Cantilever self-excited with a higher mode by a piezoelectric actuator

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Research Article

Keywords: cantilever sensor, sensitivity, self-excited oscillation, higher modes

Posted Date: March 8th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-170949/v1

Abstract

The sensitivity of vibration-type sensors can be improved using a higher resonating frequency of a cantilever resonator. Resonance in such systems can be achieved using a self-excited oscillation, which overcomes the difficulty of using an external excitation in viscous environments. To enhance the sensitivity of cantilever resonators, several groups have proposed ways to increase the natural frequency of the first mode by changing the cantilever geometry. However, the sensitivity can be further improved by using a self-excited oscillation with a higher mode in addition to the geometry-changing technique. In this study, we present a method to realize this goal. We perform a nonlinear analysis of the governing equation of a cantilever excited by a piezoelectric actuator. For each mode, we also clarify the dependence of the critical feedback gain on the location of a displacement sensor, the output of which is used for feedback control. With the aid of filters, we then devise a way to generate a self-excited oscillation with a higher mode associated with a desired higher natural frequency. Finally, we carry out experiments using a macrocantilever and report the observation of a self-excited oscillation with the second natural frequency, which is higher than the first natural frequency.

Full Text

Due to technical limitations, full-text HTML conversion of this manuscript could not be completed. However, the latest manuscript can be downloaded and accessed as a PDF.

Figures

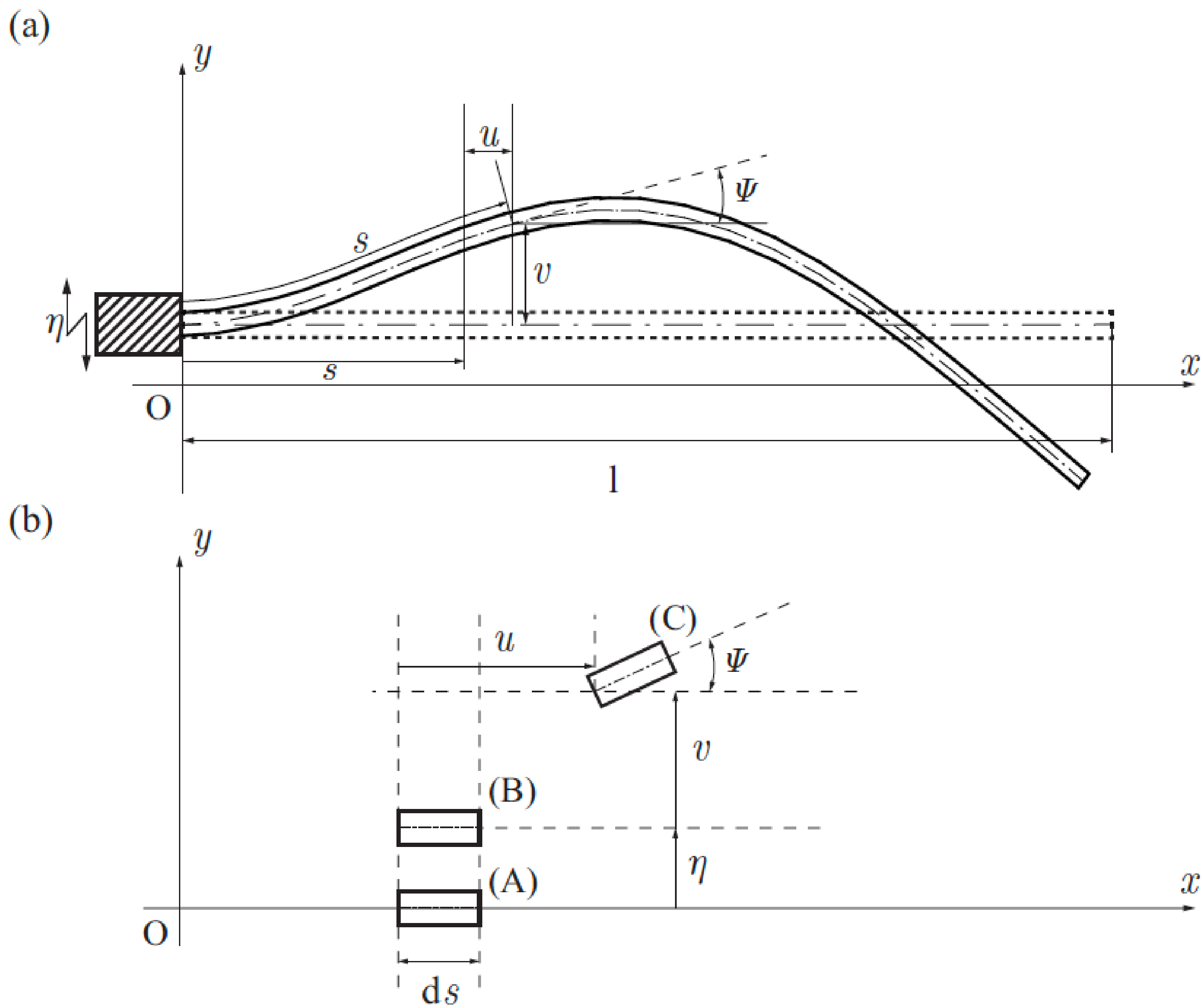

Figure 1

Analytical model of a self-excited oscillation of a cantilever beam, the fixed end of which is subject to a lateral displacement excitation, η. (a) shows the analytical model of the beam. (b) depicts configurations of an element of the beam in the deformed and undeformed states under an inextensible condition. (A) is in the static equilibrium state, (B) is excited with η but undeformed, and (C) is excited with η and deformed.

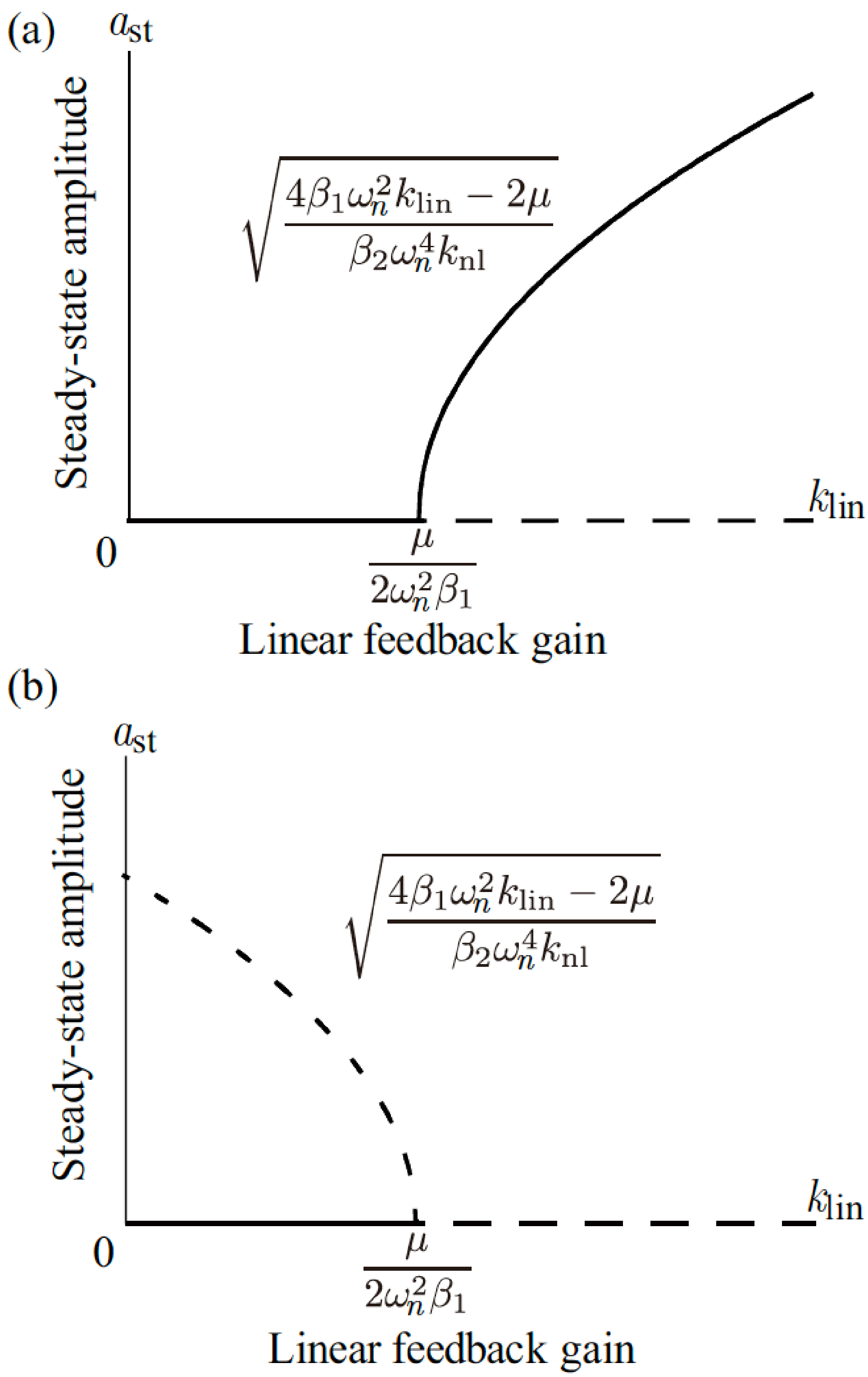

Figure 2

[See Manuscript PDF file for the complete caption] Relationship between the steady-state amplitude αst and the linear-feedback gain klin.

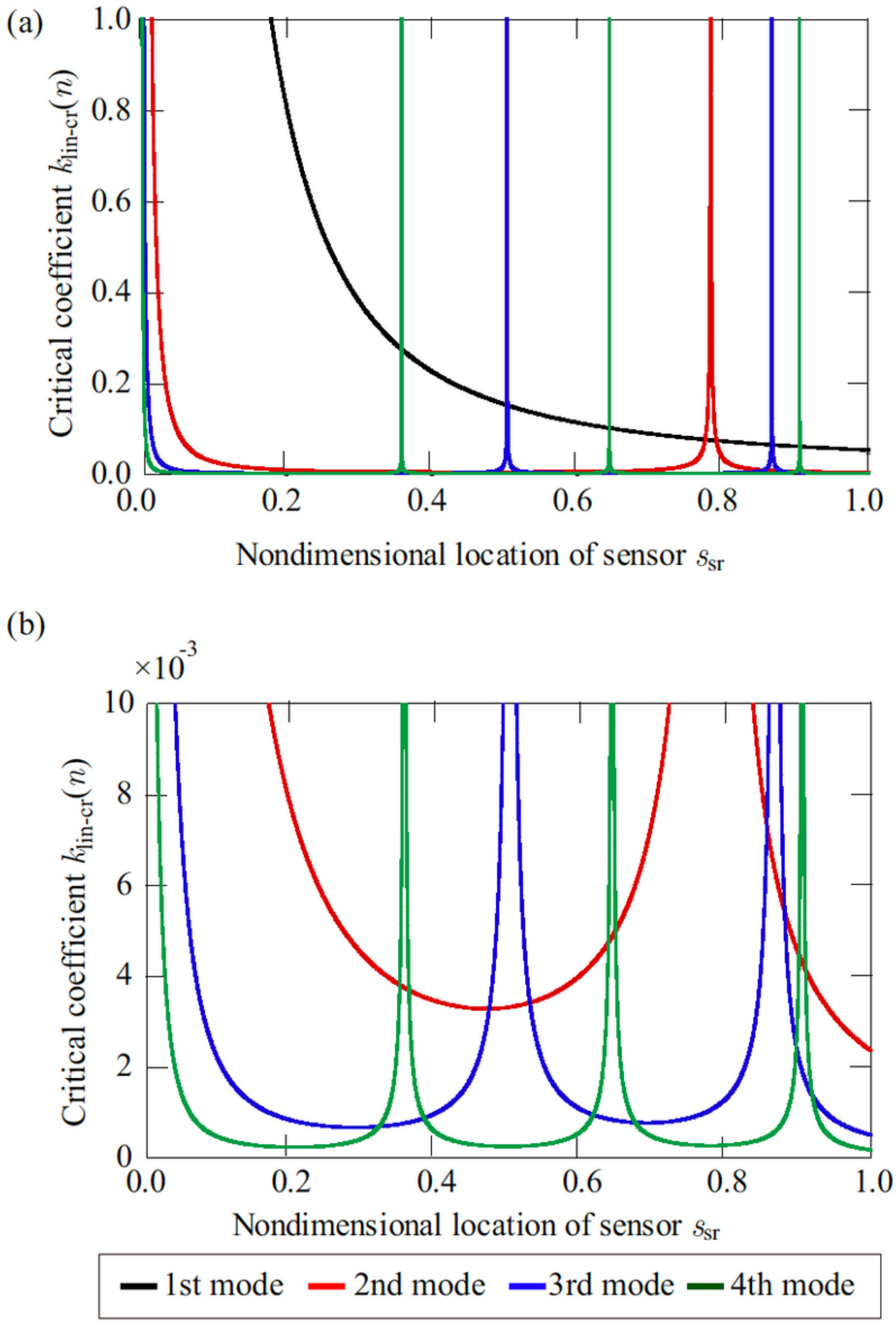

Figure 3

[See Manuscript PDF file for the complete caption] Bifurcation sets for the first mode to the fourth mode.

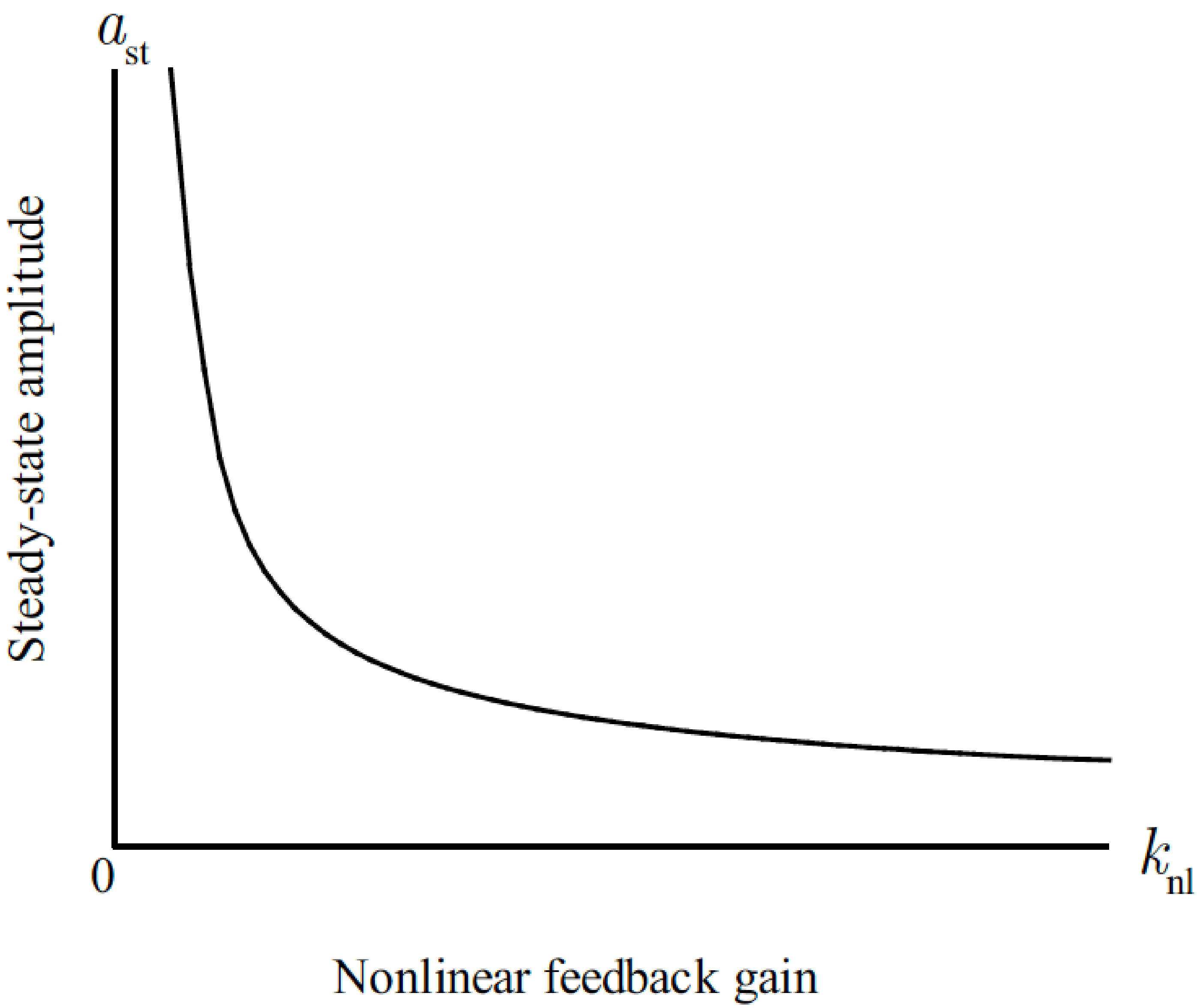

Figure 4

Relationship between the steady-state amplitude αst and the nonlinear-feedback gain knl, expressed by the second equation in Equation (28).

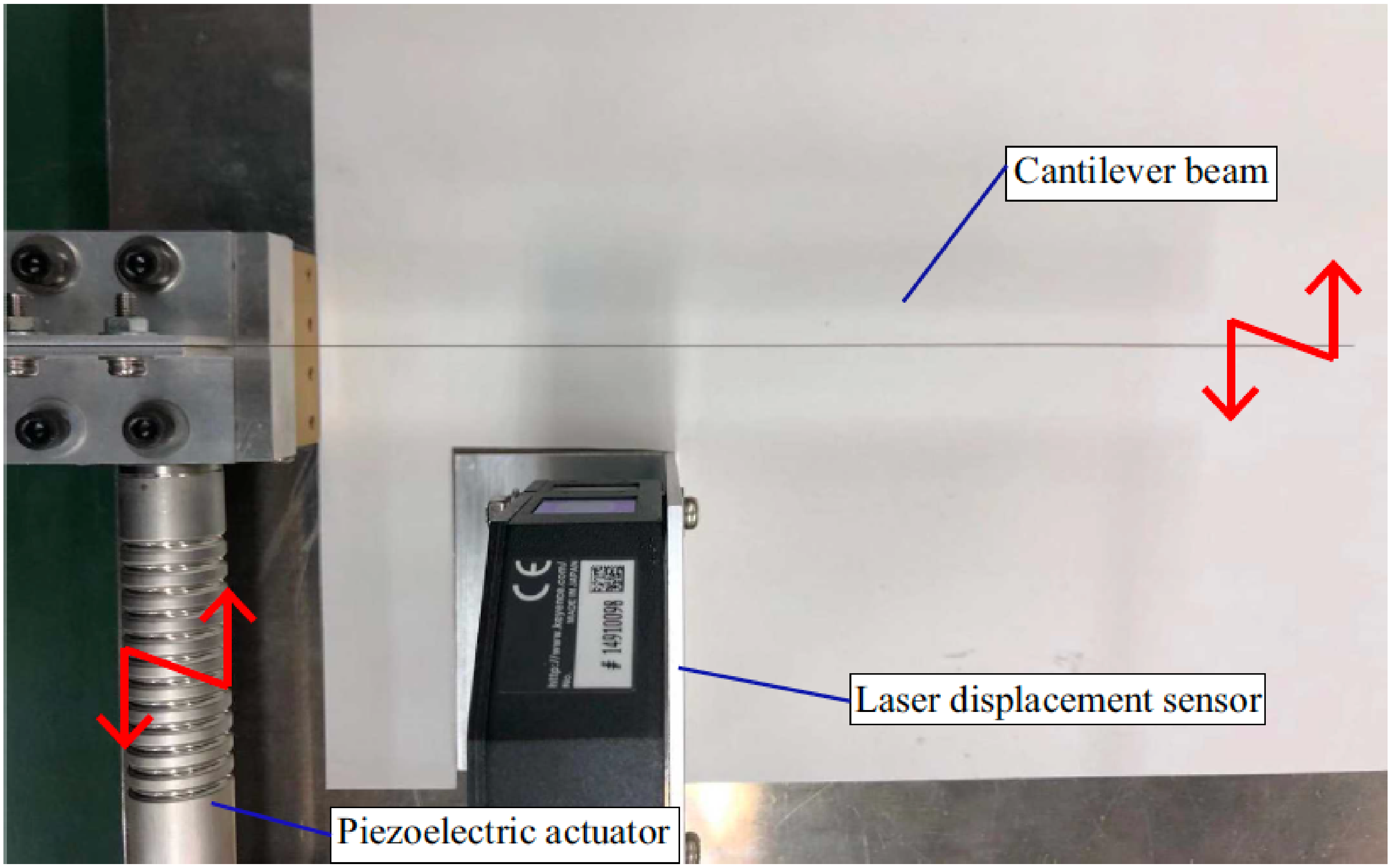

Figure 5

Details of the experimental equipment. A piezoelectric actuator provides a displacement excitation to the supporting point of a cantilever.

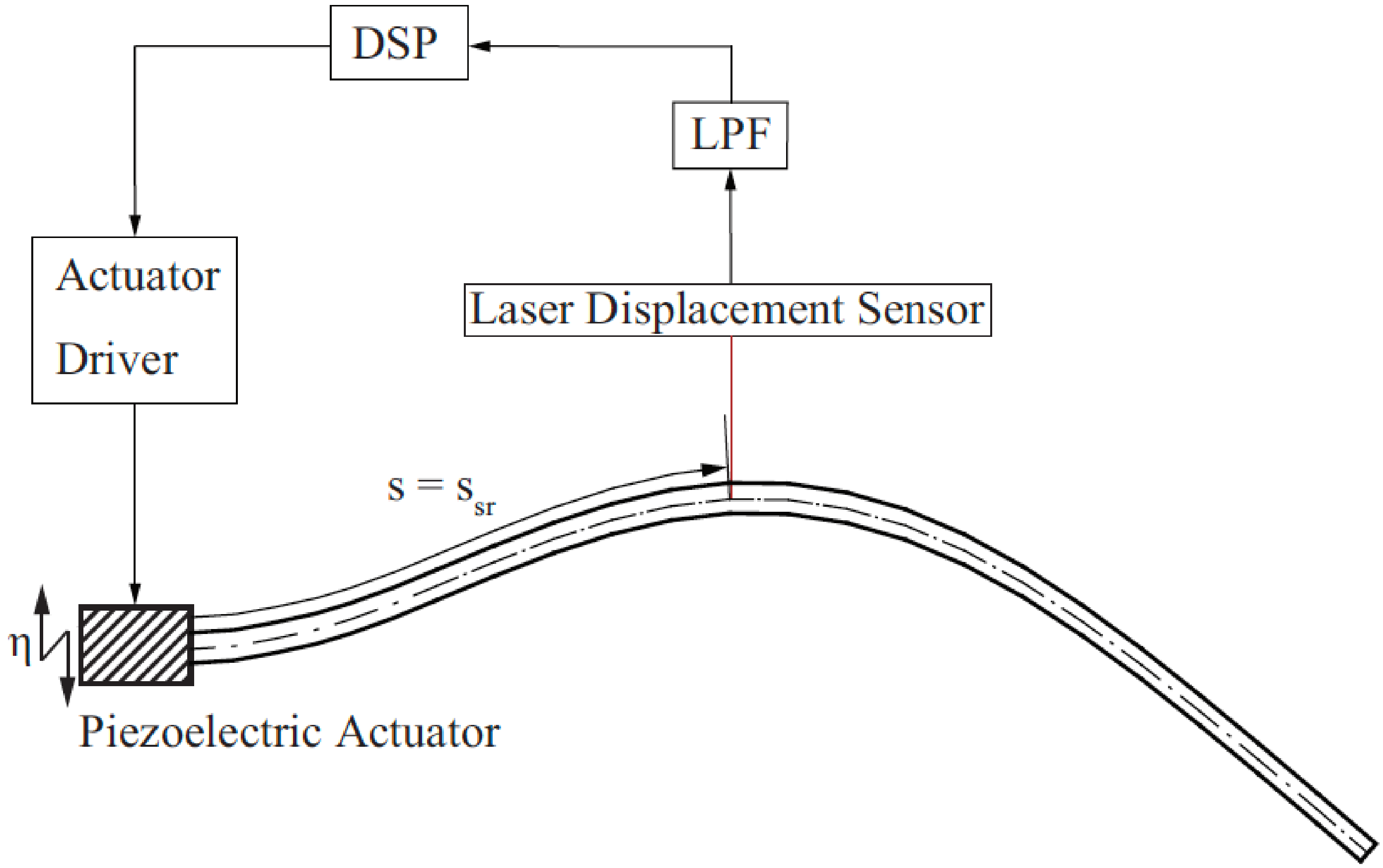

Figure 6

Signal flow in the experiments. The response displacement is measured by a laser displacement sensor. It is then fed back to make the excitation signal for the piezoelectric actuator, according to the proposed linear- and nonlinear-feedback control.

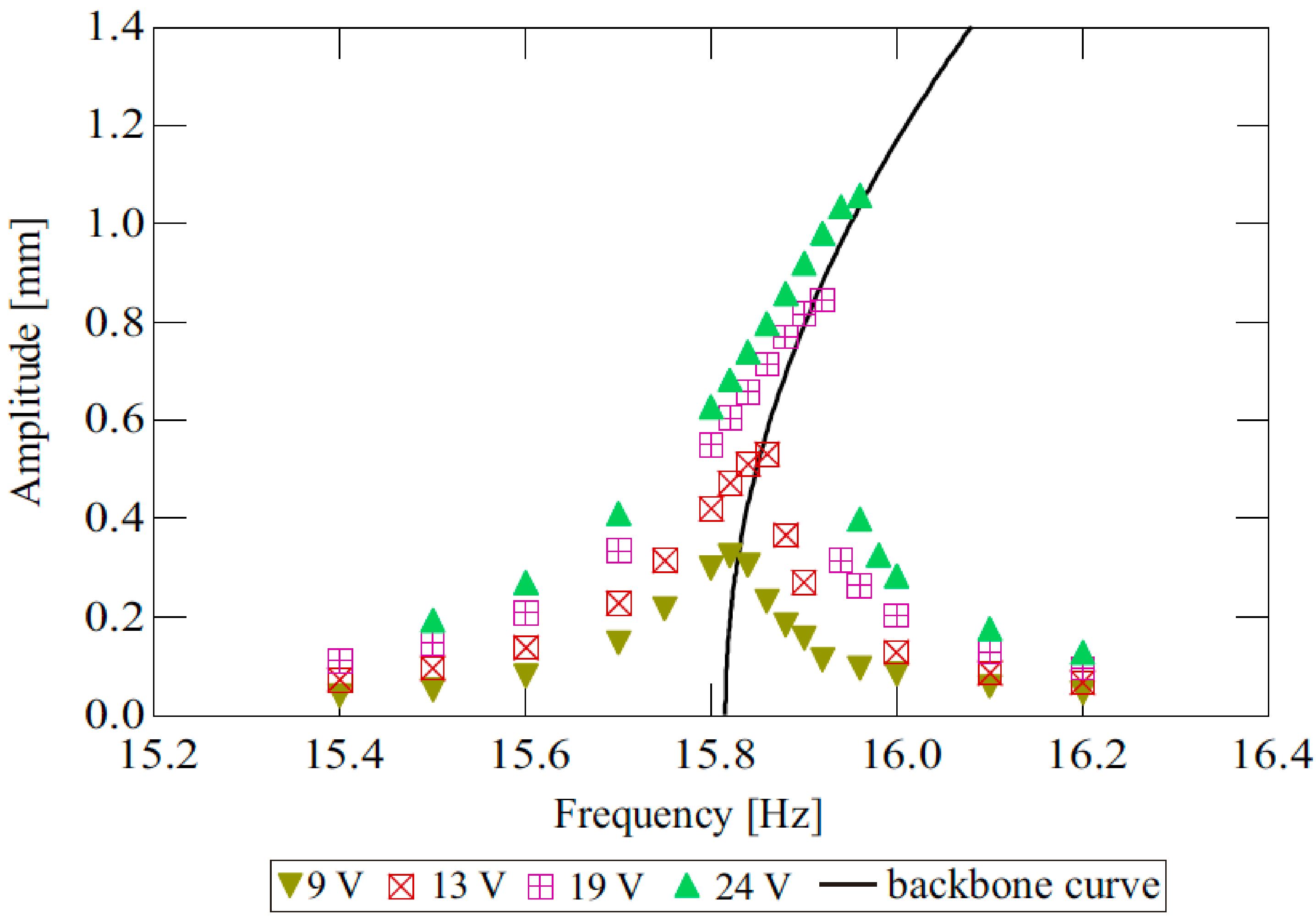

Figure 7

Frequency response curves under an external excitation, and the backbone curve. The symbols ∇, ⊠, ⊞, and Δ correspond to cases in which the amplitude of the harmonic input voltage to the piezoelectric actuator is 9 V, 13 V, 19 V, and 24 V, respectively. The solid line denotes the backbone curve that connects the peak values of the frequency response curves.

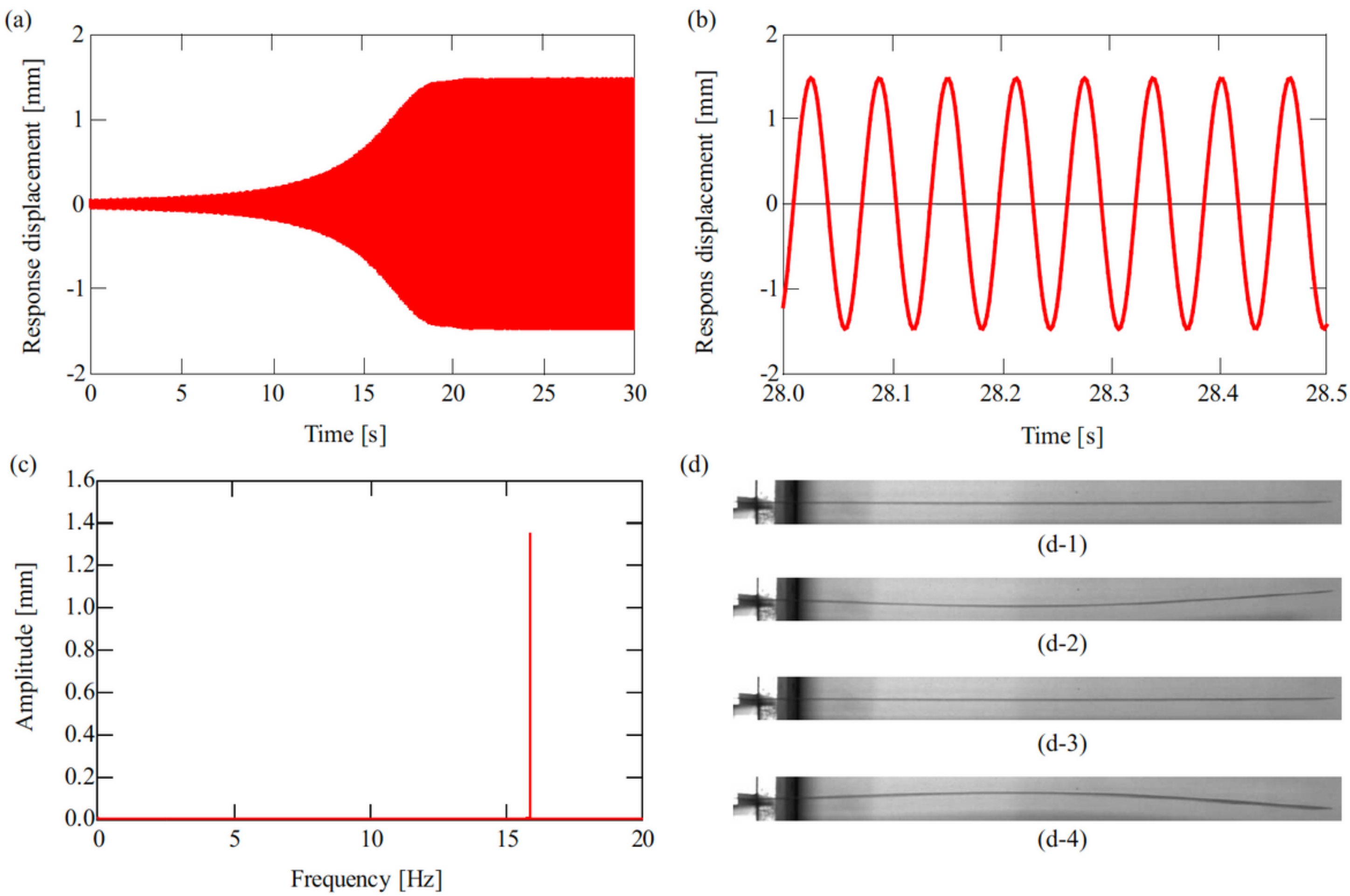

Figure 8

Self-excited oscillation of the cantilever with the second mode. (a) shows the time evolution, including the transient state and the steady state with a constant amplitude that follows the transient state. (b) depicts an extraction of the steady state in (a). (c) shows the results of a fast Fourier transform (FFT) approach for 320 s of the steady state. (d-1) illustrates the shape of the self-excited oscillation of the cantilever at a certain time, and (d-2), (d-3), and (d-4) show the shape after one-quarter, one-half, and three-quarters of a period, respectively.

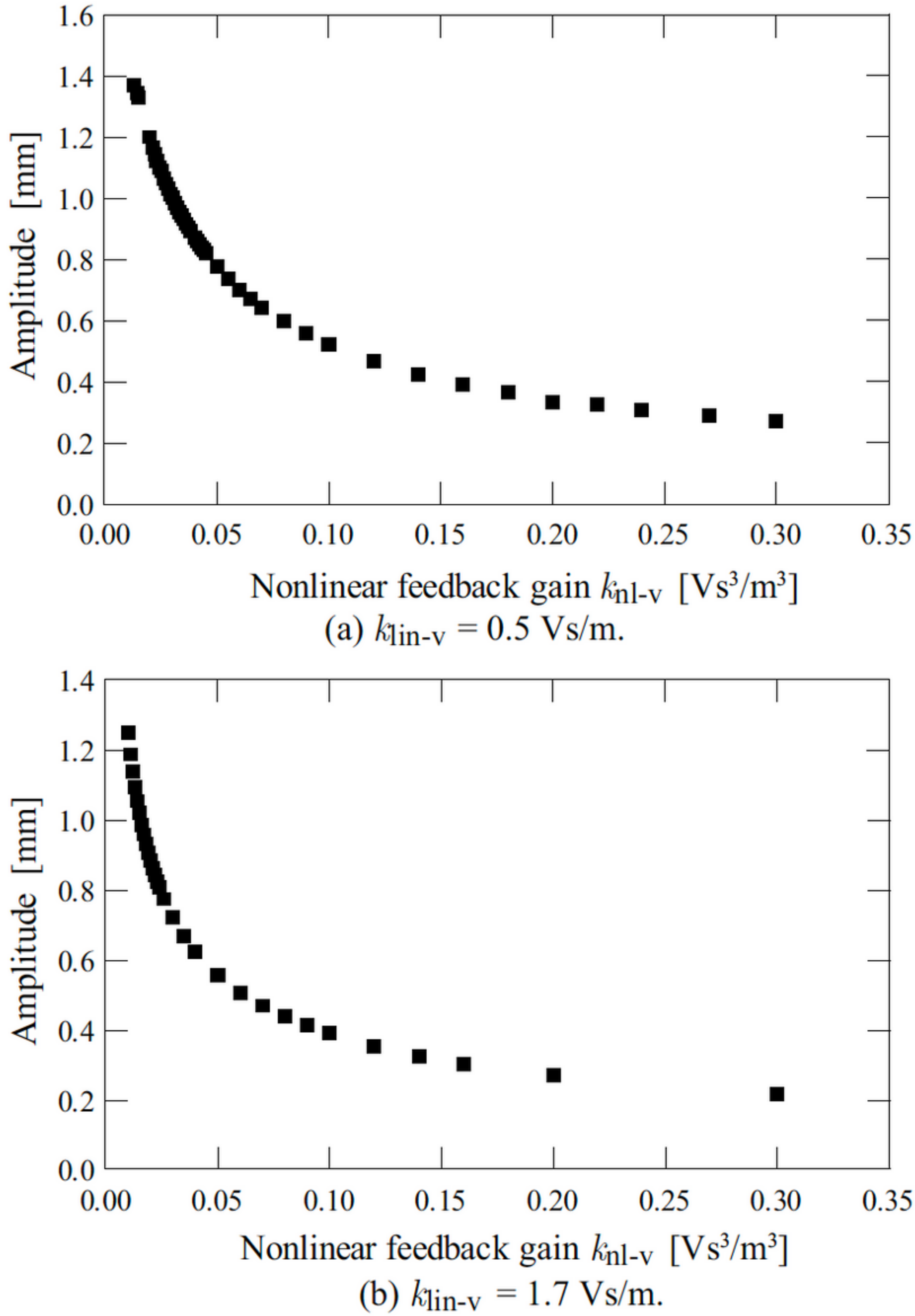

Figure 9

Steady-state amplitude versus nonlinear-feedback gain.

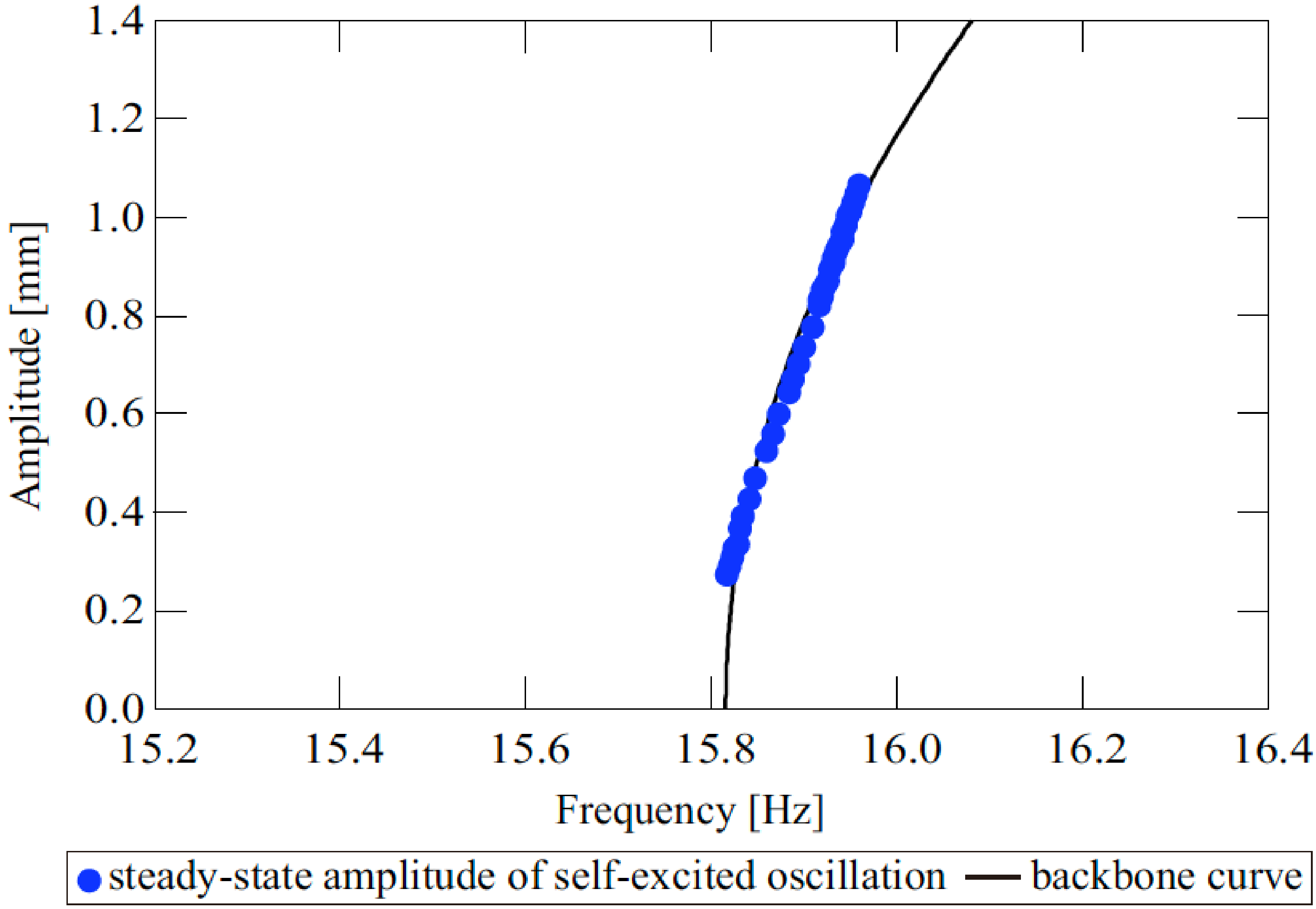

Figure 10

Dependence of the response amplitude on the response frequency, and the backbone curve. The • symbols shows the amplitude–frequency relationship and indicates that the variation of the response frequency depends on the amplitude settled to various values by changing the nonlinear- feedback gain knl−v. The solid line denotes the backbone curve obtained from the frequency response curves in Figure 7.