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Establishing the Wendelstein 7-X steady state control and data acquisition system during the first operation phase

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The Wendelstein 7-X steady state control and data acquisition system has been successfully commissioned and well established to investigate the plasma startup and run the first complex physics programs during the initial operation phase of W7-X. The main components of W7-X and a set of operational diagnostics have been integrated into the CoDaC system. The various different requests from the experimenters could be satisfied using the well established set of tools and interfaces – demonstrating their qualification for continuous operation. This paper summarizes the workflow from the users' point of view while presenting the main tools and interfaces for W7-X Segment Control.

Keywords: Wendelstein 7-X, Segment Control, continuous operation, steady state, user tools, application programming interfaces

1. W7-X Segment Control for Continuous Operation

Wendelstein 7-X has been build to investigate the steady state qualification of a stellarator for a future fusion power plant. For this, its control system has been designed to be capable of continuous operation; in detail: flexible experiment planning with inbuilt event handling for automated reaction on expected events or unforeseen component status, continuous data acquisition, data streaming and online data analysis for continuous monitoring and archiving.

Heart of the control system is the W7-X Segment Control [1, 2]. Experiment programs are divided in arbitrary time intervals called segments. A segment contains a full description of the behavior of all integrated components (so called 'tasks') and a set of exit and entry conditions. Segments can be aggregated to scenarios (Fig. 1).

Fig. 1. Structure of a W7-X experiment program

The transition between segments is defined by reaching the end conditions – at simplest: a fixed duration, or more sophisticated: the occurrence of a predefined plasma or component status, or even by exceptional component status or failures. The next segment to enter is defined by a predefined order in an experiment program and its feasibility with regard to the involved mandatory components and entry conditions.

The Segment Control system consists of a central sequence controller and subordinated components: technical systems (heating, gas inlet etc) or diagnostics – all synchronized by the central TTE timing system [3].

In preparation for an experiment the session leader selects a prepared program for execution. Consequently, all components are informed automatically which segments are planned to be executed. Before and during execution all components report their status and ability to run the announced program parts as basis for the program's online feasibility check by the central controller. The central controller continuously evaluates the current segment status and announces experiment-wide when and which segment is to be performed next.

2. W7-X CoDaC tools and interfaces

A set of applications and programming interfaces has been implemented to cover all features necessary to run W7-X Segment Control: setup, control and monitor physics program, acquire data, archive measurement and analyzed data. All tools are built generically to support both subordinated and autonomous component operation, e.g. during commissioning and tests. Implemented in JAVA or using web technologies, various platforms and programming languages are supported.

The W7-X Segment Control system and its related user tools has been in use during the stepwise commissioning of the components and its autonomous test operation over the last years. With start of the first W7-X plasma operation phase in December 2015, the central controller and its concerted operation had to be set into operation.

After the valuable test experiences at WEGA [4] and due to a large set of constantly running continuous integration tests during the ongoing development [5] and – last but not least – efficient diagnosis tools, the final commissioning ran successful and without any problems.

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2.1 Configure components and project

The configuration editor ConfiX [6] is the tool to set up the fixed configuration and project hierarchy of the integrated components including the communication paths between Segment Control and local (PLC based) operational management, and to define fixed and segment-controllable parameters of the involved CoDaStations [7] and FastControlStations [8].

Due to the separation of productive and preparation databases (Fig. 2), new component configurations or even enhancements can be prepared and widely tested in parallel to W7-X experiment operation (1). Changes become productive in experiment pauses by a strict release procedure which transfers the new settings into the productive environment (2) and adapts existing experiment programs and their segments, respectively (3). This procedure has been successful applied while integrating several new or updating existing diagnostics during the first W7-X operation phase.

Fig. 2. Manage configuration enhancements at W7-X: 1 – Prepare and test configuration changes, 2 – Release configuration to productive environment, 3 – Adapt existing segments and experiment programs to new configuration

2.2 Set up experiment programs for dry-runs and plasma discharges

The experiment program editor Xedit [9] is used to set up experiment programs out of physics oriented high level parameters including their transformation to the related technical parameters [10]. Xedit is implemented as a generic tool to edit segment programs for any W7-X-like modular component configuration.

Experiment program drafts (both for W7-X experiments and autonomous component test runs) can be generated from default settings as defined in a component's configuration; existing programs can be adapted by changing parameters and/or structure of a program. The user is assisted due to the underlying component model views [11]: expected parameter curves as well as potential constraint violations are visualized while editing. Both component models and high-low transformation functions are provided as plug-in code. Thus different versions can be used for autonomous commissioning of components, for testing of configuration enhancements and productive operation in parallel.

Experiment programs – or parts of it – can be prepared by any authorized user in advance. This even assists distributed experiment preparation: Component owners can define the tasks of their diagnostic or technical systems, test the planned behavior in autonomous operation – ready to be inserted into a W7-X experiment program (Fig. 3). More automated solutions are currently under development to assist setup and check of programs with a growing number of components.

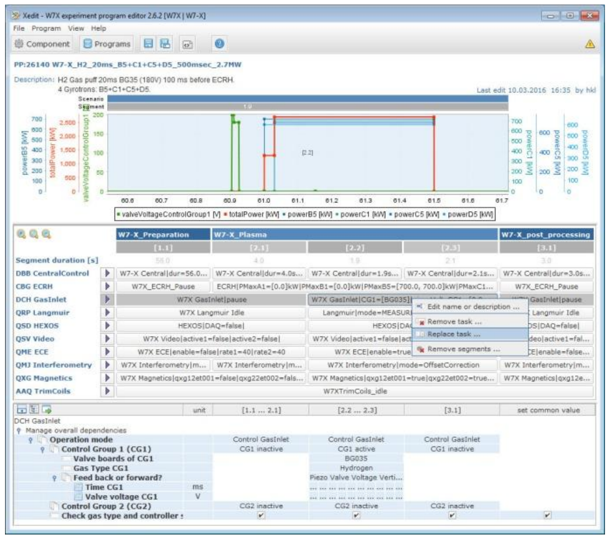

Fig. 3. Xedit: insert a prepared component task by replacing an existing task in an experiment program

Experiment programs can be set up not only for physics experiments (plasma discharges) but even for dry runs and technical tests. Appropriate labeled programs can be searched and reused for daily standard routines.

From the experiment program logs (see 2.3) any originally planned program can be restored and reused for next experiments. Here one has to bear in mind that with configuration change releases (see 2.1) the actual program has been adapted to the current configuration and may show a differing behavior, e.g. when new component parameters have been introduced and set to default values.

2.3 Run and monitor experiment programs

The Segment Control user interface Xcontrol [12] represents the session leader program. It offers a status monitor for all integrated components, the possibility to distribute session announcements, and as the main purpose: selection and start of prepared experiment programs by the session leader. The current segment execution status and program progress are displayed during experiment runs. The complete set of program parameters with timestamps and execution status for each program segment are stored with a dedicated program label in the W7-X archive [13].

Xcontrol as monitoring instance is available for any user's desktop and as a version for the control room's video wall (Fig. 4).

The DataMonitor application [14] monitors trending data, both raw and online processed (e.g. scaled or summarized) data. An online data analysis framework is currently in prototype state which allows defining data input(s) and analysis functions, and even their chaining for more complex data processing. The DataMonitor is configurable in data stream selection and interface appearance and thus can be adapted for video wall display (Fig. 4).

Using the Xcontrol inbuilt logbook view, executed programs including the stored session info can be listed by any user and commented by session leaders. Alternatively, a prototype web site (using the archive web service – see 2.4) provides logbook views and direct linking to archived data. Both implementations are presently consolidated. In this context, the component model framework [11] is currently enhanced to provide new views, e.g. to retrieve experiment classification and typical parameters from a planned program to support automated logbook entries and to assist searching and categorization.

Fig. 4. Xcontrol monitor (left) and DataMonitor on the W7-X control room's video wall

2.4 Browse and analyze machine and experiment data

The W7-X data acquisition system continuously acquires both diagnostics and engineering data – even in experiment pauses or during autonomous component tests. All data acquired by CoDaStations [7] or DataCollectors including monitoring data streams is stored with experiment-wide unique timestamps in the W7-X archive, accompanied by parameters and signal descriptions to ensure their traceability [13].

Using the DataBrowser application [15] or the archive web interface [16], archived data can be browsed by time interval and signal address. For convenient time interval selection, the logged experiment program intervals can be used to easily access experiment data in specific program phases (Fig. 5).

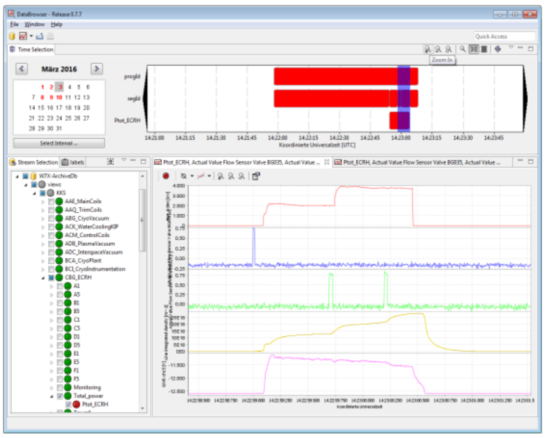

Fig. 5. DataBrowser: Browse data by experiment program time intervals and signal address paths

For further processing, all data can be accessed using the signal access JAVA application programming interface or a convenient web service based JSON interface [16]. Thus data analysis routines can be done in almost any programming language – whatever preferred by the users. A framework for experiment-wide standardized automated data analysis is still to be defined. A dedicated working group is currently under constitution.

Analysis results as well as measured data from diagnostics not yet integrated into the CoDaC system can be uploaded into the W7-X archive and accessed by the same interfaces.

The W7-X archive organization reflects the continuously acquired data streams grouped by components or even users' needs. Thus, different variants of an analysis can be uploaded into separate streams within a common stream group. Alias names can be defined for special views or even shortcuts for convenient signal access. Since all data is immutable, a framework for storing revisions is provided. Thus obviously erroneous data can be overridden while always preserving the original data.

2.5 Correlated status monitoring and trouble shooting

Besides the local component's debugging, the central notification system Xnote has been proven as a valuable tool for overall system status and failure analysis. All integrated Segment Control systems (ControlStations, user applications, archive server and interfaces) report their status, actions and exceptions including timestamps. These notifications can be displayed online at each working place and are stored centrally for later evaluation. Herewith all actions of distributed systems can easily be correlated to analyze causes and effects in case of malfunctions.

2.6 Partly supported diagnostics

For various reasons (legacy or external systems) the CoDaC team has to support diagnostics not running W7-X Segment Control. For their synchronization during a running experiment program, ersatz triggers have been implemented providing W7-X timestamps [17]. Seven dedicated triggers are configurable within a program relatively to a segment start; triggers may be configured to occur one or more times within an experiment program.

Using these trigger timestamps, measurement data of not integrated diagnostics can be provided with experiment-wide synchronized timestamps and uploaded to the W7-X archive afterwards. Thus all experiment data are stored in one place and can be accessed with the same interfaces described in 2.4 for correlated analysis.

Since this triggered, non-continuous measurement mode is limited to shot-like operation phases, it will not be applicable for the future W7-X steady state operation and more advanced experiment configuration. The aim is to fully integrate those diagnostics into the Segment Control system to benefit from continuous data streaming, complex set-up possibilities with inter-component dependencies, and sophisticated event handling within experiment programs.

2.7 W7-X CoDaC tools – generic implementations adoptable at other fusion experiments

The W7-X CoDaC tools are generic implementations and ready for use at other experiments as long as those can describe their component setup in a W7-X conform modular hierarchy. Even if an experiment does not implement Segment Control the way W7-X does, the experiment program editor Xedit can be used to configure segments as experiment phases.

This is currently demonstrated at the WEST project. The CEA CoDaC team set up the configuration and relevant parameters of the involved components using ConfiX and implemented the related component models as Xedit plugin. A mapping procedure will translate Xedit's XML export files to the necessary plasma control configuration files. During the next operation phase the WEST session leaders will use Xedit to prepare their discharge segments [18].

An equivalent statement applies for the W7-X archive implementation which can store any data as long as it comes with consecutive time stamps. DataBrowser and programming interfaces generically retrieve those data.

3. Status and ongoing development

The main components of W7-X (gas inlet, ECRH) and a set of operational diagnostics (Langmuir, ECE, Magnetics, Video, Interferometer, Spectrometer – see Fig. 4) have been integrated into the Segment Control system. During the first plasma evaluation phase, the CoDaC team faced various different requirements regarding the experiment setup: programs where requested for plasma startup studies, repetitive conditioning discharges, plasma parameter variations, running short programs in fast repetition cycles or long programs up to 10 minutes with several discharges in a row – up to 50 programs per day. Appropriate experiment programs had been prepared in advance and/or could be flexibly adjusted between program runs according to the last executions' results.

Thus all the physicists' requests could be satisfied using the well established set of tools and interfaces – demonstrating the qualification for continuous operation. The segment controlled components show the expected behavior within the planned experiment programs [17]. The data acquisition and archiving system is running reliably 24/7 for more than two years.

For the next operation phase, the CoDaC developments are focused on performance and usability enhancements, and even more automated processing to cope with increasing components and longer experiment programs.

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