Progress in Multi channel Optical System for Visible Plasma Radiation Measurement at COMPASS Tokamak

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Abstract The paper outlines main parameters and characteristics of the multichannel optical system for visible plasma radiation measurements, which is currently under construction on the COMPASS tokamak. Alignment of the fiber endpiece and the detector is described in the contribution. Measured spectra in wavelength ranges of 250–475 nm and 457–663 nm are shown for typical short-lasting discharges of the COMPASS tokamak, which is not yet equipped with a plasma position stabilization system.

Introduction The COMPASS tokamak, a divertor device with a clear H-mode and ITER-relevant geometry (R=0.56 m, a=0.23 × 0.38 m,Ip=200–400 kA, BT=1.2–2.1 T and pulse length up to 1 s), is operational at IPP Prague [1].

New multi-channel optical system for visible plasma radiation measurements was designed to monitor integral plasma radiation in a visible spectral range and to measure hydrogen and the most intensive impurity spectral lines with both high temporal (≈7 ms) and spatial (≈1 cm) resolutions. These data can be used to derive such physical quantities as impurity inflow, recycling and for a rough estimation of the particle confinement. Hydrogen and impurity emission and its evolution during tokamak discharges can be measured using interference filters with transmittance in the ranges of interest. The effective ionic charge Zeff can be evaluated from measured bremsstrahlung radiation in the line free region, here it is slightly above 520 nm, using known plasma density and temperature profiles. Two impurity survey spectrometers HR 2000+ are used for registration of the most intensive spectral lines in the ranges of 247–472 nm and 457–663 nm. There radiation is temporally integrated over the discharge duration or resolution is set to 7–10 ms. The first attempt to interpret measured spectra were done using FLYCHK code [2].

The multi-channel optical system setup The system for visible plasma radiation measurement consists of two parts, which will be installed at the same poloidal cross-section. Both parts are designed in the same manner, but viewing the plasma cross section from two different poloidal angles [3] in nearly perpendicular directions.

The design of “sandwich” structure plug was developed in order to integrate several systems for plasma radiation measurements (visible light and soft X-ray detections and bolometry) together with both a cooling channel and a shutter [4]. The NW35 vacuum window made from Spectrosil 2000 is used as a part separating vacuum and atmospheric pressure parts of the system.

The objective consists of three parts [5] and is partially located in vacuum inside the port plug. The first part, an ultra wide-angle objective achieving 110° field of view, transmits an image of the half of the plasma column into infinity. The second part is an infinite-finite distance objective that creates a real image. The third part is a system of relay lens re-imaging it onto a linear set of optical fibres directly or through an interference filter. In this part, the throughput is restricted by a maximum possible diameter of the view port and set-up of the fibre bundle that strongly depends on the available budget is organized into a linear array of the fibres. The objective is under tests in the Department of Optical Diagnostics of IPP in Turnov now.

Visible light detectors with detection range 400–1000 nm are located in the diagnostic room separated from the tokamak. Twenty-meter long optical cables with transmittance better than 95% in the range of interest are led, depending on purpose of the measurements, either to a 35-channel detector S4114-35Q by Hamamatsu, to minispectrometers HR2000+ by Ocean Optics or to
photomultipliers. An interference filter can be set as a part of optical system depending on an aim of experiments. Two stage 70-channels amplifier with amplification ratio $\approx 5 \times 10^5$ was designed, manufactured and tested in our laboratory for signal registration in the range of 0–5 V. Level of noise after amplification was registered as 2 mV. Temporal resolution of the amplifier is limited approximately to 1 MHz. The connectors between the optical cables and the detectors were designed as a part of the amplifier's board with a possibility to optimise the fibres endpiece position relatively to detectors in the array.

**First tests of channels alignment**

Two sets of measurements were performed to check alignment of the detection part of the system. The tests of non-uniformity of light registration by the detector itself were done as a reference measurement [6]. The non-uniformity was estimated as approximately 5%.

Tests of channels overlapping was done to estimate precision of spacing of fibre end-connector to detection surface of array and to evaluate level of cross-talks. Principle of these tests is shown at the Fig. 1. The fibre array was moved along the detector array, like it is shown at the scheme. As the result the distribution of light intensity depending on fibre position shift to detection surface was received for 35 channels simultaneously.

![Figure 1](image1.png)

**Figure 1.** Scheme of the measurement of channel overlapping of multi-channel system: 1–photodetecting element, 2–optical fibre, and 3–glass surface of the photodiode array. Arrows show the moving direction of the optical fibre relatively to detector surface. Green shadows show the initial and the final positions of the fibre. Grey shadows show neighbouring detecting elements.

![Figure 2](image2.png)

**Figure 2.** (a) Ratio of light intensities of i-th and 4-th channel dependent on channel’s number. (b) Overlapping of neighbouring channels in percent. Red curve is signal from the right neighbouring channel and black one is overlapping signal from the left one. The 4-th channel was chosen as a reference channel.
The ratio of light intensities of i-th and 4-th channel dependent on channel’s number is shown in Fig. 2a. It is possible to see that the channels are not equal in detection of light. It can be connected with precision of end-connectors production and its position relatively to the fibres. The overlapping measured using neighbouring channels is demonstrated in Fig. 2b. From previous tests [3] it is clear that the overlapping of the light for neighbouring channels can take place in our system, especially when fibres are not close enough to the detector surface or they are not spaced precisely enough. In Fig. 2b it is possible to see also quite strong difference between channels overlapping even in minimal distance between fibre and detection element. In the result we receive the level of overlapping different for each channel but not more than 6%.

These tests show, what it will be required to introduce calibration constants for each channel, which include differences in light transmittance and overlapping. These constants will be calculated for the assembled system for each channel separately and used during data processing.

Spectroscopic measurements

Two HR 2000+ spectrometers were used for spectral measurements in our experiments on the COMPASS tokamak. The spectrometer is located outside of tokamak hall to prevent it from X-ray radiation influence. In the first sets of experiments it was used a toroidal view to vacuum vessel, see Fig. 3 (observation point 1), for measurements of time-integrated [7] spectra or with temporal resolution 7 ms [4]. As the second step poloidal view was used (observation point 2). At this stage of tokamak operation it is not possible to make temporally resolved measurements because the tokamak discharges are quite short (<10ms) and the photosensitivity of the spectrometer’s detector is not high enough to make measurements with temporal integration less than 7ms. Therefore, only temporally integrated measurements were done for this case. Finally, the spectrometers will use sector 6/7 of the COMPASS tokamak (observation point 3).

At the current phase of COMPASS operation, the spectrum in the near UV wavelength range of 247–472 nm, integrated over the whole discharge duration, was measured from poloidal view as it is shown at Fig. 3. In future, this wavelength range will be used to observe radiation of highly ionized ions, CV line at 302.1 nm for example. But our plasma conditions at current stage of our experiments do not allow such a state (low temperature). All presented lines at Fig. 4 correspond mainly to low ionised impurity states.

It was arranged temporally resolved measurement (resolution 7–10ms) for plasma radiation to estimate impurity influx and hydrogen atomic recycling in discharges [4]. Unfortunately at this stage of experiments it is not possible to receive regularly long stable discharge, because of fast changes of plasma position, current and density. It makes quite problematic such a type of measurements and complicates results interpretation.

Figure 3. Observation scheme of visible light spectroscopy on the COMPASS tokamak (top view). Observation angles are indicated by grey color.
Conclusions

New optical system for visible plasma radiation measurements at COMPASS tokamak was developed and all components of the system were produced. During design phase some technical constraints like required wide observation angle, cooling and shutter under strong space limitation were solved. Tests of some of system components are completed (amplification, noise level) or currently provided (channels alignment).

The existing optical system for visible plasma radiation measurements at the COMPASS tokamak includes two spectrometers HR2000+ measuring in a spectral range of 247–472 nm and 457–653 nm with optical resolution 0.17 nm and 0.15 nm. This is sufficient for registration of plasma composition in different discharge regimes. The triggering of the spectrometers allows measuring spectra with a temporal resolution limited by photosensitivity of the spectrometer detector. It is \( \approx 7–10 \) ms in a range of interest. In future such measurements will allow making rough estimation of impurity influx and hydrogen atomic recycling using electron density and electron temperature (Thomson scattering, interferometry, reflectometry) measurements. It will be also possible to receive these values for chosen spectral lines with quite high temporal resolution by means of photomultipliers using interference filters.

The system will be completed in summer 2010, when optical path is planned to be finalized.

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References


Figure 4. The spectrum of the discharge #994.