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Review on Vibration Problems in Turbomachinery

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Abstract

Vibration suppression of turbomachinery is an important engineering problem. Vibration caused by mass imbalance is a common problem in rotating the turbomachinery systems. Imbalance occurs if the principal axis of inertia of the rotor is not coincident with its geometric axis. Higher speeds cause much greater centrifugal imbalance forces, and the current trend of rotating equipment toward higher power density clearly leads to higher operational speeds. In this paper, a review of the research work performed in real-time active balancing and active vibration control for turbomachinery, as well as the research work on dynamic modeling and analysis techniques of turbomachinery systems, is presented. The basic methodology and a brief assessment of major difficulties and future research needs are also provided.

Keywords: turbomachinery, rotor, vibration, control, aerodynamic loading, structural instabilities, damping, blade.

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INTRODUCTION

Vibration problems in modern turbomachinery systems instill equal concern as those in their design, manufacture and general maintenance. Considerable amount of precise energy go unused due to machinery breakdown and associated costs to machine downtime add up to unproductive overheads. The modern trend of building high-speed engines requires new, dependable techniques to reduce vibrations.[1]

Vibration problems, usually unrelated to unbalance, represent another kind of problem for turbomachinery in which the rotor vibrates at nonsynchronous (other than rotating speed) frequencies. Nonsynchronous vibrations can be subsynchronous, when the frequency is lower than the rotational speed of the shaft, supersynchronous, when the frequency is higher than the rotational speed of the shaft, or a combination of both. One of the most harrowing of rotor vibration scenarios is the case of rotor instability causing subsynchronous vibrations. The onset mechanisms of subsynchronous vibrations are related to a great diversity of destabilizing forces, some of them not well understood yet, and therefore, special attention must be paid to this type of vibration. While considerable literature exists on analyzing, predicting and implementing passive techniques for reducing vibrations due to rotor instability, no publications on active control of these phenomena exists. Active control through AMBs stands as a promising solution for the prevention of this type of vibration problem.

In this paper, a brief review is made on various vibration problems that occur in turbomachinery systems due to various factors involved such as, hydraulic/

aerodynamic unbalance, bearing misalignment, thermal gradients, aerodynamic coupling, dissymmetry, internal / external nonhomogeneity action, eccentricity, shifting of parts due to plastic deformation of rotor parts, aerodynamic/ structural instabilities and many more.

KEY CHALLENGES

Aerodynamic Forcing

- Correct prediction of forcing levels.[4]
- Taking into account details (tip clearances, cavities, etc).[4]

Aerodynamic Damping

- Correct prediction of damping levels.[4]
- Strongly dependent on steady flow phenomena.[4]
- Transition usually not modeled at all.[4]

Non-Synchronous Vibrations

- Extremely difficult to delineate any searching option.[4]
- Post-diction possible, pre-diction extremely challenging.[4]
- Usually involving 360deg models, multi row.[4]

Damping

- Correct prediction of friction dampers and novel damping.[4]
- Concepts (coatings, air film, piezo, eddy current).[4]

REVIEW OF THE PAST WORKS TO ELIMINATE VIBRATION PROBLEMS

Lateral vibrations due to response to unbalance are the most common problem experienced by spinning rotors, producing synchronous (same frequency as rotating speed) vibrations. This problem and active solution methods addressing it have been studied in great extension. Kasarda (1988) used an AMB as damper to reduce vibrations on first and second modes.

R. Firoozian and R. Stanway[2] in their paper described an integrated approach to the modelling and active control of lateral vibrations in turbomachinery. Starting with consideration of the control of multiple rotor bending modes, the generation of a state vector from available measurements using an observer is discussed together with the effect on stability of employing a controller of reduced order. The various points are illustrated in an extended case study which also compares the active schemes with one involving a simple passive damper.

B. Sternlicht and Paul Lewis [3] in their research paper presented several examples of vibrational problems recently experienced by several turbine manufacturers. These problems included stability, system critical speeds, rotor response to unbalance, and balancing of high-speed compressors and turbines. The effects of fluid-film bearings and seals, bearing pedestals, and other parts of support structure on rotor response and critical speeds are discussed. The effects of rotor stiffness, mass, and inertia distribution are presented. The paper gives a comparison between theory and practice and provides guidelines to machinery designers.

George J. Simitses presented a review of the field of dynamic stability of structures. By structure, one means a flexible solid and therefore applications to rigid solids are excluded in their research paper. Since many phenomena and many classes of problems have been included under the heading of dynamic stability, an effort is made to classify the various phenomena, and discuss similarities and differences. Furthermore, whenever applicable, criteria and estimates of critical conditions are presented. Moreover, an attempt was made to identify important effects and influences of various parameters, through proper referencing. Finally, in the case of fluid–structure type of instabilities the author tried to make the review rather sketchy.

Kirk and Miller (1977) studied the influence that high-pressure oil seals have on turbo-compressors stability, introducing some design guidelines to avoid the appearance of subsynchronous vibrations. Kirk (1985) developed a reliable compressor design taking into account the interaction of labyrinth seals with the rotor and addressed the importance of the design of labyrinth seal clearances to enhance stability. However, limitations associated with the models and understanding of other instability mechanisms results in the periodic building of turbomachines which exhibit unstable behavior even though they have passed full speed, no-load shop tests before being installed for operation.

To design an active control scheme, a reduced-order model should be used and the effect of the spillover of higher vibration modes assessed. Although the available techniques developed for dynamic analysis, rotor imbalance estimation, and active real-time balancing and vibration control can be extended to high-order systems theoretically, the computational load will be heavier and the signal-to-noise ratio of the vibration measurement will have to be higher. Hence, the available techniques could be difficult to implement in high-order systems. Therefore, it is necessary to use a low-order system to approximate the high-order system. [6]

DESIGN FOR ACTIVE BALANCING AND VIBRATION CONTROL FOR ROTATING MACHINERY

The issue of actuator/sensor placement for control of flexible structures is an active research area. This problem is often formulated as a constraint optimization problem.

The constraints of this optimization problem are the limited available locations for the actuators and sensors. The objective function of this optimization problem is closely related to the control algorithm used for the flexible structure. The main possible optimal cost functions for sensor and actuator placement are for system identification, state estimation (which is represented by the observability) and indirect control performance (which is represented by the controllability), and direct control performance (e.g., the transient response, stability). A review of the optimal actuator/sensor placement follows.

System Identification

The objective function to be maximized by Qureshi et al. (1980) is the determinant of the Fisher information matrix associated with the parameters to be identified. This cost function depends on the spatial locations of the observation points. An early survey on the sensor location problem for system identification can be found in Kubrusly and Malebranche (1985). [6]

State Estimation

Gawronski (Gawronski and Lim, 1996; Gawronski, 1997) used the balanced representation of the system to do the actuator and sensor placement. The system is balanced if its controllability and observability gramian are equal and diagonal. Lim (1993) considered the observability and controllability separately. The so-called effective independence (EI) contributions of the actuator and sensor were considered. Liu et al. (1994) used the singular value decomposition of the input matrix B and observation matrix C directly to determine the degree of controllability and observability. [6]

Direct Control Performance

The transmission zeroes were taken as the target function by Maghami and Joshi (1993a, 1993b). Sepulveda and Schmit

(1991) considered the optimization problem of structure design and actuator/sensor placement in one framework. Several different control objectives, including the structural mass, control effort, number of actuators, stability margins, controllability and observability, and so on, were taken into account simultaneously. Dhingra and Lee (1994) attempted to optimally select the actuator/sensor positioning and feedback gain simultaneously. Other optimization criteria include the spillover effect (Barker and Jacquet, 1986), system performance under possible component failure conditions (Vander Velde and 368 The Shock and Vibration Digest / September 2001 Carignan, 1984), and hyperstability of the system (Stieber, 1988). [6]

CONCLUSION

The major problem faced by the active vibration control scheme is the use of a limited number of actuators to control an infinite number of vibration modes. The gyroscopic effect caused by the rotating motion and the moment of inertia of the rotating body is a unique dynamic effect in a rotor system and should be considered in model reduction. The specific impact of this model reduction on the performance of the active balancing should also be investigated in the future.

In many active balancing and vibration control methods, the imbalance estimation is coupled with the control strategy. So far, there are no systematic methods available to show the relationship between the estimation and the control strategy. A control action is preferable if it can obtain small imbalance-induced vibration and excite the system to obtain the good imbalance estimation at the same time. Thus, the coupling effect should be investigated by considering the estimation algorithm, the system dynamics, and the control performance. [6]

This research can also lay a scientific foundation for the design of an efficient and reliable generic adaptive control system. It is clear that active balancing can suppress the imbalance-induced vibration. It is also clear that the active balancing can improve product quality and improve the fatigue life of the machine and cutting tools and, hence, reduce the system cost. However, the installation and maintenance of an active vibration system for rotating machinery will increase the system cost. How to assess the active vibration control system from a cost-effective point of view and on a higher process level is not well studied in the literature. We believe this is an interesting and important problem in the active balancing and vibration control of a rotating system.[6]

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