Development of an IR-Microbolometer-Camera for Operation in a Strong Magnetic Field

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The environmental conditions sometimes constrict the use of commercially available IR-microbolometer-cameras due to their sensitive electronics. However, a slight modification of the camera design concept can broaden the range of application. In the present paper an uncooled microbolometer-camera with 640x480 pixel is described developed for operation in stationary magnetic fields with a magnetic flux density of 3T as occurred in the fusion stellarator experiment Wendelstein7-X.

Application

The Wendelstein 7-X is being built at the Max-Planck-Institut für Plasmaphysik in Greifswald (http://www.ipp.mpg.de/ippcms/eng/pr/forschung/w7x/index.html, see fig.1). Upon completion in 2014 this device will be the world's largest fusion experiment of the stellarator type. It is to demonstrate the concept's suitability for a power plant with the essential property of continuous operation. Ten infrared viewing systems are required for monitoring the temperature of critical parts of the reactor as the divertor target plates with a spatial and temporal resolution of 10 mm and 100 ms, respectively. During the first operational period with time-limited heat and particle fluxes to the wall of the vacuum chamber the IR-cameras can be located near the plasma provided that they operate satisfactorily in a strong magnetic field. This reduces the costs of expensive IR-light transmission systems.

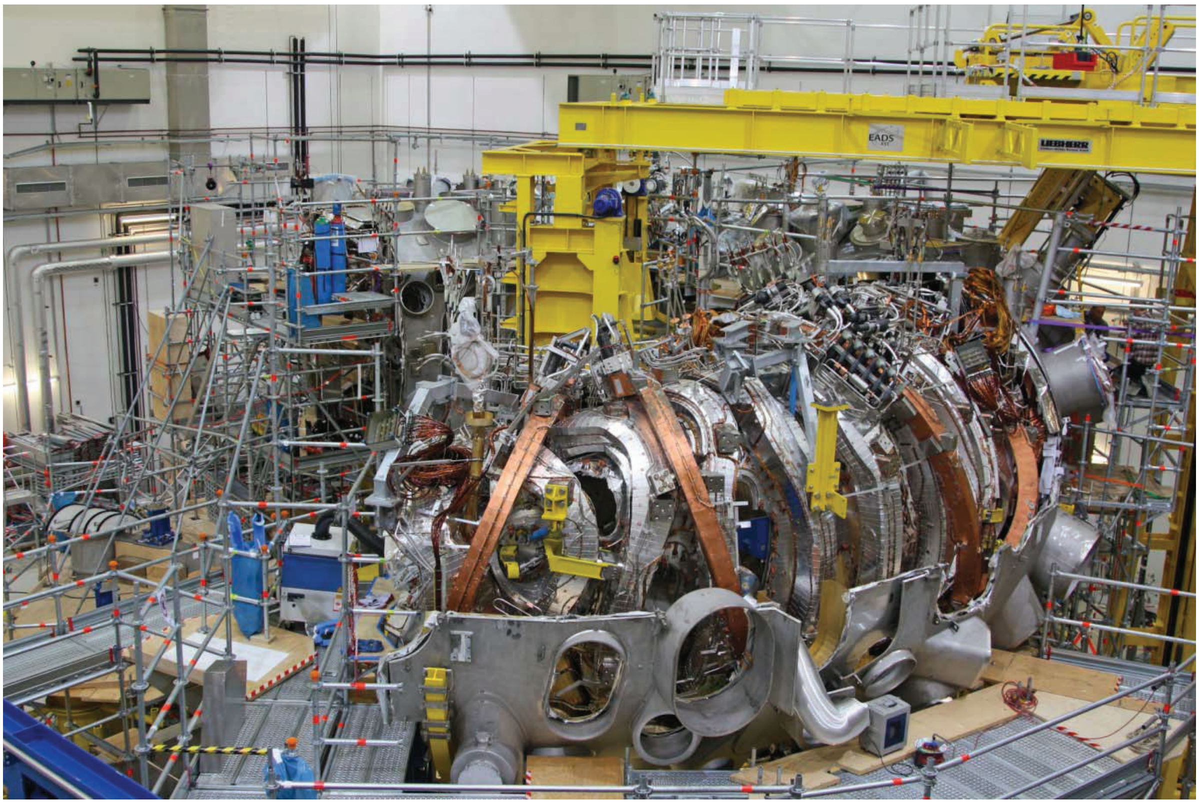

Fig.1: Construction of Wendelstein 7-X; image taken in autumn of 2010

Fig. 2 shows the immersion tube which will be inserted into the UHV-chamber of W7-X. The sensor module of the IR-camera is seen at the front side of the tube while the second module with sensitive electronics is located at the end of the tube outside the device.

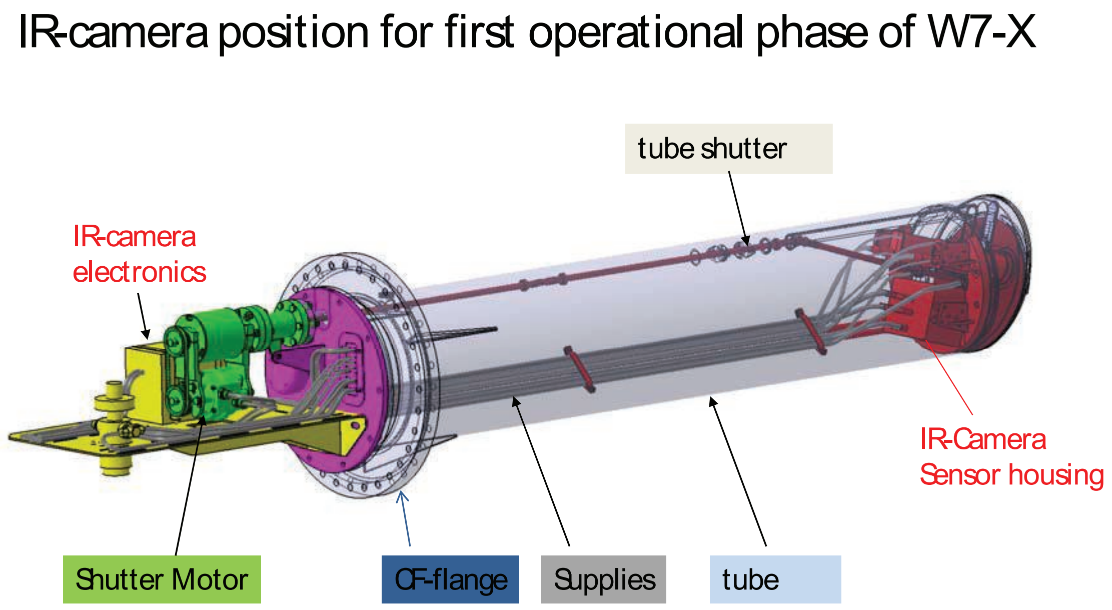

Fig.2: Arrangement of the IR-camera parts in the tube foreseen for insertion into Wendelstein 7-X

IR-Camera System

The developed camera system (Fig.3) is based on a state-of-the-art infrared detector with 640 x 480 pixels and has a Gigabit Ethernet interface. It operates in the long-wave infrared range (LWIR) and features a temperature range of 0 °C to 1800 °C. A special wide-angle lens with FOV of 116° x 82° allows monitoring of the critical components of the stellarator. For internal signal corrections, a pneumatically driven shutter is used.

Signal processing is performed by a PC connected with the camera system. Corrections that refine the accuracy of temperature measurement are carried out by the firmware within the camera. Only corrected images are provided. Data transfer between camera system and PC takes place over Gigabit Ethernet by using of standard protocols (IP). Powerful online software under Windows® allows the camera system to visualise, record, analyse and store the measured data. Furthermore an online and offline program interface is available. Efforts are made for data transfer in real time. An external trigger input for control of the image data acquisition is supplied.

The camera system consists of a camera head and an electronics box. The camera head which parts are not sensitive to the magnetic field includes a mechanical assembly group. It houses:

- detector along with power supply, clock control and A/D-conversion
- thermoelectric control of detector (built-in Peltier element, actual value sensing)
- optics (manual focusing)
- shutter (pneumatically driven)
- power driver respectively receiver

The electronics box which contains all parts expected to fail in high magnetic fields:

- power supply (DC/DC-Convertor)
- thermoelectric control of detector (switching regulator)

- digital signal processing
- digital interface (Ethernet)
- digital inputs and outputs (trigger, error, control pulses)

Both the camera head and the electronics box are sealed to IP54 standard with a rugged housing that holds up well in environments where water and dust resistance is required. Screened cable connections between them provide protection from alien cross-talk and electromagnetic interference.

Fig. 3: The developed camera system

The developed camera system incorporates special features not common to competitive products. These include in particular the electronic and shutter design.

The splitting of the camera system into two functional parts requires undisturbed data transfer of 11 clock signals, 19 data signals, 1 bidirectional bus signal and 4 analog signals as well as 5 operating voltages via cable, whereby digital signals include frequency ranges up to 20 MHz. For interference signal suppression each digital signal is transmitted over balanced transmission lines (twisted pairs) by means of a differential signal mode. The bidirectional signal is separated, transmitted and composed in each direction. For the purpose of avoiding resistive losses power supply and analog signals are connected over parallel transmission lines. A light voltage boost compensates for remaining voltage losses.

Individual wires are bundled in two separately screened cables (80+60) and are connected to both camera system parts. A locking mechanism is provided. The implemented connection leads to considerable delays during the data transfer, which would have a negative effect on the signal quality and disturb some clock processes without feedback. For this reason occurring delays have been determined associated with a revision of the whole clock generation and signal conversion. A timing control for the detector unit has been created that takes account of the features of this concept (delay times etc). Accordingly the firmware of the camera system has been adapted.

Furthermore the shutter unit has been redesigned because normally it is solenoid actuated. For the purposes of failure-free work and properties not sensitive to the magnetic field only plastic components have been used. The new designed shutter assembly is pneumatically driven, powered by a single-action pneumatic cylinder. The pneumatic cylinder of this kind can only be moved in one direction by compressed air. The return movement is caused by a spring. A shutter blade mounted to the cylinder piston is moved both inwards and outwards in front of the detector. To control the current of air to the pneumatic cylinder an electromagnetic 3/2-way valve is used. It is mounted in the electronics box, outside the strong magnetic field. This means that the valve has three connections (compressed-air connection, connection for cylinder, vent) and two switch positions (open, closed). If valve opens, air flows to the cylinder. In its closed state, vent allows air to escape from the cylinder.

The valve is operated by camera software. The shutter cycle is given by temperature changes of the optical channel. It can be synchronized to an external process and interrupted during the measurements.

Results

IR-images taken in a magnetic resonance tomograph demonstrate that the camera head operates satisfactorily in magnetic fields of 3T (Fig. 4). Data transfer and the quality of the IR-images are hardly affected.

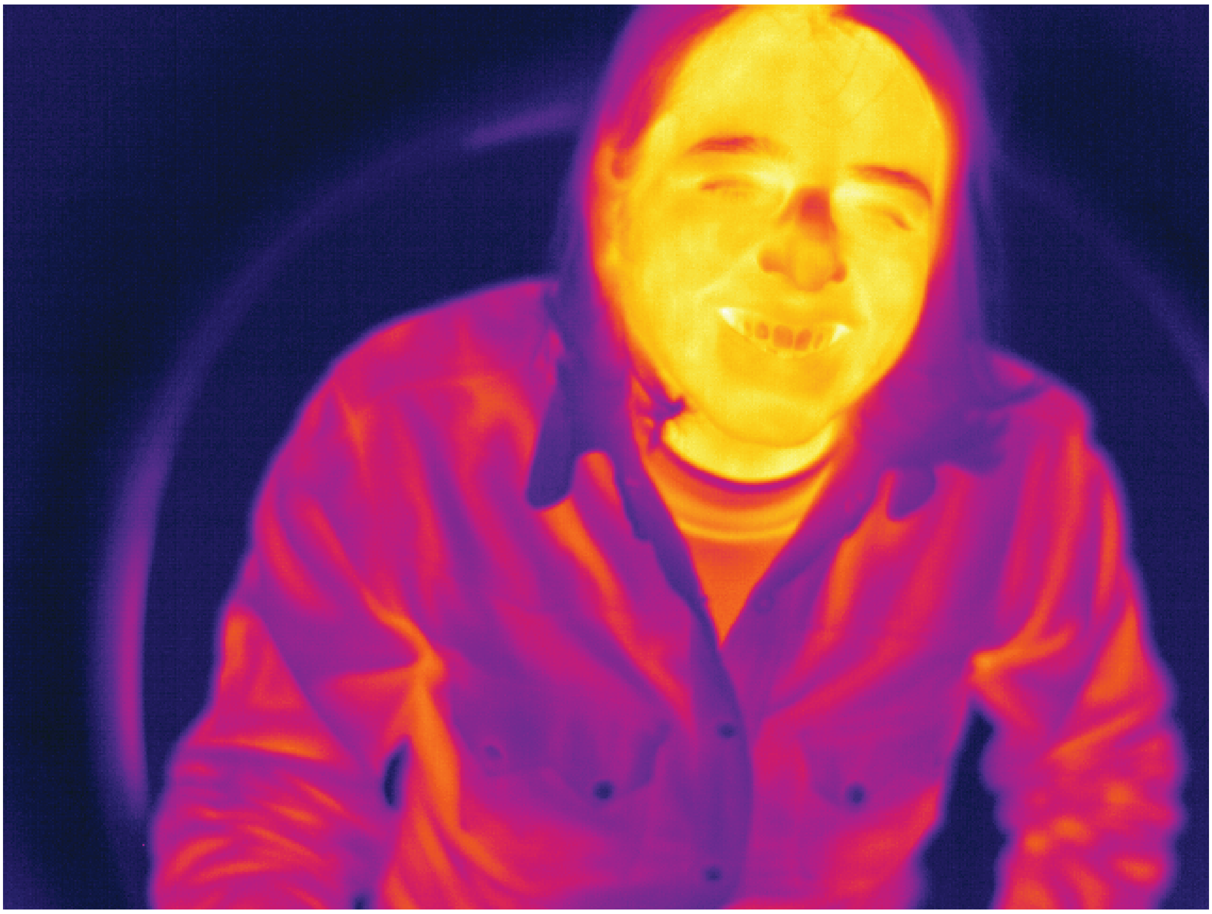

Fig.4: IR-image taken in a 3T magnetic resonance tomograph at the University of Greifswald.

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