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Test of the steady state W7-X control and data acquisition system at the WEGA stellarator

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ABSTRACT

The new quality of the superconducting fusion device Wendelstein 7-X (W7-X) is its potential of steady state operation. W7-X is also a very complex technical system. In these two aspects W7-X compares to other super conducting fusion devices (ITER, KSTAR, EAST, SST-1, Tore Supra, JT-60SA, and LHD). The modular and strongly hierarchical control, data acquisition, and communication (CoDaC) system has been designed to cope with these two aspects, unprecedented for the control systems used by most operating fusion devices.

The CoDaC system for W7-X will be thoroughly tested in a prototype installation at the WEGA stellarator in order to minimize the risks before commissioning. WEGA is a classical stellarator which allows steady state plasma pulses at a magnetic field of 0.06 T. WEGA can run pulses up to 20 s at a magnetic field up to 0.5 T. Despite its lesser complexity WEGA has the same main components as W7-X, e.g. magnetic coil systems and ECRH. It is therefore considered to be a suitable test-bed for the control system.

This paper focuses on discharges controlled by the new control system and the enhanced surveillance mechanisms introduced during the first year of operation. It shows characteristic curves for the key control parameters of the major components. Taking additionally dependencies and constraints between and within components into account a segmented discharge for each experiment is presented as result.

1. Introduction

Wendelstein 7-X (W7-X) is a very complex fusion device capable of continuous operation. A modular and strongly hierarchical control system has been developed to cope with this [1].

The core element of this control system is the Segment Control, which allows operating experiments in real time. Segment Control is PC based. Control and data acquisition features are coded as software modules. The behaviour of a module is defined by an individual configuration and can be changed dynamically by replacing certain parameter objects at runtime. The time line of an experiment program is divided into time slices, so called ‘segments’. A segment contains a complete set of parameter objects for all modules, thus fully describing the behaviour of the whole system for this fraction of time. Switching from one segment to another alters the behaviour of the system.

To minimize the risks before the commissioning of the control and data acquisition system at W7-X it will be thoroughly tested in a prototype installation at the WEGA stellarator. WEGA is a classical stellarator which allows steady state plasma pulses at a magnetic field of 0.5 T. Despite its lesser complexity WEGA has the same main components, e.g. magnetic coil systems, ECRH, and diagnostics as W7-X and is therefore considered to be a suitable test-bed for W7-X CoDaC (Control, Data acquisition, and Communication).

2. Realisation of the control system

In the first phase of the CoDaC prototype project WEGA has been adapted to the W7-X control and data acquisition standards. These standards include the W7-X component model implying that WEGA has been divided into subsystems, also known as components [2]. These are all actor systems Gas Inlet, Magnet Supplies, Microwave Heating (based on two Magnetrons) and the diagnostics necessary for operation, i.e. Interferometer. Two W7-X prototype diagnostics, magnetic probes and a spectrometer were included.

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The installation of the new W7-X like CoDaC system at WEGA has been finished in March 2008. In April 2008 final commissioning and testing of the complete system took place. An in-depth description of this phase is given in Refs. [3,4].

In a second phase some extensions have been installed. The microwave heating component has been enhanced to control a 28 GHz gyrotron in addition to the magnetron system. All legacy diagnostics of WEGA are triggered by emulating the trigger system used by the traditional WEGA control system. Thus the complete set of diagnostics set up at WEGA can be operated with the new control system and their data are available for offline analysis.

The operational safety has been enhanced by installing an interlock system. This interlock makes use of the run time resource checking features integrated in the W7-X Segment Control concept [5]. It interlocks the operation of microwave heating when the electron density signal obtained from the interferometer is below a certain threshold. During start up and low density discharges it is allowed to go below that threshold for a predefined time. When further plasma signals are available, e.g. the energy content of the plasma, the interlock system can be extended to improve its reliability.

The resource checking feature is used widely in the installation to provide proper timing for the microwave heating and the gas inlet system. It is necessary to provide these resources at the right time, because activating the auxiliary systems of these components (e.g. apply high voltage, open valves) causes a spurious emission of microwave energy or gas, respectively.

3. Experiment planning

After the commissioning of the new W7-X like control and data acquisition system for WEGA the CoDaC group executed a number of well known discharges that were already run with the traditional control system. Experiment programs for several types of discharges have been prepared and realised; some important examples will be discussed below. Generally a discharge can be divided into the four phases “Diagnostics and actor preparation”, “Start up of heating systems and plasma ignition”, “Plasma operation”, and “Shut down plasma and post processing”. Each phase consists of one or more segments. Once set up the description of a phase can be stored and reused.

3.1. Magnetron discharges at low magnetic field

A low magnetic field allows long pulse operation because the cooling system at WEGA is under such conditions capable of keeping the magnetic field coils' temperature below safe limits. Discharge durations of 1 h are technically feasible. The plasma vessel is equipped with a video inspection system to detect hot spots.

Fig. 1 shows trajectories of a long term discharge of 1/2 h duration with one magnetron for heating and depicts characteristic points in time and characteristic temporal lengths. The time between adjacent characteristic points is sometimes fixed, e.g. the ramp duration of the magnetron power ramp (2 s in Fig. 1). Sometimes it is given by the waiting time for a resource, e.g. the time between switching on a magnetron (Prepare magnetron may take up to 4 s in Fig. 2) and when the magnetron starts emitting. The traditional control system assumes a typical, fixed value for the time elapsing between preparation and emission. The new system waits for a positive acknowledgement. With the new control system setpoints can be specified by plasma physical parameters, e.g. magnetic field and greater plasma radius instead of currents in the magnetic field coils using an additional abstraction layer called “High level parameters” [6].

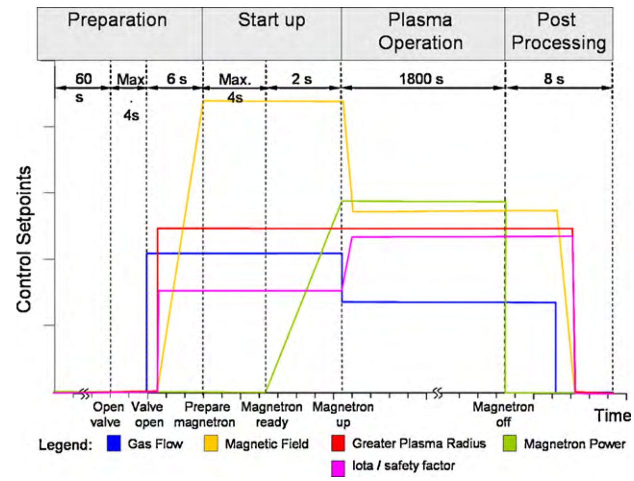

Fig. 1. Trajectories of discharge with one magnetron for heating.

The upper part of Fig. 2 illustrates the segmentation of the above described discharge in an editing view [7,8]. The four phases are depicted in bold frames in top of the figure. They are divided into group segments whose topical headlines are also depicted. The lower part of Fig. 2 shows the loaded experiment plan ready to be executed. In this view the phases are symbolised as big squares comprising segments shown as small squares. The planned duration is also shown. Segments using resources that are not yet ready for execution are marked. When for technical reasons the resources are not available when they are actually needed or fail during operation, the discharge will stop and continue with the post processing phase, thus providing a soft landing. Usually when such resources are required the predecessor segment waits for the resource up to a defined time. In this case the maximum segment duration is shown in the figures. The discharge segmentation controls and supervises actor components (called Magnet Supplies, Interferometry, Microwave Heating in Fig. 2) as well as the W7-X prototype diagnostics (Spectrometer, Magnetics), and the central coordinating and interlocking component (Central). During the plasma operation phase lasting for half an hour, eventual technical failures were monitored and the plasma density was automatically supervised. In case of a technical failure or when the plasma discontinues, the discharge program is aborted and continues with the post processing phase. In case of manual interaction the operator has the choice between an immediate stop and a switch to the next non-marked and therefore executable segment. The result of a successful run is shown in Fig. 3 for the first minute and the last 30 s of the discharge. The discharge was stable with a slight decrease in electron density. These types of discharges are used as cleaning discharges at WEGA and are considered as a candidate for cleaning discharges at W7-X too.

Fig. 4 shows trajectories of a more complicated discharge using all available magnetrons.

Preparation and post processing remain unchanged and are reused from example 1. The start up phase is essentially identical to Fig. 2; only value of the heating power has changed which cannot be seen from the qualitative trajectories but changes the segment. The plasma operation phase is more elaborate than in the first example.

3.2. Discharges at high magnetic field

Operation of the 28-GHz gyrotron is only possible at a higher magnetic field of 0.5 T to meet ECRH resonance conditions. A typical setup for a gyrotron discharge is depicted in Fig. 5. The discharge

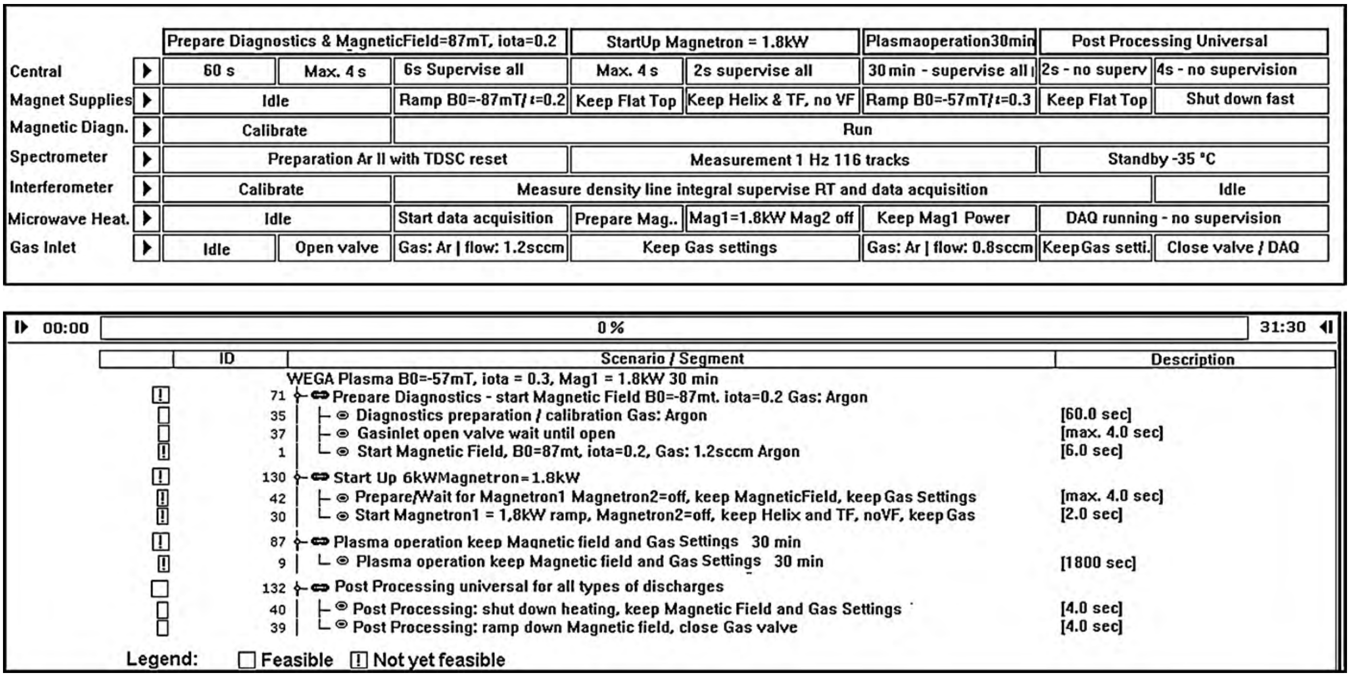

Fig. 2. Segmentation of discharge with one magnetron.

time is limited due to heating up of the magnetic field coils. When the magnetic field is up, heating should start as soon as possible. The gyrotron needs a complicated timed start up procedure during which the gyrotron magnet has to be started before high voltage is allowed at the cathode. The timing is controlled by acknowledgements. The cathode has to be preheated for some seconds before the gyrotron can emit. This time is specified by a fixed duration in this schedule.

The most advanced discharge scenario to achieve high temperatures and high densities at the same time needs gyrotron heating as well as magnetron heating with many timed operations and synchronising acknowledgements as shown in Fig. 6. The plasma must be ignited with the gyrotron since the magnetron is non resonant at high magnetic field. After the ignition phase of 1 s duration the magnetron should start as soon as possible because the time span during which the gyrotron can emit full power is limited. The preparation of the magnetron takes typically 3 s with an unknown jitter. These conditions are taken into account by defining a segment preparing the magnetron which lasts at least 3 s and starts gyrotron emission 2 s after the beginning of the segment. If the magnetron is not operational after 5 s, the plasma operation phase is skipped.

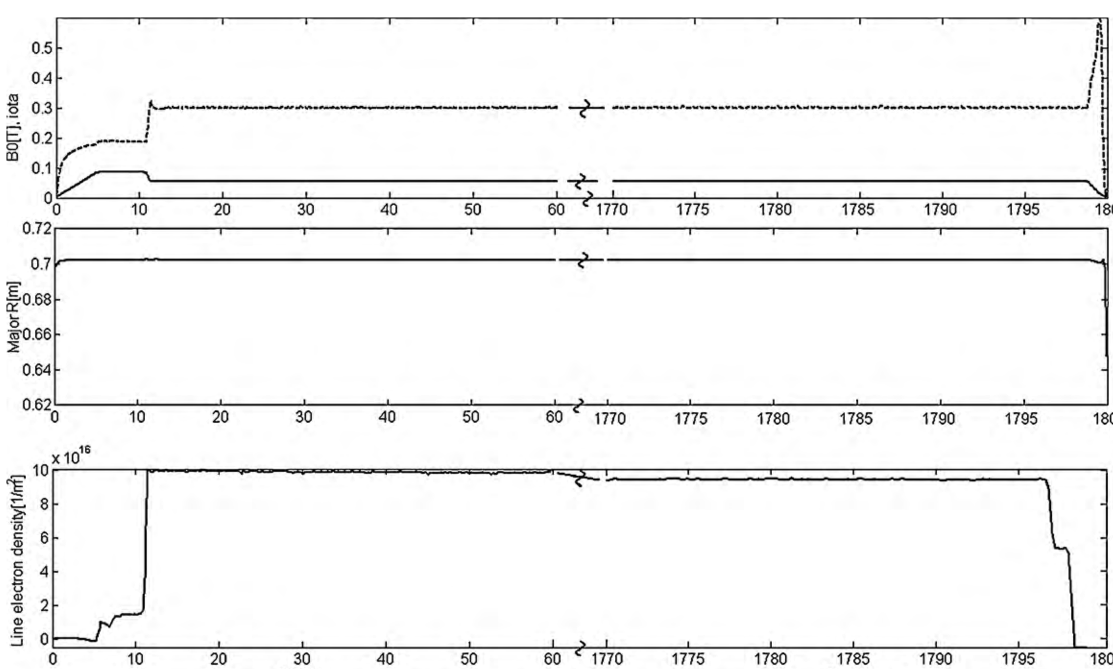

Fig. 3. Realisation of a discharge. Shown are the vacuum magnetic configuration computed from measured data and the line integrated electron density.

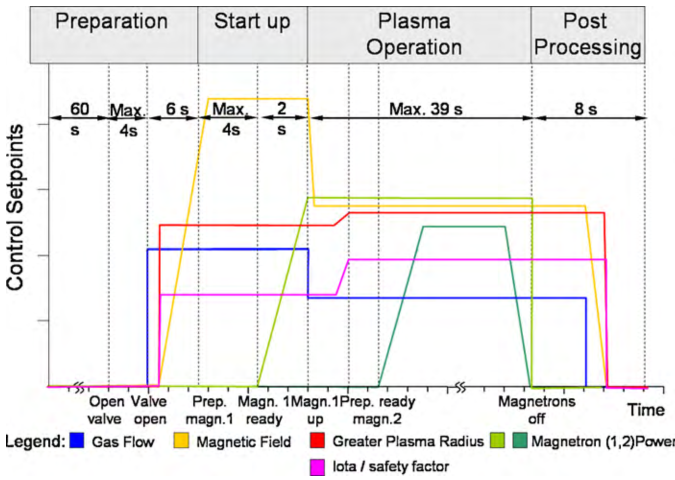

Fig. 4. Trajectories of discharge with two magnetrons for heating and a plasma shift.

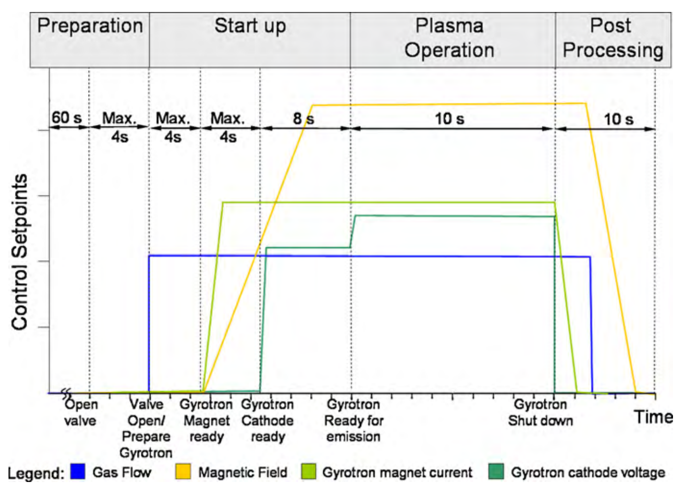

Fig. 5. Trajectories of discharge with gyrotron heating.

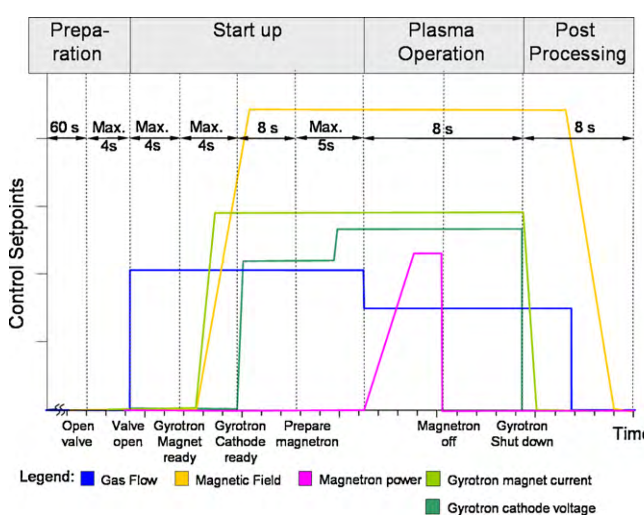

Fig. 6. Control trajectories of a high density/high temperature discharge.

4. Performing experiments

All discharges shown above have been run successfully several times at WEGA. Once a typical timing scheme as illustrated in the examples above has been set up, it is rather easy to adapt some parameters determining the amplitude and duration of setpoint trajectories, opening a wide range of experimental setups. A new editor [7] will develop this idea and will allow easy adjustments to parameters without changing the discharge structure.

Because of the enhanced supervising mechanisms some discharges have been aborted by the control system. Most abortions had a real cause, but of a sort which would not have been blocked by the traditional control system, e.g. some discharges were aborted because the interferometer showed a plasma density below a predefined threshold. The traditional control system could only measure but not supervise the density and the decision to abort a discharge was left to the machine operator and the session leader. The availability of the installation, in the sense of the number of completely executed discharges has been reduced. But these kinds of incidents do cause damage to the installation. Since damage to this small fusion device is rather easy and cheap to mend, the new system tends to overprotect the machine. Taking into account that the control system is designed to control a large, expensive fusion device the protection is considered necessary.

The new system can also be configured to stop a discharge when a diagnostic essential for the scientific output of the experiment is unavailable. The traditional system never does so. Because operating a large fusion device carries considerable costs this feature seem to be an advantage although the number of executed discharges is reduced.

Some premature discharge stops were due to false alarms because alarm thresholds were first estimated too conservative and then relaxed after a learning process. Such a leaning process can be expected with every new installation.

5. Conclusion and outlook

After a year of operation of WEGA with the W7-X like control and data acquisition system all kinds of discharges run at WEGA could be repeated. The experiment timing and operational safety has been enhanced compared to traditional experiment operation at the cost of a reduced number of discharges. In future more W7-X prototype diagnostics will be developed and tested at WEGA.

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