Vibration Monitoring as a Mechanism of Motion of a Gearbox through MIRCE Space

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Abstract

MIRCE Science is a theory for predicting expected functionability performance for a functionable system type. Accuracy of the predictions is governed by the degree of the scientific understanding of the physical mechanisms, and human rules, that govern the motion of functionable system types though MIRCE Space. The main objective of this paper is to address vibration monitoring as one of the possible mechanisms that governs motion of a gearbox through functionability states, which are contained in MIRCE Space. In general, and to illustrate this process through a case study related to heavy gearbox used in Plastics Manufacturing industry, conducted by the author with vibration data collected on site by Ian Graham (The Seasoned Analyst).

1. Introduction

The main objective of this paper is to address the vibration monitoring actions as a mechanism of the motion of functionable system type[1] through MIRCE Space[2]. In general, and to illustrate this process through a case study related to heavy gearbox used in Plastics Manufacturing industry, conducted by the author.

2. MIRCE Science Fundamentals

According to the 2nd Axiom of MIRCE Science the motion of functionable system type through MIRCE Space is a result of imposed natural phenomena or human activities, which are jointly called functionability actions [1]. At any instant of calendar time, a given functionable system type could be in one of the following two functionability states:

- Positive Functionability State (PFS), a generic name for a state in which a functionable system type is able to deliver the expected measurable function(s).
- Negative Functionability State (NFS), a generic name for a state in which a functionable system type is unable to deliver the expected measurable function(s), resulting from any reason whatsoever.

The motion of a functionable system type through the functionability states, in the direction of calendar time, is generated by functionability actions, which are classified as:

- Positive Functionability Action (PFA), a generic name for any natural process or human activity that compels a system to move to a PFS.

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[1] According to Knezevic [1], functionable system type is “a generic name for a functional system type and the set of functionability rules that govern functionability performance through calendar time.”

[2] MIRCE Space is an analytical concept used in MIRCE Science to describe the motion of functionable system through functionability states in respect to calendar time. Mathematically, it is three-dimensional space whose coordinates are; calendar time, functionability states of a functional system type and a probability of system being in any of these functionable states.

- Negative Functionability Action (NFA), a generic name for any natural process or human activity that compels a system to move to a NFS.

To scientifically understand the mechanisms that generate negative functionability events, analysis of the in-service behaviour of several thousands of components, modules and assemblies of functionable systems in defence, aerospace, nuclear, transportation, motorsport, communication and other industries have been conducted at MIRCE Akademy.

In MIRCE Science all negative functionability actions are categorised as following [1]:

- Component-internal actions that consist of:
    - Inherent actions that are introduced into components prior to their introduction into service through the activities associated with the design, manufacturing, handling, transportation, maintenance, storage and similar processes.
    - Cumulative continuous actions that are an inevitable part of the components in-service life resulting from natural decay processes such as: corrosion, fatigue, creep, wear and similar.
- Component-external actions, which are originated by:
    - Environmental phenomena that cause discrete overload, like foreign object damage; birds strike (domestic and wild animals), weather (hail, rain, snow, lightening, solar radiation, etc.,) and so forth.
    - Human activities:
        - Errors that are related to phenomena that cause overload, for example use and abuse by operators, (pilots, driver and other users), maintainers (maintenance induced errors) and logistics support personnel (bogus parts, shelf life, etc.)
        - Rules that are related to organisational policies, legal requirements, national and international, best practices or any other human imposed functionability related actions (scheduled and condition based maintenance tasks).
- System-internal actions: resulting from processes that are taking place within a system, like a change from passive to active state for certain components and modules, a change in functionability states of some of its constituent components that impact the functionability of the system.
- System-external actions: which are generated by:
    - Discrete environmental phenomena related to weather (hail, rain, snow, lightening, volcanic eruptions, strong wind, solar radiation, etc.,) and other causes that impact on the functionability of a functionable system type.
    - Human activities:
        - Errors, which are related to the phenomena of use and abuse by: operators, maintainers or supply chain personnel.
        - Rules, which are related to organisational policies, legal requirements, national and international, best practices or any other human imposed functionability actions that cause the occurrence of NFEs for the functionable systems.

3. Condition Monitoring Techniques

The objective of Condition Monitoring is to provide information with respect to the actual condition of the component/system and any change in that condition. This information is required to schedule conditional maintenance task, on a needed basis instead of relying on predetermined instances of operational or calendar times.

Generally speaking, Condition Monitoring techniques use instrumentation to gather regular or continuous measurements of condition parameters, in order to determine the physical state of an item or system. Most frequently used Condition Monitoring techniques are: Vibration monitoring, Lubricant analysis, Infrared Thermography, Ultrasonic and Acoustic Emission. [2]

Condition Monitoring basically is a measurement technology, where various methods are used to determine the condition of the item under consideration, while measuring physical phenomena like: vibration, temperature, crack length, resistance, pressure, wall thickness, conductivity etc. which are used to determine the physical condition of the item.

4. Vibration Monitoring

Equipment, which contains moving parts, in general vibrates at a variety of frequencies, which are governed by the nature of the vibration sources. If any of these parts is to change its physical state, its vibration frequencies change, and vibration analysis can be used to detect and analyse these changes. Vibration monitoring is based on the fact that rotating machines such as pumps, compressors, motors, gearboxes, turbines and so forth produce vibration change as machines deteriorate.

Changes in vibration levels can be used as an indicator for an impending incipient negative event (failure) and can sometimes be used in defining the possible cause of the malfunction. Therefore measuring and analysing the vibration level gives a good indication of the machine's condition and can be used with confidence in condition-based maintenance program either as continuously monitored parameter or in a periodic program. Vibration is characterised in terms of three parameters, namely displacement, velocity and acceleration with respective transducers, which are used to collect data on rotating machinery.

Vibration monitoring, especially, while dealing with rotating machinery, is becoming increasingly important and is one of the best-developed techniques in condition-based maintenance. The recent developments in artificial intelligence techniques have enormously helped these developments by automating the interpretation of vibration data. [2]

5. Vibration Monitoring as Negative Functionability Event

According to the 1st Axiom of MIRCE Science, functionable system type begins in-service life in Positive Functionability Sate [1]. Hence, a system will stay in PFS until is compelled to changed it due to imposing a negative functionability action (NFA). Vibration monitoring is one of numerous possible negative functionability actions which could generate a negative Functionability Event [1].

This paper addresses vibration monitoring as a NFA that causes the motion of functionable system type from PFS to NFS, as well as the positive functionability actions taken to return a system to PFS.

Unlike scheduled maintenance tasks, which take places at predetermined instances of usage or calendar time, Condition Monitoring activities are initiated by changes in the condition of a system. This is so that necessary positive functionability action can take place, when it's needed - not before and not too late. Hence, the results of vibration monitoring analysis will trigger, the human approved, transition of a system considered from PFS to NFS in order to reduce consequences of allowing system to run until the NFE is generated by the natural causes. By doing this, the consequences of the occurrences of NFE are almost eliminated and the duration of the time a system spent in NFS is shorter, in majority of cases, as the logistics support resources; qualified personnel, spare part, tools and equipment could be provided in advance.

In the remaining part of the paper, the above theoretical propositions of MIRCE Science are supported with a real life case study, conducted by the author.

6. Gearbox Based Case Study

The Condition Monitoring expert of the reliability services department was requested to inspect a gearbox at a production facility as the operator had reported an abnormal sound from it. The gearbox was still in PFS producing the product. It was a very large old extruder high torque gearbox with a single input and dual output shafts. The repair history of this gearbox was unknown but it is around 15 years old.

6.1 On Site Initial Assessment

The gearbox vibrational levels as measured under full load conditions were >20mm/s RMS. This is considered "Vibration Causing Damage" as per ISO 10816-3. The Acceleration Peak to Peak impactions at Gearmesh #1 was excessive at 162G's. There were also indications of misalignment on the 1st intermediate shaft and considerable looseness present. In addition the 1st intermediate shaft 'binds' for $^{1}/_{4}$ to $^{1}/_{3}$ of a revolution when rotated by hand.

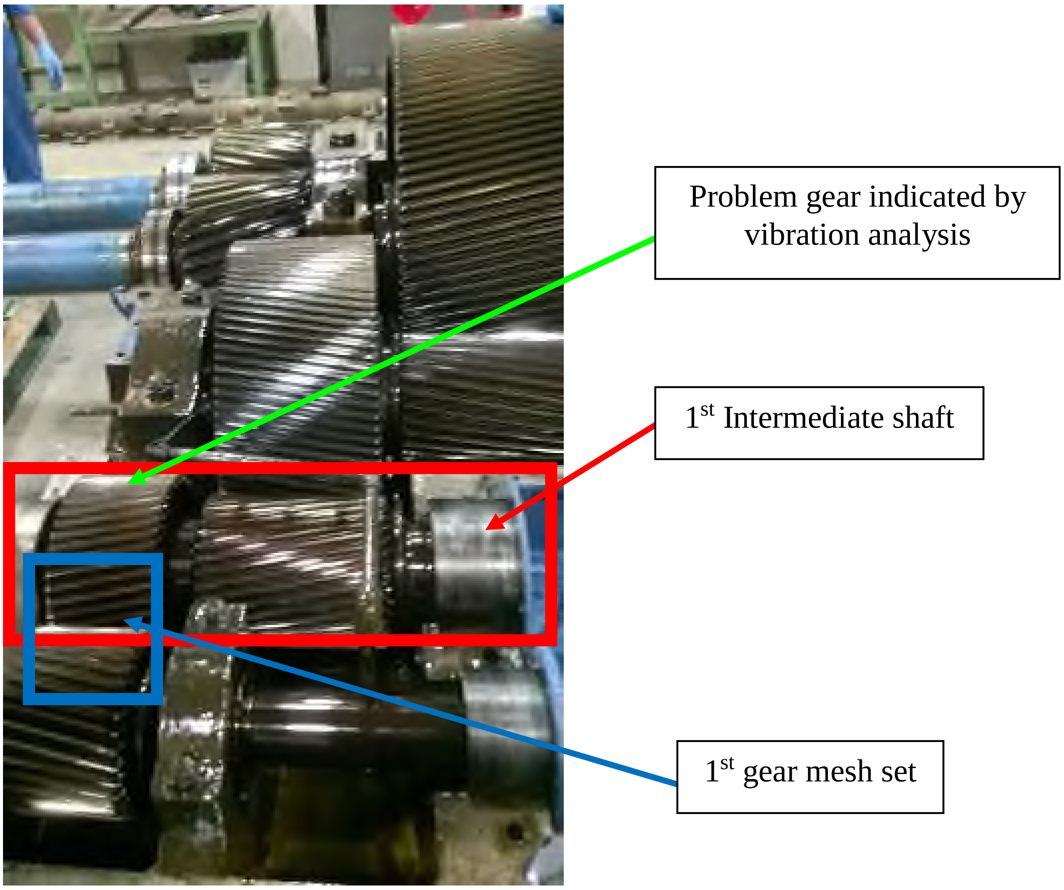

Image 1: Gearbox internals with the input shaft at the bottom of the image the two output shafts at the top left. The problem shaft indicated by the vibration analysis is highlighted by the red frame.

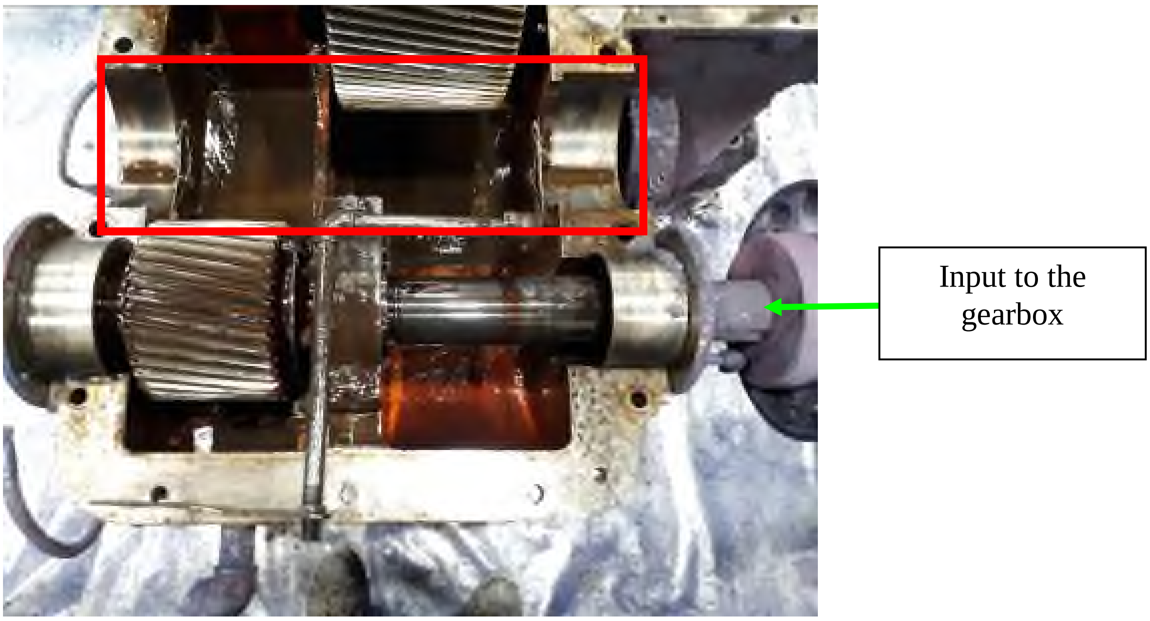

Image 2: A close view up of the problem shaft location after removal for repair.

6.2 Vibration Analysis Data

The input shaft high frequency Acceleration spectrum, shown in the Figure 1, clearly indicates a high 2x gearmesh frequency for the first gearmesh set. This also indicates that there was misalignment within the gearing setup. The sidebanding at 19.20Hz indicated that it was relative to the 1st intermediate shaft.

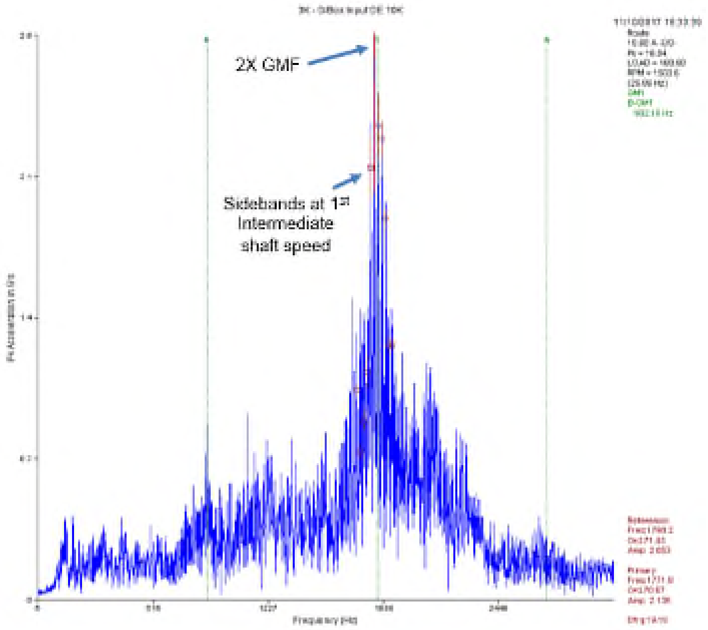

Figure 1: The input shaft high frequency Acceleration spectrum.

The peak to peak measurements on the Acceleration time waveform, shown in Figure 2, indicated that the Acceleration forces are generated from the 1st Intermediate shafting. The total reading of 162G's is highly destructive and is impacting at frequency of 19.2Hz, the 1st intermediate shaft speed. This displayed that the gear is loose and impacting very heavy once per revolution of the shaft.

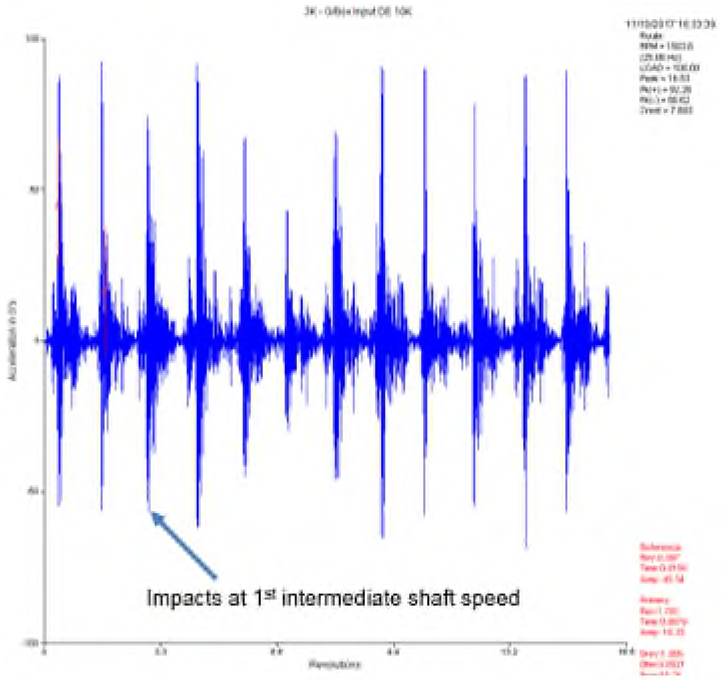

Figure 2: The peak to peak measurements on the Acceleration time waveform.

Figure 3 below is the Velocity spectrum taken from the non-drive end (NDE) of the 1st intermediate shaft, and shows a considerable amount of run speed harmonics attributed to the shaft speed. This is an indication of looseness.

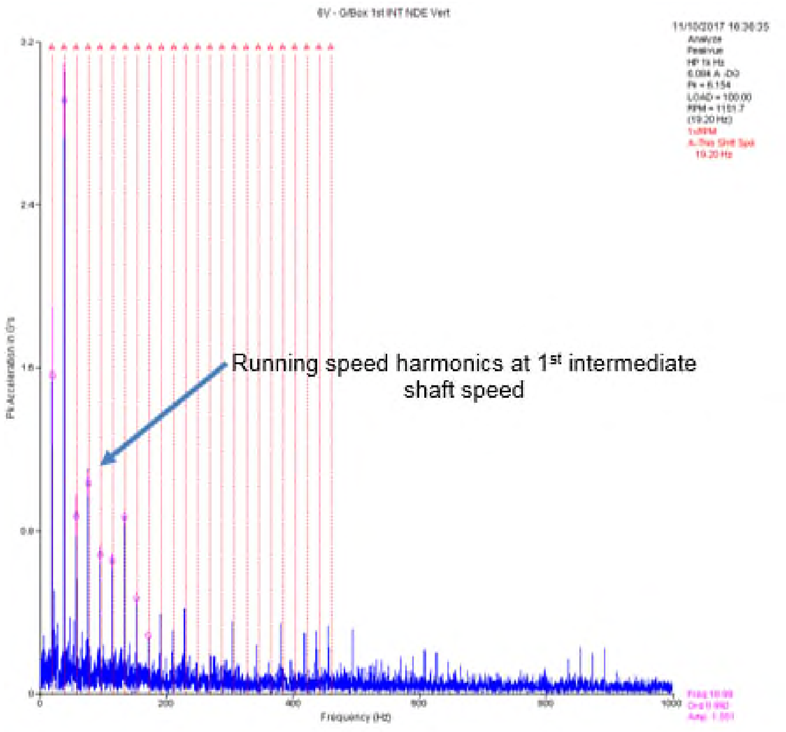

Figure 3: Velocity spectrum taken from the non-drive end (NDE) of the 1st intermediate shaft.

6.3 Vibration Analysis Summary Initiated Negative Functionability Event

The vibration analysis data collected clearly indicated a high impact once per revolution from the first gear set, highest on the 1st intermediate shaft (2nd shaft). Also, there were indications of component looseness from the same location. This all pointed to the gear and bearings on the 1st intermediate shaft. This knowledge enabled the bearings for the shaft to be pre-ordered so they arrived at the repair shop the same time as the gearbox.

Based on the evidential data gathered during the vibration measurement and analysis performed on the data obtained, the management of the company decided to stop the production process and performed necessary maintenance actions. By doing that, they would prevent further deterioration of the gearbox and avoid the consequences of gearbox failure and the transition of production system into an unplanned NFS.

6.4 Positive Functionability Actions

The negative functionability event has initiated positive functionability actions, which started with dismantling the gearbox. The inspection performed shown that the tab washer on the first intermediate shaft outer bearing had failed (Image 3). The most probable mechanism of this failure is fatigue of a washer resulting from the high shock acceleration levels (162Gs). The function of a tab washer is to lock the bearing sleeve to set the correct bearing clearances and to prevent the bearing inner raceway spinning on the shaft.

Image 3 of the failed tab washer found in the bearing cap from the 1st Intermediate shaft.

Further inspection has shown that the suspected gear on the 1st intermediate shaft was extremely loose. It was found that this shaft had been previously repaired with metal spray and this had failed. On closer inspection the stress raiser appears to be around the keyway, as there were no strengthening welds around the keyway to support the metal spray. The metal spray was to the edge of the key way at a 90 degrees angle to the keyway, this was the weak point and the stress raise. Therefore over time fatigue set in and started to crack the meatal spray around the keyway that then rapidly progressed to a catastrophic failure of the metal spray, as shown in Image 4.

Image 4: Metals spray coating that was under the 1st Intermediate shaft gear. This failed initially at the metal spray coating at the keyway.

NB: Metal spray coating (Thermal spraying) are coating processes in which finely divided metallic powder are deposited in a molten or semi-molten state to form a coating melted onto a surface. This is often used as a cost effective process to repair worn shaft journals.

7. Conclusions

This paper set out to prove that vibration monitoring is one, of numerous, mechanisms that cause the motion of functionable system type through MIRCE Space, and as such it has impact on the final functionability performance. Theoretical considerations of MIRCE Science were presented in the first part of the paper, with evidential proof through the data obtained during in-service events conducted by the author.

MIRCE Science perceives in-service life of functionable system type as a motion through positive and negative functionability states, governed by natural phenomena of human activities, jointly named, functionability actions. Vibration monitoring is one of these functionability actions that is initiated and performed by humans in order to determine the change in the state of a system in the direction of calendar time and based on the analysis of the data obtained, the decisions are made regarding the timing and the content of the future functionability actions in a such way that the probability of delivery the expected business plan is maximised.

The case study used in the paper, conducted by the author, supports the hypothesis that a vibration monitoring is a mechanism of the motion of a heavy gearbox, used in Plastics Manufacturing industry, through MIRCE Space. Through onsite vibration analysis it was possible to pinpoint that the first intermediate shaft was generating the abnormal noises and the probable failure mode(s). This knowledge enabled the bearings for the shaft to be pre-ordered so they arrived at the repair shop the same time as the gearbox.

The vibration levels recorded enabled an assessment of whole risk of failure and this was deemed to be high due to the unavailability of the gearbox gears/shafts (due to the age of the gearbox) and the very high impacting levels. Consequently, the gearbox was removed from service, introducing a human made NFA, which was performed before imminent functional failure of the system due to natural causes. In return, this NFA initiated PFA, which in this case was a quick turnaround, removed the risk of secondary damage and was completed with minimal production loss.

Even though this did cause an interruption to the function of the asset and production levels it was agreed, by all concerned, that inconvenience caused during a four day stay in NFS of a system was the better option over the risk of a catastrophic failure and the possibility of production ceasing operations for two months.

8. Acknowledgement

The author wishes to acknowledge the support received from Dr Knezevic, MIRCE Akademy, Exeter, UK, while preparing this paper. As the “father” of MIRCE Science, Dr Knezevic, has inspired me to view how every day Condition Based Monitoring can have a significant impact on functionability performance of the whole system. Consequently, I can now understand how many companies are performing Condition Based Monitoring but are not linking this to the business performance of the whole organisation/company. MIRCE Science is the body of knowledge that bring together these two very different but related disciplines, for the ultimate benefit of the user.

9. References

[1] Knezevic, J., The Origin of MIRCE Science, pp. 232, MIRCE Science, Exeter, UK, 2017. ISBN 978-1-904848-06-6

[2] Sylvester, J., Enhancing System Reliability Through Vibration Technology. The Seasoned Analyst, pp. 264, Volume 1, Issue 1, February 2018.

[3] http://en-us.fluke.com/community/fluke-news-plus/vibration/understanding-the-benefits-of-vibration-monitoring-and-analysis.html

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