stellarator news

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Europe and W7-X: An example of European collaboration

Collaboration in European fusion research has a long-standing history: in the 1970s, the European fusion laboratories joined to build and operate the Joint European Torus (JET). To coordinate research activities beyond JET, the European Fusion Development Agreement (EFDA) was created in 1999. In 2012, EFDA issued "Fusion Electricity: A roadmap to the realisation of fusion energy," and in 2014 the European Consortium for the Development of Fusion Energy (EUROfusion), representing 29 national European fusion laboratories, was formed to further develop the collaboration and efficiently implement the Roadmap. Research under EUROfusion is organized into work packages that are aligned with the eight missions outlined in the Roadmap.

One of the Roadmap missions is to develop the stellarator line to maturity as an alternative way to fusion power. Wendelstein 7-X (W7-X) is the cornerstone experiment of Mission 8. The strategic benefit for Europe is to take leadership in three-dimensional (3D) magnetic confinement physics and technology and to mitigate scientific risks in the challenges on the road to fusion electricity. In addition, W7-X is a broadly collaborative scientific project for European fusion research.

The stellarator work package comprises theory and modeling, with the preparation of experimental schemes benefiting from the smaller, but easy-to-access device TJ-II in Spain and from collaborations abroad. A backbone of European participation in W7-X, however, is the delivery, operation, and exploitation of components and diagnostics. To this end, European expertise in leading-edge systems is being developed and applied to the scientific program of W7-X. More than 12 European Research Units will contribute to the work program of W7-X in 2015.

The Hungarian video camera system is a prominent example of how W7-X benefits from European high-tech. For more than 20 years, collaborations between the Mak Planck Institut für Plasmaphysik and the Hungarian partners at the Plasma Physics Department of the Wigner Research Centre for Physics (the former KFKI-RMKI) have existed. Led by Gábor Kocsis, the Hungarian team (Gábor Bodnár, Gábor Cseh, Tamás Ilkei, Tamás Szabolics, Tamás Szepesi and Sándor Zoletnik) is delivering an intelligent fast camera system for the protection of the stellarator wall. Details are presented in the next article.

In this issue . . .

Event Detection Intelligent Camera for real-time plasma diagnostics and control at W7-X

Safety first

Wendelstein 7-X will allow quasi-steady-state operation, delivering very long discharges that are considered to be a prerequisite for any economical fusion reactor. Although the plasma is expected to be quiescent, long pulses (tens of minutes) may give rise to local overheating. Such power pulse-limiting events require implementation of detection and protective measures to avoid operational problems.

The aim of the Event Detection Intelligent Camera (EDICAM) project is to develop and operate a special fast camera system for W7-X. The main challenge our scientists had to face was the versatility such a system must have: it must provide an overview video over the full cross section of the stellarator; it must be fast enough to record plasma phenomena changing in less than one millisecond; and the video must cover the whole plasma discharge, lasting up to half an hour. The camera system must be able to protect the W7-X machine by detecting dangerous operational states when the plasma touches structural elements and rapidly communicating this to the plasma control system. Additionally, the cameras must operate in the harsh environment of a high magnetic field and irradiation by hot surrounding surfaces.

Intelligent surveillance

Even if such a camera existed, the problem of storage space would be overwhelming: usually fast cameras are used for very short time intervals, fractions of a second, but even then they can produce 10 GB of data – and W7-X can operate for 1800 seconds. And to make things even worse, we require 10 cameras to be able to monitor all inner surfaces of the machine. These problems were overcome by two innovative ideas.

The first idea was to completely change the way that a fast camera should work: using modern data acquisition technology (10 Gbits/s optical transmitter and PCI Express) we built the system so that all data from the sensor can be stored in the computer, making camera memory unnecessary. In such a system, the problem of storage space is also handled: the camera can be run at a standard frame rate but speed up the readout of interesting areas when some event happens, dropping all other frames containing no valuable information. This functionality inspired the name of this device: the Event Detection Intelligent CAMera, EDICAM. The detected events, if regarded as dangerous, can be communicated to the plasma control system, which can take measures to protect the fusion machine.

The second innovative idea was to use a special CMOS sensor with a so-called non-destructive readout (NDR) capability. Normal camera sensors are erased when the image is read out from them, and then the recording of the next movie frame is started; these sensors are also erased when only a small part of the sensor ('region-of-interest', ROI) is read out. In EDICAM it is possible to read out a small part of the sensor several times without affecting the recording of the full frame. That is, a small-sized movie, containing only a part of the whole picture, can be recorded at the same time as a full-sized movie. The EDICAM is able to handle up to 4 ROIs. It resembles a TV-camera, transmitting a football game, with four built-in slow-motion cameras, zooming into different areas of the playing field. This feature solves the speed problem: while the whole inner wall is monitored at a low speed, some components of the machine can be viewed 100–1000 times faster, providing a really fast reaction time for the event detection. Speed, light intensity, and the NDR capability are much more important for scientists than color; therefore, the special camera sensor gives a black-and-white image. However, it can differentiate between 4096 shades of gray, instead of the 256 in everyday cameras. The camera is shown in Fig. 1.

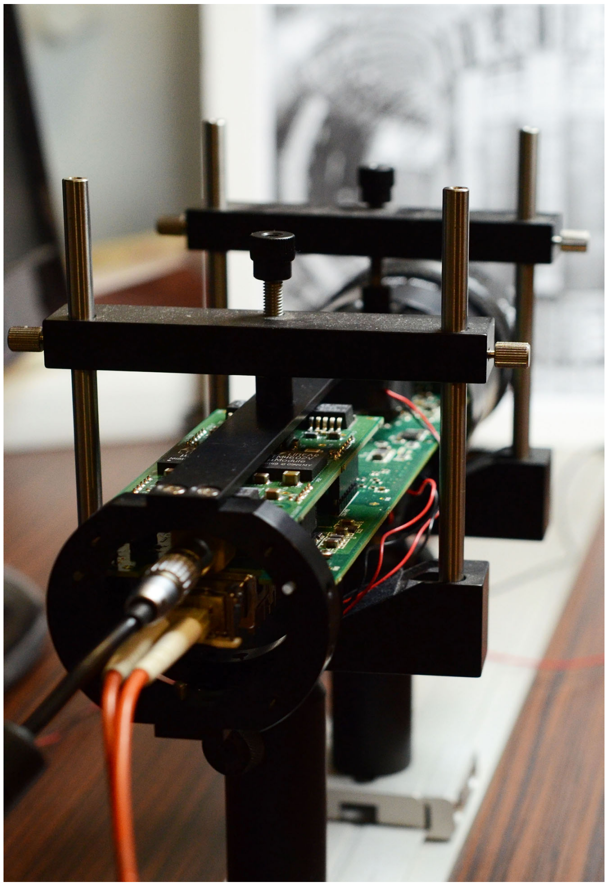

Fig. 1. The camera head of the EDICAM diagnostic system will be situated close to the plasma. This hardware is responsible for taking the images inside W7-X and transferring image data through a 100-m-long optical cable to the diagnostic hall, where one computer for each camera gathers the data and processes it for transfer to a live video stream in the control room.

However, processing fast camera video streams in real time requires very high computational power. Therefore, the EDICAM system uses field programmable gate arrays (FPGAs) for data processing as well as the camera control itself. These FPGA advanced microchips are as fast as real hardware chips, but their internal structure and hence functionality are determined by a program code loaded at startup. This allows us to develop new features and apply them without hardware modifications. An overview of the camera system as installed on W7-X is shown in Fig. 2. Figure 3 shows the view of a typical camera inside the vacuum vessel.

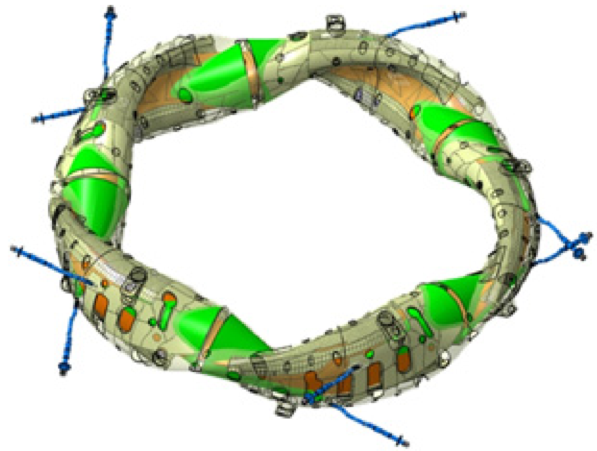

Fig. 2. The video diagnostic system at W7-X: Ten cameras, located in the ports with blue lines, will have the viewing cones shown in green and observe the complete interior of the vessel.

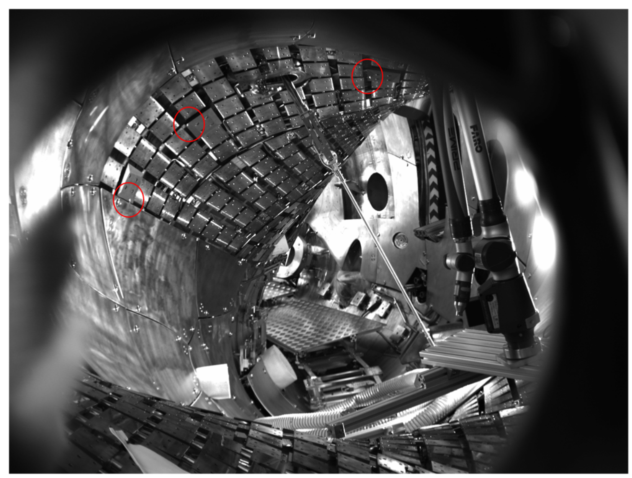

Fig. 3. View from the perspective of one camera taken during assembly. The heat sinks of the plasma vessel wall are visible at left. The rod in the center is the manipulator for magnetic flux surface measurement.s The three red circles mark fiducial points for calibration.

The most important challenge our scientists now face is to install the 10-camera system on W7-X and to get the system running by the time the first plasma is formed in the vacuum chamber of the stellarator.

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