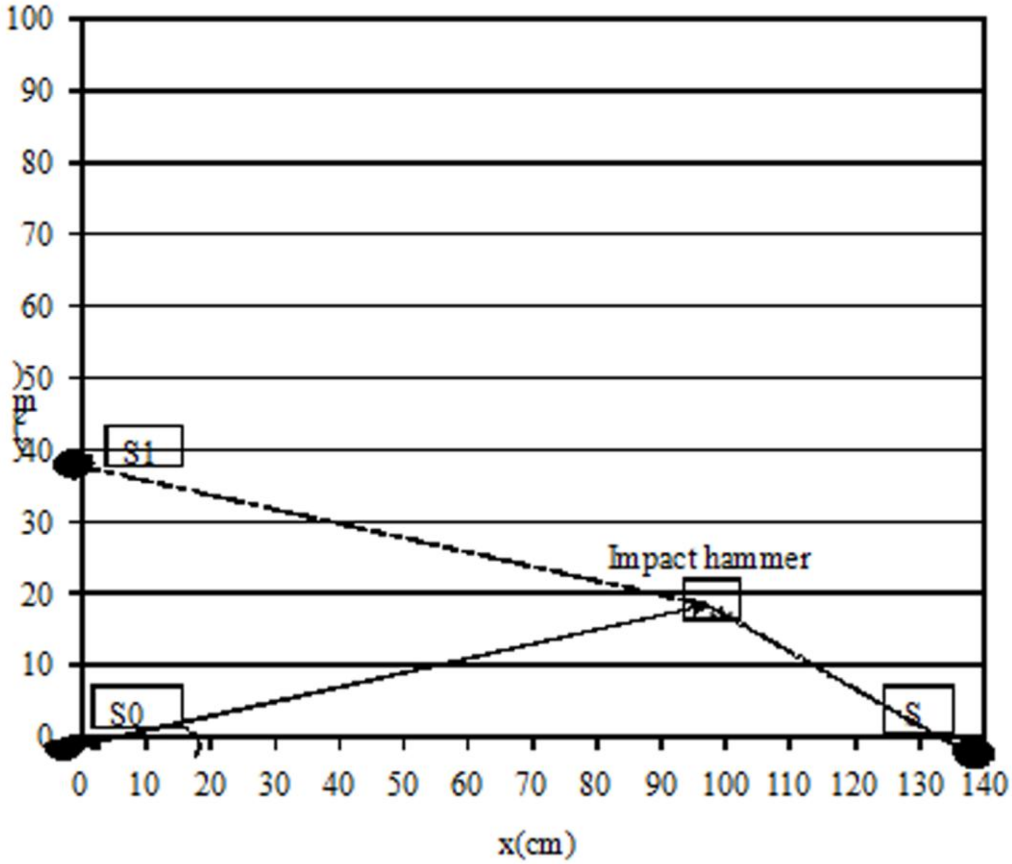

Figure 1. Graphical representation of these coordinates showing the impact location and the acoustic sensors

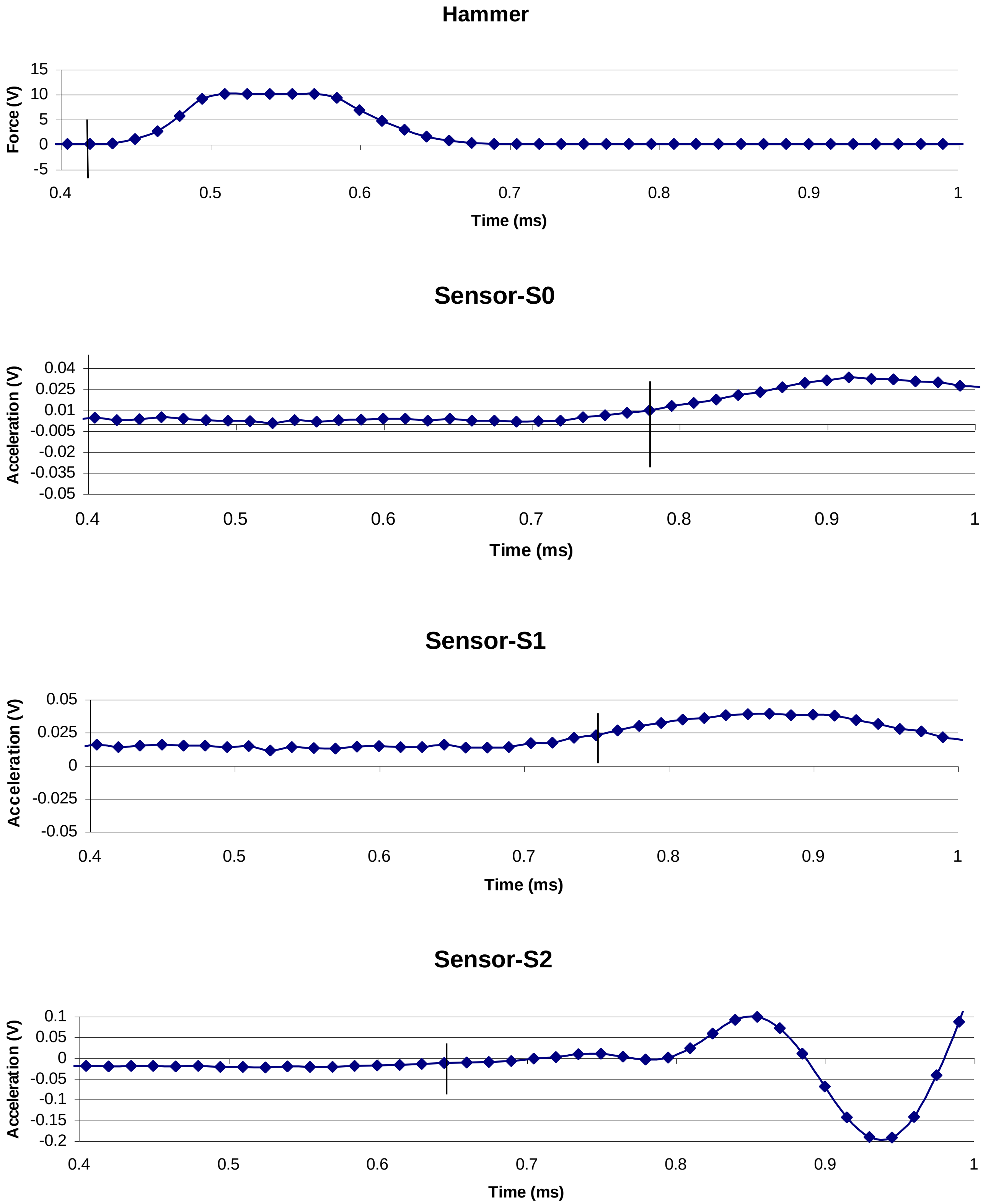

Figure 2. zoomed display of force and burst signals showing automatic detection of burst arrival

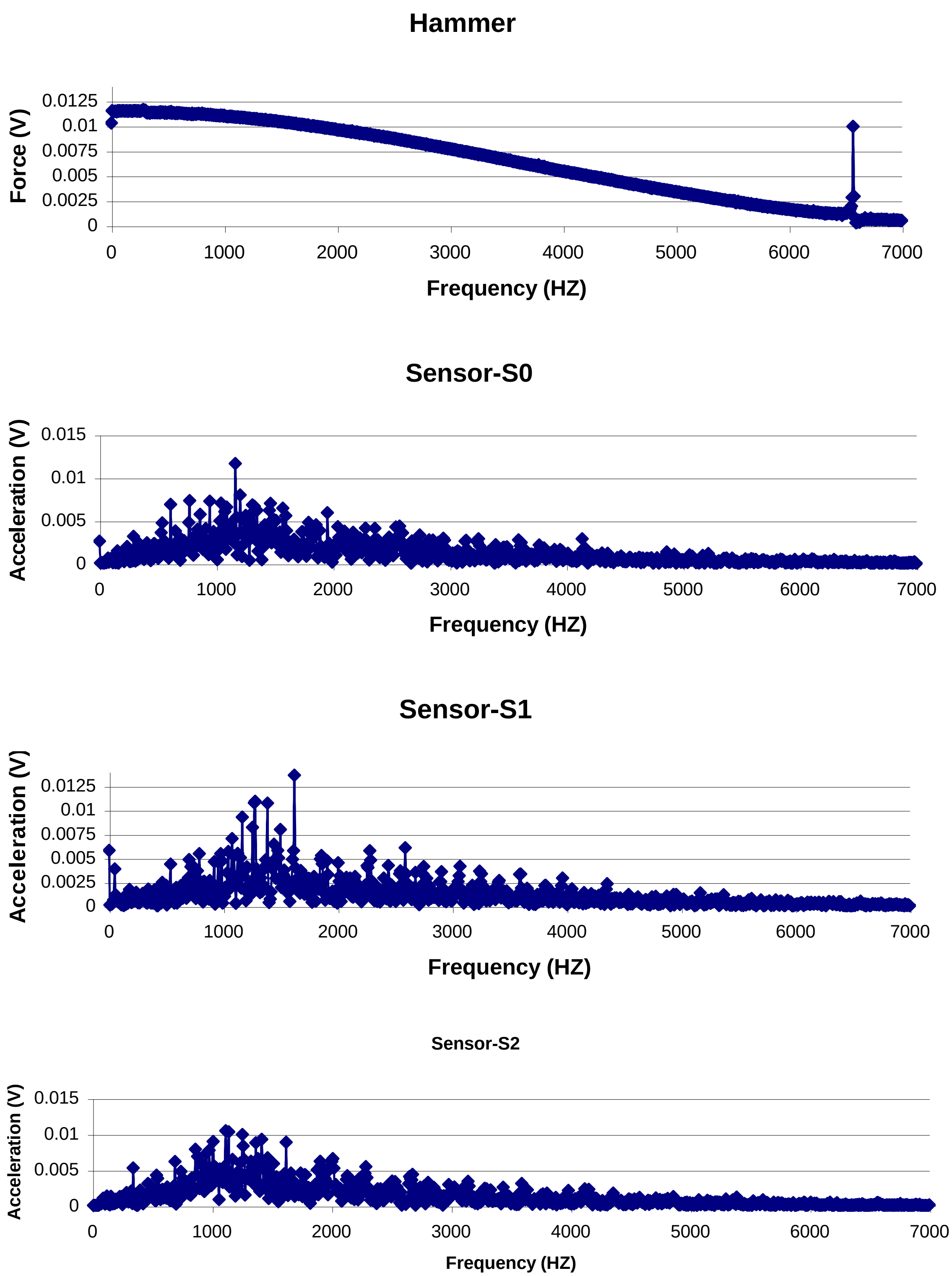

Figure3: Frequency spectra of impact force and acoustic burst signal for a typical measurement

REFERENCES

[1] Loose Part May (1981) Detection Program for the Primary System of Light Water Cooled Reactors, U.S.N.R.C. Regulatory Guide, 1.133.
[2] Acoustic Monitoring Systems for Loose Parts Detection- Characteristics, Design Criteria, and Operational Procedures, IEC-988 1990.
[3] Mayo C., "Loose Parts Monitoring System Improvements", EPRI NP-5743, The Electric Power Research Institute, CA, USA, 1988.
[4] Kryter R.C., April (1984) "Loose Parts Monitoring Programs and Recent Operational Experience in Selected US and West European Commercial Nuclear Power Stations", [1]NUREG/CR-3687, Washington D.C.
[5] Shi L., "Nuclear Reactor Loose Part Impact Activity and Damage Mechanisms", Ph.D. Thesis, North Carolina State University, USA, (1996).
[6] Mayo C., Shugars H.G., (1988) "Loose Part Monitoring System Improvements", Progress in Nuclear Energy, Vol 21.
[7] Mayo C., (1995) "Metal Impact Signal Transmission Through Reactor Structures", Proc. Specialists Meeting on Reactor Noise – SMORN-VII, Avignon, France.
[8] Gerardin J.P., (1995) "Method for Evaluating the System Instrumentation for Loose Part Detection in the Primary Cooling Circuit of French PWRs", Proc. Specialists Meeting on Reactor Noise – SMORN-VII, Avignon, France.
[9] A. Tobias, Feb (1976) " Acoustic Emission Source location in Two Dimensions by an Array of Three Sensors", Journal of Non-Destructive Testing.

Application of Vibration Analysis in Technical Process Management

Muhammad Rafiq Khan[1]

Abstract:
This paper discusses technical process management philosophy, function and scope. The technical process is shown divided into four generalized constituent parts namely, i) actuators, ii) process components, iii) instrumentation and iv) controllers. An analytical classification of the vibration analysis based condition monitoring techniques is developed that encompasses all the constituent parts of the technical processes. The role and application of the vibration analysis techniques in the overall management of technical process is in relation to the contemporary condition monitoring techniques is delineated.
Keywords: Frequency domain, Time domain, Frequency-Time domain, Fault detection and diagnosis (FDD), Accommodation of faults, analytical redundancy, hardware redundancy, I/O Data-based techniques.

Introduction:

A technical process is a part of a system and can be defined as, 'the sequentially connected interdependent and linked components which, consume single or multiple resources at each step, like employees, energy, etc, to convert input (external stimuli), like material, parts, etc into the desired form (outputs). The outputs of former step then can be inputs for the next step of a process until all linked components are complete that form the process'.

The process once designed and developed along with all necessary instrumentation &control, measures are taken to make the process robust against the malfunctioning of the constituent parts of the technical process. This increases the reliability of the processes. The comprehensive strategy to detect, diagnose and accommodate the malfunctioning of all the four constituent parts of the technical processes is referred to as, 'Technical Process Management' Herbert, August, (2009).

The constituent parts of a technical process are generalized as, i) Process components, like, pipes, tanks, pumps, supporting structures, ii) Actuators, like, motors, solenoids, cylinders, etc, iii) Instrumentation, like, sensors, transducers, signal conditioners, cables, computers, etc iv) controllers, like, feedback controllers etc. The controller is a device that operates automatically by executing some established algorithm to regulate a controlled variable(s). The controller input receives information about the status of the process variable(s) and provides an appropriate output signal to the final control element. The philosophy of technical process management is depicted in the Fig. 1. It, in fact, works in a sequence performing the fault detection, isolation, and identification and then accommodation phases of the processes' constituent parts. The fault detection is an act of knowing if something is wrong or not, the isolation determines where it is wrong. The diagnosis phase deals with extractions of information about the faults. It comprised of two activities; i) fault isolation, and ii) fault identification. The identification task is about knowing the information on the fault type and its severity while the accommodation task consists of three activities, i) removal /switching over from faulty to intact equipment, ii) fabrication of reading for the faulty controller type, alert for repair or emergency shutdown for repair.

Instrumentation FDD Schemes:

The instrumentation faults detection and diagnosis usually means the FDD of sensors as the other equipment related to instrumentation have their own simple inbuilt testing and intimation facility in case a fault occurs. However the on-line sensors' faults are difficult to detect and diagnose because of their being system embedded and due to impenetrate able system boundaries.

The sensors' on-line FDD is performed traditionally using hardware redundancy, but the approach has drawbacks regarding cost of redundant hardware and inability of this method to detect incipient faults and common mode failures etc.

1. Principle Engineer, Directorate of Nuclear Power Engineering-Plants, Pakistan Atomic Energy Commission, Ibd

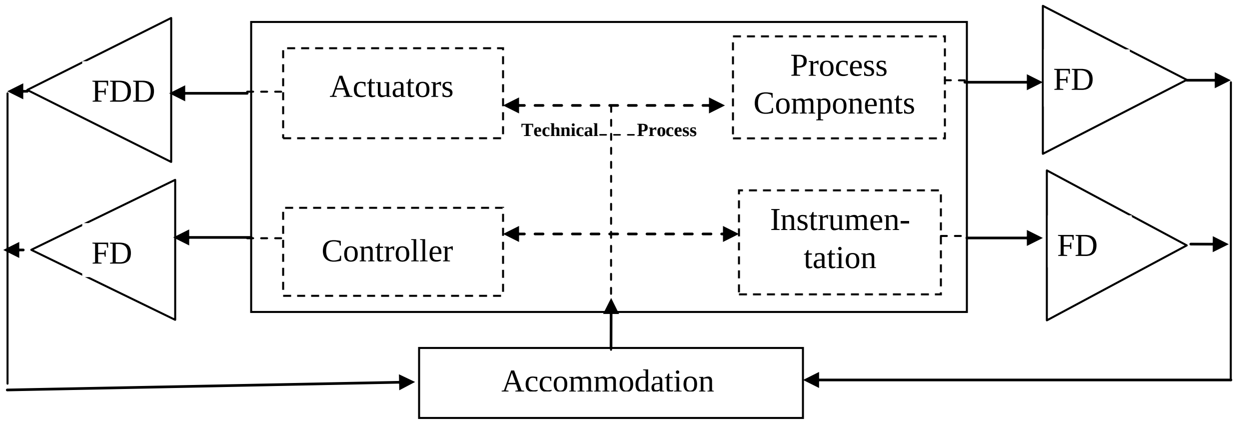

Figure 1: The Concept of Technical Process Management

equipment, etc and feeding it into the controller in case of complete failure. i.e. reconfiguration and, iii) adjustment of the faulty equipment reading in case of partial failure. The accommodation therefore takes information about a specific fault type and fault magnitude, as well as user operational criteria to determine remedial action. The accommodation tasks as mentioned above may include a change in controller gains,

Another approach is to use analytical redundancy instead of hardware to detect faults. The analytical scheme is further divided into two branches, mathematical model-based and data-driven based. The model based techniques include, parity space, observers, parameter estimation (shown in Fig. 4) techniques while the data driven methods are Principle Component Analysis (PCA) Li Shun, Fisher Discriminate Analysis Fuente, M. J., (2008) Artificial Neural Network (ANN) Azhar .S, (2010) Rahman S.A and Expert Systems techniques Paul L.F. (1986).

The Fig. 2, and 3, depicts the procedures of detection, isolation, and identification of faults of the technical process constituent parts under the process management systems. The generalized scheme of the process model-based fault detection and diagnosis is depicted in Figure 4. The aforementioned model-based techniques for sensors' FDD are equally useful for the FDD of actuators and process components, like if the coefficient of friction for an actuator begins to increase, one would suspect that a bearing has begun to fail, however several other techniques are also used for components and actuators' FDD including vibration analysis as discussed in detail in the section-4 of this paper.

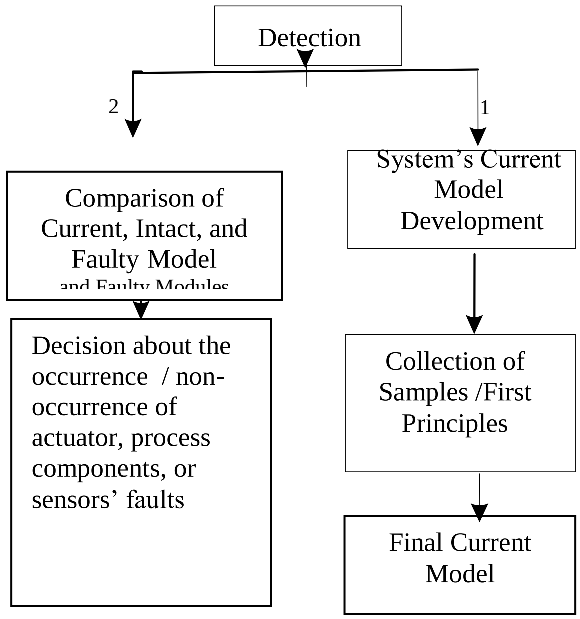

Figure. 2. Fault Detection in Technical Process Management [6]

Controllers FDD Schemes:

Controllers' faults detection and early symptoms of the likely problems is very important. The controllers / control loops may encounter various technical faults as shown in Figure 6.

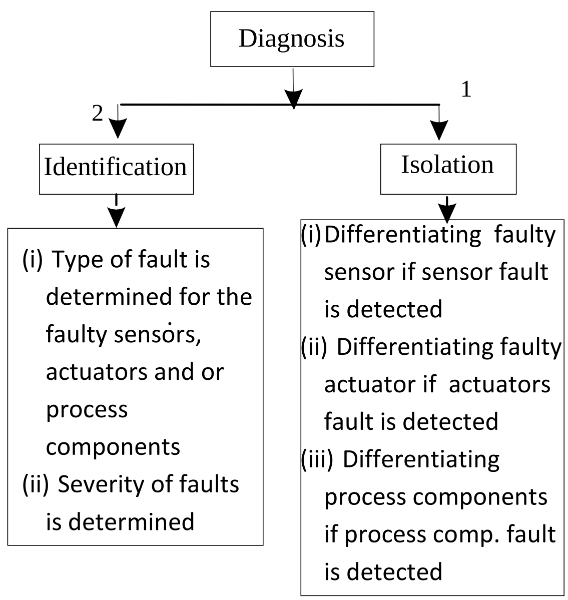

Figure 3. Fault Diagnosis in Technical Process Management [6]

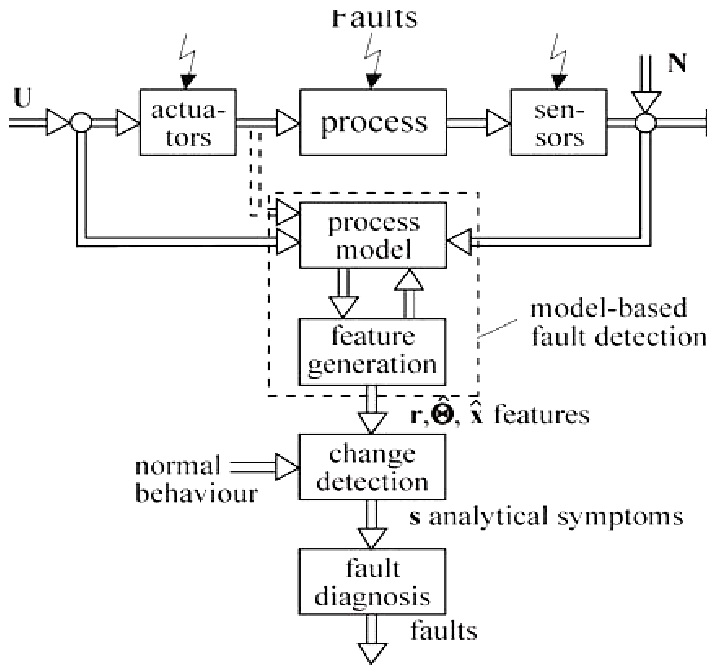

Figure 4. General Scheme of Process Model-Based Actuator, Sensor and Process component FDD [7]

The IP networks in industrial process control provide communications services for control applications and between devices as well, as shown in Figure 5. Delays or complete shutdown owing to faults in communication networks at any point in the networks may render the complete process as malfunctioning. The communication faults' FDD is done manually, however automated schemes are also being used for FDD as well as detection of early symptoms of communication problems Fault Detection in IP-Based Process Control Networks Using Data Mining, (2009).

The other types of faults are ones in which controller software and file errors are responsible for the malfunctioning of the controller. Such faults may include, a value divided by zero or reading a floating point value from EEPROM or file which has no floating point value saved inside etc. When an active controller fails, either due to software faults or hardware faults the standby controller takes over. In such situations an uninterrupted control operation is available without initialization or manual actions. The switchover generates *no* disturbances to the field output signals.

The controller faults laden processes continue to work as though nothing had happened. Redundant controllers also support the online upgrade of controller firmware. Redundant controllers can also be physically replaced online when a hardware upgrade is desired. No special cabling is required to add redundancy Emerson Process Management (2009).

The Standby controllers have the same control scheme as the Active controller. With redundancy enabled, each module calculates the required updates for the Standby controller when the module executes. The redundancy link transfers this information to the standby in milliseconds enabling controller redundancy Emerson Process Management (2009).

Application of Vibration Analysis in Technical Process Management:

As we have discussed in sections-2 and 3, the FDD of the process components, process actuators, process instrumentation and process controllers, is carried out by the model-based or data-based techniques as shown in Figs. 4 & 6. However some methods which employ signal modeling to detect and diagnose the actuator and process components faults are being used. These methods, called signal analysis methods, do not require the knowledge of the actuator or process components, or technical processes' mathematical models etc.

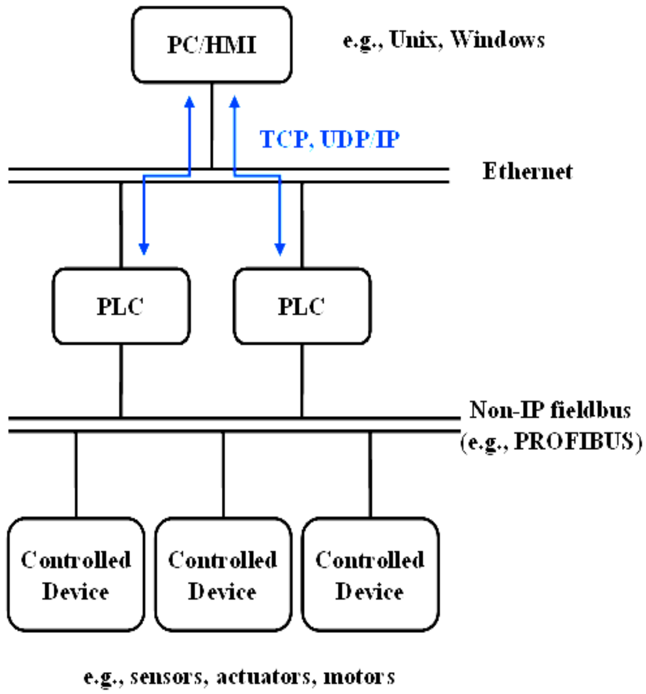

Figure 5 Architecture of Process Control Network [9]

The signal modeling methods employ analysis methods that include mechanical vibration, noise, ultrasonic, current, or voltage signals, to detect and diagnose faults. These methods are used in technical processes to monitor rotating machineries like, pumps generators, turbine engines, bearings, induction motors, gears etc.

In general by analyzing measured signals' amplitudes and frequencies and then comparing these values to the intact model of the systems the initiation and progression of machines' faults may be inferred. The signal model-based methods are relatively sensitive to the incipient faults. The vibration analysis techniques are dealt in details in the remaining sections of this paper. The ultrasonic method is applied for the bearing health monitoring as ultrasonic frequencies are produced in the early stage of bearing degradation process while the reason is lesser lubrication and wear of races. As their races begin to pit, the emissions begin to decrease in frequency. Finally, nearing catastrophic failure, the emissions intensify and move well into the audible range. The ultrasonic instrument are employed to detect vibrations in the range of

Noise /sound of the rotating machines are used to detect the malfunctioning of the rotating machines components. The method is suitable for a broad class of machining processes that emit continuous sound pattern like compressors etc. Although spectral analysis has normally been done with classic

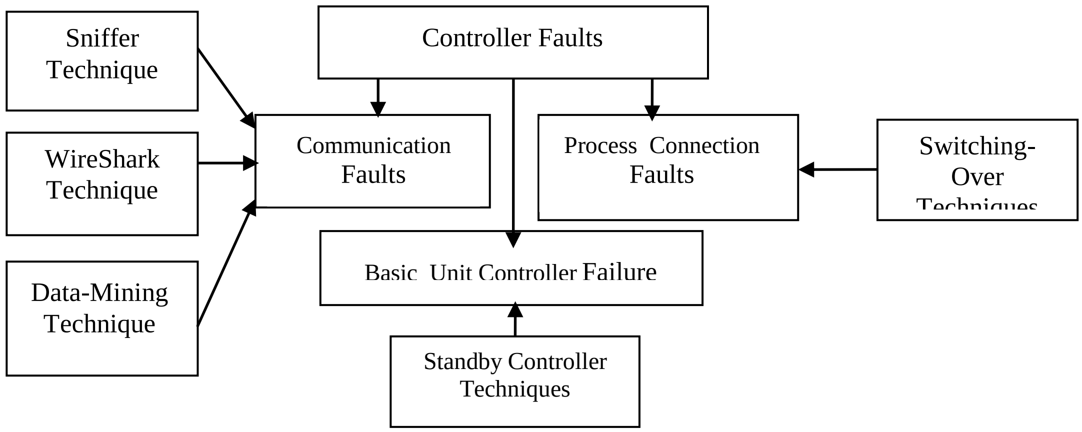

Figure 6. Controller Faults Types and Detection Techniques

20 kHz to 100 kHz. Ultrasonic signals are generated due to several types of mechanical faults. Prominent of those are rubbing or impacting types of faults.

Voltage/current spectrum is used in case of electrical motors where stator current or voltage is analyzed to find rotating machine faults. Motor current signature (MCSA) is a condition monitoring technique that is now widely used to diagnose problems such as broken rotor bars, abnormal levels of air gap eccentricity, shorted turns in low voltage stator windings, and certain mechanical problems Thomson.W.T, (2003). It is easier to detect these faults through MCSA technique as compared to vibration analysis. As shown in Figure 7, broken rotor bar produces another backward rotating magnetic field at slip speed – sNs, with side bands at 2sf1 upper and lower side.

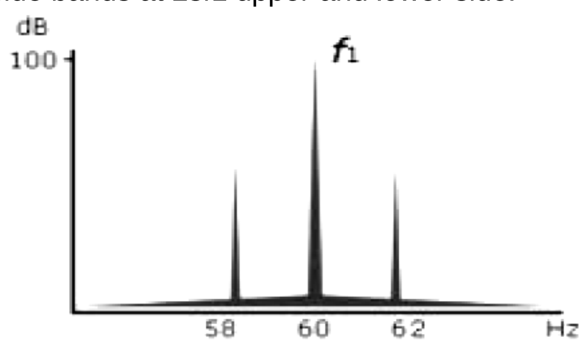

Figure 7. Idealized AC Motor Current Spectrum in Case of Two-Broken Bars

Where, f1is the supply frequency-a mathematical tools, the use of wavelet transform and beta kurtosis is currently the subject of much research.

Actuator and Process Component FDD Through Vibration Techniques:

The vibration is an oscillation wherein the vibration amplitude is a parameter that determines motion of a mechanical system etc. The types and manifestation of mechanical vibration is given in Figure 8. In vibration analysis for most of the cases it is assumed that the vibration is linear, lumped, with some degrees of freedom, may be forced or free damped or undamped etc. The mechanical vibration analysis is used for the two major constituents elements of the technical processes, i) actuator and, ii) process components. For example the electrical motors are actuators for which the vibration techniques are used for FDD while pumps and valves are the process components where vibration techniques are extensively employed for FDD. The different vibration-based techniques for the condition monitoring can be classified as shown in Figure 9.

Model Based:
There are two types in the model-based approaches, a) AR Model Residual, b) Model Parameter Estimation.

AR Model Residual It is the vibration signal averaging technique, the proposed method first establishes an autoregressive (AR) model in the healthy-state of the rotating machine. The model is then employed to predict the future-state signal after linearly filtering error from signal. The faults of the gear, for example, are diagnosed by characterizing the error signal (residual of signals between the measured and predicted signals). The results show that the AR model technique is an effective tool in the detection and diagnosis of some machine faults like, gear faults as detection of gear cracks from vibration data is a difficult task Törnqvist .D, (2006).

a) Model Parameter Estimation
The vibration models that are developed by first principles are capable to detect incipient fault using parameter estimation in some specific machine fault like, pinion gears. In this approach wideband amplitude and phase demodulation are performed through a vibration-mode that treats all

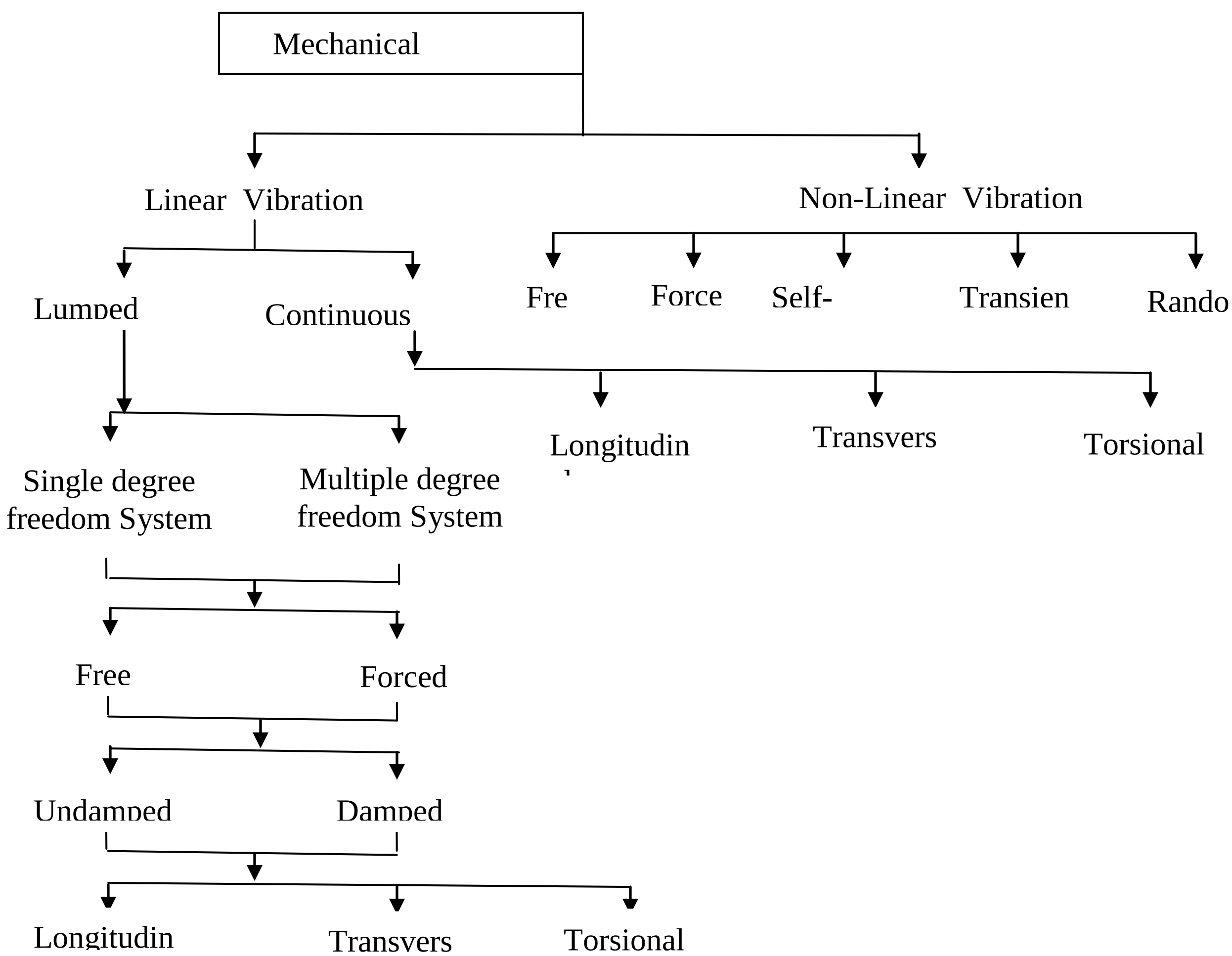

Figure 8. Spectrum of Mechanical Vibrations [11]

Disturbances and faults as part of an amplitude or phase modulation term in the model. A vibration model is given in Eq. (1), where the vibration *y*(θ) is amplitude modulated by the terma*k (*θ*)* and phase modulated by the term b*k(*θ*).* Where, X, is the signal amplitude, N is the sampling rate and k, is the no. of samples.

$$y(\theta) = \sum_{k=0}^{K} [1 + a_k(\theta)] X_k \cos[kN\theta + \phi_k + b_k(\theta)] \qquad (1)$$

Time Domain Analysis

Even before the use of spectrum analyzers the early condition monitoring of machines used to be in time domain. The advent of frequency spectrum analysis made the faults diagnosis apparently easier for rotating machines' faults. The time waveform analysis is getting importance again while researchers are finding it more helpful as compared to any other technique Moslemany M. EL., (1998). The time domain analysis is also relatively cheaper and used for simple less costly machines. However, this technique is not sensitive to small or early-stage defects.

a) Waveform Analysis

The vibration time waveform analysis is extensively used for the detection of gear faults. The frequency analysis is not as helpful as the time waveform in certain faults like gear faults. The time waveform provides information of the vibration amplitude against the time. There are some faulty conditions where the time-waveform performs better than the vibration analysis in frequency domain Moslemany M. EL., (1998), like, low frequency beat vibration, rotor rub, mechanical looseness, broken gear tooth, etc. In the low frequency beat the time-waveform gets modulated by low frequency beats, truncation of time-waveform and non-symmetry are indications of rotor rub, the broken gear tooth appear as impact peaks superimposed on the time-waveform with time interval equal to the inverse of 1xRPM.

b) Orbit Analysis

The orbit analysis is a technique where time vibration signals are used to plot orbits that specifically indicate certain faults. The advantage is that with this technique certain machine faults that are not readily detectable by the spectrum or mere time waveforms are detected by the orbit analysis method like, cracked shaft, loose rotating part, etc. The orbit is developed using two orthogonally located sensors. Figure 10 confirms that the shaft bow induced by the rubs causes very high synchronous vibrations during the run–up Bachschmid. N. (2004).

c) Beta Kurtosis

The Beta distribution can be utilized to rescale and shift to create distributions with a variety of shapes over a range. The beta distribution requires two shaping parameters. The kurtosis of the beta-

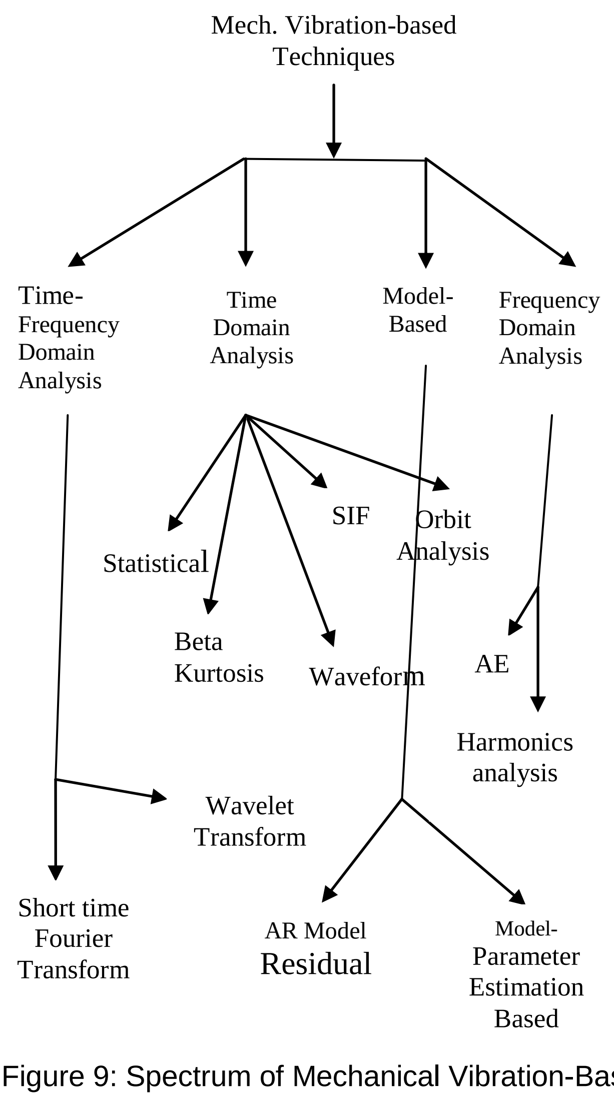

Figure 9: Spectrum of Mechanical Vibration-Based Techniques

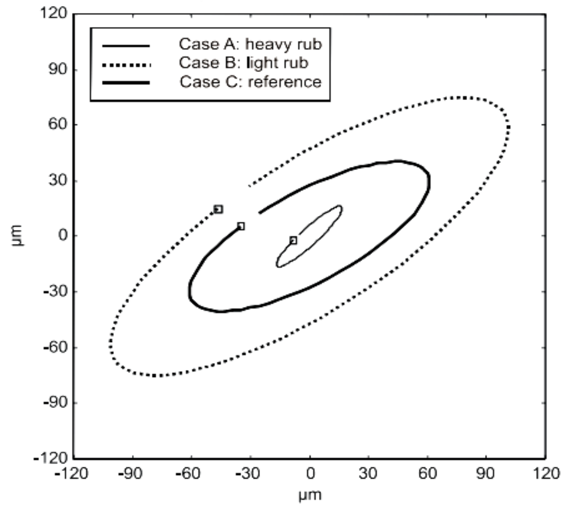

Figure 10. The Orbit Shaping in all the Three Cases Reflects Fault Occurrence [14]

Distribution has been reported in literature as a good indicator of the condition of a gear. The characteristic, or shape, parameters are usually estimated by using both the method of moments and maximum likelihood estimation (MLE) techniques. It is observed that the MLE technique provides better detection performance Wilson Q. Wang, etc. al (2001).The beta distribution describes a family of curves that are unique in that they are nonzero only on the interval (0 1). Kurtosis of the distribution is given as in Eq. 2.

$$6\frac{\alpha^3-\alpha^2(2\beta-1)+\beta^2(\beta+1)-2\alpha\beta(\beta+2)}{\alpha\beta(\alpha+\beta+2)(\alpha+\beta+3)} \quad (2)$$

$$\alpha = m\left[\frac{m(1-m)}{\sigma^2}-1\right] \ , \beta = (1-m)\left[\frac{m(1-m)}{\sigma^2}-1\right] \quad (3)$$

m, is the mean andσ, is the standard deviation.

d) Statistical

i) RMS

The power content in a vibration signal is determined by the root mean square (RMS) value of a time vibration signal. The RMS value is the normalized second order statistical moment of time vibration signal. This is a good measure of overall noise level in the vibration signal; however RMS value does not provide any diagnosis of the faults. Detection of balance in rotating machinery is usually done by calculating the RMS values as given in Eq. (4) and (5) for continuous and discrete samples resp.

$$RMS = \sqrt{\frac{1}{T}\int_0^T (x(t)-\bar{x})^2 dt} \quad (4)$$

Where,

$$\bar{x} = \int_0^T x(t)dt RMS = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1}(x(n)-\bar{x})^2 dt} \quad (5)$$

$$\bar{x} = \frac{1}{N}\sum_{n=0}^{N-1} x(n)dt$$

Where, T, and N, are length of time and total number of discrete samples, respectively.

ii) Kurtosis

Kurtosis is the normalized fourth statistical moment of the signal. It indicates the relative peakiness of the signal as compared to the normal distribution. As in faults related to gear wears and breaks this feature clearly diagnoses the faults that arises due to the increased level of vibration. The equation for kurtosis in cases of discrete and continuous signals is given by, Eq. (6) & (7) for zero mean data, respectively.

$$K = \frac{\frac{1}{N}\sum_{n=0}^{N-1}(x(n)-\bar{x})^4}{(RMS)^4} \quad (6)$$

$$K = \frac{\frac{1}{N}\int_{n=0}^{N-1}(x(n)-\bar{x})^4}{(RMS)^4} \quad (7)$$

iii) Crest Factor

The RMS value measure is found to respond indifferently in the early changes of some faults like, gear and bearing damage. An alternate solution is to use another measure that is obtained by dividing the peak level of the input signal to the RMS level. The crest factor is more sensitive than RMS values if there are peaks in the time series signals. Therefore changes in the signal pattern due to impulses generated by broken tooth of a gear or an outer race defect in a bearing are readily detected. The crest factor is depicted in Eq. (8)

$$CrestFactor = \frac{Peak}{RMS} \quad (8)$$

e) SIFT

Scale invariant feature transform (SIFT)*i*s a technique where features are extracted from the vibration signal through SIFT algorithm that transforms the (one dimension) vibration signal into image (two dimension).The extracted features are then classified using pattern classification techniques, instead of analyzing the vibration signal to determine the machine faults. The vibration signal can be classified to the corresponding faulty category, which presents the machine fault. Machines operating in industrial plants work in noisy environments, and as a result, the useless noise added in the recorded signals is unpreventable. As such, it may be an obstacle for analyzing the vibration signals. However, when the vibration signals are translated into images, the added noise is considered as the illumination of the light to the image Do .V.T, (2011).

Frequency Domain Analysis

a) Harmonics Analysis

The fundamental process in the frequency domain analysis is the conversion of the time domain vibration signal into frequency domain as faithfully as possible. The Discrete Fourier Transform etc is employed for this purpose as given in Eq.9, the letters and symbols in the equation carry the usual meaning.

$$X(m) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)e^{-j2\pi\frac{nm}{N}} \quad (9)$$

The frequencies of the vibrations of components of a rotating machine are present in the overall vibration signature. Therefore introduction of a fault into any of these components produce change in the vibration of the corresponding frequency band of the spectrum Finley, W.R.; Hodowanec, M.M.; Holter, W.G., (1999). The harmonics and their multiples of the fundamental frequency are compared for amplitude, frequency and phase, while measuring vibration in the axial, radial or transverse direction, to match various fault symptoms.

b) Acceleration Enveloping

It is a technique that extracts the periodic impact like signal buried in the complicated time waveform New Tools for Vibration Condition Monitoring, (2011). This is useful in rolling element bearing faults detection and diagnosis. When fault occurs in the rolling element or races of the bearing the hammer like impact is felt over the structure that resonant. The signal processing is aimed at filtering out the impact frequency from the vibration signal of high frequency. The final high pass filtered and full wave rectified signal is the acceleration envelop due to the structure resonances and bearing faults. The threshold at the amplitude of the spectral lines is used to detect the bearing faults very conveniently. The drawback of this technique is the difficulty in setting up the threshold as good baseline information is needed; especially it varies from system to system.

Time-Frequency Domain Analysis

a) Short Time Fourier Transform

The Short-Time Fourier Transform (STFT) is a powerful tool for signal processing. It specifies complex amplitude versus frequency and time for a given signal L. Satish (1998). The conventional FDD methods usually are developed and applied for constant speed machinery. For the non-stationary machinery working its operating conditions influence the vibration signal that may hide the presence of incipient faults or may mask the fault impacts due to the machine impacts. The impacts are due to the normal machine working requirement.

The STFT is therefore needed to overcome the variation of speed that remains present in the machinery speed profile corresponding to the segmented vibration signal. The time-frequency domain permits to analyze the frequency components of the vibration signal along with as time varies. The sum of STFT coefficients is compared to find the fault.

There are some drawbacks associated with STFT, firstly the window length. The wide window yields a good resolution in the frequency but poor resolution in the time domain. Second drawback is that raw STFT is computationally expensive. STFT of a continuous-time signal x (t) is defined as given in Eq. (10).

$$\mathrm{STFT}(f,\tau) = \int x(t)w(t-\tau)\exp(-j2\pi f t)dt \qquad -\infty < t < \infty \qquad (10)$$

Where, w (t) is the window function whose position is translated in time by z.

b) Wavelet Transform

Wavelet analysis is becoming a common tool for analyzing localized variations of power within a time series. By decomposing a time series into time–frequency space, one is able to determine both the dominant modes of variability and how those modes vary in time. The use of the wavelet transform is efficient for fault diagnosis, since the technique gives the information about the signal in the time and the frequency domains[20].Let x (t) denote a continuous-time finite energy signal, then WT of x (t) is defined as in Eq.(11)

$$\mathrm{WT}(a,b) = \int x(t)g_{(a,b)}(t)dt \qquad -\infty < t < \infty \qquad (11)$$

Where, $g_{(a,b)}(t) = |a|^{(-1/2)}g((t-b)/a)$

is called the base function or mother wavelet. a, b (real, a # 0) are the dilation and translation parameters, respectively. The wavelet unlike STFT performs multi-resolution analysis of the vibration signal by making use of short window for high frequencies and long window for low frequencies.

Conclusion

In this paper the overview of various functions and scope of the technical process management is given alongside contribution of mechanical vibration analysis technique is highlighted. Almost a dozen techniques pertaining to vibration analysis are mentioned. It can be gauged undoubtedly the immense potential and expected contribution of the vibration techniques in coming times, like emerging techniques of dynamic energy index (DEI) and cumulative impulse etc. are a valuable addition.

It is also observed that each technique supplements the other technique and has its own unique place and justification for its use. It is also worth mentioning that technical process management enhances process reliability, improves safety, reduces downtime, reduces maintenance cost and check events in their incipient stages that may lead to catastrophic situations.

Nomenclature /Abbreviations

I/O	Input / Output
FDD	Fault detection Diagnosis
EEPROM	Electrically Erasable
CPU	Central Processing Unit
s	slip
Ns	Synchronous speed
f	Line frequency
X	Vibration signal amplitude
y	Vibration amplitude
ϴ	Discrete time
ak	Amplitude modulation term
bk	Phase modulation term
α, β	Beta kurtosis parameters
σ	Standard deviation
m	mean
g()	Mother wavelet
WT()	Wavelet Transform
STFT	Short Term Fourier Transform
SIFT	Scale Invent. Feature Transform
T	Length of time
N	No of total discrete samples
x	Continuous time signal
K	Kurtosis
a, b	Dilation & Translation paramet.

References

[1] Herbert, August, (2009) Intelligent Fault Diagnosis and Control Reconfiguration, IEEE Control Systems, (1994)

[2] Li S., A Model-Based Fault Detection and Diagnostic Methodology for Secondary HVAC Systems, Ph. D. Thesis, and Drexel University.

[3] Fuente, M. J., June (2008) Fault Diagnosis in a Plant Using Fisher Discriminant Analysis, 16th Mediterranean Conference on Control and Automation, pp. 53–58, 25-27.

[4] Azhar S., (2010) Rahman S.A., Application of Artificial Neural Network in Fault Detection Study of Batch Esterification Process, International Journal of Engineering & Technology IJET-IJENS pp. 45-51, Vol.: 10 No: 03,.

[5] PAU L., April (1986) Expert Systems, volume-3, issue 2, Wiley.

[6] Isermann .R, (2006) Fault-Diagnosis Systems, Springer.

[7] Isermann .R, (2005) Model-Based Fault Detection and Diagnosis-Status and Application, Institute of Automatic Control Darmstadt University of Technology.

[8] Fault Detection in IP-Based Process Control Networks Using Data Mining, (2009) Byungchad Park, FIP/IEEE International Symposium on Integrated Network Management,.

[9] Emerson Process Management, Sept. (2009) Delta V Product Data Sheet.

[10] Thomson.W.T., Motor Current Signature Analysis to Detect Faults in Induction Motor Drives-Fundamentals, Data-interpretation, And Industrial Case Histories, Proceeding of the Thirty Second Turbo Machinery Symposium,.

[11] Singh, (2003) Mechanical Vibration and Noise Control Handbook, Basic Concepts of Vibration, Chpater-1,Khana Publishers

[12] Törnqvist .D, Statistical Fault Detection with Applications to IMU Disturbances, (2006) M.S. Thesis, Division of Automatic Control Department of Electrical Engineering Linköpings University.
[13] EL. M. Moslemany, (1998) the Power of Time Waveform in Machinery Diagnosis, Proceedings of the 1st International Symposium on Mechanical Vibrations, Ibd.
[14] Bachschmid N., April-June, (2004) Diagnostic Significance of Orbit Shape Analysis and Its Application to Improve Machine Fault Detection, Journal of the Braz. Sco. Of Mech. Sci. &Engg.
[15] Wang W.Q., etc al, September (2001) Assessment of Gear Damage Monitoring Techniques Using Vibration Measurements, Mechanical Systems and Signal Processing., Volume 15, Issue 5., pp 905-922
[16] Do .V.T, (2011) Signal Model-Based Fault Detection and Diagnosis for Induction Motors Using Features of Vibration Signal in Two Dimension Domain, Journal of Mechanical Engineering,
[17] Finley, W.R.; Hodowanec, M.M.; Holter, W.G., (1999) An Analytical Approach to Solving Motor Vibration Problems, IEEE/ Petroleum and Chemical Industry Conference, pp.217-232,.
[18] New Tools for Vibration Condition Monitoring, Oct-Dec.2011 Hydrocarbon Asia.
[19] Satish L., Short-time Fourier and Wavelet March (1998) Transform for Fault Detection in Power Transformers during Impulse Test, IEE Proc. Sci.Meas.Technol., vol-145, N0.2.
[20] Ghafari S.H., (2007) A Fault Diagnosis System for Rotary Machinery Supported by Rolling Element Bearings, Ph. D. thesis, University of Waterloo, Ontario Canada,.