Chatter reliability prediction of side milling aero-engine blade

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1. Introduction

The turbine blade is one of the key components in aero-engine. Side milling is often used for finis-milling of blades. Cylindrical or conical milling cutter of side edge is applied to machine blade, where cutters and blade maintain line contact. Due to the specific curved cavity structure of blade, hierarchical strategy is usually adopted in side milling. The cutter is mainly subject to radial cutting force. As the milling depth increases, cutter overhang lengthens and cutter stiffness becomes worse. Under the action of radial force, cutter deflection, vibration and wear become intensified, which easily tend to chatter. Chatter leads to reducing product quality, increasing tool wear and limiting production efficiency. It is a key issue to suppress chatter by optimizing process parameters.

2. Body of abstract

Reliability analysis of dynamic structural system is applied to predict chatter of side milling system for machining aero-engine blade. Chatter reliability is defined as probability of stability for processing. Reliability model of chatter is developed to forecast side milling chatter vibration, where structure parameters and spindle speed are regarded as random variables and chatter frequency is considered as intermediate variable. The first-order second-moment method is used to work out the side milling system reliability model. Reliability lobe diagram (RLD) is applied to distinguish reliable regions of chatter instead of stability lobe diagram (SLD). One example is used to validate the effectiveness of proposed method. Chatter reliability and RLD could be used to determine the probability of stability of side milling.

3. Equations, figures, and tables

For milling a 2-DOF Structure, the equation of chatter free axial cutting depth can be expressed as:

$$d_{\lim} = -\frac{2\pi}{N_t a K_T \operatorname{Re}\left[-\frac{a_{XX}G_{XX}(iS_c)+a_{YY}G_{YY}(iS_c)}{2G_{XX}(iS_c)G_{YY}(iS_c)(a_{XX}a_{YY}-a_{XY}a_{YX})}\right]} \quad (1)$$

The limit state function of the milling system considering chatter can be written as:

$$f_X(\mathrm{X}) = d_{\lim} - d \quad (2)$$

The reliability of the dynamic milling process is the probability that chatter does not occur at a given time and for the given function parameters, then the reliability of the model can be defined as:

$$R_S = P(f_X(\mathrm{X})<0) = \int_{X_R} g_X(x)dx \quad (3)$$

The limit state function of milling system is:

$$Z = f_X(\mathrm{X}) = 0 \quad (4)$$

For milling a SDOF structure, the basic random variable $X=(x_1,x_2,x_3,x_4)^T$ are related random variables in the normal distribution. x_i is m, c, k and S_c, respectively. S_c associates with m, c and k. The correlation matrix for milling system can be expressed as:

$$\rho=\begin{pmatrix} 1 & 0 & 0 & \rho_{x_1x_4} \\ 0 & 1 & 0 & \rho_{x_2x_4} \\ 0 & 0 & 1 & \rho_{x_3x_4} \\ \rho_{x_4x_1} & \rho_{x_4x_2} & \rho_{x_4x_3} & 1 \end{pmatrix} \quad (5)$$

Where $\rho_{x_ix_j}$ is the correlation coefficient between variable x_i and x_j.

The standard deviaton ς_1 , ς_2 , ς_3 and ς_4 of each random variable is ς_m , ς_c , ς_k and ς_{S_c} , the covariance matrix of milling system is:

$$\mathrm{D}=\begin{pmatrix} \varsigma_1^2 & 0 & 0 & \rho_{x_1x_4}\varsigma_1\varsigma_4 \\ 0 & \varsigma_2^2 & 0 & \rho_{x_2x_4}\varsigma_2\varsigma_4 \\ 0 & 0 & \varsigma_3^2 & \rho_{x_3x_4}\varsigma_3\varsigma_4 \\ \rho_{x_4x_1}\varsigma_1\varsigma_4 & \rho_{x_4x_2}\varsigma_2\varsigma_4 & \rho_{x_4x_3}\varsigma_3\varsigma_4 & \varsigma_4^2 \end{pmatrix} \quad (6)$$

Matrix D is a fourth-order positive definite symmetric matrix. The matrix contains four real eigenvalues and four linearly independent and orthogonal eigenvectors.

For milling a 2-DOF structure, the basic random variable $X=(x_1, x_2 \cdots x_i)^T$ are uncorrelated random variables in the normal distribution, where x_i is m_X , m_Y , c_X , c_Y , k_X , k_Y and S_c , respectively. S_c relates to m_X , m_Y , c_X , c_Y , k_X and

k_Y . The correlation matrix for milling system can be expressed as:

$$\rho=\begin{pmatrix} 1 & \cdots & 0 & \rho_{x_1x_7} \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & 1 & \rho_{x_6x_7} \\ \rho_{x_7x_1} & \cdots & \rho_{x_7x_6} & 1 \end{pmatrix}_{7\times7} \quad (7)$$

Where $\rho_{x_ix_j}$ is the correlation coefficient between variable x_i and x_j .

The standard deviation ς_{m_X} , ς_{m_Y} , ς_{c_X} , ς_{c_Y} , ς_{k_X} , ς_{k_Y} and ς_{S_c} is respectively expressed by ς_1 , ς_2 , ς_3 , ς_4 , ς_5 , ς_6 and ς_7 , the covariance matrix of milling system is :

$$D=\begin{pmatrix} \varsigma_1^2 & \cdots & 0 & \rho_{x_1x_7}\varsigma_1\varsigma_7 \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & \varsigma_6^2 & \rho_{x_6x_7}\varsigma_6\varsigma_7 \\ \rho_{x_7x_1}\varsigma_1\varsigma_7 & \cdots & \rho_{x_7x_6}\varsigma_6\varsigma_7 & \varsigma_7^2 \end{pmatrix}_{7\times7} \quad (8)$$

Matrix D is a seventh-order positive definite symmetric matrix. The matrix contains seven real eigenvalues and seven linearly independent and orthogonal eigenvectors.
Reliability probability of the milling system is defined as:

$$p_r=1-\Phi(-\beta) \quad (9)$$

Where $\Phi(\cdot)$ is cumulative function of the standard normal distribution.

Table 1 The average and standard deviation of structural parameters

		f_n (Hz)	k (N/m)	m (kg)	c (N s/m)	S (rad/s)
X	μ_X	898.22	3.35E+06	1.56	168.67	3.34
	σ_X	2.37	1.19E+05	0.18	0.31	0.03
Y	μ_Y	852.51	4.86E+06	0.85	256.77	3.34
	σ_Y	0.78	0.80E+05	0.47	0.36	0.03

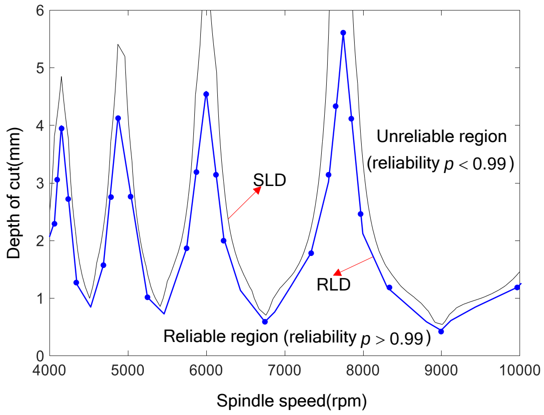

Fig.1 Reliability lobe diagram for side milling system

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