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Spectral variation of harmonic tremors observed at Sakurajima

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Harmonic tremors are one of the major types of volcanic tremors. A spectrum of the harmonic tremors is characterized by clear peaks at the fundamental frequency and its integer multiples. Also, rapid changes of a spectral structure, which is called 'jump' here, has been noticed and interpreted by analogy of a non-linear oscillation model or a self-excited oscillation of musical wind instruments such as a recorder. However, there are few works that look into the 'jump' behaviors in actual tremor signals. In this study, we analyzed the spectral variation of harmonic tremor signals in detail and reexamined the existing models.

[Analytical method and Results]
We analyzed a one-hour-long seismogram including harmonic tremors that occurred on 20 July 19 90 at Sakurajima. Using an autoregressive model which gives a high-resolution spectrum from short data has greatly improved both time resolution and frequency resolution of a running spectrum. By this analysis, we found that, through rapid spectral variations with broadening and swaying of the peaks, intervals of spectral peaks expand or shrink, or go back to the initial spacing. In most of the rapid variations, that looked like disconsinuous 'jumps' at first sight, closer examinations enable the individual peaks to be traced continuously. In durations with small variation, the spectrum takes the regular structure having a fundamental frequency and its multiples, and the fundamental frequency takes some particular values. Once the peaks deviate from these frequencies, the peaks broaden, the spectral structure becomes complicated, and the amplitude of wave tends to get smaller. From these observations, we infer the tremor source system has some stable states corresponding to the individual values of the fundamental frequency described above, and the system may transmute between these states. Paying attention to these characteristics, we compared harmonic tremors with a nonlinear oscillation model or a self-excited oscillation of musical wind instruments.

[Model 1]
The nonlinear oscillation model of viscous flow between elastics walls (Julian, 1994) shows that sub-harmonic frequencies appear depending on the system parameters (e.g. pressure) by nonlinear effects. In this study, we changed the parameters continuously and found that, even though new frequencies appear, the fundamental frequency is invariant, which is different from the observation in the harmonic tremors at Sakurajima.

[Model 2]
We also compared the harmonic tremors with the self-excited oscillation of a recorder that is the simplest wind instruments, of which mechanics has been suggested as an analog of harmonic tremors. Then we found transition of the fundamental frequency to the frequency appeared newly. The new fundamental peak grows gradually while the old fundamental peak decays. This manner of the transition is different from the continuous variation of the fundamental peak seen in the harmonic tremors at Sakurajima.

[Conclusion]
We found some stable fundamental frequencies in the harmonic tremors at Sakurajima and transition of the spectral peak between these frequencies. This phenomenon cannot be fully explained by the nonlinear oscillation model or the self-excited oscillation of musical wind instruments. More sophisticated models should be developed in the future works.

Keywords: volcanic tremor, harmonic tremor, Sakurajima, non-linear oscillation, self-excited oscillation, spectral analysis