

The Present State of “Solid” under-Platform Damper Mechanics at AERMEC - POLITO

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Abstract. The numerical simulation of friction-damped blades in turbomachinery applications requires knowledge of contact parameters to be introduced in contact models. The equilibrium and kinematics of dampers are dominated by phenomena occurring at the two interfaces between the damper and the corresponding blade platforms. A precise knowledge of parameter values is vital to ensure trustworthy predictions of blades vibration frequency and of the available amount of amplitude damping. Test rigs developed at the AERMEC lab. during the last decade are presented, and reasons for their improvements are explained. These test rigs have the primary purpose to allow direct observations of contact forces and displacements, and the ensuing estimate of contact parameters. The reliability of the measurements and of their processing is demonstrated through a worked out example.

1. Introduction

As openly stated in [1] development of models for dynamic analysis of bladed disks with friction dampers are going on since over thirty years, yet, under-platform damper (UPD) models have been developed (at 2008) “*only for dampers of simple geometric shape for the so-called wedge or cottage-roof dampers*” Such cottage roof dampers have however been modified in a number of ways, witnessed by the many patents available, not all of them investigated in depth, at least openly, in the scientific literature. A deviation from the basic cottage-roof shape has been introduced in order to allow a safe contact to be obtained not only in ideal “In-Phase” (IP) relative motion between blade platforms, but also in the “Out-of-Phase” (OOP) motion. This problem is evident, for instance, back in 1998 [2], when, while using a cottage roof damper, Şanlıturk et al. introduce a correction factor in the contact stiffness to reflect the damper rolling effect due to edge contact. However, the obvious correction is to use a flat-curved solid damper having one of the two contact surfaces in cylindrical form, thus allowing a perfect mating with the under-platforms.

There are several papers on the subject, passing through the comparative study of wedge-shaped dampers compared with others having a couple of curved contacts [3, 4], through a comparison between cottage-roof and fully cylindrical [5, 6]. And through others which is not possible to properly mention in this short paper. Worth noticing that a mixed geometry damper having one surface flat and the opposite cylindrical finally appears. A notable work is [7], where the following useful information is found (quoted) “*The idea of combining the advantages of both mentioned damper types results in an asymmetrical damper with a flat contact surface on one side and a curved contact surface on the other. ... This damper type is already used in Siemens PG gas turbines since 1985 ...*”. A laboratory damper which, although apparently different but in fact having the same mechanics is



studied in [8, 9, 10, 11]. Followed by the combined experimental-theoretical studies on proper flat-curved dampers performed in the AERMEC laboratory [12, 13, 14, 15, 16].

Paper [1] compares flexible-thin dampers with a cottage-roof solid damper having flat surfaces on both sides, and - on the same line - probably the latest work at the time of writing this paper [17] studies both theoretically and experimentally a test rig on which a flat-flat is again inserted. In all cases of this nature, two arrays of a large number of contact points are modelled so that they can take into account stick, slip, and separation during the vibration cycle. The last feature allows lift-off to be modelled, which entails, if lift-off does not occur, satisfaction of equilibrium to in-plane rotation of the damper and consequent correct position of the resultant forces on the opposite contact surfaces.

As a matter of fact, the damper can undergo two types of rolling / lift-off with concentration of contact at the edges of the surface: one due to intentional angle mismatch which can occur in OOP, as described above, the second due to the position of the resultant contact force which reaches the contact surface edge, as it may happen in IP platform motion if measures have not been taken to avoid it [2, 11, 15]. Such measures are clear and easily governed ex-ante, and independently of the amount of platform displacement, if a flat-curved damper is adopted [15]. Not so in the case the flat-flat damper.

Although theoretically necessary on the ground of contact indeterminacy, and although at AERMEC lab. we maintain that it should be adopted on the grounds of sound design and mechanical predictability, we must honestly acknowledge that flat-curved contact surface, usually but not exclusively in the cylindrical shape having a line contact with the platform, is deemed really necessary. Patent EP1249576 of 2002 [17] claims that a wedge shaped damper having contact faces subtending an angle lower - about 10 degrees - than the platforms' angle allows a further vibration damping mechanism (called "*percussive alternate contact*") to arise from the oscillations of the damper, added to the main sliding mechanism. It is all too evident, however, that this should entail the introduction of a percussive dissipation model in the simulation software. However, already in [2], but also in [11], it was seen on experimental grounds that the overall damping capability is greatly reduced by damper rolling, a fatal blow to its desirability.

This problem was implicitly known to the inventor of a 1992 US Patent [18], where the claim concerns a damper, wedge shaped in cross section and provided with a pad on one side and two pads on another side. The pads are located such that they do not lift off the platform surfaces for conditions up to the maximum coefficient of friction even in the most severe IP motion [18].

What differentiates the AERMEC approach from all others in studies of damper mechanics and optimisation is the adoption of an original and innovative test rig named "Piezo+Damper Rig I". Devices simulating bevelled platform surfaces are arranged in such a way that one is put in OOP or IP motion (or their combinations) by a couple of orthogonal piezo actuators, while the opposite one is supported by an orthogonal couple of load cells. This design allows platform displacements and forces to be directly measured; a laser arrangement is added that measures damper displacements and rotations, relating them to platform displacements and contact forces [9, 10, 11]. It was, and still is, believed that this is the most accurate way to determine contact parameters (normal and tangential contact stiffness, friction coefficient) and check, at the same time, the observed damper kinematics against the predictions of any numerical model.

All other approaches rely on measuring the frequency response of blades, where the FRF of the blade is the object of experimental observation, and the results are compared with those from a model: this is the case from the early pioneering 1980 studies [19] through the decades down to the latest 2017 achievements [20]. Contact parameters are typically tuned so that the experimental FRF of a damped blade matches its numerical counterpart. This procedure is very debatable, as it is well known that there exist multiple combinations of the four normal and tangential contact stiffness values which produce a satisfactory match between a given experimental FRF and its numerical counterpart [21].

It is interesting to remark a growing interest in using damper kinematics as a means to better understand contact conditions. In [20] a laser measurement of damper kinematics is also introduced much in the way already adopted by AERMEC in 2010 [10] and used throughout its following papers [11, 12, 13, 16]. Allowing for the differences in approach, what nonetheless makes this Imperial

College and Rolls Royce initiative [20] akin to the AERMEC line on damper testing are the twin objective, i.e., to improve the fidelity of damper modelling and to rigorously assess processes needed for reliable predictions.

2. Test Rigs available at AERMEC

Table 1 summarises the main features of the test rigs in use at the AERMEC lab.

Figure 1 shows the “Piezo+Damper Rig I” in the initial 2009 version, where the load cells on the right dummy platform are loaded through a “tripod” arranged parallel to the direction of the piezo actuators. The load cells are pre-loaded by means of a wire pulled through a pulley and dead-weights (not visible) arrangement [11]. The piezo actuators, hardly visible on the left and up, realize the platform motion through decoupling parallelograms. Figure 2 shows a detail of load cells in the later 2013 version, stiffened for higher operating frequency and tripod rotated by 45°. In “Piezo+Damper Rig I” the load measuring load cells are Dytran 1051V2, subject to leakage and thus unable to measure the static force component, thus requiring lengthy and annoying load removal procedure [11] in order to get the total force value which is necessary for equilibrium calculations. In the later rigs these load cells were replaced by KISTLER 9323AA load cells with charge amplifiers which do not filter out the static component of the measured force.

Table 1. Capabilities of AERMEC test rigs for solid dampers

	Piezo+Damper Rig I (designed 2009)	Damper+Blade Rig (designed 2014)	Piezo+Damper Rig II (designed 2016)
Scope	Stand-alone damper behaviour	Damper coupled with a blade (real or dummy)	Stand-alone damper behaviour
Input motion	All plane motions, 2 piezo actuators	Constrained by blade-platform kinematics, shaker excitation	One-directional motion, adjustable direction and amplitude, 1 piezo act.
FRF of blade	no	yes	no
Frequency range	up to 150 Hz (100 Hz practical)	Blade FRF up to 4500 Hz, damper mechanics tested up to 500 Hz	up to 500 Hz (target, to be tested)
Contact pressure (flat-on-flat)	up to 2 MPa	up to 6 MPa	up to 6 MPa
Temperature	Room temperature	Room temperature	Room temperature

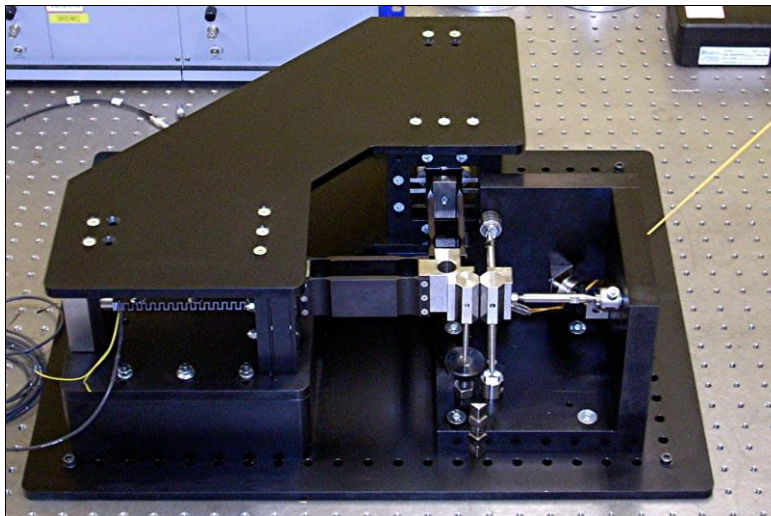


Figure 1. View of the “Piezo+Damper Rig I” in the initial 2009 version

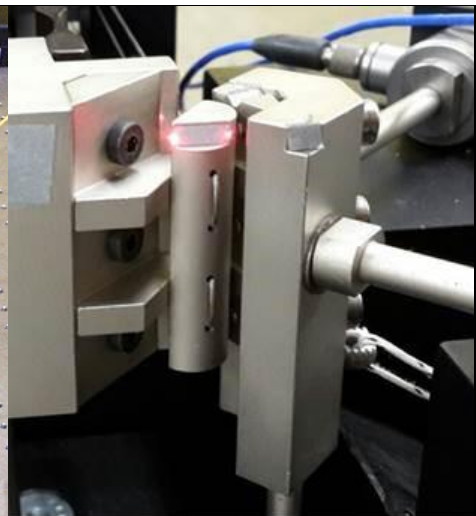


Figure 2. Tripod rotated by 45° during damper rotation observation

In 2014 AERMEC started the design of new test rig mechanically assembled the following year [22], presently used for investigations on real turbine blades [23], with capabilities and main results described also in [24]. In short, this test rig named “Damper+Blade Rig” allows a combination of FRF measurement on a blade, in principle not a dummy but a real customer’s blade, with the direct measurement of forces transmitted between damper and platforms, gaining the advantages of both methods.

A third rig at an advanced commissioning stage, named “Piezo+Damper Rig II”, is substantially an improved version of the first one, however incorporating the latest improvements. All the rigs described in this paper are intended for solid dampers, while strip damper experimental investigations require a completely different approach.

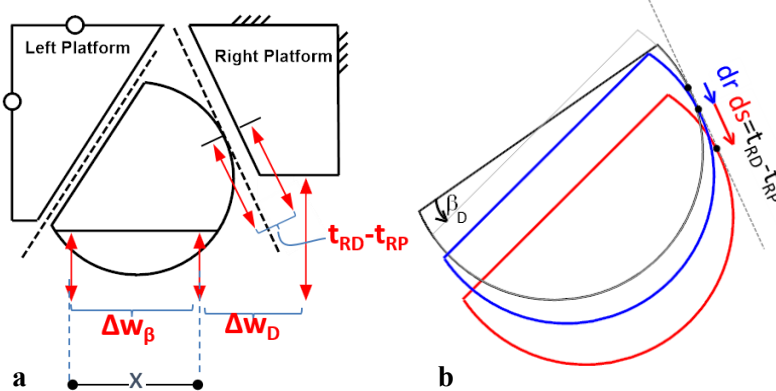
3. Experimental capabilities

Table 2 summarises the parameters which are either directly measured or derived through equilibrium and kinematic calculations, together with the standard deviations of their estimates. Within the narrow limits of this paper it will suffice to prove tangibly that measurements can be very accurate and reliable, thus making the ensuing determination of contact parameters reliable. As described in [13], by pointing two laser beams on the bottom of the damper, Figure 3a, its rotation and its displacements in a direction along the beams can be determined, while the orthogonal component comes from the constraint condition requiring the contact point to move along the platform surface direction.

Table 2. parameters either observed or derived on the basis of damper equilibrium and kinematics

	Estimated parameters	Standard deviation values	
OBSERVED	• Right Contact Forces	• 3% (≈ 0.5 N)	forces
	• Platforms relative displ. • Damper rotation • Damper vertical displ. • Damper tangential relative displ. at the contact	• $0.08 \mu\text{m}$ • 5% ($\approx 0.6 \cdot 10^{-4}$ rad) • $0.08 \mu\text{m}$ • $0.08 \mu\text{m}$	kinematics
DERIVED	• Left Contact Forces + force application point • T/N force ratios	• 3-5% (≈ 0.7 - 0.9 N), 0.5 mm • <4% (right), <9% (left)	forces

	• Damper tangential relative displ. at the contact	• 5% ($\approx 0.5 \mu\text{m}$)	kinematics
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**Figure 3.**

a) laser measurement points for damper motion, absolute (Δw) and relative to the right platform ($t_{RD} - t_{RP}$)

b) sketch of contact displ. due to rolling (dr) and damper tangential displ. due to spring/sliding ($ds = t_{RD} - t_{RP}$)

From damper rotation and displacement kinematics the motion at the contact is derived [13], as explained by Figure 3b. An example of such results is shown in Figure 4a, where the red line represents the tangential relative damper-platform displacement. The same $t_{RD} - t_{RP}$ displacement is directly observed by pointing to laser beams at the contact location, Figure 3a. As shown in Figure 4b the observed and the derived displacement do match extremely well. Thus the tangential displacement vs. the corresponding variation of tangential force, observed as well, gives a very reliable estimate for the tangential contact stiffness ($k_{tR} = 30 \pm 7 \text{ N}/\mu\text{m}$) for a cylindrical contact length of 8 mm. The same values are obtained for this damper when coupled to a blade on the “Damper+Blade Rig” [23, 24].

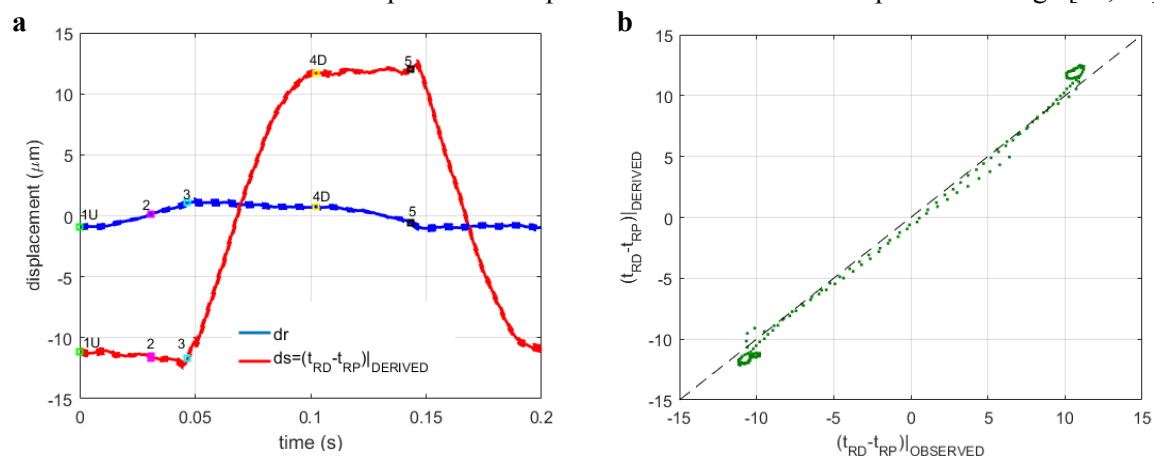


Figure 4. a: dr and $ds = t_{RD} - t_{RP}$ as derived from laser measurements of damper kinematics
b: comparison of kinematically derived $ds = t_{RD} - t_{RP}$ vs. its observed counterpart

4. Conclusion

The test rigs developed so far for the simultaneous and direct experimental observation of forces exchanged between a solid damper and the contacting blade platforms and damper kinematics, have been presented. At the same time, the main reasons for their improvements have been highlighted. Methods currently in use for the determination of contact parameters have been concisely reviewed and commented. It has once more been stressed that contact parameter tuning through FRFs is an undetermined problem, since the same result may depend on parameter combinations. One example for all has been put forward, showing how direct experimental observation can be devised to the purpose of determining tangential contact stiffness. The tangential force directly observed by means of load cells is related to the corresponding tangential damper-platform relative displacement which is either observe directly or derived from an independent reconstruction of damper kinematics. Both methods produce results with a striking degree of similarity. This cross-confirmation between two

independent determinations of the same parameter makes the whole process very trustworthy. References are provided which allow the reader to explore how similar methods can be applied to the determination of all other contact parameters.

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