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Original article

Optimized anti-vibratory system for stretched canvas artwork hanging in a museum

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ABSTRACT

To prevent the deterioration of artwork on stretched canvas in a museum, it is often necessary to neutralize the transmission of vibrations from sources such as the wall or the floor. An anti-vibratory system easily optimizes vibrations that are transmitted from the floor because the artwork's motion occurs in vertical translation. Hanging artwork, which receives vibrations from the wall, presents a more complex case because the motion consists of a translation and a rotation. This paper presents a model to determine a cutting frequency above which vibrations transmitted to the artwork are lowered. A procedure to obtain the parameters of this model is also presented. Experiments in a laboratory and in the Louvre Museum validate the predicted cutting frequency given by the model. A downloadable spreadsheet is available to apply this method to specific artwork.

1. Research aims

Controlling environmental conditions in museums is essential for the preservation of displayed objects [1,2]. Although chemical pollution, humidity, temperature and lighting are easily regulated, it is considerably more difficult to manage the vibration levels of an exhibit containing collections and artifacts, particularly paintings on stretched canvas.

Vibrations of the supporting structure that are transmitted to a stretched canvas induce curvatures of the canvas and consequently produce strains on the pictorial layers [3]. These strains can damage the painting by causing cracks through or between the layers. The curvature level of the canvas depends on its mode shape under vibrations, which, in turn, depends on the excitation frequency, the tensions, and the mass per unit area of the canvas. Each artwork has its own sensitivity. To avoid the necessity to determine the behavior of each stretched canvas, museums have generally decided that the root mean square of the acceleration of an artwork's frame must be kept lower than 110 dB (reference acceleration: $a_0 = 10^{-6}$ m.s^{-2})[2].

Visitors, traffic (underground, railway), construction work in the surrounding area or within the museum itself, and even earthquakes are potential sources of vibrations.

Depending on the type of excitation source, transient or steady vibrations have to be evaluated. For example, earthquake-induced vibrations are optimized through passive control by using an isolation device [4,5] that prevents the artwork from falling. The calculated nonlinear transient response allows these devices to be modelled as a rigid block simply supported on a pedestal. In the case of steady excitation (visitors, vehicles, construction, etc.), the response of the artwork must be calculated according to each excitation frequency. Anti-vibratory systems can also be optimized to decrease the level of vibrations that is transmitted to the object. This optimization is strongly dependent on the shape, the dimensions, and the mass repartition of the object, as well as the type of contact the artwork has with the wall or floor of the museum.

Our study investigated museum paintings displayed using a chair rail hanging system connected to rings, which were fixed to the upper part of the artwork's frame (Fig. 1a).

This hanging system produces a natural position of the artwork under the effect of gravity that results in direct contact of the bottom frame bar with the vibrating wall. This study aimed to quantify the effects of introducing an anti-vibratory system to obtain an optimum decrease in the transmitted vibration levels.

A model of the hanging artwork's vibrations, represented by a two-degrees-of-freedom system, is presented in Section 2: we define the parameters, provide a detailed description of the method used to obtain the motion equations, and calculate the two natural frequencies.

The anti-vibratory system minimized the amplitude of the acceleration for frequencies higher than a cutting frequency that is determined in the following section. Results of this process are

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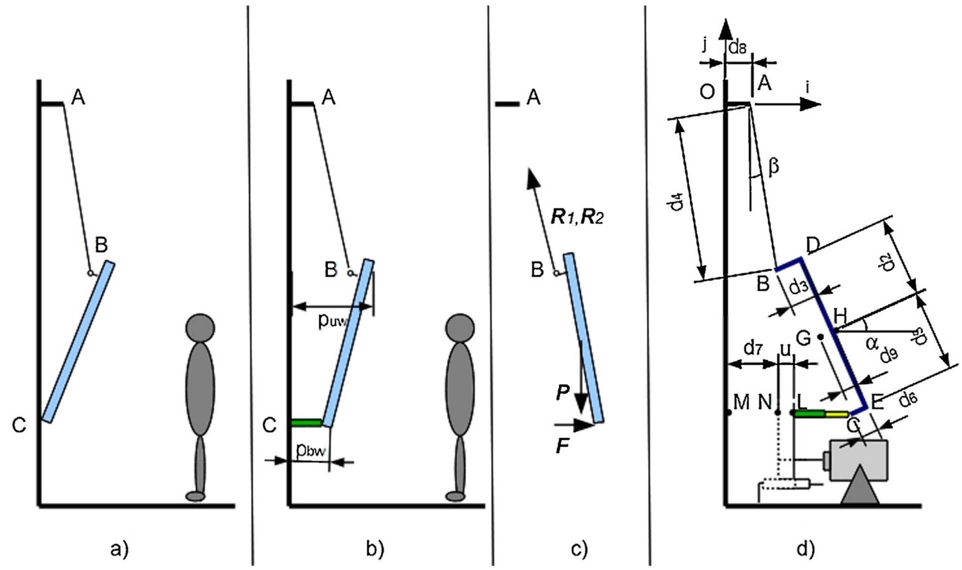

Fig. 1. Positioning a painting in a museum.

available as a downloadable spreadsheet: these data make it possible to evaluate the influence of the anti-vibratory system's stiffness on the theoretical cutting frequency and thus to choose a stiffness which induce a cutting frequency lower than the excitation frequencies or the first resonance frequency of the canvas (if it is known).

Section 3 describes a laboratory experiment using stretched canvas: experimental cutting frequencies were determined for three anti-vibratory systems of different stiffness. A comparison with these experimental results validated the predictions of the model. Finally, we applied the method to an artwork on display at the Louvre Museum.

Based on the example of the painting "La Prairie" by P. Potter, our main result shows that an optimized anti-vibratory system (in this case, with a stiffness of less than 1550 N.m^{-1}) successfully protects this artwork from wall-induced vibrations because the cutting frequency is kept lower than the first resonance frequency of the canvas.

2. Model

2.1. Model assumptions

Our model considered the artwork on stretched canvas as a rigid block with a mass m and an inertia J around the axis G**i** and the center of mass G. The painting, hanging on the wall attached to two inextensible wires, was in contact with the wall through an anti-vibratory system assumed equivalent to a spring with a stiffness k. The model was designed to obtain the two modal frequencies of this two-degrees-of-freedom system, f_1 and f_2.

This simplified model cannot evaluate the coupled modal frequencies f_{cnm} of the canvas, where (n,m) denotes the number of nodal lines in each direction. In fact, if the frame is considered at rest, a continuous model of a stretched membrane or of a thin plate under tension can be used to find the uncoupled modal frequencies of the canvas f_{nm}. If the frame is considered in motion, a coupled model of the canvas and a rigid frame in motion has to be built. If there is a considerable difference between the f_1 and f_2 values and the f_{nm} value, the frequency shift between the uncoupled f_{nm} and the coupled modal frequencies f_{cnm}, which can be evaluated using a Rayleigh method, remains negligible compared to f_{nm}. The ultimate goal of this study was to choose the stiffness k such that $\sqrt{2}f_2 < f_{00}$, thereby obtaining a decoupling of the frame and canvas motions, which would validate our hypothesis of considering the painting as a rigid block.

The stiffness of the wall in the vertical direction is considerably greater than its stiffness in the horizontal direction; therefore, vertical vibrations can generally be neglected. If vibrations are present at point A, the chair rails (whose mass is negligible compared to the total mass of the system) between points A and B filter these vibrations, which then no longer present any risk to the artwork. Conversely, if vibrations at point C are directly transmitted to the frame, the painting may be in danger of degradation and it would be favorable to mount an anti-vibratory system between the wall and the frame (Fig. 1b).

For a translational motion of a given mass m_1, an anti-vibratory system with a stiffness k filters vibrations that are higher than the cutting frequency

$$f_c = \sqrt{2}\frac{\omega_0}{2\pi} \tag{1}$$

The natural circular frequency of the system in translation is denoted by ω_0 [6]:

$$\omega_0 = \sqrt{\frac{k}{m_1}} \tag{2}$$

However, if vibrations are transmitted from the wall to the artwork, the resulting motion can be decomposed into a translation and a rotation. A rotational vibration of the object is introduced because the force exerted by the anti-vibratory system is not on the line of the artwork's center of mass G. Classical dimensioning of the anti-vibratory system (Eq. 1–2) is no longer valid.

The system can be modelled as a two-degrees-of-freedom system (Fig. 1c): to determine the position of the painting, two angles must be specified with respect to time: $\beta(t)$ between the chair rail and the vertical direction and $\alpha(t)$ between the direction normal to the plane of the canvas and the horizontal direction. Each angle is decomposed into a rest value with the subscript $._0$ and an oscillating angle using the superscript $\tilde{}$:

$$\alpha(t) = \alpha_0 + \tilde{\alpha}(t) \tag{3}$$

$$\beta(t) = \beta_0 + \tilde{\beta}(t) \tag{4}$$

where t denotes time. At rest, β_0 is positive and α_0 is negative. The painting's center of mass G is subject to a translation and a