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MicroMED, design of a particle analyzer for Mars

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A R T I C L E I N F O

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A B S T R A C T

Airborne dust monitoring is crucial to characterize Martian atmosphere' thermal structure, balance and dynamics. In order to achieve this objective, the MicroMED instrument has been selected to join the Dust Suite payload within the ExoMars 2020 mission. The particle analyzer is mainly developed to characterize the dust on Mars but, the instrument is suitable to be mounted on different landers or rovers thanks to the limited mass and size. In this study, the design of the instrument has been reported as long as preliminary testing in representative environment of a mockup of the pumping system.

1. Introduction

Airborne dust monitoring is very important for planetary climatology. Dust absorbs and scatter solar and thermal radiation, strongly modifying atmospheric thermal structure and balance. Moreover, blowing of sand and dust causes planetary surfaces shaping through the formation of sand dunes, ripples, erosion of rocks and transport of soil particles. Martian atmosphere is characterized by regional and global dust storms that cause absorption of the incoming sunlight and consequently an intense atmospheric heating. Airborne dust is therefore a crucial climate component to be monitored. Beside dust and size distribution, knowledge of surface flux and granulometry would allow improvements of the existing Mars climate models. These are actually different observations of the dust haze from orbit but, the primary airborne dust size measurement (i.e. the one lifted from ground) has not been performed yet. This is the primary objective of MicroMED (Micro MEDUSA), miniaturized version of the instrument MEDUSA (Martian Environmental Dust Systematic Analyzer), developed for the Humboldt payload of the ExoMars mission [1]. MicroMED would allow measurement of the abundance and size distribution of dust, not in the atmospheric column, but close to the surface, where dust is lifted, allowing monitoring of the dust injection into the atmosphere.

Particle analyzers have been widely used in space missions for the detection of dust particles in the interplanetary medium. The adopted technology is generally the detection via impact [2,3] as this is more efficient in the hypervelocity regime, typical of particles dispersed in the interplanetary medium and captured by spacecrafts. In situ detection and monitoring of low velocity particles (< 100 m/s), typical of planetary atmosphere, generally has not been performed directly but via remote sensing measurements. Anyway, this solution is indirect and return information on the entire observed atmospheric column with poor vertical resolution. The chosen technique for the proposed instrument, MicroMED, has never been used in space, and will provide direct (the size distribution will be built starting from single grain detections) and local measurements (in the atmospheric layer close to the surface where the instrument is located – not atmospheric column measurements) of dust properties.

Thus, the MicroMED has been selected to be mounted on the Dust Suite onboard the ExoMars 2020, suite of five sensors devoted to the study of Aeolian processes on Mars. Beside the MicroMED, Conductivity Sensor, Impact Sensor, Electric Probes and EM-sensor are present. The MicroMED is an optical particle counter that analyzes the light scattered from single dust particles to measure their size and abundance.

A proper fluid-dynamic collector [4], including a pump [5] and a sampling head, allows the sampling of the Martian atmosphere with embedded dust. The instrument working principle is common to ground based devices nevertheless, the application to the Martian environment implies quite different design requirements. The allocated instrument mass and power consumption, 0.5 kg and 2 W, are incompatible with any ground instrument. Moreover, the resistance to the acceleration loads specified for launch and landing phases is a challenging requirement for any instrument.

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Despite the main measurement is the scattered light, the instrument is a complex system whose output relay on a fluid dynamic system that must warrant a controlled flow of Martian atmosphere is generated. The low density of the atmosphere, about one-hundredth of the earth one, along with its wide temperature range, from −70 °C to +30 °C make the measurement of the flow rate a challenge itself. The adopted strategy is based on the measurement of the pressure drop across the fluidic path within the instrument along with the environmental parameters to derive the flow rate. With this approach, an accurate calibration of the fluidic characteristic of the circuit and of the pumping system are critical to achieve (and measure) the desired flow rates in every expected environmental condition.

The work undertaken for the preliminary design of the optical system of the instrument is described in this paper along with its pumping system. In particular, finite element models of the instrument main components have been developed to prove the fulfillment of the design requirements in terms of resistance against expected mechanical environment and allocated mass. Finally, the testing activity of a mockup of the pumping system has been reported as proof of the proposed concept in low pressure environment.

2. MicroMED feasibility design

2.1. Instrument optical layout

MicroMED instrument performs the measurement of the size of single dust grains and dust size distribution. The optical design has been optimized in order to concentrate the laser beam in a very small volume, the sampling volume, where sampled particles are illuminated. This allowed to obtain the requested optical density (> 0.44 W/mm^2) using a low power laser. An on-board processing capability has also been implemented in order to tune operations with respect to dusty conditions and limit the output data volume.

A particle flux is created by a pumping system through a sampling volume, and a laser beam light is focused in the sampling volume by means of an optical collimator. A collecting mirror conveys to a photodiode detector light scattered by particles flux. In order to reach the sampling volume with the laser, an optical fiber is used. This allows locating the diode laser source outside even quite far from the sampling head, moreover, it eases the instrument optical alignment. Thus, the optical system can be divided in three different sections:

- Laser diode source with a collimating system feeding the optical fiber; and
- Focusing system of the light beam at the exit of the optical fiber, into a sampling volume; and
- Parabolic mirror, collecting and focusing the light, scattered by particles, onto the detector.

Moreover, in order to monitor laser diode performance that may change due to aging or exposure to radiation, an additional detector measures the laser optical power deriving a fraction of it from the light trap. The Zemax NSC model of the instrument optical layout is shown in Fig. 1.

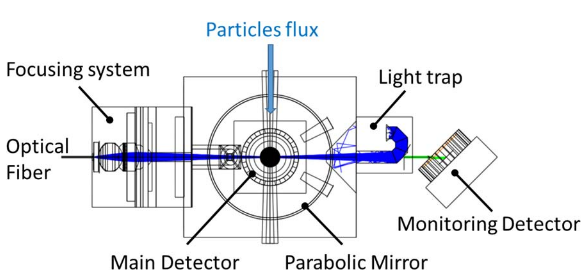

Fig. 1. MicroMED optical layout (Zemax NSC model).

The optical design is suitable for 780 ÷ 940 nm wavelength band, using fused silica glasses. Ray tracing analyses have been performed to derive the efficiency of the focusing system and obtain the optical density in the sampling volume. For the optical density computation a conservative assumption of 128 mW input power (i.e. 85% of laser power) has been made.

Fig. 2 shows the shape of the spot obtained in a rectangular detector (1.6 mm × 600 µm), placed on the center of the sampling volume, along the optical axis. More than the 88% of the rays emitted by the fiber are collected by the rectangular detector, as preliminary validation of the optical design layout.

The design is still an ongoing activity aiming to the definition of the opto-mechanical manufacturing tolerances, assessing the influence of working temperature and pressure conditions. Moreover, analysis of the sensitivity of the MicroMED is being performed.

2.2. Thermo-mechanical design

2.2.1. Thermal analysis

Instruments mounted on the Dust Complex suite are expected to work within controlled temperature range between −20 °C and 40 °C [6]. Storage temperature range is between −40 °C and 50 °C. The thermal requirements are not critical for the intended application where the atmospheric temperature exhibit much wider temperature. Anyway, a thermal model of the MicroMED envelope has been developed to assess if the highest interface temperature would lead to critical temperatures on the instrument internal components, electronics in particular.

Model comprises the MicroMED envelope, the optical stage and the preliminary electronics board layout. Materials and optical properties are summarized in Table 1. Temperature constraint at 40 °C is set at the instrument base, whereas expected dissipated power is added to the instrument electronic board. Thermal resistances have been computed at the joined interfaces. Steady state analyses have been performed with radiative environment at 40 °C and 1 W dissipated power by the electronics. The computed temperature distribution is shown in Fig. 3.

On the electronic board the temperature increase with respect the environment by few degrees Celsius. Thus, no criticalities are foreseen both for the instrument and the electronics nevertheless the detailed analysis of the electronic board with component-level resolution is ongoing to assess also temperature differences between different components.

2.2.2. Mechanical requirements

Several requirements must be considered within the design of the MicroMED optical bench, mainly coming from the accelerations during launch and landing operations [6]. Quasi-static acceleration defined for the entry phase is somehow low, i.e. about 100 m/s^2. However, for the initial design phase, a quasi-static acceleration 10 times larger was considered. This was done on the basis of previously designed instruments [7–9] and to account for the dynamic amplifications that will be evaluated only at later design stages, this a conservative approach that most of the time is not penalizing for this kind of applications where stiffness requirements are often the design drivers. Mission dynamic requirement bounds the lower resonance frequencies to be accepted in the design phase above 150 Hz; this value that allows a safety margin with respect to the strong sine excitation (ranging up to 80 Hz) during the takeoff. Size of the instrument has been locked by preliminary interaction with the Roscosmos team which is in charge of the design of the Exomars lander. Interface drawing is shown in Fig. 4. Mass allocation of the MicroMED is about 500 g including a maturity margin of 20%. From the instrument mass budget the available mass for the optical bench (OB) and cover is 110 g, including the supports of the main instrument components and fasteners.