Characterization of a Fourier transform spectrometer for solar UV irradiance measurements

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Primary radiometric standards like e.g. black body radiators [1] or cryogenic radiometers [2] are not suitable for the dissemination of radiometric units to remote measuring sites that are used for solar irradiance measurements. For this reason, portable reference instruments have to be used as transfer standards. Within the European Metrology Research Project EMRP ENV03 "Traceability for surface spectral solar ultraviolet radiation" the feasibility of using a commercially available Fourier transform spectrometer (FTS) as an alternative reference spectroradiometer will be examined. For that purpose, a Bruker FTS VERTEX 80v has been adapted for measurements in the ultraviolet spectral range from 280 nm to 400 nm by adding a UV detector and a UV beam splitter. Furthermore, the modified FTS has been characterized with respect to the suitability for solar UV irradiance measurements with low uncertainties. A global entrance optics will be fitted in order to perform irradiance measurements, and an absolute calibration of the instrument against a black body radiator with known temperature will be performed. Furthermore, the uncertainty budget with regard to solar UV irradiance measurements in the wavelength range from 280 nm to 400 nm will be determined, and a comparison of the performance of the modified FTS against a portable scanning spectroradiometer will be made.

Up to now, scanning spectroradiometers are in use as reference instruments [3]. This type of radiometer has a couple of disadvantages. For example, the solar spectrum is scanned sequentially which needs several minutes of time for each spectrum and limits the temporal resolution of the radiometer. This is a big disadvantage considering varying atmospheric conditions. The standard uncertainty of these instruments for solar irradiance measurements is around 2.3% to 4.4% depending on wavelength and solar zenith angle [3].

It is the goal of the European Metrology Research Project ENV03 to enhance the reliability of spectral solar UV radiation measurements at the Earth's surface by developing new techniques and devices that enable a traceability of solar UV irradiance measurements of better than 2%. For this reason, wavelength accuracies of better than 50 pm are required to reach nominal uncertainties of 1% to 2% due to the steep decrease of solar UV irradiance below 330 nm over many orders of magnitude. For the same reason, a high dynamic range over at least five orders of magnitude is necessary to cover the wavelength range between 280 nm and 400 nm. Furthermore, the rapid temporal variation of solar UV radiation due to varying atmospheric conditions (e.g. fast moving clouds) requires fast spectroradiometers.

Considering these demands, the usage of Fourier transform spectroradiometers may improve the dissemination of absolute irradiance scales due to the specific advantages of these instruments [4, 5]:

- Fourier transform spectrometers have a high throughput which is caused by the circular aperture of these instruments (Jacquinot or throughput advantage). This gives a comparable high signal-to-noise ratio.
- There are no diffraction losses to higher-order spectra as it is the case in grating spectrometers. This also enhances the signal-to-noise ratio.
- The whole spectrum is measured simultaneously which allows fast measurements (multiplex advantage). This is important in the case of rapid temporal variations of solar UV radiation due to atmospheric conditions (e.g. fast moving clouds).
- Fourier transform spectrometers have a wide free spectral range and therefore cover broad spectral ranges with high resolution and high wavenumber accuracy.
- Modern FT spectrometers often use integrated HeNe lasers for the measurement of the position of the moveable mirror of the FTS interferometer. This laser can be used for the wavenumber calibration of the FTS. In this way, the wavenumber scale of the FTS is inherently traced to the SI.
- Instrumental distortions are often calculable and correctable.

Traceability of the wavelength scale

The knowledge of the position of the movable FTS interferometer mirror is necessary to calculate the absolute wavenumber scale of the measured spectra. The Fourier transform spectrometer Bruker VERTEX 80v uses the radiation of a HeNe laser at 633 nm to determine the sampling positions of the interferogram [6]. The HeNe laser beam is coupled into the interferometer nearly coaxial to the radiation under investigation and generates an additional sinusoidal interferogram which is measured by a separate detector. Following a recommendation of the CIPM (International Committee for Weights and Measures), the frequency (respectively the wavelength) of unstabilized HeNe lasers has been added to the list of standard frequencies of the *mise en pratique* of the definition of the meter [7, 8]. For this reason, the SI unit *meter* can be realized by using the wavelength of an unstabilized HeNe laser as a primary standard. Consequently, the wavenumber scale of the FTS can be assumed to be traceable to the SI provided that:

- the laser is a non-tuneable helium–neon laser operating on the 3s2 → 2p4 transition (633 nm) without contamination by radiation from other transitions (e.g. 640 nm) [8],
- the built-in laser is perfectly in line with the beam under test because any misalignment leads to a wavenumber error.

Both conditions may be checked by performing an FTS measurement of the wavenumber of an external HeNe laser with well known properties. Several measurements concerning the wavenumber calibration and the spectral resolution have been performed with two Fourier transform spectrometers of the same type (Bruker VERTEX 80v). In particular, the wavelength uncertainties have been measured by using the radiation of a well known external HeNe laser and of the spectral lines of a mercury pencil lamp (Oriel Model 6034). The wavelengths of the mercury lines are well known from literature [9, 10].

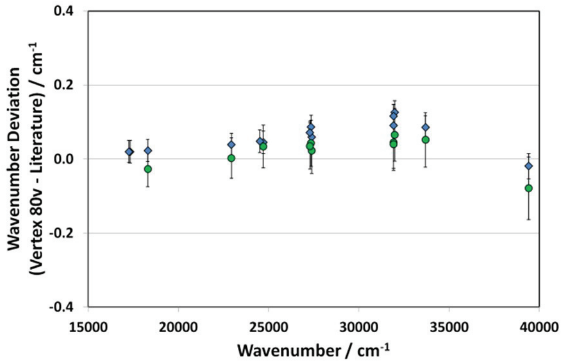

Figure 1. Deviations of measured mercury peak wavenumbers from the literature data after performing an SI-traceable wavenumber calibration of the FTS against an external HeNe laser at 633 nm.

It has been found that the measured wavenumber of the external HeNe laser can slightly deviate from the SI value (up to 0.12 cm^{-1}). This deviation is probably caused by a marginal misalignment of the internal HeNe laser. However, it has to be noted that the deviation is rather small compared to the demands of the JRP ENV03 and can simply be added to the wavenumber uncertainty of the FTS. And, if smallest possible wavelength uncertainties are desired, the misalignment error can easily be corrected either by an optimized adjusting of the internal HeNe laser or more easily by using an external HeNe laser to set the FTS' wavenumber scale (Fig. 1).

The combined wavelength standard uncertainty of the Bruker VERTEX 80v is between 3 pm and 6 pm in the spectral range from 250 nm to 500 nm. These wavelength uncertainties are an order of magnitude below the demanded 50 pm which are required to reach irradiance uncertainties of 1% to 2%. The wavelength uncertainty will therefore not limit the uncertainty of solar UV irradiance measurements.

Responsivity and stability

The spectral responsivity of the FTS is mainly determined by the responsivity of the used detector (Si or GaP) and by the properties of the beam splitter. All FTS mirrors are aluminum coated and do not limit the desired wavelength range from 280 nm to 400 nm. The irradiance calibration of this spectroradiometer will be performed by using the calculable radiation of a black body radiator [11, 12, 13]. A main influence on the stability of the FTS is given by the temperature dependence of the detectors that are used within the FTS. The temperature sensitivity of the Bruker VERTEX 80v has therefore been investigated for Si and GaP detectors. As a result, the temperature of the FTS should be stable within about ± 1 K with respect to the temperature during the irradiance calibration in order to confine the uncertainty contribution of the temperature dependence to the uncertainty of solar irradiance measurements which should be less than 2%.

Results

The usage of Fourier transform spectroradiometers may improve the dissemination of absolute irradiance scales due to the specific advantages of these instruments. The investigated Fourier transform spectrometer Bruker VERTEX 80v has a comparatively small wavelength uncertainty of less than 6 pm in the wavelength range from 250 nm to 500 nm. This is well below the 50 pm which are demanded to obtain an uncertainty of irradiance measurements of less than 2%. Furthermore, the wavelength scale can be assumed to be traceable to the SI via the built-in HeNe laser or via a wavenumber measurement of an external HeNe laser. This property is a big advantage compared with scanning spectroradiometers.

Acknowledgement. This report was compiled within the EMRP ENV03 Project “Traceability for surface spectral solar ultraviolet radiation.” The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

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