International Conference on Mechanical, Industrial and Materials Engineering 2017 (ICMIME2017)
28-30 December, 2017, RUET, Rajshahi, Bangladesh.

Paper ID: KL-02

Condition Monitoring of Rotating Machinery: A Recent Trend

Rajiv Tiwari, Professor,
Department of Mechanical Engineering, Indian Institute of Technology Guwahati,
Guwahati, Assam, 781039 (rtiwari@iitg.ernet.in)

ABSTRACT

Rotating machinery is known for its most dense power generation units. Due to generation of large power through smaller rotating machines, there is a sudden big shift of demand for ultra-high speed rotors with rotational speed of order of 50 krpm to 100 krpm. This demand exists not only in aerospace applications but also in the manufacturing and medical applications. Rotors with such high speeds are realized with the help of modern passive bearings, such as the ceramic ball bearings and foil bearings, or with active bearings, such as the magneto-rheological or active magnetic bearings (AMBs). For more critical application AMBs are preferred because of its several advantages such as (i) it acts as simple bearing to carry static load of the rotor, (ii) it controls excessive vibrations during transients by changing rotordynamic parameters of bearings and (iii) it acts as an external exciter for system parameter characterization. These advantages have been exploited individually and mainly by treating AMB as an external unit, that means after the rotor design, manufacturing and commissioning is over, design of the AMBs are performed. Condition monitoring of such critical machinery is challenging and traditional condition monitoring to be replaced by a smart condition monitoring.

Due to aforementioned advantages, now the development is towards using AMBs integrated with the rotor system during the rotor design phase itself. The present presentation will cover an integrated rotor-AMB modeling and analysis, and application of such models for the condition monitoring of rotor systems. The approach will deal with model based fault identification and utilization of both rotor vibration and AMB current information. The basic theme is based on when AMB is integrated with the rotor system; it would suppress the unnecessary vibrations emanating from the faults so vibration alone would not give fault condition and we need to use current information also, which suppresses excessive vibration for acquiring complete information of faults. Some simple cases on the flexible rotor balancing, bearing characterization and crack faults will be illustrated during presentation through the numerical and experimental examples.

Keywords: Condition Monitoring (CM); Rotor Systems; Active Magnetic Bearings; Automation in CM; Vibrations.

1. Introduction

Condition monitoring (CM) of rotating machinery is quite old subject now. Depending upon the sensors available and signal processing techniques utilized the CM has gradually improved a lot over the years. In early days only signal's level used to be monitored for finding condition of machines. Signals of wide variety depending upon the system to be monitored were utilized; for example, pressure, temperature, vibration, acoustics, current, etc. Subsequently, these signals were transformed into frequency and timefrequency domains, and characteristic frequencies were monitored (Sohre, 1991; Mitchell, 1993; Martin, 1994). These procedures are effective for simple systems, however, for complex system several characteristic frequencies overlap and make understanding the condition of machine is very cumbersome (Edwards et al., 1998). This demands automation of the CM with the help of machine learning algorithms, for example, the artificial neural network, fuzzy-logic, support vector machines, etc. (El-Shafei and Rieger, 2003; Bordoloi and Tiwari, 2014; Gangsar and Tiwari 2016; Janani and Tiwari, 2016). These methods rely on data acquired from machines overall a period of time and associated history of fault conditions. Apart from such pure data-driven condition monitoring now trend is towards utilization of physics based mathematical models of dynamic systems and seek its unknown critical fault parameters based on fitting of available experimental data in to it (Shravankumar and Tiwari, 2013) and preferably with active devices (Singh and Tiwari, 2016).

2. Abstract Representation of Condition Monitoring Procedures

Figure 1 shows CM based on output (e.g., vibration) from the dynamic (e.g. rotating machine) system. In this methodology no information of the system as such is required and can be considered as black box (grey colour) and only output (green) is utilized for the CM. Usually vibration level trending can be used as indicator of the condition of the system as a whole.

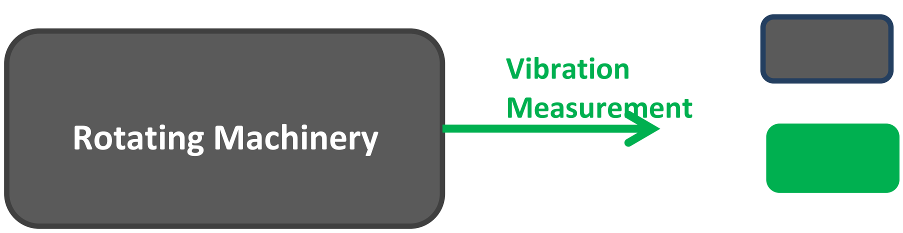

Figure 1: Output Feature Based Fault Detection

Unknown

Known

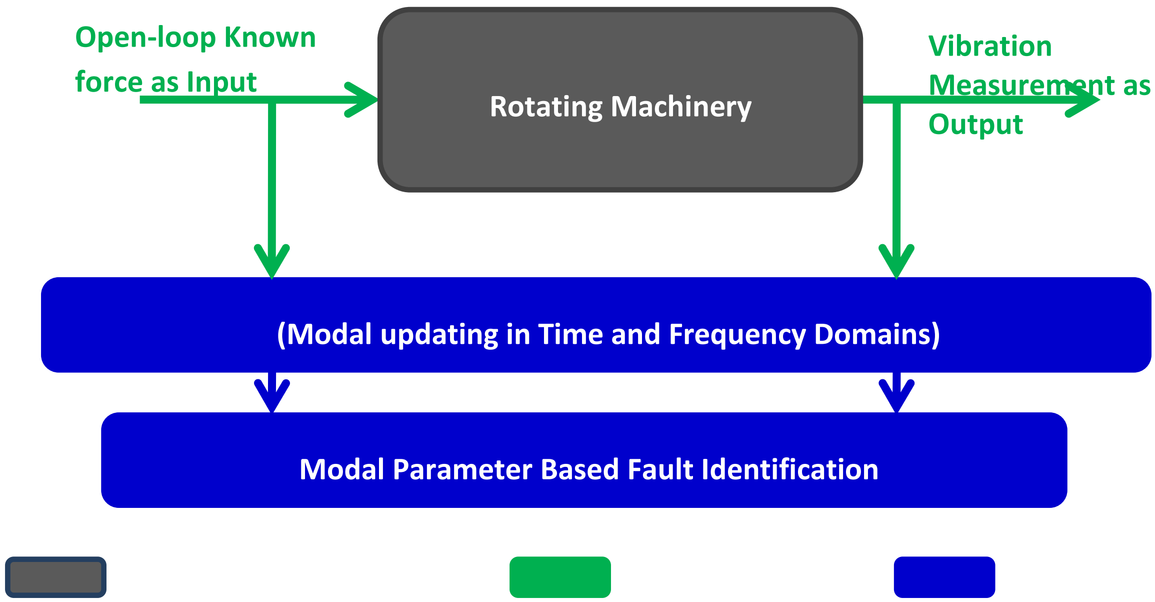

Figure 2: Input-Output Feature Based Fault Detection (Modal Updating)

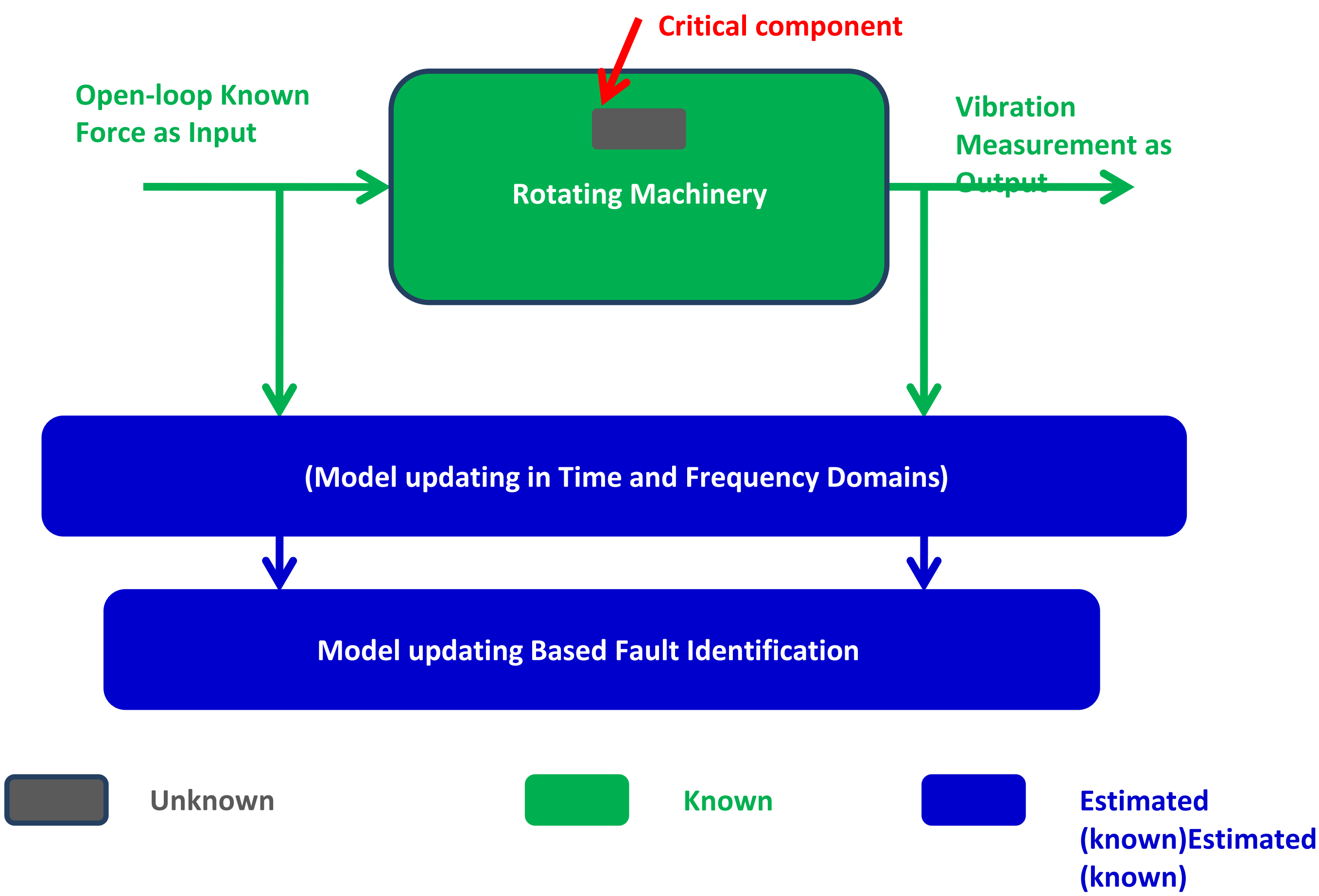

Figure 3: Input-Output Feature Based Fault Detection (Model Updating)

Figure 2 show modal testing based updating technique, in which system level dynamic modal properties, like natural frequencies, modal damping, modal mass and modal forces are obtained based on the input-output correlations (Maia et al., 1997). The system is excited by a known input (e.g. excitation forces; green colour) and corresponding output (e.g. vibrations; green colour) are measured. Based on these estimated modal parameters (blue colour) the condition of the machine is often judged. To have assessment at component level of machine model updating (Friswell and Mottershed, 1995) is referred in which instead of system level modal parameters the estimation of component level fault parameters is performed (refer to Figure 3). Advantage of this methodology is that instead of obtaining estimates of whole system, in which often some components (green colour) may be modelled quite accurately (for example rotor model) so estimation of these parameters are not desired and some crucial components like bearing, foundation, and faults only need to be identified (grey colour). Herein again based on inputout information from the system its critical parameters are estimated (blue colour) so as to have updating of its mathematical model parameters, which may be used as a fault indicator and isolator.

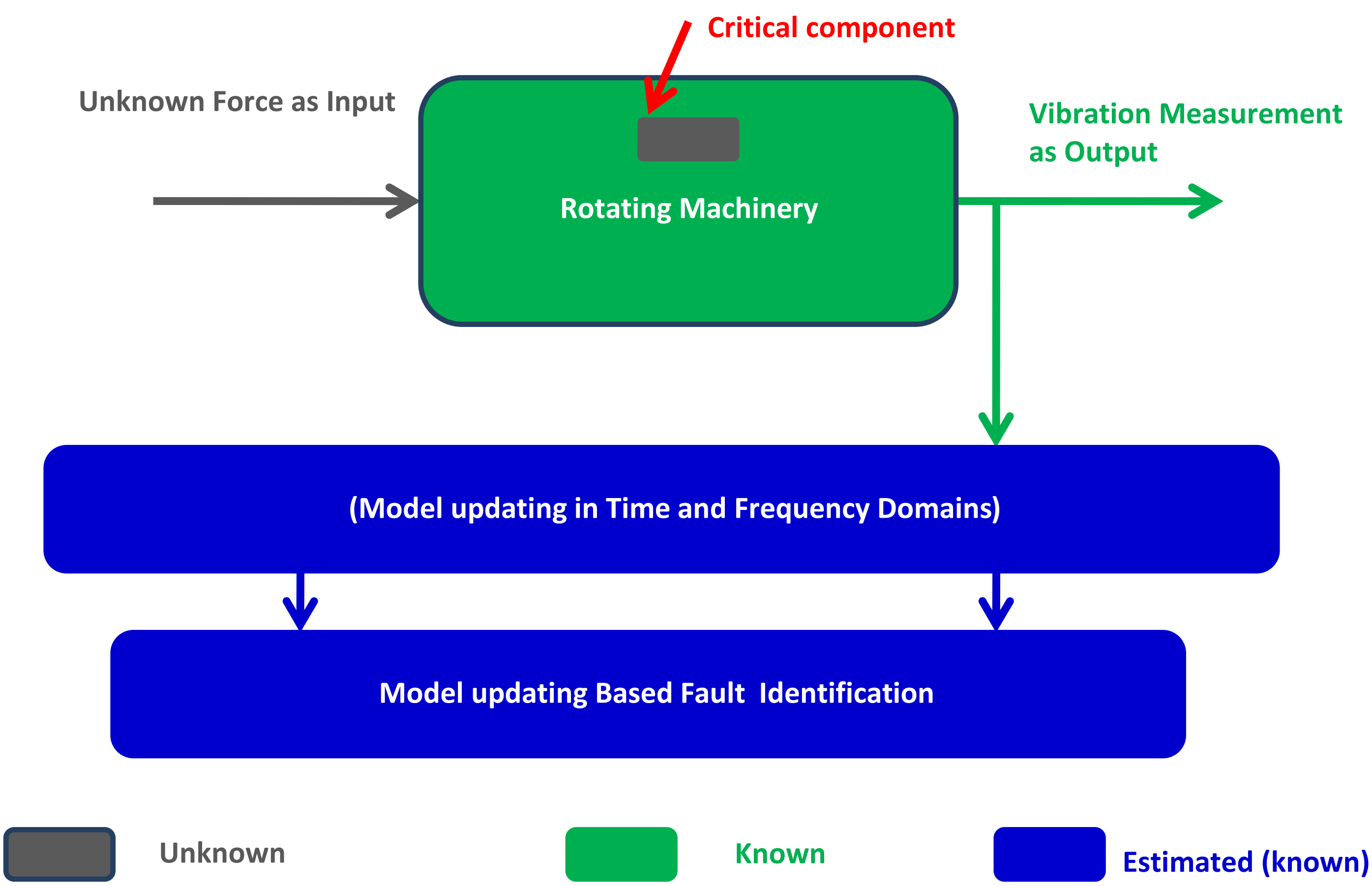

Figure 4: Output only Feature Based Fault Detection (Model Updating)

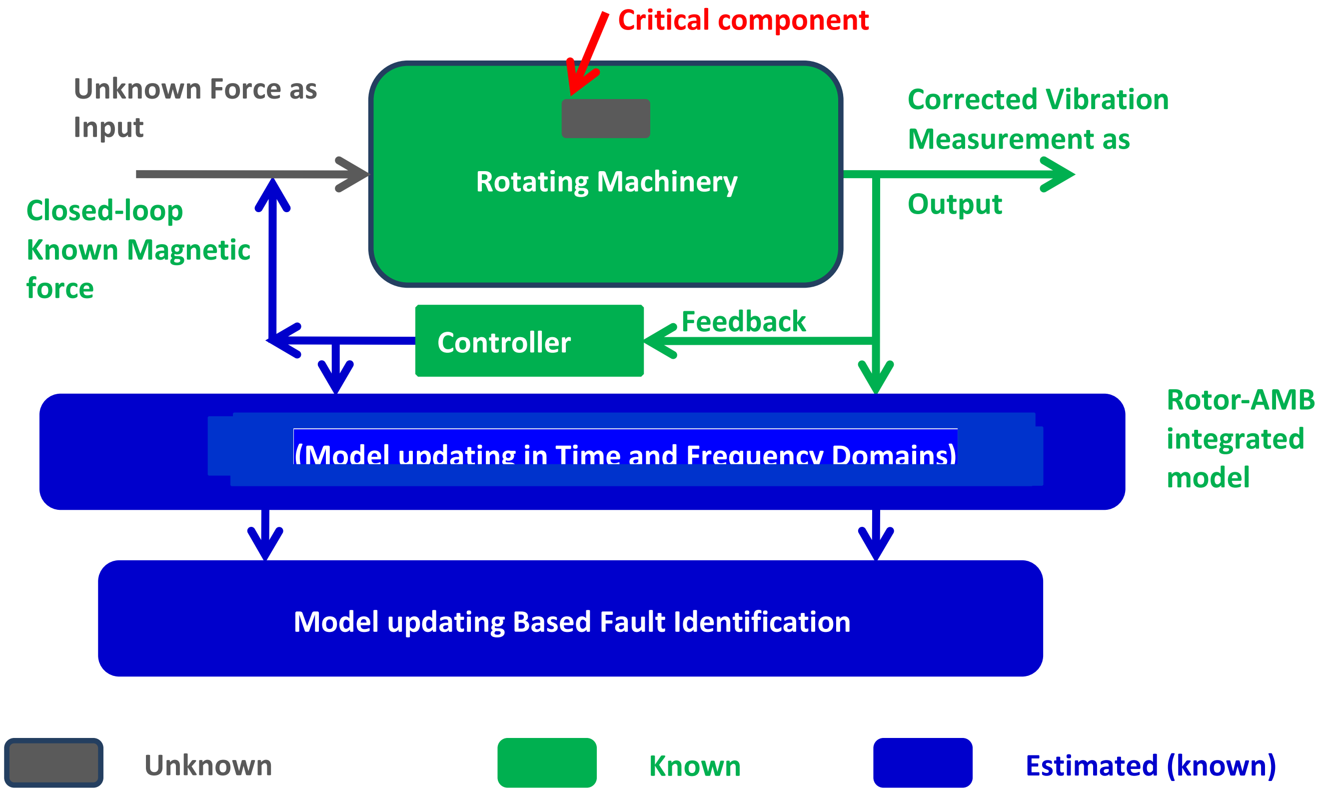

Figure 5: Model Updating Based on Active Devices

Figure 4 shows similar to the case of Figure 3 with a difference that input to the system is unknown. This situation often arises in rotor systems where inherent forces (for example, unbalance, bow and bend in shaft, misalignment, crack, etc.) that give excitation to machines and these input forces (grey colour) are usually unknown. Apart these some of critical parameters of rotor are also unknown. So in this case not only these critical parameters but also input forces are also estimated during the model updating (Shravankumar and Tiwari, 2013). Often excessive vibration in machine due to inherent input forces may lead to fatigue and to overcome that often active devices [for example active magnetic bearings (AMBs)] are used to suppress the vibrations (Figure 5). For small duration suppression of inherent forces due to fault conditions is okay but for a prolong period it is not profitable and not safe if fault grow to a critical value. Tt may be beneficial if the suppression force (e.g., actuator magnetic forces) along with output information (vibration) may be used for model updating of critical parameters (Singh and Tiwari, 2016). It should be noted that now due to suppression forces the output from the system also will be in suppressed form. Suppression force measurement may be done by measuring current and displacement at AMB locations in rotating machinery. These critical parameters could be inherent forces emanating from faults. The present CM fall under smart CM. Since AMBs are not only acting to keep the vibration level minimum but also it gives indication of incipient fault through model updating. However, the smart condition monitoring is still a research area and lot of potential exist in it.

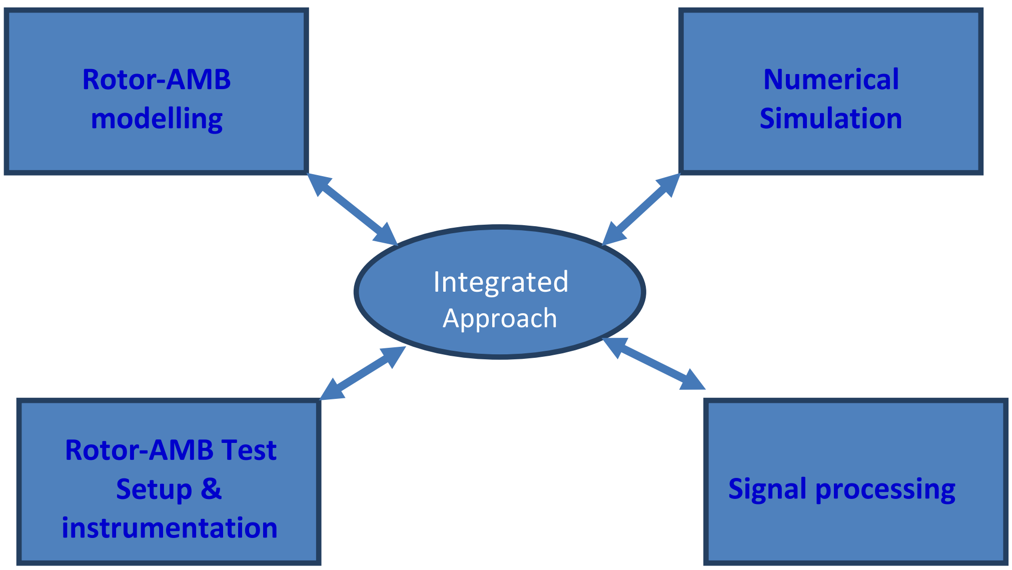

Figure 6: Overall Condition Monitoring Strategy

Figure 6 shows an integrated approach of condition monitoring in which basic four components can be seen (i) system mathematical model (ii) numerical simulation (iii) test setup and instrumentation and (iv) signal processing and model updating. In the present day CM one has to use a balance of all these four component in an integrated way to achieve an effective and efficient smart condition monitoring.

3. Final Remarks

In the present paper smart condition monitoring concept has been outlined. During presentation few case studies will be presented to support the present smart condition monitoring hypothesis (Tiwari and Chougale, 2014; Singh and Tiwari, 2016; Tiwari, 2017). One of them will be dynamic balancing of flexible rotor system, which is a real challenge for real rotor systems. Apart from this some cases of bearing parameter estimation and crack force estimation will be covered during the presentation.

References

Bordoloi D.J. and Tiwari R. (2014), Optimum multi-fault classification of gears with integration of evolutionary and SVM algorithms. *Mechanism and Machine Theory*, 73, 49-60.

Edwards, S., Lees, A.W. and Friswell, M.I. (1998), Fault diagnosis of rotating machinery. *Shock and Vibration Digest*, **30**(1), 4-13.

El-Shafei, A., & Rieger, N. (2003). Automated diagnostics of rotating machinery. ASME Turbo Expo, vol. 4, Atlanta, GA, USA, pp. 491-498.

Friswell, M.I. and Mottershead, J.E., 1995, "*Finite Element Model Updating in Structural Dynamics*," Kluwer Academic Publishers, London.

Gangsar, P. and Tiwari, R. (2016b). Taxonomy of induction-motor mechanical-fault based on time-domain vibration signals by multiclass SVM classifiers. Intelligent Industrial Systems, 2(3), 269-281.2.

Janani, S. R. and Tiwari, R. (2016), Experimental Time-domain Vibration Based Fault Diagnosis of Centrifugal Pumps using SVM. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering*, 3(4), 044501 (7 pages).

Maia, N.M.M., Silva, J.M.M., He, J., Lieven, N.A.J., Lin, R.M., Skingle, G.W., To, W.M. and Urgueira, A.P.V., 1997, *Theoretical and Experimental Modal Analysis*, Research Studies Press Ltd., John Wiley & Sons Inc., New York, (Edited by Maia, N.M.M. and Silva, J.M.M.)

Martin, K. F. (1994). A review by discussion of condition monitoring and fault diagnosis in machine tools. International Journal of Machine Tools and Manufacture, 34(4), 527-551.

Mitchell, J.S., 1993, *An Introduction to Machinery Analysis and Monitoring*, PannWell Books, Tulsa, Oklahoma.

Shravankumar C. and Tiwari R. (2013), Identification of stiffness and periodic excitation forces of a transverse switching crack in a Laval rotor, *Fatigue & Fracture of Engineering Materials & Structures*; 36(3), 254-269.

Singh, S. and Tiwari, R. (2016), Model-based switching-crack identification in a Jeffcott rotor with an offset disk integrated with an active magnetic bearing. *Journal of Dynamic Systems, Measurement, and Control, 138*(3), 031006.

Sohre, J.S. (1991), Turbomachinery Problems and their Correction, *Standardization and Condition Monitoring, Workshop*, March 11-13, (Chapter 7), Houston.

Tiwari, R. (2017), Rotor Systems: Analysis and Identification. Boca Raton: CRC Press, Taylor & Francis Group.

Tiwari, R. and Chougale A. (2014), Identification of bearing dynamic parameters and unbalance states in a flexible rotor system fully levitated on active magnetic bearings, Mechatronics, vol. 24, pp. 274-286, 2014.