A STUDY OF THE VIBRATION SIGNALS BEHAVIOUR

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ABSTRACT

Identification of defects in structures and its components is a crucial aspect in decision making about their repair and replacement. This project presents a study on the application of free and force vibration signals on difference surface beam to detect resonance frequency or natural frequency and the statistical characteristics. The well-established statistical parameters such as kurtosis, mean value, standard deviation, RMS and variance are utilized in the study. Free and force vibration experiments are to determine the natural frequency of the beam from the vibration signal and the vibration signal is use to be analysis on statistical analysis. Under ideal conditions, the modal testing method can be used to identify the natural frequency and mode shape, because it more accurate compares to free and force vibration experiment. The effect of surface beam on the performance of the statistical method is also studied. Results from the study show that the statistical parameters are affected by the surface beam due to the change of the beam structure of which have difference natural frequencies

ABSTRAK

Pengenalan kecacatan dalam struktur dan komponen merupakan aspek yang penting dalam membuat keputusan mengenai pembaikian dan penggantian. Projek ini membentangkan kajian atas getaran bebas and paksa terhadap pelbagai permukaan rasuk untuk mengesan frekuensi, resonans dan ciri-ciri statistic. Parameter statistik seperti kurtosis, nilai min, sisihan piawai, RMS dan varians digunakan dalam kajian ini. Eksperimen getaran bebas and paksa adalah untuk menentukan rasuk frekuensi resonans daripada isyarat getaran dan isyarat getaran ini akan gunakan untuk menjadi analisis statistik. Dalam kaedah ujian mod boleh digunakan untuk mengenal pasti frekuensi resonans dan bentuk mod, disebabkan ia lebih tepat dibandingkan dengan getaran bebas dan paksa. Kesan daripada permukaan rasuk bagi statistik juga dikajikan. Hasil daripada kajian menunjukkan bahawa parameter statistik dipengaruhi oleh permukaan rasuk, hal ini disebabkan oleh perubahan rasuk struktur yang mempunyai frekuensi resonans yang berbezaan.

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LIST OF SYMBOLS

$\tilde{x}$	Mean
x_{RMS}	Root mean square
Kur	Kurtosis
$\emptyset$	Phase shift
f_n	natural frequency
ζ	damping ratio

LIST OF ABBREVIATIONS

DUT	Device under test
FFT	The fast fourier transform
DFT	Discrete fourier transforms
IDFT	Inverse discrete fourier transforms
RMS	Root mean square

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

This chapter explains about the background of study, problem statement, objectives and the scopes of this study. The main purpose for this study can be identified by referring at the problem statement of this study. Furthermore, the details of this study and outcome can be achieved on the objectives and its scopes.

1.1 BACKGROUND OF STUDY

Vibration can be mention as the motion of a subject or a body or system of connected bodies and displaced from a position of equilibrium. Some of the vibrations are phenomena that undesirable in machines or structures in our reality life because vibrations can produce stresses, causes the system to lose energy, tools will easily wear and tear. Vibration occurs when a system is displaced from a position of stable equilibrium. Which mean that a system is under the restoring forces such as the elastic forces, gravitational forces like a simple pendulum keeps moving back and forth across its position of equilibrium and at the end system is able to return to the it's equilibrium position. A system is a combination of varies element intended to work with each other to fulfill an object. An automobile like a car is a good example of system whose elements are the wheels, suspension, seat, and car body.

Vibration mostly can divide into a two major part which is free and forced vibration. The different between the two parts can be easy recognizing. Free vibration can be simply represent the natural frequency of a system example the vibration of a pendulum is free vibration which needs no external force to vibrate. While for a forced vibration can be explained when a periodically varying force is applied on a system, the system will vibrate in accordance to the frequency of applied force. The frequency of vibration of the system is the same as the frequency of the applied force.

Vibration signal can be obtain by using vibration transducers which is accelerometers, velocity transducers and displacement transducers. Each vibration transducer has its own specific characteristics and use in different applications depend on the process of vibration analysis. Accelerometers are the famous and most widely used vibration transducers for measuring vibrations on stationary machine elements. An accelerometer is a full-contact transducer mounted directly on a system or device under test (DUT). When a system is vibrate or change in motion will produce a force that causes the mass inside the sensor to "squeeze" the piezoelectric which produces an electrical charge that is proportional to the force exerted upon it. Base from the equation, $F = ma$ the charge produce by the piezoelectric is proportional to the force, while the mass is a constant for anytime, and the charge is proportional to the acceleration. The benefits of an accelerometer include linearity over a wide frequency range and a large dynamic range can be using most accelerometers in hazardous environments because of their rugged and reliable construction.

1.2 PROBLEM STATEMENT

Mostly of the structures or an object are weakened by cracks. When the crack size increases in course of time, the structure becomes weaker than its previous condition. Finally, the structure may breakdown due to a minute crack. Therefore, crack detection and signal vibrate for classification is a very important issue. In this study, free and forced vibration analysis of a cracked beam was performed in order to identify the crack situation and the signal of vibration compare with uncrack beam. Structures is required that must be good in condition during its service life that to confirm that the environment is under guarded and safety. Cracks are among the most encountered damage types in the structures. Cracks in a structure may be hazardous due to static or dynamic loadings, so that study on crack vibration signal plays an important role for structural health monitoring applications.

1.4 OBJECTIVES

The objectives of this project are:

i. To study the natural frequency of the free and forced vibration signals with difference depth of crack.
ii. To study the statistical analysis of the free and forced vibration signals with difference depth of crack.

1.4 SCOPE

The scopes of this project are:

i. Perform experimental testing for the data measurement purposes
ii. Perform statistical analysis and frequency-time domain analysis
iii. Signal classification base on the value of the statistical parameter

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUTION

This chapter is a review of the literature that discusses to identify studies relevant to the topic. The purpose of this chapter is to know more about the detail of the cracked beam vibration signal under the free and forced axial loading analysis by using DASY LAB software. There are three categories discuss in this chapter: type of vibration, frequency and time domain and the statistical analysis. The first topic explains about the signal. The second topic explains about variable forces and force act on the cracked beam. The third topic explains about the frequency on the reaction beam when it vibrates. Lastly fourth topic explains about the statistical analysis that used to classify the signal based on the statistical parameter.

2.1 SIGNAL

Signal is detectable transmitted energy that can be used to carry information. Beside signal also is time-dependent variation of a characteristic of a physical phenomenon, used to convey information. Signal can as applied to electronics, any transmitted electrical impulse. Operationally, signal is a type of message, the text of which consists of one or more letters, words, characters, signal flags, visual displays, or special sounds, with prearranged meaning and which is conveyed or transmitted by visual, acoustical, or electrical means. The measured signal is usually converted into an electric signal, which it passed through a series of electrical or electronic circuits to achieve the required processing. (Leonhard, 1999)

2.1.1 Random

Random signals are random variables which evolve, often with time, but also with distance or sometimes another parameter. White noise is a random signal or process with a flat power spectral density. In other words, the signal contains equal power within a fixed bandwidth at any centre frequency. Random signals are unpredictable in their frequency content and their amplitude level, but they still have relatively uniform statistical characteristics over time. Examples of random signals are rain falling on a roof, jet engine noise, turbulence in pump flow patterns and cavitation. (Shanmugam & Breiphol, 1988)

2.1.2 Stationary

The first natural division of all signals is into either stationary or non-stationary categories. Stationary signals are constant in their statistical parameters over time. If look at a stationary signal for a few moments and then wait an hour and look at it again, it would look essentially the same. Rotating machinery generally produces stationary vibration signals. (Groepner, 1991)

2.1.3 Non-Stationary Signals

Non-stationary signals are divided into continuous and transient types. Transient signals are defined as signals which start and end at zero level and last a finite amount of time. They may be very short, or quite long. Examples of transient signals are a hammer blow, an airplane flyover noise, or a vibration signature of a machine run up or run down. (Crocker & Malcom, 1998)

2.1.4 Deterministic Signal

Deterministic signals are a special class of stationary signals, and they have a relatively constant frequency and level content over a long time period. Deterministic signals are generated by rotating machines, musical instruments, and electronic function generators. They are further divisible into periodic and quasi-periodic signals. Periodic signals have waveforms whose pattern repeats at equal increments of time, whereas quasi-periodic signals have waveforms whose repetition rate varies over time, but still appears to the eye to be periodic. Sometimes, rotating machines will produce quasi-periodic signals, especially belt-driven equipment. (Temme, 1998)

2.2 FREE VIBRATION

The simplest natural vibration system, having mass and a linear stiffness element, in a time domain gives rise to pure harmonic motion. Free vibration occurs when a mechanical system is set off with an initial input and then allowed to vibrate freely. Real free vibration always gradually decreases in amplitude due to system energy losses. Free vibration also is the natural response of a structure to some impact or displacement. The response is completely determined by the properties of the structure, and its vibration can be understood by examining the structure's mechanical properties. (Feldmen, 1985)

For the steady state (solid line), the signal of vibration is in steady mode, smooth and average show in figure 2.1. Steady state vibration exists in a system if the velocity is a continuous periodic quantity. (Lin & Hsiao, 2001)

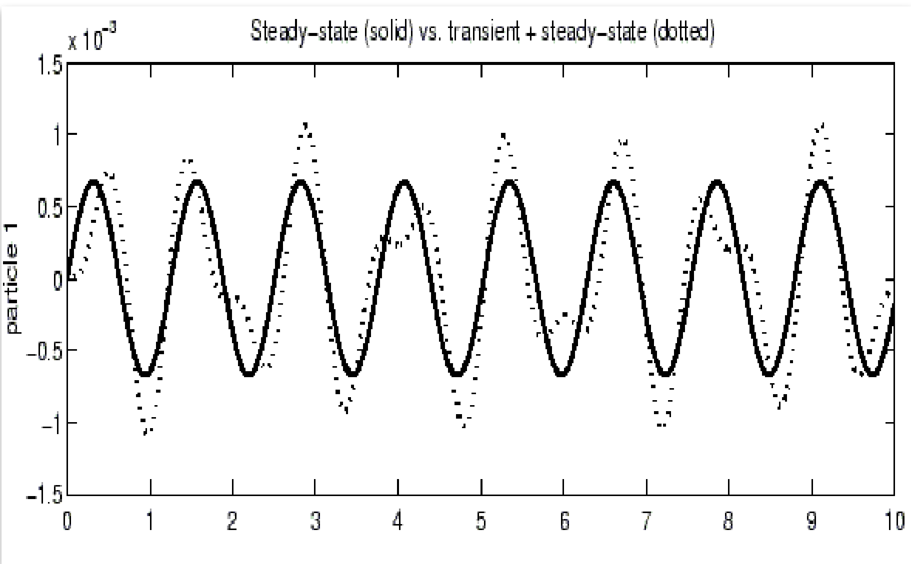

Figure 2.1: Steady State

The questions for free vibration without damping:

$$F = -kx \tag{2.1}$$

F is represent as the force generated by the system, k is represent the stiffness of the spring and x is represent the amplitude of the vibration.

Amplitude x also can be derived as below:

$$x(t) = Acos(2\pi f_n t) \tag{2.2}$$

A is represent by maximum amplitude of the vibration system, f_n is represent by the un-damped natural frequency and t is represent the vibration time.

Natural frequency f_n also can be derived as below:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{2.3}$$

k is represent by the stiffness and m is represent the mass. (Chen & Yang, 1985)

The equations for free vibration with damping:

$$F = -c\dot{x} \tag{2.4}$$

c is represent the damping coefficient and $\dot{x}$ is represent the velocity.

The equations for un-damped natural frequency:

$$f_d = \sqrt{1 - \zeta^2 f_n} \tag{2.5}$$

f_n is represent the natural frequency and ζ is represent the damping ratio ζ also can derive as below:

$$\zeta = \frac{c}{2\sqrt{km}} \tag{2.6}$$

c is represent the damping coefficient, k is represent by the stiffness and m is represent the mass.

The damped natural frequency is less than the un-damped natural frequency, but for many practical cases the damping ratio is relatively small and hence the difference is negligible. Therefore the damped and un-damped description is often dropped when stating the natural frequency. (Hagood & Flotow, 1991)

2.3 FORCED VIBRATION

Forced vibration is the response of a structure to a repetitive forcing function that causes the structure to vibrate at the frequency of the excitation. In forced vibration there is a relationship between the amplitude of the forcing function and the corresponding vibration level. The relationship is dictated by the properties of the structure. Forced vibration is when an alternating force or motion is applied to a mechanical system. (Oniszczuk, 2003)

The equations for forced vibration with damping:

$$F = F_0 \cos(2\pi f t) \tag{2.7}$$

Sum the forces on the mass:

$$m\ddot{x} + c\dot{x} + kx = F_0 \cos(2\pi f t) \tag{2.8}$$

The steady state:

$$x(t) = Xcos(2\pi f t - \emptyset) \tag{2.9}$$

The result states that the mass will oscillate at the same frequency, f of the applied force, but with a phase shift, $\emptyset$.

The amplitude of the vibration X is defined by the following formula.

$$X = \frac{F_0}{k} \frac{1}{(1-r^2)^2 + (2\,\zeta r)^2} \tag{2.10}$$

Where r is represent as the ratio of the harmonic force frequency over the un-damped natural frequency of the mass-spring-damper model.

$$r = \frac{f}{f_n} \tag{2.11}$$

The phase shift$\emptyset$, is defined by following formula.

$$\emptyset = arctan(\frac{2\,\zeta r}{1-r^2}) \tag{2.12}$$

Transient vibration is defined as a temporarily sustained vibration of a mechanical system. It may consist of forced or free vibrations, or both. Transient loading, also known as impact, or mechanical shock, is a non-periodic excitation, which is characterized by a sudden and severe application. For the figure 2.2 of forced vibration, the signal of vibration is not steady at the start but will become stable after a period. (Timoshenko & Young, 1974)

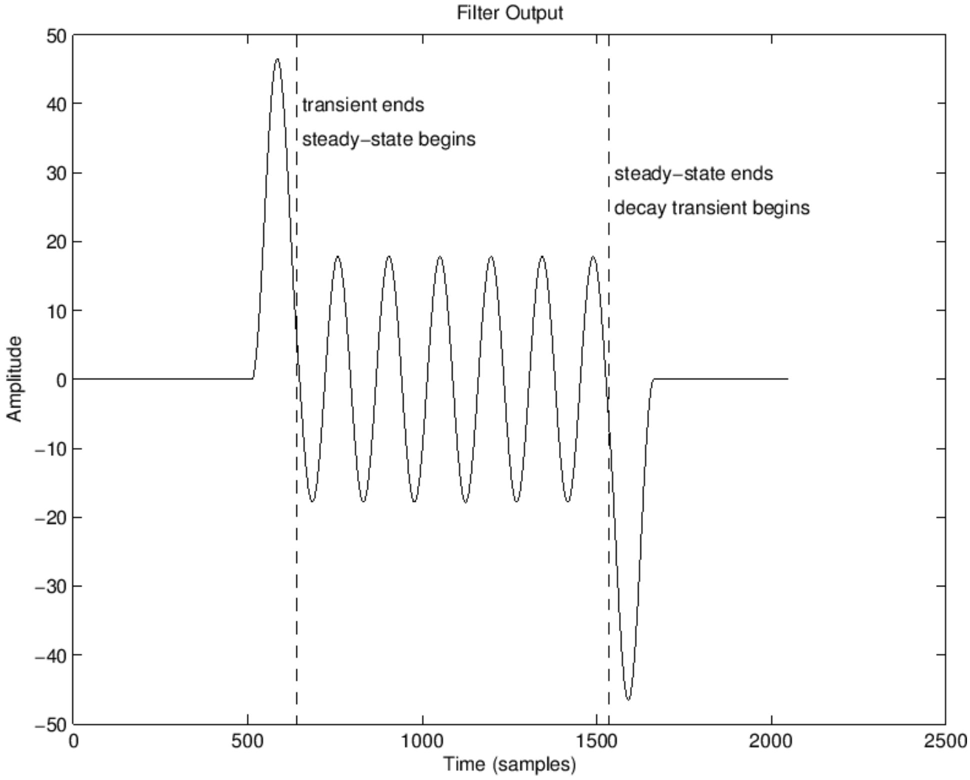

Figure 2.2: Steady State and Transient

2.4 FREE AND FORCED VIBRATION ON CRACKED BEAM

Kim and Zhao (2004) proposed a novel crack detection method using harmonic response. In their method, displacement and slope modes of a cracked cantilever beam are considered first, and then the approximate formula for displacement and slope response under single-point harmonic excitation is derived. They conclude that the slope response has a sharp change with the crack location and the depth of crack, and therefore, it can be used as a crack detection criterion. Ruotolo et al (1996) investigated forced response of a cantilever beam with a crack that fully opens or closes, to determine depth and location of the crack. In their study, left end of the beam is cantilevered and right end is free. The harmonic sine force was applied on the free end of the beam. Vibration amplitude of the free end of the beam was taken into consideration. It was shown that vibration amplitude changes, when depth and location of the crack change.

Pugno and Surace (2000) analyzed the response to harmonic sinusoidal force of a cantilever beam with several breathing cracks of different size and location, using a harmonic balance method. Their conclusion is that the presence of breathing cracks in a beam results in a nonlinear dynamic behaviour which gives rise to super harmonics in the spectrum of the response signals, the amplitude of which depends on the number, location and depth of any cracks present. Moreover, they stated that the harmonic balance method reduces the computation times by approximately 100 times compared to direct numerical integration.

The free bending vibrations of an Euler-Bernoulli beam of a constant rectangular cross-section are given by the following differential equation as given in below:

$$EI\frac{d^4y}{dx^4} - mw_i^2 y = 0 \tag{2.13}$$

Where m is the mass of the beam per unit length (kg/m) w_i is the natural frequency of the i th mode (rad/s), E is the modulus of elasticity (N/m^2) and, I is the area moment of Inertia (m^4).

By defining $\lambda^4 = \frac{w_i^2 m}{EI}$ is rearranged as a fourth-order differential equation as follows:

$$\frac{d^4y}{dx^4} - \lambda_i^2 y = 0 \tag{2.14}$$

The general solution is:

$$y = Acos\lambda_i x + Bsin\lambda_i x + Ccosh\lambda_i x + Dsinh\lambda_i x \tag{2.15}$$

Where A, B, C, D are constants and λ_i is a frequency parameter. Since the bending vibration is studied, edge crack is modeled as a rotational spring with a lumped stiffness. The crack is assumed open. Based on this modeling, the beam is divided into two segments: the first and second segments are left and right-hand side of the crack, respectively. When this equation is solved by applying beam boundary conditions and compatibility relations, the natural frequency of the i th mode for un-cracked (2.16) and cracked beams (2.17) is finally obtained.

$$w_{i0} = c_i\sqrt{\frac{EI}{mL^4}} \tag{2.16}$$

$$w_i = r_i c_i\sqrt{\frac{EI}{mL^4}} \tag{2.17}$$

Where w_{i0} is the ith mode frequency of the un-cracked beam and c_i is a known constant depending on the mode number and beam end conditions. w_i is the ih mode frequency of the cracked beam, r_i is the ratio between the natural frequencies of the cracked and un-cracked beam. L is length of the beam. (Dado, 1997)

2.5 FREQUENCY AND TIME DOMAIN

Frequency analysis also provides valuable information about structural vibration. Any time history signal can be transformed into the frequency domain. The most common mathematical technique for transforming time signals into the frequency domain is called the Fourier Transform, after the French Mathematician Jean Baptiste Fourier. The math is complex, but today's signal analyzers race through it automatically, in real-time. Fourier Transform theory says that any periodic signal can be represented by a series of pure sine tones. In structural analysis, usually time waveforms are measured and their Fourier Transforms computed. The Fast Fourier Transform (FFT) is a computationally optimized version of the Fourier Transform. (Ratcliffe, 1997*)*

The equation for Discrete Fourier transforms (DFT):

$$X(k) = \sum_{k=0}^{N-1} x(n)W_N^{kx} \text{ , } 0 \leq k \leq N-1 \tag{2.18}$$

$$W_N = e^{\frac{-j2\pi}{N}} \tag{2.19}$$

The equation for Inverse Discrete Fourier transforms (IDFT),

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k)W_N^{-kx} \text{ , } 0 \leq n \leq N-1 \tag{2.20}$$

Time domain analysis starts by analysing the signal as a function of time. An oscilloscope, data acquisition device, or signal analyser can be used to acquire the signal. The plot of vibration versus time provides information that helps characterize the behaviour of the structure. It behaviour can be characterized by measuring the maximum vibration or the peak level, or finding the period time between zero crossings. (Senra & Correa, 2002)

Loutridis (2005) applied the instantaneous frequency and empirical mode decomposition methods for crack detection in a cantilever beam with single breathing crack, example, opens and closes during vibration. They investigated the dynamic behaviour of the beam under harmonic excitation, both, theoretically and experimentally. A single degree-of-freedom mathematical model with varying stiffness is employed to simulate the dynamic response of the beam. They modelled the time varying stiffness using a simple periodic function. Both simulated and experimental response data are analysed by applying empirical mode decomposition and the Hilbert transform. By this way, the instantaneous frequency of each oscillatory mode is obtained. They concluded that the variation of the instantaneous frequency increases with increasing crack depth and the harmonic distortion increases with crack depth following definite trends and can also be used as an effective indicator for crack size. They also stated that the proposed time-frequency approach is superior compared to Fourier analysis.

Differences in natural frequencies for different crack depth and location have been used for crack detection for a long time. It is reported that the natural frequency shift is not very sensitive to cracks. For example, a modal frequency shift of less than 5% was obtained for a crack depth of 50% of the structure thickness. Thus, researchers have been studied alternative methods. The harmonic response analysis is one of the alternative methods. (Han, 2005).

2.6 STATISTICAL ANALYSIS

Statistics is a mathematical science and study of how to collect, organize, analysis, interpreted, or in the way to present a set of data. Basically statistics can be consider in mathematical body of science pertaining to the collection, analysis, interpretation or explanation, and presentation of data (Moses & Lincoln, 1986), while on the other hand, statistics may also consider it a branch of mathematics (Hays & William, 1973) concerned with collecting and interpreting data. Statistics usually considered being a distinct mathematical science rather than a branch of mathematics, because of its empirical roots and its focus on applications. (Moore & David, 1992)

Statistics is closely related to the probability theory, with which it is often grouped and the difference is roughly that in probability theory, one starts from the given parameters of a total population to deduce probabilities pertaining to samples, but statistical inference moves in the opposite direction, inductive inference from samples to the parameters of a larger or total population.

2.6.1 STATISTICS PARAMETER

In statistics, mean can define as arithmetic mean of a sample also called the un-weighted average. Equation for mean:

$$\tilde{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i \qquad (2.21)$$

$\tilde{x}$ is represent mean, n is represent the total number of the data in a set of values, and x_i is represent the data. The mean is the minimum point, by dividing a series of numbers in to an average point (Feller & William, 1950)

The root mean square also defines as the quadratic mean. The root mean square is a statistical measure of the magnitude of a set of numbers. Equation for RMS:

$$x_{RMS} = \sqrt{\frac{\sum_{i=1}^{n} x_i^2}{n}} \qquad (2.22)$$

x_{RMS} is represent root mean square, n is represent the total number of the data in a set of values, and x_i is represent the data. The root mean square is square root of the average of the squares of a variable quantity. (Cartwright & Kenneth, 2007).

Kurtosis characterizes the relative peakedness or flatness of a distribution compared to the normal distribution. Equation of kurtosis:

$$Kur = \frac{\sum_{i=1}^{n}(x_i - \tilde{x})^4}{(n-1)s^4} \tag{2.23}$$

$\tilde{x}$ is represent mean, n is represent the total number of the data in a set of values, and x_i is represent the data, s is standard deviation (Kevin & MacGillivray, 1988). Positive kurtosis indicates a relatively peaked distribution (figure 2.3). Negative kurtosis indicates a relatively flat distribution (figure 2.4)

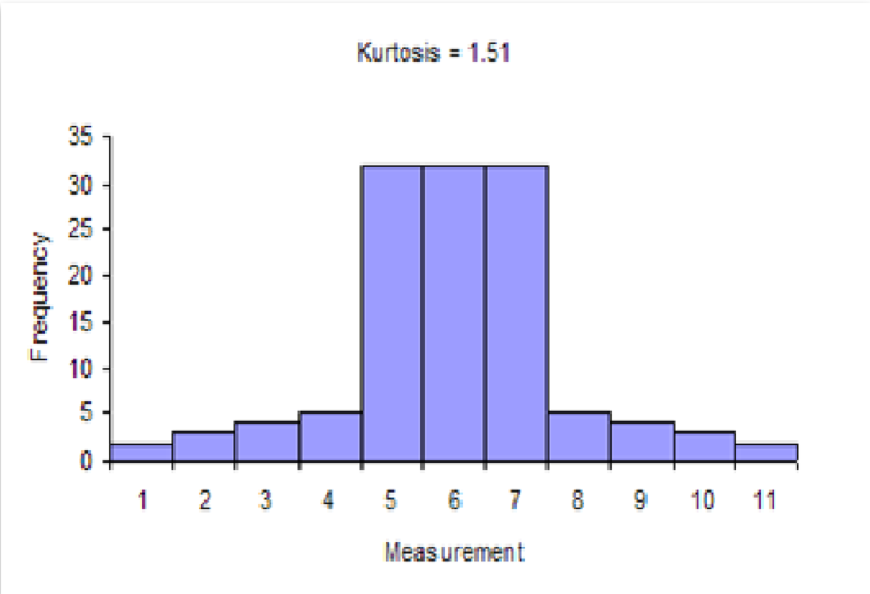

Figure 2.3: Distribution with Too Much Peak (Kurtosis > 0)