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Detailergebnisse / Details

TEXTOR

Commissioning of TEXTOR with the Dynamic Ergodic Divertor (DED)

Technical Concept of the DED

The Dynamic Ergodic Divertor (DED) has been installed in TEXTOR in order to influence transport parameters in the plasma edge and to study the resulting effects on heat exhaust, edge cooling, impurity screening, plasma confinement and stability. The DED consists of four sets of coils at the inboard side of the TEXTOR vacuum vessel, each with four helical conductors (Fig. 1). Two additional conductors at the top and at the bottom are necessary for the compensation of edge effects due to the combination of four coils each at the vacuum feed-throughs.

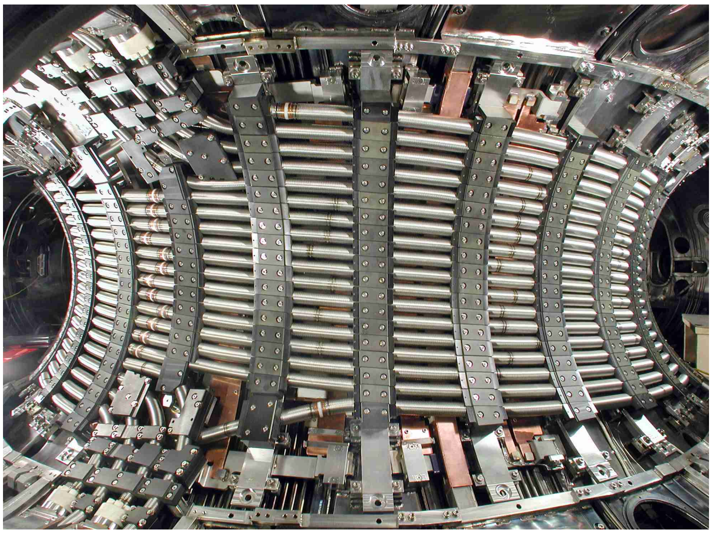


***Fig. 1**: Location of the DED coils inside the TEXTOR vacuum vessel.*

For the installation of the coils the TEXTOR liner has been removed, a 120 degrees section cut out poloidally and re-inserted. A support structure welded to the vacuum vessel clamps the coils and also the target plates to the vessel. Coaxial vacuum feed-throughs include connections for coil currents and cooling media.

The coil sets are energized by DC or 4-phase currents at selected frequencies (50 Hz and between 1 kHz and 10 kHz) with amplitudes of up to 15 kA.

DED Prototype Testing and Simulation

Numerous tests of the support structures, the coils, the feed-throughs, the eddy current heating and the assembly of DED components have been performed using a specially built mock-up, which is equipped with a spare toroidal field coil of TEXTOR for generation of relevant magnetic fields and a prototype power converter, allowing for the operation of the DED coils at the full frequency range (DC and 50 Hz to 10 kHz).

Integration of the DED

During the major shut down all preparations for the DED have been performed and the components have been integrated. In parallel TEXTOR components have been modified to allow for the integration of the DED and for improvements of the TEXTOR performance. General maintenance has been carried out, subsystems have been improved and wear parts exchanged.

New platforms have been planned, manufactured and set up in the TEXTOR bunker in order to allow for the installation of DED-components as well as diagnostics.

The main steps of the DED installation have been:

- opening of the TEXTOR bunker (removal of the roof and parts of a wall)
- removal of diagnostics (control cabinets and diagnostic equipment including flanges to the vacuum vessel)
- dismantling of TEXTOR (after splitting the vacuum vessel, the liner, poloidal coils, transformer yokes and other components are removed)
- removal, modification and reintegration of the modified liner
- adjustment of the modified liner inside the vacuum vessel (using specially designed turnable supports)
- construction, assembly, adjustment of a laser measuring system and an alignment rail system used for precise positioning of DED in-vessel components
- assembly and installation of the coaxial feed throughs and high frequency shielding
- welding of pads for DED coil supports onto the vacuum vessel
- installation of the coil clamps and DED coils
- installation of the divertor supports and divertor target plates

Electrical Systems

Only two separate power supplies are required to produce 4-phase currents. Nine power supply units with 750 kW each (Fig. 2) supplied by a single rectifier transformer are foreseen to limit the unit size, to have 9 identical units and to allow for special asymmetrical patterns of current distribution. Each power supply unit feeds a load unit of two coils. The details of the power supply concept have been defined together with industry.

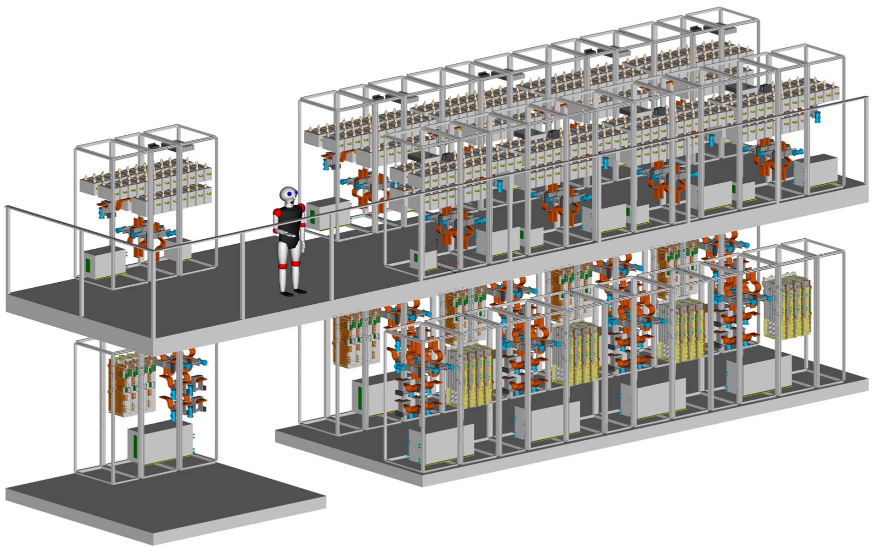


***Fig. 2**: Arrangement of the DED power supply system.*

The maximum operating frequency of 10 kHz led to the choice of IGBT inverters. Between 1 kHz and 10 kHz the reactive load is about 20 times the active load. For compensation capacitor banks are connected in series to the load thus forming resonant circuits. Two capacitor banks in three different configurations each, plus the parallel connection of both, yield 7 resonant frequencies.

The DED power supply system has been completely installed and commissioned. After testing with a full size dummy load and final modification of the control software the system has passed the final acceptance test.

Commissioning of TEXTOR

Apart from usual commissioning procedures for

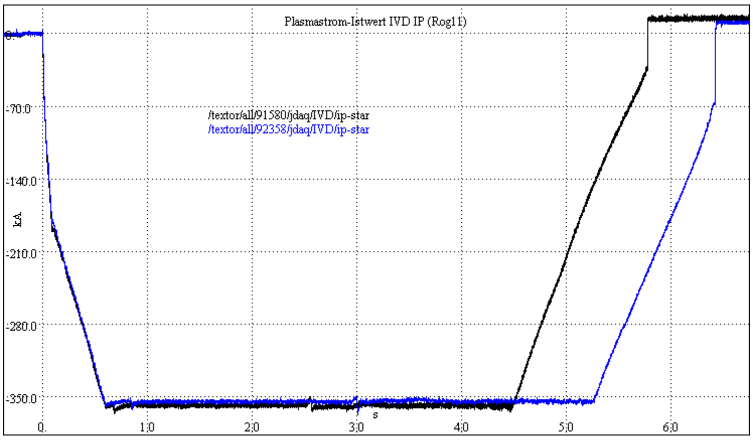
- the vacuum system,
- the heating system,
- the cooling system,
- the power supplies,
- the control and data acquisition,
- the main diagnostics

the situation after integration of the DED required particular attention to the new operating characteristics of TEXTOR.

During shut down the TEXTOR liner with 120 degrees poloidally cut out has been modified in order to redistribute the liner heating current. The heating of the liner has carefully been observed and analyzed in order to be sure to have a proper surface conditioning and to avoid partial overheating. With the DED coils and their support structure as well as the divertor a huge amount of additional surfaces had to be conditioned – many of them being heated via radiation from the liner and the vacuum vessel only. Even if – due to outgassing of polyimide – the base pressure in TEXTOR for a couple of weeks did not reach the level observed before the integration of the DED, plasma operation started.

The start-up phase of the plasma also had to be adjusted after major modifications. TEXTOR start up works at maximum pre-magnetization of the iron core in order to maximize the shot length (up to more than 10 s). The ionization process at application of the break down voltage is very sensitive to the presence of stray fields even in the order of 0.1 mT. Using the stray field diagnostics appropriate start-up conditions could be found.

Glow discharge cleaning and boronization of TEXTOR finally led to first successful shots and to improved performance (Fig. 3).



***<u>Fig. 3</u>:** Plasma current of TEXTOR shot #92358 at improved performance after boronization. The black trace shows reference shot #91580 before DED installation. The shot length is influenced by auxiliary heating.*

After improvement of the vacuum condition the feed-back control systems have been adjusted to the new situation resulting in a plasma performance comparable to that before DED integration.

According to experiences during commissioning of the DED power supply system on a dummy load induced error signals have to be expected at medium frequency operation. In order to prevent this, a fibre optic transmission was developed. More than 50 diagnostic signals being sensitive to disturbances have been equipped with this.

A couple of machine diagnostics have been modernized during shut down. One of them being the magnetic diagnostic of the TEXTOR iron core had to be replaced because repair of the old system was impossible. After appropriate adjustment and calibration the performance and accuracy of the old system could be reached (Fig. 4). Thus, the diagnostic is available again for pre-control of the plasma current feed back control resulting in an improved performance.

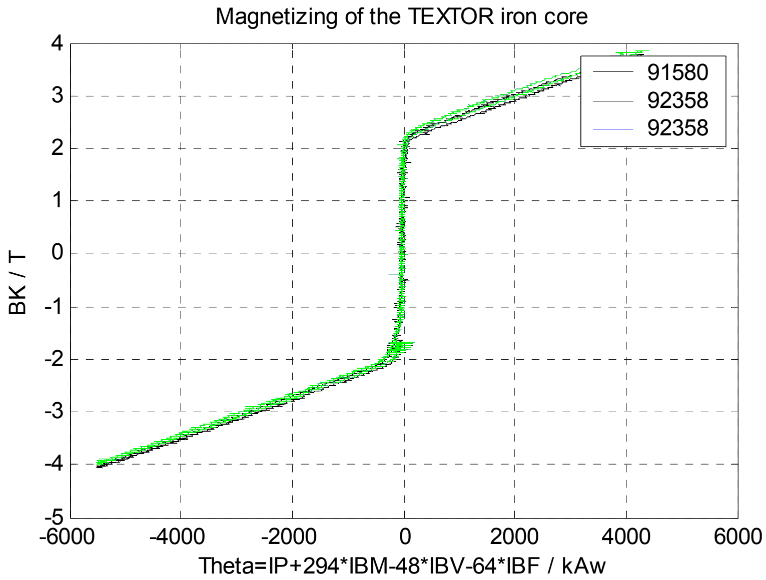


***Fig. 4:** Magnetizing of the TEXTOR iron core – comparison of results of the old (black and new (blue, green) diagnostic.*

Commissioning of the DED

The DED power supply system has been commissioned on a full size dummy load before cabling with the DED coils. Thus, necessary control parameters already were available. Since the dummy load could not simulate several inductive couplings as well as mirror currents in the TEXTOR vacuum vessel an additional commissioning with the real DED coils was required. After tuning the power supply control parameters to fit the real load and tuning of the de-coupling transformer optimum, AC operation without mutual disturbances and without influence on the plasma position could be achieved (Fig. 5).

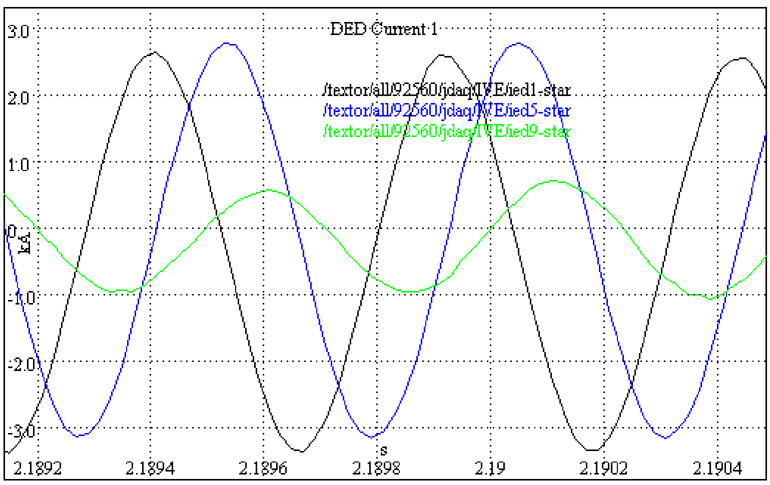


***Fig. 5:** DED current traces. Operation at 2 kHz and 3 kA in shot #92560. 0 degree system (black, inverted), 90 degree system (blue), compensation coils (green).*

In addition to the originally planned operation of the DED at DC and AC between 1 kHz and 10 kHz a low frequency mode was prepared and successfully applied. Slow ramping of the DED currents in DC mode results in low frequency field with a DC component overlaid (Fig. 6).

After finishing the DED commissioning at all frequencies the DED was applied to the plasma for the first time. As expected the influence of the magnetic perturbation field could clearly be seen in a certain pattern of radiation from the divertor target plates (Fig. 7).

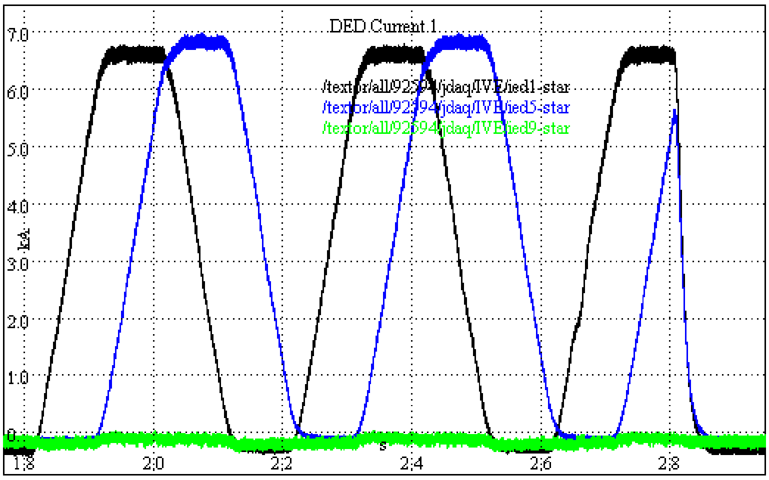


Fig. 6: *DED current traces for operation at 2 Hz and 7 kA in shot #92594. Low frequency operation is produced by ramping in DC mode. 0 degree system (black, inverted), 90 degree system (blue), compensation coils (green).*

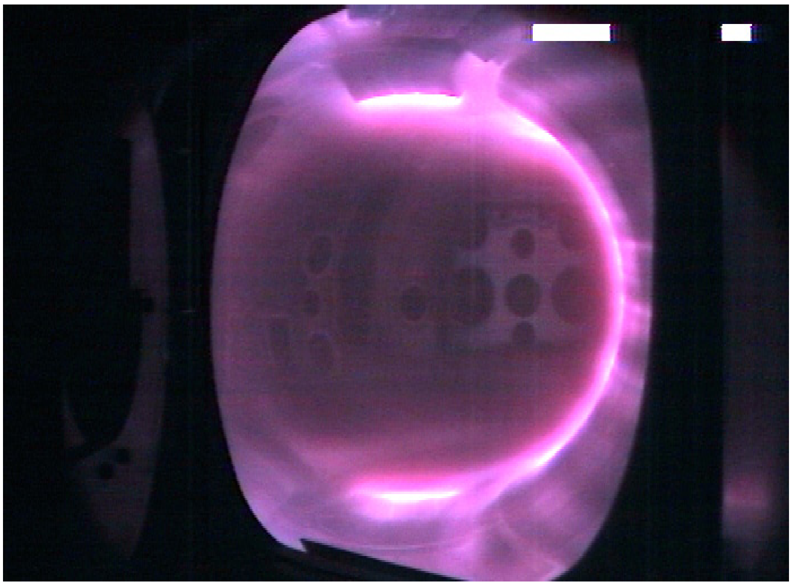


Fig. 7: *Influence of the perturbation field on the distribution of radiation in front of the divertor in TEXTOR shot #92573.*

Improvement of the DED

First operating experience showed the need of minor improvements of the DED. At DED operation with plasma arcing occurred to the DED coils. In order to avoid damage of the outer tubes of the DED coils additional insulation has been inserted in a short shut down in 2003. In addition to this, grounding resistances have been connected to all tile support structures. This defines the electric potential during glow discharge cleaning on one hand and allows for voltage measurement on the other hand. The value of the resistance has been chosen for limiting the currents flowing during disruptions.

Large holes in the liner have been mechanically reinforced by stainless steel bridges during DED installation. Experiences with liner heating showed the necessity to relieve those bridges from the liner heating current. This has been done by adding copper strips in parallel.

Preparation of the DED 3/1 mode operation

In parallel to the experimental programme with the DED in the 12/4 mode all preparations have been done to allow for first experiments in the 3/1 mode in 2004. For this purpose a second set of coaxial cables had to be routed, configured and connected. At the end of TEXTOR operation in 2003 all cables of the 12/4 mode have finally been replaced by the 3/1 mode cables. This was followed by a measurement of the complete inductance matrix of the DED coils including cabling. These results were required in order to adjust the power supply system control to the new load. Estimates of the parameters could only be roughly made in advance, since in 3/1 mode uncompensated feeding of the currents adds considerable couplings to the inductance matrix.

Data Acquisition and Processing

In 2003, first experiments with the Dynamic Ergodic Divertor (DED) have been performed on TEXTOR. Furthermore, a large part of the diagnostic systems moved from the old fashioned VMS based data acquisition software to the new platform independent Java based architecture JDAQ. The diagnostic data is now acquired under JDAQ control and subsequently transferred to the common storage facility (CSF) for every discharge.

Even during experiments with a large number of participating scientists and many diagnostics being online, the access to the data – once having been stored at the CSF – is very fast. The available disk space of the CSF – amounting to 1.5 TByte – was not enough for the envisaged aim to store one complete year of TEXTOR experiments. In consequence, additional disk space of 3 TByte has been added. The huge increase of the data volume per discharge stems from the fact that a lot of diagnostics have been upgraded during the TEXTOR shutdown (more channels per diagnostic system and a better time resolution). Furthermore, several new diagnostics – each producing additional data in the order of ~ 100 MByte per discharge (and even more) – a have been developed and became operational.

For the detailed analysis of the data mainly IDL and MATLAB licenses have been bought and installed on the PCs in the TEXTOR control room. These packages are used because the application of these high level data analysis tools drastically reduces the time for programme development due to the large number of ready-to-use functions. Several client libraries have been developed to allow for raw and pre-processed data access using these software packages. For a simple and oscilloscope-like visualisation of raw and pre-processed data a Java based software from Padua University (jScope) is used while being under continuous development.

Several programmes to calculate physical quantities from the raw data of various diagnostic subsystems were developed. These codes have been implemented into the so called "Chain1 automated intershot data analysis". The intershot control programme launches these programmes and stores the derived physical quantities into the TEXTOR Physics Database (TPD), an Oracle database running on a dedicated server machine. The main process of the intershot data analysis is based on Unix script languages like sh, awk, and make. However, the individual analysis programmes can be written in any standard programming language, like C, C++, Fortran or Java, respectively. The intershot main process starts the various analysis programmes in parallel, making the whole analysis quite fast. For a better control and fault tracking of the intershot analysis log files for every discharge and every calculation step are written automatically and can be accessed with a standard internet browser. For those diagnostics which still need a large amount of manual control a web interface to allow the upload of data files has been developed. A second command line driven interface based on tcl/tk is available, too, and can easily be integrated into the user-side analysis codes.

The TPD itself is discharge oriented, being able to store 1- and 2-dimensional data. Support of 3- or more-dimensional data can be implemented easily. Post-processing of already available data is foreseen in future. A version control scheme is available, which keeps track of the various data uploads. The most recent version of a signal will be returned from the TPD server, as long as no special version number is specified. For a fast access, the data is indexed by the discharge number. The number of available signals from the TPD has steadily increased over the year and the TPD as one of the main data stores is now widely used by scientists working at TEXTOR.