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Torsion effect of swing frame on the measurement of horizontal two-plane balancing machine

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ABSTRACT

In this paper, the vibration model of swing frame of two-plane balancing machine is established to calculate the vibration center position of swing frame first. The torsional stiffness formula of spring plate twisting around the vibration center is then deduced by using superposition principle. Finally, the dynamic balancing experiments prove the irrationality of A-B-C algorithm which ignores the torsion effect, and show that the torsional stiffness deduced by experiments is consistent with the torsional stiffness calculated by theory. The experimental datas show the influence of the torsion effect of swing frame on the separation ratio of sided balancing machines, which reveals the sources of measurement error and assesses the application scope of A-B-C algorithm.

1. Introduction

Sided horizontal dynamic balancing machine is based on two-plane balancing theory, which can simplify the unbalance of the rigid rotor into the measurement of two specific correction planes. There are two mechanical approaches of two-plane dynamic balancing machine: influence coefficient method and A-B-C algorithm. A-B-C algorithm is simple to operate, as the setting is completed when values of A, B, C are determined, see Fig. 1. The traditional A-B-C algorithm only considered translational stiffness of the supporting spring plate, but ignored torsional stiffness (namely ignored the effect of inertia moment and torsion). In addition, the traditional swing frame structure failed to separate the translational vibration and the torsion vibration effectively. And the vibration center of vibration system varies with the position of the test weight. Therefore, there exists large measurement error of dynamic balancing machine.

In the field of dynamic balance, Lee et al. [1] and Chung et al. [2] investigated the equations of motion of dynamic balancing machine based on the Lagrange's approach. Yeh [3] derived the formula of error rate ignoring inertia moment, and presented that the error rate was different when the correction plane changed. Cao et al. [4] introduced the parameter λ, which is the ratio of translational stiffness and torsional stiffness. And the exact solution of λ, which indicates the influence of torsional stiffness on the dynamic balance measurement, is reverse to resolve by using influence coefficient method. Hedaya and Sharp [5] introduced a new type of automatic balancer to compensate for unbalanced inertia forces, and proposed new autobalancing concepts. Sperling et al. [6] investigated a two-plane automatic balancing device, considering

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Nomenclature

M	rotor mass
X_G	the displacement of rotor center G in x direction
X_1, X_2	displacement of two rotor bearings in x direction
k	spring stiffness
ω	rotating speed of rotor
U_0	concentrated unbalanced force
J_T	total moment of inertia of rotor
θ_Y	spin angle of the rotor about y-axis
l_d	distance between frames in $z$direction
d	axial distance from unbalance to the rotor center
L'	distance between rotor center to the vibration center in z direction
h, b, l	length,width, height of the spring plate
L	distance from the section centroid of spring plate to x-axis
$L_i'(i = 1, 2, 3, 4, 5, 6, 7)$	between rotor center to the vibration center in z direction when test weight is in position i
H	distance from the section centroid of spring plate to z-axis
θ	twist angle
β	initial angle
F_X, F_Y, F_Z	forces acting on the spring plate in x, y, z directions
M_0	torque
F_T	tangential force
F_N	normal force
S	displacement of the rotor center under F_T
I	area moment of inertia
E	Young's modulus of elasticity
k_{to}	total torsional stiffness
k_{to1}	torsional stiffness under F_T
k_{to2}	torsional stiffness under M_0
$k_i(i = 1, 2, 3, 4)$	torsional stiffness of four spring plates
k_{tos}	total torsional stiffness of the system
G	shear modulus
λ'	the parameter related to h/b
F	unbalanced force
N_L	reaction force of left bearings
N_R	reaction force of right bearings
K_{left}, K_{right}	proportional coefficients of left and right sensors
left reading	left sensor reading
right reading	right sensor reading
k_{tr1}	transnational stiffness of each plate
k_{tr}	total transnational stiffness
J_1	moment of inertia of rotor center part
J_2	moment of inertia of rotor end part
M_m	mass of larger diameter (ϕ100mm) part of the rotor
M_e	mass of smaller diameter (ϕ40mm) part of the rotor
J_{weight}	the moment of inertia of the test weight to the central axis of rotor
m	mass of test weight
k_{to}^L, k_{to}^R	actual torsional stiffness of left and right spring plates
L^L, L^R	distance from the section centroid of left and right spring plates to the twist center
δ_L, δ_R	error rate of torsional stiffness of left and right spring plates
T	total torque
N_L'', N_R''	torsional forces on left and right spring plates
N_L', N_R'	reaction forces on left and right sensors
F_L, F_R	unbalanced forces on left and right planes
λ	separation ratio
ω_X	natural frequency of translational vibration
ω_θ	natural frequency of rotation

out-of-plane motions. Rodrigues et al. [7] put forward a calculation method for optimization plane separating effect of rigid rotor. Wang [8] introduced a new swing frame structure, which achieved the separation of static and couple movement effectively and was far better than traditional swing frame structure. In studies of bending-torsion coupling, Yuan and Chu [9] investigated the external and internal coupling effects of rotor's bending and torsional vibrations by theoretical analysis and numerical simulation. Mohiuddin et al. [10] derived the model of coupled bending and torsional motions of the rotating shaft using the Lagrangian approach. Sun et al. [11] established a mathematical model of an impacting-rub rotor system with bending-torsion coupling, which is compared with that without bending-torsion coupling, and analyzed the calculation results. Bending–torsional coupled vibration of cracked rotor was studied by Xiao et al. [12], Zhao et al. [13], and Zhu et al. [14]. Hsieh [15] analyzed the torsional vibration of the symmetric rotor-bearing system using the improved the transfer matrix method (TMM). In terms of dither present in low speed rotor, Hou et al. [16] investigated the instability of low-speed rotor with elastic supports caused by torsional vibration, analyzed the vibration frequency by signal processing, and established correction coefficients by mathematical method. Di [17] analyzed the influence of the pulse width modulation (PWM) switching frequency and delay on the performance of the rotor at low speed. Young et al. [18] analyzed the dynamic stability of rotor-bearing system under the excitation of unbalanced forces. In dynamics of unbalanced vibration system, Ma et al. [19] investigated the high speed nonlinear dynamics of dynamic balance vibration system, discussed the dynamic characteristics of the vibration system under different rotating speed and the influence of the rotational speed on the measurement of unbalance. In the field of elastic mechanics, Wang [20] investigated the restrained torsion and distortion effect of thin-walled beams. In signal processing, Green [21] analyzed how to filter other interfering signals accurately from vibration signals and separate the unbalance signals accurately.

In traditional research, the torsion center of the vibration system is usually considered as a constant, without considering