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# A direct experimental–numerical method for investigations of a laboratory under-platform damper behavior

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ABSTRACT

Under-platform dampers are commonly adopted in order to mitigate resonant vibration of turbine blades. The need for reliable models for the design of under-platform dampers has led to a considerable amount of technical literature on under-platform damper modeling in the last three decades.

Although much effort has been devoted to the under-platform damper modeling in order to avail of a predictive tool for new damper designs, experimental validation of the modeling is still necessary. This is due to the complexity caused by the interaction of the contacts at the two damper-platform interfaces with the additional complication of the variablity of physical contact parameters (in particularly friction) and their nonlinearity. The traditional experimental configuration for evaluating under-platform damper behavior is measuring the blade tip response by incorporating the damper between two adjacent blades (representing a cyclic segment of the bladed disk) under controlled excitation. The effectiveness of the damper is revealed by the difference in blade tip response depending on whether the damper is applied or not. With this approach one cannot investigate the damper behavior directly and no measurements of the contact parameters can be undertake. Consequently, tentative values for the contact parameters are assigned from previous experience and then case-by-case finely tuned until the numerical predictions are consistent with the experimental evidence. In this method the physical determination of the contact parameters is obtained using test rigs designed to produce single contact tests which simulate the local damper-platfom contact geometry. However, the significant limitation of single contact test results is that they do not reveal the dependence of contact parameters on the real damper contact conditions. The method proposed in this paper overcomes this problem.

In this new approach a purposely developed test rig allows the in-plane forces transferred through the damper between the two simulated platforms to be measured, while at the same time monitoring in-plane relative displacements of the platforms. The in-plane damper kinematics are reconstructed from the experimental data using the contact constraints and two damper motion measurements, one translational and one rotational. The measurement procedures provide reliable results, which allow very fine details of contact kinematics to be revealed. It is demonstrated that the highly satisfactory performance of the test rig and the related procedures allows fine tuning of the contact parameters (local friction coefficients and contact stiffness), which can be safely fed into a direct time integration numerical model.

The numerical model is, in turn, cross-checked against the experimental results, and then used to acquire deeper understanding of the damper behavior (e.g. contact state, slipping and sticking displacement at all contact points), giving an insight into those features which the measurements alone are not capable of producing. The numerical model of the system is based on one key assumption: the contact model does not take into account the microslip effect that exists in the experiments.

Although there is room for improvement of both experimental configuration and numerical modeling, which future work will consider, the results obtained with this approach demonstrate that the optimization of dampers can be less a matter of trial and error development and more a matter of knowledge of damper dynamics.

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## 1. Introduction

In turbine bladed system, some damping in addition to material damping is needed to attenuate forced vibration resonance amplitude and prevent high cycle fatigue of blades. Dry friction damping is recognized as an efficient way for the passive vibration control in turbine industry.

The so called under-platform dampers are widely used as a source of friction damping in turbo engines. The device itself is a piece of metal which, during service, is loaded by centrifugal force against both platform undersides of two adjacent blades. When the relative movement between the blades increases such that slip between damper and platform surfaces happens, energy of blade vibration is dissipated through friction.

Damper geometry influences the contact conditions and the damper dynamics through coupling of the two interfaces. Yang and Menq (1998a,b) proposed the coupled dual-interface model to predict the wedge shaped under-platform damper behavior. The real contact on each interface was modeled as a point contact represented by a spring plus a Coulomb slider. The kinematics was simplified by considering only those cases where interfaces were always in a surface contact with the peculiar assumption that the resultant force is exchanged through the surface center. Analytical transition criteria between slip and stick states coupling two interfaces were established to be integrated in the calculation algorithm involving the blade structure response by using HBM. Sanliturk et al. (1998) performed a similar analysis onto wedge under-platform dampers and brought in experimentally measured contact characteristics (hysteresis loops) for the description of the basic contact behavior of given material combination with respective surface finish. Furthermore a correction factor was introduced in the equivalent complex contact stiffness to reflect the damper rolling effect which implies edge contact.

In addition to wedge shaped dampers, other geometries are also studied like cylindrical dampers (Panning et al., 2000; Jareland et al., 2001) or dampers with two rounded contact surfaces with offset of the centers (Csaba et al., 1999), asymmetrical dampers (Panning et al., 2004), and dampers with parabolic surfaces (Pfeiffer and Hajek, 1992). It should be pointed out that until today, people have no common conclusions on which geometry is the optimized one and in industry the easily manufactured ones are preferred.

An improvement to the spring–slider contact model was the introduction of the microslip effect. This was taken into account with a macroslip array of tangential contact stiffness in parallel (Sanliturk et al., 1998). A spatial contact model, based on the discretization of the contact zone into several 3D point contact elements was used in Panning et al. (2000) to take into account microslip and roughness effects. Csaba et al. (1999) used the brush model to simulate the microslip characteristics in the hysteresis.

Models in Panning et al. (2000, 2004) and Csaba et al. (1999) included the damper inertia and considered a rotational contribution to the damper kinematics leading to a possible lift off from the blade platforms. Moreover normal contact stiffness was added to the contact model. More recently Cigeroglu et al. (2007) added to the FE model of the primary structure (the blades) the model of a secondary structure (the damper) coupled to the first by means of a full set of distributed springs and related tangential sliders.

Later developments (Firrone et al., 2011) proposed the treatment of the non-uniqueness of the static normal preloads in certain conditions. A static/dynamic coupled HBM was developed to get a unique force vibration response of the blades interacting with the under-platform damper. As a supplementary experimental investigation, the kinematics of two types of under-platform dampers (wedge and cylindrical) in the traditional damper-blade test rig was measured (Zucca et al., 2012). Most studies (Yang and Menq, 1998b; Sanliturk et al., 1998; Panning et al., 2000, 2004; Csaba et al., 1999; Zucca et al., 2012) evaluate the capability of under-platform damper by measuring the vibration response of blade pairs combined with finite element dynamic simulations.

In the frame of the damper design the main object in the literature is the development of a calculation procedure that integrates blades FE model, kinematic damper model and contact model in order to predict the damper performance through the solution of the nonlinear dynamic response of the system (Firrone et al., 2006). All numerical models require knowledge of contact parameters, which are established either through fine tuning of values from experience or direct frictional measurements, done with the help of a separate single contact test arrangement (Sanliturk et al., 1998). More generally Schwingshackl et al. (2012) investigated systematically the contact parameters (mainly including friction coefficient, tangential stiffness) for 1D macro point-point friction test under different temperatures and normal forces. They obtained repeatable measurement data within reasonable variation range and suggested averaged values for the contact pair which is not put into test. The measurement data are implemented in the test rig's nonlinear dynamic analysis and good agreements between simulation and experiment are shown.

For under-platform damper, the contact condition is more complex since different contact interfaces coexist. In order to avoid the separation between damper geometry, kinematics and contact condition, the authors of the present study propose a novel method to investigate under-platform dampers' performance and estimate relevant contact parameters. The forces transmitted between the platforms through the damper are directly measured and related to the relative damper-platform movement. The experimental approach is completed by a direct time integration numerical model which draws from the experimental evidence both its validation and its relevant input contact parameters. Error estimates and propagation methods are applied to all measured quantities in order to assign the experimental results a proper level of trust. These authors' purpose in this paper is to investigate under which conditions the current numerical models match the experimental results, and what variability is to be expected depending on real contact parameters.

A laboratory damper (shown in Fig. 3(b)) is tested within the experimental damper-platform system for its pre-determined contact positions. Two kinds of input motion are investigated within this paper: OoP (Out-of-Phase) and IP (In-Phase) motion. They refer to two critical modal shapes of the blade-disk system with respect to two neighboring resonant frequencies (Sanliturk et al., 1998) where the blade response is greater than the one of the other modes. During IP vibration the two blades bend with the same direction and amplitude of deflection in one period, while during OoP vibration the two blades bend with opposite direction and same amplitude of deflection approaching for half a period and moving away for the other half.

The experimental procedure followed to characterize the damper transfer characteristics in terms of its kinematics and force equilibrium will be described, together with its numerical counterpart based on simplified system model. A step-by-step analysis of the damper transfer function allows gaining a clear understanding of all contact events (stick, slip, lift) which take place during the cycle, and on how they influence the damping performance. This analysis method will be exemplified for one representative IP case, while OoP hysteresis cycles will be used in the estimation of contact stiffness and sensitivity analysis of friction coefficients.

It should be emphasized that due to the scope and assumptions of the experimental–numerical method described in this paper, only limited and specific aspects of damper behavior can be extracted. The real contact condition and 3D kinematics in real life still require refined and deeper investigations.