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Updating Stockbridge dampers features inside a digital twin model for cable fatigue estimation due to VIV

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SUMMARY
Monitoring cable structures subject to Vortex Induced Vibrations (VIV) is useful to keep under control eventual fatigue issues. In this view, digital twins represent powerful tools to take advantage of both numerical modelling and vibration data acquired through sensors installed on the structure. However, dynamic features of mechanical devices such as dampers may vary in time due to many factors. This work focuses on the characterization of three samples of dampers dismantled from a large observation wheel. The samples were tested in laboratory and the characteristic curve obtained were compared with the one of brand-new dampers. It is shown how the dynamic performance of the Stockbridge dampers has varied in time, especially in terms of damping, and it is demonstrated that it is necessary to update the damper characteristic curves in the digital twin of the structure.

Keywords: Vortex Induced Vibrations, digital twin, Stockbridge dampers

1. INTRODUCTION

Cables, being stranded and slender elements, are subject to wind-induced vibrations that can threaten their durability if not suitably mitigated (EPRI, 2009). To this aim, Stockbridge dampers with more than one frequency of vibration, were designed and installed on different types of cable structures. Nonetheless, it is important to get feedback on their efficiency in suppressing Vortex Induced Vibrations (VIV) in the field. Today, smart systems composed of wired or wireless sensors (Zanelli et al., 2022) give the possibility to get real time data from the monitored structure and feed digital twin models to assess health status. However, in this context, it is extremely important to perform model updating of the dynamical features of mechanical elements present in the model that can vary in time (Zhang et al., 2025). In this work, the focus is put on the evaluation of Stockbridge dampers performance after 10 years of installation on a large observation wheel. The dynamic characterization is employed inside a digital twin of the structure to estimate the residual fatigue life of spoke cables.

1.1. Digital twin of a large observation wheel

The digital twin is schematically represented in Figure 1. The numerical model is based on the Energy Balance Principle (EBP) and it computes the maximum amplitude of vibration and the stresses in the point of interest balancing the wind energy input with the energy dissipated by cable and dampers (Zanelli, 2022). The actual level of vibration is provided to the digital twin by an accelerometer mounted in a suitable position on each spoke cable of the observation wheel. Hence, stresses at the clamp can be computed and the related cycles, obtained with the Rainflow algorithm, cumulated in time. Having at disposal the Wohler curve for the spoke cable, the residual fatigue life is then estimated on a monthly basis.

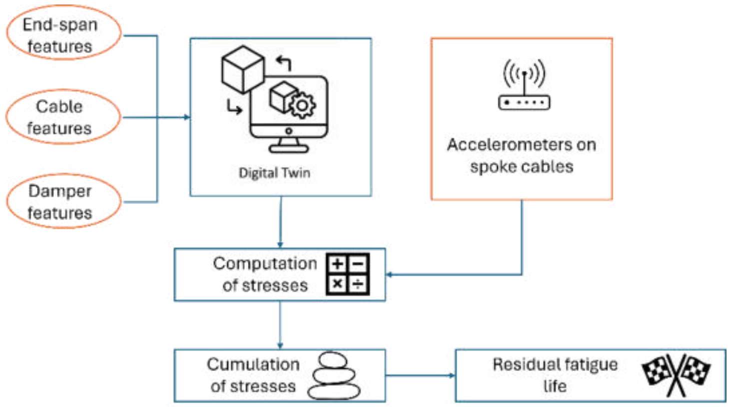

Figure 1. Digital twin schematization

1.2.Implementation of the Stockbridge damper in the digital twin

The features of Stockbridge dampers are inserted in the model by means of their characteristic curves, which express their dynamic performances. The characteristic curve, obtained as output of a shaker test, is expressed as the harmonic force/displacement transfer function of the damper clamp, presented in magnitude and phase. The amount of energy dissipated by the dampers is then computed in the model as reported in Eq. (1), for each one of the dampers present on the cable, and for each natural frequency (Claren and Diana, 1969).

$$E_{damper} = \pi \left(\frac{F}{u_d} \right) u_d^2 \sin \varphi \qquad (1)$$

Where F/u_d is the damper force per unit displacement of the damper clamp, u_d is the conductor vibration amplitude at the damper clamp and φ is the phase between force and displacement.
Since the level of stresses on the cable is strictly related to the efficiency of Stockbridge dampers in mitigating the vibrations excited by the wind action, it is of the utmost importance to update the dynamic performance of dampers if they have varied in time due to ageing for vibrations and environmental agents (e.g. salt pollution, sand pit, etc.).
Three dampers were then removed from the structure, and a testing campaign was arranged to verify their dynamic performances.

2. EXPERIMENTAL TEST

The three samples of dampers plus clamping system removed from the large observation wheel (identified with IDs 1, 5 and 6) were characterized according to the IEC 61897-7.11.2 standard in the laboratories of Department of Mechanics of Politecnico di Milano.

2.1.Set-up description

The excitation was, in this case, provided to the damper through a hydraulic actuator (MTS 248.01, visible in Figure 2) to guarantee an optimum performance of the test system also at low frequencies (below 5Hz). The measurement devices employed to derive the dampers characteristic curves were two piezoelectric load cells (Kistler 9341B) and one piezoelectric accelerometer (PCB Piezotronics 333B30). The test has been run at constant vibration velocity (100 mm/s).

Figure 2. Stockbridge damper plus clamp mounted on the hydraulic actuator

2.2.Test results

The results of the test are represented by the damper characteristic curves reported in Figure 3 for the three different samples tested. As can be noted, the test repeatability is good and only a small deviation is observed in the phase relative to the second natural frequency of damper ID 5.

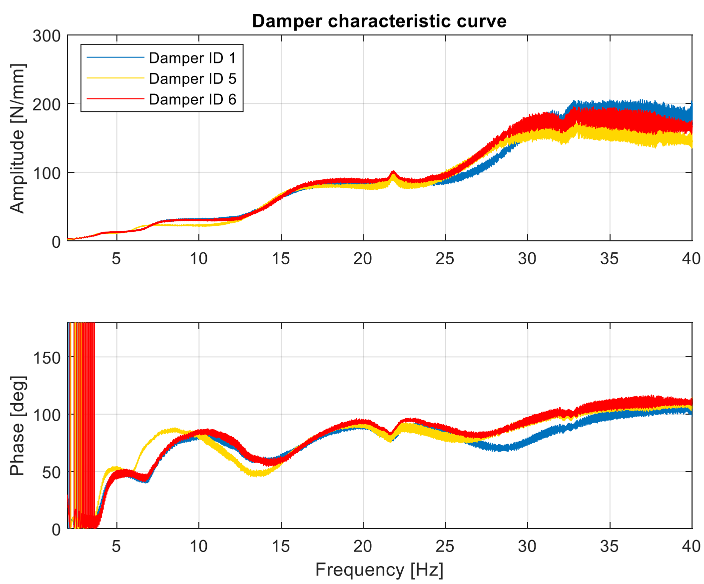

Figure 3. Stockbridge damper characteristic curves

3. CHARACTERISTIC CURVES COMPARISON

To compare the dynamic performances between samples removed from the structure (i.e. ID 1, 5 and 6) and brand-new devices, the characteristic curve of the "mean" damper has been computed as the mean of the real and imaginary parts of the transfer functions obtained for the three samples.

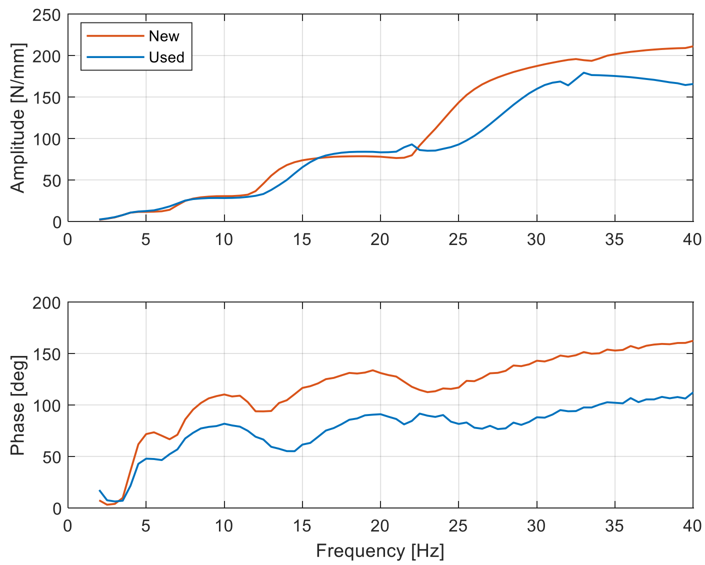

Figure 4. Comparison between characteristic curves of the mean “new” damper versus the mean "used" one

From Figure 4 two considerations can be drawn. Firstly, the stiffness of the damper has not varied since the four natural frequencies did not almost change from the “new” to the “used” damper status. Concerning the damping, it is possible to observe that the phase of the “used” damper is constantly lower than the one of the “new” dampers. The reason for this behavior can be found in the lowering of friction between the wires of the messenger cable, which can be attributed to fatigue due to vibrations or to the effect of the variation of the weight force associated with the wheel revolution. It is therefore of the utmost importance considering the variation of the dynamic stiffness of the Stockbridge damper, updating the characteristic curve in the digital twin to keep obtaining reliable results in terms of residual fatigue life estimation.

4. CONCLUSIONS

The use of a digital twin model for fatigue life estimation of the spoke cables of a large observation wheel was introduced. In this context, an experimental activity was carried out for the characterization of Stockbridge dampers dismantled from the structure during a maintenance activity. It was demonstrated that updating the dynamic features of these devices is necessary to obtain reliable results in time concerning structural health status.

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