System Integration of the ASDEX-Upgrade Timing System

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Abstract

This paper describes the integration methods applied to incorporate a trigger-timer system into the control system of a tokamak. The described system is a unified means to initiate local actions at each component necessary to create, measure and maintain a plasma. Abstract data representation and model building was used to unify the transmission to the tokamak's components. Lists of a priori scheduled actions as well as online detected events are disseminated by merging them into one stream of high level messages.

I. INTRODUCTION

The work carried out was performed in the context of the large scale experiment ASDEX-Upgrade which is a plasma physics device for controlled nuclear fusion [1]. ASDEX-Upgrade generates and keeps divertor plasmas at temperatures of up to 10 - 30 Mio degrees for a few seconds.

The motivation for this work was the real-time control of a tokamak. To control the plasma discharge dozens of real-time computers and programmable logic controllers (PLCs) are necessary. The trigger-timer system bridges the gap between the pure discharge control system which is spatially concentrated and the PLCs which are distributed over several buildings.

Other potential areas of applications for the described trigger-timer system are in the system control of power plants, accelerators or factories. They always have the problem to interconnect the core of the control system which consists of high performance computers with spatially distributed PLCs. High level information has to be passed, if possible in real time, between those two parts of the control system.

The differences to contemporary timer systems [2-5] in other fusion devices are in functionality, reliability and performance. In terms of functionality the trigger-timer system is the unified means to initiate and protocol real-time actions in all components of ASDEX-Upgrade, e.g. machine control, discharge control, additional heatings and diagnostics. The unification was possible by an abstract representation of the components actions regardless of type or subsystem. This eases the burden of programming local actions on a central site. In terms of reliability the trigger-timer system uses message transmission on glass fiber links, which can not be influenced by the high electrical and magnetic disturbances of the tokamak. Error detecting and correcting message coding together with component receivers with internally hardware doubling and voting mechanism for fault tolerance guarantee a safe transmission under all circumstances. The component receivers are denoted 'local timers'.

For performance reasons one-way message passing between a central timing unit and up to 255 receiving local timing units was chosen providing 100 ns time resolution. This ensures at least one order of magnitude higher precision compared with the required timescales of the major physical processes which are not faster than some micro seconds.

II. PROPERTIES OF THE TRIGGER-TIMER SYSTEM

The basic task of the trigger-timer system is to trigger actions at arbitrary subsystems by transmitting messages from a central control to distributed components. (The term 'component' is used as a synonym for 'subsystem'). For a plasma discharge tens of sequence informations have to be disseminated before the plasma starts to ignite. The procedure of transmitting actions in a predefined schedule can be compared with the count down procedure of a rocket launch. During plasma discharge online detected events about plasma and machine state become more important and have to be transmitted to those components which measure, monitor and control the plasma.

The second task of the trigger-timer system is to provide a global clock pulse as a time standard. Watch functions can be derived from those pulses by counting them locally. This means that virtually all components are clocked by a single high precision quartz in the central timer. Due to the real-time properties of the participating subsystems clock generation and distribution is a major issue. The third task is to protocol output actions in the field over a considerable period of time e.g. one day for later comparison with the protocols of the other local timers. The motivation for local protocolling comes from the fact that local data is of most interest to the system that has produced it and of minor interest to the central control. An example for that locality of data are test runs for a subsystem whose detailed sequencing is locally important while the result of the tests are also of central interest. For overall statistics and other central purposes there is a means to collect the local protocols into a central database. Each local timer has a standard serial and parallel interface which is connected with a workstation. All workstations operate in a network environment.

As illustrated in Fig. 1 the trigger-timer system consists of three parts: The first part is the central timer unit which is closely attached to the real-time computer of the discharge control system (transputer link connection). This unit is a complete transputer based computer in itself and can be programmed in occam on the lowest level or in terms of time sequences and event lists as high level input. The second part is formed by the many distributed local timers adjacent to the subsystems they control. For performance reasons they don´t rely on software but on dedicated hardware. The third and most expensive part is the electrical/optical conversion system together with the glass fiber star as the transmitting media for the real-time messages.

The functions that can be performed with this setup are in the first place the indirect control of the 8 electrical output channels each local timer has. Therefore, a broadcast for simultaneously accessing of all local timers as well as individual addressing has been implemented. Additionally, local protocol memories as part of each local timer continuously provide protocolling of all executed messages together with a systemwide valid timestamp. Remote control like watch resetting or locking is provided for better handling the multitude of local timers.

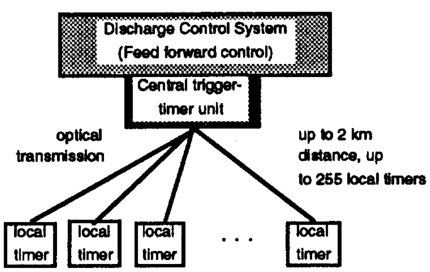

Fig. 1: Physical setup of the trigger-timer system.

III. SYSTEM INTEGRATION

As shown in Fig. 2 local timers control actions of the machine control system, the discharge control system, the additional heatings and the diagnostics, each consisting of several subsystems. To ease the task and not to overload the knowledge the central timer has to have, an abstract representation of the status of each local timer output pin was introduced in form of so called timer 'events'. Therefore the electrical output values of the local timers are not defined explicitly by the central timer. Only abstract events of systemwide or special interest are issued centrally. With this method the programming of a plasma discharge is performed the following way: before the tokamak starts its operation a list of desired actions that should happen during the discharge is prepared in a 'shot' file. Each action can be chosen from a set of predefined events like 'start toroidal magnetic field' or 'ignite OH transformer'. At this point there has to be no knowledge which output pin of the specific local timer, connected with the OH transformer or the TF coils, has to be driven high or low.

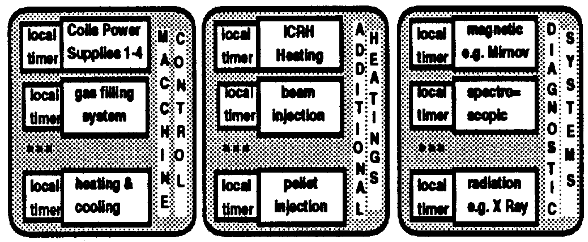

Fig. 2: Unified trigger-timer system for all components of ASDEX-Upgrade.

Only the event itself is necessary. During real-time execution of this list the receiving local timer maps the event messages into electrical values by its local program. This partitions the task of controlling a subsystem into an abstract event which is centrally issued and a subsystem specific dataset in the local timers. The mapping is implemented using the event number to address EPROMs in the local timer. Their programmed data directly drive the output pins. So a model of each subsystem is built by defining central events or commands for each subsystem and by mapping them into command values by local knowledge. Fig 3. illustrates the mapping process.

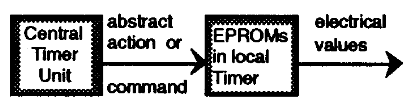

Fig. 3: Abstract system representation in form of events or commands is mapped into electrical values at the outputs of the local timers.

Another property of the trigger-timer system eases its integration into the system compound. Due to the fact that the central timer is connected with the discharge control system by a high speed link, real-time state information about plasma and tokamak can by issued by the same system. Information like 'flywheel generator has sufficient r.p.m.' or 'disruption occured' are merged by software with the event list in the shot program into one coherent stream of messages. This combining process is depicted in Fig. 4. The built-in task switch properties of the transputer and its efficient occam programming ensure that all messages are issued in real time. Additionally, the central timer has 16 hardware input links which directly trigger the issuing of high priority events like 'plasma disruption imminent' which is of overall significance for all components. In total the central timer has to handle three different sources of data: the scheduled list events, the online detected state events and the high priority hardwired events. They are seamlessly integrated into one stream of information together with a common clock pulse. The response time is 0.8 ms for the hardware triggered messages and 10 ms for the state events. By virtue of the collision free point-to-point connections between sender and receivers real-time broadcasting can be guaranteed.

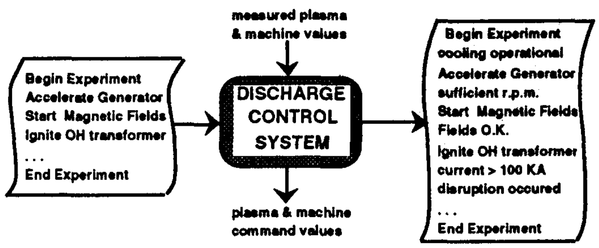

Fig. 4: Merging offline and online and hardware triggered events into one stream of messages to control the tokamak subsystems.

On the local timer side incoming events are filtered and only relevant events are further processed. Filtering is performed by a second set of EPROMs that generate an 'enable' signal only for that event or command subset that has to initiate actions at the specific local timer. The maximum number of commands in one subset is 64 K. The resulting values of the output pins of an arbitrary local timer are shown in Fig. 5.

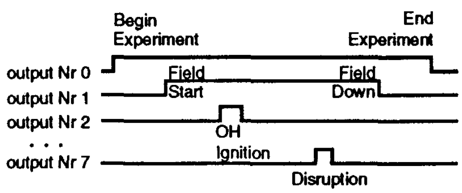

Fig. 5: Resulting example output at an arbitrary local timer.

The contents of all EPROMs are defined by means of a special editor and are entered in a central database which has various access keys to allow a convenient display of the stored data. The key issue is that each person who attends his component can make 'his own' EPROMs. Due to the abstract event representation of the output values the central control personnel does not have to have knowledge about it when outputting events or commands.

The third system integration aspect is the post shot analysis of the locally stored events of different timers. The prerequisite for this is to protocol actions together with timestamps to order and compare the sequence of entries.

Additionally, each component user can store user definable 32-bit values in his local timer for own purposes e.g. test or timing data. Both data sets together give a complete picture of the local trigger and sequencing actions that happened for subsystem control. Fig 6. illustrates the protocol features.

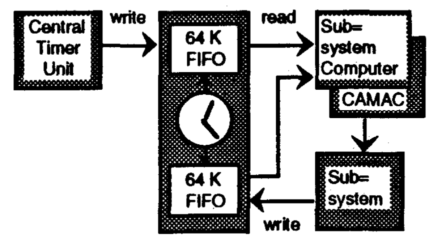

Fig. 6: Protocolling of central timer messages and subsystem output.

IV. RESULTS

For the control of a tokamak a trigger-timer system is mandatory. The extension of such a system to a generalized broadcasting of real-time messages enhances performance and reduces cost because other sequencing equipment can be eliminated. But to cope with the increased complexity a unified system has, an event oriented method had to be chosen with local mapping of centrally issued data. As a result the addition of new local timer units is simple because of the encapsulation of the implementation details. During the last two years of operation the ASDEX-Upgrade trigger-timer system has fulfilled its specification in every day usage. System integration has proven to be straightforward.

V. REFERENCES

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