Dynamic reliability analysis of turbine blisk radial deformation via moving extremum surrogate modeling strategy

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1. Introduction

As a key component of an aeroengine, high-pressure turbine blisk plays an important role in energy conversion to provide kinetic energy. If turbine blisk occurs failure, it will affect the integrity of aeroengine system function and even appear catastrophic event. According to the statistics, about 25% of aeroengine performance disorders are caused by turbine blisk failure, and more than half of them are caused by turbine blisk stiffness failure. Besides, turbine blisk suffers from complex loads, e.g., fluid loads, thermal loads, structural loads, and so on, during aeroengine operation, and these parameters process dynamic characteristics and strong uncertainties. To guarantee the safety of aeroengine system, it is urgent to investigate the effect of dynamic parameters on the reliability of turbine blisk radial deformation under uncertainties from probabilistic perspective.

Numerous approaches have emerged with the development of structural reliability analysis and design. The MC simulation holds high computing precision for structural reliability estimation, however, the computational burden is heavy due to running thousands of simulations with the FE model. To avoid the existing defects of the numerical approaches, surrogate modeling strategies are proposed to perform structural reliability analysis, which mainly include response surface method (RSM, short for), support vector machine, artificial neural network and Kriging model. Nevertheless, the relevant parameters of rotor structures have dynamic and time-varying characteristics during aeroengine operation, we need to establish numerous models to derive structural reliability estimation within a time domain by using these surrogate modeling strategies, which leads to increased computational difficulty and heavy computational tasks. For improving the computing efficiency, extremum RSM (ERSM) is proposed to discuss the dynamic reliability assessment of aeroengine rotor structures [18, 19]. Although the ERSM can greatly lighten the computational burden, the dynamic reliability estimation of an aeroengine turbine blisk involves multiple variables coming from multi-physical fields, and these parameters process high-nonlinearity, the analytical accuracy with the ERSM cannot meet the engineering requirements owing to the limitation of quadratic polynomials with the least square method. We therefore need to explore a computationally efficient and accurate technique for the dynamic reliability estimation of an aeroengine turbine blisk radial deformation. Therefore, it is urgent to seek for an efficient algorithm for structuring high-precise model.

2. Body of abstract

The purpose of this paper is to develop an efficient and accurate surrogate modelling strategy, called moving extremum surrogate modeling strategy (MESMS), for performing the dynamic reliability estimation of an aeroengine turbine blisk radial deformation, by considering the fluid-thermal-structural interaction, the randomness of workloads and the randomness of material parameters including inlet velocity, inlet pressure, outlet pressure, gas temperature, rotational speed, material density, and so forth. This strategy integrates the ERSM and moving least square technique, in which the ERSM is used to handle the dynamic process of output response within a time domain to improve computational efficiency, and the moving least square technique is employed to derive the mathematical model of analytical objective with the efficient samples to highlight predicted accuracy. The derived model with important sampling method is then utilized to perform the dynamic reliability analysis of an aeroengine turbine blisk radial deformation within the time domain [0, T]. We firstly elaborate the analytical procedure and basic theory of the MESMS for dynamic reliability estimation of turbine blisk radial deformation. Based on the developed method and important sampling method, the dynamic reliability analysis of an aeroengine high-pressure turbine blisk radial deformation is then performed regarding the fluid-thermal-structural interaction. Finally, we verify the effectiveness of this method in terms of approximate precision and simulation performance, by comparison of the direct simulation, ERSM and ERSM-based weighted regression (ERERSM). The efforts of this paper provide a useful means for performing structural reliability evaluation