International Journal of Science, Technology and Society
2014; 2(6): 179-185
Published online November 20, 2014 (http://www.sciencepublishinggroup.com/j/ijsts)
doi: 10.11648/j.ijsts.20140206.13
ISSN: 2330-7412 (Print); ISSN: 2330-7420 (Online)

The estimation of dynamic motions of a constraint wind turbine for the safety- control with the indirect measurement

Raiwung Park

Dept. of Technology Education, Mechatronics, Sehan University, 526-702, Jeonnam, Korea

Email address:
park1@sehan.ac.kr

To cite this article:
Raiwung Park. The Estimation of Dynamic Motions of a Constraint Wind Turbine for the Safety- Control with the Indirect Measurement. *International Journal of Science, Technology and Society.* Vol. 2, No. 6, 2014, pp. 179-185. doi: 10.11648/j.ijsts.20140206.13

Abstract: This work shows a method to develop a safety control mode according to a wind turbine based on the operating principle of the Darrieus rotor and to estimate a model of a safety control for a wind turbine. It is not easy to timely righteously estimate and evaluate the states. But it is very important for the safe operation in time domain system. The synthesis of this problem presumes that all state variables are observable for the concerned system. But it seems that it is not always feasible to measure all of states directly. A practical way to solve these problems is the estimation of the state variables by the use of the observers which can estimate system characteristics of linear or nonlinear states and effects as a mode, so called, "Indirect measurement". For this procedure, the mathematical model of the concerned physical system which consists of a vertical standing shaft with two journal bearings at the ends of the rotor is derived with the significant remarks such as friction, gravitation, and Coriolis force. This is a basic system. The concrete assignment is to design the observer that estimates the characteristics of the states and velocities based on the measurement vectors. The main artifice is to approximate the characteristics with a fictitious model that may describe the modes of system errors. As a practical and convenient fictitious model, the characteristics of nonlinear effects are assumed as approximately stepwise contact. An identity observer is obtained whose state variables are the estimate of the state variable of the corresponding "observer system". It consists of a simulated model with a correction feedback of the estimation

Keywords: System Diagnosis, Wind Turbine, Observer, Constraint, Indirect Measurement

1. Introduction

Concerning of increasing high energy consumption, using the wind energy is an important part as an alternative energy. In this renewable energy plant which is equipped with vertical rotating wind turbine, the high requirement of the structure of modern control systems and the reliability of a system are strongly considered. Especially, when the interest comes to the early notices of the system defect by the operation, the safe operation is getting more and more important. This is obviously verified when a part of systems suddenly goes out of function. It can cause an entire system defect, and this is able to bring up a dangerous situation for employee and material losses. To take precautions against these kinds of troubles, many scientists in the world have been making efforts for long time. For this, it is required the inspection during the operation certainty and system assessment. Only by this way, the sudden appearance of defects and the alteration of the processes can be founded out and the reason for the troubles and the place are detected (FDI). It is important that the fault must be sensed early enough for avoiding the damages in the system (Fault Detection, Isolation and Accommodation, FDIA). When this process goes without man's help, it's called automated fault detection, in the other word, "System Diagnosis". Under meaning of fault, we can understand every abnormal derivations or divergences from the required process behavior and the abrupt fault is meaningful of the safe operation. The FDI process needs certain characteristics being able to give the threshold of the decision: Residuum, residue. The method of fault, here called 'error', estimate by using the Hardware-redundancy is very costly and less practicable. The model-based methods were presented by [1]. The methods by creating the parameters, or state space estimate were given in [2]. There have been some other ways to settle the problem with fault through the consideration of the property of the robustness [3]. A practical solution to this problem was the estimation of the states or its velocities by the use of observers which can estimate a system characteristics of linear or nonlinear states and effects as a mode, so called, "Indirect measurement"[4,10]. In this work, for this procedure, the mathematical model of the concerned physical system, which has a shaft and two journal bearings at the ends of the rotor, is derived with the significant remarks such as friction, gravitation, and Coriolis force. With the indirect measurements on two bearing, an observer is designed and the results are going to get the control mode for the system.

2. Mathematical Modeling of Rotor Dynamic with the Constraint Bearings

In order to control and diagnose complex systems, one would like to obtain quantitative mathematical model of a system by symbolic representation involving an abstract mathematical formulation. Though a mathematical model can be adequate for a certain purpose in mind, it never describes the physical phenomenon exactly. Since the final goal of this work is to develop a diagnosis strategy, the inevitable conclusion is that the modeling problem and the diagnosis problem are not independent. Here, the necessary adequate models for the proposed diagnosis policies are built

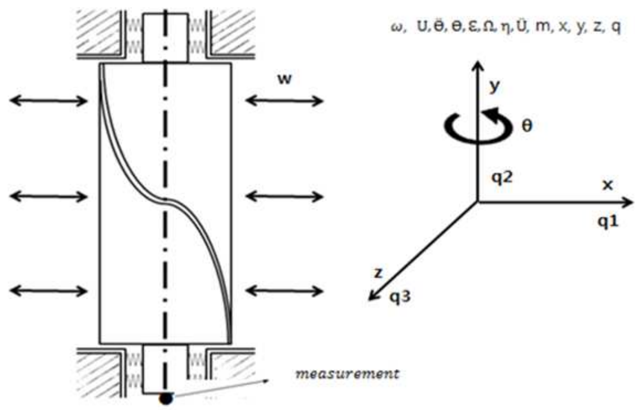

Fig. 1. A constraint rotor system with wind direction

These were comprised of the rotor model, the environment model, and model for the interaction between shaft and bearings. A vertical rotor is usually composed of the shaft connected by couplings into a kinematic chain with the bearing in the operation situation. The shafts can be either cylindrical or revolute, and are driven by wind power. In this work only cylindrical shaft will be considered. For the purpose of modeling, the three interacting parts such as, the transmission, and the bearing will be studied first separately and then, the complete model will be built. The wind power is the energy that makes the rotor move. The dynamic behavior of joint system can be modeled by analogy to [9] as follows.

2.1. I Equation of Motion

$$\begin{bmatrix} m & 0 & 0 & 0 \\ 0 & m & 0 & 0 \\ 0 & 0 & m & 0 \\ 0 & 0 & 0 & \Omega \end{bmatrix}\begin{bmatrix} \ddot{q}_x \\ \ddot{q}_y \\ \ddot{q}_z \\ \ddot{\Theta}_y \end{bmatrix} + \begin{bmatrix} d & -G_{xy} & 0 & 0 \\ 0 & d & 0 & 0 \\ -G_{xz} & 0 & d & -\Omega\theta_p \\ 0 & 0 & -\Omega\theta_p & d \end{bmatrix}\begin{bmatrix} \dot{q}_x \\ \dot{q}_y \\ \dot{q}_z \\ \dot{\Theta}_y \end{bmatrix}$$
$$\begin{bmatrix} K_{xx} & 0 & 0 & 0 \\ 0 & K_{yy} & 0 & 0 \\ 0 & 0 & K_{xz} & 0 \\ 0 & 0 & 0 & K_{yy} \end{bmatrix}\begin{bmatrix} q_x \\ q_y \\ q_z \\ \Theta_y \end{bmatrix} = mg\begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} + \left(\varepsilon_u \Omega^2\right)\begin{bmatrix} \cos(\Omega t + \eta_u) \\ \sin(\Omega t + \eta_u) \\ 0 \\ 0 \end{bmatrix} \quad (1)$$

$$A = \begin{bmatrix} 0 & \vdots & E \\ \cdots & \cdots & \cdots \\ -(M;\Omega)^{-1}(K+\delta(t)K_{r}) & \vdots & (M;\Omega)^{-1}(D+G) \end{bmatrix} \quad (2)$$

$$f_b = \begin{bmatrix} 0 \\ \cdots \\ -(M;\Omega)^{-1}B \end{bmatrix} \quad (3)$$

$$y = \begin{bmatrix} C_a & 0 \\ 0 & C_g \end{bmatrix} \quad (4)$$

$$B = \begin{bmatrix} 0 & 0 & 0 & fak1 & 0 & 0 \\ 0 & 0 & fak2 & 0 & 0 & 0 \end{bmatrix}^T \quad (5)$$

The factors $fak1$ and $fak2$ denote mass unbalances in x and y coordinates respectively as follows

$$fak1 = \varepsilon m\Omega^2 \cos(\Omega t + \eta_u) \quad (6)$$

$$fak2 = \varepsilon m\Omega^2 \sin(\Omega t + \eta_u) \quad (7)$$

Die mass as an input is given as follows

$$fg = \begin{bmatrix} 0 & mg & 0 & 0 & 0 & mg & 0 & 0 \end{bmatrix}^T \quad (8)$$

It is normally convenient for further operation to write the equation above via state space notation with $x(t) = [q(t)^T \quad \dot{q}(t)^T]$ including the nonlinearities of the motion created by any defects in system.

$$\dot{x}(t) = Ax(t) + u(t) + N_R n_R(x(t)) + N_u n_u(t) \quad (9)$$

The equation of the measurement is given by

$$y = Cx(t) \quad (10)$$

where, A is $(N_n \text{ x } N_n)$ dimensional system matrix which is responsible for the system dynamic with $N_n = 2nn$, $u(t)$ denotes r dimensional vector of the excitation inputs due to gravitation and unbalances, and C presents $(m_e \text{ x } N_n)$ dimensional measurement matrix, respectively.

Here, the vector $n_R(x(t))$ and $n_u(x(t))$ characterizes the n_f dimensional vector of nonlinear functions due to the fault such as mass unbalance and crack, respectively. N_u and

N_R are the input matrices of the linear and the nonlinearities, and the order of N_R is of $(N_n \text{ x } n_f)$. It is presupposed that the matrices A, B, C, N_R, the vector $u(t)$ and $y(t)$ are already known.

Now it remains to reconstruct the unknown linear vector $n_u(x(t),t)$ and nonlinear vector $n_R(x(t),t)$ which mentions the disturbance force caused by a fault such as mass unbalance and crack. The basic idea is to get the signals from $n_R(x(t))$ approximated by the linear fictitious model [4, 5, 6, 7].

Now it remains to reconstruct the unknown linear vector $n_u(x(t),t)$ and nonlinear vector $n_R(x(t),t)$ which mentions the disturbance the linear fictitious model [4, 5, 6, 7].

In terms of the fictitious model [4, 5], an observer [7] is designed and to get a signal phase an estimator is established.

$$\begin{bmatrix} \dot{\hat{x}}_i(t) \\ \dot{\hat{v}}_1(t) \\ \dot{\hat{v}}_2(t) \end{bmatrix} = \begin{bmatrix} A-L_xC & N_RH_1 & N_uH_2 \\ -L_{v1}C & V_1 & 0 \\ -L_{v2}C & 0 & V_2 \end{bmatrix} \begin{bmatrix} \hat{x}_i(t) \\ \hat{v}_1(t) \\ \hat{v}_2(t) \end{bmatrix} + \begin{bmatrix} I \\ 0 \\ 0 \end{bmatrix} u(t) + \begin{bmatrix} L_x \\ L_{v1} \\ L_{v2} \end{bmatrix} y(t) \qquad (11)$$

For the guarantee of the observer ability of estimator, the requirement

$$rank \begin{bmatrix} -\lambda I_{N_n} - A & -N_{v1}H_1 & -N_{un}H_2 \\ 0 & \lambda I_{s1} - V1 & 0 \\ 0 & 0 & \lambda I_{s2} - V_2 \\ C & 0 & 0 \end{bmatrix} \qquad (12)$$

$$\begin{aligned} &= \dim(x(t)) + \dim(v_1(t)) + \dim(v_2(t)) \\ &= N_n + n_f + 2n_f \qquad \forall \lambda \in C^+ \end{aligned} \qquad (13)$$

and the requirement of the control ability

$$rank\begin{bmatrix} \lambda I_{N_n} - A & B \end{bmatrix} = N_n \qquad (14)$$

must be satisfied. The output equation for the measurement is presented as follows.

$$\hat{y}(t) = \begin{bmatrix} C & 0 & 0 \end{bmatrix} \begin{bmatrix} x(t) \\ v_1(t) \\ v_2(t) \end{bmatrix} \qquad (15)$$

where matrices L_x and L_v are the gain matrix of the observer. The above Eq. (11) means that the observer consists of a simulated model with a correction feedback of the estimation error between real and simulated measurements. The matrix A_o has $(N_n + n_f \text{ x } N_n + n_f)$ dimensions and represents the dynamic behavior of the elementary observer. The asymptotic stability of the elementary observer can guaranteed by a suitable design of the gain matrices L_x and L_v which are possible under the conditions of detect ability or the ability to observation of the extended system. To enable the successful estimation under the asymptotic stability, the eigenvalue of the considered observer (A_o) must be settled on the left side of the eigenvalue of the given system (A_e) to make the dynamic of the observer faster than the dynamic of the system. The fictitious model of the fault behaviors is able to be designed using integrator model [7, 8] based on the chosen crack model as follows. The observer gain matrices L_x and L_v can be calculated by pole assignment or by the Riccati equation [4] as follows.

$$AP + PA^T - PC^T R_m^{-1} CP + Q = 0 \qquad (16)$$

$$L_v \begin{bmatrix} L_x \\ \cdots \\ L_v \end{bmatrix} = PC^T R_m^{-1} \qquad (17)$$

The weighting matrix Q and R_m has to be suitably chosen by the trial and errors.

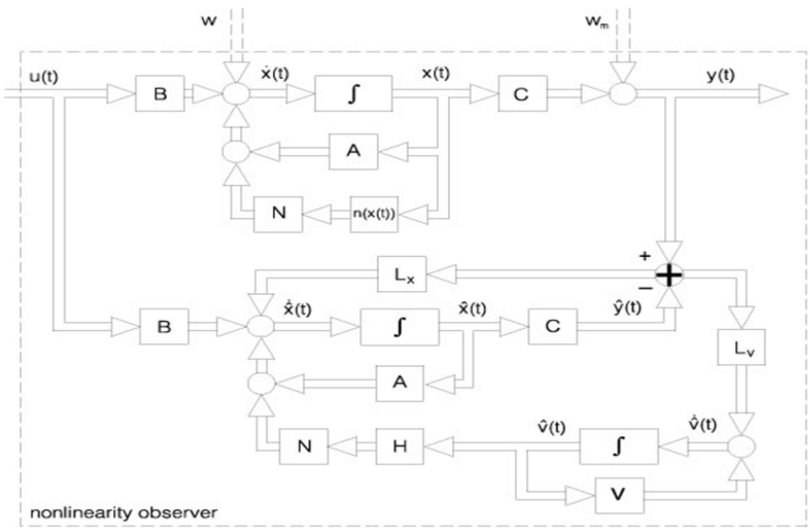

Fig. 2. *Nonlinar observer*

3. Estimator Design for System Errors

In the above section it has been studied how to design the elementary estimator for the detection at a given local position. It means that a certain place on the shaft is initially given as the position. The elementary estimator on the bearing has to survey not only the assigned local position but also any other place on the shaft and to give the signals whether a fault exists or not. As it has been known, it is possible to detect the fault assigned certain place along on the shaft. In the case a fault appears at any subsystem in running time, it must be detected as well. But in many cases, it has been shown that it is impossible or very difficult to estimate the position of the fault at all subsystem on the shaft with one estimator. Generally, it depends on the number of the subsystem and the number of estimator. For the estimation of a position of mass unbalance or crack, an estimator bank based on estimator is designed. The main idea is to reconstruct the related forces of a mass unbalance or crack from certain local position to the arranged elementary estimator. This is main task in this section. The structure of the estimator considered is in the work [7] presented. It consists of a few elementary estimator depends on the number of the subsystem is modeled. Every elementary estimator which is distinguished from the distribution vector $Ls_{(i_e)}$ gets the same input (excitation) $u(t)$ and the feedback of the measurements, and is going to be set up at a suitable place on the given system. For the appreciate arrangement of Observe, the distribution matrix on the analogy of (14) has been applied. In this way the estimator bank is established with the estimator. To estimate the local place of the fault, there are two steps. First of all, the estimator must be observable to certain local place in the meaning of the asymptotical stability in the system. The requirement has been satisfied by the criteria from [4, 7]. This means that the estimator has to be capable of estimating the fault at any location, where estimator is situated on the given system. The unknown fault position is to be found by the estimator arranged in a certain local place with the related crack forces resulting from the crack. To guarantee this condition (12) is supposed to be fulfilled. In this work three estimators are arranged on the under bearing and upper bearing

$$Ls(i) = [11 \quad ,\cdots, \quad 0000 \quad ,\cdots, \quad 11]^T \qquad (18)$$

The unknown position of a fault is found by the estimator according to the related forces, displacement, and torque of some other location on the shaft.

$$\begin{bmatrix}\dot{\hat{x}}_i(t)\\ \dot{\hat{v}}_{1_i}(t)\\ \dot{\hat{v}}_{2_i}(t)\end{bmatrix} = \begin{bmatrix} A-L_{x_i}C & N_{R_i}H_1 & N_{u_i}H_2\\ -L_{v1_i}C & V_1 & 0\\ -L_{v2_i}C & 0 & V_2\end{bmatrix}\begin{bmatrix}\hat{x}_i(t)\\ \hat{v}_{1_i}(t)\\ \hat{v}_{2_i}(t)\end{bmatrix} + \begin{bmatrix}I\\ 0\\ 0\end{bmatrix}u(t) + \begin{bmatrix}L_{x_i}\\ L_{v1_i}\\ L_{v2_i,}\end{bmatrix}y(t), \quad i = 2,4,6 \qquad (19)$$

4. Numerical Simulation on the Rotor Shaft

The estimator bank consists of two elementary estimators. The 1st estimator A is situated at the under bearing and the 2nd estimator B is placed at the upper bearing. The criteria for the detection of the error, it is necessary to choose the maximal magnitude of the phase from all estimators by the comparison among the phase turned out: forces, displacements and torque. In the case, the estimator shows none of the force, there is not any mass unbalance in this system considered. If any one of the estimator gives signals of the force, it means that the system has a defect in a corresponding position. The figures illustrate the phases with the mass unbalance under the rpm (107.5). As the 1st example, the nominal system behavior is considered with given mass unbalance. It is at the 1st of the node in the system.

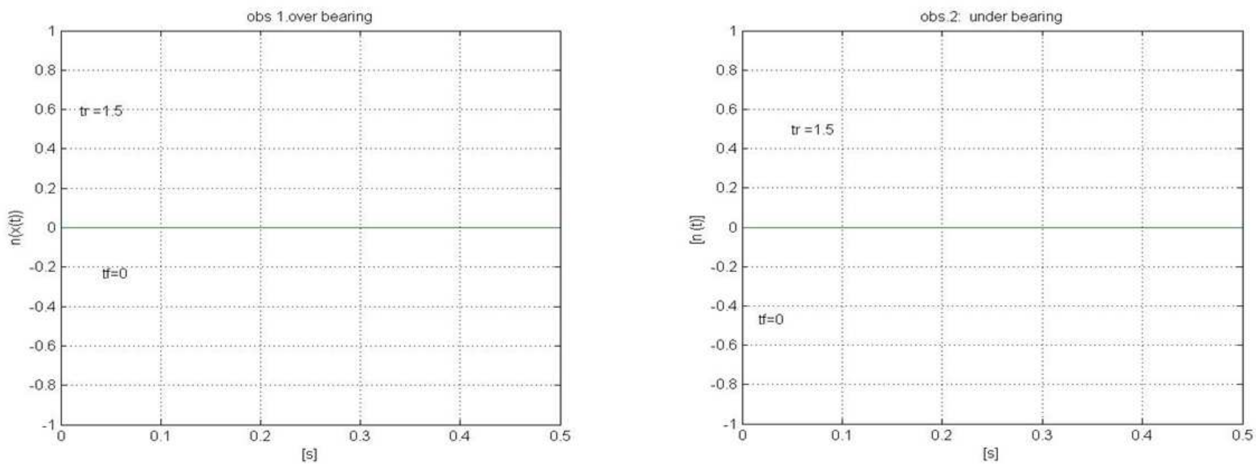

Fig. 3. *Phase 1 non errors*

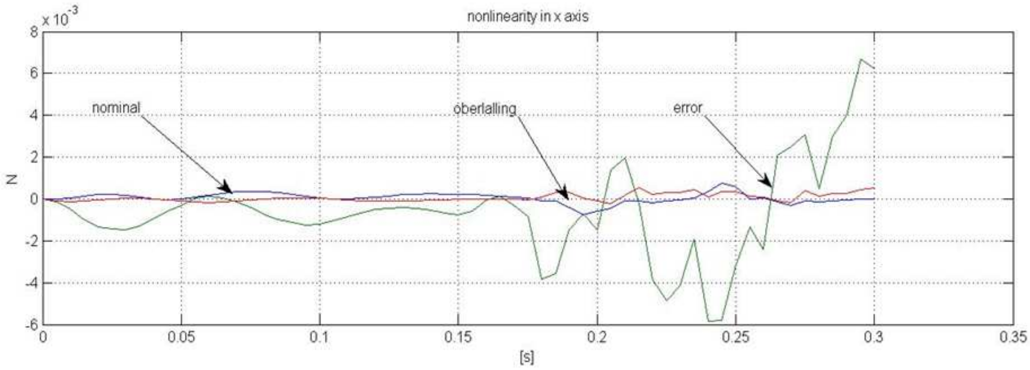

Fig. 4. *Phase 2 phases of vertical rotor without errors.*

The y axis shows the force which denotes nonlinearity and the x axis illustrates the corresponding time. This phase is nominated as a phase of a zero fault. The fig.3 shows that the estimator recognizes the non- existence of errors. By the comparison of the forces, there is some difference between estimated and simulated phase. However, the derivation is small enough and acceptable.

The following Fig. 4 illustrates the Phase of the vertical rotor without errors. The observer 1 and 2 show us non amplitude. This is a nominal signal that the system has no defect and trouble. The Fig. 4 also denotes that mass unbalance do not play much role by the vertical arrangement of the rotor than by the horizontal one.

The results show that the model describes the fault existence (force of mass unbalance) in the 2nd node under the influence of a crack in the runtime operation. Up to 0.15[sec], the forces of mass unbalance and crack have been overlapped. This denotes that mass unbalance and crack exist in the same place (node) on the shaft. It has been already mentioned that the breathing direction of a crack and the position of the mass unbalance on the radius of the diameter of shaft are on the same line.

The result in the Fig. 5 illustrates the appearance of the errors as phase 4-th node: the forces of mass unbalance, in the middle of the shaft.

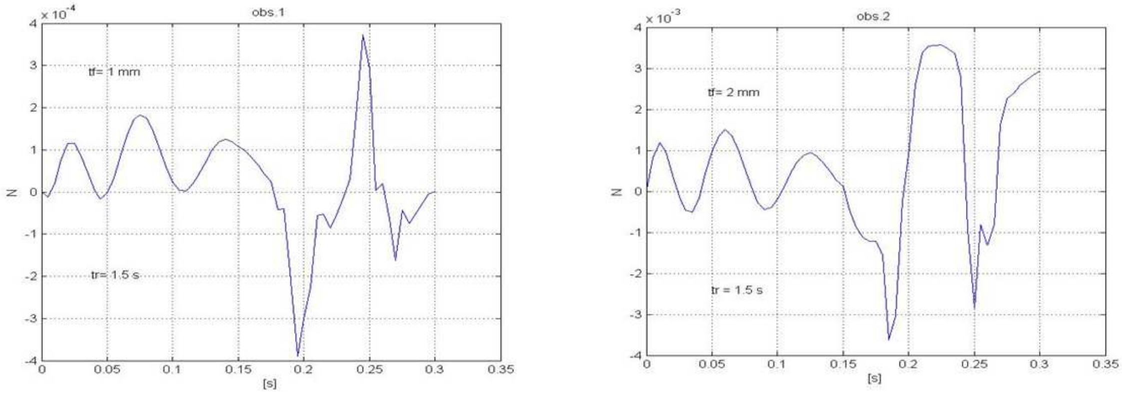

Fig. 5. *Phase 3.appearanceof the error at the 4 –th node*

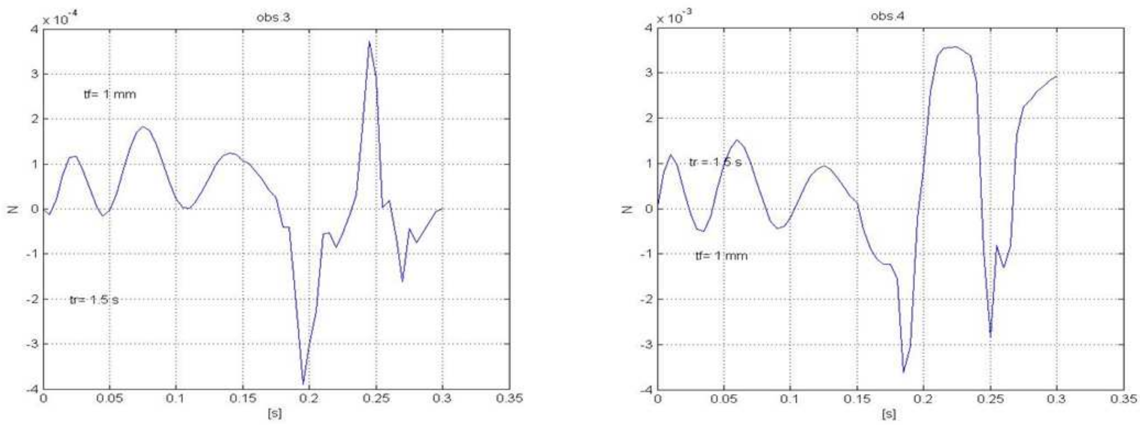

Fig. 6. *Phase 4 system defect*

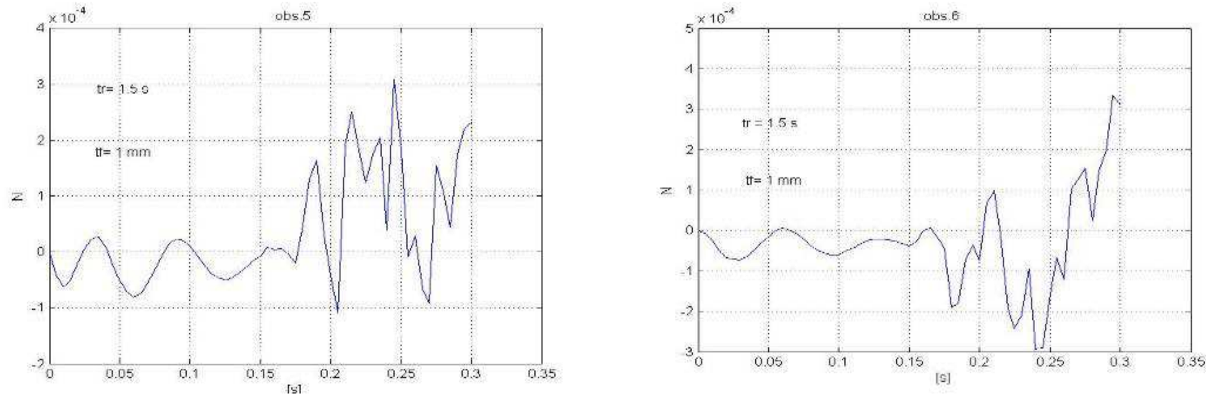

Fig. 7. *Phase 5 fault in the bearing*

The fig. 6 gives a notice of an appearance of a system defect. From the start to 0.15sec the figures the mass unbalance. After this point, obs.3 and obs.4 show the changes of the given signals. The fig. 5 shows the signal from the observer 1 and 2 and the fig. 6 denotes the signal from the observer 3 and 4. The two signals look almost the same in their magnitude of the amplitudes. It means that the two estimators have the same distances from the defect spot. There can be various interpretations.

The result in the Fig.7 tells us the coming up of the fault in the position of under bearing. The forces of masses unbalances at the 1st node under the influence under the same direction between mass unbalance and the crack.

5. Conclusion

From physical model, the mathematical constraint model of the vertical rotating shaft with bearings has been presented. Based on the mathematical model, the elementary observer based on the measurement only on the bearing and the observer bank has been developed. With this observer bank, the estimation of the system errors have been done in phase and compared with the horizontal rotating shaft. The method gives a clear relation between the shaft with a mass unbalance and the damaged shaft by a crack. The phenomena at both bearings show that the influence of the mass unbalance in vertical rotating system is not so significant than the horizontal system. Successful theoretical results have been given in graphics. The data in forces in the results are the internal one, which have been reconstructed as disturbance forces-controllers created by the mass unbalance and crack. It has been theoretically shown, that it is possible to estimate localization of a mass unbalance with the opposite direction of a crack or mass unbalances. The suggested methods are very significant not only for the further theoretical research and development but also for the transfer in experiments.

Appendices

The data used in simulation are given as follows:

A (2) is the system matrix of order (64 x 64). The length of subsystem of load mass makes el = 0.2m, diameter of the subsystem of the load mass m makes ed = 0.25m,. The mass of load is of $m = \pi$ el ρ $ed^2/4$, and the density makes ρ=7860kg/m^3. The nominated elements n_1, n_2, n_3, and n_4 are of -0.0084, -0.8321, -0.3747, -0.0321 respectively. The others are of :fg = f (g, in = 1, …, N) + fu = f(g, in = 1, …, 30, 31, 32) = 0 ;f(g,2,‘”, 29) = - mg, f(u,; , 21) = f(u,; , 25) = - em Ω^2 m(ex) sin(Ω t + β),f(u,; , 18) = f (u,; , 22) = em Ω^2 m(ex) cos(Ω t + β),w where the order of the fg and fu are of (32x1) respectively. The eccentricity: em = 0.001, mass of eccentricity e(ex) = 4 mm. The modulus E is of 2.0 x 10^6 N/ mm^2. The measurement matrix has the order(4x64), C(i,j) = 0 , except C(1,2;63,64) = =1.The number of nonlinearities nf are of 2. and the measurements makes 4. The elementary matrices (2) Me, Ke, and Dg which depend on the geometry, are given in (Waller and Schmidt, 1989; Link 1989, Barthe, 1990)6 The weighting matrix Q(i, j=1, 64) = 1, Q(i,j=3,516) = 5.2510,Q(i,j=17, 32) = 2.5 10^6,Q(i, j=33, 45) = 5.5 10, and Q (i, j=46, 63) = 58 10^2. The factors (6,7)Fak1 and fak2 be calculated with $\Omega = 2\pi$ ed and $\eta = 5^o$

Acknowledgment

This research was supported by the Sanhak Sehan univerity

References

[1] R.V. Beard, Failure accommodation in linear system through self recognition, Rept. MVT-71-1, Man vehicle laboratory, M.I.T., Cambridge, Mass., Feburar (2005)

[2] R. J. Patton and S. M. Kangetehe, Robust fault diagnosis using eigen structure assignment of observers, In R, Patton, P.

[3] Frank, and R. Clark, Herausgeber, Fault diagnosis in dynamic systems, Prentice Hall (1984)

[4] R. Iserman, Identification dynamischer systeme, Band I and II, Spring Verlag, Berlin(1984)

[5] P.C. Mueller, Estimation and compensation of nonlinearities, *Proc. Of 1st Asian Confer.,* Tokyo, (1994) 228-234.

[6] R.W. Park, Estimation of a mass unbalance under the crack on the rotating shaft, ICASE, Vol. 2, No. 4, (2000) 228-234.

[7] R. W. Park, Crack detection, localization and estimation of a depth in a turbo rotor, KSME International Journal, V01. 14, No. 7, (2000), 732-729.

[8] R.W. Park and P. C. Mueller, A contribution to crack detection, localization and estimation of a depth in a turbo rotor, *ASCC, proc.* Vol. II, (1997) 427-430

[9] R. W. Park and S. Cho, Noise and fault diagnosis using control theory, international session paper, *Proc 13th Korea Automation Control Conference*, ICASE, (1998) 301-307.

[10] R. W. Park, A system diagnosis through the recognition of the mode of dynamic motions of a shaft by the indirect measurement in journal bearing, The 28th *International Symposium 0n Automation and Robotic in Construction*, ISARC, (2011) 233-238.