Nonlinear System Identification of a Beam with Magnetic Restoring Forces

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Summary. Nonlinearities in engineering structures may influence the dynamic behavior significantly. When it comes to system identification linear methods will lead to wrong results if essential nonlinear forces are present. In this paper a linear beam with magnetic restoring forces is analyzed applying the recently developed FNSI method for nonlinear system identification.

Background

We study a cantilever beam made from aluminum which is attached to a shaker and equipped with acceleration sensors. A pair of permanent magnets is placed near the beams tip such that they are close to the nodal point of the second bending mode. Another pair of magnets is fixed to the inertial frame in such a way that there is a magnetic repulsive force acting between the two magnet pairs. First the system is excited by a sine sweep signal and its response is measured for forward and backward sweep. During the further procedure the frequency domain nonlinear subspace identification method (FNSI [2], [3]) is applied and we identify the amplitude-frequency-curve for the vibration at the first mode.

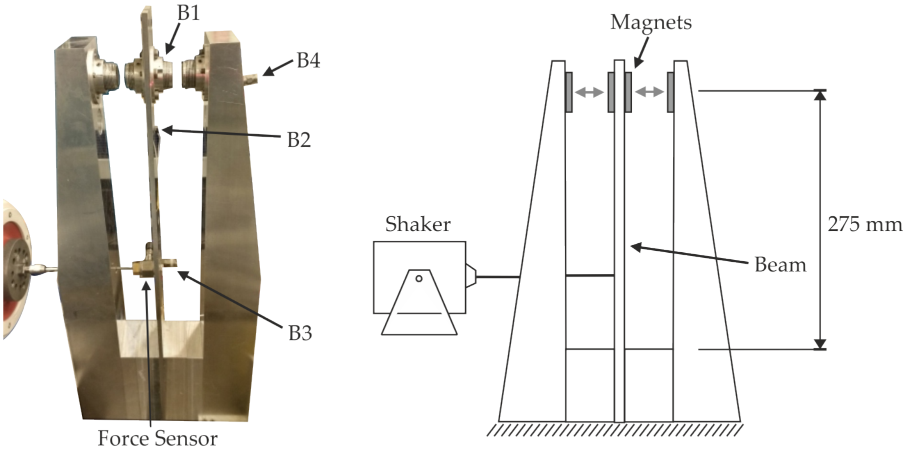

Figure 1: Experimental set up of a beam with permanent magnets equipped with acceleration sensors

Experimental results

Figure 1 shows the experimental setup, standard shaker and measurement hardware was used. Figure 2 shows the experimental results obtained during a sine sweep from low to high frequencies (logarithmic sweep rate: 20-200 Hz, sweep time: 440 s) and vice versa. The first resonance peak which appears after approximately 147 s corresponds to the first bending mode (at approx. 44 Hz) and the second peak which appears after 315 s (at approx. 180 Hz) are clearly visible. The nonlinearity of the system is obvious for the first mode. The second mode is only slightly affected by the nonlinear magnetic forces. The form of the jump phenomenon of the first mode indicates that the magnetic forces have a progressive character (stiffening).

Nonlinear System Identification

According to the survey given in [1], phase resonance and phase separation methods can be distinguished. In this work, we apply the free decay identification and the FNSI method in order to obtain the amplitude-frequency-dependence of

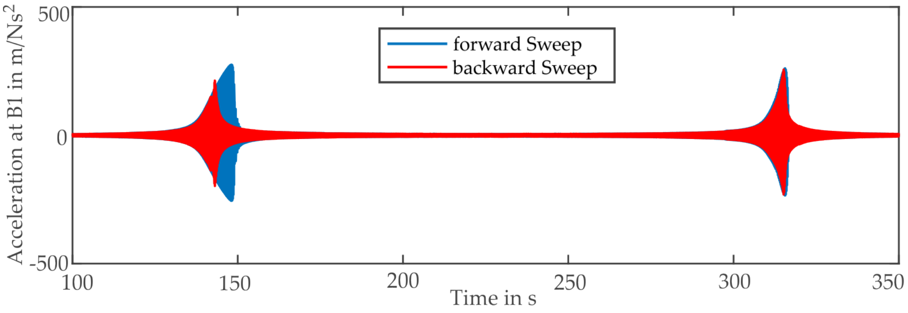

Figure 2: Forward and backward frequency sweep of the beam with magnetic restoring forces

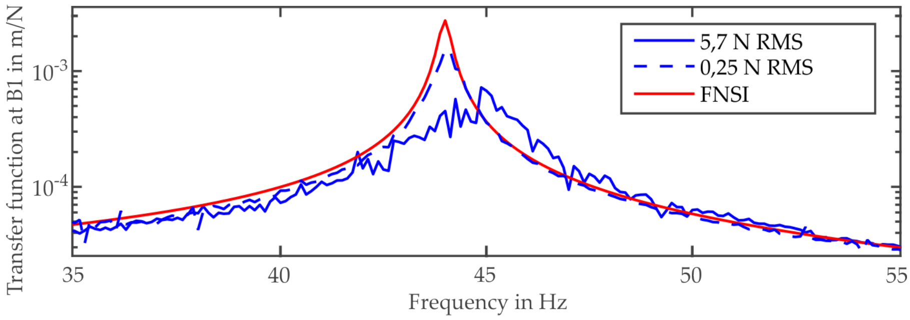

Figure 3: Frequeny response at different energy levels and system identification results

the first bending motion of the beam. In a first step the beam was excited in its first resonance mode and the excitation frequency was tuned manually to get as close as possible to the maximum response amplitude of the first nonlinear normal mode of the system. The observation of the time series from the acceleration sensors showed a purely synchronous motion of the sensor points. Eventually, the excitation was turned off and the free oscillations were recorded.

Then the recently developed FNSI method, which belongs to the phase separation methods, was applied. Here, the nonlinear system is considered as a linear system with localized nonlinearities. For this method, the qualitative form of the local nonlinearity was assumed to be approximately cubic in this case. The frequency response for low and high level excitation of the beam is given in Figure 3. The low energy level is associated with a quite linear behavior, whereas at high energy level the maximum of the response function is shifted to higher frequencies and the overall appearance of the frequency response is obviously distorted.

The response of the underlying linear system was computed by the FNSI method and is in good agreement with the beam's response at low energy level. The calculated resonance amplitude however is higher than the one observed in the measurement.

A main benefit of the FNSI is that it also allows the determination of the system's nonlinearity parameters. Figure 4 shows the calculated amplitude-frequency-curve for the system where the nonlinearity parameters, which have been obtained by the FNSI, were used. It is compared to the amplitude-frequency-curve of the same system which was determined experimentally at free decay. It is clearly seen that the two curves are not identical. The frequency shift between the curves results from the shaker connection, which corrupts the dynamic behavior of the structure during free decay by additional mass and stiffness. This fact has been proved by impact modal analysis experiments at low level energy.

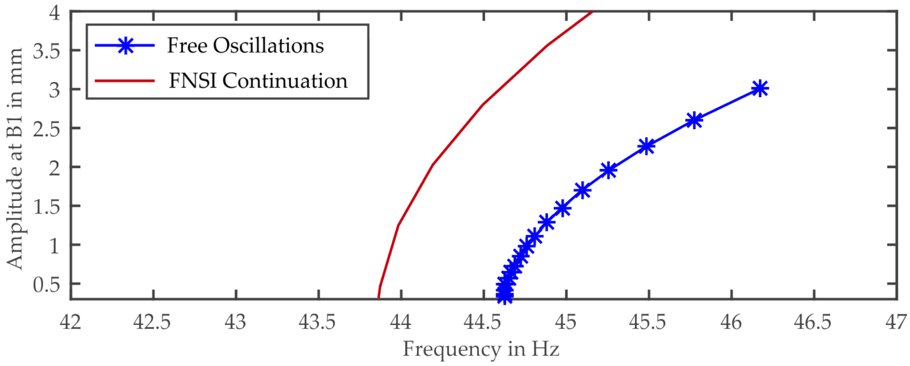

Figure 4: Amplitude-Frequency-Curves from free oscillations and from FNSI continuation

References

[1] De Moor B., Van Overschee, P., Favoreel, W. (1999) Algorithms for Subspace State-Space System Identification: An Overview. *Applied and Computational Control, Signals, and Circuits* 247-311.

[2] Noël J.P., Kerschen G. (2013) Frequency-doamin subspace identification for nonlinear mechanical systems. *Mechanical Systems and Signal Processing 40* 701-717.

[3] Noël J.P., Renson, L., Grappasoni, C., Kerschen G. (2016) Identification of nonlinear normal modes of engineering structures under broadband forcing. *Mechanical Systems and Signal Processing 74* 95-110.

[4] Kleyman G. (2016) Untersuchung experimenteller Methoden der nichtlinearen Modalanalyse. *Master Thesis, Institute of Dynamics and Vibration Research, Leibniz Universität Hannover*.