. The heart of the DEMO reactor will consist of a toroidal, or doughnut-shaped, chamber formed by powerful superconducting magnets to contain the plasma at the high temperatures required to sustain fusion. These magnets will include toroidal field coils (TFCs), which produce a magnetic field in the toroidal direction (the long way around the doughnut), poloidal field coils (PFCs), which produce fields that run the short way around the doughnut, and the central solenoid (CS) magnet, which is used to heat the plasma and tweak the shape of the toroid. The DEMO magnet system consists of 18 TFCs, six PFCs and one CS. The TFCs in DEMO are expected to be about 17 meters high and 13 meters wide.

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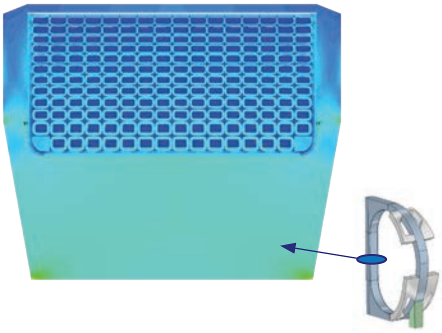
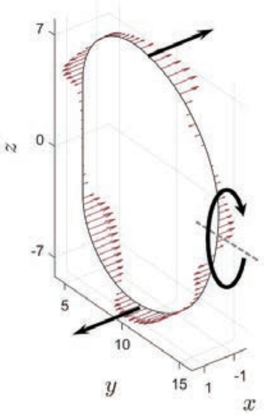


Electromagnetic loads on TFC including cross-section

When these magnets are energized, they will exert enormous forces on the TFC and PFC structures as well as on the outer intercoil structures (OISs), which circle the outer circumference of the toroid to resist bursting forces. The maximum in-plane forces exerted on the coil packs will be 10 Meganewtons and the maximum out-of-plane forces will be 14 Meganewtons. The out-of-plane forces are approximately equal to 77,000 tons, which is more than three-quarters of the displacement of a Nimitz class aircraft carrier.

APDL SCRIPTS ENABLES COMPLETE PARAMETRIC SIMULATION OF PFCs AND TFCs

Since the geometry of the DEMO magnets will change frequently as the project proceeds, the TFCs and PFCs are being designed using the power of ANSYS APDL scripting that completely parameterizes the magnet geometry. This makes it easy to implement future changes to the magnet dimensions, including both the exterior dimensions and inner parameters such as the conductor size and steel jacket thickness. The DEMO magnets are superconducting so they will be brought down to a temperature of 4 K before the magnets are turned on, which generates considerable thermal stresses. The script simulates both the cooldown and the electromagnetic stresses. The additional complication of the insertion of mechanical contacts in the TFCs was also included in the scripts.

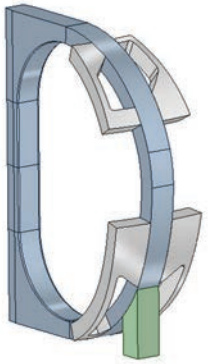


OISs must resist large and highly variable out-of-plane forces ranging up to 77,000 tons.

OPTIMIZING SHAPE, WEIGHT AND COST OF OISs

In the initial concept design, the OISs were designed with a uniform shape that weighed 367 tons for each support. But because the out-of-plane forces vary greatly around the circumference, ENEA engineers felt that the high cost of these structures could be reduced by optimizing them to remove material where it was not needed. Traditional simulation methods, in which designs are explored one at a time by manually varying their dimensions, could have generated considerable cost savings. But the amount of time required to define the geometry and simulate each design would have made it impossible to come close to optimizing the design.

Engineers used ANSYS topology optimization, which is integrated with ANSYS Mechanical and the ANSYS Workbench platform to automate the process of starting from nothing and iterating to an optimized design while changing both the shape and the dimensions of the OISs. They started by simulating the winding pack using ANSYS Mechanical to determine the mechanical loads applied to the OISs. Thermal loading was not a major factor with the OISs because they do not contain superconducting windings. Engineers defined the features that must be maintained in the final design, such as the outer boundaries and mounting surfaces, and assigned the optimization objective to be the minimization of the weight of the part while holding stress to a specified maximum value based on the material properties. The ANSYS topology optimizer identified the minimum geometry that meets the design requirements. After convergence of the optimization, engineers imported the topology density distribution into ANSYS SpaceClaim Direct Modeler and used it to tweak the final design, which weighs 228 tons — 38 percent less than the original design.



OIS design optimized with ANSYS topology optimizer and ANSYS SpaceClaim weighs 228 tons.

The simulations performed by ENEA will help deliver a structurally sound and cost-competitive fusion power reactor to satisfy future world energy demands. The substantial reduction in material content in the magnetic systems will significantly reduce the cost of building the power plant. The use of APDL scripts enables the design to easily be re-optimized as it evolves over the coming decade.