Delivering real CBM results in IoT4.0 for industry

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Abstract

Drive Management Services are a reliability services business, providing condition monitoring services and solutions for traditional industry sectors. We recognized in 2012 that the way we monitor assets was changing from conventional methods to those which are remote, interactive and non-intrusive.
As a developer of fixed continuous monitoring systems, we believed the future was based on providing a first-class diagnostic service via the web / internet.
In 2017 we partnered with a UK ThingWorx integrator to develop a truly flexible and dynamic IoT solution.
In 2019, DMS launched a new IoT platform named "DMS Asset Minder", utilizing various sensors to monitor and deliver real time machine asset health. The system is now installed in the following industrial sectors delivering accurate meaningful results: -

- Quarrying & mineral processing
- Water treatment
- Metal and alloy production
- Fuel pumping
- Food Production

All hardware used is currently UK manufactured covering vibration, oil condition, temperature, pressure and flow.
This paper will demonstrate the technology used, the success stories and how with further development in the coming 12 months the product will become one of the leading condition monitoring platforms either as a stand-alone system or as part of a further integration into larger IoT platforms.

1. Introduction

DMS were invited to work with a UK specialist fuel pumping company to closely monitor and assess the performance of their critical multi-stage pumps. These multi-stage pumps are globally renowned for pumping fuel thousands of miles to critical transportation depots. Historically these pumps are reliable and have run untroubled for years and years. A number of these pumps are over 40 years old and spares availability

is becoming extremely difficult due to obsolescence. Generally a catastrophic failure on one of these pumps sets can cost six figure significant monies for a complete overhaul / repair.
These pumping stations tend to be unmanned and generally remote, making maintenance of these critical assets extremely difficult and due to their locations; cost inefficient.
Due to the criticality of these pumps, the end clients (transportation depots) have severe contractual penalty clauses in place against failure to deliver fuel. These assets have been notoriously difficult to monitor periodically or continuously due to the fact that these are located in remote ATEX installations.

2. The Challenge & Specific instructions

2.1 The Challenge

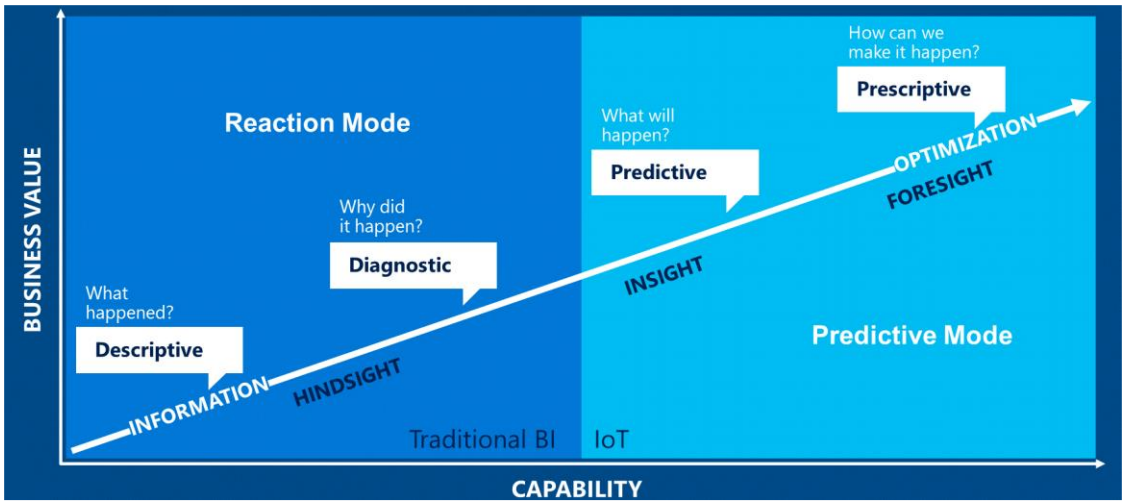
Following a number of serious failures in the last 12 months on a number of their UK sites, the client decided that they needed to find a better solution and somehow implement a reliable *live* condition based monitoring system with full diagnostic support. This was the challenge that they set DMS. On discussing the requirements with the maintenance manager, it was agreed that the following key components would need to be delivered if the solution was to be effective.
Namely, continuous "24 hours a day" monitoring, multilevel, complex alarms to identify specific events, wireless communication, ATEX sensors, and remote monitoring and diagnostics c/w information delivered in real time.
The client required automated alerts due the remote location of these pumping stations and a monitoring platform that was easy to understand but also enabled the supplier to provide online diagnostics.
During the initial negotiations, DMS were confident that our latest IoT 4.0 platform named Asset Minder, using our "MachineGuard" hardware would be ideal for this application. To prove the equipment and deliverables, DMS installed a system on one of these fuel pumps on a remote pumping station.

2.2 What is the Internet of Things?

The Internet of Things(IoT) is the network of physical objects, devices, vehicles, buildings and other items which are embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data.
The Internet of Things allows objects to be sensed and controlled remotely across an existing network infrastructure, creating opportunities for more-direct integration between the physical world and computer-based systems, resulting in improved efficiency, accuracy and economic benefit. Each thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure.
It is estimated that IoT will consist of almost 50 billion objects by 2020.

Historically, industry has been slow to engage with the potential capabilities of the Internet of Things. Above & beyond all this, it is believed that the Internet of Things

will also signal the possibility for a change in the business model for some businesses.* (* Bernard Marr – Forbes August 17th 2015).



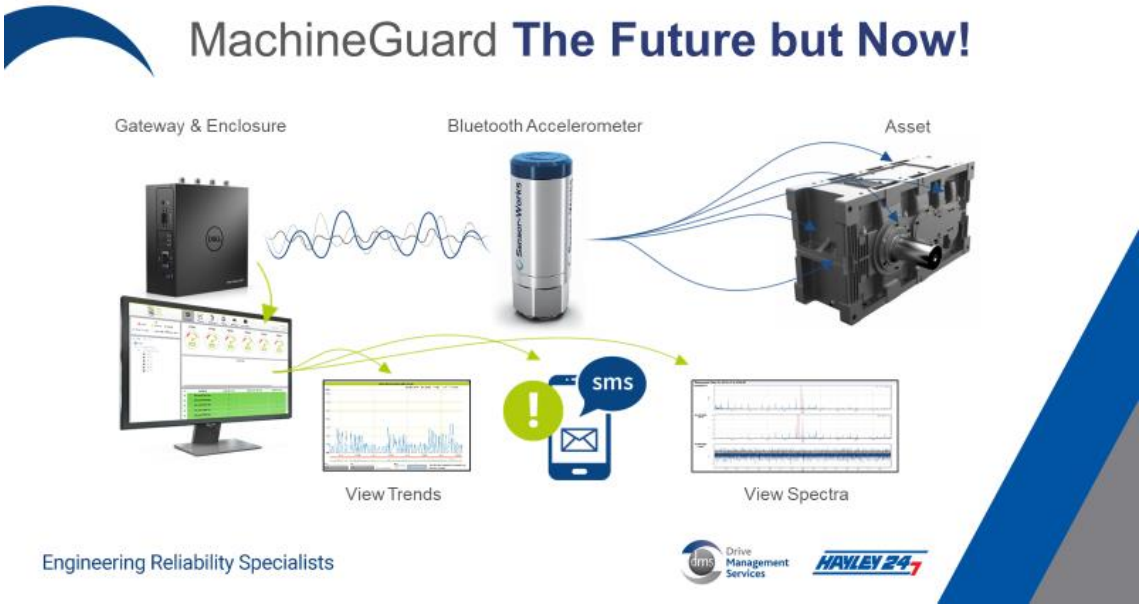
(Image no.1.)

The world of IoT will enable us as a specialist business to transition very easily from the predictive phase into the prescriptive phase (detailed above in image no.1.).

This potential change in our business models will enable us to use the data and analytics to support our prescriptive service.

*2.2.1 **MachineGuard Asset Minder Platform & Hardware***

The equipment supplied in this instance is the DMS MachineGuard Asset Minder, which is a package consisting of the hardware detailed below, combined with the Asset Minder IoT Platform.



(Image no.2.)

The Asset Minder platform is written in ThingWorx and was developed by the UK's leading ThingWorx intergrator – InVMA Ltd based in Chesterfield. ThingWorx is an industrial innovation suite from PTC Corporation. PTC are recognised by Gartner, Forrester and IDC (Global research & advisory firms specialising in IT) as one of the global market leaders in the field of IoT.

PTC and Microsoft have partnered to use the scalability of Azure with the deployment speed of ThingWorx to provide a secure and scalable platform, which delivers and;

- Monitors IoT endpoints and event streams
- Supports a variety of manufacturer and industry proprietary protocols.
- Analyses data at the edge and in the cloud
- Integrates and engages IT and OT systems in data sharing and consumption
- Enables application development and deployment
- Enrich and supplement OT functions for improved asset management life cycle strategies and processes

2.2.2 ***MachineGuard Blue Tooth Accelerometers***

The BluVib Atex wireless vibration sensor certified for use in hazardous locations, is an ultra-low power, battery operated, wireless sensor that measures vibration and temperature. It uses the latest Bluetooth 5 low power wireless communications standard and can operate stand alone, or in a network of multiple sensor devices.
Operation is user programmable, waking up at pre-determined intervals to take vibration and temperature measurements, through near continuous operation, constantly monitoring data and signaling pre-set 'events'.

Raw data is then transferred to our Asset Minder IoT cloud platform for processing, trending and archiving. The main components of the wireless sensor are a piezo-electric accelerometer, signal conditioning electronics, anti-aliaising low pass filter, analog-to-digital conversion, processor section, power/wake-up control and a low power radio module. The field replaceable battery is contained in a sealed compartment and the device mounts, via a screw thread, directly onto the machine which it is monitoring.

The wireless vibration sensor provides a solution for condition monitoring of rotating machinery. It is used primarily in process industries where common applications are monitoring motors, fans, pumps, gearboxes etc. The device provides data from which overall values of vibration, bearing condition and temperature (often referred to as process variables) as well as high resolution spectra of vibration and bearing envelope, can be determined. When compared with wired alternatives, the wireless vibration sensor offers the advantages of extreme ease of installation and battery life up to 5 years.

Measurement Specification as follows:-
Sensitivity: Programmable (50mV/g, 100mV/g, 200 mV/g, 500mV/g)
Measurement Range: +/-20g at 50mV/g
Frequency Range (+/-3dB): 0.3 to 10000 Hz
Resonant Frequency: 25kHz

Amplitude Linearity: ±1% typical in passband
Dynamic Range: >70dB

Data Acquisition Specification as follows:-
ADC: 16-bit SAR
Sample Rate: Programmable from 256Hz to 25.6kHz
Anti-Aliasing Filter: Compound analog/digital
Data Block Lengths: 64 to 32768 samples
Spectral Line Equivalent: 100 to 12800 lines
Modes: Continuous, Wake Up, Triggered ('g' level) Manual wake-up via magnetic switch

Processing & Communications Specification as follows;-
Processor: Ultra Low Power, 32 bit
Configuration: Over Radio Network
Programming: Firmware upgrades over radio network
Network: Bluetooth 5 Low Power
Certifications: Europe: R&TTE
USA, Canada, International: FCC/IC

2.2.3 ***MachineGuard Gateways***

The gateways used in the MachineGuard system are predominantly Dell Edge 3000 series. Other gateways have been used such as Technexion or Aplicon depending on specific customer requirements.
The Dell Edge 3000 series gateway has been used as it has the best MTBF in the marketplace. These gateways are preconfigured with Ubuntu and Kepware operating systems, dependent on the customers requirement.
These operating system frameworks are robust, flexible and enable remote connectivity which provides us the capability to reconfigure existing systems, adding additional assets and sensors. The Dell Edge Gateway 3000 series are intelligent devices designed to aggregate, secure, analyse and relay data from diverse sensors and equipment at the edge of the network.

Each gateway is installed in a stainless steel industrial IP67 rated enclosure, fitted with MCB. The Gateway is capable of communicating with over 200 off BluVib accelerometers or other types of sensors, providing a small footprint but big connectivity, c/w solid-state drive with a wide range of connectivity (WiFi, BlueTooth, LTE, etc).

3. Fuel Pump Application Installation Details

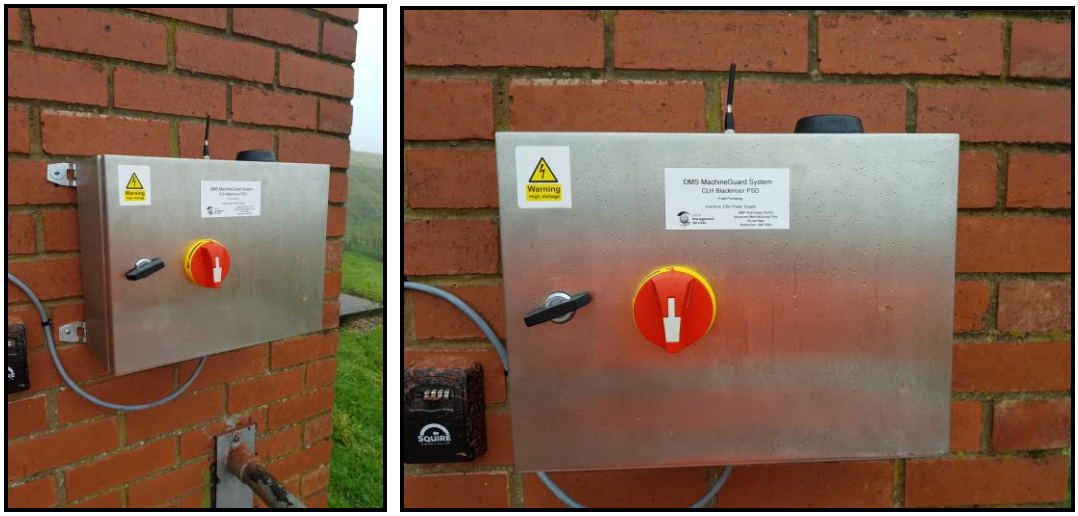
The application detailed below is what the equipment was installed on, and this consists of the following:-

- David Brown 8 stage multi-stage pump, ref:- 6X811B type MSD-D, 2198 ft Head, 1248 GPM (white metal thrust & radial bearings)
- Parsons Peebles 820.0kW, 2965rpm (two pole) HV 3.3kV foot mounted motor (white metal bearings)

The trial system was installed in late November 2019 consisting of 5 off ATEX "MachineGuard" Blue Tooth accelerometers on both the motor bearings in the radial plain, as well as fitted on both the inboard & outboard pump bearings, along with one fitted on the pump outboard bearing on the axial position. These ATEX Blue Tooth accelerometers have a Blue Tooth communication range of approx. 50 metres in an industrial environment (See images no.3, 4, 5 & 6 below).

(Image no.s 3, 4, 5 & 6)

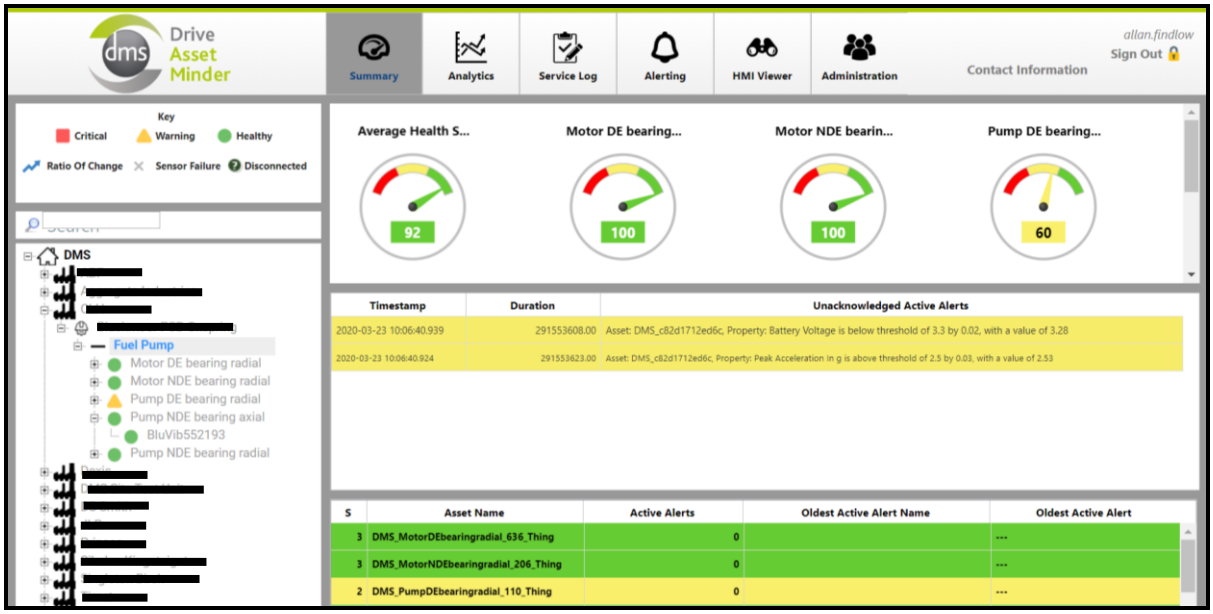
Located on the outside wall of an "out house" building on site, in the safe zone, we installed our "MachineGuard" enclosure which housed the receiving gateway, antenna and associated power supply / terminals. The gateway receives the signals from each accelerometer and sends this raw data up to our Asset Minder platform at pre-determined times (see image no.s 7 & 8 below).



(Image no.s 7 & 8)

4. Test Vibration Data & Results

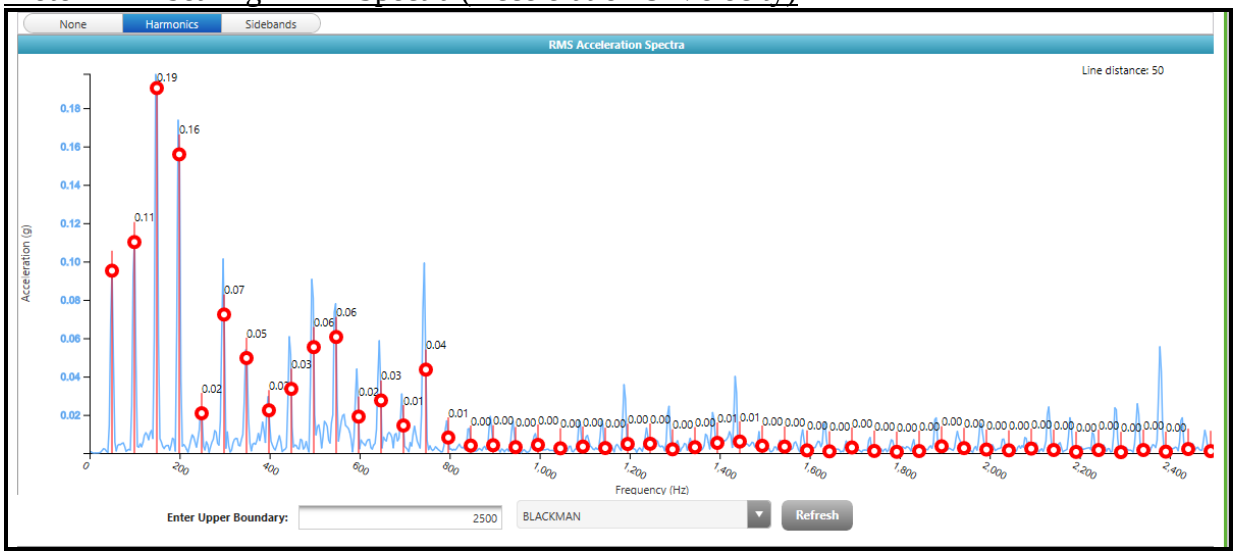
On completion of the installation, the data produced was displayed on our Asset Minder IoT platform (see image no.9. below).



(Image no.9)

Within the first month, both the client and DMS were receiving alerts (via e-mail) informing us that the white metal motor bearings were going into warning on both RMS acceleration and peak-to-peak acceleration. On investigation using the FFT spectral analysis we identified a form of rotational mechanical looseness at motor running speed which can be seen in the FFT screen shots below. DMS suggested to the end client that the suggested mechanical looseness was probably associated with significant wear on the white metal bearings and as a consequence should be investigated on an urgent basis.

Motor NDE bearing – FFT Spectra (Acceleration & Velocity)



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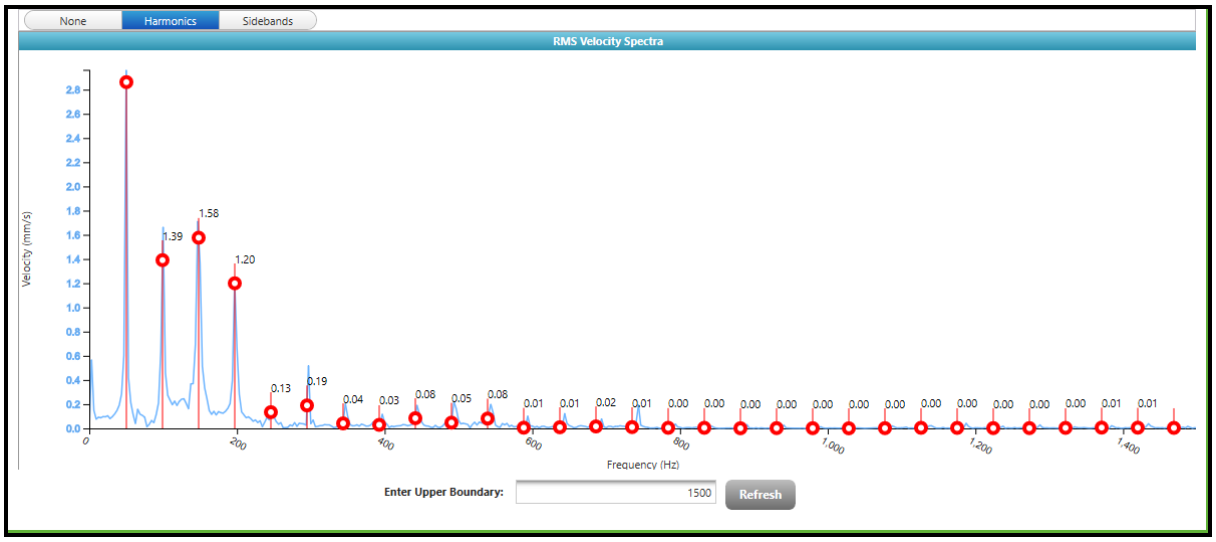
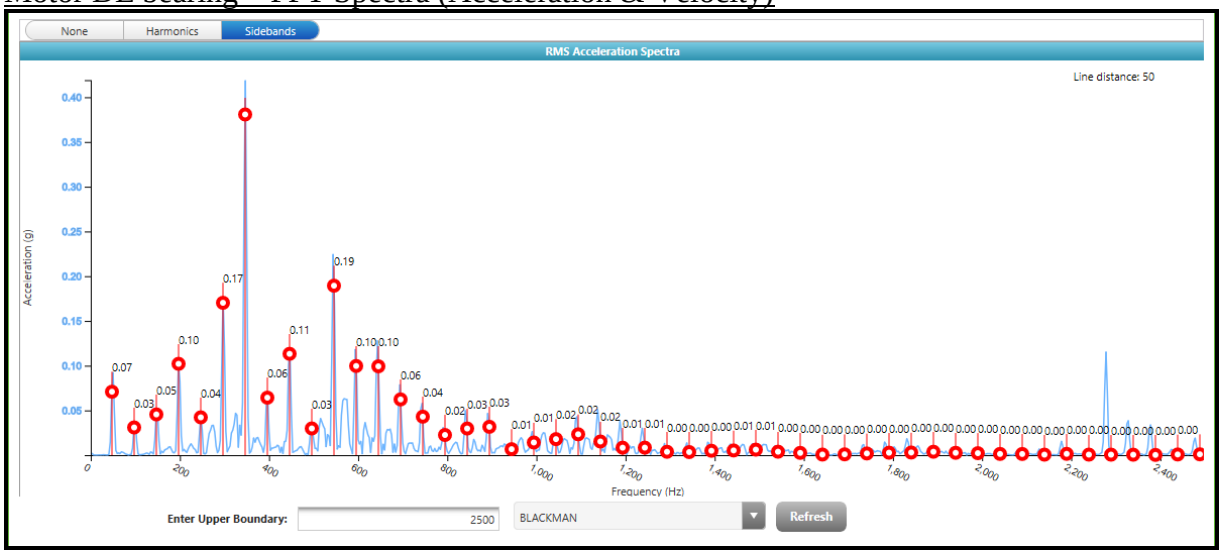


(Image no.11.)

Motor DE bearing – FFT Spectra (Acceleration & Velocity)



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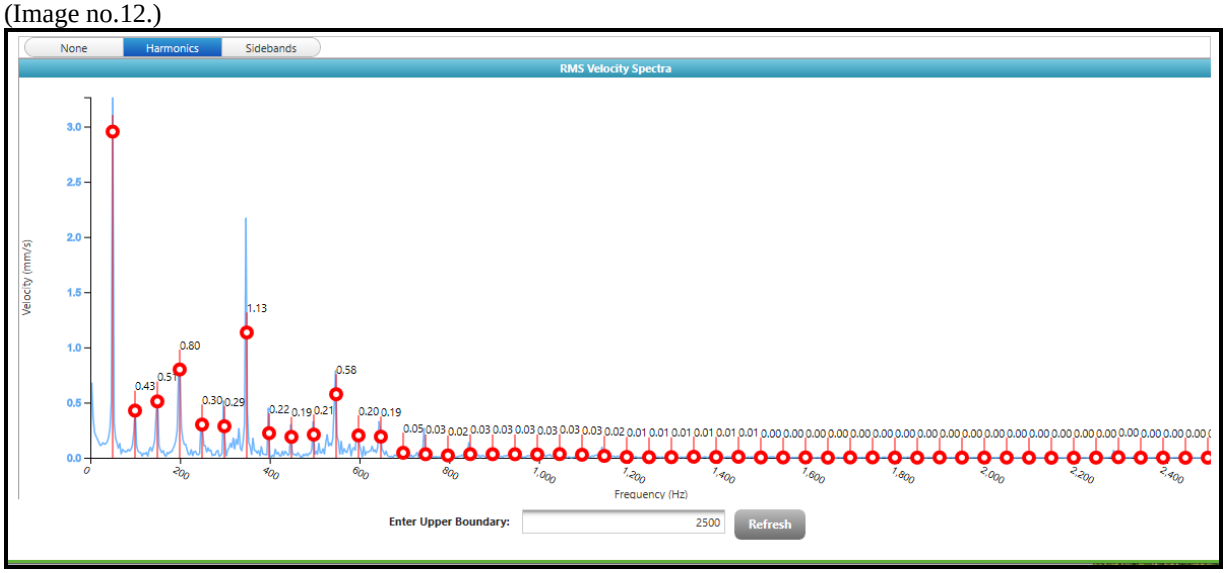
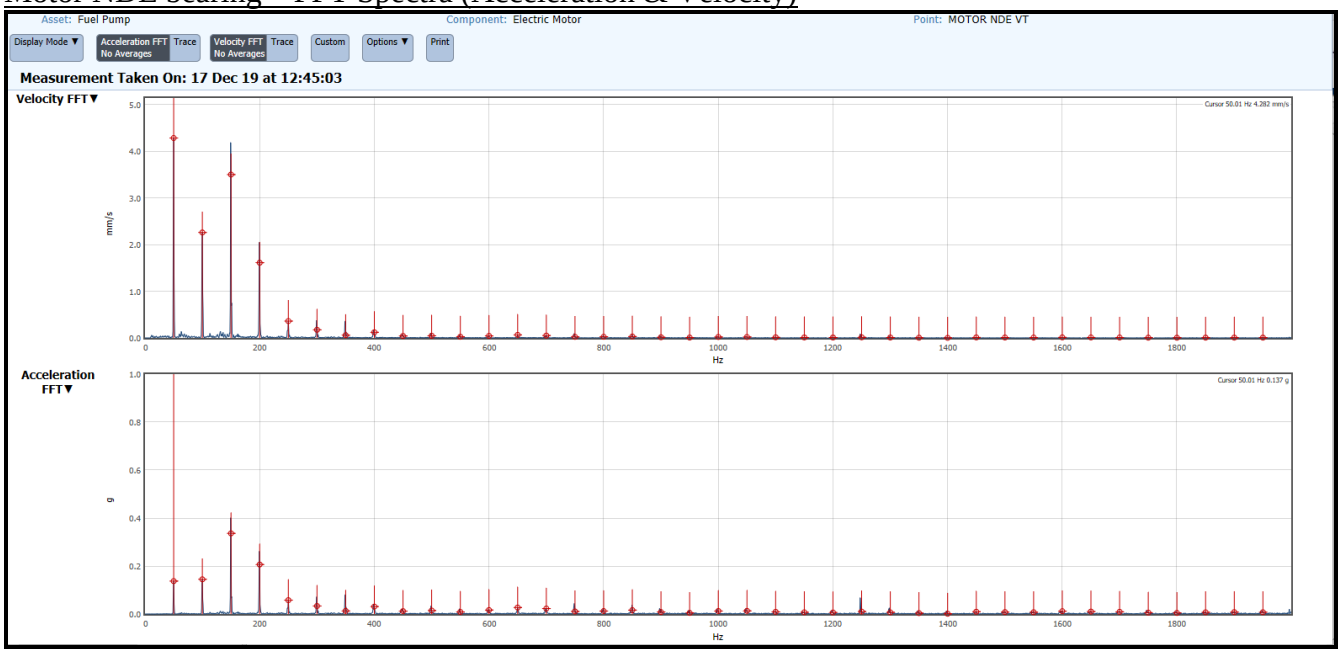


(Image no.13.)

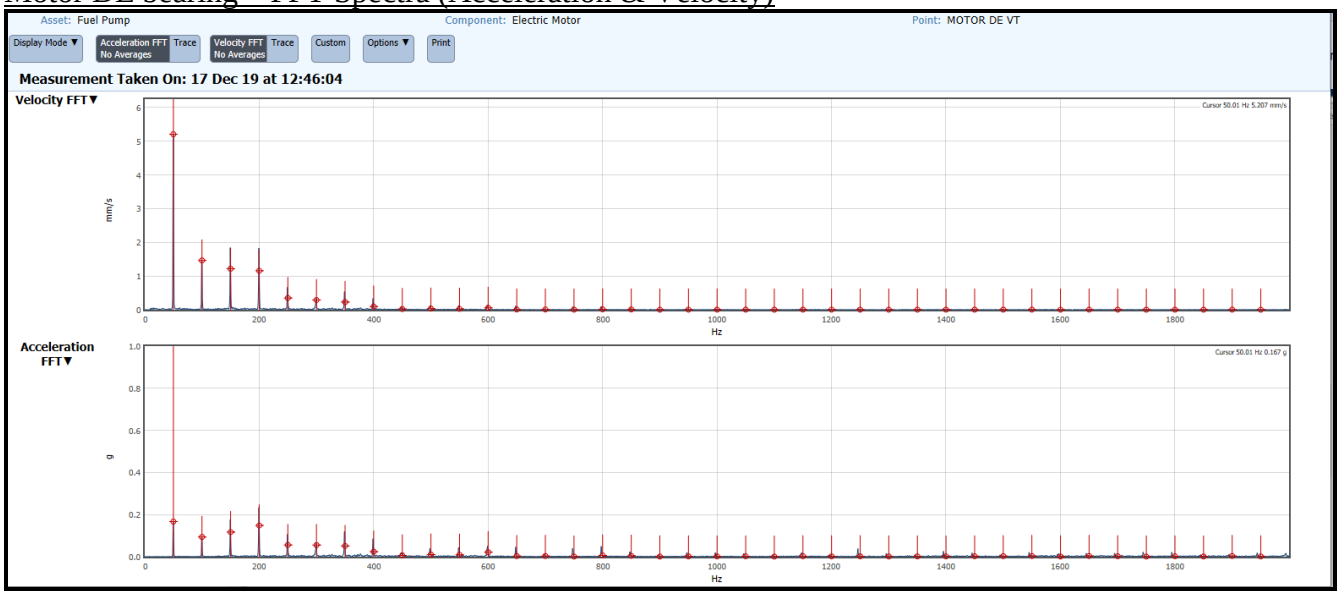
Obviously, the client wanted some form of additional confirmation, so we arranged for one of our CBM engineers to visit site with their hand held vibration analysis equipment to undertake a full set of readings and collaborate the above readings being recorded on our system.
During the next few days the DMS CBM engineer conducted a full hand held vibration survey on the motor & pump and the following FFT spectral information was recorded.

Motor NDE bearing – FFT Spectra (Acceleration & Velocity)



(Image no.14.)

Motor DE bearing – FFT Spectra (Acceleration & Velocity)

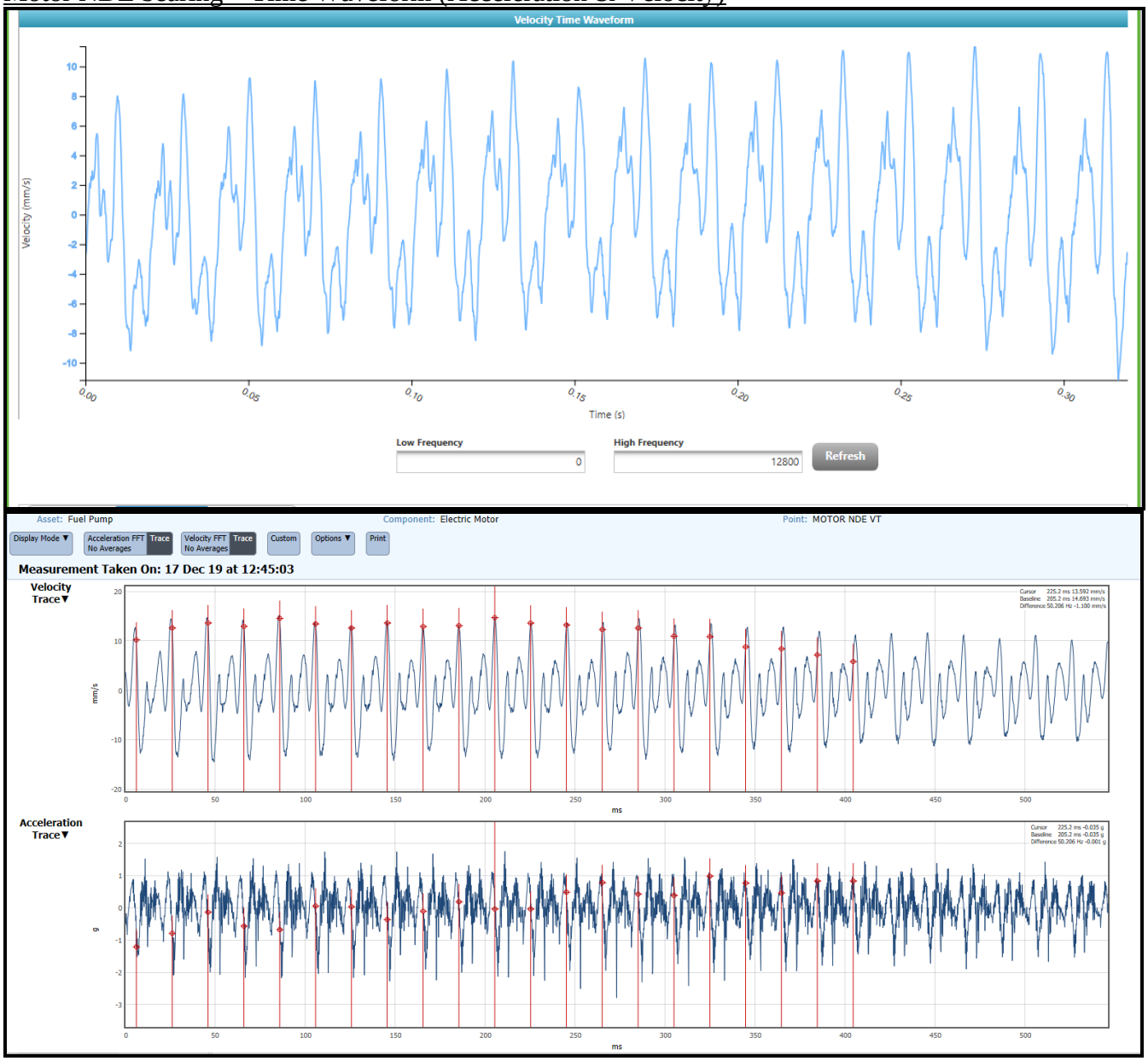


(Image no.15.)

We could see from the above FFT Spectral information recorded by our on site CBM engineer, that this information / data is similar if not identical to that recorded by our

"MachineGuard" Blue Tooth accelerometers and transferred to our Asset Minder web platform.
We could also see the exact same pattern in both time waveforms which is a classic example of component looseness (see below).

Motor NDE bearing – Time Waveform (Acceleration & Velocity)



(Image no.16.)

Based on the above confirmed data the client decided to remove the motor and pump assembly from service.

5. Independent Pump & Drive Motor Inspection Report

As mentioned in section 4 of this paper, the above complete pump and drive assembly was removed from site and delivered to an independent local engineering repair centre, who specialise in motor & pump overhauls.

On completion of their inspection the following remedial work was identified:-

5.1. Motor Inspection

Rotor repair

- Repair end covers fitting new mesh and sound proofing
- Rotor repairs
- Inspect and record all details including TIR
- If necessary; re-centre
- Record all prep sizes NDT prepared journals and report
- Inspect record prep sizes mask off and prepare 2 off bearing journals for metal spray, shot blast and inspect set up and metal spray
- Journals with Bescote 3604 to size plus grinding allowance De-mask and clean overspray.
- Proof grind and inspect, crack detect and record finish grind to customer advised size and tolerance flash grind 2 off bands true with the bearing journals to aid balancing Inspect and record final sizes and TIR

White metal bearing repairs

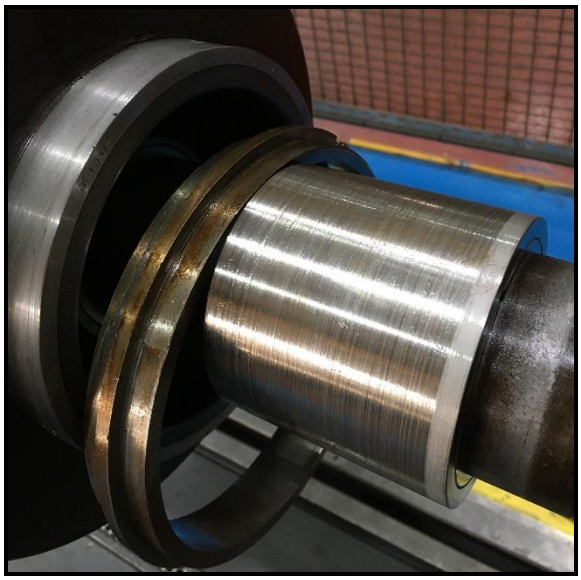
- Take details of the 2 x bearings. Melt out the old white metal, re-tin, jig and cast with new white metal conforming to BS3332 Grade B. Proof machine, bond test, detail and finish machine to size.
- Ultrasonically test the white metal surface and supply a third-party report/certificate to confirm the integrity of the white metal bond. Carry out scrap procedure

5.2. Pump Inspection

Pump assembly repair

- One area of concern is the throttle sleeve and bush which has worn oversize and become tapered. Repair: the bush will be skimmed to clean up and the sleeve replaced with a new oversized sleeve on outside diameter to suit. (see image no.17. below)
- The impellor hub locations are worn and scored. To replace the impellor rings and the rotor, would require the assembly to be stripped down into component parts but there is a concern that undertaking this work, may cause some further damage. This current wear is not seen as a major issue, as it is not affecting the pump dynamics or creating an unbalance in the rotor: hence no consequence on the pump reliability. The only consequence of the wear, is the possible slight reduction of the pump efficiency, hardly appreciable. No repair will be undertaken on these parts. (see image no.18. below)
- The mechanical seals require an amount of remedial work and are currently undergoing a complete refurbishment. The following parts will be replaced:
    - rotating ring and rotary faces.
    - carrier plate (chrome oxide coated)
    - main spring, O-rings, seals and fixings.
    - All remaining parts will be cleaned and reused.
- The pump gasket, is the original and hence is very old. This needs to be replaced with a new one.

- The journal bearings will be reconditioned by replacing the old white metal with new machined at required size. (see image no.19. below)
- The 1st impeller suction will undergo dressing of the vane tips to return to a round smooth profile. This will reduce the efficiency losses (slight) the current edged profile may be causing and extend the impeller life. (see image no.20. below)
- Similarly, the cutwaters in the top and bottom pump halves of the pump casing will undergo dressing to return to round & more efficient profile.


(Image no.17.)


(Image no.18.)


(Image no.19.)


(Image no.20.)

6. Root Cause Analysis

The above inspection undertaken at the workshop confirmed that the white metal babbitted radial bearings in both the pump and high voltage AC motor, were significantly worn and had a progressive loss of white metal material over the loaded zone. The removed pump inboard (image no.19. above) white metal babbit bearing displays some heat discolouration and patchy contact, which is normally an indication of a bearing that is oil starved. However, this could be the result of excessive movement in the motor bearings causing the hydrodynamic film to be degraded across the whole assembly.

This significant wear is more than likely to be the result of long-term wear, which has increased the internal radial clearance of the white metal babbit bearings and has resulted in the increase in both velocity and acceleration. This significant increase in the internal radial clearance also has a detrimental effect on the hydrodynamic lubrication film, which will increase the operating temperature in the loaded zone and if allowed to continue, will create further secondary machine issues.

The impellor hub locations are worn and scored which suggests that the hub has been subjected to excessive radial displacement, which has resulted in the hub "rubbing" against the bush. This is probably the result of the wear identified in all the pump white metal babbit radial bearings.

The possible reduction in the hydrodynamic film due to the increased wear in the white metal bearings can also have a detrimental effect on the white metal bearings capacity to cope with adequate loads in both normal operation and also in an overload situation.
Based on the information provided by the Electrical Appartus Service Association Convention in June 2007, named "Sleeve Bearing Repair"[(2)], one of their conclusions, is that high power two pole motors require extra measures, and the main one, is that velocity increase is the first indication of bearing friction and the beginning of white metal babbit bearing "wipe".

Multi stage high pressure pumps of this type of design generally operate at approximately 80% hydraulic efficiency (speed dependent). However, any small changes mechanically to the pump assembly can dramatically affect the efficiency, costing literally thousands of pounds. For example, a motor over 500.0kW power running at two pole speed, with a loss of 1% could cost a business £25,000 in additional electricity used (Darren Harris – Hayley 247 Engineering Services Ltd., Pumps Division, Service Manager).
We know from our experience in vibration analysis that mechanical looseness in induction motors is a common problem caused by loose bolts, structural damage, improper fit, or increased clearance between components, and results in increased vibration and wear. Detection of mechanical looseness in the white metal babbit type sleeve bearings of industrial motors mainly relies on vibration analysis, which has been proven in this report.

7. Conclusions

We can conclude that from the information and data detailed above in this report that the MachineGuard Asset Minder product / service identified a potential serious issue within the pump and motor drive assembly. Our remote diagnosis, that the white metal bearings were significantly worn was proven to be correct, confirmed by the report generated by the independent engineering repair centre.

The Blue Tooth accelerometers performed exactly as anticipated and mirrored the results taken with our hand held data-collectors. This accuracy enables our diagnostic engineers to produce remote reports for clients with real confidence.

The Blue Tooth connectivity of the ATEX sensors provided the client with a quick and efficient installation, without interrupting any operational requirements, which was a major advantage. The installation took one man approx. 2 hours including the enclosure mounting, testing & commissioning.

We know from our experience in vibration analysis that mechanical looseness in induction motors is a common problem caused by loose bolts, structural damage, improper fit, or increased clearance between components, and results in increased vibration and wear. Detection of mechanical looseness in the white metal babbit type sleeve bearings of industrial motors mainly relies on vibration analysis, which has been proven in this report.

The Blue Tooth accelerometers used in conjunction with the Asset Minder platform was the ideal combination for monitoring these critical assets. The alerts produced by the system (SMS text message & e-mail alert) enabled our office and site based diagnostic engineers to analyse the data quickly and present our findings to the customer. Based on these findings the customer was able to remove the pump & motor assembly from service in a controlled manner.
This early detection enabled the client to eradicate any penalty clauses, reduce the costs associated with a full overhaul and repair normally associated with a catastrophic failure; whilst assisting in maintaining the long term efficiency of the pump assembly.

The accuary of the diagnosis enabled the independent local engineering repair centre to provide the end client with a quick assessment and budgetary leadtime to undertake the repair. This enabled the client to consider their options for the site and put an operational plan in place to the company board of directors.

Acknowledgements

Hayley 247 Engineering Services Ltd t/a Drive Management Services
Darren Harris, Pump Services Manager, Hayley 247 Engineering Services Ltd.
Pat Nash, Managing Director, InVMA Ltd., Chesterfield, United Kingdom
Ian Bain, Director, Sensor Works Ltd, Livingston, United Kingdom
PTC Corporation, USA

References and footnotes

1. Chuck Yung, Technical Support Specialist, Electrical Apparatus Service Association, “Sleeve Bearing Repair Tips” ESEA Convention Centre, Minneapolis, June 27th 2007.
2. Lyle A. Branagan, Pioneer Bearing Company, Kings Mountain, USA, “Survey of Damage Investigation og Babbitted Industrial Bearings” article ISSN 2075-4442, Lubricants Journal 2015, 3, 91-112.
3. Bernard Marr, is an internationally best-selling business author, keynote speaker and strategic advisor to companies and governments. He is one of the world's most highly respected voices anywhere when it comes to data in business and has been recognized by LinkedIn as one of the world's top 5 business influencers working for Forbes.