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A multi-purpose manipulator system for W7-X as user facility for plasma edge investigation

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HIGHLIGHTS

- Investigation of edge plasma at W7-X with new multi-purpose manipulator (MPM)
- MPM components, functionalities and the unique interface to the probe head.
- Presentation of the scope of physical parameters.
- Operational parameters for the movement.
- Electrical environment for measurements.

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ABSTRACT

The investigation of edge plasmas at the stellarator W7-X requires a flexible tool for integration of a variety of different diagnostics as e.g. electrical probes, probing magnetic coils, material collection, or material exposition probes, and gas injection. A multi-purpose manipulator (MPM) system has been developed and attached to the W7-X vessel before the operational phase 1.1. The system was designed as user facility for many diagnostics, which can be mounted on a unique interface without breaking the W7-X vacuum. The manipulator system, located in the equatorial plane, transports the inserted diagnostic probe to the edge of the inner vacuum vessel. From there, the probe can be moved over a maximum distance of 350 mm to different positions inside the plasma with a maximum acceleration and deceleration of 30 m/s^2. Acceleration, speed, and stroke depth are individually adjustable and programmable by a PLC system within predetermined limits. The MPM system can be equipped with multifunctional probes and is prepared for cooling/heating of the probe head, gas injection, and a flexible setting of the electrical diagnostic. In the paper, the MPM components, their functionalities, and the interface to the probe head are described. The scope of physical parameters is presented for the development of diagnostic probes applicable in the MPM user facility. This also includes the operational parameters for the movements and the electrical environment for measurements. The operation of the MPM during the OP1.1 is demonstrated on the application of a multipurpose probe head, including electric, magnetic, and thermal probes.

1. Introduction

Within the operational planning for the Wendelstein7-X (W7-X) stellarator at the Max Planck Institute for Plasma Physics in Greifswald, it was decided to include a system for investigation of edge plasmas within the early operation phase OP1.1 [1] as one of few non-machine diagnostics. For later operation, W7-X requires a flexible tool for integration of a variety of different diagnostics as e.g. electrical probes, probing magnetic coils, deposition or erosion probes, and gas injection [2]. The early operation of the multi-purpose manipulator (MPM) system gave the opportunity to prepare the system as user facility for many diagnostics, which can be mounted on a unique electro/mechanical interface. Adapter for

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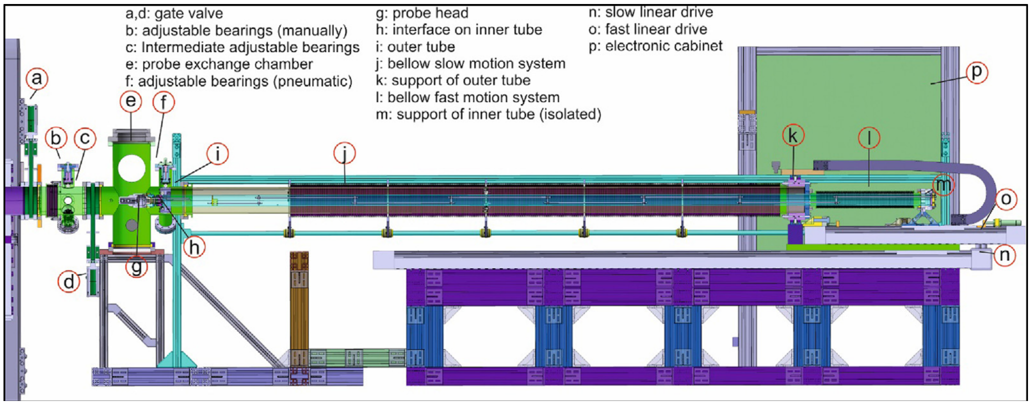

Fig. 1. Mechanical components of the MPM system.

this interface is available, supporting the design of additional diagnostic probes. The manipulator system is equipped with a probe exchange chamber, which is decoupled from the W7-X main vessel vacuum by two serial gate valves. Conditioning of the probe (probe heating system is possible) is done in the autonomous vacuum system of the MPM. Falling below the W7-X safety level of $1 \cdot 10^{-5}$ mbar allows the gate valves to be opened. The electrical driven low speed axis transports the inserted diagnostic probe to the edge of the inner vacuum vessel. From there, the probe can be moved over a maximum distance of 350 mm to different positions inside the plasma by the high speed drive. Acceleration, speed, and stroke depth are individually adjustable and programmable by a PLC system within predetermined limits [3]. Operation is inhibited if the temperature of the inserted probe, which is permanently controlled, is above a given threshold. The operation is remotely controlled from the central control room of W7-X (Fig. 1).

2. Mechanical setting/components

The MPM system consists of two independently pumped UHV chambers, which are arranged in line and separated by a gate valve. For safety reasons, an intermediate chamber was integrated and is connected to the W7-X chamber via a gate valve. This chamber also includes three adjustable bearings as support for the outer tube. The second gate valve at the end of the intermediate chamber is followed by the probe exchange chamber. Due to multiple ports, the manual exchange of the probe head can be done here. In addition, the chamber is equipped with four windows for observation of the probe by cameras if access to the torus hall is not possible. To fix and center the retracted outer tube, the probe chamber is followed by a second set of three adjustable bearings. For operation, this set is retractable by pneumatic pistons to limit the amount of supports of the tube to two positions during operation. The main vacuum vessel is continued by the first edge welded bellow, containing the central carrier for the probes which consist of two coaxially arranged tubes. The outer tube driven by the slow linear motion system transports the probe through the duct in the cryostat to the inner vessel wall. A second linear motion drive, carried on the slow system, then does the controlled fast movement for the inner tube. Industrial systems with a toothed belt are used for the drives. They allow an acceleration value up to 50 m/s^2. The belts are driven by PLC-controlled servo motors with gear ratios of 3 (3.3 kW) for the fast and 10 (1.4 kW) for the slow system [3]. The central carrier tube of the manipulator contains a unique interface, which is provided to the user. It allows fast exchange of the probes. The system finally is covered by the second edge welded bellow.

Both vacuum systems are separately equipped with a rotary vane pump in combination with a turbo-molecular pump. The

Table 1
Absolute probe head positions (150 mm long) OP1.2.

W7-X coordinate	Parking pos. (mm)	Max stroke pos. (mm)
X	−5873	−5548
Y	−2232	−2103
Z	−168	−168
R	6283	5933

pumping systems are retracted from the magnetic field of W7X by additional pipes in order to keep the magnetic stress below 10 mT. Pumping capacity of the systems is 65 l/s (TURBOVAC SL 80 DN 63 CF) for the intermediate chamber and 400 l/s (TURBOVAC 361; DN 160CF) for the main vacuum.

3. Main operation positions of the manipulator motion

The MPM system is equipped with two mechanical coupled, electrical driven, linear drives. For OP1.1, three different modes of operation have been defined.

a Service Both linear drives are completely retracted. The slow and fast motion systems are mechanically blocked by massive pistons in this position. Both gate valves to the vessel are closed. The probe head is accessible within the service chamber for maintenance or exchange.
b Parking Both gate valves to the W7-X vessel are open. The probe head is moved 2457 mm through the duct of port AEK40 by the slow motion system and stays close to the virtual inner vessel surface within this port (0.2 m/s). The low speed axis again is locked in this position by a piston.
c Operation All positions from parking position to maximum stroke depth into the inner vessel are handled by the fast linear drive. The maximum penetration depth is 350 mm. A fixed position, multiple steps, or up to three (more in preparation) repeated strokes to certain positions are programmable by the PLC system [3]. For OP1.1, a maximum acceleration of 30 m/s^2 was used. The design value of the maximum speed is set to 3.5 m/s. For the whole cycle of one 350 mm stroke, a time of 432 ms was achieved.

4. MPM location at W7-X

The MPM system is located at W7X-port AEK40 near the equatorial plane. The absolute Cartesian coordinates of the parking position and the maximum stroke position, using a probe head, 150 mm long, are given in Table 1. The values are valid for OP1.2, during OP1.1 both positions were retracted by 61 mm.

The access to the same magnetic flux tubes, which simultaneously are observed by means of spectroscopic methods at the lower

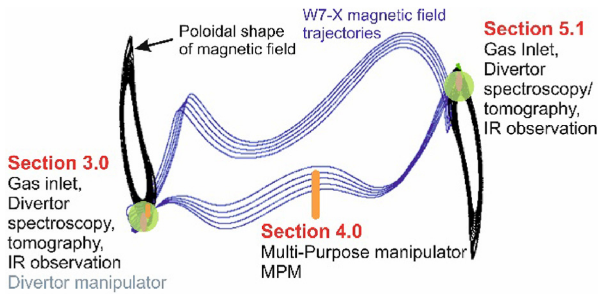

Fig. 2. Location of diagnostics with identical magnetic flux tubes at W7-X.

(Section 3.0) and upper divertor regions (Section 5.1) in the neighboring sections of W7-X, is shown in Fig. 2. In all sections, short gas pulses can be injected into the flux tubes to investigate the toroidal and radial transport of plasma particles [4]. Due to the large stroke depth of 350 mm for all magnetic configurations in W7-X, the LCFS is accessible, only limited by the toroidal heat load.

5. Probe head interface

To obtain an easy use and exchange of different probe systems, a new probe interface was designed (Fig. 3). The probe head is mounted on a base adapter with an external 70 mm thread. This adapter has to be fixed by a knurled nut on the manipulator system. For the probe itself, the dimensions are restricted to a maximum length of 150 mm, a diameter of 120 mm, and a weight of 2000 g. The interface includes 32 electrical contacts (max. values: 3 A, 500 V). Four pins are reserved for thermal measurement; 28 are free for application. One gas inlet system with an inner diameter of 3 mm is also available. The carrier of the probe head allows three different modes of electrical operation (floating, grounded, biased). The maximum allowed isolation voltage is defined to 1 kV.

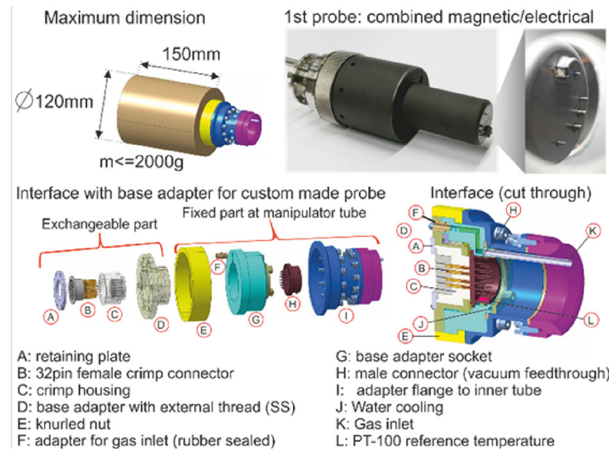

Fig. 3. Probe head and mechanical interface.

6. Electrical measurement

In order to reduce measurement noise even for very small signals, the electrical measurement system was divided into three parts (Fig. 4). Close to the probe head (cable length of 12 m), a first amplification stage with different options for isolation could be used. Inside the cubical at the manipulator rack, two 19″, 3U racks are placed. Those racks are designed for quick exchange to give the opportunity of preparing a dedicated sensor electronic for every unique probe head. Second and third cubicles are placed inside the W7X torus hall (SWG-OG1-E2/E3). One cabinet is equipped with power electronics, e.g. for biasing, and the other contains additional isolating amplifier and the MDS plus based data acquisition systems. With the example, the configuration of electronics is shown during use of a combined electrical/magnetic probe head [5]. Most of the electrical standard signals (e.g. motor current and encoder

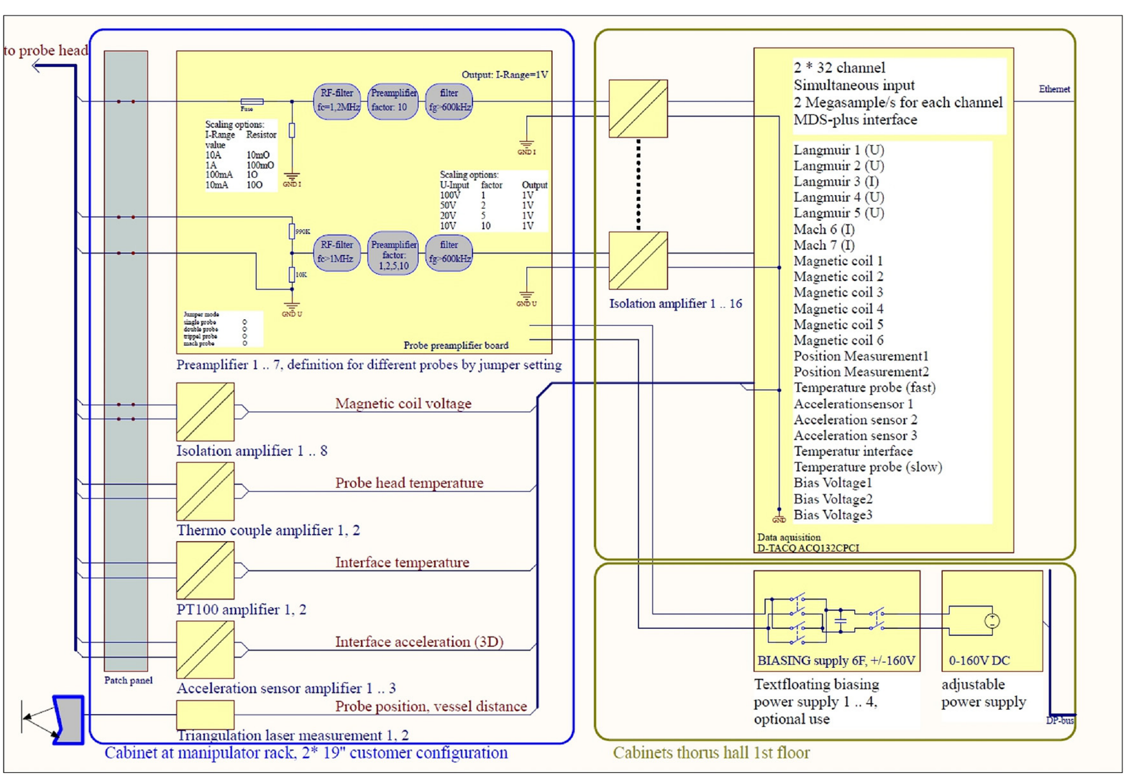

Fig. 4. Scheme of sensor electronics.

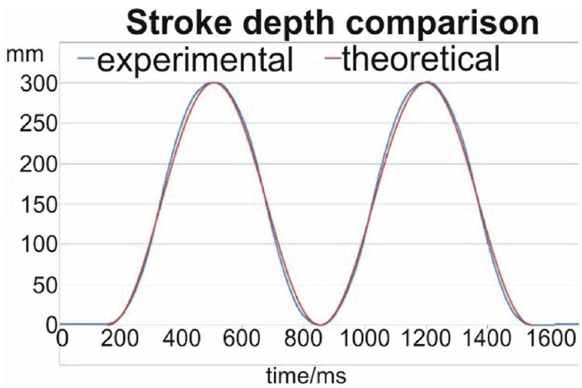

Fig. 5. Comparison of calculated versus measured movement.

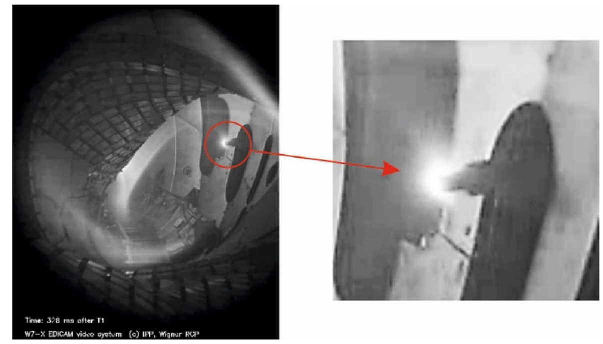

Fig. 6. Plasma contact at 275 mm stroke depth.

drive position) are logged by the PLC system. In addition, some diagnostics are used to generate important basic signals for each stroke:

- Two Pt100 sensors to measure the flange temperature of the probe head. These sensors are placed inside the plug of the probe interface. They are also used as cold-junction compensation for thermo-couples of the probe head. In addition, operation of the manipulator is blocked if the interface temperature rises above 100 °C.
- Two thermocouple sensors within the probe head are mandatory. As standard the K-type is used, other types are possible.
- Two independent optical distance measurement (laser triangulation). One signal gives the position of the MPM low speed axis in relation to the W7X cryostat to verify the distance of those systems which are decoupled by a bellow. The second sensor measures the stroke depth of the fast system in relation to the MPM low speed axis. With those measurements (time resolution ≥100 µs), the position of the probe head in W7X is well defined within a range of ±0.2 mm at a speed of 2 m/s.
- To get some information on mechanical oscillation or vibration of the probe head, which may influence the measured data, a three-dimensional acceleration measurement is placed inside the inner carrier tube, right behind the probe head interface. The sensors can measure acceleration up to 100 m/s^2 with 1 ms time resolution.

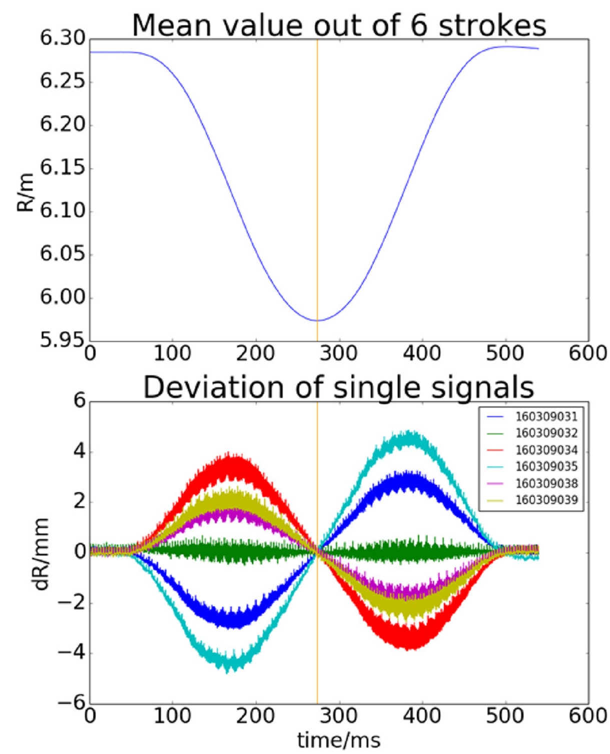

Fig. 7. Dynamic behavior for repeated strokes.

7. First operation, measured data

Operation of the MPM system started with commissioning of the drives at FZ-Jülich. Fig. 5 shows a good accordance between the theoretical progress of the movement and the real measurement. After transportation of the complete and preset system to Greifswald, it was installed at W7-X. First operation during plasma campaign OP1.1 was started. A video snapshot shows the probe head in contact with the outer plasma region (Fig. 6).

During the experiments, several shots with identical parameter sets have been performed. Fig. 7 shows the maximum deviation of the positioning signal in comparison with the mean value for six discharges. During the dynamic phases of acceleration and deceleration, a deviation up to 5 mm could be measured between a single signal and a calculated mean value out of six experiments with identical parameters. Therefore, the position signal is important for all calculations during the acceleration or deceleration phase. Another relevant result of this measurement is the good accuracy of the maximum stroke depth, which is essential for the constant heat load of the probe head during similar experiments. The maximum difference in that point is below 0.2 mm. First results of probe data have been shown in Drews [5].

8. Conclusion

With the MPM system, a new, powerful diagnostic is operational at W7X. During the development, one of the main goals was to build a highly flexible tool which could be accessed by many users and allows a fast change of different probe systems and their electronics. For the positioning system, this flexibility was already demonstrated in OP1.1, but development of new drive cycles is still going on for additional applications. Within OP1.2 of W7X, the MPM increasingly will be used with different probe heads, also for this challenge the system is well prepared.

Acknowledgments

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