Observations with the visible overview video diagnostic system during the first operational campaign of Wendelstein 7-X

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A ten channel overview video diagnostic system, observing the visible radiation emitted by the plasma, was installed and commissioned at Wendelstein 7-X (W7-X) optimized stellarator [1]. The main aim of the video diagnostic is machine protection, achieved by monitoring plasma-wall interaction and the plasma edge itself. For this reason the observation views are equally distributed around the torus in tangentially looking ports. The foreseen secondary, but almost equally important aims of the system are physics investigations, such as pellet monitoring. In the first operation phase of W7-X, three out of the ten views were used for other purposes (e.g. vacuum magnetic flux surface measurements or fast imaging); these are beyond the scope of this contribution. The remaining seven channels are equipped with EDICAMs, 1.3 Mpixel CMOS cameras (400 fps at full frame) [2]. The spatio-temporal evolution of the plasma size in all five segments of W7-X has been monitored using the EDICAM system. The typical evolution of a discharge observed by these cameras starts with a brilliant flash when the ECRH is turned on. This start-up phase could not be resolved by the EDICAMs – the sensors were usually saturated – in order to be able detect the low light levels from the plasma edge during the flat-top phase. Depending on wall conditions, this plateau phase lasted 50 ms to 6.5 s, terminated by switching off the ECRH or impurity accumulation causing a radiation collapse.

A typical discharge is shown in Fig.1. from five camera views. The radiative collapse at 750 ms is clearly visible on both the average brightness plot (left) and the heat map showing the time evolution of a line cut (middle). The collapse was initiated by a gas puff at ca. 330 ms, seen only by the AEQ41 and AEQ50 cameras (looking roughly to the same plasma volume from opposite directions) as a large spike in the average intensity plots. The camera images (on the right) also reveal that this event was localized both radially and poloidally. As expected, the additional gas was quickly distributed toroidally, causing a clear step-like increase in the average pixel intensity of all cameras (also at ca. 330 ms).

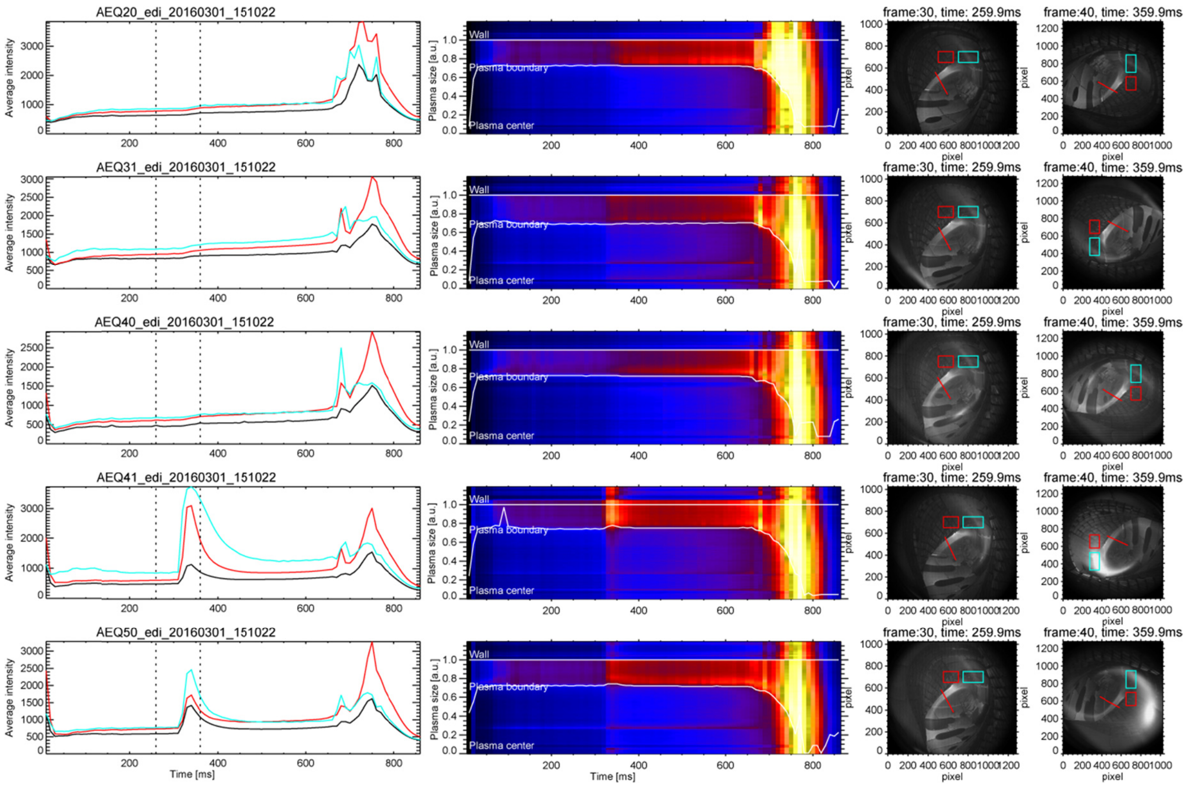

Fig.1. Overview plot of a W7-X discharge, summarizing the measurements of 5 EDICAM cameras (each row presents a different view). The left column shows the average pixel brightness of the whole image (black) and in two pre-selected regions (cyan and red, shown in the images on the right). The middle contour plot shows the light intensity along a straight line reaching from ca. the plasma center to wall element, covering the total plasma extension along the minor radius from the cameras' perspective (denoted by a red line in the images on the right). In right camera images are shown at time instants marked by dotted lines in the left plots. The rightmost images have the proper orientation i.e. the vertical pixel coordinate lies along the z-axis while the horizontal pixel coordinates represent the major radius direction.

EDICAM images can be used to determine the size of the plasma and its displacement in the R-z plane relative to the ideal vacuum field position. Since W7-X is a stellarator, the plasma is not toroidal-symmetric, and hence the observed edge radiation detected by the tangentially viewing cameras is the superposition of light intensities coming from a flux surface with a shape depending on the toroidal position. The resulting radiation pattern does not resemble any of the flux surface shapes; therefore a straightforward conversion to plasma size is not possible. Instead, a synthetic radiation image is produced by projecting the 3D coordinates of a flux surface in toroidal positions covered by the view onto the 2D plane of the camera sensor, and "summing up" the light intensity along each camera pixel (equivalent to a line-of-sight in the machine reference frame), see Fig.2. In this study, the following assumptions were made when producing the synthetic image: 1) The radiation is coming only from a single flux surface (i.e. the radiation is localized in minor radius). 2) The light intensity on the flux surface is uniform, both in poloidal and toroidal direction.

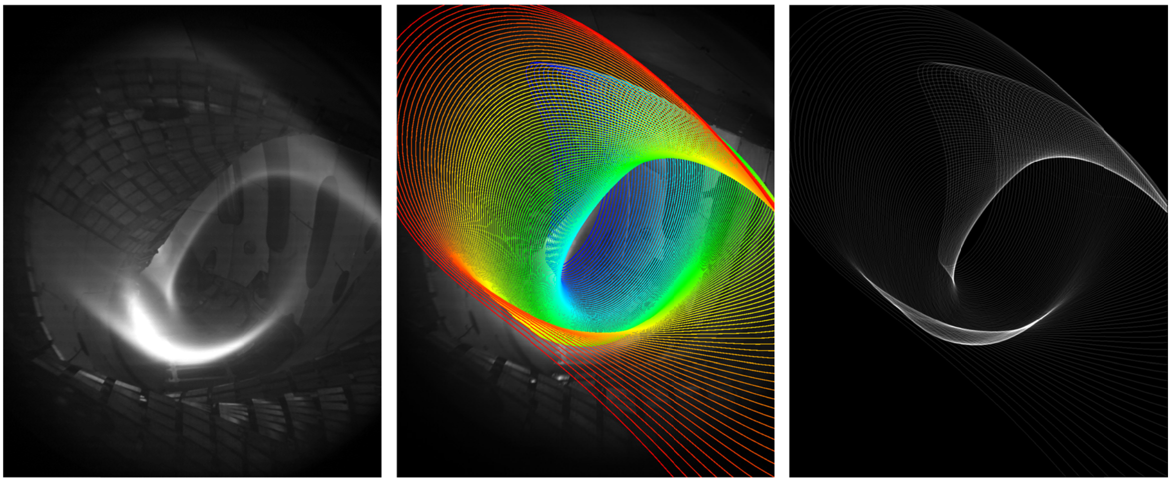

Fig.2. Left: EDICAM camera image. Middle: spatially calibrated image with LCFSs overplotted at several toroidal positions (denoted by colors: toroidal angle φ = 161-216° red-blue). Right: synthetic image.

EDICAM images can be used to determine the size of the plasma and its displacement in the R-z plane relative to the position set by the ideal vacuum magnetic field. In order to reduce computational time, the algorithm is divided into two steps. First, to determine the plasma size, a synthetic image is produced for 16 magnetic flux surfaces in the range of 0.0-1.0 normalized effective minor radius (r_{eff}). The synthetic images are used as a mask: each pixel value of a camera image is multiplied by the pixel intensity of the synthetic image, resulting in a weighted image. By summing up the pixel values of the weighted image, the total weighted brightness is calculated. This process is repeated for all 16 synthetic images. The synthetic image with the largest total weighted brightness corresponds to the best fitting flux surface, hence the plasma size.

In the next step, plasma displacement is fitted using additional synthetic images: at each r_{eff} the coordinates of the flux surface are shifted by in 2 cm steps in both the R and the z-direction (maximum displacement is ±6 cm), resulting in 49 possible variations for each r_{eff}. In this second step, however, r_{eff} is not scanned again, only in the vicinity of the value found in step 1, otherwise the fitting method is similar, but now the problem is 3-dimensional. See Fig.3. for the illustration of the process.

Each segment of W7-X is equipped with a trim coil, which, in addition to error field correction, can be used to modify the plasma position. This set of trim coils was used to investigate effect of plasma positioning on the heat load onto the five limiters. The applied n=1 perturbation is supposed to displace the plasma as a rigid body.

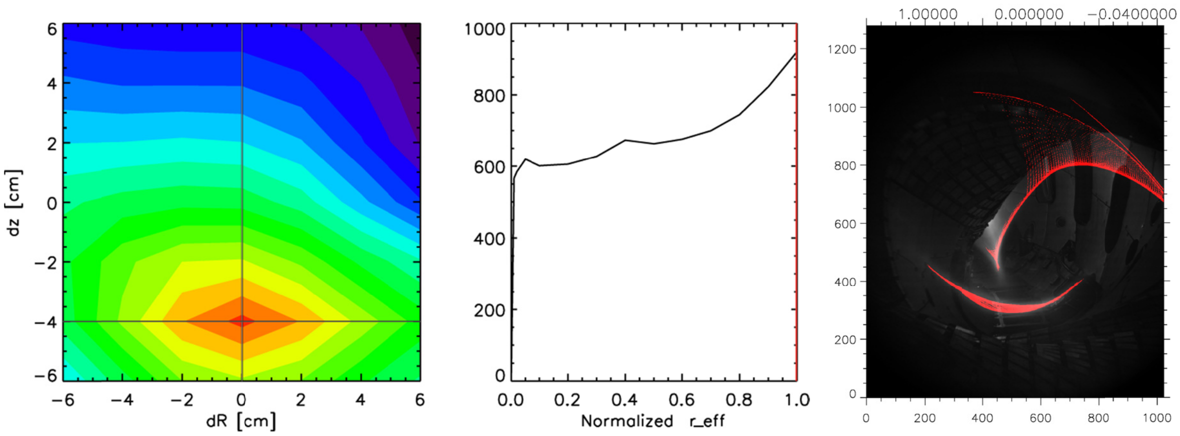

Fig.3. The process of fitting the synthetic image onto the measurement. The contour plot on the left shows the total weighted brightness as a function of displacement in the R-z directions (resolution: 2 cm), while the middle figure shows the same as a function of plasma size. The result is shown on the right: the camera image is overplotted by the fitted synthetic image in red, the numbers on the top are r_{eff}, *dR* [m] and *dz* [m], respectively.

It can be seen on Fig.4. that the plasma responds to the magnetic field perturbation. The result fits to prior expectations: more displacement in the radial direction is observed. Additionally, the largest displacement is found when the maximum coil perturbation is one module away ($\Delta\varphi = 72°$) from the observed location, which is consistent with other diagnostics' findings.

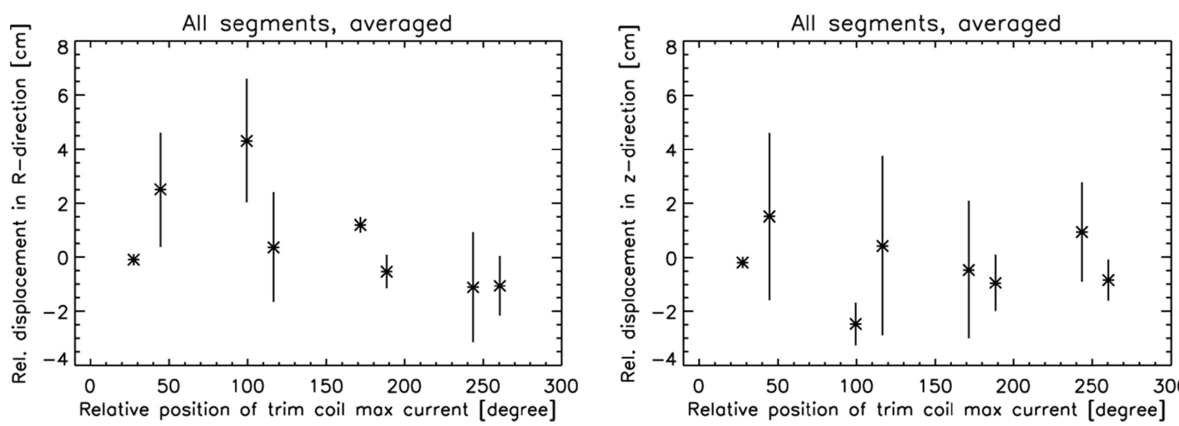

Fig.4. Relative displacement of the LCFS as a function of the relative position of the maximum trim coil current location.

[1] G. Kocsis et al, Fus. Eng. Des. 96-97 (2015) 808

[2] S. Zoletnik et al, Fus. Eng. Des. **88** (2013) 1405

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