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Optimisation of design parameters for collimators and pin-holes of bolometer cameras

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ABSTRACT

The total radiation emission profile of fusion experiments is usually determined using the bolometer diagnostic. In order to evaluate the spatially resolved profile, many line integrated measurements are inverted using tomographic reconstruction techniques. Their success depends on a well known and optimised definition of the viewing cones of every line-of-sight. To this aim a set of equations has been derived and put in hierarchical order to define the design parameters for bolometer cameras in fusion experiments. In particular, previous considerations, which focussed on the beam width overlap and light yield optimisation, are extended to explicitly take geometrical boundary conditions imposed by the experimental device into account, with an emphasis on small gap sizes through which viewing cones have to pass through. The equations are derived for both camera types, collimator and pin-hole versions. The results obtained can be used to design bolometer cameras for any fusion device, but in particular also for ITER. An example of such an application is given and implications for the realisation of the optimal design are discussed.

1. Introduction

To derive the total plasma radiation emitted from a fusion device the most common diagnostic used is the bolometer diagnostic. It is based on an absorber, which is heated by the plasma radiation. The increase in temperature is monitored using a thermometer giving thus the possibility to deduce the absorbed radiational power. Depending on the type of this thermometer the different variants of bolometers are distinguished. Metal resistor bolometers use a thin metal resistor on the back side of the absorber [1] combined with a reference detector, which is shielded from the direct plasma radiation to compensate for uncertainties in the measurement due to changes in the temperature of the environment or the effect of neutron radiation. Imaging bolometers use a thin metal foil behind a pin-hole whose temperature is monitored by an IR CCD camera [2]. Observing the plasma radiation through many lines-of-sight (LOS) provides the possibility to deduce the local emission profile by the application of tomographic reconstruction techniques. However, to accurately perform the tomographic reconstruction, the geometrical properties of the viewing cones should be optimised and well known. Usually, several individual detector pixels and thus LOS are combined within one bolometer camera. A cross-section of the plasma is observed by several cameras providing LOS in many different directions thus covering the projection space for optimal tomography [3].

There are two generic types of cameras in use, the pin-hole and the collimator camera. The first uses one aperture, the pin-hole, for all detector pixels within the camera. The latter provides an individual aperture for every detector pixel, both connected by the collimator channel. The pin-hole camera is relatively simple and robust from the point of view of the principle design and manufacturing demands. Furthermore, it allows the integration of many LOS within one camera (up to 48 in the case of ASDEX Upgrade), which are then arranged along a semi-circle. In the case of imaging bolometers the plasma radiation is mapped via a pin-hole onto an absorption foil which is observed by the IR CCD camera and the individual "detectors" are represented by the image of the CCD pixels on the absorber foil. The collimator camera usually incorporates fewer detector channels within one housing but offers a significantly higher flexibility in their arrangement and angular distribution. Also, they allow for a reduced size in the housing compared to the pin-hole camera while achieving the same spatial resolution.

For both camera types the geometrical properties of the viewing cone, in particular the opening angle, are determined by the sizes and locations of aperture(s) and detector pixels. They can

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be optimised using basic considerations from geometrical optics. However, geometrical boundary conditions imposed by the experimental device, e.g. a restricted length of the collimator or camera due to space availability, have to be taken into account and an optimisation with respect to light yield is also desirable. Thus, a hierarchy for the calculations needs to be established.

The optimisation of apertures and collimators has already been considered from the point of view of optimising light yield, spatial resolution and beamwidth overlap for reduced aliasing during tomographic reconstructions [4]. This paper focuses on extending these considerations including explicitly the geometrical boundary conditions imposed by the experimental device. Design criteria focussing on the optimisation of measurements due to effects other than those related to the viewing cones, e.g. impact of neutral particles or microwave shielding, are not considered.

In the remainder a set of hierarchically organised equations are presented which determines the optimal design parameters for bolometer cameras. The results can be used to design bolometer cameras for any fusion device, but in particular also for ITER. Section 2 defines general considerations for bolometer camera design and gives the boundary conditions for which the calculations in the following sections are valid. Then, Section 3 discusses the calculations for a collimator camera and Section 4 the ones for a pin-hole camera. Within Section 5 the equations derived are applied to the task of defining design parameters for an exemplary ITER bolometer camera. Section 6 discusses these results and draws conclusions for the optimal design of bolometer cameras. Finally, Appendix A gives a table with the definition of all acronyms and symbols used.

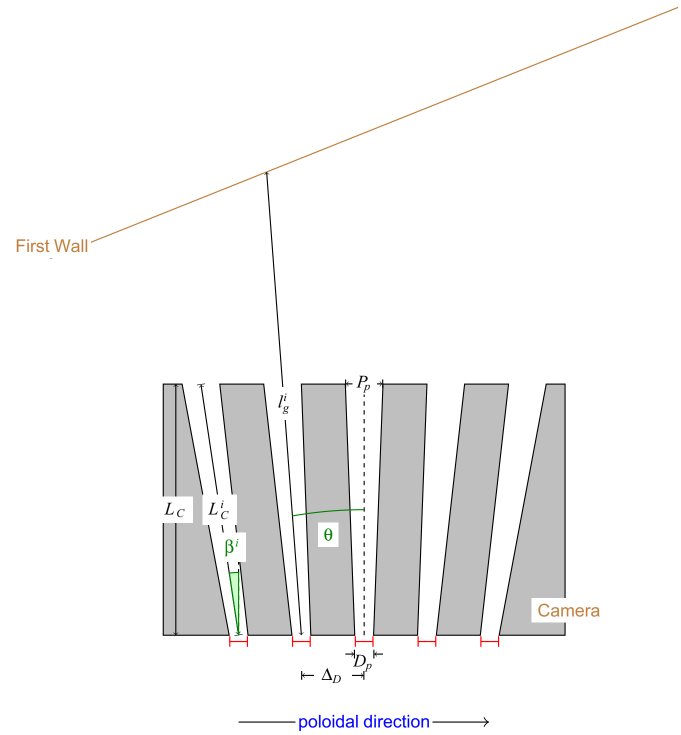

Fig. 1. Arrangement of a bolometer camera in the poloidal plane, including some dimensions used.

2. General considerations for camera optimisations

Prerequisite to any optimisation is that an optimal LOS arrangement is determined, which takes the desired spatial resolution and LOS coverage of the reconstruction space into account. This defines the number and orientation of the LOS for which in the following sections an optimisation procedure is given to determine the parameters of the apertures of bolometer cameras used to define the viewing cones.

For this work only cameras are considered whose surfaces of detector and collimator aperture are rectangular and parallel to each other. In this case the 3D viewing cones can be optimised in poloidal and toroidal directions separately [4]. Also, the planes of the collimator channel in toroidal direction are considered to be parallel. This is equivalent to the size of the detector and aperture being the same for the toroidal direction.

Furthermore, it is assumed that the viewing cones of the bolometer cameras are limited by components in the vacuum vessel only in toroidal direction; the poloidal extent of the viewing cone is considered to be unlimited. The limitation of the viewing cone in toroidal direction leads to more complex designs in case very narrow viewing angles have to be achieved. In particular, this gives rise to the definition of additional structures within a collimator channel to further restrict the viewing cone. They will be called sub-collimators. As shown in Fig. 2, in the simplest case the sub-collimators are defined by inserting additional planes in toroidal direction within the collimator channel over the whole length. This is also the approach chosen for this work.

The main aim of the camera design is to assure that the viewing cone of each LOS is defined by the camera and avoids any edges of components placed in front of the diagnostic assembly. Otherwise leading edges could cause changes in the étendue during operation if they e.g. move because of thermal expansion. Thus, sizes of gaps between which the viewing cone must pass are assumed to be given with some margins. To derive the optimal design parameters for the bolometer camera, the optimisation procedure must aim towards the following, in order of priority:

1 minimise the number of sub-collimators in toroidal direction
2 assure the resolution of the LOS in poloidal direction due to requirements from physics considerations
3 maximise the étendue of the detector, i.e. maximise the light yield or, equivalently, maximise the viewing cone by minimising the length of the collimator.

According to [4] for tomography a reasonable compromise between maximising the resolution and keeping the aliasing acceptable is achieved in case adjacent LOS overlap in the imaging plane at half maximum, i.e. the full-width at half-maximum (FWHM) of the viewing cone of the LOS is the resolution of the detector. In this context, the poloidal resolution is given by the distance between adjacent LOS in the image plane, i.e. in the plane being in a distance of l_p from the detector, adjacent LOS are separated by r_p. The last upgrade of the JET bolometer diagnostic made use of this principle and checked the implementation experimentally [5]. Please note, that adjacent LOS do not have to be necessarily in the same bolometer camera.

For a successful tomographic reconstruction of the 2D radiation emission profile in one poloidal plane it has to be assured that the extension of the viewing cones in toroidal direction is smaller than variations in the emissivity profile in toroidal direction. In the case of large experimental devices, like e.g. ITER, this is usually well fulfilled due to the small gap sizes in toroidal direction. For other devices with large gap sizes in toroidal direction this should be checked explicitly.

3. Optimisation of a collimator camera

Fig. 1 shows a sketch of a bolometer camera placed behind the first wall. The annotations denote some of the dimensions used