Mechanical design of a miniaturized UV-VIS spectrometer for space applications

T. Peschel and C. Damm

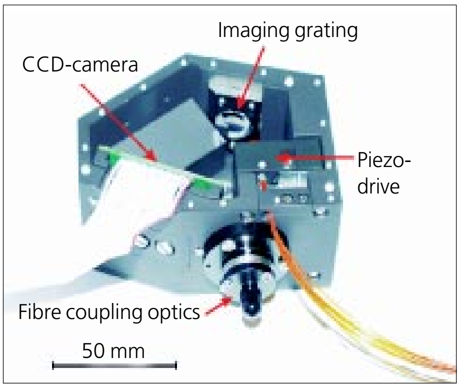

Fig. 1:
View of the spectrometer head with cover plate removed.

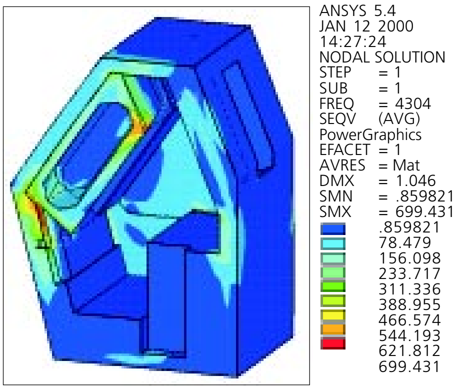

Fig. 2:
Deformation and stress distribution corresponding to the lowest vibration mode of the spectrometer. The cover plate was removed only for the display of results.

Under a contract with the European Space and Technology Center (ESTEC) the Institut für Physikalische Hochtechnologie (IPHT) and the Fraunhofer Insitute für Angewandte Optik und Feinmechanik (IOF) developed a prototype miniaturized UV-VIS spectrometer for space applications (see Figs. 1 and 3).

In the framework of the project the IPHT was in charge of the general layout of the spectrometer optics which relies on their double array architecture /1–5/ and operates as a HADAMARD transform spectrometer. As a subcontractor Carl Zeiss Jena GmbH performed the detailed optical design (together with IPHT) as well as the fabrication of the grating. The optics relies on a holographically structured imaging grating.

The slit mask is driven by a piezo-electric actuator which was fabricated by the company piezosysteme jena GmbH.

The spectrometer uses a commercially available CCD-array as its sensor. The sensor electronics was supplied by the company highRes Ingenieurgesellschaft mbH.

The mechanical design of the spectrometer was performed by IOF. The design is based on a rigid aluminum frame with precision manufactured reference flats, which hold the optical components. The frame is covered by aluminum plates on its bottom and top sides. This symmetric layout allows to realize a nearly homogeneous stress distribution which guarantees a minimum dislocation of the optical elements under both acceleration and thermal loads.

The whole spectrometer head is covered with a Plasmocer® /6/ coating to suppress stray light. Additionally stray light traps, which are integrated into the bottom and top cover plate, suppress the undesired diffraction orders of the grating. In connection with the new coded mask technology of IPHT for the entrance slits this allows to reach a stray light level which is limited only by scattering at the grating itself.

To ensure that the mechanical design provides for the necessary stability of the spectrometer setup during launch and operation of the spacecraft the mechanical and thermal properties were investigated via Finite Element Analysis already in the design phase. For the vibration stability the eigenfrequencies of the housing are of particular importance. Our calculations predicted a lowest frequency of 4.3 kHz which is well above the excitation spectrum during launch (see Fig. 2). Correspondingly no severe resonance frequencies were found in the vibration tests.

The parts of the spectrometer housing were manufactured by milling. Finally the inner contour of the frame of the spectrometer head with its reference flats for the optical parts was finished by wire-eroding.

Before assembly the actual dimensions of all vital parts were measured either on a tactile 3-D measuring machine or optically. With the resulting data optimum positions for adjustment of the optical components were determined.

Alignment of the optical components was performed in two steps. First the slit assembly was adjusted. The following position accuracy (r.m.s. errors) of the slit assembly with respect to the position of the grating could be reached:

– distance 20 µm,
– in-plane position 13 µm, and
– out-of plane position 7 µm.

Finally the CCD was adjusted according to the measured spectral images.

The results of the following tests of optical and mechanical performance agreed completely with the goals of the project.

The achieved optical and mechanical parameters of the spectrometer are summarized in the table 1.
Taking into account the achieved performance parameters our instrument is the smallest high-resolution grating spectrometer available today.

Optical performance	
spectral range	250–675 nm
spectral resolution	1.2 nm (using self-adjustment software by IPHT)
stray light level	about $2.5 \cdot 10^{-5}$
numerical aperture	0.08
interface to multimode fiber	with NA = 0.2
Mechanical parameters	
mass of the spectrometer head	650 g
size of the spectrometer head	300 cm^3
shock, vibration and temperature tests according to Ariane launch loads	passed

Table 1:
Performance parameters of the micro-spectrometer

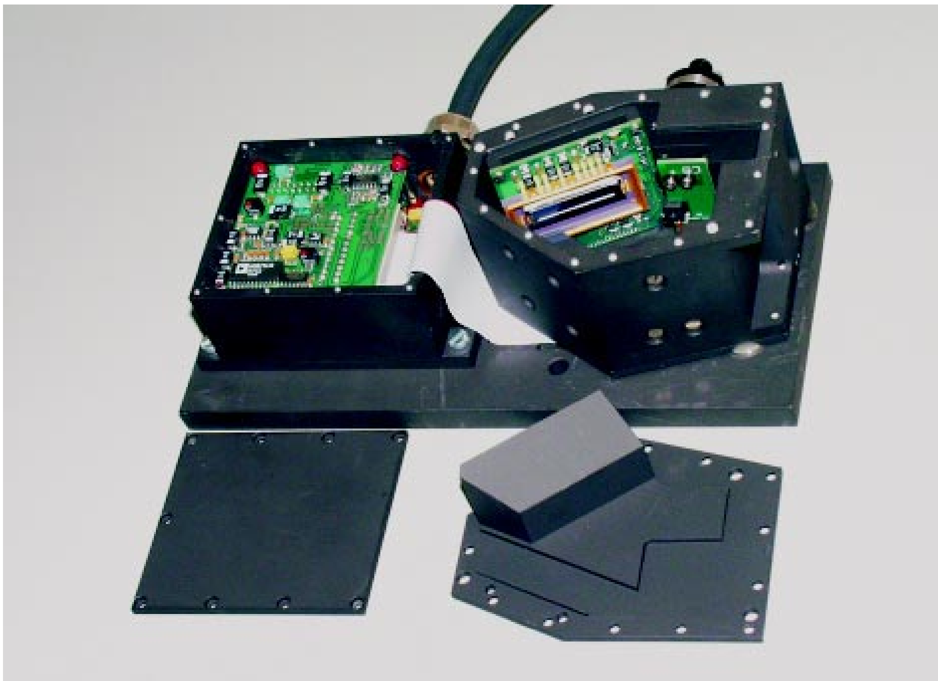

Fig. 3:
View of the complete spectrometer

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