FREQUENCY DOMAIN ANALYSIS ON ACOUSTIC EMISSION SIGNAL IN BONE TISSUES

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ABSTRACT

The purpose of this study is to study acoustic emission signal in bone tissues. The objectives of this research are to determine acoustic emission (AE) signal in different types of bone tissue; hard and soft bone’s tissue and to observe the trend of acoustic emission signal for penetration during pedicle screw fixation procedure. It also to propose a method to help medical practitioner in penetration process during pedicle screw fixation procedure using acoustic emission technique. Generally, the medical practitioner had a hard time while doing the pedicle screw fixation procedure when it involved with cervical spine. The cervical spine is the most complicated articular system in the body because the anatomy of the region which are close to spinal cord. This study would help to monitor the penetration process. For this study, goat vertebras were use as specimen. During pedicle screw fixation procedure, pedicle probe is used to penetrate the specimen and sensor captured the AE signal and recorded data with help of AEWin Software. Using FFT analysis the result show dominant frequency in compact bone is high compare to spongy bone. AE signal also can be measure when pedicle probe penetrated through the interface of the bone tissues during the pedicle screw fixation procedure. In conclusion, AE technique can use for monitoring acoustic emission signal produced by specimen in pedicle screw fixation procedure.

ABSTRAK

Tujuan kajian ini adalah untuk mengkaji isyarat pancaran akustik dalam tisu tulang. Objektif kajian ini adalah untuk menentukan isyarat pancaran akustik (AE) dalam tisu tulang yang lembut dan keras dan untuk melihat pola isyarat pancaran akustik untuk penembusan semasa prosedur pemasangan skru. Tujuan kajian ini juga adalah untuk mencadangkan satu kaedah untuk membantu pengamal perubatan dalam proses penetrasi semasa prosedur pemasangan skru menggunakan teknik pelepasan akustik. Kebiasaannya, pengamal perubatan mengalami kesukaran ketika melakukan prosedur pemasangan skru apabila melibatkan dengan tulang servikal. Tulang servikal merupakan sistem artikular yang paling rumit di dalam badan kerana berhampiran dengan saraf tunjang. Kajian ini akan membantu untuk memantau proses penetrasi. Untuk kajian ini, tulang belakang kambing telah digunakan sebagai spesimen. Semasa prosedur pemasangan skru, prob pedikel digunakan untuk menembusi spesimen dan sensor akan menangkap isyarat AE dan merekodkan data dengan bantuan perisian AEWin. Dengan menggunakan FFT analisis, frekuensi dominan dalam tulang padat adalah lebih tinggi berbanding tulang berongga. Isyarat AE juga boleh diukur apabila prob pedikel menembusi tisu tulang semasa prosedur pemasangan skru. Kesimpulannya AE teknik boleh digunakan untuk memantau isyarat pancaran akustik yang dihasilkan oleh spesimen dalam prosedur pemasangan skru.

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AE	Acoustic emission
FDA	Frequency domain analysis
FFT	Fast Fourier Transform

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In medical practices, bone penetration is one of the processes that need to be master by physicians especially by orthopaedic surgeon. In orthopaedic surgery always involved the musculoskeletal system and surgeon need to use both surgical and non-surgical means to treat musculoskeletal trauma, sports injuries, degenerative diseases, infections, tumours and congenital conditions. Before this, bone penetrations used in surgery totally depend on surgeon's manual skills to stop the penetration when completing a hole. Human bones consist of cancellous and cortical bones that are very different in density and thickness. This soft and hard bone tissue could be estimated in order to assist the surgeon while penetration process. During the procedure, the surgeon has to insure uniform penetration through the bone. The problem in bone penetration can sometimes be the occurrence of bone necrosis, which means the irreversible death of bone cell near the hole.

The need of pedicle screw fixation is important in treating the bone fracture, causes many researcher and organizations are trying to build any devices or ways in order to improve penetration technique, which is relatively low cost and time saving. During the penetration process, a hole to fix screw needed and it is totally depending on the surgeon manual skill to complete a hole. The surgeon has to put enough pressure according to the bone tissue either hard or soft. Sometimes, it is hard for surgeon to complete a hole in cervical or thoracic region because the anatomy of the region itself are closed to spinal cord and major vein that could lead to other side effect to the patient if the process goes wrong. Realizing the shortage that could risk the patient, this study would enhance the process with the knowledge of acoustic emissions (AE) to ensure the safety of the patients and give courage and confident to the surgeon while doing this procedure.

In this project, the acoustic emission (AE) technique was use to monitor the penetration process. This technique was developed base on the theory of transient elastic waves that emitted from rapid strain energy release inside a material that subjected to stress. Acoustic Emission signal events will give different results when across these layers and to study the trend and it characteristics the results was investigate. During penetration procedure, pedicle probe used by surgeon when perforating a hole produced elastic wave. The AE sensors that attached at the vertebra sensed the transient elastic wave known as AE signal events. The AE signal events was further analysed to indicate the component’s condition into the time and frequency domain. Time and frequency domain will justify some parameter such as peak amplitude and frequency.

1.2 OBJECTIVES

For this project, two main objectives are list as below:

i. To determine Acoustic Emission (AE) signal in different types of bone tissue; hard and soft bone’s tissue.
ii. To observe the trend of Acoustic Emission signal for penetration during pedicle screw fixation procedure.

1.3 SCOPE OF STUDY

For this case study, the acoustic emission technique used to monitor penetration in the bone. An animal bone penetrated into the tissue; for the real situation, human bones will be use, usually at spinal cord. During the process, the acoustic emission signal acquired. Data from the acoustic emission signal were then analysed using frequency domain analysis in order to get acoustic characteristic whenever the tissues hit in term of time domain. Acoustic emission is a suitable method for recognizing the crossing of interfaces between the hard and soft tissues to discriminate among layers of different tissues.

1.4 PROJECT BACKGROUND

The problem of bone fracture in medicine has existed from the times when humans started to treat other people and animals. In case of fracture, it is most important to return the fractured parts into their initial position and to fixate them in the best possible way. In modern medicine, there are two basic approaches to fracture; a conventional approach and a direct one. In the conventional approach, the immobilisation of the fractured parts done from the outside. The surgeons treat the fracture by setting it and placing the immobilisation aids from outside. A great disadvantages of this approach lies in the fact that the fractured parts cannot be optimally aligned, and in case of some types of bone fractures the alignment from outside is not possible. Besides, long patient recovery is an additional disadvantage of this approach. The direct approach, on the other hand, is a more recent method in which the surgeon penetrated the bone around the fracture site in order to set the immobilisation screws and plates and perform bone fixation. Pedicle probe was use by surgeons while pedicle screws fixation process. This research is important to surgeon in order to monitor the penetrations procedure that vital in orthopaedic surgery. It can assist the surgeon in the perforation process to be more precisely and accurately. This research also can help the surgeon from doing careless mistake in order to save life. The interests in monitoring penetration or perforation processes, frequency domain become very essential since it is relatively low cost and the result could be save more life and pain.

CHAPTER 2

LITERATURE REVIEW

2.1 BASIC BONE ANATOMY

Bone is the basic unit of the human skeletal system and provides the framework for and bears the weight of the body, protects the vital organs, supports mechanical movement, hosts hematopoietic cells, and maintains iron homeostasis. A bone is made-up of several different tissues working together (Yang, 2010). Bone tissue is a specialized form of connective tissue and is the main element of the skeletal tissues. It is composed of cells and an extracellular matrix in which fibres are embedding. Bone is a hard, but brittle, tissue and is relatively light per unit volume. Bone is a dynamic tissue, which throughout life bone tissue is continually being forms and resorbed.

2.1.1 Function Of Bone Tissue

Skeletal system is the biological system providing support in living organism, which is build from bone tissue. Bone provides the internal support of the body and sites of attachment of tendons and muscles that is essential for locomotion. It also provides protection for the vital organs of the body where the skull protects the brain and the ribs protect the heart and lungs and is need to assist in movement along with skeletal muscles. The skeleton functions not only as the support for the body but also in haematopoiesis. The hematopoietic bone marrow is protects by the surrounding bony tissue. The main store of calcium and phosphate is in bone. Bone has several metabolic functions especially in calcium homeostasis.

Bone tissue can be classified in several ways, including texture, matrix arrangement, maturity, and developmental origin. Bone in human and other mammal bodies are generally classifies into two main categories of tissues that is cortical bone also known as compact bone and trabecular bone also known as cancellous or spongy bone (Yang, 2010). These two types are classifies based on texture of cross sections. Cortical bone is founds to be primary in the shaft of long bones and form the outer shell around spongy bone at the end of joints and vertebrae. Spongy bone is sponge like with numerous cavities. It is located within the medullary cavity and consists of extensively connected bony trabeculae that are oriented along the lines of stress. It is founds to be in the end of long bones in vertebrae and in flat bones like the pelvis (Yang, 2010).

2.1.2 Compact Bone

In compact bone, tissue contains few spaces and is the strongest form of bone tissue. Compact bone is ivory like and dense in texture without cavities. It is the shell of many bones and surrounds the trabecular bone in the centre. Compact bone consists mainly of haversian systems or secondary osteons tissue that arranged into repeating units (Yang, 2010). Bones are characterized anatomically as long bones (humerus, femur), flat bones (membrane bones) and irregular bones (such as the vertebrae). Usually, compact bone tissue is found beneath the periosteum of all bones and it form as diaphyses of long bones. Furthermore, the used of compact bone tissue is to provides protection and support and resists the stresses produced by weight and movement. These osteons are aligns in the same direction along lines of stress (Yang, 2010).

2.1.3 Spongy Bone

In contrast to compact bone, complete osteons are usually absent in sponge bone due to the thinness of the trabeculae; lamellae arranged in an irregular lattice of thin columns or network of branching bone spicules. The macroscopic spaces between the trabeculae help make bone lighter and sometimes it can be fills by red bone marrow (Yang, 2010). Spongy bone tissue forms most of the bone tissue of short, flat and irregularly shaped bones. The trabeculae of spongy bone tissue also are precisely oriented along lines of stress that it is very important to help bones resist stresses and transfer force without breaking. Usually, spongy bone tends to be located where bones are not heavily stresses or where stresses are applies from many directions. Spongy bone tissue is light, which reduces the overall weight of a bone and as a result it move more readily when pulled by a skeletal muscle. Sponge bone is also more metabolically active than compact bone because of its much larger surface area for remodelling (Yang, 2010). All these bone types, regardless of their anatomical form, are composed of both spongy and compact bone.

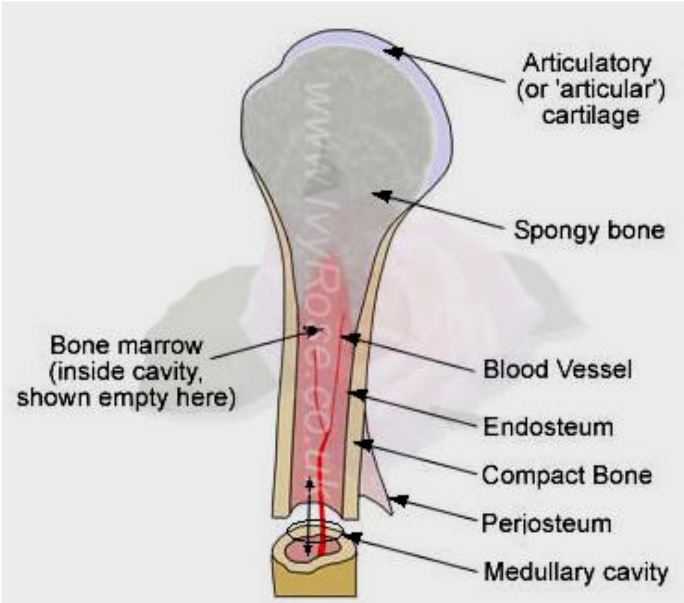

Figure 2.1: Compact and Spongy Bone

Source: Rose (2007)

2.1.4 Vertebral Column

The vertebral column (Figure 2.2) also called spine or backbone formed about two-fifths of human total height and consists of a series of bones called vertebrae. The vertebral column consists of bone and connective tissue; the spinal cord that is surrounds and protects consists of nervous and connective tissues (Cumming, 2007). Besides, the vertebral column functions as a strong, flexible rod with elements that can move forward, backward and sideways either rotate. In addition to protecting and enclosing the spinal cord, it supports the head and serves as a point of attachment for the ribs, pelvic girdle and muscles of the back. The vertebral column can be show as in figure below.

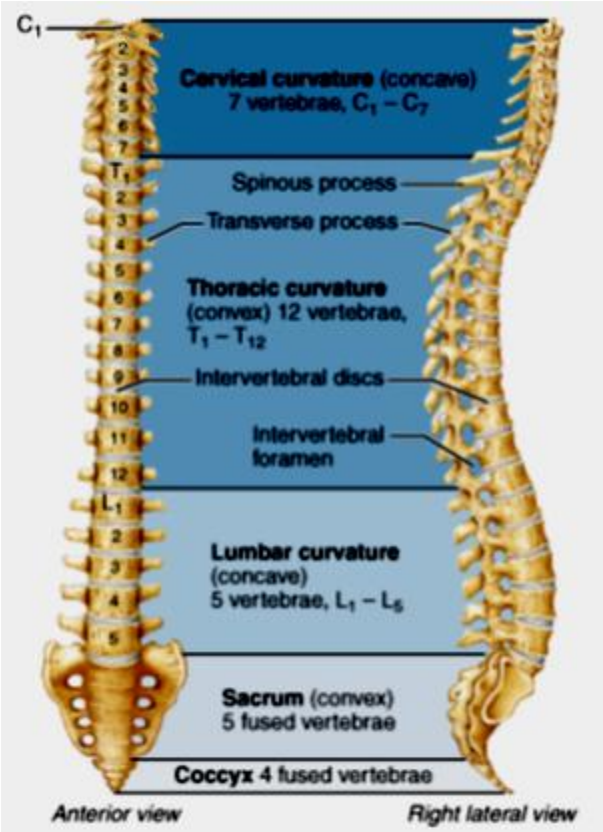

Figure 2.2: Anterior view and right lateral view

Source: Cumming (2007)

2.1.5 Region of Vertebral Column

The vertebral columns consist of five regions that vertebrae in each region numbered in sequence, from superior to inferior. The regions known as cervical region, thoracic region, lumbar region, sacrum and lastly is coccyx. According to the physician, the most risky part during the process is the cervical region because it is smalls compared to other region and close to bloodline and spinal cord itself.

2.1.6 Cervical Region

The cervical region is the upper part of the spine that begins directly below the skull and ends at the top of the thoracic spine. Seven vertebrae and the discs that separate them constitute the cervical region (Jenkins, 2009). These vertebrae, designated C1 through C7, shaped like a backward C, forming a lordotic curve. The lumbar section of the spine forms a similar curve, while the thoracic and the sacral regions of the spine form kyphotic curves. This configuration of opposing curves helps distribute the mechanical stress that continually bombards the spine.

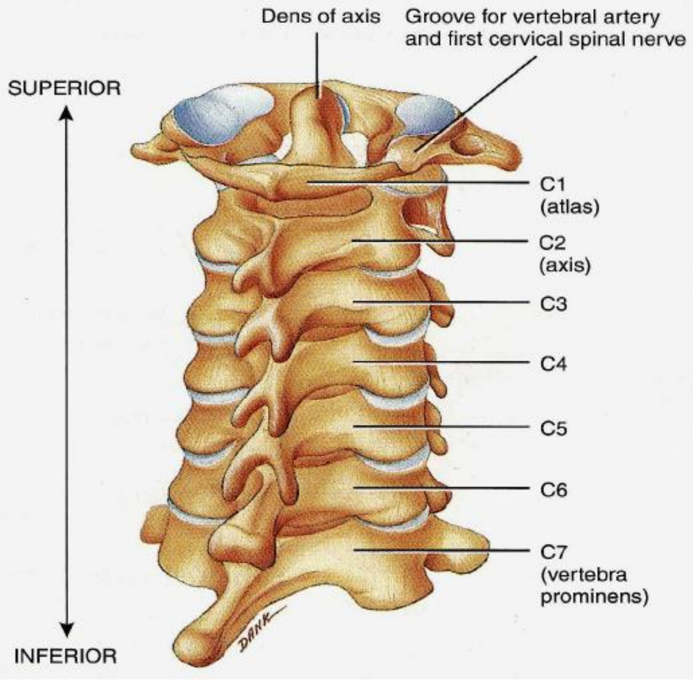

Figure 2.3: Posterior view of cervical vertebrae

Source: Tortora et al. (2006)

2.1.7 Pedicle Screw

Bone screws had been use in spinal instrumentation since the 1960s. A pedicle screw is a particular type of bone screw designed for implantation into a vertebral pedicle (Susan, 2010).The pedicle screw, which is sometimes use as an adjunct to spinal fusion surgery, provides a means of gripping a spinal segment. The screws themselves do not fixate the spinal segment, but act as firm anchor points that can be connect with a rod (Peter et al., 2009).

The screws were place at two or three consecutive spine segments (lumbar segment 4 and 5) and then a short rod was use to connect the screws. This construct prevents motion at the segments that fused.

Figure 2.4: MRI of Pedicle Screws in Place (lateral view)

Source: Peter et al. (2009)

Nowadays, polyaxial pedicle screw made of Titanium, which is highly resistant to corrosion and fatigue, and is MRI compatible. The screw was thread and the head is mobile; it swivels helping to defray vertebral stress. Polyaxial pedicle screw length ranges from 30mm to 60mm (up to 2-1/2 inches). The diameter ranges from 5.0mm to 8.5mm (up to 1/4 inch) (Susan, 2010).These screws are use to correct deformity, and/or treat trauma. Similar to other bone screws, pedicle screws may be use in instrumentation procedures to affix rods and plates to the spine. The screws may also be use to immobilize part of the spine to assist fusion by holding bony structures together.

Initially, the safety and effectiveness of pedicle screws was call into question. However, the initial controversy has been favourably resolved and pedicle screws are now approve by the FDA for use in the lower (lumbar) spine for specific conditions. There is, however, a steep learning curve in the technique for placing the pedicle screws, and only surgeons comfortable and experienced with the technique should use those **(**Peter et al., 2009).

2.2 ACOUSTIC EMMISION (AE)

Acoustic emission is the elastic energy that is spontaneously release by materials when they undergo deformation. In the early 1960s, a new non-destructive testing technology was born when it was recognize that growing cracks and discontinuities in pressure vessels could be detect by monitoring their acoustic emission signals. Formally, defined, acoustic emission is "the class of phenomena where transient elastic waves are generated by the rapid release of energy from localized sources within a material, or the transient elastic waves so generated" (McIntire, 2011). A wide variety of structures and can be monitored by acoustic emission techniques during the application of an external stress (load). The primary acoustic emission mechanism varies with different materials and should be characterize before applying acoustic emission techniques to a new type of material (Miller, 2011). Once the characteristic acoustic emission response has been define, acoustic emission tests can be use to evaluate the structural integrity of a component.

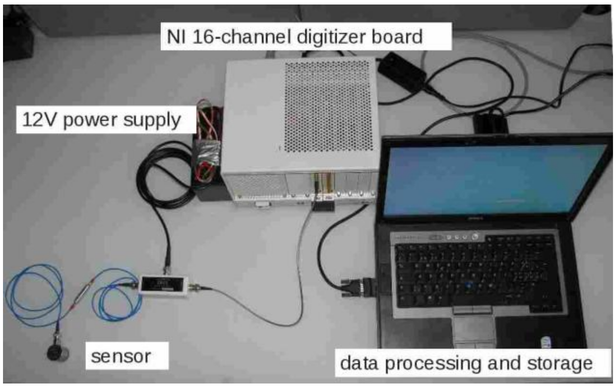

Figure 2.5: Acoustic Emission equipment

Source: Acoustic Emission journal

2.2.1 Detection of AE Signals

Sources of AE include many different mechanisms of deformations and fracture whilst the detection process remains the same. As a crack grows, a number of emissions are releases. When the AE wave front arrives at the surface of a test specimens minute movements of the surface molecules occur. The function of AE sensors is to detect this mechanical movement and convert it into a useable electric signal. This process can be describes as signal detection (Holford, 2005).

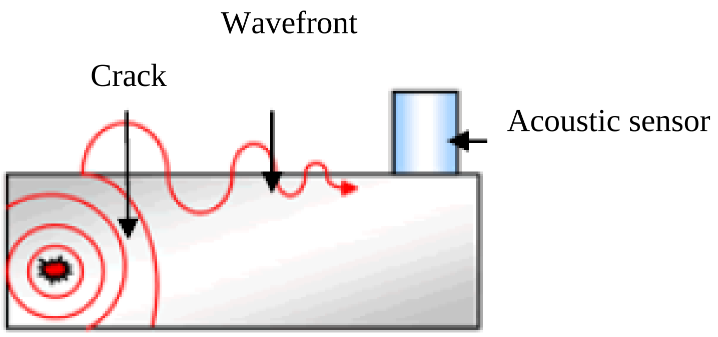

Figure 2.6: AE Detection

Source: http://www.acousticemission.net

2.2.2 Processing of AE Signals

The sensor is attach to the test surface and held in place with tape or adhesive. An operator then monitors the signals, which are excite by the induced stresses in the object. When a useful transient, or burst signal is correctly obtained, parameters like amplitude, counts, measured area under the rectified signal envelope (MARSE), duration, and rise time can be gathered (Holford, 2005).

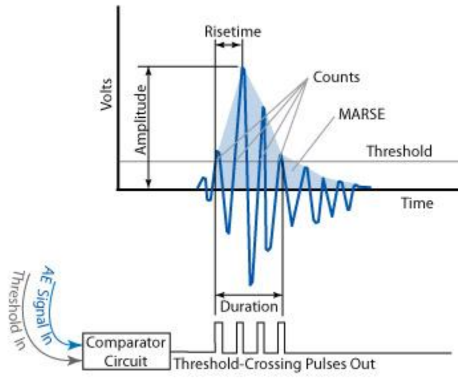

Figure 2.7: Acoustic Emission signals

Source: http://www.ndt-ed.org

2.2.3 Displaying AE Signals

Location of collected waveforms identifies the origin of the detected AE events. These can be graphed by X coordinates, X-Y coordinates, or by channel for linear computed-source location, planar computed-source location, and zone location techniques. Activity displays show AE activity as a function of time on an X-Y. Each bar on the graphs represents a specified amount of time (Holford, 2005).

2.2.4 Locating AE Signal Technique

There are four main techniques to locate the source of AE signal. For multiple sensors/channels during testing, allowing them to record a hit from a single AE event. Linear location is often uses to evaluate struts on truss bridges. Zonal location aims to trace the waves to a specific zone or region around a sensor. In order for point location to be justified, signals must be detect in a minimum number of sensors: two for linear, three for planar, four for volumetric (Holford, 2005).

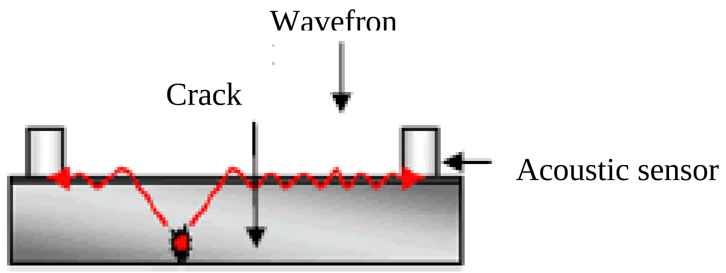

Figure 2.8: Locating AE Signal

Source: http://www.acousticemission.net

2.3 SIGNAL ANALYSIS

2.3.1 Frequency Domain

Frequency-domain analysis (FDA) is a way of processing interferograms to obtain surface profiles. Analysing data in the frequency domain means that we are thinking about the different phases and optical frequencies that contribute to a fringe pattern created by an interferometer (Edward, 2008). For example, in the old days, interferograms of optical surfaces were often pain staking analyzed by hand, using a photograph of the fringes. It is now much more common to perform some form of phase shifting interferometry (PSI), which allows us to transform the interference pattern electronically into a matrix of phase values.

These phase values can be directly relates to relative height values, if the wavelength or optical frequency of the source light known. The transformation from fringes to phases accomplished with an algorithm such as the familiar five buckets method. All signals have a frequencydomain representation and in 1822, Baron Jean Baptiste Fourier detailed the theory that any real world waveform can be generates by the addition of sinusoidal waves. This was arguably developed first by Gauss in 1805 (Edward, 2008). The following diagram shows an example of this process:

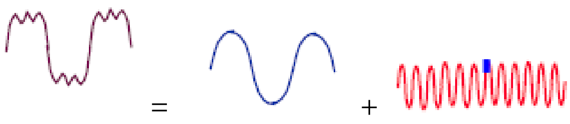

Figure 2.9: Waveforms

Source: Frequency Domain Theory and Applications journal

Signals can be transforms between the time and the frequency domain through various transforms. The signals can be processes within these domains and each process in one domain has a corollary in the other, as shown:

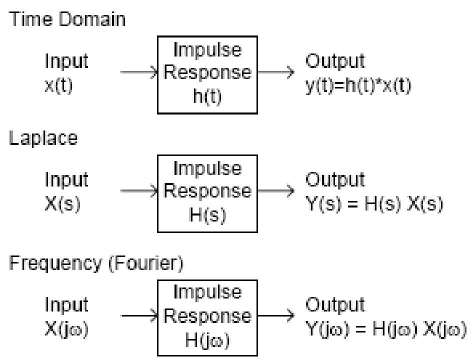

Figure 2.10: Signal process

The most important process translation between the time and frequency domain is thatconvolution in the time domain is the equivalent to multiplication in thefrequency domain and V.V. Within the real, continuous time world, systems are defines in the s-domain.

2.3.2 Frequency Domain Convolution and Correlation

Convolution in the time domain is equal to multiplication in the frequency domain and vice versa. Correlation in the frequency domain is equivalent to convolution, with one array time reversed. The output length must be greater than N +

M – 1, where N and M are the lengths of the input vectors. It is important that the FFT length is also therefore greater than N + M – 1. The first thing that is required is that the inputs require zero-padding, otherwise the result is circular convolution or correlation. The benefits of this are the potential large computational savings. For many applications, it is possible to pre-compute the convolution or correlation kernel FFT for more efficiency (Edward, 2008).

2.3.3 The Fast Fourier Transform (FFT)

The Fourier transform can be consider a bank of band-pass filters that takes in a signal and the magnitude of the output of each filter is proportional to the total input energy into that filter. Each of these filters is convolving the input with a set of filter coefficients that are sinusoidal in nature, with the frequency of oscillation equal to the centre frequency of the filter. When performing the convolution over all the banks, many of the multiplications of data and coefficient values are repeated and therefore redundant (Edward, 2008).

2.3.4 Representing Signals

Signals can be represents in many different ways. From Fourier's theory, we know that we can represent any real world signal by the combination of two or more sinusoids. Therefore, we need to be able to understand how sinusoids work, in order that we can understand how the complex signals operate.

2.3.5 Post FFT Processing

FFT processing is not useful in itself, but the post FFT processing that is usually the important issue, and it defines what information can be extract from the information. Power Spectrum Estimation is one of the common post FFT calculations and is calculate by averaging the outputs from successive FFTs. The following equations show how to calculate the magnitude and phase of the signals (Edward, 2008).