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Impact of system anisotropy on vibration reduction of rotating machinery and its evaluation method

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ABSTRACT

The orbit shape responded from each concerned section of anisotropic rotating machinery varies along with the axial position of unbalance force, especially its parameters like the inclination angle and the major to minor axis ratio. Considering the axial position difference between the original unbalance mass existed and the balancing planes adopted, vibration reduction with balancing could be disturbed by the anisotropy of rotating machinery. Through in-depth analysis on these mechanisms, a method for anisotropy evaluation is presented based on the dispersion characteristics estimation of system difference coefficients. Balancing experiments under different degrees of system difference coefficients dispersion and different unbalance mass distribution are implemented to show the effectiveness of this method. Essentially, the unbalance response of each concerned section is a synthesis of system difference coefficients and unbalance mass. Therefore, as weight coefficients of unbalance mass, the dispersion evaluation indexes of system difference coefficients can be used in distributing the original unbalance mass to further reduce the disturbance of system anisotropy to vibration reduction.

1. Introduction

Balancing is an important method for vibration reduction of rotating machinery, and the theoretical researches on dynamic balancing method now are well-established [1–3]. In recent years, related researches mainly focus on two aspects. One is about how to further improve the balancing efficiency—non-trial balancing method [4–7] and active balancing control [8–10] which are two typical research directions in this field. The other aims at how to enhance the vibration reduction effect of dynamic balancing operation. Among all factors that could be involved, system anisotropy has been confirmed as one of the most important factors that could seriously affect balancing result. Meanwhile, balancing anisotropic rotating machinery has also attracted the attention of researchers around the world. Fujisawa and Shiohata [11] fused the information that acquired from two mutually perpendicular radial directions and used the least square influence coefficients method obtaining balancing scheme. Kang et al. [12,13] utilized the precession information of concerned sections to give consideration to system anisotropy. Qu et al. [14,15] presented a holobalancing method based on the research of holospectrum, which uses the initial phase vector of orbits to represent unbalance response.

The balancing methods mentioned above are all based on comprehensive utilization of the vibration information that collected from different radial directions of concerned sections, and they consider system anisotropy as well as the optimization

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Nomenclature

$A_{i,k}$, $\gamma_{i,k}$ amplitude and phase of influence coefficient in X direction
$\boldsymbol{C}_{xx}$, $\boldsymbol{C}_{yy}$, $\boldsymbol{C}_{yx}$, $\boldsymbol{C}_{xy}$ damping matrices
$\boldsymbol{F}$ transition matrix of unbalance mass to system generalized force
$\boldsymbol{fx}_i$, $\boldsymbol{fy}_i$ generalized excitation forces in the *i*th element
$\boldsymbol{G}$ rotation matrix
i, k, pi, qk axial position indexes of an element
j imaginary number (=$\sqrt{-1}$)
$\boldsymbol{K}_{xx}$, $\boldsymbol{K}_{yy}$, $\boldsymbol{K}_{xy}$, $\boldsymbol{K}_{yx}$ stiffness matrices
$\boldsymbol{M}_{xx}$, $\boldsymbol{M}_{yy}$ inertia parameter matrices
m number of concerned elements
n number of discrete equivalent elements
t time variable
$\boldsymbol{R}_{pi}$, $\boldsymbol{Q}_{pi,k}$ deviation matrices
$\boldsymbol{p}_i$, $\boldsymbol{q}_i$ generalized displacements of the *i*th element
$\boldsymbol{T}_x$, $\boldsymbol{T}_y$ influence coefficient matrices in X and Y direction
X, Y, Z directions of coordinate system
x_i, y_i displacement response of the *i*th element in X and Y direction
$\chi \exp^{j\varsigma}$ average system difference coefficient
$\chi_{i,k}$, $\varsigma_{i,k}$ amplitude and phase of system difference coefficient
χ_i, ς_i amplitude and phase of response system difference coefficient
$\bar{\chi}_{pi}$, $\bar{\varsigma}_{pi}$ amplitude and phase of response difference coefficient to pure correction mass excitation
θx_i, θy_i deflection angles of the *i*th element in X and Y direction
φ_i initial phase of orbit excited by original unbalance
$\bar{\varphi}_{pi}$ initial phase of orbit excited by pure correction mass
$\frown{\varphi}_{pi}$, $\frown{\varphi}_{pi,k}$ initial phase of orbit of equivalent response
λ_i, ϕ_i amplitude and phase response of the *i*th element (under original unbalance excitation) in X direction
$\bar{\lambda}_{pi}$, $\bar{\phi}_{pi}$ amplitude and phase response to pure correction mass excitation in X direction
$\hat{\lambda}_{pi}$, $\hat{\phi}_{pi}$ amplitude and phase response after balancing in X direction
$\frown{\lambda}_{pi}$, $\frown{\phi}_{pi}$ amplitude and phase of equivalent response of average system difference coefficient in X direction
μ_i, α_i weight and phase of unbalance in the *i*th element
σ_k normalized system deviation
$\frown{\tau}_{pi}$, $\frown{\tau}_{pi,k}$ orbit scale factors of equivalent response
υ_k normalized coefficient
ω circular frequency
ξ_i, ψ_i amplitude and phase response of the *i*th element (under original unbalance excitation) in Y direction
$\bar{\xi}_{pi}$, $\bar{\psi}_{pi}$ amplitude and phase response to pure correction mass excitation in Y direction
$\hat{\xi}_{pi}$, $\hat{\psi}_{pi}$ amplitude and phase response after balancing in Y direction
$\frown{\xi}_{pi}$, $\frown{\psi}_{pi}$ amplitude and phase of equivalent response of average system difference coefficient in Y direction

Operators
$(.)^T$ transpose of a matrix or a vector
$[\cdot]$ matrix or vector
$[\cdot]_{pi}$ vector of displacement response of the *pi*th element
$[]\cdot[]$ dot product of matrices or vectors
$|\cdot|$ modulus of a complex number
angle $(\cdot)$ argument of a complex number
tr$(\cdot)$ trace of a matrix

Abbreviations
ASDC average system difference coefficient
OSF orbit scale factor
RDC response difference coefficient
SDC system difference coefficient

of balancing schemes. Nevertheless, related analysis further show that: Once the number and axial position of balancing planes are determined, theoretically an optimal balancing effect on rotating machinery with certain distribution of unbalance mass will be determined as well. Then, no matter which method is applied, the actual balancing result can only