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A new vibration absorber based on the hysteresis of multi-configuration NiTiNOL-steel wire ropes assemblies

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Abstract. A new vibration absorber based on the restoring forces of NiTiNOL and mixed NiTiNOL-steel wire ropes subject to flexural and coupled tensile-flexural states is presented. The peculiar hysteresis of the device is due to the simultaneous presence of interwire friction and phase tranformations. An extension of the Bouc-Wen model is proposed to fit the experimental force-displacement cycles by employing the Differential Evolutionary optimization algorithm. The genetic-like optimization is carried out both for the constitutive identification and for the design of the vibration absorber. The effectiveness of the device is proved experimentally by a series of shaking table tests on a multi-story scale building.

1 Introduction

Wire ropes are structural elements usually employed to resist large loads thanks to the funicular load-bearing mechanism. However, when a short wire rope is forced to deform, a relative motion with friction between individual wires takes place together with dissipation of energy. The idea to exploit this mechanism for mitigating the oscillations of long suspended transmission cables was first proposed by Stockbridge [1]. Vestroni et al. [2,3] patented a vibration absorber (VA) based on the hysteretic restoring force of short clamped-clamped steel ropes subject to flexural cycles. If the wires are made of NiTiNOL the energy dissipation is also due to phase transformations in the material itself.

Here a novel prototype of Tuned Mass Damper (TMD) constituted by assemblies of NiTiNOL and mixed NiTiNOL-steel wire ropes is presented. The interwire friction and phase tranformations give rise to a pinching at the origin of the force-displacement cycles. The device can operate following different wire ropes arrangements in some of which geometric nonlinearities can be induced. Quasilinear-softening, strongly pinched hardening and slightly pinched hardening constitutive behaviors can be achieved. The proposed TMD is employed to control the dynamic response of a multi-story scale building mounted on a shaking table.

2 The TMD response curves and performance: experimental and numerical investigations

The TMD is shown in Fig. 1a. It is made of a rectangular steel frame to which two steel bars are connected through a group of wire ropes. The rectangular frame must be fixed on the structure to control while the two bars represent the moving masses. Figure 1b shows the cross section of the wire rope prototype. The mathematical representation of the experimentally observed force-displacement curves has been achieved enriching the classic Bouc-Wen model of hysteresis so as to have inflexion points

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along the loading/unloading branches (Fig. 1c). The model parameters, which best fit the experimental force-displacement cycles, are identified employing the Differential Evolutionary (DE) algorithm [4]. Frequency-response curves of a one-degree-of-freedom system are obtained using a path following procedure based on the Poincaré map [5].

A scale steel building was constructed in house to investigate the performance of the new TMD by means of shaking table tests. After a first experimental champaign aiming at the identification of the damping ratio and the frequencies of the building, the TMD configuration that best mitigates the dynamic response of the structure has been designed employing the DE algorithm. A two-degree-of-freedom system is considered. It is constituted by a main mass attached to the ground through linear stiffness and damping and by a TMD mass attached to the structure with a nonlinear hysteretic stiffness here described by the enriched Bouc-Wen model. The constitutive parameters of the TMD are optimized to obtain the numerical frequency-response curves with the lowest subtended area in a given bandwidth. Afterwards static tests were conducted with the universal Material Test System machine (MTS) to identify the wires ropes assembly capable of reproducing the numerically optimal hysteretic cycles.

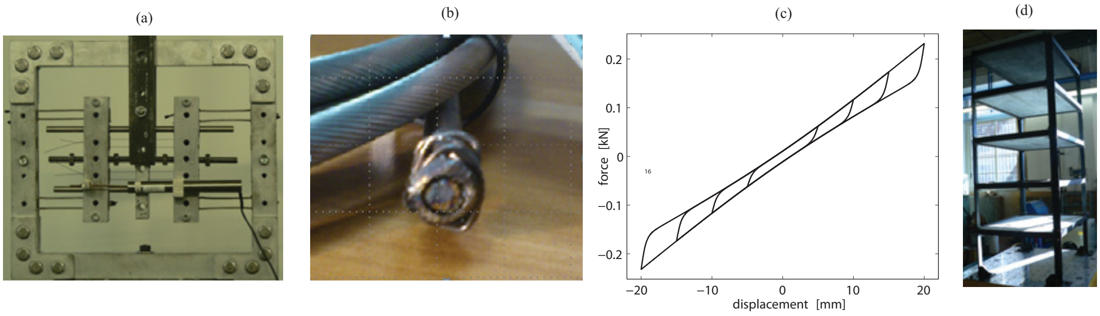

Fig. 1. Part (a) shows the TMD prototype; part (b) is a picture of the mixed NiTiNOL-steel wire rope; part (c) shows a set of optimal hysteretic cycles of the TMD; part (d) shows the multi-story scale building mounted on the MOOG shaking table.

The steel scale building is shown in Fig.1d. It is constituted by 5 concrete floors for a total weight of 645 kg. The building height is 2.5 m and the TMD is placed on the fifth floor. The mass of the TMD is 1% of the structural mass excited by the first mode. A six-degree-of-freedom model is considered to describe the dynamic response of the building. Frequency-response curves and time histories of the controlled and uncontrolled structure are computed numerically considering periodic base excitations and base acceleration histories, respectively. Finally the results obtained experimentally through the shaking table tests are compared with the numerical results.

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