CONF-891007-95

GA–A19742

DESIGN OF DIII–D ADVANCED DIVERTOR

by
J.P. SMITH, C.B. BAXI, E. REIS,
M. SCHAFFER, AND G. THURSTON

NOVEMBER 1989

GENERAL ATOMICS

DESIGN OF DIII–D ADVANCED DIVERTOR

J.P. Smith, C.B. Baxi, E. Reis,
M. Schaffer, and G. Thurston
General Atomics, P.O. Box 85608
San Diego, California 92138-5608

Abstract: The Advanced Divertor is a modification being designed for the plasma chamber of the DIII–D tokamak in order to optimize the divertor configuration and allow a broader range of experiments to be carried out. The Advanced Divertor will enable two classes of physics experiments to be run in DIII–D: Divertor biasing and Divertor baffling. The Advanced Divertor has two principal components: (1) a toroidally symmetric baffle; and (2) a continuous ring electrode. The tokamak can be run in baffle, bias, or standard DIII–D divertor modes by accurate positioning of the outer divertor strike point through the use of the DIII–D plasma control system.

The baffle will contain approximately 50,000 l/s pumping for particle removal in the outer bottom corner of the vacuum vessel. The strike point will be positioned at the entrance aperture for the baffle mode. The aperture geometry is designed to facilitate a large particle influx plus a high probability that backstreaming particles will be reionized and redirected to the aperture. Where the baffling plates meet, gas sealing is required to prevent recycling of neutrals back into the plasma.

The electrode is a continuous water-cooled ring, armored with graphite. The ring is electrically isolated from the vessel wall and is biasable to 1 kV and 20 kA. The outer leg of the divertor will be positioned on the graphite covered ring during biasing experiments.

The supports for the ring are radially flexible to handle the differential thermal growth between the ring and the vessel wall but stiff in the vertical direction to restrain the ring against large disruption forces. The coolant and electrical feeds are designed in a similar manner. All the feeds are supported from and maintain a 5 kV isolation to the vessel wall.

In order to maintain electrical insulation along the field lines, plasma-facing insulators are needed. In addition, all biased surfaces behind and underneath the ring, must be insulated to prevent breakdown along the field lines. Tests of insulators were made in DIII–D during plasma operations prior to deciding on the final design. Other testing and analysis was performed to evaluate insulating materials and concepts.

Introduction

GA and several collaborators are developing and building the Advanced Divertor for the DIII–D experiment. The goals of the program are to obtain H–mode density control for transport and current drive studies, to study the effects of edge heating on plasma stability, to test dc helicity injection steady-state current drive, and to study divertor engineering and improvements for future tokamaks such as CIT and ITER.

Two new major components will be installed in the machine to perform the Advanced Divertor experiments (Fig. 1). The first is an electrically isolated toroidal continuous ring electrode in the outboard lower divertor region that will be capable of up to 20 kA and 1 kV. The second major addition is a toroidally continuous gas baffle between the outer wall and the biasable ring. By adjusting the position of the outer divertor strike point using the field-shaping coil system, either divertor

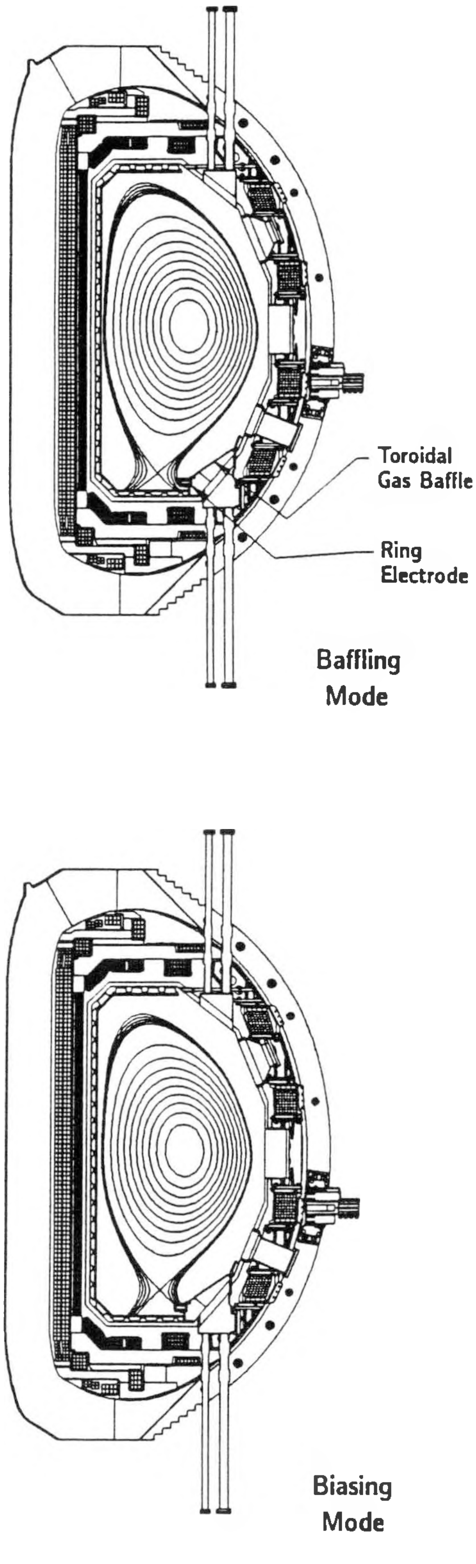

Fig. 1. Operation modes of advanced divertor.

bias or divertor baffle modes can be run. In the bias mode, an external power supply will drive up to 20 kA into the plasma scrapeoff layer, allowing experiments to study particle transport modification, second stability limits, and helicity injection current drive. Current will return to the vessel through the inner divertor strike point. The baffle mode will test density control, particle exhaust, and tokamak operation with net particle throughput. In addition, by moving the separatrix further inboard, the plasma can be removed from interaction with the Advanced Divertor and standard plasma experiments. The volume created behind the toroidal baffle will be equipped with either cryogenic or getter pumps (>50,000 l/s). The entire Advanced Divertor system was designed for minimal intrusion on the plasma volume and minimal limitations on normal plasma operation.

Discussion

Ring Electrode

The toroidally continuous ring is made of Inconel 625 for its strength, electrical resistivity, and high-temperature capability. The ring has two parallel coolant channels machined and welded into it. These coolant channels are connected to the vacuum vessel air/water system. During bakeout, hot gas flows through the channels, and during operation, water is the coolant. The gas does not provide much cooling to the ring during bakeout, but during operation, the water is necessary to keep the temperatures of the ring below 150°C to limit the thermal expansion of ring [1].

The outboard divertor leg will rest on the graphite tiles, mounted to the ring electrode, during bias experiments. During baffle experiments, the scrapeoff layer of the plasma will graze the front edge of the graphite tile. The graphite tile will be of the same basic design and material, and use the same mounting configuration as the vessel armor tile [2]. A complete thermal and stress analysis was performed for the graphite tile [1].

The ring is supported off the vessel floor by local Inconel 718 brackets (Fig. 2). During bakeout, there is a calculated transient temperature difference between the vessel and the ring of 100°C. The supports are flexible in the radial direction to accommodate the differential thermal growth during both bakeout and operation.

Disruption loads were analyzed for the continuous ring. The standard disruption loads from induced toroidal current scale with the cross sectional area of the Inconel ring (resistive limit). Recent theory and observation in DIII–D show that there is significant poloidal current flow in the plasma edge during disruptions that will also flow into the ring. This current increases the disruption forces on the ring. The supports are stiff in the vertical direction to manage these large vertical loads. The radial loads caused by disruptions are reacted internally by the ring, with the ring having a safety factor of at least 5 for out-of-plane buckling. To insulate the biasable ring from the vessel wall, an insulated bolt is used at the ring/support joint.

For the ring to fit through one of the large midplane ports, it is necessary to use four 90° segments which are reassembled inside with bolts and shear pins. Each section of the ring has two cooling circuits with inlets at one end and the outlets at the other (Fig. 3). In parallel with the water feeds will be the electrical feeds for the ring electrode. The feed lines have a toroidal section to them for flexibility for the difference in growth between the ring and the vessel. This section is toroidal to minimize the I × B force. Because the feed lines could have a tremendous current flowing through them due to a disruption (as much as 250 kA each), a surge inductor will be placed between the ring and its power supply. This protects the power supply and limits peak I × B force in the feeds.

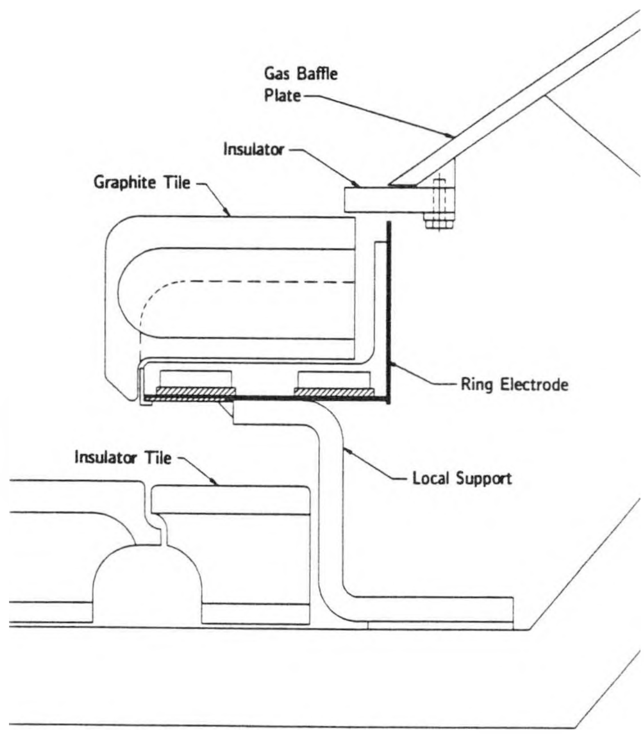

Fig. 2. Key components of advanced divertor.

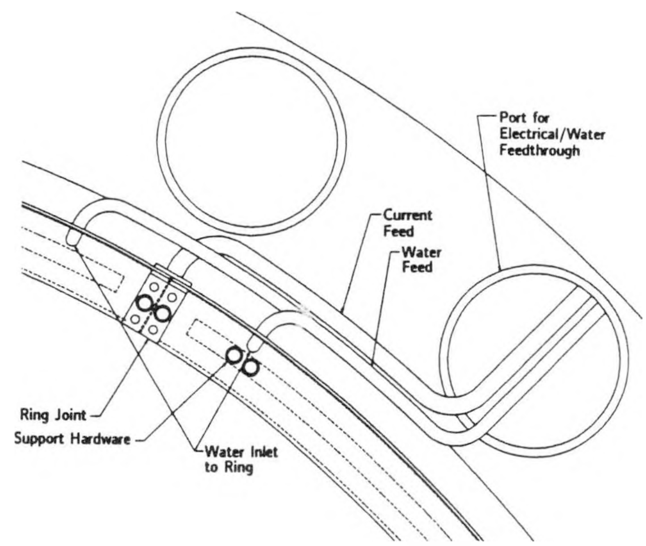

Fig. 3. Plan view of advanced divertor and water/electrical feeds.

Electrical Insulators

Two plasma-facing insulator rings are required to prevent arcs along field lines to the vessel. The first insulator ring is on the floor of the vessel. It provides electrical insulation against current flow along magnetic field lines from the ring to the vessel floor. The ring is positioned such that field lines at angles of $45 \pm 10°$ off the lower inside corner of the electrode are flanked by 1 cm of cross-field insulation along the top surface of the insulator tile. The design of the insulator tile is the same as the graphite floor tile it is replacing, except shorter in poloidal length. The other insulator ring provides 1 cm of cross-field insulation between the electrode graphite tile and the baffle plate. Initially, both insulators will be made from boron nitride. The selection of boron nitride was based on analysis and testing. Two- and three-dimensional thermal/stress analyses were performed for different materials on the same models to compare peak temperatures and stresses to the allowable values for the materials. Testing of plasma-facing insulator materials was completed at SNLA in the E–beam. From the results of these tests and analyses, boron nitride was chosen.

In addition to the plasma-facing insulators, there are many other insulators in the design. The surfaces on the back and bottom of the ring electrode are covered with electrical insulation to prevent breakdown to the vessel along field lines through residual plasma. To accomplish this, a redundant insulation design is used by plasma-spraying alumina on the ring and attaching Mica Mat plate, an inorganically bonded mica product, over it. On the bottom of the ring, the heat load is large enough to require a heat shield over the Mica Mat. The cooling/feed lines also are electrically insulated for the same reason by using plasma-sprayed alumina on the tube covered with braided Nextel sleeving.

Gas Baffle

The baffle traps neutrals behind the ring and limits their recycling back into the plasma. The entrance aperture was designed for 50,000 l/s pumping speed using the DEGAS code. The height of the ring off the vessel floor tiles is 3.5 cm to give the necessary aperture conductance. The modeling and pumping analysis was done by Oak Ridge National Laboratory (ORNL). Allowed leakage from baffle joints is set at a total conductance of 5000 l/s. Initially, the Advanced Divertor will be installed without pumps, while a testing program evaluates cryogenic and getter pumps. The pumps will be installed in late 1990.

The baffle is made up of 24 individual Inconel plates supported off the vessel wall. They extend from the ring to the outer wall of the vacuum vessel (Fig. 4). The plates are connected together with flexible Inconel strips to form a toroidally electrically continuous shell. This strategy avoids relying on gaps between plates to prevent current flow. The consequence of an arc between plates would be to concentrate current flow and, thus, localize forces to a small area. Disruption loads on the plates were analyzed using the poloidal current model. In this scenario, current can flow from the collapsing plasma, through the plates to the vessel wall, giving a pressure loading on the plates of 2.5 atm.

Thermal analysis of the plates concluded that during bakeout, the plates will be heated inductively to a temperature of 425°C, while the vessel is at 400°C. The baffle plate temperature will lead the vessel wall temperature on heatup, creating a maximum ΔT of 200°C. During operation, the plates reach a higher ΔT of 300°C, and the supports to the vessel wall are designed to allow for the differential thermal growth between the cold vessel wall and the hotter baffle plates. The lower portion of

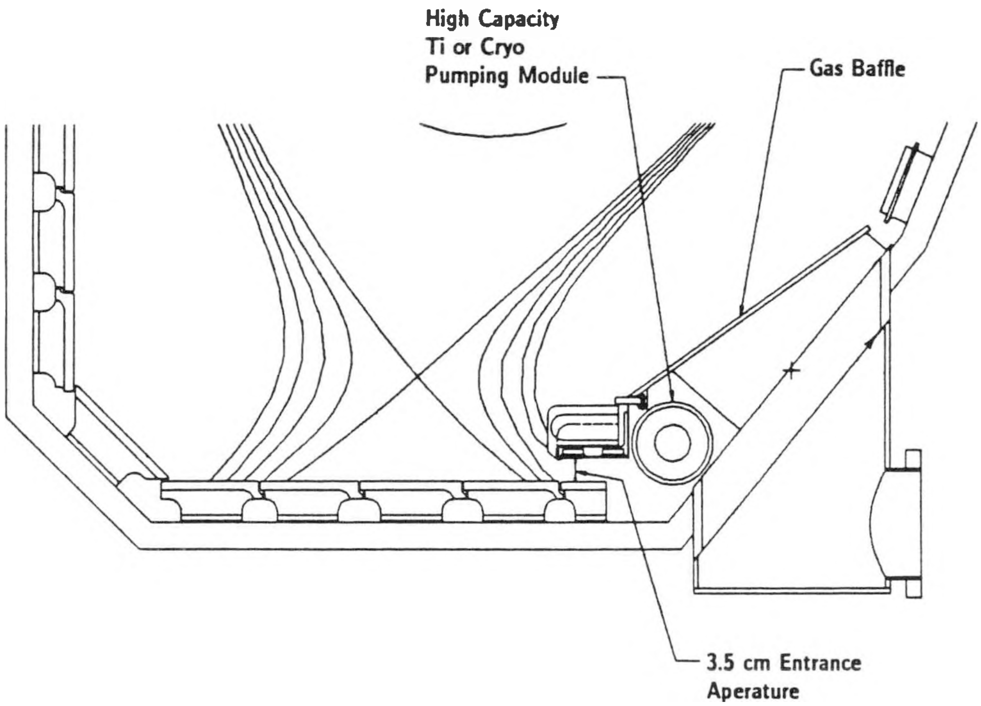

Fig. 4. Advanced divertor pumping.

the baffle plates near the ring require some armor to protect the Inconel against the high heat loads near the strike point. The baffle insulator ring, previously mentioned, is supported from the baffle plates.

The thin Inconel strips electrically connecting the baffle plates serve a secondary purpose: to seal the gap between plates and prevent neutrals from recycling back into the plasma. Other areas under the baffle require gas sealing to limit the leak conductance to 5000 l/s.

Testing

Many new materials were proposed throughout the design of the Advanced Divertor, and a testing program was implemented to evaluate the materials. Heat flux tests, outgassing tests, and electrical tests were performed. Sandia National Laboratories, Albuquerque (SNLA), conducted heat flux tests using an electron beam to thermally shock candidate materials. The best grade of boron nitride withstood at least 2.5 times higher heat flux than silicon carbide. In addition, the failure mode of the boron nitride was sublimation, whereas the silicon carbide failed by shattering. These results led to the selection of boron nitride as the material for plasma-facing insulators. Prototype tiles are being made and will be tested in the ion beam at SNLA.

Sandia National Laboratories Livermore (SNLL) performed outgassing tests for all proposed new vacuum materials. The materials were tested in a vacuum test chamber and the pressure and residual gas monitored. Temperatures of the test runs were chosen to simulate temperatures seen in the vessel. The data was then evaluated to determine if the outgassing is below acceptable limits.

Electrical testing was done at GA. A test was done to measure the voltage standoff capability of Nextel sleeving. This test was completed in vacuum, gas, and glow discharge environments. Insulator tests were also done in DIII–D to measure cross-field insulation of both smooth and grooved surfaces. No difference was observed. A test was also made on a prototype insulated support joint. In this test, one side of the joint was biased up to 1 kV without breakdown.

Diagnostics and Installation

Many new diagnostics will be added to DIII–D to study plasma performance with the Advanced Divertor. Included are tile current monitors to measure the current flowing in the scrape-off layer, upgraded Langmuir probes, and pressure gauges. Two reciprocating fast probes will be installed later in the program. Installation of the primary components of the Advanced Divertor will occur in early 1990 with baffle experiments starting first in mid-1990.

Acknowledgment

This work was sponsored by the U.S. Department of Energy under Contract No. DE-AC03-89ER51114.

References

[1] Baxi, C.B., E. Reis, and J. Smith, "Thermal Design and Analysis of DIII–D Advanced Divertor," GA Report GA–A19750, to be presented at the *13th Symposium on Fusion Engineering*, October 2–6, 1989, Knoxville, Tennessee.

[2] Smith, J.P., P.M. Anderson, and C.B. Baxi, "Design of DIII–D Armor Tiles," *Proceedings*, Vol. 1, *12th Symposium on Fusion Engineering*, October 12–16, 1987, Monterey, California.