Tracking of Resonance Frequencies of Vibrating Beams by Phase-Locked Loops (PLL)

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Abstract

The use of phase-locked-loops (PLL) is wide spread in electronics. It is the basis e.g. of FM-radios and other applications. However, in mechanical systems in general a PLL is only applied if the system also contains electric parts like in some ultrasonic motors [1]. In the present paper the goal is to apply such a PLL to track the resonance frequency of a vibrating beam. These frequency changes may occur due to changing masses or due to a changing longitudinal force in the beam

1 Introduction

The use of phase-locked-loops is widespread in electronics. Such systems are used for example in FM radios to generate and reconstruct the original signal by tracking the frequency of the carrier wave. The principle is that the PLL consists of a voltage controled oscillator (VCO) which has an output frequency which is proportional to its input voltage. This input voltage is the output of a controller which adjusts the phase of the VCO's output to a second signal. This second signal may be the signal of a sensor which measures the output of a mechanical system. The vibration of the mechanical part in return is excited by the VCO and an amplifier. In such a configuration both input signals of the controller do have the same frequency, but the phase shift between both signals is a function of the frequency. If there is a mechanical system in between, e.g. in form of a one dof oscillator, and the displacement is measured, then the phase difference may increase from zero (far below resonance) to 180 degrees (far above resonance).

In a cooperation between the Institute of Applied Mechanics of the University of Karlsruhe and the Institute of Production Technology, the goal was to develop an adaptive strut for a machine with parallel kinematics. Within this strut, the longitudinal force was first measured by the vibrating string principle. The changing frequency of the string was obtained by counting the maxima of the free vibration.

A second possibility, which is the topic of this presentation is to use a beam with piezoceramic patches to excite and sense the resonance vibration of the beam. The resonance frequencies of the beam change due to the changing longitudinal force. In other applications like bio sensors the resonance frequency may change if the mass along the beam changes, e.g. in microbeams where added molecules may stick to the beam, see figure 1.

2 Principle of a PLL

The principle of a phase locked loop is that a voltage-controlled oscillator (VCO) is driven by a controller which has the phase difference of two signals as its input signal. The output frequency of the VCO is proportional to the input voltage. The phase difference in general is detected by multiplying the two input signals of the phase detector and integrating the product. The phase of

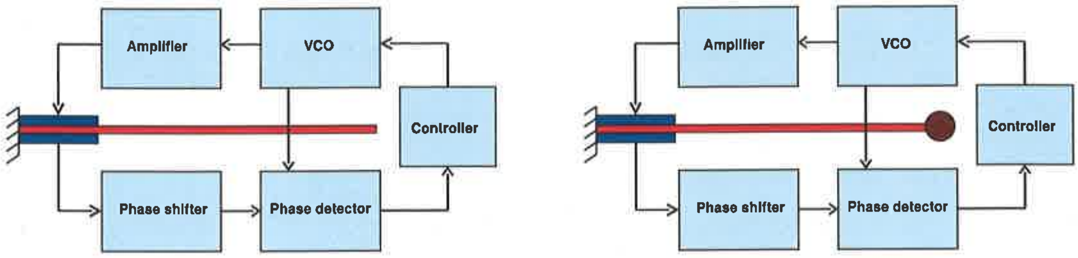

Figure 1: Principle of a phase locked loop (PLL) for a beam with changing mass

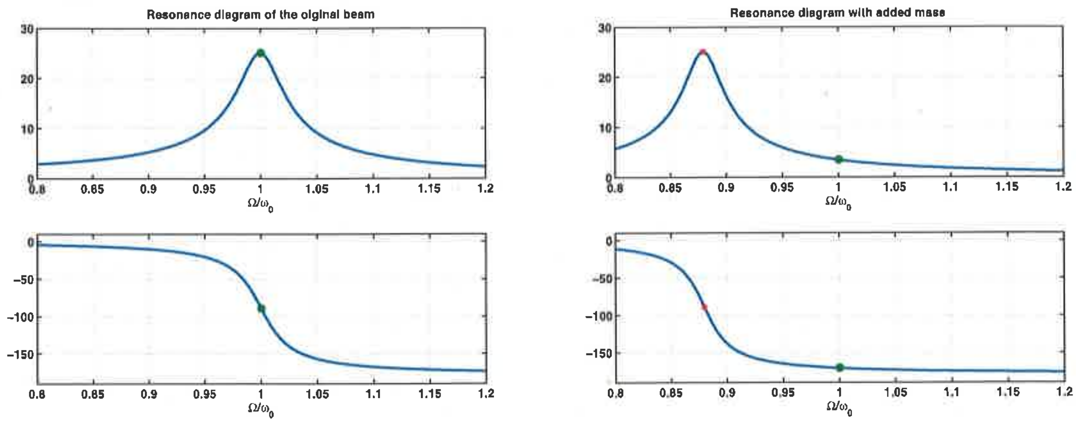

Figure 2: Sketch of the phase of the output signal with and without additional mass as a function of the excitation frequency

the mechanical system for a given excitation frequency with and without an additional mass e.g. are given in figure 2. In order to have the same phase of the mechanical system, the controller has to lower the excitation frequency of the beam with additional mass and this frequency change means that the input voltage of the VCO has to be changed, which can be measured very easily.

3 Phase relation between electric input of the beam and input signal of the phase detector

In order to track the resonance frequency of a beam, the phase difference between input and output of the mechanical part is important. Therefore, in this presentation the beam is modeled by Bernoulli-Euler theory and by assuming that the differential equation is given by the equation of motion for a beam with axial load and external damping. Damping may be important, because it affects the phase shift between excitation and output. The excitation of the beam may be modeled based on pin-force-models or on Bernoulli-Euler-models [2]. To sense the vibration, it is important to specify if the output voltage of a piezoelectric sensor is used or if the charge of the sensor is measured. In the first case, the output voltage has to be calculated based on the fact that between the sensor electrodes no charge is flowing while, in the second case, the electrodes of the sensor may be taken to be short circuited and the total charge between the electrodes corresponds to the integral of the local electric displacement.

In order to do the analysis, a time harmonic solution is assumed in such a way that all quantities like voltage, displacement, stress, strain and charge are harmonic functions of time with given circular frequency of the excitation.

4 Results

At the moment results are not yet available. They will be presented at the conference. For several vibration modes, the frequency-phase plots will be given as well as the relation between axial force and phase for a fixed vibration frequency. For the application in a strut of a parallel machine, higher modes are of special interest in order to get a high dynamics of the measurement system.

References

[1] W. Seemann, Smart Motors in Germany. In: Smart Materials, Structures and MEMS, Editors Aatre, K.V., Varadan, K.V., Varadan, V.V., SPIE-Vol. 3321, 1996, 472-483.

[2] W. Seemann, Exact Pin-Force Models for Piezoceramic Excitation. In: ZAMM, Vol. 78, 1998, S727-S728.

[3] P. V. Brennan, Phase-locked loops: principles and practice. Mcmillan, 1996.