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# Effecting of Temperature Variation on Gear Tooth Fault Detection by Using AE in Helical Gear

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## Abstract

This work will seek to describe in its experiments on spur/helical gears the possibility of occurrence of each of the normal and synthetic gear tooth defects (pitting, wear, crack and surface defects). Monitoring during the experiments period has been focused on temperature, spectrometric oil samples, vibration, and AE were monitored continuously in order to compare and relate these techniques to the degradation of gears life. The experiments of this study will run on back-to-back gearbox test rig. It is built for purpose of the study, and it's prepared to appropriate the ability of identifying early indications of probable failure. Oil analysis, thermal analysis, vibration analysis and AE are the main tools which will be used in parallel during the whole test. The results of this research showed a clear relationship between helical gear teeth defect initiation and AE activities in several operation conditions. And prevent the suddenly shock of the machine and find a technique to know the time remaining before the total failure of the gearbox.

***Keywords: Online monitoring, acoustic emission, vibration, gears defects***

## 10.Background

Gearbox faults often associate with gear teeth, these faults fall into complete fracture of the gear tooth and damage or destruction of the working surfaces of the gear tooth. Gear tooth surface failures fall into failure by the formation of cracks in the involute surfaces of the gear tooth, plastic deformation of the gear teeth and failure caused by the removal of metal particles from the involute surfaces of the teeth on one gear by the mating surfaces of the teeth on any gears which mesh with it [1-8]. The function of any gearbox or transmission is to offer a drive, which often consists of a range of selected intermediate gear ratios, between the power unit and the last source of the drive, whether it is to be used in an automotive, marine or industrial application.

The gearbox unit includes four main components or units, the gearbox casings, the gears and shafts, the bearings, the lubrication system. Any one of these units can be the reason of ultimate failure in the transmission system. In the common type of failures, it is usually damage to the gear tooth surfaces which cause the first complaints to be raised, [9].

Systematic analyses of the failure of the gears begin to classify the type of defects. The type of defect is usually depends on the creation of the defect and the growth process or mechanism of failure. After the mechanism of a failure has been established, it remains to determine what caused the failure. In general, an understanding of the failure mechanism is of considerable assistance in isolating the cause or causes of a failure.

Types of gear failures have been grouped into four general classes which are wear, surface fatigue, plastic flow, and breakage, [10]. Condition monitoring can be defined as the ability to identify early indicators of potential failure. Monitoring failures have been found in predicting and preventing unexpected failures which could have a negative impact on the efficiency and safety or usefulness of gearboxes. Through early warning of the possibility of failure, preventive maintenance or corrective could set a timetable for the least disruptive time. Oil analysis, thermal analysis, vibration analysis and acoustic emission are the most common tools used. Early detection of signs of failure in gearboxes is the key, and that is the focus of this project.

Implementation of monitoring and vibration analysis to diagnose the defects in gearboxes was common in the investigation and its application in industry will be established. Whereas Diagnosis of rotating machines faults by application of AE is in its infancy [11], [12], [13], and [14]. On the other hand, it was not until the last tens of years or so, that the acoustic emission developed so-called modern technology. Acoustic emission presents some advantages over the methods of vibration analysis. Acoustic emission waves spread in all directions from the source while vibration is unidirectional to a large extent, the highest frequency of early detection by the sensors; there are less effect due to the nature of the operation and activities of the process to give a clearer and more direct indication of the existence of the fault mechanism. It is much more effective at low speed for rotors, linear and plain bearings where the conventional techniques of vibration is difficult because of the weakness of the signals to the proportion of noise in the very low frequencies [15].

## 2. Experimental setup

### 2.1. Test rig

The test device employed in the present work is shown in Figure 1. The system was powered by 1.1 Kw motor with helical (214M15) steel test gears. Please refer to the table 1 for specification of test gears. Mobil gear 632 oil (see end of table 1 for specification of the oil) was used as lubricant for the gearboxes which were operated at a speed of 690 rpm and to apply the torque (380 N.m) on the gears a pair of coupling flanges to be twisted relative to each other, and locked in position, was employed.

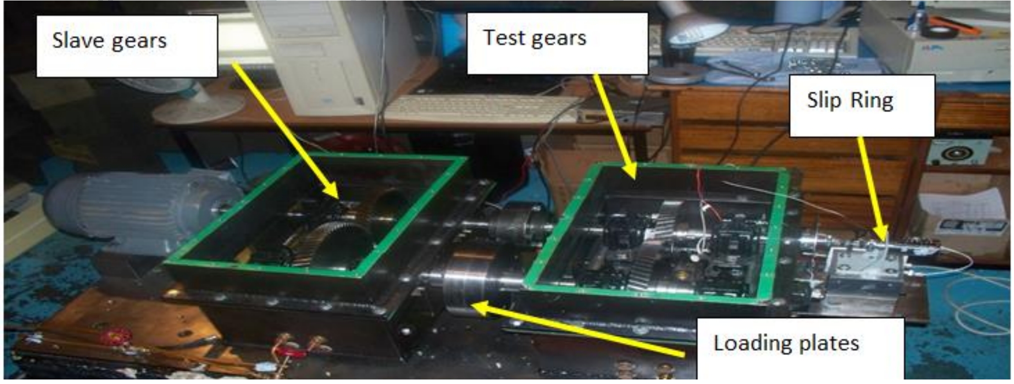

**Figure 1: Back-to-back Gearbox test rig**

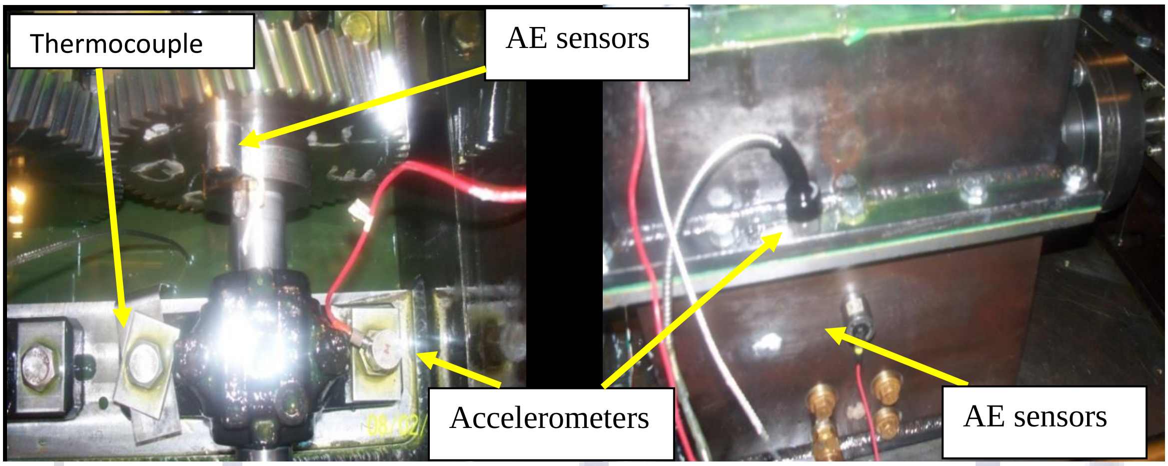

**Figure 2: AE and vibration sensors locations**

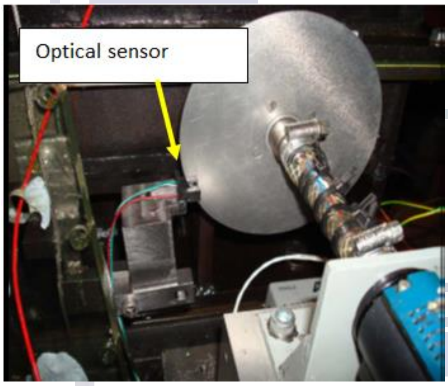

**Figure 3 : Data acquisition triggering mechanism.**

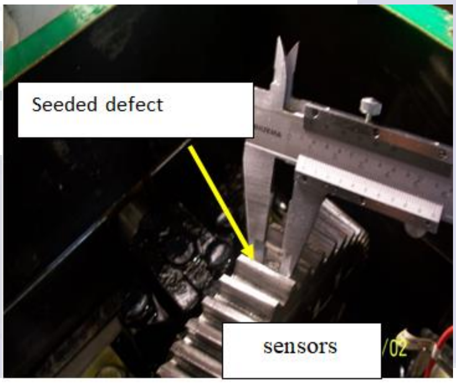

**Figure 4: Seeded defect on the tooth surface.**

## 2.2. Instrumentation and data acquisition system

A wide-band AE sensor (type WD, from Physical Acoustic Limited) was used to measure AE throughout the test. One sensor was placed on the pinion (first channel) and the other on the gearbox casing (second channel) as shown in Figure 2. The cable connecting the sensor placed on the pinion with the pre-amplifier was fed into the shaft and connected to a slip ring placed at the end of test gearbox as shown in Figure 3. This arrangement allowed the AE sensor to be placed as close as possible to the gear teeth. Using super glue, both sensors were held in place. AE signals were pre-amplified at 60 dB for both sensors. The 5A PH-12 slip device manufactured by IDM Electronics Ltd was used. The slip ring uses silver contacts and can accommodate up to 12 channels. The AE sensors were differential-type with a relatively flat response between 100 kHz and 1 MHz. AE was recorded with MISTRAS AE DSP-32/16 data acquisition card at a sampling rate of 5 MHz. Accelerometers (ISOBASE 236 Endevco) used had an operating range of between 10 and 8000 Hz.

Figure 2 shows the way the accelerometers were mounted, one mounted on the bearing pedestal of test gear and the other on the gearbox casing. All vibration data was recorded at a sampling rate of 10 Khz. J-type thermocouple, rated from -60 C° to +850 C° was placed inside the oil bath for temperature monitoring during the experiment in Figure 2. It was important that any data recorded was taken from a well defined circumferential point at every revolution because this experiment focused on assessing the applicability of AE for identifying seeded defects on helical gears. For this reason, an optical actuating mechanism was used. The operating system consists of a metal disc with a diameter of 2 mm and an optical sensor. Each time the hole passed through the optical sensor the AE and vibration acquisition systems were triggered (Figure 3).

Analogue-to-digital converter (ADC) controlling software was used to calculate continuous AE Root mean square (rms) values in real time. The hardware accelerator used by the software enabled the calculations of the AE rms in real time. Each value from the ADC was squared and added into the accumulator by the hardware accelerator for a programmable time interval, 90 m/s in this case which corresponds to very slightly below one complete revolution of the pinion at the rotational speed (690 rpm). To calculate the rms, the square root of the accumulated squared ADC readings was used. The accumulator was reset at the start of each new time interval and the same process was repeated. The time interval for the acquisition was set at 90 m/s.

**Table 1: Specification of test gears and oil**

| **Specification of test gears** | **Pinion** | **Wheel** |
|---|---|---|
| Number of teeth | 51 | 70 |
| Module | 3 mm | 3 mm |
| Pressure angle | 20 | 20 |
| Helix angle | 17.5 | 17.5 |
| Contact ratio | 1.7 | 1.7 |
| Face width | 25.1 mm | 25.1 mm |
| Direction | Right Hand | Left Hand |
| Hardness | 137 Hv30 | 137 Hv30 |
| Surface roughness | 1.327 lm | 1.327 lm |
| Pitch circle diameter | 160.65 mm | 220.50 mm |
| Size of Addendum | 3 mm | 3 mm |
| Size of Dedendum | 3.75 mm | 3.75 mm |
| **Specification of the oil** | | |
| Lubricant properties | | Mobil gear 632 |
| Kinematics viscosity at 40 | | 664 (cSt) |
| Kinematics viscosity at 100 | | 62.8 (cSt) |
| Viscosity index ASTM D2270 | | 165 |
| Density at 15_ ASTM D4052 | | 0.87 |

## 3. Test procedure

Gearbox was operated in a planned load and speed (380 N.m/690 rpm) with defect free for period 5hrs such that the gearbox reaches a stabilised temperature. It was essential to capture AE and vibration data that included the tooth which planned to simulate defect on it and as such. The acquisition time window of 16 teeth was set for which the trigger mechanism allowed an acquisition duration of 0.0256 sec, which corresponds to 16 teeth at 690 rpm for each set of data (see Figure 6). At the beginning of the test a defect free recording of AE and vibration was undertaken. The instantaneous recording was made to allow exploring the influence of temperature on the levels of AE and vibration. The AE and vibration signals were recorded while running the gearbox long enough for the specific temperature degree (after each 3 degrees) until the temperature stabilized (reached 51C°). In order to ensure repeatability, the tests were repeated twice. In order to carry out the seeded defect test, the test rig was stopped and the pitch line defect introduced on the tooth as rectangular deep scratch (8mm x 3mm x 2mm) as shown in Figure 4. The gearbox was then restarted and the same procedure was followed for the seeded defect run.

## 4. Results and discussion

### 4.1 Results based on acoustic emission AE monitoring

The AE sensors on the pinion and gearbox casing were synchronized, that means both AE sensors captured data simultaneously. Figure 6 shows typical waveform for free defect condition at 380 Nm. Type AE continuous waveform is prevalent although transient AE bursts whose amplitude exceeds the basic continuous wave also existed. The frequency of the periodicity of the AE bursts represents the number of meshing teeth within the acquisition window. [1] observed same results when studied AE waveforms in a induced gear network where both continuous and transient forms of AE activity were evident. They concluded that rolling contact on the pitch line of the spur gear mesh was responsible for generating of high amplitude AE transient burst, whilst sliding contact was because of generation a large part of the continuous waveform. In the case of helical gears, the contact between a particular gear pair begins as a fine point of contact that increases the contact length on the gear pair while joining the contact length on the unjointed pair of gears. The contact length varies along the pitch line of the helical gears but in spur gears the contact length remains constant. Furthermore, the continued variation in the contact length during meshing of helical gears which directly influences the load conditions experienced by the gear, will lead to instantaneous changes in oil film thickness [2]. Therefore, AE waveforms associated with the helical gear mesh were expected to be of the continuous type with amplitude variations attributed to the gear mesh, refer to Figure 6.

Typical AE waveforms associated with defect is displayed in Figure 7 which shows relatively large transient AE bursts. The transient AE bursts were noted to occurs in the area of the tooth where the defect was seeded. Such observations were not observed in a similar test with spur gears; that means the seeded defects were not evident in the waveforms [3], [4].

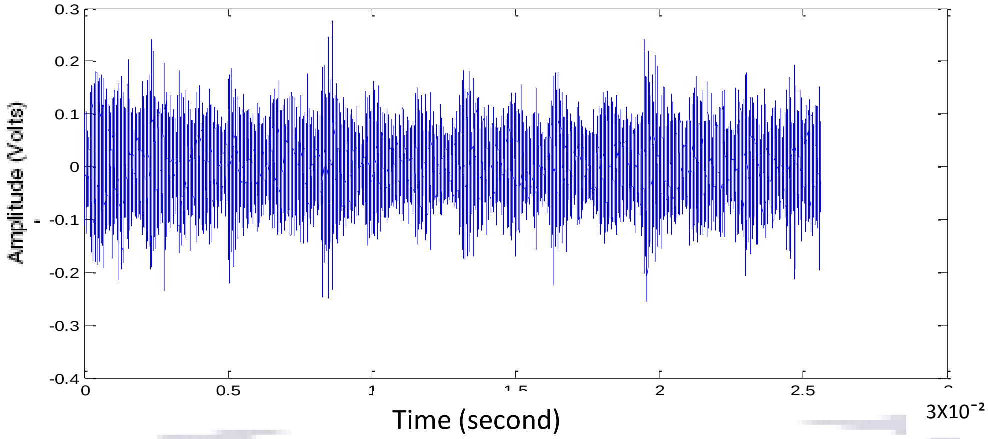

**Figure 6: AE waveform associated with a defect free condition.**

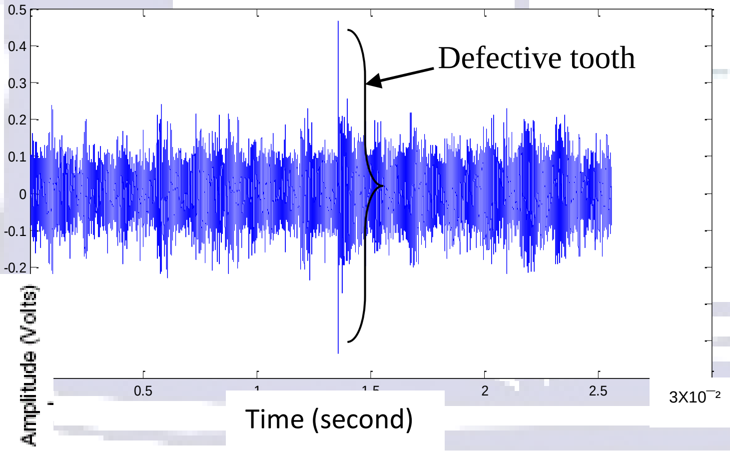

**Figure 7: AE waveform associated with a defect.**

The difference in the oil temperature with the operating time is shown in Figure 8. It is clear from Figure 8 that the raise in oil temperature for both free/seeded defect was simila Thi behavior allowed acquiring AE data under the identical conditions. In both the cases, temperature increased at a rapid rate in the first hour then the increase reduces. The gearbox system reached a stable temperature only after at least 5 hours of continuous operation for both experiments conditions.

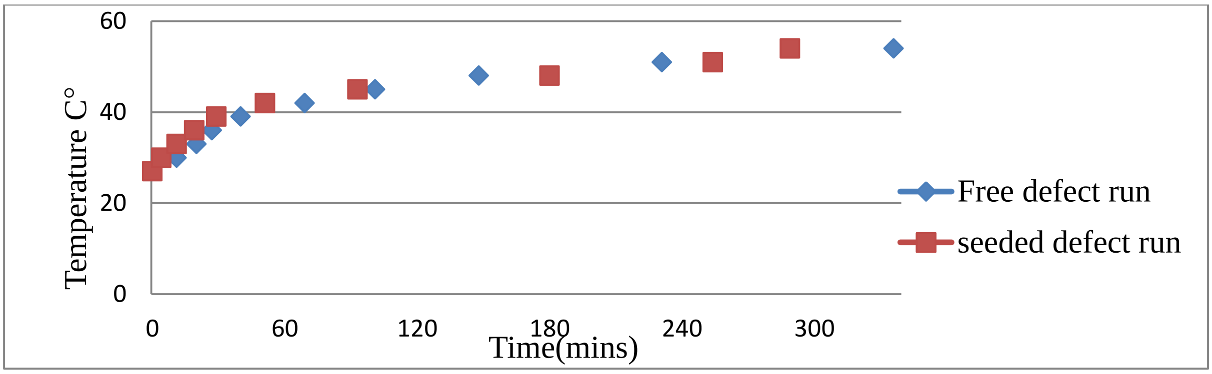

Figure 8: Oil temperatures monitoring with free defect and Seeded defect.

Figure 9 shows AE-RMS variation with temperature for different channels. For the seeded defect test related to gear AE sensor (first channel) it can be noticed that the AE RMS levels increased as the oil temperature increased. This trend of RMS with oil temperature shows the detection of simulated defect in gear tooth. However, the AE RMS levels from the gearbox casing sensor (second channel) do not show any significant variation due to the dissipation and attenuation of the signal before it received by this sensor. The relation between AE absolute energy and oil temperature related to the both AE signals channels for both free/seeded defect tests is shown in Figure10. Here as well the AE energy for the first channel increased with the oil temperature in the seeded defect test, while no specific behaviour trend is noticed in the case of the second channel.

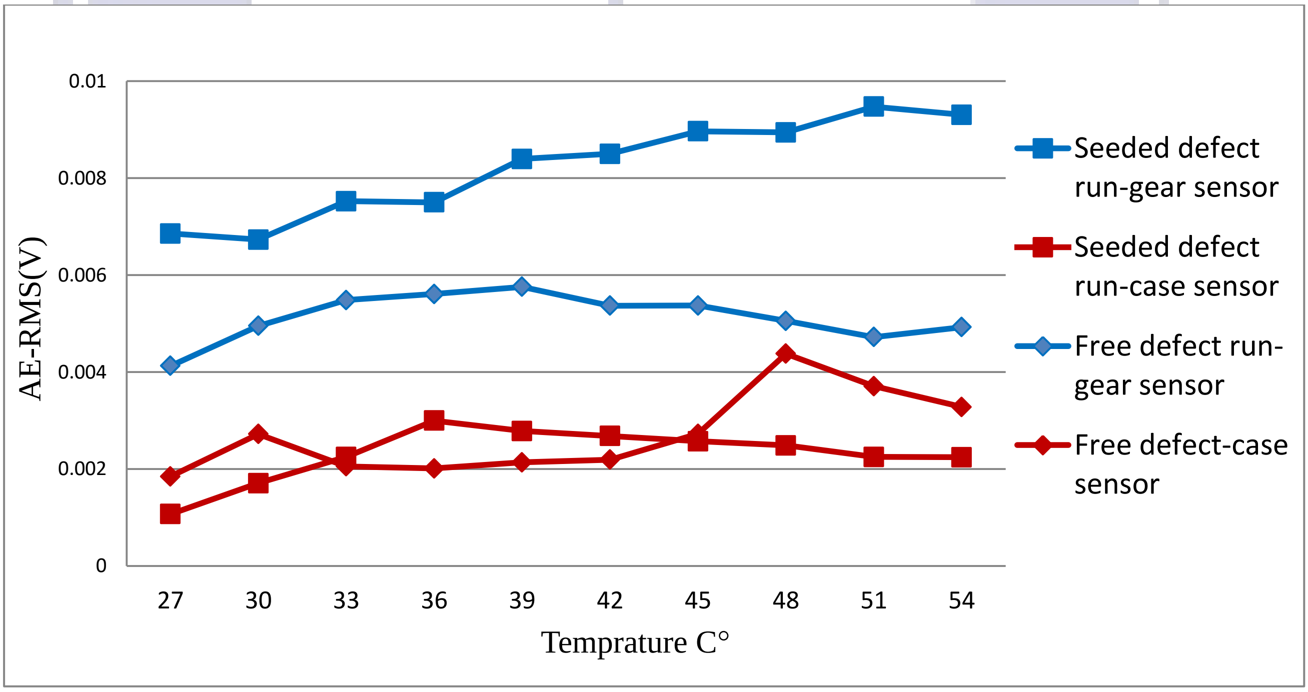

Figure 9: AE RMS values for each sensor condition

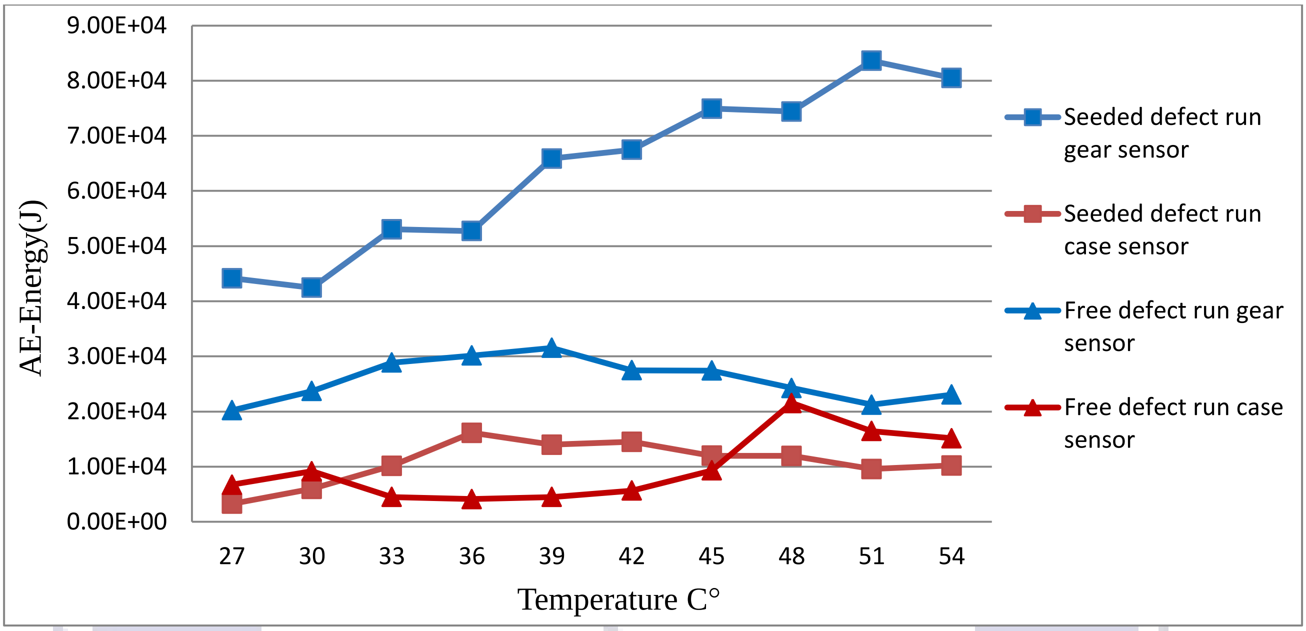

**Figure 10: AE Energy values for each sensor condition**

## 4.2 Results based on vibration signatures

In this case as well as the vibration sensors on bearing pedestal and gearbox casing were synchronized, so when the data acquisition system was triggered, both AE sensors captured data simultaneously. Sets of data for each defect free and seeded defect test based on 10 KHz sampling rate were captured and synchronously averaged. Vibration RMS values obtained for each test condition are illustrated in Figure. 11. The vibration RMS levels at each test condition are remained almost constant for the range of oil temperatures. At the same conditions the continuous vibration RMS values were plotted during increasing temperature and presented; it was observed that the vibration RMS remained rather constant in both free/seeded defect (Bearing pedestal-ND/Bearing pedestal-SD) with increasing temperature. The detection of defect and its severity level with increasing temperature could not be ascertained from this feature, especially at the earlier stage.

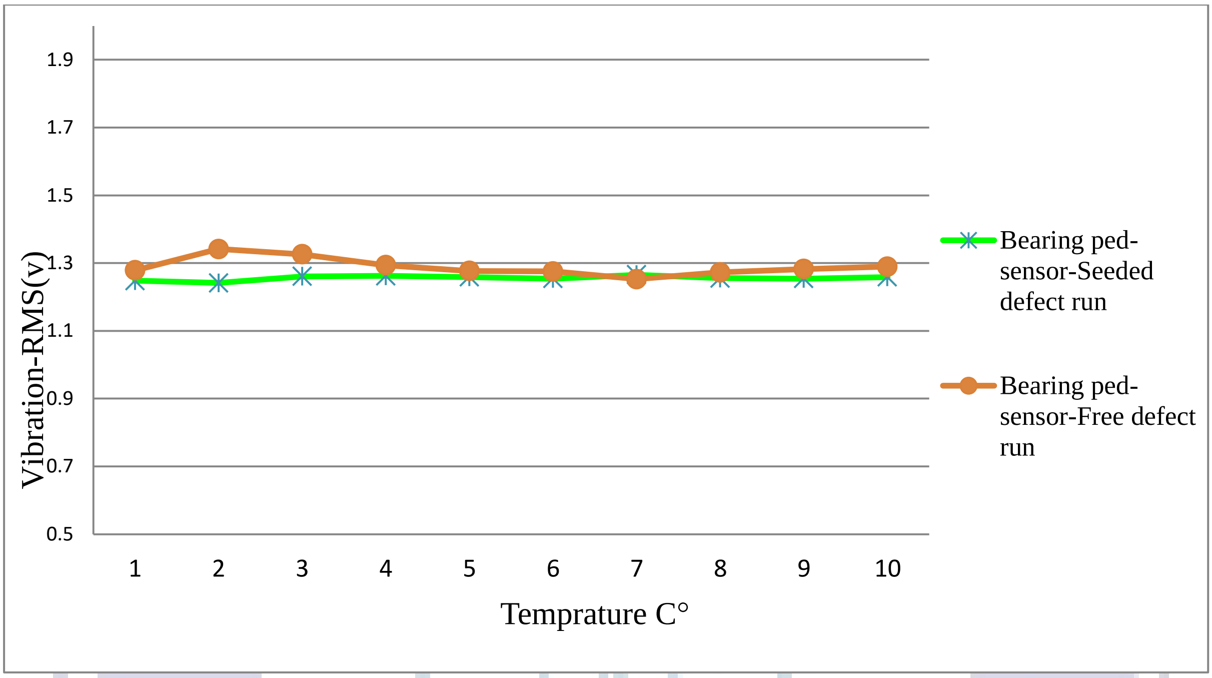

**Figure 11: Vibration RMS values for bearing pedestal sensor condition**

## 5 Conclusion

It can be concluded from the results presented here that at constant process conditions speeds and loads, increasing oil temperature in the gear system has negligible effect on vibration RMS. Also, the detection of the defect and its level of severity with increasing temperature cannot be verified from the vibration features of the early stage.

However, increasing oil temperature had a considerable effect on the AE indicators. This shows a clear relationship between variation of temperature and AE activities for gear (gear sensor), however this relationship was absent from case sensor. Thus, empirically seeded defect determination of AE RMS gearbox housing and energy ware not satisfactory.

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