International Journal of Advanced Engineering and Technology
ISSN: 2456-7655
Impact Factor: RJIF 5.54
www.newengineeringjournal.com
Volume 2; Issue 1; January 2018; Page No. 16-19

Optimal vibration control and simulation for gearbox of wind turbine

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Abstract
The optimal vibration control and simulation problem of wind turbine gearbox system is studied. A nonlinear, coupling and uncertain dynamic model of the wind turbine gearbox is considered. Because it is difficult to design the controller for the wind turbine gearbox control system, the nonlinear and coupling uncertain control system is simplified, and a linear model is obtained. Then, based on optimal control approach, an optimal controller is designed for the wind turbine gearbox. Numerical simulations illustrate the effectiveness of the proposed controller.

Keywords: optimal control, vibration control, wind turbine

1. Introduction

Wind energy is a renewable energy source that is available at large scale. This form of energy is known to be one of the most reliable and environment friendly energy resources. With the rapid development of the world economy, the energy demand has doubled [1, 2, 3].

In the wind farm scale, wind turbine is blown over the wind generator in the near formation. When the fan is called the fan blade, the part of the wind can be rotated. It is turned into mechanical energy, showing the decrease of wind speed, that is, the wind is in the wind [4, 5, 6]. The wind speed of the motor group is less than that of the upper wind turbine, and the fan is at the same time. The rotation of the fan blade produces a part of turbulent kinetic energy in the direction of the outflow. The wind will go through a rotating wind wheel. Changes in characteristics such as velocity, this effect on the initial air flow and it is called the wake effect of the fan. The observation shows that the fan disturbance in the direction of the upper wind. The moving wake will weaken the wind speed downstream and cause the downstream atmosphere [7, 8]. The increase of turbulent kinetic energy leads to the loss of power and power of the fan in the direction of the wind [9, 10]. The weather and even the climate may also have an impact. The scope and intensity of the effect of tail flow on the operating efficiency of the fan, and the influence on the surrounding atmosphere is observed and simulated.

2. Dynamical system

Wind turbines are usually composed of wind turbines, generators (including devices), adjustment devices (tail wings), tower frames, speed limit safety mechanisms and energy storage devices.

Modal characteristics and mode energy distributions of a wind turbine gearbox composed of a two-stage planetary gears and a high-speed output shaft are obtained based on the lumped mass model according to torsional of geared rotor system.

The measured vibrations on bench test and on-site test show the modal characteristics, vibration responses, and vibrations induced by faults that are also valuable for wind turbine design. The dynamical of gearbox vibration control system is as following:

$$\begin{aligned} Ml\ddot{\theta}(t) &= (M+m)g\theta(t) - u(t), \\ M\ddot{s}(t) &= u(t) + mg\theta(t) \end{aligned} \tag{1}$$

Choose state variables for the dynamical of gearbox vibration control system (1) in the following:

$$x_1(t)=\theta(t), x_2(t)=\dot{\theta}(t), x_3(t)=s(t), x_4(t)=\dot{s}(t). \tag{2}$$

And its Output is as following:

$$y = x_3(t) = s(t). \tag{3}$$

And the system (1) is rewritten in the state-space representation:

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{x}_3(t) \\ \dot{x}_4(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ \frac{M+m}{Ml}g & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ -\frac{m}{M}g & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ x_4(t) \end{bmatrix} + \begin{bmatrix} 0 \\ -\frac{1}{Ml} \\ 0 \\ \frac{1}{M} \end{bmatrix} u(t), \tag{4}$$

$$y = [0 \quad 0 \quad 1 \quad 0][x_1(t) \quad x_2(t) \quad x_3(t) \quad x_4(t)]^T$$

So the system (4) is rewritten in the following form:

$$\begin{aligned} \dot{\boldsymbol{x}}(t) &= \boldsymbol{A}\boldsymbol{x}(t) + \boldsymbol{B}\boldsymbol{u}(t), \\ \boldsymbol{y}(t) &= \boldsymbol{C}\boldsymbol{x}(t) + \boldsymbol{D}\boldsymbol{u}(t), \end{aligned} \tag{5}$$

in which:

$$\boldsymbol{A}=\begin{bmatrix}0 & 1 & 0 & 0\\ \frac{M+m}{Ml}g & 0 & 0 & 0\\ 0 & 0 & 0 & 1\\ -\frac{m}{M}g & 0 & 0 & 0\end{bmatrix},\quad \boldsymbol{B}=\begin{bmatrix}0\\ -\frac{1}{Ml}\\ 0\\ \frac{1}{M}\end{bmatrix},\quad \boldsymbol{C}=\begin{bmatrix}0\\0\\1\\0\end{bmatrix}^T,\quad D=0.$$

3. Optimal vibration control and simulation

Let *m=0.1kg*, *l*=0.5m, sampling period *T*=0.1s, the discrete system of (5) is as following:

$$\begin{aligned}X(k+1)&=GX(k)+HU(k),\\ Y(k)&=CX(k)+DU(k),\end{aligned}\tag{6}$$

in which:

$$G=\begin{bmatrix}1.1408 & 0.1035 & 0 & 0\\ 2.1316 & 1.1048 & 0 & 0\\ -0.0025 & -0.0001 & 1 & 0.1\\ -0.0508 & -0.0025 & 0 & 1\end{bmatrix},H=\begin{bmatrix}-0.0051\\ -0.1035\\ 0.0025\\ 0.0501\end{bmatrix}.\tag{7}$$

Therefore, the augmented system for the discrete system (5) is as following:

$$\begin{aligned}P(k+1)&=G_1P(k)+H_1W(k),\\ W(k)&=-K_1P(k),\end{aligned}\tag{8}$$

in which:

$$G_1=\begin{bmatrix}G & 0\\ -GG & 1\end{bmatrix},H_1=\begin{bmatrix}H\\ -CK\end{bmatrix},K_1=\begin{bmatrix}K & -K_1\end{bmatrix}.$$

Therefore, the problem of the optimal vibration control for the gearbox of wind turbine is just to design K_1 to make the performance index in (9) minimum, and the performance index is as following:

$$J=\frac{1}{2}\sum_{k=0}^{\infty}\left[P^TQP+W^TRW\right],\tag{9}$$

in which:

$$Q=\text{diag}\left(\begin{bmatrix}10, & 1, & 100, & 1 & 1\end{bmatrix}\right),R=1.$$

In order to seek K_1 to make the performance index in (9) minimum, we design the Matlab program to simulate the control effect.

```
A= [0 1 0 0;20.601 0 0 0; 0 0 0 1;-0.4905 0 0 0];
B= [0;-1;0;0.5];
C= [0 0 1 0];
D= 0;
[G,H]= c2d(A,B,0.1)
G1= [G,zeros(4,1);-C*G,1];
H1= [H;-C*H];R=1;
Q= diag ([10,1,100,1,1]);
[K1,P,e] =dlqr(G1,H1,Q,R); disp('Optimal feedback gain matrices:')
Ki= -K1(1,5)
K= K1(1,1:4)
%Step response
%The states of the closed loop system is (GC,HC,CC,DC)
GC= G1-H1*K1;
HC= [0;0;0;0;1];
CC= [0 0 1 0 0];DC=0; figure(1)
V= [0 100 0 1.2];
[Y,X]= dstep(GC,HC,CC,DC,1,100);
KK= 1:length(Y);
Plot (KK,Y,'Ok',KK,Y,'-W')
Axis (V)
%title (Step response)
Xlabel ('sampling')
Ylabel ('Y')
Figure (2)
V= [0 100 -0.2 0.8];
WW= [1,0,0,0,0];Y1=X*WW';
Plot (KK,Y1,'Ok',KK,Y1,'-W')
Axis (V)
Xlabel ('sampling')
Ylabel ('X1')
Figure (3)
V= [0 100 -0.2 0.8];
WW= [0,1,0,0,0];Y1=X*WW';
Plot (KK,Y1,'Ok',KK,Y1,'-W')
Axis (V)
Xlabel ('sampling')
Ylabel ('X2')
Figure (4)
V= [0 100 -0.2 0.8];
WW= [0,0,0,1,0];Y1=X*WW';
Plot (KK,Y1,'Ok',KK,Y1,'-W')
Axis (V)
Xlabel ('sampling')
Ylabel ('X4')
Figure (5)
V= [0 100 -5 25];
WW= [0,0,0,0,1];Y1=X*WW';
Plot (KK,Y1,'Ok',KK,Y1,'-W')
Axis (V)
Xlabel ('sampling')
Ylabel ('X5')
```

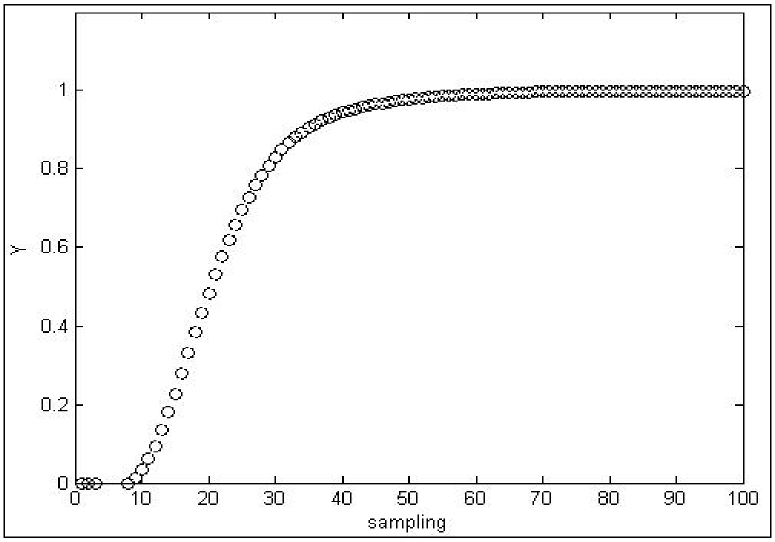

Fig 1: Curve of the output

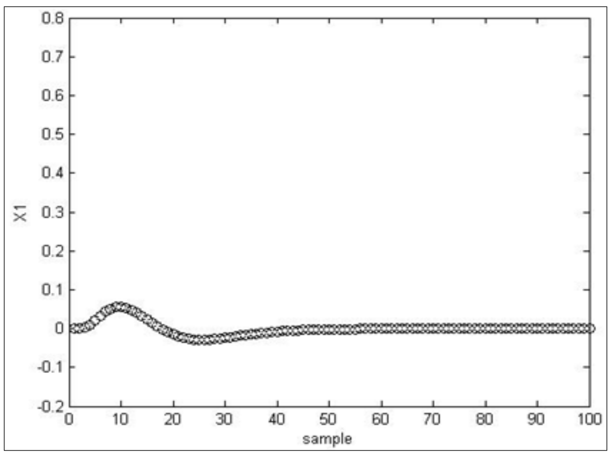

Fig 2: Curve of x_1

The load-sharing distributions of the gears within the wind turbine transmission chain are also compared considering different internal excitation and external load. The measured tooth strains under different load-sharing conditions show that the prediction based on the torsional model of the geared rotor system is acceptable, and the results of them are shown in fig 1.

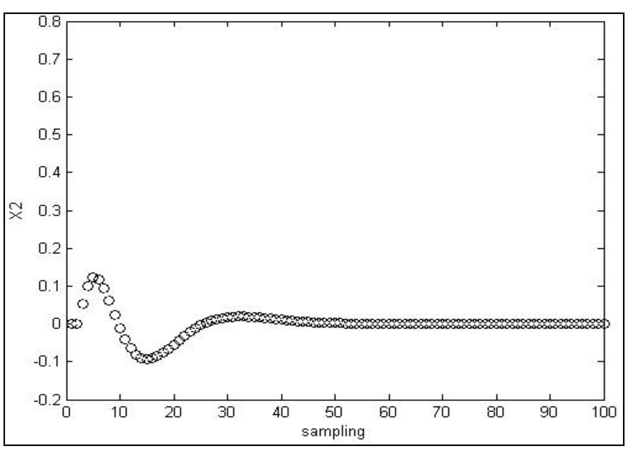

Fig 3: Curve of x_2.

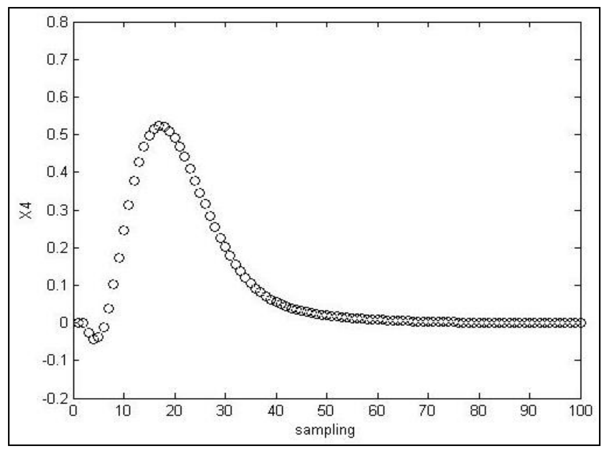

Fig 4: Curve of x_4

The modal characteristics of the gearbox are also analyzed based on the whole gearbox finite element model by using finite element method. The operating modal measurements are also obtained to check the calculated modes for the whole machine based on the whole gearbox finite element model. The results of the gearbox vibration control are shown in fig.2-fig5.

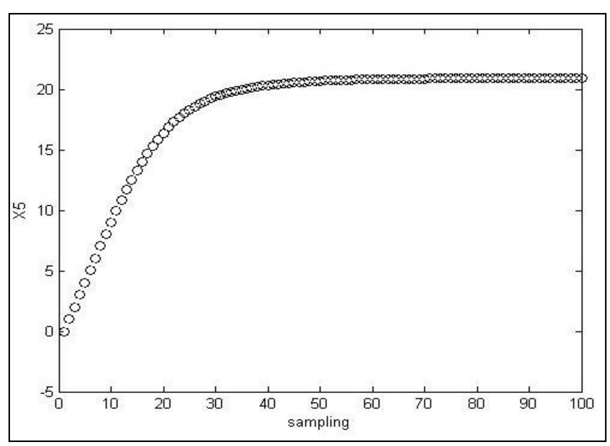

Fig 5: Curve of x_5.

4. Conclusions

With the large-scale construction of the energy industry, the environmental and ecological problems caused by fossil fuels such as oil and coal have attracted the attention of the international community. Especially in recent decades, the increasing depletion of nonrenewable energy and the pressure brought by global warming make more and more attention to renewable energy such as wind and solar energy. In the past decade, the development of large area wind farms in the world has made the wind energy resources becoming the fastest renewable energy.

5. References

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