Science Fellowship Award to Mr *Christopher Burden*

was bestowed to recognise his ***“"unique contribution to the scientific understanding of the decay process of maintainable systems as a basis for the development of accurate prognostics methods"*** by the authority of the Council of Fellows and in accordance with the Constitution of the MIRCE Akademy

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Prognostic Engineering Science
- the attributes of decay that affect functionability-

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Abstract

Condition monitoring of engineered operational products/systems has been a life time career for me. Having commenced employment in September 1971, starting as a 16 year old engineering apprentice by Rolls-Royce (1971) Defence Engine Division at Bristol through 43 years in the same company seriously involved in product measurement engineering, I hold enormous knowledge of the ‘science’ discipline.
I have completed an engineering apprenticeship with a Higher National Certificate in Engineering followed by a personal Technology/Science education through the Open University. These educations and operations started the association of how many engineered products with a different operational analysis can map to an understanding of how functional decay can be detected and understood.

My vision for condition monitoring, as the human race advances in science and requirements for the future, is that it will be absolutely essential that a discrete condition/health monitoring system integrated into the product/system as a prime consideration of the product/system design, is not treated as an 'add on', as currently considered.

The decay in the operation of an engineered product/system will gradually affect the functionability of the product/system and consequently start to define the probability routes to an ultimate failure mode manifestation. However the definitions for the probability routes that lead to the failure modes are far more complicated than expected, envisaged and perhaps understood and these issues I hope to express in this document for prosperity.

*For example, one of the key witnesses to a failure mode probability route maturing is the '**increase'** in ascertainable 'change' 'seen' and reported in the monitoring of the operational device, by for example a vibration transducer.*

*In vibration monitoring the most common understanding is that an 'increase' in monitored vibration levels point at the 'operational functionability change' and define the precursory view of decay onset, commencing the countdown to system ultimate failure. This is not necessarily the case as 'elastic stress' wave sensors can/do experience a '**decrease'** in the signature levels as the functionability changes, let's explore, within the realms of the title Condition Monitoring.*

Virtually all operational products / systems demonstrate a phenomenon of operational witness. For example, a living human operating normally will demonstrate a heartbeat and a breathing action detectable via the 'feature' witnesses of a pulse, the expansion of the chest and usually structural movements. These three functions/operations portray large variance in 'feature' perception; typical describing nomenclature from the 'professions' and the normal public includes 'heart rate', 'fluctuations of beat', 'deep breathing', 'shallow breathing', 'panting', 'shortness of breath', 'wheezing', 'chest pain', 'angina' , 'twitches', etc.

Part 1

Words that describe the 'state' of the humans three prime 'functionality' to which understanding of 'condition' can be applied, but clearly these statements lack key information as to the functionability, most of which is taken for granted.
This metric of detail to support functionability in modern science, engineering and condition monitoring (all types) demands and requires to be taken more seriously than at present and it is essential that the functionability features and phenomena are better evaluated and built on.

These 'conditions' supported by the 'witness' of just heartbeat, breathing and motion offer understanding of the human condition. However, these conditions are just the 'tip of the iceberg' in world of condition monitoring as there are so many more 'features' that an operational product/system is affected by.

These ‘conditions’ and the ‘features’ are the key ‘witness’ to the functionality and the functionability of the product/system and will hold a certain series of signatures of operation throughout the products/systems functional life, only deviating from the ‘normal’ signature when ‘features’ manifest to invoke product/system operational ‘change’.

The problem with the current condition monitoring philosophy is that the observed onset of final operational functionability is very weak, a philosophy usually driven by the monitoring systems inability to detect ‘change’ with which to attribute a ‘feature’ witness and no perceived ‘business’ requirement needed to increase that fidelity of detection.

The evolution of the engineering monitoring capability has provided many operational questions in my experience. The questions posed demanded investigation and as the transition from a measurement engineering occupation to an engineering health monitoring occupation resulted in deep investigations to better explain, with evidence, the nature of ascertainable operational monitored events with their associated ‘features’.

This drove the idea of how to best comparator ‘change’ in operational ‘features’ with all associated phenomena surrounding the product/system operational environment. The first issue (in my personal history) in this campaign was the improvement in the ‘change’ detection and occurred in the middle to late 1980’s when engineering research was still a prime function of forward looking manufacturers and before engineering measurement degraded to ‘not core business’. In my quest for better capability at the time, frequency bandwidth was and still is the main issue of recording media. In those days broad band tape speeds on tape decks (up to 20 kHz) enable certain measurement technologies to progress, like vibration, pressure transducers, pulse probes for speeds, strain gauges, pulse modulation like FM grids and thermocouples for temperature capture. In today’s engineering measurement recording requirements the same issue still exists, for example when instrumentation stimulus bandwidth requirements exceed 60 kHz, because the digitisers (just like magnetic tape) cannot capture spectra with the necessary fidelity, event recording is compromised, missed altogether and the event magnitude degraded in severity.
So the hunt was on for a dedicated system with fidelity and data capture that focused on a new idea. The rational I arrived at was the need to move up the frequency spectra away from the low frequency range to find evidence of ‘higher frequencies’ that manifest during product/system operation, usually portraying a picture evidence of ‘normal’ that when ‘change’ occurred could be distinguished and build a knowledge data base of ‘Cause and Effect’. I discovered the world of Acoustic Emission base on personal studies of Raleigh Waves, Elastic Stress waves, and Lamb waves and very quickly realised that these were the prime drives to the engineering measurement world I needed to be able to express to peers my experiences and findings,.
However due to many facets of the business world, vested interests, complexities and other strange cultures and following a presentation and a runner up commendation at the 2003 National Measurement Awards for my Acoustic Emission science studies, pushing the ideas forward is harder than running the many marathons I have completed.

However I did not acquiesce to the negative pressures because my ideas are key to the future of product/system health and condition monitoring. Fortunately the Acoustic monitoring measurement system moved to a productionised/development system. I saw the need to investigate the capability as I had many personal examples of 'intuitive change' events while conducting engineering test experiments that I could not explain but more importantly capture in a format that I could portray to others to create discussion.

The program of investigations were a personal campaign to demonstrate capability from discrete components through to complex high power engines, all of which grew in confidence that the capability does map detection of 'change' during operation and gradually started to relate detection to 'features' and probability routes to failure modes.

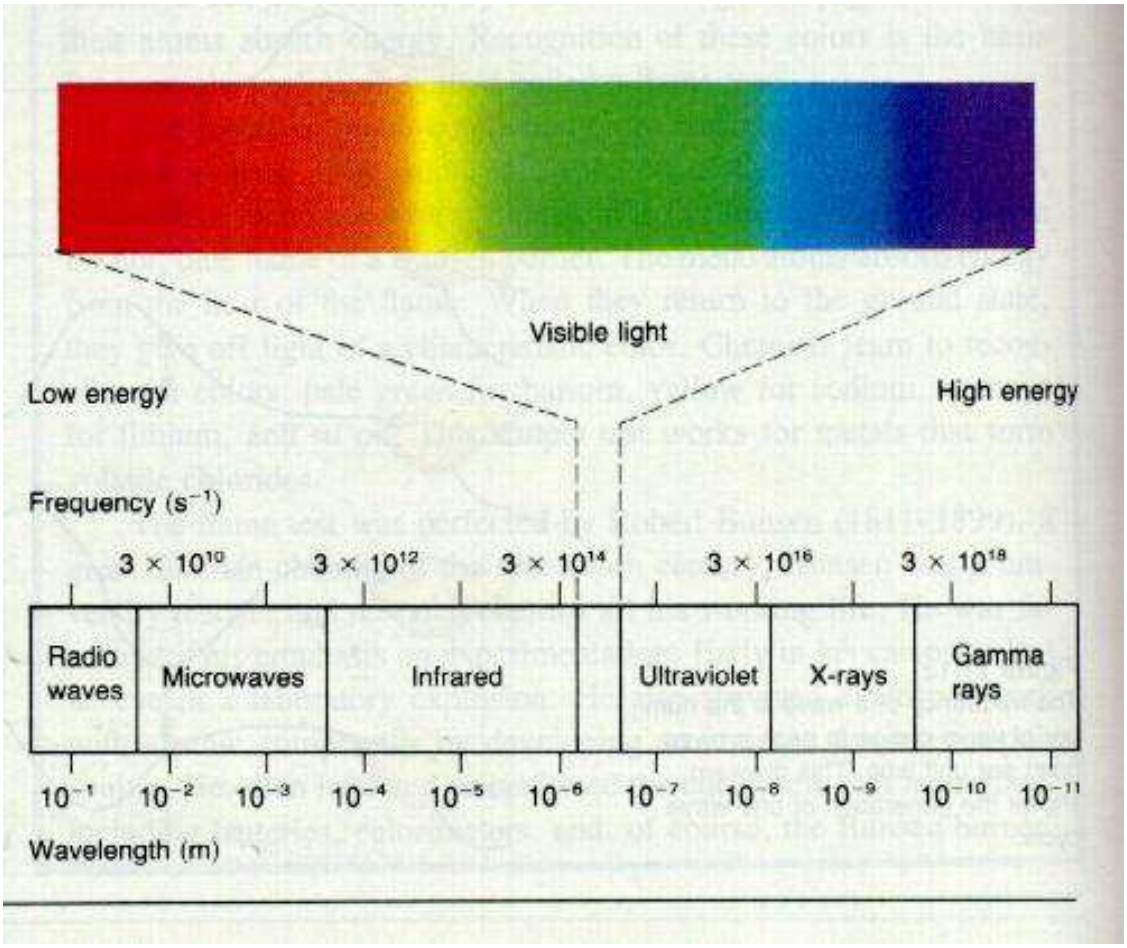
One major problem was the name of the technology. Acoustic emission technology insinuates an 'air borne' transfer of energy to a sensor. This is not the case and my renaming of the technology was to better define the location in science where the technology sits.

The technology operates in the medium frequency domain between 60 kHz and 700 kHz, it captures the energy in the product/system as it operates and transfers it to the sensor (piezo crystal) from which the computer and software create an instance presentation of the spectra, thus the Medium Frequency Energy Transfer, **MFET** acronym was created. In the creation of the MFET acronym a period of 'seismic emission' was adopted but as seismology applies to geology the name was always contestable. This is a very brief back ground into my condition monitoring engineering history (1971 to 2003). There are many more aspects to this history which are very important dimensions to add to the feature clarity, but they are deeper and very complex for this abstract, now back to the science.

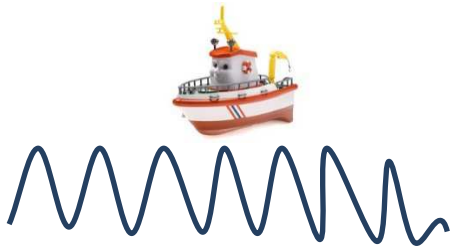
Energies exist in all products /systems, all are quantum related in the atom and sub atom forms moving to multi atomic, molecular, Newtonian structures of all types. These energies that exist in the product/system invariably operate over regions of the frequency spectra from dc to gamma rays and this formed my common denominator from which to mount my sensor suit against and to allocate 'features' of functionality for the product/system operation.

Clearly frequencies of operation that are monitored in the low frequency spectra like vibration are easy to capture both with vibration/acceleration transducers, the 'pulse' of sense by the human body, a glass of water, a moving article on a shaking structure, etc., usually the repetitive sound pulse can be audibly heard and 'change' detection easily discernible. However the eye captures the motion of the water ripple and the eye operates in the visual light spectra and always has; the frequency (range) is in the sub atomic particle region where photons and phonons are created so our eyes work in the quantum field

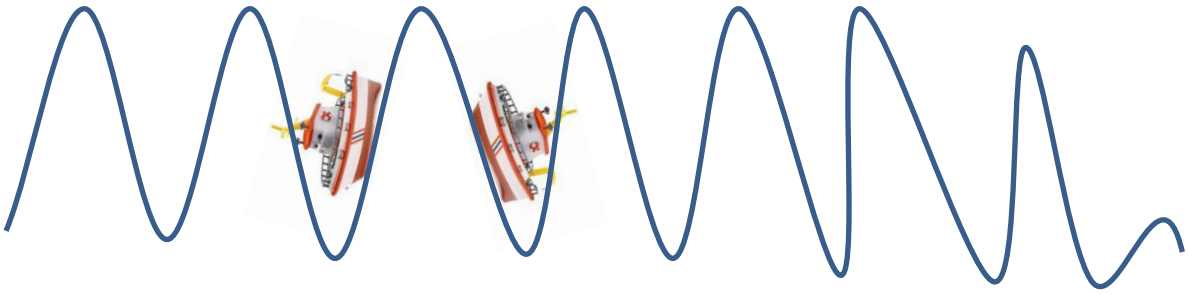
The main issue with these very low frequencies are that determinable 'change' usually associates with serious degradation of the product/system functionality, potentially moving towards a failure mode rapidly.



Imagine a boat riding the waves, the frequency is high the wave lengths are short; therefore the waves under the boat are tight together making the boat surf on a flat surface so things are “good”. Now stretch the wave lengths out so they are long the frequency is low and the boat is now experiencing a very rough sea and things are “bad”. This is exactly the way that vibration works, but the real problem is the short period of time in the transition from the higher frequency short wave length to the lower frequency long wave length.

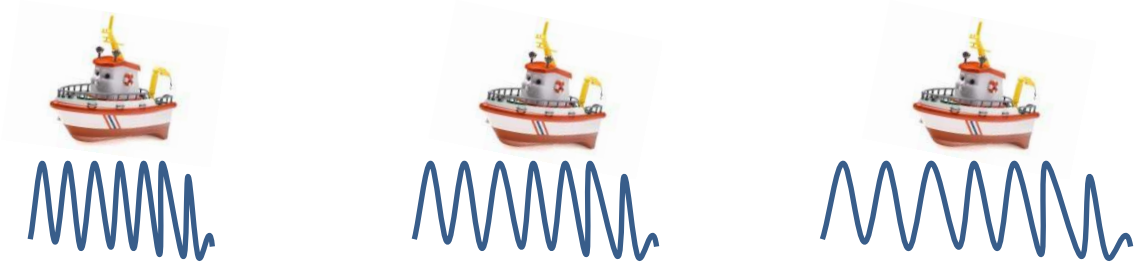


In this very short time duration because the change is so small, decay modes occur rapidly giving very little chance to “capture” the operational product/system operation, shut it down and save a major failure.



Also the change in amplitude occurs usually because of the decay in frequency and it is this enlarged stimulus that excites the vibration transducer to incite the ‘increase’ in vibration levels, trigger alarms and raise concerns.

If however the system detection monitored in a higher frequency domain and captured changes in the high frequency moving to a slightly lower frequency the boat would still be “good” but a “change” has been detected and we are on alert.



Feature 1“normal” Feature 2 “First change” Feature 3 “Second Change”

This is a very ‘simple’ demonstration of wave capture because the actual wave forms are also generated at various angles to the ‘main’ wave and are the cause of ‘side bands’. Unfortunately these witness bands usually fall outside ‘normal’ operational vibration monitoring for event/witness capture and key witness/evidence is lost/ignored for product/system decay/safety monitoring.

The MFET (Elastic Stress Wave) sensor capability moves the frequency domain up into frequencies that are above the low Hz values and in my experience into the medium wave frequency region where ‘change’ effects clearly have longer periods of time to mature before a failure mode is created, hours , months, years. These medium wave frequencies exist with full spectra frequencies and offer a total insight to the ‘status’ of the product/system if we bother to understand it!

So let’s examine key elements of the science we are discussing here.
The expressions of the frequency range then expanded to the obvious, my eyes operate in the Quantum field! This acceptance, discovery, fact call it what you will is so obvious that immediately I had taken the frequency spectrum from DC to visual light and to take it to gamma was a formality when discussed with fellows of the X-

Ray world. So I now had the **denominator** to assimilate the witness phenomena of prognostic understanding against, frequency and therefore wave length.
This denominator also has a ‘cross over’ point where ‘Newtonian Physics’ integrates with ‘Quantum Physics’ for the frequencies defined. This cross over point in the Newtonian field of molecule displacement to electromagnetic field excitement and displacement is very important, but essentially just to understand.

So getting back to presentations of the denominator idea, the magnitude of the denominator is massive when the range of frequencies are applied, so to represent this on an A3 sheet of paper was impossible when clarity around the 700kHz bandwidth over the full frequency spectra resulted in the time period the width of my pencil! Clearly the ‘Newtonian’ frequency features needed to be frequency ‘banded’, as would the ‘Quantum’ features to enable clarity of all presentations. The problem is that for decay/prognostics/functionality/functionability/witness etc. the dissections of the product/system to component parts, to best define frequency phenomena, can interfere with the ‘total’ product/system understanding.

This is where and why the current ideology of prognostics does not deliver, resulting in the culture of ‘normalisation of deviance’, basically it’s been ok before therefore it will be ok (Professor D.Vaughan Columbia University on the Challenger Shuttle Disaster). This disaster was ‘O’ ring seal related, a physical component part, not even condition monitored signatures from sensors. So how can subjective sensor data drive safety, by being accepted as creditable, believed, understood and engaged in our culture of science.

This stance is unacceptable to me and the prime reasons for the need to look across the frequency spectrum as a whole and link all product/system operational phenomena together to ‘lock down’ ‘change events’ and define all the witness occurrences that could have caused that or the ‘change event instance’.

The need for this pedantic attitude to prognostics and decay/change/witness management is to be ahead of the failure mode game and be professional in the detection of the functionability change.

When we (the human race) move to more complex products/systems that are essentially monitored to prevent loss of life, the product/system integrity must match the expectation of product/system operational success to as near 100% as possible.
I think this is a good point to close the rationale behind my prognostic theorems and the first of many papers/abstracts for the Science.