VERIFICATION OF THE AUTOFOCUSING SYSTEM FOR THE RAMAN SPECTROMETER ON THE MMX ROVER.

S. Mori[1]*, T. Belenguer[2], U. Böttger[3], M. Buder[3], Y. Cho[1], E. Dietz[3], T. Hagelschuer[3], H.-W. Hübers[3], S. Kameda[4], E. Kopp[3], A. G. Moral Inza[2], A. J. Ogura[1], O. Prieto-Ballesteros[5], S. Rockstein[3], S. Rodd-Routley[3], F. Rull[6], C. Ryan[3], T. Säuberlich[3], F. Schrandt[3], T. Usui[7], and K. Yumoto[1]. [1]Department of Earth and Planetary Science, The University of Tokyo, Tokyo, Japan, [2]Instituto National de Técnica Aerospacial (INTA), Spain., [3]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin, Germany, [4]Department of Physics, Rikkyo University, Tokyo, Japan., [5]Centro de Astrobiologia, Spain., [6]Universidad de Valladolid, Valladolid, Spain., [7]Japan Aerospace Exploration Agency (JAXA), Institute of Space and Astronautical Science, Kanagawa, Japan. (*mori-shoki945 [at] g.ecc.u-tokyo.ac.jp)

Introduction: Raman spectroscopy is a powerful tool to identify minerals by acquiring the signals characteristic to molecule vibrational modes. Raman scattering was discovered in 1928 [1] and four Raman spectrometers have been developed or are under development for planetary explorations. SuperCam is equipped with the stand-off Raman spectrometer for NASA's Perseverance rover [2]. Perseverance also has a continuous deep UV Raman spectrometer attached to the robotic arm [3]. Raman Laser Spectrometer (RLS) was developed for ESA's ExoMars Mission [4]. The Raman spectrometer for MMX (RAX) is onboard the Rover, which is carried by JAXA's Martian Moons Exploration mission (MMX) [5,6]. RAX is the smallest of the four to fit in the volume of the compact Phobos rover. In fact, the volume allocated for RAX main box is 81 × 98 × 125 mm^3 [7,8], requiring a very compact and lightweight instrument.

Because Raman scattering is very weak (10^{-4} of Rayleigh scattering [1]), the following two conditions are important to obtain high-quality Raman spectra. First, in order to gather the weak light efficiently, the numerical aperture (NA) of the objective lens should be maximized. Second, to maximize the number of photons yielded by Raman scattering, precisely focusing the excitation laser beam (CW, 532 nm) on targets is necessary. Thus, as a part of the entire RAX instrument, developing a small, lightweight, robust, and power-saving focusing system was needed.

We designed and manufactured the development model (DM) of the Autofocusing Subsystem (AFS) (Fig. 1) for the first integrated performance test. The DM has the design and components exactly identical to the engineering / qualification model (EQM), but was not subject to the qualification tests. For the DM, we conducted three test campaigns: functionality test to verify the design and function of the AFS, end-to-end test to acquire Raman spectra with a breadboard model (BBM) and the DM, and vibration test to detect any workmanship errors during its assembly. Here we report the results of these tests to show the capability of the AFS.

Design of Autofocusing subsystem: The function of the AFS is to translate the objective lens barrel along the optical axis and to adjust the distance between the target and the objective lens. The objective lens system was designed to achieve high transmittance (>90%) in the wavelength range used for Raman spectroscopy, low wavefront aberration ($<0.22\lambda$), and high numerical aperture (NA > 0.2). The linear stroke and working distance of the focus mechanism were designed to be 13 mm and 78 mm, respectively. Rotations of the stepping motor are converted to lead screw rotations that translate the lens in the vertical direction on Phobos. Because of the constraints on size and number of communication ports, no encoder is equipped with the AFS. The position of the lens will be estimated by counting the number of pulses transmitted to the motor. The reference point of the position can be nevertheless determined with the photo interrupter placed at the bottom end.

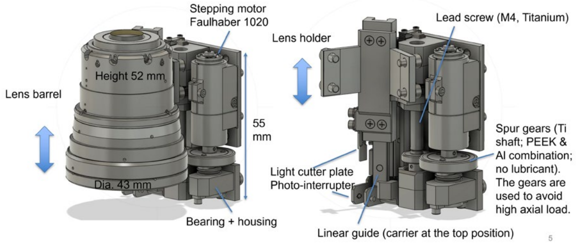

Figure 1: Design of AFS shown with and without the objective lens.

Functional tests results: A series of functional tests were conducted to verify the performances of AFS using the newly-developed DM. First, the optical functional tests of the objective lens revealed the following: (1) the transmittance was higher than 94 % over 532-680 nm range, which corresponds to the Raman shift of < 4000cm^{-1}; (2) Root-mean-square wavefront aberration of the optics was lower than 0.1λ; and (3) Numerical aperture (NA) was 0.22. These results demonstrate the high light-collection capability and minimal optical aberration caused by the optics.

Second, the lens-barrel moved 1.33 mm when 400 pulses were applied to the stepping motor, leading to the vertical motion resolution of 3.3 µm per step. The actuator stroke was measured to be 14 mm from the top end to the bottom end. Backlash of the lens barrel was measured to be less than 80 µm.

The mass of AFS was measured to be 223 g including the objective lens (129 g). The maximum power consumption was 0.9 W.

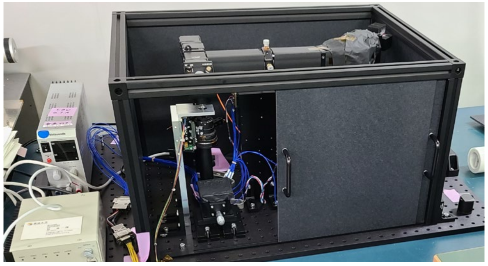

Figure 2: Development Model (DM) of the Autofocusing subsystem (AFS) attached to the Raman spectrometer BBM for the end-to-end test campaign in Japan.

End-to-End Raman spectroscopy test with breadboard: In addition to the component-level tests, we conducted a Raman spectroscopy test using the DM. We attached the DM to the breadboard model (BBM), which has been developed by the RAX team at DLR-OS in Berlin [9]. The BBM has been rebuilt at the University of Tokyo in order to early proof the feasibility of Raman spectra acquisition.

First, we measured the working distance by moving a z-stage vertically until the laser was optimally focused. Our preliminary measurement revealed that the working distance was 79 ± 2 mm, consistent with the design within the uncertainty of the measurement. The laser spot diameter at the best focus was measured to be ~50 µm using the knife-edge approach.

Then, we acquired Raman spectra with olivine, brucite, and calcite samples at different lens positions. Fig. 3 shows a series of Raman spectra for calcite. The intensity of Raman scattering and fluorescence varied as the lens position. Fig. 4 shows that the focusing with AFS enhanced the intensity of the main peak approximately ten times compared to that obtained at 2 mm away from the best-focus position, for a transparent mineral like calcite. Furthermore, Fig. 3 and Fig. 4 show that the intensities are comparable to each other. This result indicates that 330 µm off-focus measurement can still yield high Raman signals.

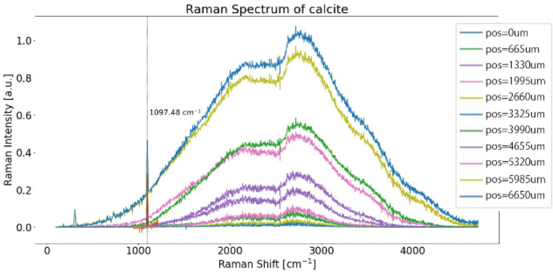

Figure 3: Raman spectra of calcite at different lens positions.

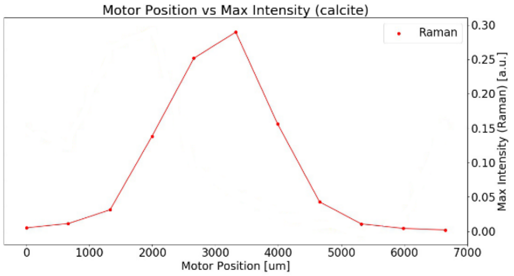

Figure 4: Intensity of the strongest Raman peak at different lens positions.

Vibration test: After the end-to-end test with the BBM, the AFS was subject to a vibration test in the direction perpendicular to the optical axis (Fig. 5). We applied up to 10 G sine wave vibration up for 5-100 Hz at a sweep rate of 2 octave/min and 7 G root-mean-square random vibration consisting of 20-2000 Hz to the AFS. The mechanical and electrical functional tests after the vibration test showed the performance of the AFS remained unchanged.

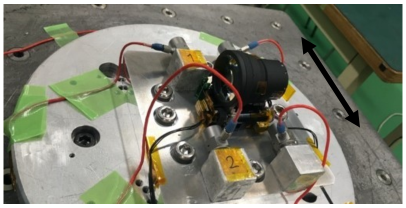

Figure 5: Vibration test setup. The AFS sits on the vibration bench with acceleration sensors. The arrow shows the direction of the vibration.

Summary: The results of the initial verification campaign demonstrated that the basic performance of the AFS was achieved as designed.

References: [1] Hamaguchi, H., Iwata, K., and Kodansha-Scientific. *Raman Spectroscopy*. Japanese. Kodansha, 2015. [2] Wiens, R. et al. (2021) *SSR 217, 4*. [3] Beegle, L. et al., (2015) SHERLOC: Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals, *IEEE Aerosp. Conf. Proc*. [4] Rull, F. et al. (2017) *Astrobiology* 17, 627-654. [5] Kawakatsu, Y. et al. (2019) Mission Definition of Martian Moon Exploration (MMX), *IAC 2019*. [6] Ulamec, S. et al. (2019) "A rover for the JAXA MMX Mission to Phobos". In: *IAC 2019*. IAC–19. [7] Schröder, S. et al. (2020) *LPSC-51*. Abstract #2019. [8] Hagelschuer, T. et al. (2019) "The Raman spectrometer onboard the MMX rover for Phobos". *IAC 2019*. [9] Rodd-Routley, S. et al. (2021) "Optical design and breadboard of the Raman spectrometer for MMX – RAX". *LPSC-52*. Abstract.