# Fractional controller design for suppressing smart beam vibrations

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**Abstract**

**Purpose** – The purpose of this paper is to detail the design of a fractional controller which was developed for the suppression of the flexural vibrations of the first mode of a smart beam.

**Design/methodology/approach** – During the design of the fractional controller, in addition to the classical control parameters such as the controller gain and the bandwidth; the order of the derivative effect was also included as another design parameter. The controller was then designed by considering the closed loop frequency responses of different fractional orders of Continued Fraction Expansion (CFE) method.

**Findings** – The first, second, third and fourth order approximations of CFE method were studied for the performance analysis of the controller. It was determined that the increase in the order resulted in better vibration level suppression at the resonance. The robustness analysis of the developed controllers was also conducted.

**Practical implications** – The experimentally obtained free and forced vibration results indicated that the increase in the order of the approximations yielded better performance around the first flexural resonance region of the smart beam and proved to yield better performance than the classical integer order controllers.

**Originality/value** – Evaluation of the performance of a developed fractional controller was realized by using different approach orders of the CFE method for the suppression of the flexural vibrations of a smart beam.

**Keywords** Controllers, Vibration, Smart beam, Lead zirconate titanate, Vibration control, Fractional control

**Paper type** Research paper

## Introduction

Fractional order control systems have transfer functions with fractional derivatives $s^{\alpha}$ and fractional integrals $s^{-\alpha}$ where $\alpha$ € R. It is not an easy and straightforward task to compute the frequency and time domain behaviours of such fractional order transfer functions with available software packages. It is well known that the commercially available simulation programs have been prepared to deal with the integer power of derivatives only. Also, the hardware required for the implementation of the designed controllers use electronic components which are only suitable for the integer order transfer functions. Although, there are some recent works dealing with the implementation of a controller using a fractance device (Nakagava and Sorimachi, 1992), this area deserves further studies. Therefore, the problem of integer order approximations of fractional order functions becomes a very important one to be solved. A fractional transfer function can be replaced with an integer order transfer function which has almost the same behaviour with the real transfer function but much more easy to deal with. There are several methods for obtaining rational approximations of fractional order systems like Carlson's method, Matsuda's method, Oustaloup's method, the Grünwald-Letnikoff approximation, Maclaurin series based approximations, time response based approximations, etc. (Podlubny *et al.*, 2002). One of the most important approximations for fractional order systems is the continued fraction expansion (CFE) method.

In this study a fractional order controller, by using the CFE method, was designed and implemented for the suppression of the flexural vibrations of a smart beam. The first, second, third and fourth order approximations of CFE method were studied for the performance analysis of the controller. The robustness analysis of the controllers was also conducted by attaching various point masses to the free end of the smart beam. Experimentally obtained results were presented for the suppression of the free and forced vibrations of the smart beam.

## Smart beam

The smart beam used in the study is shown in Figure 1(a). It is a cantilever passive aluminium beam having the dimensions of 490 × 51 × 2 mm and with eight surfaces bonded SensorTech – BM500 (25 × 20 × 0.5 mm) PZT (Lead-Zirconate-Titanate) patches. A typical PZT patch is shown in Figure 1(b) (Sensor Technologies Limited, 2002). A thin isolation layer is placed between the aluminium beam and each PZT patch, so that each PZT patch may be employed as a sensor and an actuator independently.

In this study, the piezoelectric patches are nominated with respect to the positions on each surface of the aluminium beam and are identified by number and surface names. As shown in Figure 2, on surface A, piezoelectric patches are labelled

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