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Dynamics analysis and Vibration Suppression of a Flexible Rotation Beam

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Abstract: This paper studies the complex transverse vibration behavior of drill string. The drill string was simplified as flexible rotation beam, and drill string of complex load was simplified for flexible rotation beam system. The nonlinear dynamic equations of flexible rotation beam is established and the complex dynamic response of flexible rotation beam in resonance case is analyzed by using method of nonlinear dynamics method. Research result show that the chaotic responses are sensitive to the revolving speed, the nonlinear oscillation of drilling string can be controlled by changing the rotating speed. This study has guiding significance to keep sidewall stability in the process of horizontal wells of sidetrack, improve the drilling rate and reduce the cost of the drilling.

Introduction

Scholars have done a lot of work and achieved many results in the drill string research [1, 2]. However, previous drill string of transverse vibration are based on the existing research theory of linear analysis, concentrated more on the bottom downhole assembly BHA section, and ignored the influence of nonlinear factors and flexible characteristics drill string of [4, 5]. This paper simplified the drill string as flexible rotation beam, set up the nonlinear differential equation for the flexible rotation beams . Through the dynamic response analysis of flexible rotation beam, this paper discusses transverse vibration behaviour, analyzes complex dynamic response.Research results providing theoretical guidance for well drilling process of transverse vibration problem.

The Establishment of the Kinetic Equation

For ease of analysis, the drill string is simplified to a rotating flexible beam; we define the beam axis before deformation as the X-axis, shown in Fig. 1:

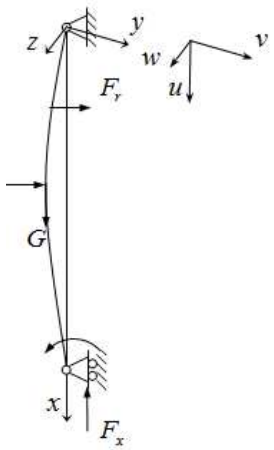

Fig. 1 The mechanical model of flexible rotating beam

Selecting the displacement field as the following equation

$$u=-y\frac{\partial v_0}{\partial x}-z\frac{\partial w_0}{\partial x},\quad v=v_0(x,t),\quad w=w_0(x,t) \tag{1}$$

Considering the huge geometric deformation

$$\varepsilon_x=-z\frac{\partial^2 w_0}{\partial x^2}-y\frac{\partial^2 v_0}{\partial x^2}+\frac{1}{2}\left(\frac{\partial w_0}{\partial x}\right)^2+\frac{1}{2}\left(\frac{\partial v_0}{\partial x}\right)^2,\quad \varepsilon_{xz}=\frac{1}{2}\frac{\partial w_0}{\partial x},\quad \varepsilon_{xy}=\frac{1}{2}\frac{\partial v_0}{\partial x} \tag{2}$$

Consider that the drill string is made up of single material, so the simplified flexible beam the have two independent stiffness E_{11} and E_{12} ,Simplify the force of the drill string at the drill as flexible beam axial force F_x , the power's variation at corresponding displacement Δ of F_x, When rotate with angular velocity ω , flexible beam have to withstand the centrifugal force ,the variation of centrifugal force's power is $\omega^2\sqrt{v^2+w^2}\delta\left(\sqrt{v^2+w^2}\right)$, take advantage of Hamilton's principle to get the kinetic equation

$$\begin{aligned}&\frac{1}{2}A_{11}\left(\frac{\partial w_0}{\partial x}\right)^2\frac{\partial^2 v_0}{\partial x^2}+A_{11}\frac{\partial w_0}{\partial x}\frac{\partial v_0}{\partial x}\frac{\partial^2 w_0}{\partial x^2}+\frac{3}{2}A_{11}\left(\frac{\partial v_0}{\partial x}\right)^2\frac{\partial^2 v_0}{\partial x^2}+\left(\frac{1}{2}A_{12}-P\right)\frac{\partial^2 v_0}{\partial x^2}+H_1\omega_4^2 v_0\\&=I_0\frac{\partial\ddot{v}_0}{\partial t^2}-I_2\frac{\partial^2\ddot{v}_0}{\partial x^2}\end{aligned} \tag{3a}$$

$$\begin{aligned}&\frac{1}{2}A_{11}\left(\frac{\partial v_0}{\partial x}\right)^2\frac{\partial^2 w_0}{\partial x^2}+A_{11}\frac{\partial w_0}{\partial x}\frac{\partial v_0}{\partial x}\frac{\partial^2 v_0}{\partial x^2}+\frac{3}{2}A_{11}\left(\frac{\partial w_0}{\partial x}\right)^2\frac{\partial^2 w_0}{\partial x^2}+\left(\frac{1}{2}A_{12}-P\right)\frac{\partial^2 w_0}{\partial x^2}\\&+H_1\omega_4^2 w_0-D_{11}\frac{\partial^4 w_0}{\partial x^4}=I_0\frac{\partial\ddot{w}_0}{\partial t^2}-I_2\frac{\partial^2\ddot{w}_0}{\partial x^2}\end{aligned} \tag{3b}$$

Where

$$A_{11}=\iint_\Omega E_{11}dydz\quad,\quad A_{12}=\iint_\Omega E_{12}dydz\quad,\quad D_{11}=\iint_\Omega y^2E_{11}dydz\quad,\quad P=\iint_\Omega F_x dydz\quad,$$
$$H_1=\iint_\Omega dydz, I_0=\iint_\Omega\rho dydz,\ I_2=\iint_\Omega\rho y^2dydz$$

For ease of analysis, introduce $\overline{w}_0=\frac{w_0}{l}$, $\overline{v}_0=\frac{v_0}{l}$, $\overline{x}=\frac{x}{l}$ etc dimensionless transform, for the convenience of expression, the overline of dimensionless equations is removed, the following equation's parameters are all dimensionless parameters, and take the transverse vibration displacement's two-order mode as : $w_0=w_1(t)\sin 2\pi x$, $v_0=v_1(t)\sin 2\pi x$.Using the method of Galerkin to discretize, obtained the motion equations of transverse vibration as show Eq. (4)

$$\begin{aligned}&\ddot{v}_1+c_3\dot{v}_1+\frac{1}{2I_2a^2\pi^2+2I_0a^4}\left(-\pi^2A_{12}a^2-8D_{11}\pi^4+\frac{1}{2}I_0\omega^2a^4+2\pi^2Pa^2\right)v_1\\&-\frac{3\pi^4A_{11}R_1^2}{8I_2a^2\pi^2+8I_0a^4}v_1w_1^2-\frac{3\pi^4A_{11}R_1^2}{8I_2a^2\pi^2+8I_0a^4}v_1^3=0\end{aligned} \tag{4a}$$

$$\ddot{w}_1 + c_3\dot{w}_1 + \frac{1}{2I_2a^2\pi^2 + 2I_0a^4}\left(-\pi^2 A_{12}a^2 - 8D_{11}\pi^4 + \frac{1}{2}I_0\omega^2a^4 + 2\pi^2 Pa^2\right)w_1$$
$$-\frac{3\pi^4 A_{11}R_1^2}{8I_2a^2\pi^2 + 8I_0a^4}w_1v_1^2 - \frac{3\pi^4 A_{11}R_1^2}{8I_2a^2\pi^2 + 8I_0a^4}w_1^3 = 0 \tag{4b}$$

Perturbation Analysis

Selecting an appropriate parameter for the perturbation analysis and using the method of multiple scales to obtain the average equation of equation (4).Considering the main parametric resonance and 1:1 resonance, through the consolidation of the formula, we can get average equation in Cartesian coordinate, as show Eq. (5)

$$\dot{x}_1 = -\frac{1}{8a^2I_2\pi^2 + 2I_0a^4}\left(\frac{2}{R_1}a^4C_3x_1 - a^2\pi^2Px_2 - a^4I_0\omega_4^2x_2\right.$$
$$+\frac{9}{32}R_1^2\pi^4A_{11}x_2^3 + \frac{9}{32}R_1^2\pi^4A_{11}x_2x_4^2 + \frac{3}{16}R_1^2\pi^4A_{11}x_1x_3x_4$$
$$\left.+\frac{3}{32}R_1^2\pi^4A_{11}x_2x_3^2 + \frac{9}{32}R_1^2\pi^4A_{11}x_2x_1^2\right) \tag{5a}$$

$$\dot{x}_2 = \frac{1}{8a^2I_2\pi^2 + 2I_0a^4}\left(\frac{2}{R_1}a^4C_3x_2 - a^2\pi^2Px_1 - a^4I_0\omega_4^2x_1\right.$$
$$+\frac{9}{32}R_1^2\pi^4A_{11}x_1^3 + \frac{9}{32}R_1^2\pi^4A_{11}x_1x_3^2 + \frac{3}{16}R_1^2\pi^4A_{11}x_2x_3x_4 \tag{5b}$$
$$\left.+\frac{3}{32}R_1^2\pi^4A_{11}x_1x_4^2 + \frac{9}{32}R_1^2\pi^4A_{11}x_1x_2^2\right)$$

$$\dot{x}_3 = -\frac{1}{8a^2I_2\pi^2 + 2I_0a^4}\left(\frac{2}{R_1}a^4C_3x_3 - a^2\pi^2Px_4 - a^4I_0\omega_4^2x_4\right.$$
$$+\frac{9}{32}R_1^2\pi^4A_{11}x_4^3 + \frac{9}{32}R_1^2\pi^4A_{11}x_4x_3^2 + \frac{3}{16}R_1^2\pi^4A_{11}x_1x_2x_3 \tag{5c}$$
$$\left.+\frac{3}{32}R_1^2\pi^4A_{11}x_4x_1^2 + \frac{9}{32}R_1^2\pi^4A_{11}x_4x_2^2\right)$$

$$\dot{x}_4 = \frac{1}{8a^2I_2\pi^2 + 2I_0a^4}\left(\frac{2}{R_1}a^4C_3x_4 - a^2\pi^2Px_3 - a^4I_0\omega_4^2x_3\right.$$
$$+\frac{9}{32}R_1^2\pi^4A_{11}x_3^3 + \frac{9}{32}R_1^2\pi^4A_{11}x_3x_4^2 + \frac{3}{16}R_1^2\pi^4A_{11}x_1x_2x_4 \tag{5d}$$
$$\left.+\frac{3}{32}R_1^2\pi^4A_{11}x_3x_2^2 + \frac{9}{32}R_1^2\pi^4A_{11}x_3x_1^2\right)$$

According to the average equation, the drill string vibration related the two variable parameters: rotation speed and axial force. The drill string axial force is difficult to forecast caused by external load, but the drill string speed can be changed. We also observed that the two parameters in the same equations, so a parameters on the effect of vibration by adjusting the other parameters to weaken.

Nonlinear Dynamics and Bifurcation Analysis

In this section, the average Eq. (5) is simulated and analyzed by using numerical methods, and get the nonlinear dynamic system response. Example 1: Fig. 2 (a) and Fig. 2 (b) are bifurcation diagrams of the system's two modal response with the angular velocity changes, the system initial conditions and parameter values of the figures are $x_{10}=-7.9$, $x_{20}=-13$, $x_{30}=-20$, $x_{40}=15.5$, $c_3=0.033$, $\rho=1.36$, $A_{11}=0.365$.

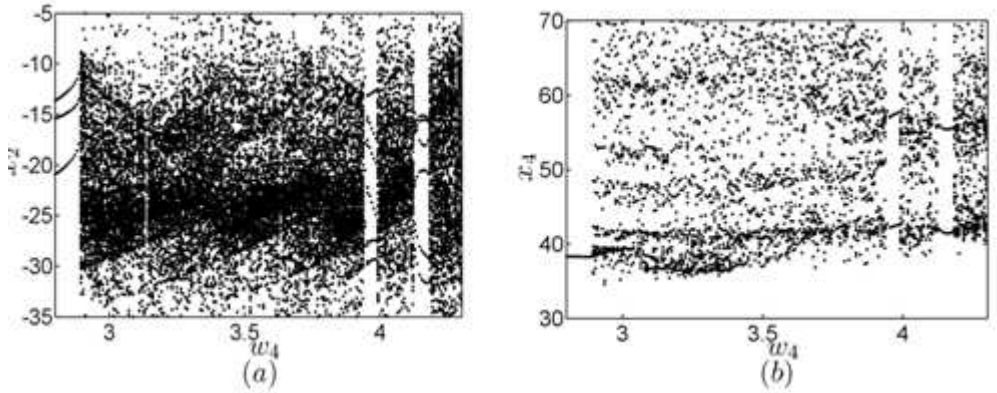

Fig. 2 Speed bifurcation diagram

From Fig. 2 we can see, the response of system has gone through the process of cycle--chaos--twice the cycle, response amplitude appear jumping phenomenon, the mechanism of the phenomenon is the energy conversion between the two modal. Only change the angular velocity ω_4 of Fig.2, the system's initial conditions and other parameters are unchanged, when $\omega_4=2.8$, the system will appear almost periodic motion, as shown in Fig. 3.

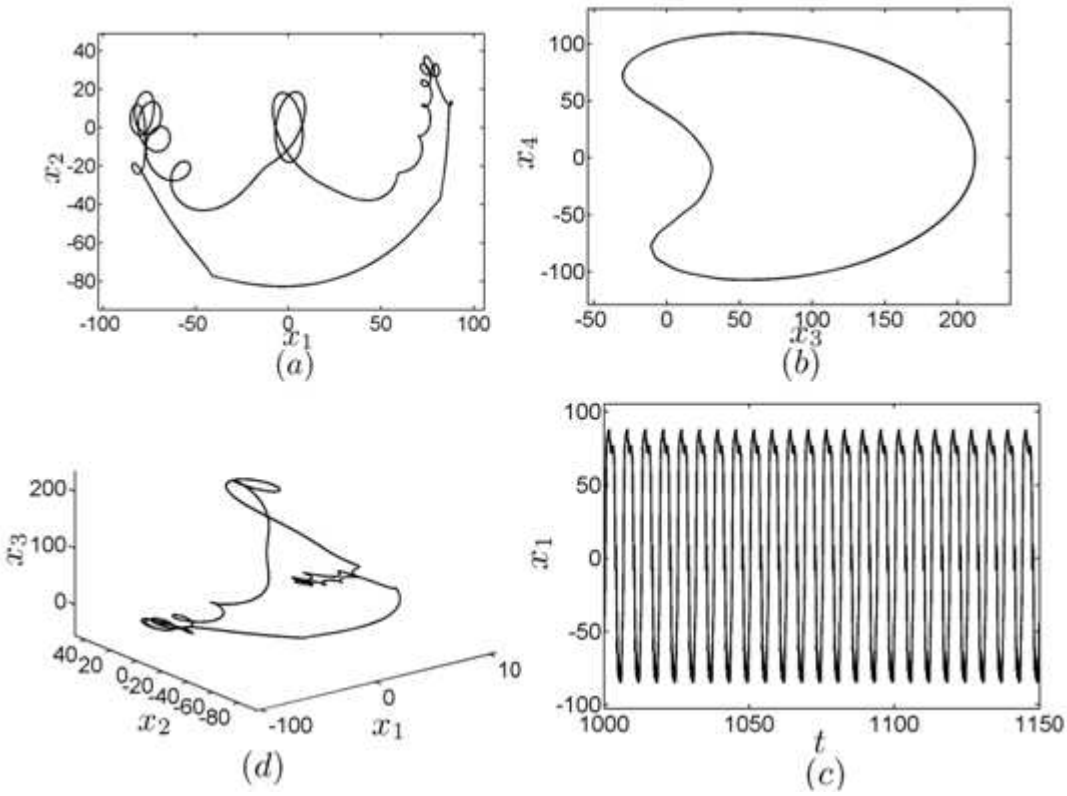

Fig. 3 When $\omega_4=2.8$ the cycle response of system

When increase the angular velocity $\omega_4=2.896$, the almost periodic motion of the system will change into six-fold periodic motion, as shown in Fig. 4.

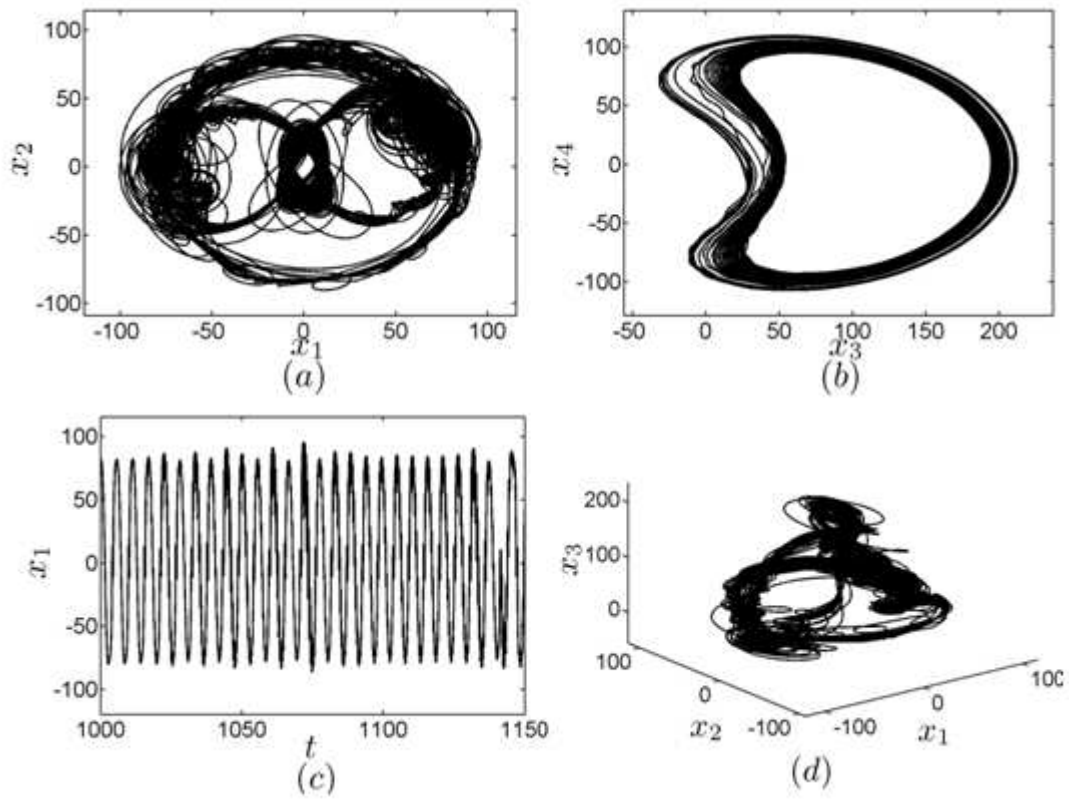

Fig. 4 When $\omega_4 = 2.896$ the chaotic response of system

Continue to increase the angular velocity $\omega_4 = 3.944$, the system becomes twice the periodic motion, as shown in Fig. 5.

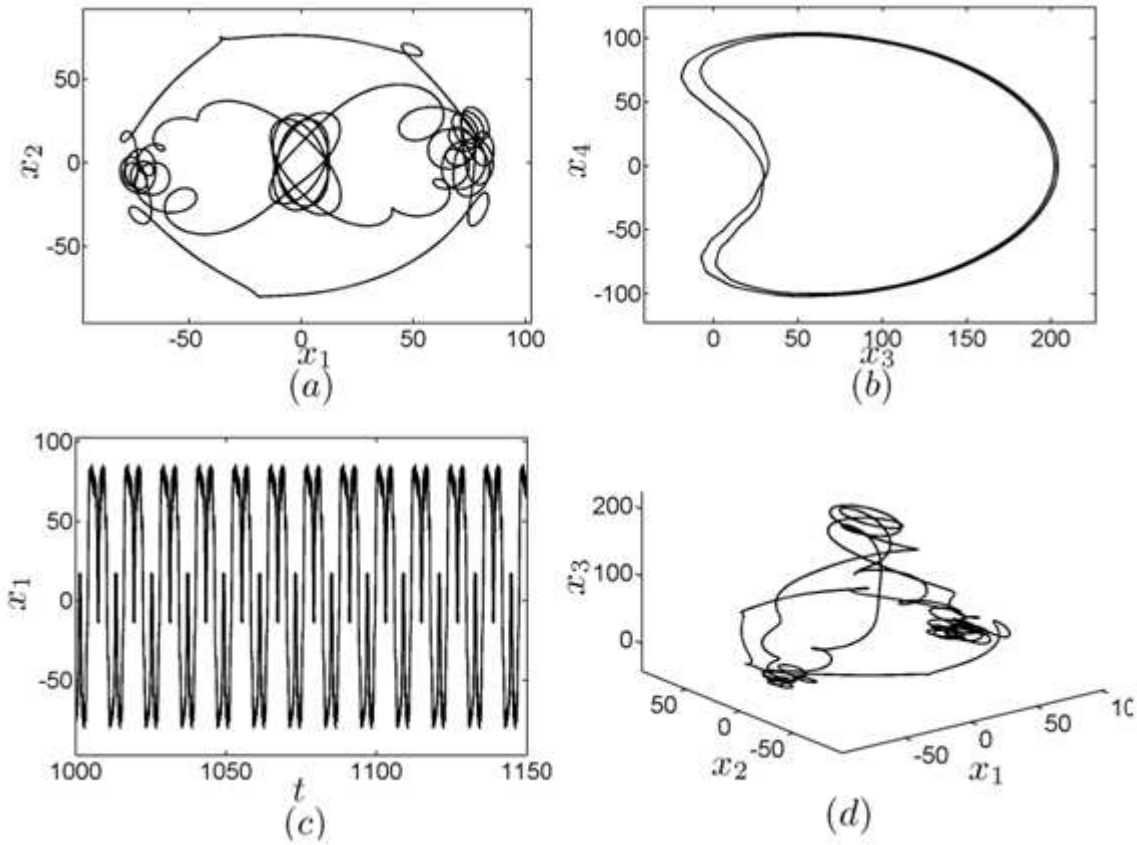

Fig. 5 When $\omega_4 = 3.944$ the cycle response of system

Example 2: The bifurcation diagrams of the system's two modal response with the angular velocity changes, as shown in Fig. 6. The system initial conditions and parameter values of the figures are $x_{10}=8.0$, $x_{20}=8.8$ $x_{30}=-14.3$ $x_{40}=0.3$ $c_3=0.089$ $\rho=1.43$ $A_{11}=0.015$

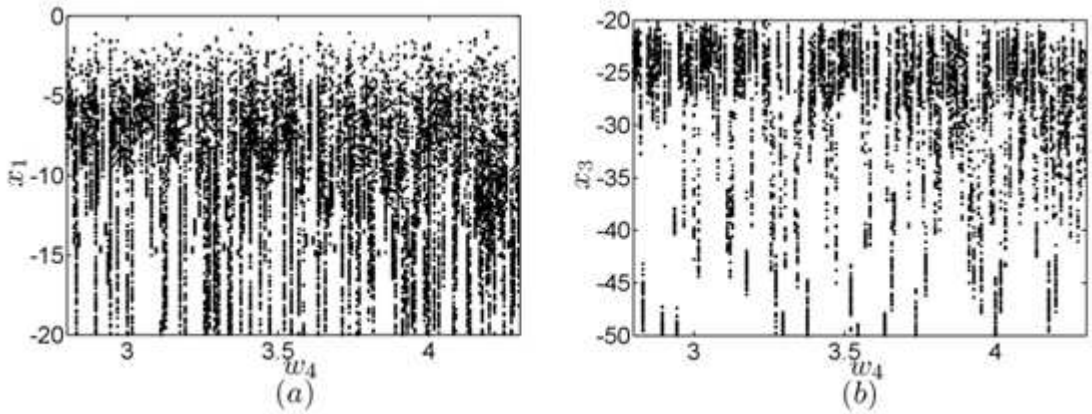

Fig. 6 Speed bifurcation diagram

From Fig. 6 we can see, most of the response of the system is chaotic, but there are cycle's responses between chaotic responses. Only change the angular velocity ω_4 of Fig. 6, the system's initial conditions and other parameters are unchanged, when $\omega_4=2.872$, the system will appear chaotic motion, as shown in Fig. 7.

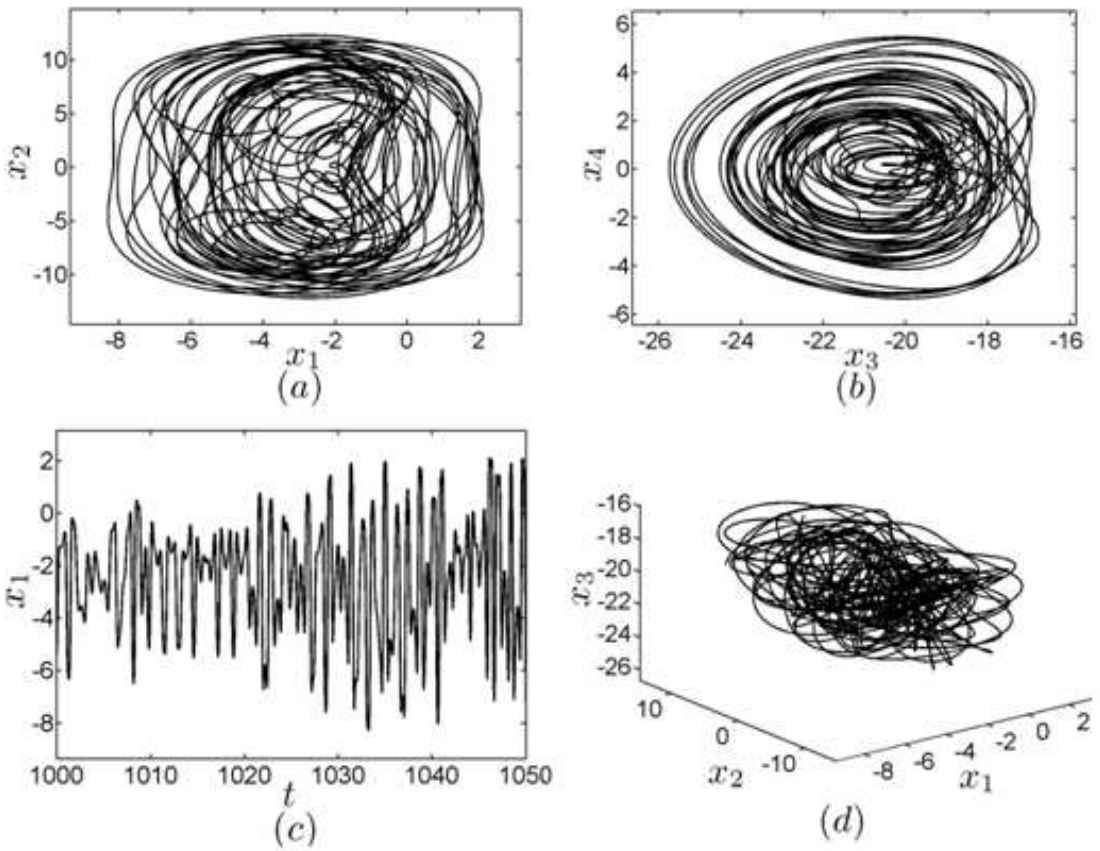

Fig. 7 When $\omega_4=2.872$ the chaotic response of system

When increase the angular velocity $\omega_4=2.912$, the system will change chaos into six-fold periodic motion, as shown in Fig. 8.

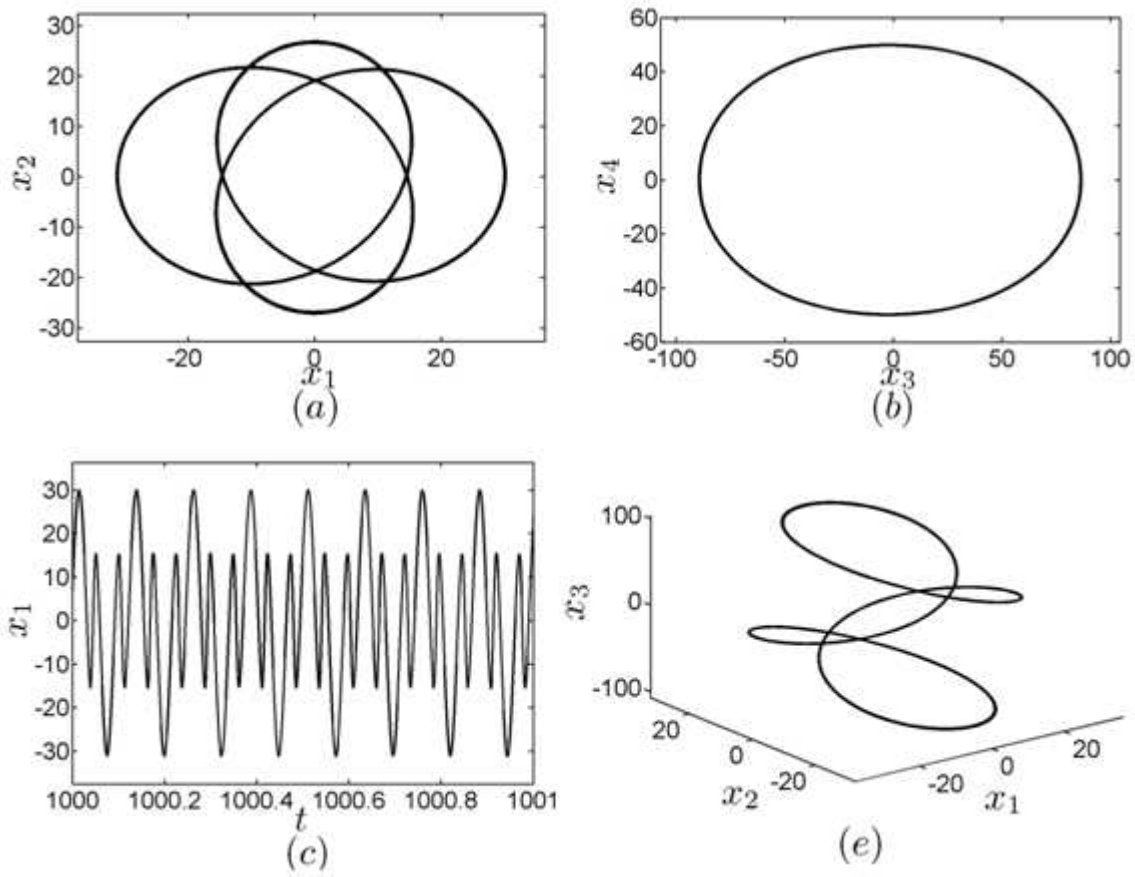

Fig. 8 When $\omega_4 = 2.912$ the cycle response of system

Through the phase diagram and the bifurcate diagram analysis, the response of the system has experienced the process of cycle-chaos-two times the cycle, response amplitude appear jumping phenomenon. The analysis results show that the flexible rotating beam's amplitude is not infinite, but limited, at the condition of v resonance. At the same time, the additional and axial force which due to the speed change work in the same item in the equation, can offset each other, when the axial force changes, for the sake of qualitatively and quantitatively controlling the flexible rotating beam vibration, can through controlling the speed's change, significantly reduce the amplitude of the vibration ,control system vary from almost periodic to single cycle times, maintain the stability of the system, control system produce period-doubling bifurcation solution ,thus prevent the system via the period-doubling bifurcation into chaos movement ,and give the control bifurcate figure.

Conclusion

The average equation of flexible rotating beam is set up considering the nonlinear dynamics;

The complex dynamic response of flexible drill string is analysed in the case of resonance and control bifurcation diagrams is given.

In the drilling process, we can adjust the rotation rate to control the transverse vibration of drill string under constant pressure drilling condition

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References

[1] A. D. Batako, V. I. Babitsky, N. A. Halliwell, A self-excited system for percussive- rotary drilling[C]. Journal of Sound and Vibration, 2003, 259(1): 97-118, .

[2] Eva M. Navarro-López, Domingo Cortés, Avoiding harmful oscillations in a drillstring through dynamical analysis[C]. Journal of Sound and Vibration, 2007: 307(23): 152-171, .

[3] Eva.M.Navarro-López,EduardoLicéaga-Castro, Non-desired transitions and sliding-mode control of a multi-DOF mechanical system with stick-slip oscillations, Chaos[C].Solitons and Fractals,2009, 41(4):2035-2044, .

[4] Li Guoqing,Wang Hongjun,Liu Xiushan,et al.Analysis and application of drill string vibration[J].Petroleum Drilling Techniques,2007, 35(6):54~56.

[5] Zhu Xiaohua,Tong hua,Liu Qingyou,et al.Research on the dynamic boundary condition between revolving drill string and borehole wall[J].China Mechanical Engineering,2007,

[6] Han Chunjie,Yantie.. Transverse drill string vibration in horizontal holes [J]. China petroleum machinery, 2005, 33(1):8~10.

[7] QU Zhan. Influen ce of in and out drillin g f luid on t ransverse vib rat ion of th e drilling string[J].China Petroleum Machinery, 1995, 23(4):40- 43.