ULTRASOUND PROPAGATION IN THE MARTIAN ATMOSPHERE

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A Lander may be trapped, if the underground is too soft, i.e. the shear velocity of the formation is small. In Earth, the ultrasound technique has been successfully applied for the measurement of shear velocities of formations in acoustic loggings. It is important to study whether the ultrasonic technique could be used in Mars to inspect the soft formation for the safety of the moving Lander. From literatures, the theoretical absorption of acoustic waves in the Martian atmosphere is quite large due to the low pressure and the large concentration of CO_2. In this paper, we have completed experiments to study propagation characteristics of ultrasonic waves in the low-pressure air and CO_2, respectively, in a vacuum chamber. The pitch-catch method using four pairs of piezoelectric actuators and sensors, with central frequencies being 21, 25, 34, and 40 kHz respectively, is applied to generate and receive acoustic signals. The pressure in the chamber drops from 10^5 Pa to 600 Pa. From experimental results, attenuation and sound speeds of waves at different frequencies and pressures have been collected and analyzed. It is found that the 21 and 25 kHz ultrasonic waves have the potential to detect the soft Mars formation, and the 34 and 40 kHz waves could be used to measure the wind speed in Mars.
Keywords: Mars, wave propagation, attenuation, low pressure

1. Introduction

Recent years have seen more acoustic probes in Martian exploration, as sound interacts with matter intimately [1]. The probes are the specially designed microphone to record the ambient sounds [2], the acoustic anemometer to measure the wind speed and direction [3], and the acoustic inspector to detect the soft subsurface of Martian soil.

The typical Martian atmosphere is quite different from that on earth. The atmospheric pressure is 600-1000 Pa, and the temperatures are expected to be around -140-30℃. Another critical factor which influences the wave-propagation characteristics is the chemical composition of the Marian atmosphere. The composition has been established by ground based observations in previous missions [4]. That is, the dominant constituent is Carbon dioxide (about 95%) with a minor amount of Nitrogen and Argon and a smaller amount of water vapour [4]. It is expected that characteristics of wave propagation in Mars are much different from that in earth.

The investigation of wave propagation in Martian atmosphere [5-7] is vital for applications of all the acoustic probes which need to be specially designed for the extraterrestrial Mars environment.

However, very little work has been done to quantify acoustic wave propagation in Martian atmosphere based on experiments.

In this paper, we carried out sets of experiments to study the influences of the pressure, frequency, and chemical composition variations on the ultrasound attenuation in a vacuum chamber filled with tenuous air or CO_2, respectively. The objective is to explore properties of acoustic wave propagation in Mars atmosphere, so that to design Martian-specific acoustic sensors for the future China Mars Landers.

2. Test chamber and acoustic measurement system

As shown in Fig. 1, the 1.6 m length, 0.8 m diameter, cylindrical vacuum chamber filled with the low-pressure CO_2 gas in Beijing Institute of Spacecraft Environment Engineering was used to simulate the tenuous Martian atmosphere. Two pairs of piezo transducers are installed on a remote controlled linear stage. The emitters are fixed, and the receivers can horizontally move along the stage, so that to change the transducer separation length, *L*, to be 0.8, 0.6, 0.4, and 0.2 m, respectively. Central frequencies of four pairs of transducers are 21, 25, 34, and 40 kHz, respectively.

The chamber was initially filled with 10^5 Pa air, and it is connecting to a rotary vane pump which is able to reduce the pressure to 10^{-3} Pa and a vacuum gauge which can precisely measure the pressure. And then the CO_2 gas was filled in the vacuum chamber, so that the pressure reduction process went again. The emitted and received ultrasound signals at pressure ranges from 10^5 to 600 Pa are recorded to analyze the absorption of sound.

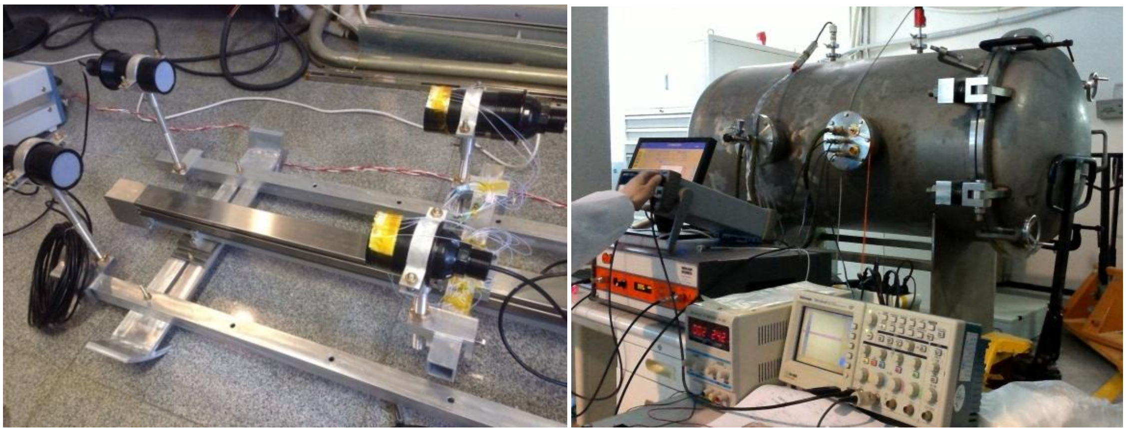

Figure 1: Photographs of two pairs of PZT transducers fixed on the remote controlled linear stage (right), the vacuum chamber and the acoustic emitting, amplifying, and analyzing equipments (left).

3. Experimental results

Typical results of emitted and received signals of 21 kHz ultrasound in 600 and 1000 Pa air and CO_2 are given in Fig.2. It can be seen that the 21 kHz ultrasonic pulse can propagate at least 0.4 m in the tenuous 600 Pa air and CO_2 gas. By comparing the received signals in Figures 2(a) to 2(d), it seems that the amplitude of the 21 kHz ultrasound wave decreases with the reducing pressure. And the signal of noise ratio (SNR) of the 21 kHz pulse in the low-pressure CO_2 is much smaller than that in the low-pressure air. For instance, when the path length is L = 0.8 m, the SNR of the received 21 kHz pulse is too small to be recognized in the 800 Pa CO_2.

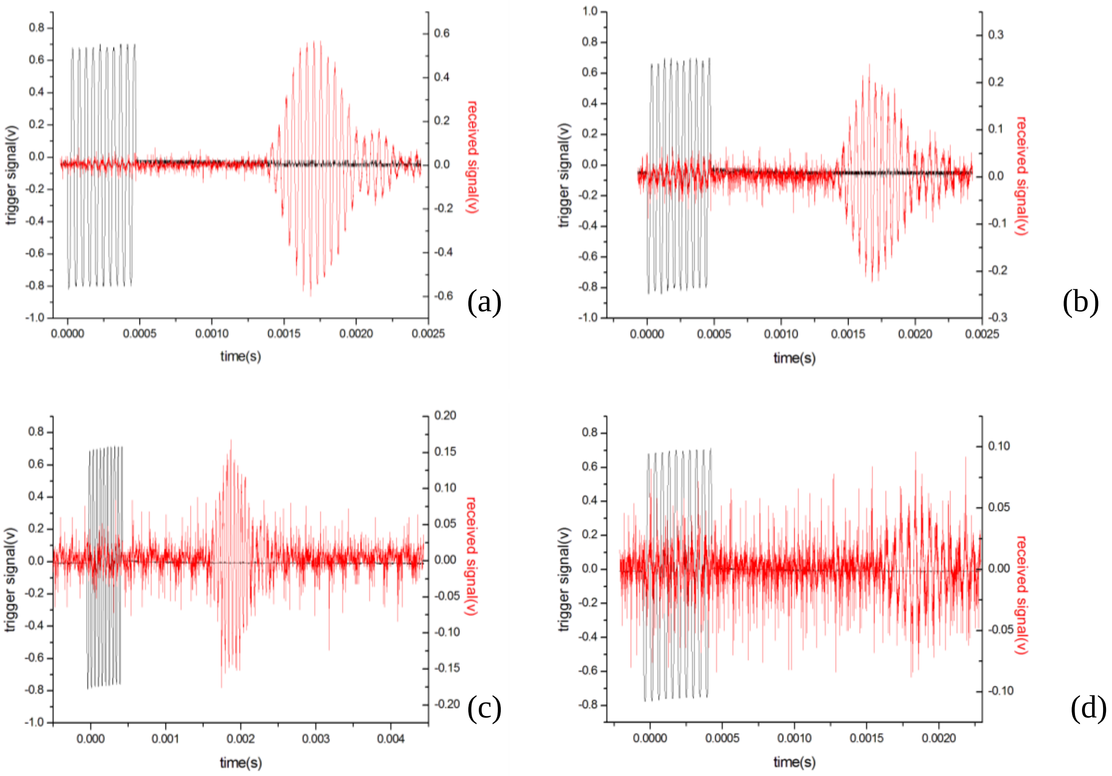

Figure 2: The 21 kHz emitted (black lines) and received signals (red lines) in the 1000 Pa (a) and 600 Pa (b) air, in the 1000 Pa (c) and 600 Pa (d) pure CO_2 gas. Here, the transducer separation distance L =0.4 m.

The amplitudes of the received 21 kHz ultrasonic signals in the air and CO_2 are presented in Fig.3. The pressure in the tank varies from 10^5 to 600 Pa, and the path length, L, is 0.4, 0.6, and 0.8 m, respectively. In both figures, the amplitude of the 21 kHz signal drops sharply with the reducing pressure in air and in CO_2. At the typical pressure of Martian surface (600-1000 Pa), as zoomed in the inset of Fig. 3(b), the wave amplitude in the tenuous CO_2 is close to zero. The wave amplitude also decreases with the increasing path length. Moreover, from comparisons of Figures 3(a) and 3(b), for the 21 kHz pulse, at the same pressure, the amplitude of wave in the CO_2 is much smaller than that in the air. This experimental result conforms to the theoretical predict that the wave absorption in CO_2 is stronger than that in air, because the vibrational specific heat of CO_2 is about 20 times larger than that of N_2 around the room temperature [4].

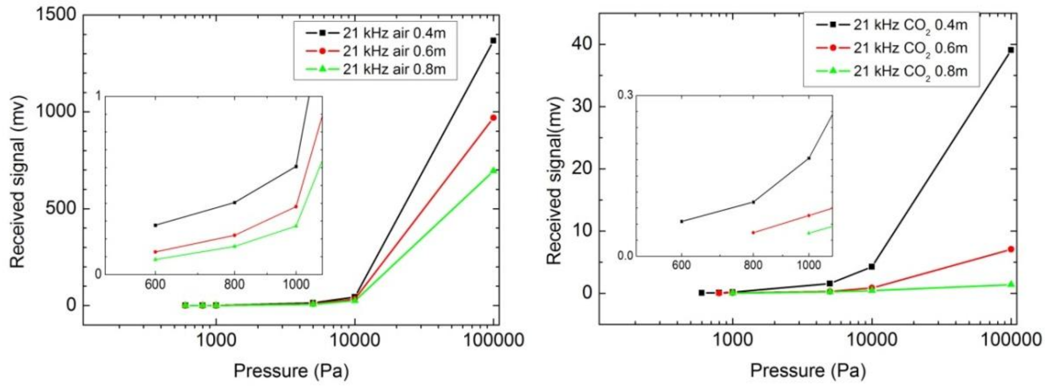

Figure 3: Amplitudes of the received 21 kHz pulses at different pressures and path lengths in the chamber filled with air (a) and CO_2 (b), respectively.

Another impact factor on wave propagation in the tenuous Martian atmosphere is the frequency. Petculescu and Lueptow [5] predicted the sound speed and acoustic attenuation that are frequency-dependent in the frequency range of 0.1-10^7 Hz. Williams [8] theoretically predicted that sounds at the higher end ($3 < f < 20$ kHz) of the audible frequencies will be severely attenuated as the absorption is frequency dependent, and sounds of 20 Hz $< f <$ 3 kHz might propagate less than 100 m. Our experimental results of the available propagation-distances of 21-40 kHz ultrasound waves in the low-pressure air and CO_2 are listed in Table 1. Under the current experimental condition, because of the severe acoustic-impedance mismatch between the piezo-transducer and the tenuous air or CO_2, the ultrasound waves of frequencies 21-40 kHz only propagate no more than one meter at the typical pressure on Martian surface (600-1000 Pa).

Table 1 Propagation-distances of waves in the 600 Pa and 1000 Pa air and CO_2.

	CO_2				Air			
f (kHz)	21	25	34	40	21	25	34	40
1000Pa	0.8 m	0.4 m	0.6 m	0.2 m	0.8 m	0.8 m	0.6 m	0.4 m
600Pa	0.4 m	0.2 m	0.2 m	0.2 m	0.8 m	0.4 m	0.4 m	0.4 m

4. Conclusions

From experimental results, it has been shown that the attenuation of 21-40 kHz ultrasound in the 600-1000 Pa CO_2 is much stronger than that in the low-pressure air. And because of the transducer-air acoustic impedance mismatch, in the 600 Pa CO_2, the 21-40 kHz pulses only propagate less than 0.5 m.

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