Available online at www.sciencedirect.com
ScienceDirect
Aerospace Science and Technology 10 (2006) 501–508
Aerospace Science and Technology
www.elsevier.com/locate/aescte

Aeroengine turbine blade containment tests using high-speed rotor spin testing facility

Xuan Hai-jun *, Wu Rong-ren

Institute of Chemical Process Machinery, College of Material Science and Chemical Engineering, Zhejiang University,
38 Zheda Road, Hangzhou 310027, China

Received 3 October 2005; received in revised form 14 April 2006; accepted 19 April 2006

Abstract

The blade containment test is regarded as an essential assessment of aeroengine safety. This paper presents the results of a series of blade containment tests where a double edge notched blade was released at certain rotating speed which subsequently impacted the inner wall of the containment ring. These tests were conducted over a range of blade lengths (113–123 mm) and releasing speeds (6800–15 000 rpm) using the high-speed rotor spin testing facility in the laboratory. It is shown that great attention should be paid to the failure of the containment rings caused by the second impact. Numerical simulations are carried out using nonlinear finite element method to study the impact process. The simulation results agree with the experimental results. Current experimental and numerical methods will be extended to actual aeroengine cases involving more complex blades and containment rings.

Keywords: Gas turbine aeroengine; Blade containment test; High-speed spin testing facility; Nonlinear finite element method

1. Introduction

A major risk in modern aviation is the failure of aeroengine turbine blades at very high rotating speed. The blade is the component that is most likely to be failed due to high cycle fatigue (HCF) [1]. HCF-induced failure can not be avoided in modern aircraft gas turbine engines [2]. High energy blade fragments may penetrate the wall of the containment ring and damage fluid lines, control cables, oil tanks and airframes, which may seriously affect the flying performance and threaten the safety of airplane and passengers. In order to contain the blade fragments, a containment ring around the gas turbine rotor is required. Federal Aviation Administration (FAA) in the United States requires all commercial aeroengines to have a containment ring which will not be perforated in the event of a blade failure during engine operation [3,4]. FAA further requires engine manufacturers to demonstrate through a certification test that the most critical blade must be contained when it is released at the maximum rotating speed of the engine. Similar requirements are also shown in British defense standard 00-971 [5].

In the design of a modern engine containment ring, a careful selection of material, geometry and wall thickness is needed to reduce the weight of the ring and offer sufficient perforation resistance. For this objective, the blade containment remains an active research area for aircraft industry. Such kind of tests is very costly and requires special testing facilities and instrumentations. Only limited research results can be found in open publications. A literature review on the design and analysis of turbine rotor fragment containment has been presented in [6]. With increasing computational power and improving dynamic nonlinear finite element methods, a number of 3D simulations on the blade containment design have been conducted, as shown in [7–9].

The purpose of this paper is to present a series of blade containment tests and their simulations using nonlinear finite element method. This article consists of four sections. Following this brief introduction, Section 2 describes the experimental devices, procedures and results. Section 3 presents a detailed case study using the finite element simulation, which is followed by conclusions.

---

[*] Corresponding author.
E-mail address: marine_xuan@yahoo.com.cn (H. Xuan).

1270-9638/$ – see front matter © 2006 Published by Elsevier SAS.
doi:10.1016/j.ast.2006.04.006

2. Experiments and results

A blade containment experiment using high-speed rotor spin testing facility is an appropriate method that can provide details of the impact effects. A complete description of the tester and the instruments for data acquisition is beyond the scope of this paper, but a brief summary will be given.

2.1. High-speed rotor spin testing facility

The tests had been conducted using the high-speed rotor spin testing facility at the High-Speed Rotating Machinery Laboratory in the Institute of Chemical Process Machinery in Zhejiang University. The facility has an upward vertical configuration and employs a 45 kW, 0–3000 rpm speed variable DC motor. The motor is connected to the drive shaft of a speed increasing gear box (1:10) to give an output speed range of up to 30 000 rpm. A flexible shaft is connected to the driven shaft of the gear box with a tapered mating surface so that the flexible shaft and the testing bladed disk can be installed and removed easily. The testing chamber is armored with two layers of lead bricks and a steel ring to protect and enhance the safety of operational personnel and prevent the damage of the outer casing of the facility. A cylindrical copper bearing is placed close to the overhung bladed disk as a contact protection bearing. After a blade is released from a disk, large vibration caused by mass unbalance is limited by rolling surface contact between the flexible shaft and the copper bearing, giving time for the operator to slow and stop the rotor without damage the testing facilities.

2.2. Blade containment tests

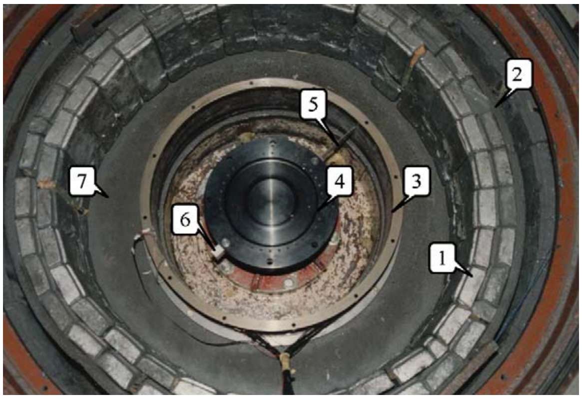

Fig. 1. Pre-test photo in testing chamber. (1) Lead bricks layer, (2) steel ring protection, (3) containment ring, (4) disk, (5) blade, (6) balance mass, (7) testing chamber.

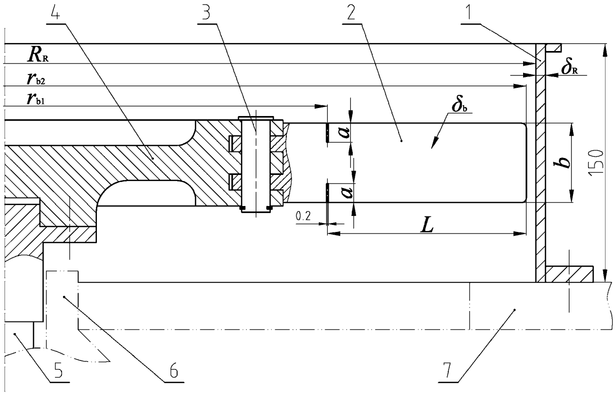

Fig. 2. Sketch of the experimental set-up. (1) Containment ring, (2) blade, (3) connection pin, (4) disk, (5) flexible shaft, (6) protection bearing, (7) testing chamber floor.

Table 1
Parameters of the rings and the blades

No.	Containment rings		Released blades				
	δ_R (mm)	D_R (mm)	Material	a (mm)	L (mm)	$B \times \delta_b$ (mm × mm)	m_b (g)
1	2	622	45	12.20	115	40 × 3	108
2	3	620	30CrMnSiA	14.65	113		106
3	3	620	30CrMnSiA	13.50	113		106
4	2	622	45	17.35	115		108
5	3	620	30CrMnSiA	12.07	123		116
6	2	622	30CrMnSiA	13.70	113		106
7	6	668	45	7.47	115	50 × 3.6	162

In these tests, the responses and deformations of both the containment ring and the released blade were studies within the preset speed range. The test rig was designed to satisfy several requirements, i.e. (a) the blade must be released at a preset speed, (b) the rotor speed at the instant of blade release must be recorded by speed meter, (c) the blade and the containment ring should be easily replaced for further tests, and (d) the test must be operated in vacuum so that aerodynamic effects can be eliminated. A plate blade and its balance mass on the opposite sides were connected to the rim of the disk with round pins, as shown in Figs. 1 and 2. Two edges of the blade were notched to the same depth. With the different lengths of the slots, the blades were predicted to release at different rotating speeds. Initial rotating speed and kinetic energy of the released blade can be calculated by a method presented in Section 2.3. The containment ring was mounted on the testing chamber floor. There was a radial clearance between the blade tip and the inner surface of the ring. The offset between the rotational axis of the disk and the geometric center axis of the ring was maintained within an acceptable tolerance by adjusting the position of the ring. A series of tests were performed using different containment rings and different blades mounted to the same disk. The material of the containment ring is Chinese standard #20 steel. Different wall thicknesses of the containment rings, various materials, and dimensions of the blades which were used in the tests, are as listed in Table 1.

Although great efforts were made to achieve a preset blade releasing speed, it is practically difficult to release the blade at the preset speed. This might be caused by the variations of the tensile strength of the tested blades and/or by the cutting accuracy of the notches. Thus, one of the major requirements in the tests was to catch the instant rotating speed of the rotor at the time when the blade was released. An enamel insulated circuit wire with 0.4 mm in diameter was affixed on inner wall surface of the containment ring, which was connected in series with the