Mechanical Systems and Signal Processing 100 (2018) 344–359

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

A novel test rig to investigate under-platform damper dynamics

Daniele Botto *, Muhammad Umer

Politecnico di Torino, Department of Mechanical and Aerospace Engineering, corso Duca degli Abruzzi, 24, 10129 Torino, Italy

ARTICLE INFO

Article history:
Received 12 April 2017
Received in revised form 16 June 2017
Accepted 22 July 2017

Keywords:
Turbine blade vibrations
Nonlinear dynamics
Friction damping
Under-platform damper
Test rig
Contact force measurement

ABSTRACT

In the field of turbomachinery, vibration amplitude is often reduced by dissipating the kinetic energy of the blades with devices that utilize dry friction. Under-platform dampers, for example, are often placed in the underside of two consecutive turbine blades. Dampers are kept in contact with the under-platform of the respective blades by means of the centrifugal force. If the damper is well designed, vibration of blades instigate a relative motion between the under-platform and the damper. A friction force, that is a non-conservative force, arises in the contact and partly dissipates the vibration energy. Several contact models are available in the literature to simulate the contact between the damper and the under-platform. However, the actual dynamics of the blade-damper interaction have not fully understood yet. Several test rigs have been previously developed to experimentally investigate the performance of under-platform dampers. The majority of these experimental setups aim to evaluate the overall damper efficiency in terms of reduction in response amplitude of the blade for a given exciting force that simulates the aerodynamic loads. Unfortunately, the experimental data acquired on the blade dynamics do not provide enough information to understand the damper dynamics. Therefore, the uncertainty on the damper behavior remains a big issue.

In this work, a novel experimental test rig has been developed to extensively investigate the damper dynamic behavior. A single replaceable blade is clamped in the rig with a specific clamping device. With this device the blade root is pressed against a groove machined in the test rig. The pushing force is controllable and measurable, to better simulate the actual centrifugal load acting on the blade. Two dampers, one on each side of the blade, are in contact with the blade under-platforms and with platforms on force measuring supports. These supports have been specifically designed to measure the contact forces on the damper. The contact forces on the blade are computed by post processing the measured forces and assuming the static equilibrium of the damper. The damper kinematics is rebuilt by using the relative displacement, measured with a differential laser, between the damper and the blade under-platform.

This article describes the main concepts behind this new approach and explains the design and working of this novel test rig. Moreover, the influence of the damper contact forces on the dynamic behavior of the blade is discussed in the result section.

* Corresponding author.
E-mail addresses: daniele.botto@polito.it (D. Botto), muhammad.umer@polito.it (M. Umer).
URL: http://www.dimeas.polito.it (D. Botto).

http://dx.doi.org/10.1016/j.ymssp.2017.07.046
0888-3270/

1. Introduction

1.1. Background and motivation

Gas and steam turbines is a widespread technology in power and thrust generation, commonly used in power plants, aircrafts, helicopters, ships, etc. Turbine blades undergo variable aerodynamic loads that are a potential source of detrimental vibrations. If the frequency of the cyclic aerodynamic loads is close to a blade/disk resonance the amplitude of the vibration increases and the blade could experience fatigue damage, that in the worst case leads to its failure. To reduce the vibration amplitude to a safe limit external damping is added to the blade. Devices such as Under-Platform Dampers (UPD), tip or part-span shrouds and damper rings are commonly used to reduce the vibration amplitude in turbine blades. These devices dissipate the friction energy of two contact surfaces that move relative to each other. The working principle of UPDs is described with the help of Fig. 1, that shows a common configuration in which one damper is inserted between two consecutive blades. The centrifugal force F_C pushes the damper against the blades so that the upside of the damper makes a contact with the left and right blade under-platforms. In static conditions, i.e. neglecting the blade dynamics, the normal contact forces are constant and depend on the nature of the contact between the damper and the under-platform. When the blades vibrate, the damper dynamics come into play and the normal contact forces are no longer constant. Moreover, if the damper and the under-platforms undergo a relative motion, a tangential force develops on the contact surfaces. The tangential force T increases with the relative displacement δ up to its maximum value, namely the normal contact force N times the friction coefficient $T = \mu N$. Characteristics of the frictional contacts are commonly described by hysteresis loops, which present the change in tangential force with respect to the relative displacement [1]. The enclosed area of the hysteresis loop is to the energy dissipated in the contact, which in turn is related to the damping property of the contact. The slope of the hysteresis loop at the onset of the relative motion is denoted as contact stiffness. Both the dissipated energy and the contact stiffness affect the dynamic behavior of the blade assembly.

Several test rigs were previously developed to experimentally investigate the effect of the under-platform damper on the blade dynamics. In [2] an experimental apparatus made with a single blade/single damper was developed to measure the damper performance in terms of vibration stress reduction. The experimental results were used to assess the capability of a new contact model [3]. Nowadays, a typical test rig architecture is composed by one damper placed between two blades excited with a shaker [4–8]. In [9] and later in [10] also the damper rotation was measured to better understand the damper kinematics. A modified architecture was used in [11,12] in which two dampers were in contact with the different platforms of the same test blade. The other side of the damper was in contact with a more rigid structure called dummy blade. Moreover, the blade was excited by a pulsating air jet. In all these experimental setups the centrifugal force acting on the damper was simulated by a static force applied by dead weights attached to the damper through a wires and pulleys arrangement or solid strips. In a more complex test rig [13] a 24 blades assembly was excited with a rotating force to investigate the damper behavior at different nodal diameters. In this rig, dampers were loaded with dead weights as well. Dampers are loaded in a more realistic way when tests are performed with a rotating disks. In this regard, in [14] an experimental and numerical study was carried out on a thin-walled damper in a rotating disk with blades excited with piezoelectric actuators. The test rig described in [15,16] was used to measure the effect of wedge shaped dampers on the dynamic response of a simple bladed disk. In this test rig, a non-contact magnetic excitation was applied along with a non-contact measuring system. The previously cited experimental setups, which are not exhaustive of all the test rigs that can be find in the literature, aimed to study the overall effect of the damper on the blade dynamics in terms of vibration amplitude reduction and resonant frequency shift. This black-box like approach is functional to evaluate the capability of the damper to reduce displacements at resonance, but it does not provide a better comprehension of the damper behavior. These test rigs are not capable of ana-

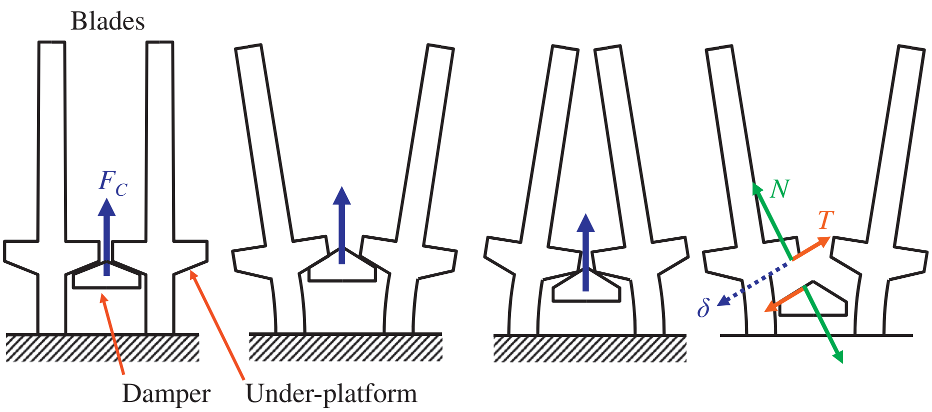

Fig. 1. Sketch of an under-platform damper/blade configuration.