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Identifying the Characteristics of Acoustic Excitation for Structural Health Monitoring of Blisks

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ABSTRACT

In this work an integrated testing for a preliminary calibration blisk procedure is presented. The procedure presented is used for the future benefit of the highly efficient and accurate calibration procedure for mistuning identification (ID) in one piece bladed disks (blisks). Mistuning identification is a particular type of structural damage that can be performed with Acoustic Excitation (AE) in testing the Structural Health Monitoring (SHM) of bladed disks. In this paper the linearity of the results of the AE test data analyzed using the scanning laser vibrometer are put under discussion and related to structural damage.

KEYWORDS: Acoustic Excitation (AE), Structural Health Monitoring (SHM), mistuning identification (ID), bladed disk, speaker

1. Introduction

The process of implementing a damage detection strategy for aerospace, civil and mechanical engineering infrastructure is referred to as *structural health monitoring (SHM)*. Here *damage* is defined as changes to the material and/or geometric properties of these systems, including changes to the boundary conditions and system connectivity, which adversely affect the system's performance. The SHM process involves the observation of a system over time using periodically sampled dynamic response measurements from an array of sensors, the extraction of damage-sensitive features from these measurements, and the statistical analysis of these features to determine the current state of system health.

Small differences among blades, called mistuning, can lead to severe increases in the maximum vibration amplitude and stress levels of bladed disks [1–3]. The increased stress can cause premature high cycle fatigue failure [4]. Therefore, it is of interest to experimentally identify mistuning and assess the mistuned forced response characteristics of actual, manufactured bladed disks. One can measure the natural frequencies of individual blades directly for disks with inserted blades, but not for one-piece bladed disks (blisks). Therefore, several techniques have been developed recently [5–24] to perform mistuning identification (ID) based on experimental measurements of the vibration response of a full blisk. While many of these studies have presented general mistuning ID experiments [5, 6, 9, 25, 11–13, 16, 20, 22, 23] methods for improving the efficiency and convergence of the testing procedure have not been considered. It is very important to calibrate the excitation system. Normally, this calibration involves the measurement of the excitation output from each actuator [20].

Acoustic pressure fluctuations with a propagation speed being the speed of sound can cause high level vibrations of mechanical structures. There is only one frequency of an acoustical resonance and its wave length has to fit with a geometrical length to generate high pressure levels. Bleed cavities in turbo machines have this kind of resonance.

The frequency depends only on the geometry and not on the flow velocity. Similar to the sound radiation of a Helmholtz-Resonator the frequency is influenced by the resonator volume, the speed of sound and the diameter of the neck or the hole in the resonator body (Fletcher and Rossing 1991) [25]. The excitation is a function of the vortex shedding frequency, which is caused by the tangential flow across the inlet hole.

Parker and Stoneman (1985) [26,27] also conclude that the source of an acoustic resonance excitation in turbo machines is due to vortex shedding from the rotor or stator blades or even from support struts.

Vortex shedding, however, does not necessarily need to excite an acoustic field. Particularly in the immediate vicinity of the blade pressure fluctuations can be generated the propagation speed of which differs from the speed of sound.

2. Acoustical Measurements and Instrumentation Bases

Most of the acoustical measurement and instrumentation systems can be broken down into three components:

1) Sensors
2) Data Acquisition
3) Analysis

The most common sensor used for acoustic measurement is the microphone. Measurement grade microphones are different from the typical recording-studio microphones because they can provide a detailed calibration for their response and sensitivity. Other sensors include hydrophones for measuring sound in water or accelerometers for measuring vibrations causing sound. The three main groups of microphones are pressure, free-field, and random-incidence, each with their own correction factors for different applications.

In this paper another type of instrumentation aided by a scanning laser vibrometer is used to measure the vibrations of the speaker membrane which generates sound. These method gives a higher precision than the microphone in the acoustic frequency response concerning.

3. Experimental Set-up

In order to avoid altering the test specimen and unintentionally introducing mistuning, non-contacting excitation is desired. In addition, in order to achieve a full range of excitation patterns, a means of exciting each blade independently is needed. Previous experiments (Kruse and Pierre [28, 29]) have used electromagnets to provide non-contacting excitation of the blades; electromagnets, however, present a number of difficulties. Most notably, the force provided by an electromagnet varies inversely with the cube of the separation between magnet and blade, so force amplitudes are quite sensitive to any blade to blade variation in this distance.

In order to avoid these issues, acoustic excitation is chosen. A small speaker was positioned approximately at 1 mm (0.039 inch) from the rear surface of each blade. The speakers have a diameter of 10 mm (0.39 inch) and a maximum thickness of 3 mm (0.12 inch), with an electrical impedance of 8 ohms and a maximum power of 0.3 watts. The speakers were positioned to lie parallel to the blade faces by means of acrylic blocks cut to the same angle as the blades from the plane of the disk (as can be seen in Figure 1). Each speaker was epoxied to its own acrylic block, which was then attached with a small bolt to an acrylic plate mounted behind the test specimen.

These speakers are driven by a series of Hewlett-Packard 8904 Multifunction Synthesizers, each with two independent but phase-synchronized channels. Before reaching each speaker, the output signals from H-P 8904 were conditioned by being passed through gain amplifiers [30].

4. Measurement Technique

A sketch of our experimental setup is shown in Figure 3. Each speaker is carefully mounted on an acrylic block first (as can be seen in Figure 2). Then, a sinusoidal signal was sent to each speaker, one at a time in order to measure its frequency response.

Before any given speaker was used to provide excitation in the system, its frequency response function was measured for acoustical calibration purposes. The laser beam of the scanning laser vibrometer was focused in the middle open area of the speaker that gives access to the oscillating membrane causing sound. The laser vibrometer is used to measure the membrane surface velocity wave forms at various frequencies supplied to the speaker. The output of the laser vibrometer is Fourier transformed, using the specialized software developed with the laser vibrometer used for measurements. The vibrometer has digitizing rates up to 200 kHz, so that vibration frequencies up to about 100 kHz can be measured.

The laser beam is aimed normally at the specimen surface. In such a situation, the specimen was coated with some retroreflective powder applied uniformely to the specimen, such that the beam size in the range of ~2–3 mm sets the spatial resolution for the vibrometer. The vibrometer measures the surface velocity in a direction parallel to the laser beam.

For the purpose of the acoustical calibration, each speaker was driven in the frequencies range of 1600 Hz up to 1800 Hz. This range was chosen based on the resonant frequency identified for each blade in the system. The frequency response of one speaker used for excitation is presented in Figure 4. As can be seen the response in magnitude is not as flat as expected. This fact will yield in some error quantification in the blisk calibration procedure that is desired to account for, since the calibration algorithm uses the principle of reciprocity in frequency also. In contrast to the magnitude response, the phase response of the speakers is very linear that will lead in a highly accurate blisk calibration in the phase content.

Note that the blisk calibration algorithm is beyond the scope of this paper and the concern of a future paper. The blisk calibration algorithm will be derived to iteratively calibrate the excitation applied to each blade so that the differences among the blade excitation magnitudes can be minimized for a single blade excitation, and also the excitation phases can be accurately set to achieve the desired excitation phase differences between different blades. For this purpose, as a linear characteristic of the acoustical excitation it is necessary, if possible, to be supplied in the experimental set-up, and each speaker will be individually measured and the frequency characterized.

Fig. 1. *Speakers positioned to lie parallel to the blade faces*

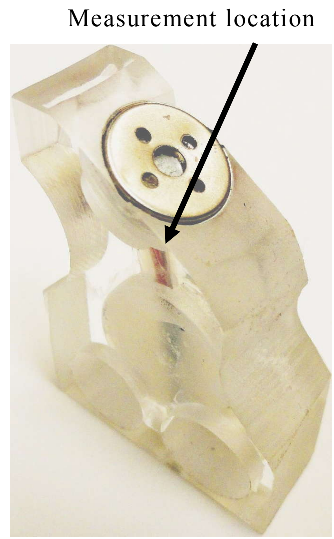

Fig. 2. *Speaker mounted on the plastic fixtures*

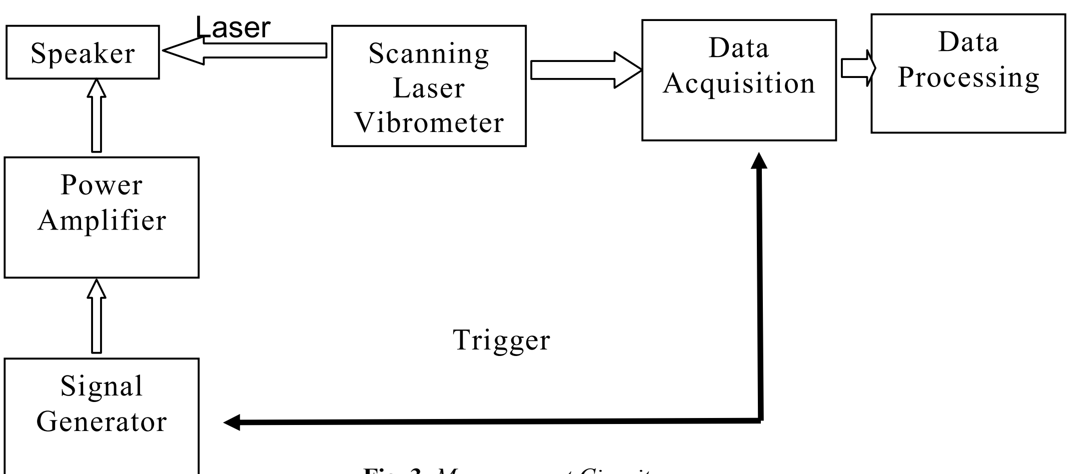

Fig. 3. *Measurement Circuit*

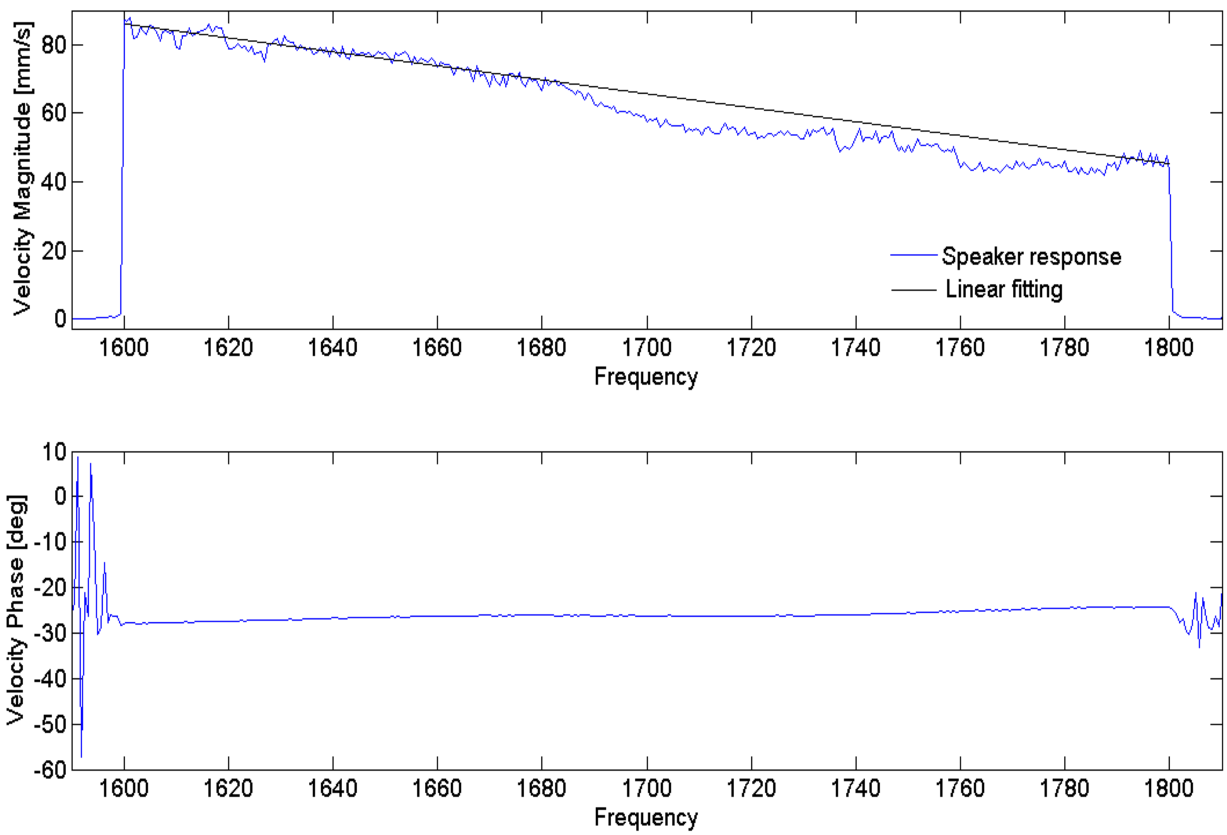

Fig. 4. *Speaker Frequency Response*

The speaker figured out in the present paper was excited with a frequency range between [1600 - 1800Hz]. For the first excitation frequency of 1600Hz, the velocity magnitude obtained is 80 mm/s. By increasing the excitation frequency, the velocity magnitude decreases monotonically up to 1700Hz. Further, a non-monotonic dependency is achieved between the velocity magnitude and excitation frequency up to 1800 Hz. This behavior leads to a nonlinear characteristic of the speaker. Based on the known nonlinearity, the error of the blades excitation could be calculated. The error is proportional to the slope of the velocity magnitude – frequency dependence. For the considered experiment, the slope is 8.53 degree which corresponds to a length of 202 mm/s. The achieved output power of the speaker could be up to half of the initial value in terms of the frequency range chosen for the excitation. This frequency range corresponds to the first family of the specimen blisk (first flex).

5. Conclusion

In this work an integrated testing for a preliminary calibration blisk procedure was presented. The frequency response linearity of the results of the AE test data analyzed using the scanning laser vibrometer were put under discussion and related to structural damage.

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Identificarea caracteristicii excitației acustice pentru monitorizarea integrității structurale a rotoarelor

Rezumat

În această lucrare este prezentat un test integrat premergător procedurii de calibrare a unui blisk. Procedura de fata este utilizata pentru a beneficia mai departe de un algoritm de calibrare extrem de eficient şi exact de identificare a mistuning-ului(ID), dintr-un disc cu palete turnat (blisks). Identificarea mistuning-ului reprezintă un tip special de daune structurale ce se poate repera experimental cu ajutorul excitației acustice (EA), în procesul de monitorizare structurala a sănătății (SHM) a discurilor cu palete. În această lucrare linearitatea datelor rezultate în urma testării prin excitație acustica (EA) şi vizualizate cu ajutorul unui vibrometru laser cu scanare sunt puse în discuție şi relaționate cu daunele structurale.

Identifier les caractéristiques de l'excitation acoustique pour la surveillance de l'état des structures de rotors

Résumé

Dans cet article, un test intégré précurseur d'une procédure d'étalonnage d’un blisk est présenté. La présente procédure est utilisée pour un futur bénéfice d'un algorithme d'étalonnage extrêmement efficace et précis d'identification désaccordage en un seul morceau disques à lames (DAM). D'identification désaccordage est un catégorie particulier de dommages structuraux qui peut être réalisées expérimentalement avec excitation acoustique (EA), dans le processus de surveillance de la santé structurelle (SHM) de disques à lames. Dans cet article, la linéarité des résultats des données résultant de tests par l'excitation acoustique (AE) analysées en utilisant le vibromètre laser à balayage sont mis en discussion et en relation avec des dommages structurels.