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THE DESIGN AND DEVELOPMENT OF A TUNABLE AND PORTABLE RADIATION SOURCE FOR IN SITU SPECTROMETER CHARACTERISATION

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Abstract

For spectrometers the characterisation of their wavelength scale and spectral bandwidth underpins the quality of their measured data. This characterisation can be performed using metrology-grade tuneable monochromatic sources, which are currently available only in a few laboratories world-wide. Yet in numerous applications only the in-field calibration is a feasible solution. We have designed and developed a Tuneable and Portable radiation Source (TuPS) in the wavelength range from 300 nm to 350 nm for the in-field characterization of Dobson and Brewer spectrometers wavelength scale and slit-function with uncertainties better than 0.02 nm in wavelength with emitted radiation bandwidth smaller than 0,1 nm. The TuPS is designed such that only minor modification of its optical system extends/shifts its spectral range towards visible and near-infrared spectral regions and thus expand its application for spectral characterisation of any spectrometers in the relevant spectral region of interest.

Keywords: Radiometry, Spectrometers, In-field Characterisation

1 Motivation, specific objective

The Dobson and Brewer spectrophotometers are the main instruments used to monitor the ozone layer, even though Dobson spectrophotometers are no longer being manufactured. Although each network-type is in itself consistent, total column ozone retrieved from the two instrument types differ by up to 3 %, significantly larger than the consistency of better than ±0.5 % which can be achieved within Brewer or Dobson spectrometers instruments network. This large discrepancy currently precludes a merging of both datasets and an eventual replacement of one instrument with another type. There is therefore a need for an improved characterization and calibration of the Dobson and Brewer instruments, particularly by involving the reference instruments of each network. The bandwidths and wavelength scale accuracy of the Dobson spectrophotometer are not known for each instrument, but assumed to be equal to the world reference Dobson. Currently tuneable monochromatic sources which could be used for characterisation of Dobsons and Brewers are complex and cumbersome systems that are only found in a few laboratories world-wide and cannot be used for in field calibrations as requested by this global spectrometers network. Such laboratory–based characterisations were performed in CMI and PTB (Köhler, et al., 2018) having requested typically a couple of days' time for each spectrometer plus additional time necessary for shipping of often heavy and large DUTs from their permanent in-filed installation down to the metrology laboratory.

This work describes the design and development of a field Tuneable and Portable radiation Source (TuPS) for the wavelength range 300 nm to 350 nm dedicated for an in-field characterization of Dobson spectrometers wavelength scale accuracy and slit-function measurement with uncertainties of better than 0.02 nm emitting the output radiation with the bandwidth of 0,1 nm or less and reports on its long-term temporal stability. This tuneable light source was designed such that only minor modifications of its optical system can extend/shift its spectral range towards visible and near-infrared spectral region and thus expand its application for spectral characterisation of any spectrometers in relevant spectral region of interest.

2 Methods

The TuPS is composed of the combination of a broadband source and an optical tuneable dispersion system; the latter rejects all but a narrow wavelength band, thus rendering the combination a narrow-band, tuneable source. The dispersion system is optically similar to a spectrometer but modified to act as a narrow-band tuneable filter for a broadband source. With regards to the spectral bandwidth and the uncertainty of the wavelength scale of emitted radiation the requested parameters are given directly by the spectral dependence of the expected slit functions to be characterized. The values were set to 0,1 nm Full Width at Half Maximum (FWHM) for bandwidth and 0,05 nm OR better in the uncertainty of setting the central wavelength of emitted radiation. Optimal level of total radiant flux emitted from TuPS was found experimentally during the laboratory-based characterization of Dobson #074 (Köhler, et al., 2018) as a value that ranges from 10 nW to 1000 nW for an input spectral bandwidth of 0.1 nm. The optical layout was designed using the optical simulation tool Zemax with the aim to design a tuning machine that uses exclusively commercially available off the shelf opto-mechanical components and that provides the high spectral accuracy, the narrow bandwidth and the necessary optical power required by the Dobson. A further constraint was on the TuPS physical dimensions requiring it to be being easily transportable such that it could be used for in field characterization of Dobson spectrophotometers.

The schematic diagram of the resulting layout of the TuPS dispersion system is shown in Fig. 1 below.

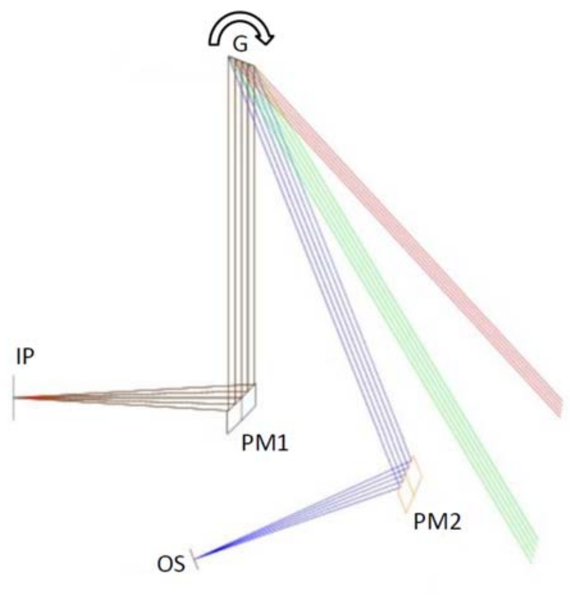

Figure 1 – Schematic diagram of TuPS diffraction system's layout

It consists of a 100 µm input pinhole (IP), a 100 µm output slit vertically oriented (OS), two identical off axis-parabolic mirrors (PM1 And PM2) and 3600 l/mm grating optimised for a spectral range of interest. Radiation from the input pinhole is collimated by a parabolic mirror and illuminates the grating. The resulting diffracted radiation is focussed by the second parabolic mirror forming a spectrum across the exit slit. The central output wavelength is controlled by the angle of the grating, and the bandwidth by the width of the exit slit. A very small vertical shift in the image at the exit port is associated with the rotation of the grating. This shift is of no consequence to the subsequent use of the instrument other than that an exit pinhole may block some of the radiation as the image moves. Therefore a vertical oriented exit slit is used instead. An optical fibre coupled high intensity broadband UV discharge lamp was used as input radiation source. The system was designed such that the FWHM of emitted radiation didn't exceed the value of 0.05 nm for whole spectral range of interest.

The optical set up of the first prototype of TuPS is shown in Figure 2 below.

The TuPS is built on a custom made 400 mm x 400 mm optical board where the grating and the second parabolic mirror positions are fixed; the input pinhole, the first parabolic mirror and the output slit are mounted on high precision micro metric linear stages to provide the fine adjustment needed to compensate for the focal length tolerance of the parabolic mirrors . Both parabolic mirrors and the grating are mounted on adjustable stages to adjust the mirrors orientation angles for their optical alignment. The motorized rotation stage that sets the grating angle uses a high resolution encoder with an accuracy of better than 0.001°. The TuPS light engine is enclosed in a light tight housing.

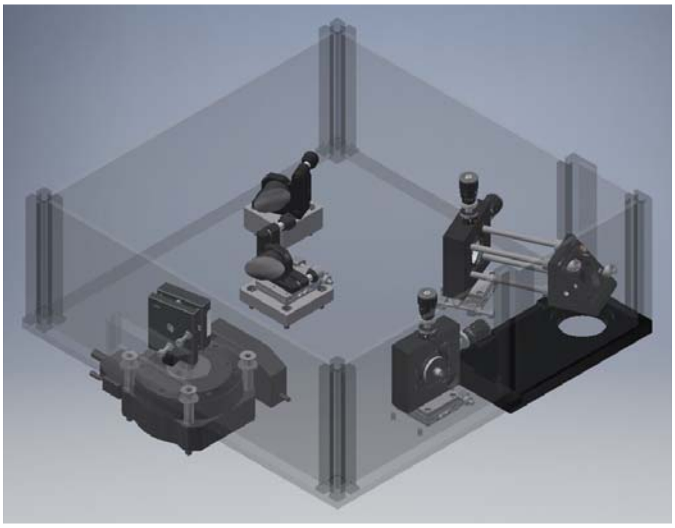

Figure 2 – The optical setup of 1st prototype of TuPS

3 Results

Optical characterisation of TuPS light engine was performed using the fiber coupled CMI tunable optical parametric oscillator laser facility (OPO). The OPO laser radiation wavelength and its stability is monitored by calibrated wavemeter with accuracy better than 0.01 nm (Balling, et al., 2012). Schematic diagram of the measurement setup is shown in Fig.3.

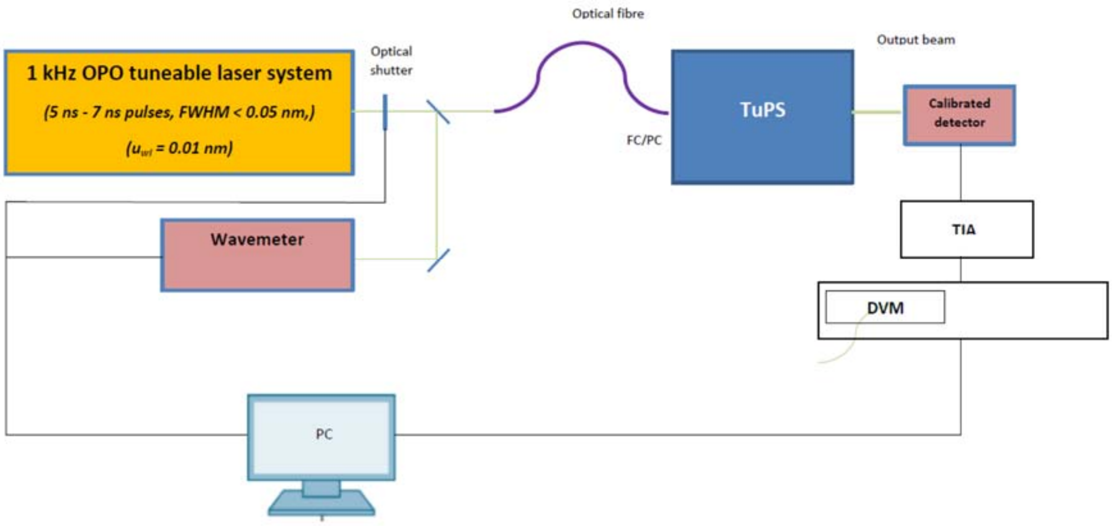

Figure 3 – Schematic diagram of the TuPS characterisation measurement setup

The optical radiation at the OS was measured by a calibrated 10 mm x 10 mm Si photodiode placed at the output of the TuPS in conjunction with a trans-impedance amplifier (TIA). The measurements were performed at wavelengths ranging from 300 nm to 330 nm with 5 nm step plus the 6 typical values measured by the Dobson i.e. 305.5 nm, 311.5 nm, 317.5 nm, 325.0

nm, 332.4 nm, 339.5 nm (in red in Figure 4). For each wavelength a set of 60 grating angle values were set around the expected angle with an angular step of 0.001 °.

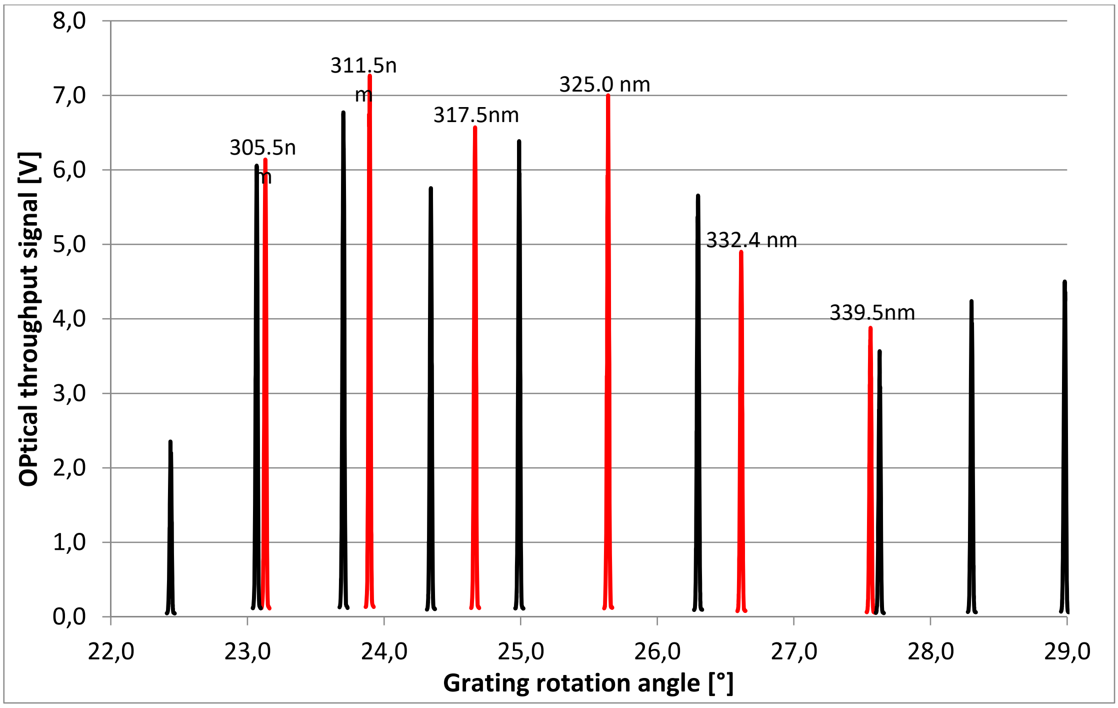

Figure 4 – TuPS wavelength calibration with CMI OPO facility. In red the values of interest for the Dobson spectrometer

For each wavelength the angular position of the peak A_λ relative to the laser line λ is calculated using the centroid formula. The resulting relationship between the TuPS grating angle and the TuPS wavelength at the output slit (OS) is then determined.

Using the same data set and the linear relationship between grating angle and wavelength it is also possible to easily assess the bandwidth performance of the TuPS. In the Figure 5 is reported the TuPS bandwidth measurement performed at 305 nm using the OPO as monochromatic source. The measured grating rotation of 0.015° required to obtain a FWHM corresponds to a wavelength bandwidth of 0.12 nm. That presents a sufficient result providing that we take into account a finite bandwidth of measuring laser radiation of about 0.02 nm.

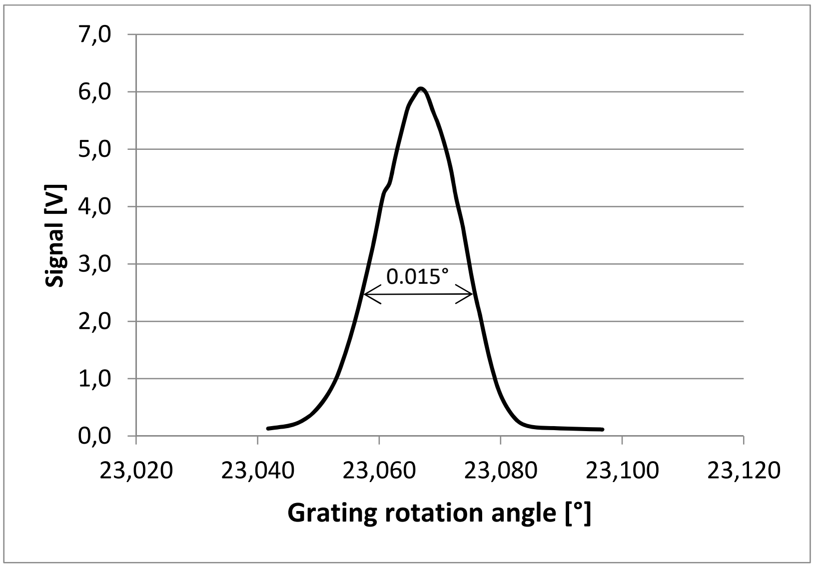

Figure 5 – TuPS TuPS bandwidth measurement performed at 305 nm

With the same measurement setup used for the TuPS wavelength and bandwidth calibration described above we measured the optical power output of TuPS light engine in the spectral region of interest: a calibrated Si photodiode with its area of 20 mm x 20 mm was positioned at TuPS output. Considering the output beam shape and its divergence angle the position of calibrated detector was set such that its sensitive area was underfilled. The photodiode photocurrent is converted by a calibrated trans-impedance amplifier. As shown in Figure 6Figure 6 the measured values are above 25 nW on 0,1 nm FWHM in all range of interest. Based on the data acquired in CMI during the Dobson calibration performed with the CMI monochromator-based facility the optical power value of 20 nW is sufficiently intense to be detected by the Dobson with a convenient signal to noise ratio.

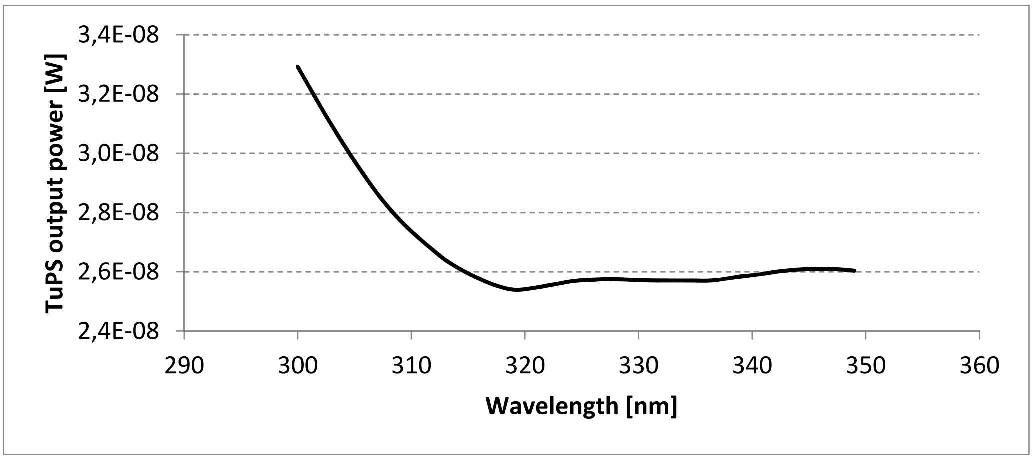

Figure 6 –Optical power output of TuPS light engine in the spectral region of interest

Temporal stability of the TuPS light engine was investigated over a period of 2 years from 2017. During the year 2017 the TuPS has participated to five measurement campaigns where it performed the complete characterization of a total of 14 Dobson spectrometers. Before and after each measurement campaign the TuPS wavelength scale has been recalibrated in CMI laboratory using the OPO laser facility. The results for calibrations between before and after each campaign are reported in Figure 7. The largest difference is about of 0.025 nm has been recorded after the measurements AEMET Izana in Spain and the Deutscher Wetterdienst (DWD) in Germany campaigns over a time interval of 45 days. The TuPS was ground shipped in its protective plastic box together with a number of Dobson spectrometers for the international Dobson comparison in Izana conducted in September 2017. The different environmental conditions in which the TuPS operated varied from strictly controlled laboratory environments to real in field measurement conditions with temperature as high as 26°C..

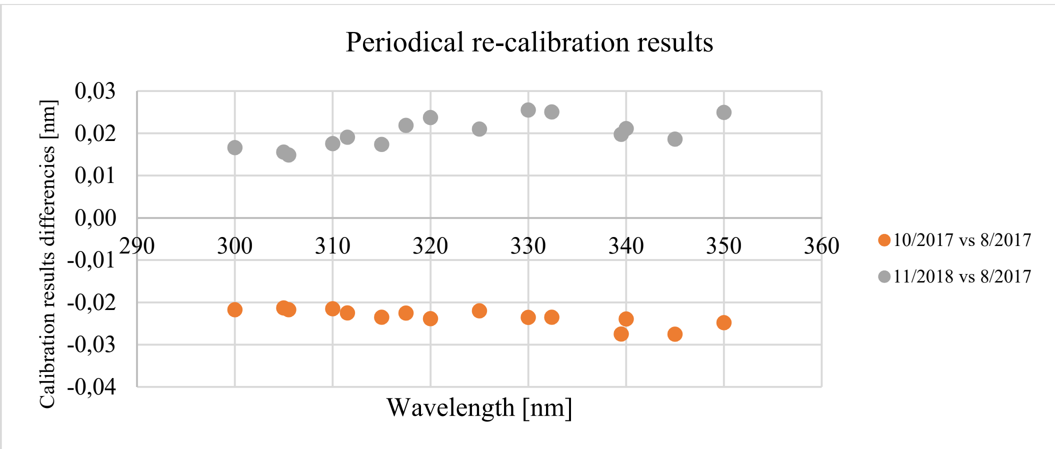

Figure 7 – TuPS results of periodical recalibration of the wavelelngth scale after each in-field measurement

4 Conclusions

The TuPS was developed as an instrument to be used for determining the slit function and centre wavelength of a Dobson Spectrophotometer. The TuPS was characterized at CMI for both bandwidth and the central wavelength accuracy all over the spectral range of interest. Wavelength scale calibration and the investigation of FWHM bandwidth of emitted radiation was performed using the fibre coupled CMI tuneable laser facility – 1kHz ns pulsed OPO in combination with the CMI reference wave meter and they were proved to be better than 0.1 nm and 0.02 nm respectively. Moreover the long term (one year) temporal stability of both key parameters is better than 0.02 nm. This one-year operation included few in-filed calibrations campaigns abroad involving both shipping and in-field installations. Thanks to the TuPS design it is possible with only minor modifications to extend/shift its spectral range towards visible and near-infrared spectral regions and thus to expand its application for the spectral characterisation of any spectrometers in the relevant spectral region of interest.

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