Design of the Inboard Passive Stabilizer for TPX*

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ABSTRACT

The Inboard Passive Stabilizer (IPS) is part of the plasma stabilizing system built into the TPX. Its purpose is to provide passive stabilization of the plasma vertical instability on short time scales. With carbon fiber composite (CFC) armor tiles it serves as a startup limiter, protects the vacuum vessel from radiation heat load during steady state operation and also functions as Neutral Beam armor. The inboard passive stabilizer is a saddle coil, constructed of a ring of copper plates, armored with CFC tiles, that surrounds the inner vacuum vessel at the midplane. The design of the plates, the support structure, cooling lines, CFC tiles and tile attach method is described. Tiles that experience only the normal heat load of 0.4 MW/m^2 are attached with mechanical fasteners. Tiles in the neutral beam shine through area are exposed to as much as 1.7 MW/m^2 and are brazed to the IPS. Significant forces are generated in the plates by the stabilization currents as well as during the frequent bakeout cycles. These plates are required to be fully remotely handled, including tile replacement, and the influence of this requirement on the design is discussed.

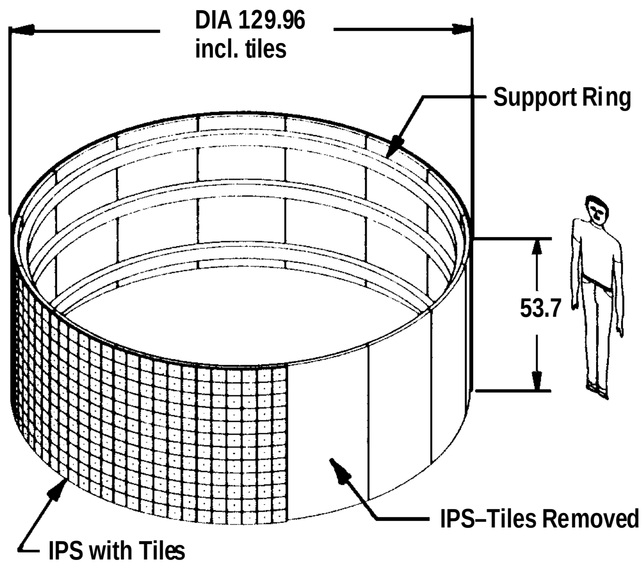

Fig. 1. IPS assembly

INTRODUCTION

The inner passive stabilizer (IPS) of TPX has several functions to perform. The first is the passive vertical stabilization of the plasma. To perform this task, the IPS must be capable of withstanding the forces caused by the currents generated due to the vertical movement of the plasma. The second function is to act as a startup limiter. Another function is to act as neutral beam armor to protect the vacuum vessel from neutral beam shine-through [1]. The final function is to act as a heat shield and protect the vacuum vessel center post wall from the radiation heat load generated by the burning plasma.

The inner passive stabilizer is a cylinder consisting of 16 curved copper plates 3.30 cm (1.3 in.) thick, 136.4 cm (53.7 in.) high, each spanning an arc of 22.5°, having an outer radius of 162.7 cm (64.05 in.). This cylinder is installed symmetrical to the machine mid plane (see Fig. 1).

Fig. 2 shows the electrical saddle coil configuration obtained by the IPS assembly.

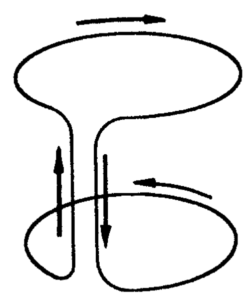

Fig. 2. Current plan in IPS

DESIGN DESCRIPTION

A. *Support Structure*

Three support rings manufactured from dispersion strengthened copper tie the plates into the cylindrical shape.

The rings are attached to the titanium vacuum vessel by 90 elastic titanium "Finger Brackets" (Alloy Ti-6Al-4V). 26 stiff titanium brackets are used at the toroidal gap (Alloy Ti-6Al-4V).

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Copper was chosen as ring material to keep the IPS assembly round during operating conditions and to avoid distortions of the assembly during the high temperature bake-out cycles. Fig. 3 shows an isometric view of this arrangement without the plates proper. Analysis showed [2, 3], that a two ring design resulted in too high local stresses. The plates are bolted to the rings with remote handling fasteners. At the toroidal location of 157.5° there is a gap in the IPS structure to establish the saddle coil configuration.

The components of this support system have to resist both the forces created by the current crossing the magnetic field lines and also the thermal expansion forces created during the bake-out cycle. The bake-out temperature is 350°C and the thermal expansion forces originate mostly from the difference of the coefficients of thermal expansion between copper IPS and titanium vessel.

The titanium alloy finger brackets are designed to support the rings with the plates attached. They are flexible in the radial direction, to take up radial thermal expansion. In the vertical direction, the brackets are considerably stiffer in order to support the weight of the assembly, but flexible enough to take the thermal deflections without overstressing. In the tangential direction the brackets are very stiff.

The support brackets at the toroidal gap represent a point of fixity of the rings to the vessel and are described in detail later.

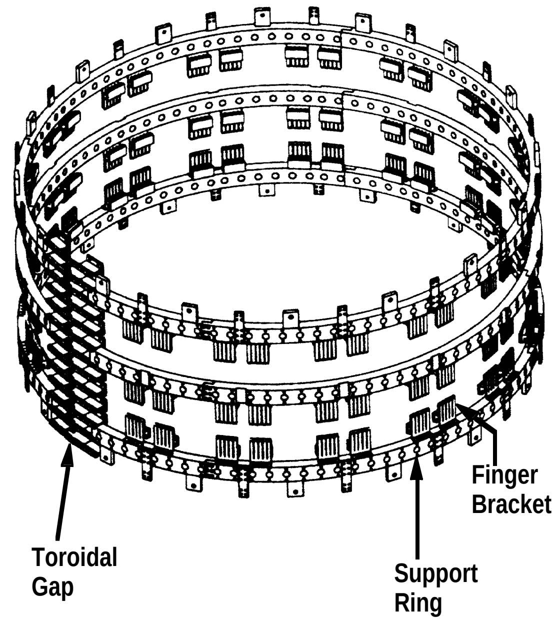

Fig. 3. Support ring design

B. *Passive Plate Design*

The material chosen for the IPS is copper alloy C18150 (Cu-0.9% Cr-0.1% Zr). This material provides the best overall strength, while it is still weldable by the electron beamwelding process. The plates provide the current path for the induced current to counteract the plasma movement prior to a disruption. To this purpose they are connected to each other by copper straps at their upper and lower ends. This continuous connection is interrupted only at the toroidal break.

Fig. 4 shows an isometric view of the IPS from front and back.

Each plate has facets on its plasma facing side to provide a flat surface for mounting the protective CFC tiles. Coolant channels are drilled into the plate to circulate liquid for heat

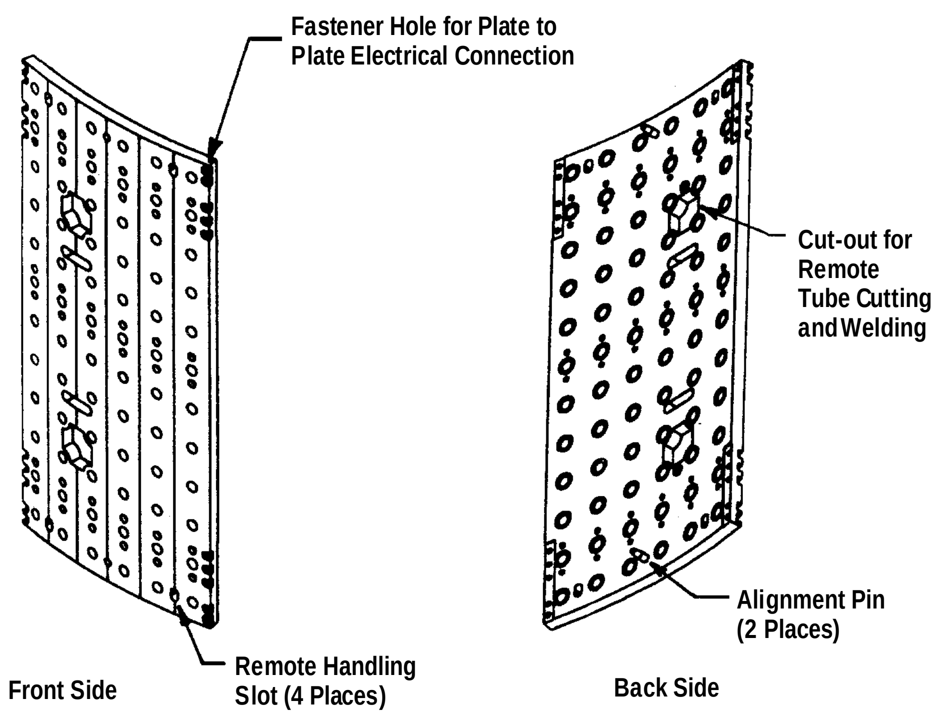

Fig. 4. IPS plate, front and back side view

removal [4]. Each plate has two alignment pins at its centerline to help position the plate during remote handling operations. Four remote handling slots are also provided for the remote handling fixture. Each plate has four cut-outs for remote handling access to the coolant tubes on its backside.

Fig. 5 shows details of the coolant line and its relative position to the cut-out for remote cutting and welding.

In neutral beam shine-through areas the tiles are brazed to the IPS to enhance heat transfer. In those areas the tile attachment fastener holes have been omitted.

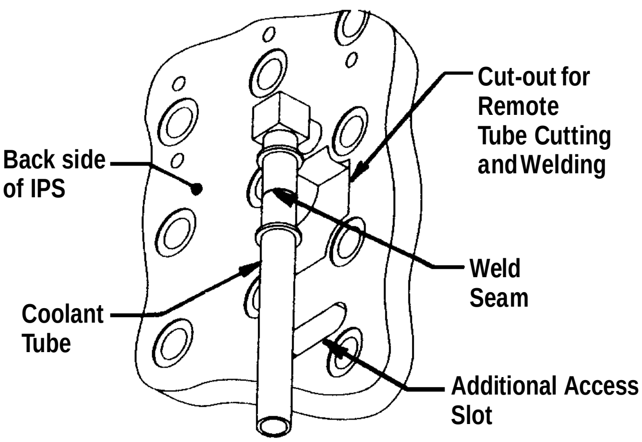

Fig. 5. Detail of coolant line

C. *Tile Design*

The tiles covering the plasma side of the IPS are manufactured from CFC material. One central fastener attaches the tile to the IPS. The fastener design provides spring elements to compensate for thermal expansion and to provide a uniform contact pressure between tile and IPS. A thin layer of grafoil 0.05 cm (0.02 in.) thick, permanently attached to the tile for remote handling, enhances the heat transfer between tile and plate. Thermal analysis shows a maximum tile temperature of 402°C and a maximum IPS temperature of 232°C for a heat load of 40 W/cm^2 from plasma radiation [5–7]. For greater heat flux the tile has to be brazed to the copper heat sink to enable proper heat transmission. The thermal analysis shows a maximum tile temperature of 623°C and a maximum IPS temperature of 272°C for a heat load of 170 W/cm^2 from neutral beam shine-through.

The central fastener design shown in Fig. 6 depicts one of several options. It represents the so-called "Quarter Turn Fastener". The main advantage of this concept is that tile and fastener form one subassembly and can be removed together.

D. *Toroidal Gap Design*

Fig. 7 shows an isometric view of the toroidal gap area. The plates are not shown. The highest disruption forces of 6.3 x 10^3 lbs/in occur at the toroidal gap [8–10] due to a current of

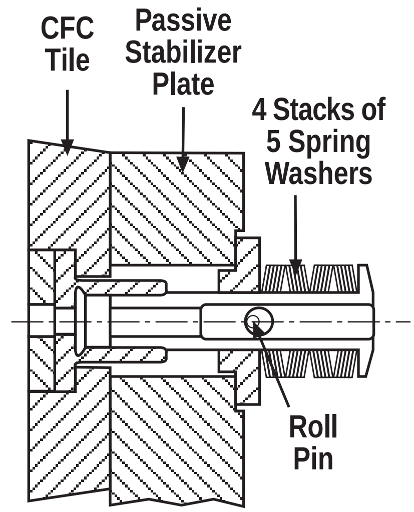

Fig. 6. Tile attachment fastener concept

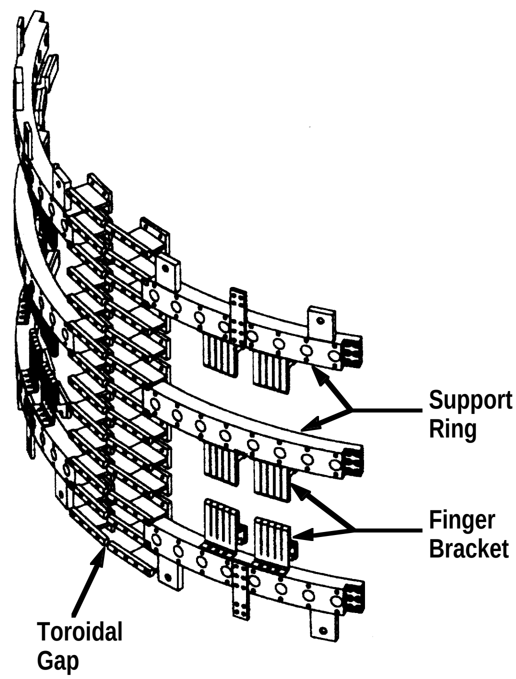

Fig. 7. Support design for toroidal gap

the vertical currents shown in Fig. 2, crossing the magnetic field lines.

Thirteen brackets on each side of the gap transfer the forces into the vacuum vessel center post. This joint is strong and stiff in the radial direction, but flexible enough in the vertical direction to allow thermal expansion without overstressing the components.

A strong connection between IPS and vacuum vessel is required at this point. At the same time the ohmic resistance across this toroidal gap must be more than 70 μΩ to help during startup of the plasma. The initial design concept was to attempt to use no insulators to eliminate the possibility of insulator failure or shorting and increase reliability of the remote design. The gap design makes use of the relative high resistivity of titanium by generating a tortuous path from side to side, using the vacuum vessel inner wall also as part of the high resistance path [11].

A recent increase in disruption currents makes the design of the toroidal break area obsolete. A current increase from 200 kA to 450 kA increased the radial loads along the toroidal gap from 6,281 lbs/in to 14,130 lbs/in. for a total radial force of 565,000 lbs. This will cause excessive stresses in all components including the vacuum vessel.

A change in design philosophy is required. A design using insulators similar to the ASDEX-UPGRADE "Current Bridge" must be considered to buck the loads before they reach the vacuum vessel. The concerns with this approach will be structural and electrical failure of the insulator, the remote handling requirements and the remote replacement of failed insulators.

E. *Remote Handling*

The requirement for remote handling exists for the IPS proper and for the bolted tiles.

The bolted tiles are attached to the IPS with one central fastener. The proposed design of this spring loaded fastener is such, that after unbolting, the whole fastener assembly is removed with the tile. Remote tile removal will be necessary in case of a tile failure or in case of an IPS failure.

Before the IPS can be remotely handled, the tiles covering the attach fasteners of IPS to support rings, the tiles covering the electrical straps that connect one IPS to the next and thetiles covering the coolant tube access holes have to be remotely removed. The four handling slots are used by the handling tool to hold the IPS during remote operations. Remote tube cutters and later tube welders are used to disconnect and later reconnect the coolant tubes.

SUMMARY

The design of the IPS meets the design criteria for the currents specified in the design documents [8–10,12-14]**.** The increase in design current however will require re-thinking of the design concept and a search for new solutions.

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