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Research on Full Vector Dynamic Balancing Algorithm for Rotors

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Abstract: Influence coefficient method and the modal balancing method are often used in the dynamic balancing in the past days. These methods sometimes exist a lot of big measurement errors. So, in order to make these errors much smaller, and to use the vibration information of the rotor more sufficiently, at last, we put forward the full vector dynamic balancing algorithm. Though the theoretical analysis, and the experiment tests, we can compare with the new method and the old method , study the relationship between the dynamic balancing and the rotation equipment, and the direction of the development. The full vector dynamic balancing algorithm theory can be inferred from the Jeffcott rotor. To compare with the methods which are mentioned before, we can find that the full vector dynamic balancing algorithm is much better than the influence coefficient method and the modal balancing method. We can use the MATLAB program to prove that the full vector dynamic balancing algorithm is much better. So the conclusion is completely right.

Keywords: full vector dynamic balancing algorithm; unbalanced response; balancing effect; MATLAB

1 Introduction

Rotating machinery in orderly stable normal operation will not only enable the practitioners to reap huge economic benefits, but also drive the economic development of the entire society and enable the various industries in the society to carry out the relevant production safely and efficiently. On the contrary, the vibration caused by mechanical vibration not only brings about one part of the damage, when the overall operation of the machine, but not in a timely manner when the relevant checks, where the vibration will not be effectively controlled and adjusted, a rat bad soup, so, the other parts of the overall mechanical system will inevitably be dragged down, even more so as to damage and malfunction of the equipment. More serious accidents may cause more serious safety accidents and threaten the lives and property of many enterprises and people. All vector dynamic balance technology developed will be able to overcome the effect of dynamic balance shortage phenomenon of the traditional influence coefficient method caused by sensor installation direction, reduce the specific influence to the balance effect of equilibrium in the direction of the installation of sensors.

2 Full vector dynamic balance algorithm

Suppose there is a rigid body around a fixed point to rotate, we can see the centrifugal force is

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$$F = R(\pi n/30)^2 * G/g$$

Based on this principle, firstly, we make a research on single-sided high-speed dynamic balancing method: Measure the original vibration of the rotor named V_0, then add test weight P_0 to the top of the rotor and measure the vibration again, named V_1. Calculate the effect of aggravating on vibration. Derive the relevant formula: $x = (V_1 - V_0)/P_0$, x refers to the amount of vibration per unit mass trial.

Calculate the balance weight Q_0 that should be added to the rotor, we can deduce

$$Q_0 = -V_0/x$$

Two-sided high-speed dynamic balancing principle and manner is similar to a single side. The first plane is weighted gain factor is $x_{110} = (V_{110} - V_{100})/P_1$, $x_{210} = (V_{210} - V_{200})/P_{10}$.

The second plane is weighted gain factor is $x_{120} = (V_{120} - V_{100})/P_{10}$, $x_{220} = (V_{220} - V_{200})/P_{10}$.

Assuming that the first measured vibration plane should be added to the equilibrium weight Q_{10}, assuming that the second measured vibration plane should be added to the balanced weight Q_{20}, we can make a conclusion:

$$x_{110}Q_{10} + x_{120}Q_{20} + V_{10} = 0,\ \text{and}\ x_{210}Q_{10} + x_{220}Q_{20} + V_{20} = 0$$

By solving the two equations above, we can get the final result.

3 Rotor eddy differential equation

Now consider the model of the single disk symmetric Jeffcott rotor in Figure 1.

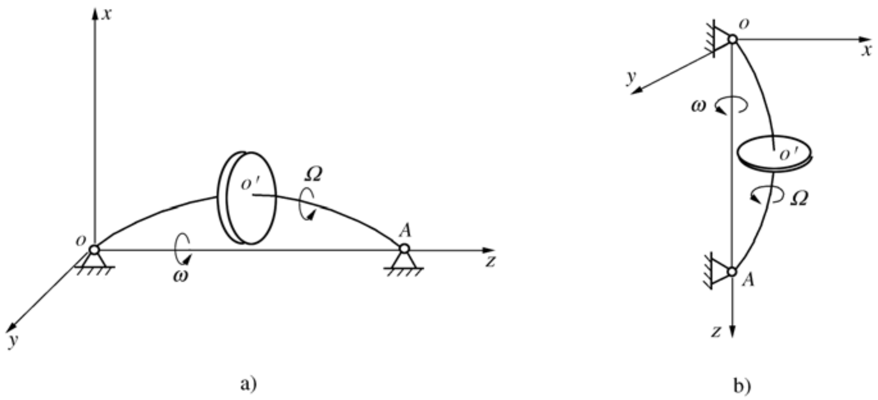

Figure 1 Single disc symmetrical Jeffcott rotor

Assuming m is the mass of the disk, k is the stiffness coefficient of the rotor, we can get the elastic force of the rotor

$$F = -kr,\ M\ddot{x} = Fx = -kx,\ m\ddot{y} = Fy = -ky$$

Suppose $\delta^2 = k/m$, then we can deduce:

$$\ddot{x} + x\delta^2 = 0,\quad \ddot{y} + y\delta^2 = 0$$

From these, we can deduce

$$x = X\cos(\delta t + \varphi_x),\quad y = Y\cos(\delta t + \varphi_y)$$

Where: X and Y are the amplitude of motion; φ_x and φ_y are the phase angles.

Suppose $X_c = X\cos\varphi_y$, $X_s = X\sin\varphi_x$, $Y_c = Y\cos\varphi_y$, $Y_s = Y\sin\varphi_y$, then we can deduce:

$$x = \sqrt{X_c^{\ 2} + X_s^{\ 2}}, \quad y = \sqrt{Y_c^{\ 2} + Y_s^{\ 2}}, \quad \tan\varphi_x = X_s/X_c,\ \tan\varphi_y = Y_s/Y_c.$$

Where: $x = X_c\cos(\delta t) - X_s\sin(\delta t)$, $y = Y_c\cos(\delta t) - Y_s(\sin\delta t)$. Finally. We get the eddy trajectory equation:

$$[(Y_c^{\ 2} + Y_s^{\ 2})x^2 + (X_c^{\ 2} + X_s^{\ 2})y^2 - 2(X_cY_c + X_sY_s)xy]/(X_sY_c - X_cY_s)^2 = 1$$

Suppose $A = X_c^{\ 2} + X_s^{\ 2}$; $B = Y_c^{\ 2} + Y_s^{\ 2}$; $C = X_cY_c + X_sY_s$; $D = X_s + Y_c$; $E = X_c - Y_s$. Then, we can deduce:

Ellipse half-length shaft named $R_1 = \sqrt{\frac{1}{2}(A+B) + [\frac{1}{4}(A-B)^2 + C]^{\frac{1}{2}}}$.

Disk center phase angle $\varphi = \arctan(D/E)$.

So we can deduce:

$$X_p = \frac{\sqrt{(X_c - Y_s)^2 + (X_s + Y_c)^2}}{2},\ X_r = \frac{\sqrt{(Y_s + X_c)^2 + (Y_c - X_s)^2}}{2},$$

$$\tan\varphi_p = (X_s + Y_c)/(X_c - Y_s),\ \tan\varphi_r = (Y_c - X_s)/(X_c + Y_s).$$

So, from the above analysis we can obtaine oval geometric parameters:

$$R_l = X_p + X_r, \quad R_s = X_p - X_r, \quad \phi = \varphi_p, \quad \tan 2\alpha = \tan(\varphi_p + \phi_r)$$

4 Experimental scheme

1) Single X-direction and single Y-direction dynamic balance of the experimental analysis process

Single X direction:

The initial vibration amplitude and the corresponding phase angle are measured as follows: 54.3∠254, after adding two grams of counterweight at a zero angle: 98.0∠238; Theoretical calculation of the need to add the weight: 2.2g∠215, actually added during the experiment of the counterweight: 2.2g ∠ 225; Residual main vibration vector measured after adding counterweight: 13.7∠258; balance efficiency calculation result: 77.3%

Single Y direction:

The initial vibration amplitude and the corresponding phase angle are measured as follows: 47.5∠170, after adding two grams of counterweight at a zero angle: 75.6 ° 157; Theoretical calculation of the need to add the weight: 3g ∠ 214, actually added during the experiment of the weight: 3g ∠ 215; After the counterweight measured residual main vibration vector: 15.1 ∠ 320, balance efficiency calculation result: 75.0%

2) Synthesis of the whole vector from both sides of the equilibrium analysis of the experimental process

After X, Y plane synthesis:

The main vector of unbalance of total vector: X_0: 60.5∠268.

Single X direction: the initial vibration amplitude and the corresponding phase angle are measured as follows: X_0X: 57.2∠263,

Single Y direction: the initial vibration amplitude and the corresponding phase angle are measured as follows: X_0Y: 52.2∠184,

After adding two grams of counterweights at a zero angle, you get through the PDES instrument and the influence coefficient method:

X_1: 106.9∠253, after adding two grams of counterweights at a zero angle, the components in the X direction are obtained by the PDES instrument and the influence coefficient method:
X_1X: 105.4∠250, after adding two grams of counterweights at a zero angle, the components in the Y direction are obtained by the PDES instrument and the influence coefficient method:
X_1Y: 89.1∠166; theoretical calculation of the need to add the weight: 2.4g ∠ 214. In fact, the weight added during the experiment: 2.4g∠225,

After the counterweight measured residual main vibration vector: X_2: 9.9 ∠ 263, residual principal vibration in the X direction measured after adding the counterweight: 9.9∠259; Residual principal vibration in Y direction measured after adding counterweight: 4.5∠180, balanced efficiency calculation result: 83.6%.

3) The experimental data analysis and conclusions

From the single X-direction, the single Y-direction, and the above experimental data on the balance of the full vector balance after synthesis in both directions and the efficiency of the balance thus calculated, it is possible to analyze the following conclusions: the efficiency of the full vector balance after synthesis from both sides is higher than the efficiency of the balance from the single-X plane or the single-Y plane. Therefore, the effect of the full vector balance after synthesis from both sides is better than that from the single-X direction or the single Y-direction. The full vector dynamic balancing algorithm integrates full spectrum techniques and makes perfect use of the information generated by two vertical signals. In addition, the full vector dynamic balancing algorithm can overcome the various deficiencies and reduce the number of dynamic balance effectively. Finally, we can make a conclusion that the full vector balance is easier to achieve a better balance effect.

5 Use MATLAB program to verify effect of full vector dynamic balancing algorithm

As MATLAB program can be used for rotor unbalance response analysis, the statement is easy to understand, so it is widely used in matrix calculation, suitable for dynamic analysis. The reliability of the conclusions above is again proven by computer software now.

$Ax_0=54.3;Jx_0=254/180*pi$; (Initial response)
$Ay_0=47.5;Jy_0=170/180*pi$; (Initial response)
$U=2.2$; (Add weight)
$JU=215/180*pi$;
$Ax_1=98;Jx_1=238/180*pi$; (The response after adding weight)
$Ay_1=75.6;Jy_1=157/180*pi$; (The response after adding weight)
$Xc_0=Ax_0*\cos(Jx_0);Xs_0=Ax_0*\sin(Jx_0)$;
$Yc_0=Ay_0*\cos(Jy_0);Ys_0=Ay_0*\sin(Jy_0)$;
$A_0=Xc_0\hat{}2+Xs_0\hat{}2;B_0=Yc_0\hat{}2+Ys_0\hat{}2$;
$C_0=Xc_0*Yc_0+Xs_0*Ys_0;D_0=Xs_0+Yc_0;E_0=Xc_0-Ys_0$;
$RL_0=((1/2)*(A_0+B_0)+((1/4)*(A_0-B_0)\hat{}2+C_0)\hat{}(1/2))\hat{}(1/2)$;
$FI_0=a\tan2(D_0,E_0)$;
$Xc_1=Ax_1*\cos(Jx_1);Xs_1=Ax_1*\sin(Jx_1)$;

$Yc_1 = Ay_1 * \cos(Jy_1); Ys_1 = Ay_1 * \sin(Jy_1);$

$A_1 = Xc_1\hat{}2 + Xs_1\hat{}2; B_1 = Yc_1\hat{}2 + Ys_1\hat{}2;$

$C_1 = Xc_1 * Yc_1 + Xs_1 * Ys_1; D_1 = Xs_1 + Yc_1; E_1 = Xc_1 - Ys_1;$

$RL_1 = ((1/2) * (A_1 + B_1) + ((1/4) * (A_1 - B_1)\hat{}2 + C_1)\hat{}(1/2))\hat{}(1/2);$

$FI_1 = a\tan2(D_1, E_1);$

$S_0 = RL_0 * \cos(FI_0) + i * RL_0 * \sin(FI_0);$

$S_1 = RL_1 * \cos(FI_1) + i * RL_1 * \sin(FI_1);$

$U_0 = U * \cos(JU) + i * U * \sin(JU);$

$a = (S_1 - S_0)/U_0;$

$u = -S_0/a;$

abs(u)

angle(u) * 180/pi+180

ans = 2.509 4

ans = 246.915 1

The last two results respectively correspond to the amplitude and phase angle of the residual main vibration vector. The program running is shown in Figure 2.

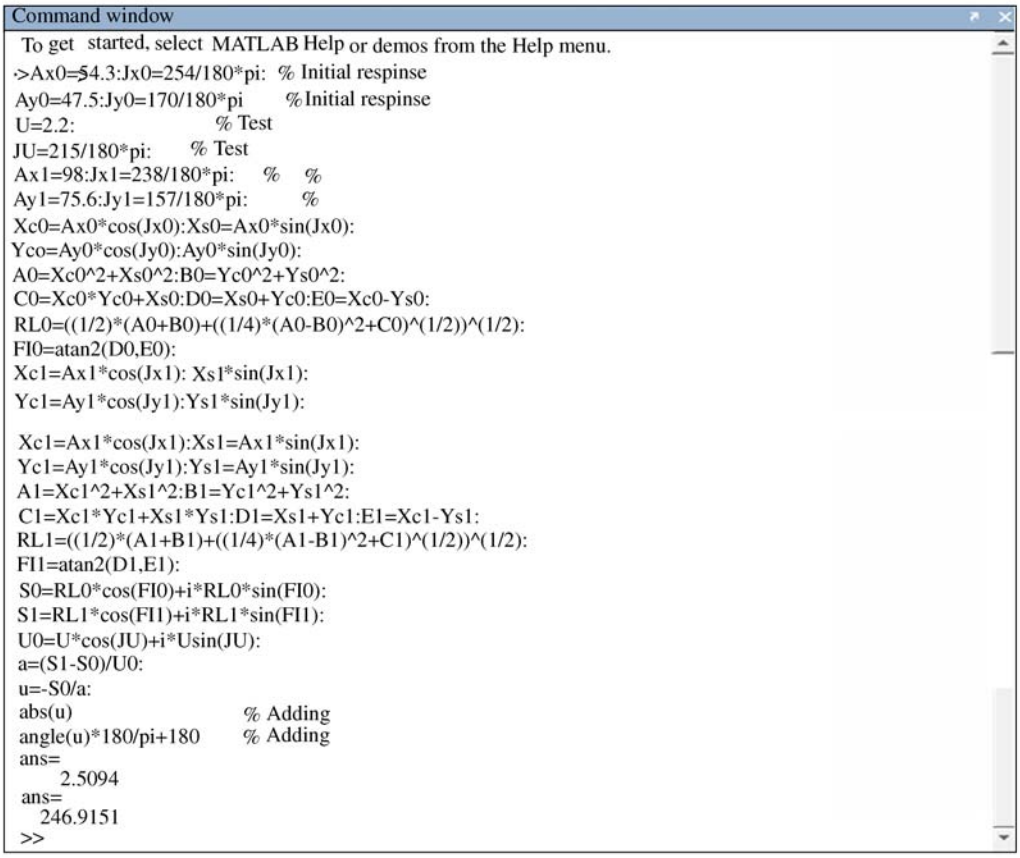

Figure 2 Screenshot of the program running

Therefore, it is easy to have a better understanding that the efficiency and effect of the full vector balance after synthesis from both sides are higher than the balance from the single-X plane or the single-Y plane and direction or the single Y-direction. Moreover, the full vector dynamic balancing algorithm can make the rotor horizontal and vertical vibration reduced effectively, so it can achieve effective control of rotor vibration, but we can not get the similar effects by using the traditional way.

6 Conclusions

1) The full vector dynamic balancing algorithm has high precision balance: The full vector dynamic balancing algorithm does not need to be influenced by the sensor installation direction like the traditional methods. The vibration of the whole section is reduced. In addition, it can reduce the measurement error.

2) The full vector dynamic balancing algorithm has better balance effect: The full vector dynamic balancing algorithm can reduce the overall cross section vibration and solve the problem that the traditional methods only reduce the unidirectional vibration.

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