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A simple predistortion technique for suppression of nonlinear effects in periodic signals generated by nonlinear transducers

A. Novak *, L. Simon, P. Lotton

Laboratoire d'Acoustique de l'Université du Mans (LAUM, UMR CNRS 6613), 72085 Le Mans, France

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ABSTRACT

Mechanical transducers, such as shakers, loudspeakers and compression drivers that are used as excitation devices to excite acoustical or mechanical nonlinear systems under test are imperfect. Due to their nonlinear behaviour, unwanted contributions appear at their output besides the wanted part of the signal. Since these devices are used to study nonlinear systems, it should be required to measure properly the systems under test by overcoming the influence of the nonlinear excitation device. In this paper, a simple method that corrects distorted output signal of the excitation device by means of predistortion of its input signal is presented. A periodic signal is applied to the input of the excitation device and, from analysing the output signal of the device, the input signal is modified in such a way that the undesirable spectral components in the output of the excitation device are cancelled out after few iterations of real-time processing. The experimental results provided on an electrodynamic shaker show that the spectral purity of the generated acceleration output approaches 100 dB after few iterations (1 s). This output signal, applied to the system under test, is thus cleaned from the undesirable components produced by the excitation device; this is an important condition to ensure a correct measurement of the nonlinear system under test.

1. Introduction

Consider a nonlinear physical system under test whose input signal $x(t)$ (displacement, mechanical force, acoustical pressure, …) is generated by an excitation device (shaker, compression driver, loudspeaker, …). If a high excitation level is applied, which is usually the case in order to emphasize the nonlinear phenomena of the system under test, the level of nonlinearities generated by the excitation device can not be considered as negligible [1,2]. The excitation device used for the measurement is usually driven by an electrical signal $u(t)$ created either by a signal generator or by a Data Acquisition (DAQ) device that enables an easy generation of signals. A general block diagram of such measurement setup using a DAQ is depicted in Fig. 1. For a linear excitation device, if the input signal $u(t)$ is a sine signal, the output $x(t)$ will also be a sine signal at exactly the same frequency. However, if the excitation device is nonlinear, added frequency components with frequencies equal to multiple integers of the fundamental input frequency can appear at the output signal $x(t)$ (the effect being called harmonic distortion) as schematically depicted in Fig. 1. If the input signal $u(t)$ consists of several harmonic components, harmonic distortion of each component and inter-modulation distortion between each pair of components can appear in the output signal $x(t)$. Consequently, the output signal $y(t)$ of the system under test will be distorted by both nonlinear systems: the excitation device and the system under test.

* Corresponding author.
E-mail address: antonin.novak@univ-lemans.fr (A. Novak).

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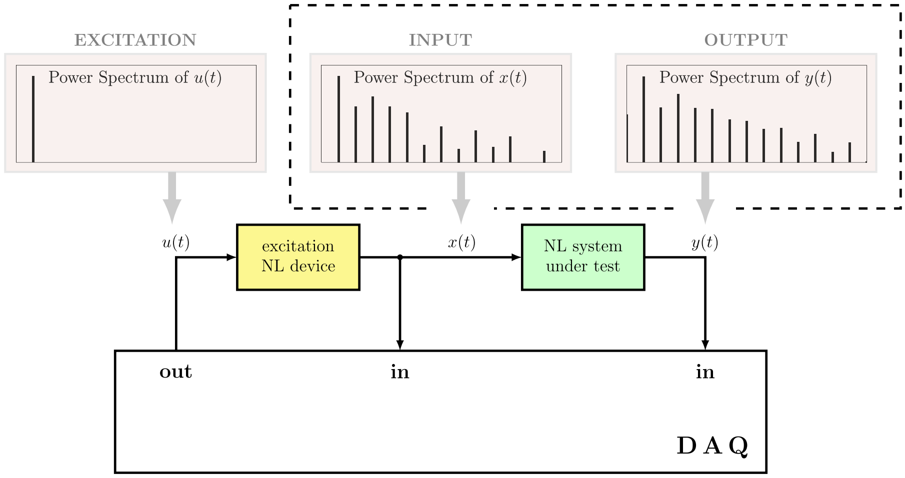

Fig. 1. Measurement setup of a nonlinear experimental bench. A high-level input signal $u(t)$ is applied to the excitation device (shaker, loudspeaker, …). Due to its nonlinear behavior higher harmonics and/or inter-modulation products are added to the signal $x(t)$ generated by the device. The output $y(t)$ of the NL system under test thus contains nonlinear components of both devices.

Since many experimental and theoretical studies are focused on nonlinear acoustics and nonlinear vibration systems [3,4], and for which the experiments are conducted under high-amplitude acoustic wave [5,6] or large-amplitude vibrations [7,8], a need to ensure a non-distorted signal at the output of the excitation device is very important. To overcome the difficulties caused by a nonlinear excitation device, a technique that correct the excitation signal (based on adaptive [9–18], control [19–23], or harmonic injection [24,25] methods), or a technique that takes into account the nonlinearities of the excitation device [26] must be used.

In this paper, we show that using a very simple approach inspired by Ref. [27], spectrally pure signals can be generated at the output of a nonlinear mechanical excitation device using a real-time signal processing implemented on a personal computer and a data acquisition device (DAQ). This method is based on hypothesis that the excitation device has a dominant linear path. Such devices behave linearly for low amplitudes and become nonlinear for higher amplitudes - as usually observed in case of loudspeakers, shakers, or compression drivers. A periodic signal (sinusoidal or multi-harmonic excitation) is applied to the excitation device, the signal generated by the device is acquired and analysed and the input signal of the excitation device is adaptively modified in such a way that the undesirable spectral peaks in the output of the excitation device are completely cancelled out after few iterations of real-time processing. The signal applied to the system under test is thus cleaned from the undesirable components produced by the excitation device, allowing an accurate measurement of the nonlinear system under test with no influence of the nonlinearities of the excitation device.

The predistortion algorithm and a its theoretical description are described in Section 2. The method is next experimentally verified in Section 3 for an electrodynamic shaker which produces a high-amplitude acceleration, measured by an accelerometer, with a spectral purity approaching 100 dB. A discussion on the efficiency, applicability, advantages and drawbacks of the method is finally proposed in Section 4.

2. Predistortion of the excitation signal $u(t)$

2.1. Theoretical description of the predistortion

The basic idea of the predistortion consists in modifying the amplitude U_m and the phase ϕ_m of the harmonic components (including the DC component U_0) of the signal $u(t)$ generated by the DAQ (Fig. 2)

$$u(t) = U_0 + \sum_{m=1}^{M} U_m \cos\left(m\, 2\pi f_0 t + \phi_m\right), \tag{1}$$

f_0 being the fundamental frequency and M being the number of harmonics, in such a way that the measured amplitudes X_m and phases ψ_m of the harmonic components of the signal $x(t)$

$$x(t) = X_0 + \sum_{m=1}^{M} X_m \cos\left(m\, 2\pi f_0 t + \psi_m\right), \tag{2}$$