Axisymmetric MHD-stable mirror as a neutron source and a driver for a fusion-fission hybrid*

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Topics: Compact 14 MeV neutron source for blanket development;
Mirrors as drivers for hybrids

Mirrors have a number of attractive features as future fusion devices: they are inherently steady-state, can operate at high beta, have natural "divertors" (no problems with heat load), the main confinement volume in them is a simple linear solenoid, and there are no externally-driven axial plasma currents.

Over the past decades, largely after the termination of the mirror program in USA, several techniques have been suggested for making mirrors stable in axisymmetric geometry. Aforementioned general advantages of mirrors are tremendously amplified in the case of axial symmetry. In particular, neoclassical and resonant transport are completely eliminated; engineering simplicity and general flexibility of the device increase significantly; much higher magnetic fields become available for mirror throats, etc. Axisymmetry is a game-changer in the mirror systems!

One particular technique for making MHD-stable axisymmetric mirrors has been thoroughly investigated with the Gas-Dynamic Trap facility at Novosibirsk, where stabilization was provided by the exhaust plasma in the favorable magnetic curvature of end-tanks. The stability was further enhanced by creating a slow azimuthal rotation by controlling the radial potential distribution (a luxury that mirrors have because of the possibility of controlling potential distribution over end-plates). This allowed achieving beta as high as 60% in a fully axisymmetric configuration.

At present it is clear that parallel electron heat loss in mirror systems can be brought to a classical, quasuneutrality-based limit (one lost electron per one lost ion), by using strong expansion of the magnetic flux in the end tanks and providing a good pumping of the recombined particles. This issue has been assessed theoretically and explored in significant detail with the GDT facility.

Finally, it became clear that using of the sloshing ions – a technique pioneered by the TMX-U team at Livermore decades ago – has very strong favorable effect on plasma microstability. Indeed, on the GDT device the behavior of the sloshing ions was classical, with no signs of anomalous scattering.

When combined, these three techniques lead to an attractive source of fusion neutrons for material and subcomponent testing of future hybrid systems (and pure fusion reactors). The source providing the flux of fusion neutrons up to 3 MW/m^2 over the test area of ~1 m^2 (cylindrical test zone with an i.d. ~ 20 cm and length 1-1.5 m) can be built with minimum extrapolation from the existing facility (see White Paper by T. Simonen for details of a source with the flux of 1 MW/m^2). The availability of such a source is of a paramount importance for developing fusion-fission hybrids, as it will allow one to test the subcomponents of the blanket under conditions very similar to those to be met in a

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real hybrid facility. Such a source is critically important for obtaining information required for the licensing process for any of the versions of a fusion-fission hybrid.

Importantly, accumulating of 10 MW-yr/m^2 fluence requires consumption of only 700 g of tritium, thereby allowing one not to use tritium breeding in the source itself.

This source cannot be replaced by either a point-like accelerator-based neutron source (too small a volume and wrong neutron spectrum), or by a full-blown fusion source based on other magnetic configurations (the chicken-and-egg-problem and the need to breed tritium from day one in order to accumulate any reasonable fluence). Accelerator-based source and a large-scale MFE source with tritium breeding are desirable in future but cannot substitute the mirror-based neutron source.

Interestingly, if one does not want to make any extrapolations from the plasma parameters already obtained with the GDT device, one would already be able to produce neutron flux of order 0.1 MW/m^2 by using the DT mix. Although the basic version of the mirror source is steady state, one can also include the option of modulating the neutron flux at frequencies in the range from 1 Hz to 1 KHz, which could allow imitating some (not all) aspects of rep-rate pulsed fusion engines.

Several workshops and other forums were convened by a multi-institution "Mirror Study Group" organized by Tom Simonen to assess the physics basis of the mirror neutron source and its technological readiness. The conclusion was generally favorable. The physics was concluded to be sufficiently robust. The major technology development would be reaching a steady state operation. This development is, however, common to all other MFE-based devices. The most challenging issues are related to producing steady-state atomic beams, tritium recirculating system, and vacuum system. However, as the mirror-based neutron source is a compact facility (mirror-to-mirror length ~ 10 m) and has a small volume of both plasma and the confining field, these issues will be easier and less costly to solve than for larger neutron sources based on other configurations.

Significant experience has been accumulated in USA, Russia and Japan in engineering aspects of mirrors; USA, Russia and Germany have also made detailed designs of mirror-based neutron sources. All this will greatly help to jump-start the work of developing a compact mirror-based neutron source.

On a longer time-scale, axisymmetric mirrors may become an excellent driver for modest-Q version of hybrid systems. The schemes that provide MHD stability for axisymmetric mirrors are not limited to the stabilization by the outflowing plasma, GDT-style. They include also other approaches that may be better suited to systems with a better axial confinement than GDT. Combined with a simple mirror (not using tandem mirror end plugs) they can become a basis for a mirror facility with Q~1 which, due to its simple geometry, easy access to the plasma and flexible dimensions can serve as a very attractive driver for hybrid systems. Unlike the neutron source, there will be a need of testing the physics principles of the new stabilization techniques. This can, however, be done at a relatively low cost due to the engineering simplicity of axisymmetric mirrors.

All these considerations make a strong case for including mirror systems into the road map for developing fusion-fission hybrids. Their prime role at an early stage of the project would be providing a reliable source of fusion neutrons for testing of sub-components of blankets and accumulating information needed for the licensing next-step facilities. In the longer perspective, mirrors would become a very attractive driver for modest Q (Q=1-2) hybrid systems.