Assembly and Commissioning of the ASDEX Tokamak

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Die nachstehende Arbeit wurde im Rahmen des Vertrages zwischen dem Max-Planck-Institut für Plasmaphysik und der Europäischen Atomgemeinschaft über die Zusammenarbeit auf dem Gebiete der Plasmaphysik durchgeführt.

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Abstract

The paper reviews progress in assembling and commissioning of ASDEX since the last conference on Engineering Problems in Fusion Research at Knoxville in October 1977.

The inner poloidal field coils (ohmic heating transformer, vertical and radial field coils, divertor field compensating coils) have been assembled and the switching circuitry completed. The coils have been successfully tested at full design values. A switch for interrupting the current in the ohmic heating circuit (AEG safety switch AP 490) was delivered and installed in October. The outer poloidal field coils are assembled and will be tested in the next weeks. The two multipole (divertor) coil triplets have been incorporated in the vacuum vessel. Both coil triplets have been tested with full current of 45 kA inside the vacuum vessel.

The two halves of the vacuum vessel have been mounted inside the core of the toroidal field coils and connected by insulating gaps made of laminated fibre glass. The connections have been successfully leak-tested.

The ti sublimators and the LN_2-cooled getter panels of the divertor pumping system have been assembled. The LN_2-cooling system is complete and tested.

The outer pumping system, consisting of 8 turbomolecular pumps with 3500 l/s air speed each, is being assembled at present.

The central control system and most of the subsystems are completed and are now being put into operation. The same is true of the distribution elements and switches necessary to connect the coils with the power supply systems of the institute (mainly two fly-wheel generators with 1.5 and 0.5 GJ respectively).

The experiment is complete and should be operational by the end of this year.

Introduction

ASDEX is a tokamak of circular plasma cross-section with two axisymmetric divertors. The whole experiment can be divided into two halves in order to install the poloidal field coils and the divisible vacuum vessel. All poloidal field coils are situated within the core of the toroidal field coils. The multipole coils (divertor field coils) for producing the divertor field are inside the vacuum vessel. The main components of ASDEX are described in /1,2,3/. The experiment is nearly complete and will be operational by the end of this year.

Coil Systems

Toroidal Field Coils

The toroidal magnetic field is produced by 16 equal, D-shaped coils (Fig.1). They have been completed and were already tested in May and June 1977 /4/. These tests showed that the toroidal field coils can be operated with the planned current of 45 kA corresponding to about 2.8 T at the plasma centre, and with a flat-top time of about 5 s. The copper windings are fully embedded in stainless steel casings, by which the magnetic forces are transmitted to the support structure. The measured motion and elastic deformation of the windings in their casings, caused by thermal expansion and magnetic forces, are within tolerable limits and are in good agreement with the calculations.

The cooling system is able to cool the windings within 6 minutes, guaranteeing little temperature differences in the windings by programmed reduction of the water temperature.

The compression rate and the elongation of the central column, due to centripetal forces, are in good agreement with model tests.

Ohmic Heating System and Vertical Field Coils

The poloidal field coil system (Fig.2) consists of the ohmic heating (air core) transformer coils to induce the plasma current, the vertical field coils to stabilize the plasma position and the multipole coils to produce the divertor field, which is largely compensated in the plasma region by compensating coils. All poloidal field coils are composed of detachable segments with bolted winding connections.

After assembling of the 18 inner OH transformer coils and of the switching circuit, this system was tested separately and also tested together with the toroidal field.

In the test the following parameters were measured:

- currents and voltages of coils and in the current breaker circuitry
- cooling water and coil temperature
- motion and deformation of the coils, current leads and mechanical structures
- tilting motion of the toroidal field coils and structure.

To protect the coils against damage, the following parameters were checked by an automatic monitoring system:

- water flow rate in all cooling circuits
- symmetry of the voltage drops in the coil system
- resistance between the casings of the toroidal field coils and ground
- motion of the toroidal field windings within their casings
- compression of the central column
- current in the transformer coils and possible ground currents of the coils in the case of arcing.

Electronic monitoring systems and a data acquisition system including a multiplexer system with 126 channels and a PDP 11/20 process computer are used to record and plot the signals.

The transformer coil system was operated with a current of 30 kA, corresponding to 2.5 Vs, the voltage at current breaking was 20 kV. The measurements showed that the coil system can be operated with the full design parameters; it worked satisfactorily with respect to the electrical and mechanical characteristcs. Deformations, motion and the asymmetry of the motion are tolerable.

The switching circuit worked satisfactorily. To interrupt the OH current, a preliminary air blast breaker was used, whose electrodes have to be exchanged after a few hundred shots. So we replaced the breaker by a AEG-safety switch AP 490, which was installed in the last few days and it will go into operation with ASDEX.

The inner vertical field coils, the divertor compensating field coils and two radial field coils were also tested after completion. There were no difficulties, the coils working at their planned parameters.

Multipole (Divertor) Field Coils

ASDEX has a "double inside divertor" with stagnation points above and below the plasma. The separatrix is produced by a multipole triplet with zero net current (quadrupole field)/5/.

The coils of the divertor field triplet can be operated in series or separately. This allows firstly an operation mode with circular plasma cross-section and, secondly, operation with elliptic or D-shaped plasma cross-section in normal or divertor tokamak operation. The multipole coils have circular cross-sections and comprise 4 and 8 turns respectively.

The coils were delivered at the end of 1978. After initial tests the joints of the half-coils had to be fitted and screwed together and the 6 coils had to be assembled as triplets. One of the two triplets was tested with the rated current of 45 kA. This test showed the mechanical and thermal behaviour of the coils at almost full load: only the interaction with the toroidal field could not be simulated. Measurements of the temperature rise in the BeCu joints, of the cooling process and of the relative motion and deformation showed that the coils can be operated by 45 kA pulses, with the pulse time being limited to 4.3 s.

The only way to install the coils in the vacuum vessel halves was to open the joints of the triplets and insert the half-triplets by means of sophisticated rail and carriage devices. Once the vessel halves were inserted in the coil system and bolted together, these devices also enabled relative motion of the coils in all three directions to rejoin the turns within the vessel and to secure the coils in their fixtures. Once installed, the coils were operated with 45 kA pulses and together with the toroidal field in order to test the fixtures within the vessel and the interaction with the toroidal field and in order to stress the joints before enclosing them in the welded, vacuum-tight, stainless-steel jackets.

The design and manufacturing of the divisible poloidal field coils was difficult because of the narrow space available for the coils, their turn cross-overs and their current leads and because of the accurate tooling necessary for the joints. In the case of the divertor field coils, manufacturing difficulties concerning the cross-over parts made of beryllium copper castings have resulted in great time delay.

Vacuum Vessel

The vacuum vessel (Fig.4) was delivered in spring 1977. Subsequently, it was heated to 150^{o} C by means of overheated water. For this purpose a system of pipes is soldered to the outer walls of the vessel and covered with thermal insulation. After baking the vessel it was successfully leak-tested. Almost all fixtures for the divertor field coils, for the divertor pumping system and for diagnostics have been fitted and preinstalled in the open vessel halves. The two triplets of the multipole coils were then fitted inside the vessel and the two halves of the vacuum vessel were mounted inside the core of the toroidal field coils. The halves were connected by insulating gaps made of laminated fibre glass. These connections were successfully leak-tested. The divertor chamber separating plates, getter panels belonging to the divertor pumping system, the Ti sublimators, and the passive plasma stabilizing coils were also incorporated. Many built-in diagnostic facilities are also installed, e.g. electromagnetic probes and loops, microwave diagnostics and equipment for preionization.

Vacuum System

The external for base vacuum system consisting of 8 turbomolecular pumps, each with 3500 l/s air speed, is already complete, installed and partly leak-tested.

After the divertor field coils have been installed the 26 liquid-nitrogen-cooled getter panels, part of the divertor pumping system, were fitted into the vacuum vessel. The getter panels are of serrated aluminium plates which provide the required area increase. A set of tubes on these plates is part of a closed cooling system through which liquid nitrogen circulates.

Each of these 26 chambers contains two titanium sublimators, each comprising 19 Ti-Mo filaments. The 19 wires are directly heated by a current of 750 - 1000 A. The sublimators can be replaced from outside the vacuum vessel. Fig.5 shows a getter panel with two Ti sublimators in a divertor chamber model.

The cooling and heating system for this purpose is already complete and tested. It pumps the nitrogen through the getter panels. By pumping pure liquid, mixed liquid-gaseous or heated gaseous nitrogen through the panels it is possible to set temperature between 80 K and 150^{o} C.

Power Supply System

The different coil systems and devices of ASDEX are powered by the following generators and power supplies:

The toroidal field coils are powered by the

- 1.5 GJ flywheel generator with diode bridge.
  Main data: 150 MVA, 100 Hz, DC 45 kA, 33 kV.

The ohmic heating transformer with feedback control of the flat-top plasma current, the vertical field coils with feedback control of the radial plasma position, the divertor field coils with programmed current are fed by the

- 500 MJ flywheel generator with 10 separate thyristor rectifier modules
  Main Data: 144 MVA, 100 Hz, DC 22.5 kV, 5 s, 1.2 kV per module.

For alternative powering of the ohmic heating transformer a

- 15 MJ flywheel generator with mercury arc rectifier is available .

The radial field coils for feedback controlling the vertical plasma position are powered by a

- 4-quadrant transistor amplifier with 250 kW.

The Ti Sublimators of the divertor pumping system consist of cooled high-current feed-through on 4 1/2"CF flange and two parallel Cu bars between which the Ti/MO wires are clamped. The sublimators are powered by a supply with 2 x 10 V, 13 kA, 250 kW.

All distribution elements and switches necessary to connect the coils with the power supply systems of the institute have been completed.

Control Systems

To allow joints as well as separate operation of all systems of ASDEX, the control system is hierarchically organized. It is controlled by a central control unit and most of the sub-control and auxiliary systems are complete and pretested.

Feedback System

The plasma position in ASDEX is to be safeguarded from radial displacement by a thyristor-operated vertical field control circuit, from vertical displacement by a radial field control circuit with power transistors. The essential magnetic coupling and time constants were therefore determined in a model of ASDEX /6/. These systems are already complete and pretested.

References

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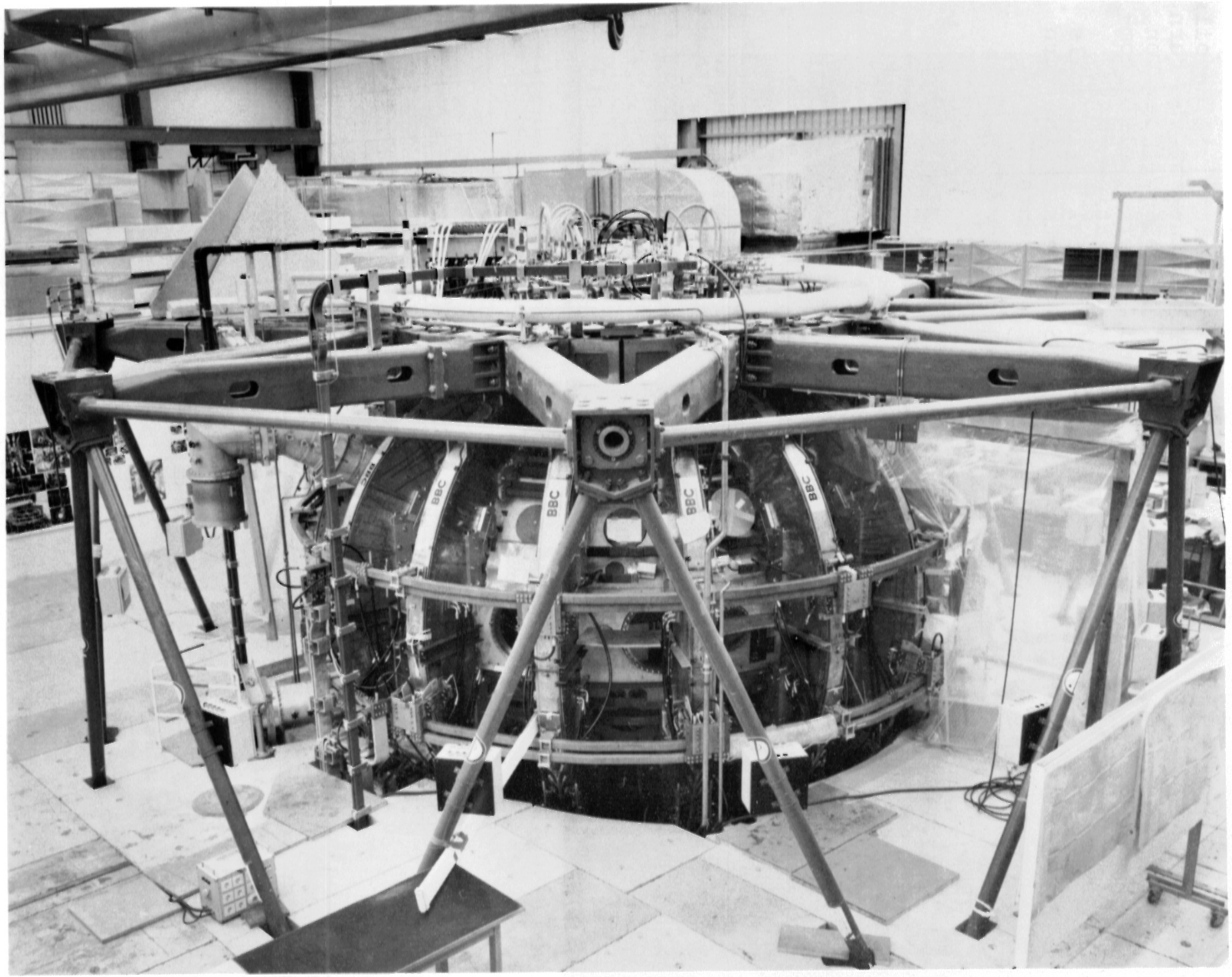

Fig. 1: General view of ASDEX with toroidal field coil system, structure and vacuum vessel

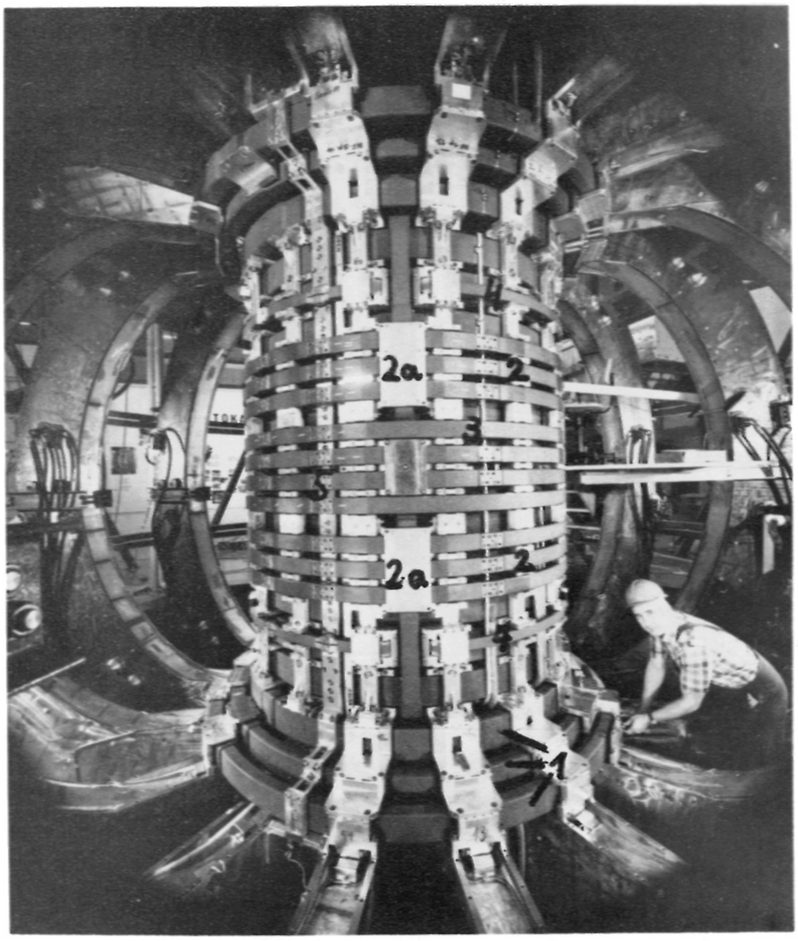

Fig. 2:
1 OH-transformer field coils
2 Vertical field coils
2a Fixture of the turn cross-over section
3 Divertor field compensating coils
4 Radial field coils
5 Joints of the turn segments

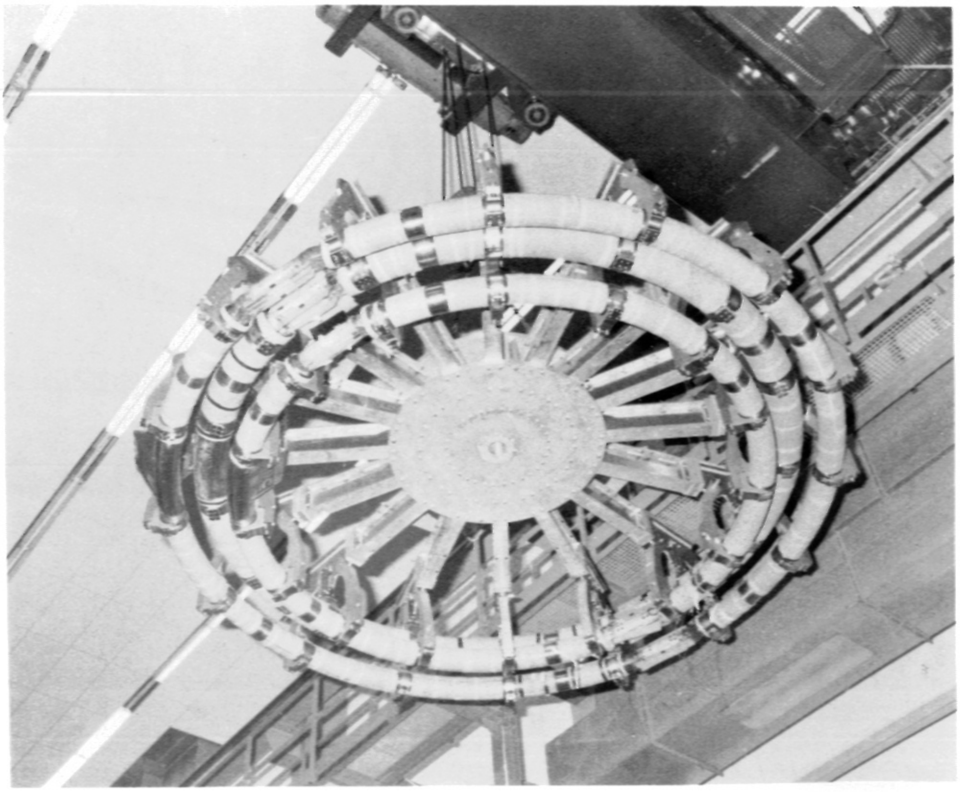

Fig. 3: Divertor field coil triplet

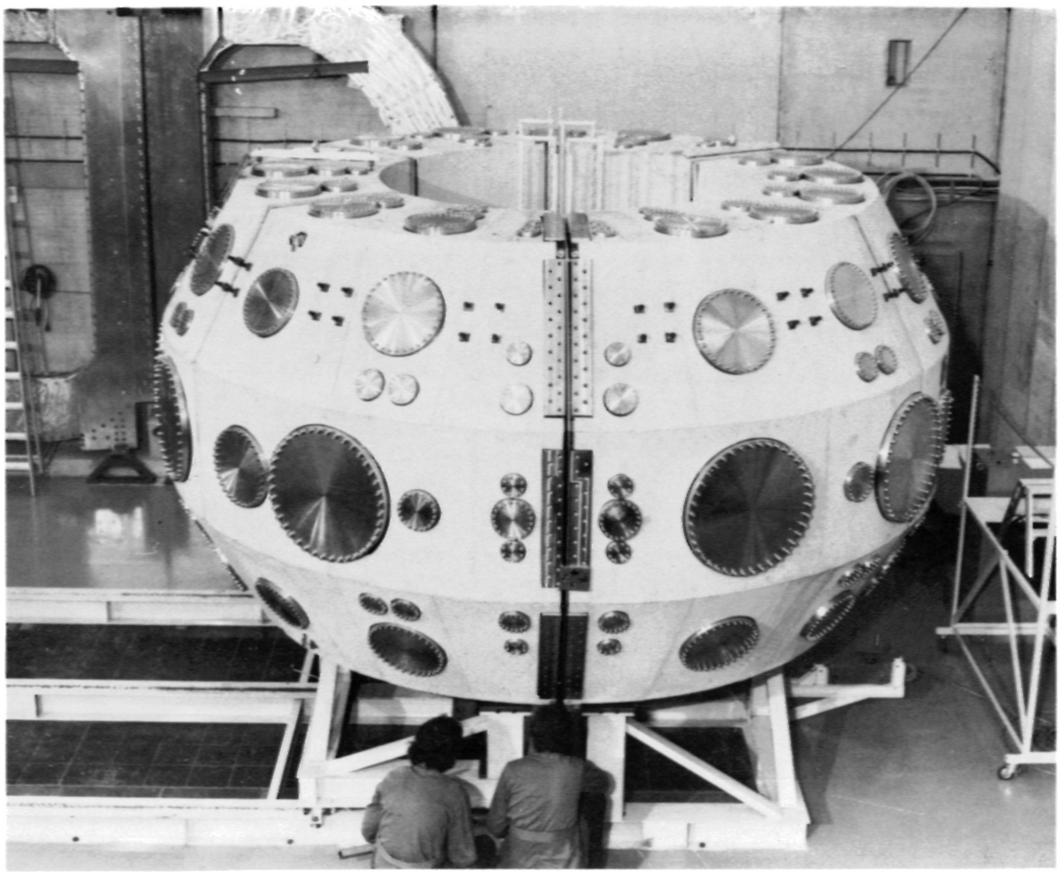

Fig. 4: Vacuum vessel

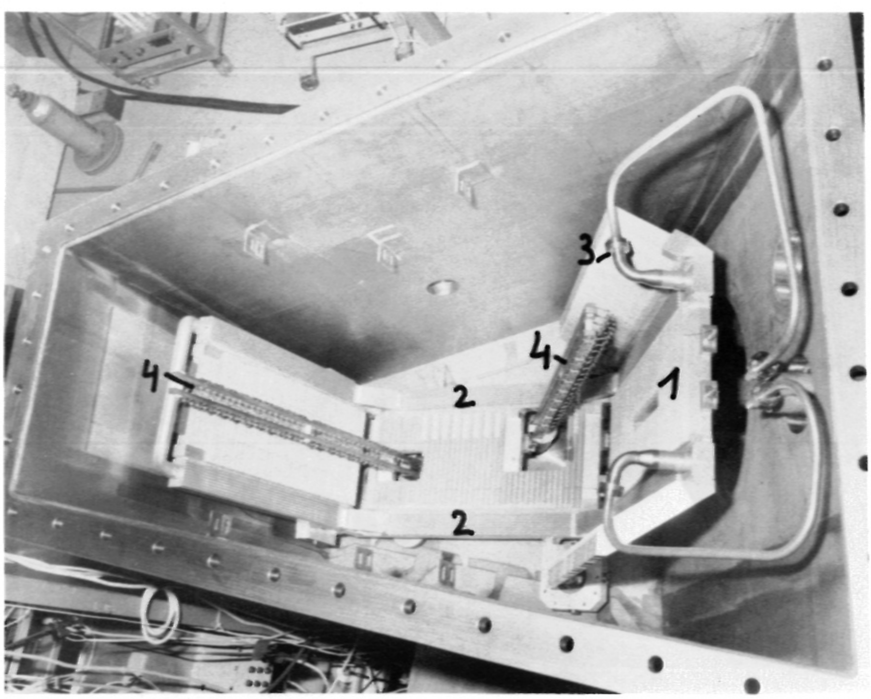

Fig. 5:
One getter panel of the divertor pumping system

1 Aluminium profiles welded onto aluminium
2 Aluminium bars
3 Nitrogen inlets and outlets
4 Titanium sublimators