# Vibration, Lubrication and Machinery Consideration for a Mixer Gearbox Related to Iran Oil Industries

Omid A. Zargar

***Abstract*—**In this paper, some common gearboxes vibration analysis methods and condition monitoring systems are explained. In addition, an experimental gearbox vibration analysis is discussed through a critical case history for a mixer gearbox related to Iran oil industry. The case history also consists of gear manufacturing (machining) recommendations, lubrication condition of gearbox and machinery maintenance activities that caused reduction in noise and vibration of the gearbox. Besides some of the recent patents and innovations in gearboxes, lubrication and vibration monitoring systems explained. Finally micro pitting and surface fatigue in pinion and bevel of mentioned horizontal to vertical gearbox discussed in details.

***Keywords*—**Gear box, condition monitoring, time wave form (TWF), fast Fourier transform (FFT), gear mesh frequency (GMF), Shock Pulse measurement (SPM), bearing condition unit (BCU), pinion, bevel gear, micro pitting, surface fatigue.

## I. Introduction

GEARBOX vibration analysis is considered as one of the most complex concepts in preventive maintenance. Gearboxes are produced complex fast Fourier transform (FFT) and time waveform (TWF).

Three main vibration analysis methods are explained in this part. Traditional FFT vibration analysis indicated that faults could produce side band families around tooth mesh frequency (TMF) or gear mesh frequency (GMF). GMF is calculated by data collector software automatically. The gear dimension, geometry, the number of teeth and RPM of different shafts in gearboxes are inputted in options then the software (like spectra pro) could introduce the TMF in cursors automatically and accurately. FFT and TWF samples in GMF are shown in Fig. 1.

Impacts (high amplitude peaks) in TWF indicates bad gear condition. In addition, the amplitude of side bands, harmonics and gear box noise are increased considerably by increasing the amount of wear in gears. The philosophy of harmonics specially second and third harmonic is related to gear boxes inner shaft alignment. This phenomena caused second and third harmonic because the alignment behavior (1X, 2X and 3X). Besides, it is important to input machine information like RPM, bearings and gears characteristics in software accurately. Otherwise, the vibration analysis may guide us to some wrong maintenance decisions and recommendations [1].

Omid A. Zargar is with the Department of Mechanical Engineering - Jawaharlal Nehru Technological University Hyderabad, Kukatpally, Hyderabad-500085,Andra Pradesh India (phone: +91-40-23158661 to 4; fax: +91-40-23156184; e-mail: hyd2_jntuadm@sancharnet.in).

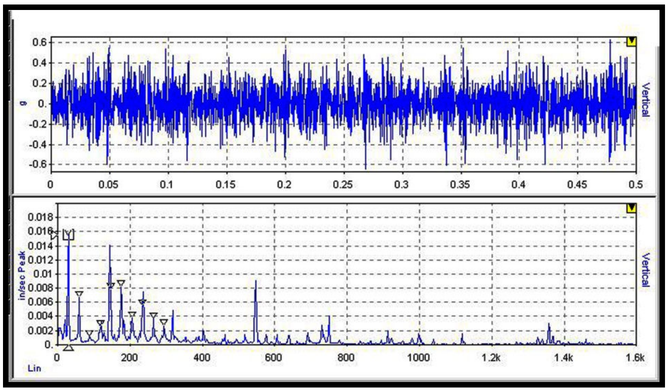


Fig. 1 FFT and TWF samples in GMF

Secondly, Shock Pulse Method is a signal processing technique used to measure metal impact and rolling noise such as those found in rolling element bearings and gears. Much more refined than other high frequency measurements, Shock Pulse is widely used throughout the world as a basis for predictive maintenance. Rolling element bearings and different type of gear conditions are the most common measurement for Shock Pulse but the measurement technique has a number of other applications such as, compressor condition and other applications where metal-to-metal contact is a source of wear. When two pieces of metal, in motion, contact each other, two interrelated, yet distinct processes occur.

On initial impact, a shock or pressure wave develops and quickly propagates through the metal. This Shock Pulse is in the ultrasonic frequency band and typically occurs around a center frequency of 36 kilohertz. The amplitude of the Shock Pulse is relative to the velocity of the impact. As the signal expands from its point of origin, it is dissipated by carbon and other imperfections in the metal. This shock or pressure wave is what we are interested in measuring using the shock pulse method. As the impact continues to develop, the metal surfaces are compressed and deflected. As the objects recoil, the metal components then rebound and continue to flex for a number of cycles until the energy is dissipated.

This second phase of the collision is vibration and its frequency depends on the shape, mass, stiffness, and dampening of the metal. Shock Pulse Method filters out this phase of the collision, as the magnitude of the vibration is structure and material dependent. Typical SPM data collector and methodology had shown in Figs. 2 and 3 respectively.

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:8, No:3, 2014

Fig. 2 Shock Pulse Transducer with Probe TRA-22 and a typical SPM data collector

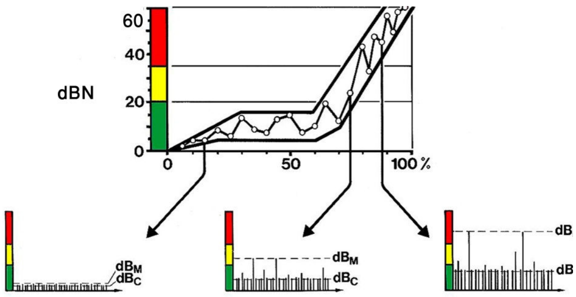


Fig. 3 Steps in measuring SPM

*A. Carpet Value (Lubrication Condition)*

Metal impacting metal always occurs in rolling element bearings. Even a new bearing under normal operating conditions starts its journey towards wearing out. If lubrication were perfect, bearings would never wear out. When there is no damage to the bearing, the metal-to-metal contact creates a background noise of Shock Pulse. This is referred to as the Carpet Value. When the lubrication begins to break down, there is more metal-to-metal contact and the Carpet Value will reflect this by increasing in its amplitudes. This increase tells one that the bearing is experiencing more metal strikes in a given period. The most likely cause of increasing Carpet Value is a decrease in the protective properties of the bearing lubrication.

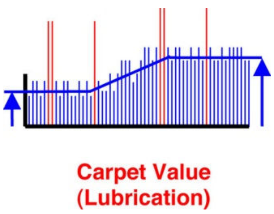


Fig. 4 Carpet Value (lubrication condition)

*B. Maximum Value (Bearing or gear Damage):*

When a defect occurs on a bearings or gears element, it is periodically hit by another element in the bearing or gears. For example, a defect on the outer raceway of a bearing is hit each time a ball or roller passes over the defect. This periodic collision creates a high amplitude burst of Shock Pulse waves that stands above the carpet value. It is similar to hitting a pothole with your car. This stands out above the normal road noise. With the application of some peak hold signal processing, we can distinguish this peak from the carpet of background Shock Pulse signal. As bearing, damage first develops then propagates the Max Value increases. Max Value thereby is an excellent indicator of damage in rolling element bearings or gears teeth.

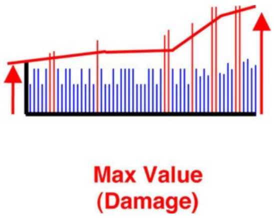


Fig. 5 Maximum Value (Bearing or gear Damage)

The dBi value is calculated once the RPM and shaft diameter have been input into the Tester. This becomes the starting point for 0-60 scale. dbm and dbc represented maximum value and carpet value respectively. The yellow represented alert condition and red represented danger condition in gearbox.

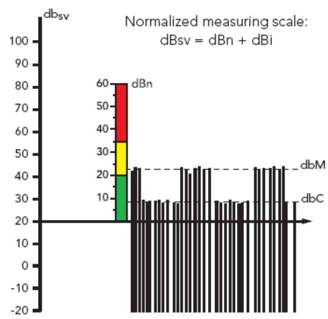


Fig. 6 Shock Pulse Method Evaluation; Range/Scale

The gear boxes are produced too much noise pollution. Online systems are developed recently. These systems are monitored the SPM data directly and continually with excellent accuracy [2].

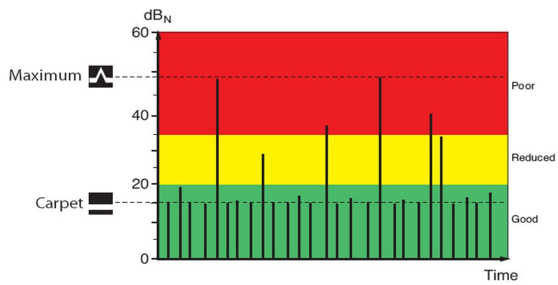


Fig. 7 Typical on line SPM condition monitoring system

In addition, bearing condition unit (BCU) trends analysis is developed for gearboxes in different industries recently. The gearboxes usually have complex TWF and FFT by several peaks with different amplitudes. Maximum peaks in FFT connected to each other (carpeting) and a new TWF is achieved. New FFT is drawn from this imaginary wave (TWF) called envelope. Envelope can represented prisoned energy inside bearings or gears. First the frequency bands are introduced by indicating the geometry and mechanical characteristic of the specific bearing or gear. Then the condition of gear or bearing is evaluated by a number (BCU). BCU trending or monitoring can evaluated the condition of gears or bearings effectively for different types of gear boxes in different industries [3].

*C. Literature/Past Research Review*

Today it is possible to use calculative methods to predict the relative displacements of gears under operating load and conditions. Displacements and deformations originating from shafts, bearings and housing are considered [4]. Three-dimensional model of a bevel gear with spiral teeth developed in recent years [5]. Kinematical optimization and sensitivity analysis of circular-cut spiral bevel gears are investigated Based on the Gleason spiral bevel gear generator and EPG test machine, a mathematical model is proposed to simulate the tooth contact conditions of the spiral bevel gear set [6].

In addition, a simplified model of the original engineering problem with industrial restriction and the practical value of the pertinent optimization program are recently investigated [7]. Furthermore, some manufacturing simulation for bevel gear cutting has been investigated. Besides, the simulation modeling of the tool, work piece and kinematics is performed as well as a geometrical penetration calculation [8]. An optimized approach to straight bevel gear design is developed in 2004 and discussed some critical challenges in this area. This method widely used by gearbox designer in recent years because of its simplicity and accuracy [9].

It is worthy to know that traditional vibration analysis methodology is discussed in [10]. Besides some gear boxes vibration analysis case reports and investigations are discussed in [11]-[13]. In addition gear failures, micro pitting and surface fatigue discussed in [14]-[16].

In this paper different aspect of gearboxes mechanical, vibrational and operational behaviors simultaneously discussed in details for the first time (through a critical case history related to Iran oil industries).

## II. Experimental details

The gearbox related to mixer T-RA-1301-A is most critical equipment for the petrochemical plant process. The gear box have the history of wear in gears from 2 years ago first of all the vibration history of the gear box is explained. In July 2011 the gear damage caused to replacement of the specific gears in gear box. The installation and assemble backlash was in the range of technical documents. All critical parameter like the overall backlash of the gear units, backlash values of the individual gear sets, axial of the input shaft in millimeter and axial bearing clearances all was in the range of technical document.

The gearbox was in service in free run condition with low 1000 RPM for 2 hours and with high 1500 RPM for 4 hours. During these two periods the vibration and graphs was monitored. During this period any changes was not appeared in the gearbox condition. The highest frequency was related to pinion gear and engaged bevel gear. After that, gearbox coupled with mixer and operates in service first in low RPM and with high RPM in the next stage. There was not any abnormal frequency or amplitude in FFT. All vibrations almost were in GMF. The highest amplitudes were related to pinion gear and bevel gear.

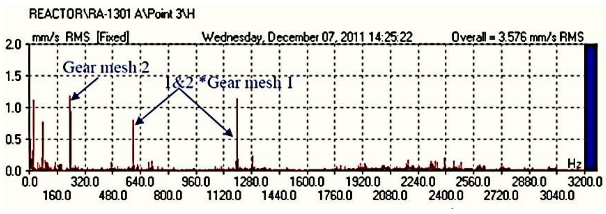


Fig. 8 Vibration data (FFT) in couple condition start up

After 4 hours that mixer was running in high RPM in operation full load the equipment shifted to low RPM because of some electrical problem. In the next stage operation shifted the mixer to high speed and monitoring data showed any changes was not occurred in overall vibration or FFT. Speed was changed two times for process purpose and the monitoring trend of critical points results was as following:

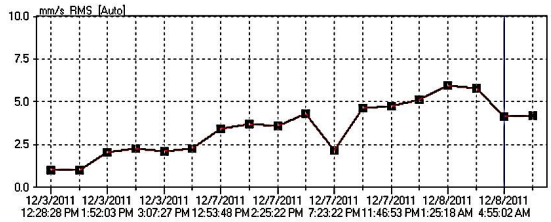


Fig. 9 Over all vibration trend

Analysis the FFT showed that we have 25 Hz shift between main frequencies. 25 Hz is also equal to pinion frequency. Nevertheless, fortunately the amplitude of these frequencies not considerably high and the mixer could continue the operation by close monitoring (maximum overall vibration was 4.6 mm/s rms).

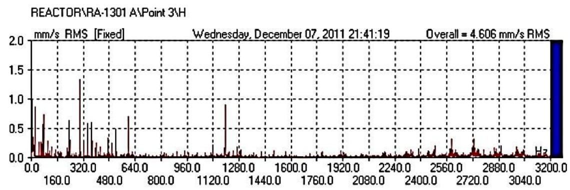


Fig. 10 FFT in close monitoring condition

Unfortunately, after 12 hours close monitoring, the overall vibration of mixer increased considerably. In addition, this value reached 5.9 mm/s RMS. The frequency analysis showed that this vibration mainly is in the same frequency of pinion and bevel gear frequency in previous FFT.

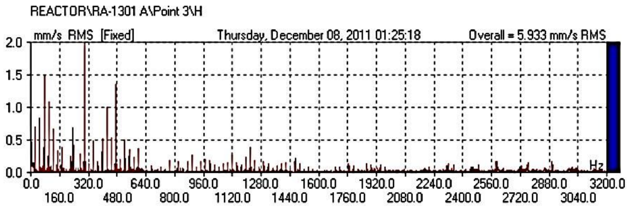


Fig. 11 FFT after 12 hours close monitoring

The vibration evidences showed that the pinion damaged seriously and recommended the process to change mixer with spare equipment then the machinery group checked the gearbox pinion and it was damaged in 1/3 of its parts.

Fig. 12 Damaged pinion

It is worthy to know that the pinion gear damages sometimes occurred in low vibrations and this equipment should always under close monitoring. The vibration monitoring of this machine in October 2012 showed some new frequencies adjusted themselves by GMF but in acceptable amplitude.

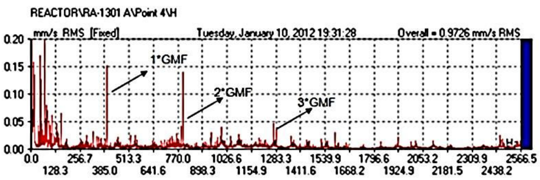


Fig. 13 FFT in good overall vibration condition

In addition, we had another abnormal behavior in 150 Hz and its side bands 2.4 Hz related to output gearbox shaft in our low 1000 RPM. The mixer was under close monitoring then in December 2012 the vibration behavior of machine changed dramatically again but it was in a good condition yet (maximum 2.7 mm/s RMS).

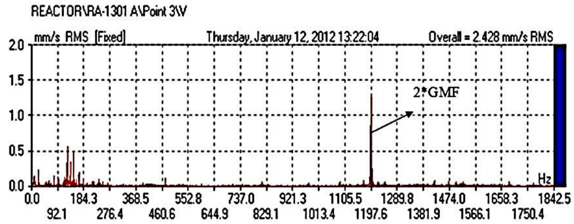


Fig. 14 FFT in critical point in vertical direction

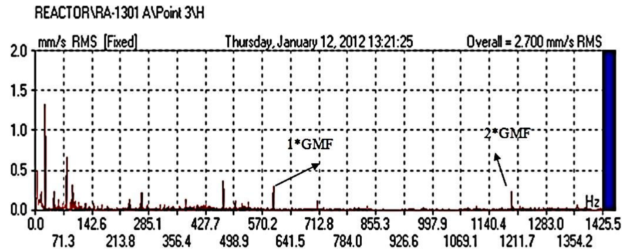


Fig. 15 FFT in critical point in horizontal direction

The abnormal noise was increased in gearbox considerably then the monitoring group decided to recommend the machinery to check the gears. Both pinion and bevel was damaged. [17].

Fig. 16 Damaged gear (pinion)

Misalignment and unbalance are the most causes of machine vibration. An unbalanced rotor always causes more vibration and generates excessive force in the bearing area and reduces the life of the machine. Understanding and practicing the fundamentals of rotating shaft parameters is the first step in reducing unnecessary vibration, reducing maintenance costs and increasing machine uptime. In the gearbox systems, the wear in gear may create unbalance in machine but because the RPM in gear boxes usually low or reduce the vibration could not amplify itself in low frequencies. However, mixer unbalance usually occurs because of the mixed material nature. In such cases mixer rotor should be sent to balance shop. Besides, several methods developed for rotor unbalance modeling in recent years [18].

Roller bearing and ball bearing damage also are the most common faults in gearboxes. The prediction of these kind of failure consist of traditional and BCU methods. In traditional methods, the bearing code should be inputted to the software options. The software is adapted the geometry and materials of bearing with assist of frequency formulation and could introduced the high frequency cursors, its harmonic and side bands to detect inner shafts misalignments. Besides, fault diagnosis for all parts of bearing like inner race frequency, outer race frequency, ball travel speed frequency, ball rotational speed frequency and cage frequency are calculated with the software. In addition, we could monitor the BCU on critical bearings [19].

## III. Results and Discussion

In this part, metallurgical consideration of this horizontal to vertical gearbox and its critical pinion and bevel behavior is discussed in details. By increasing the noise in this gearbox, three teeth of pinion was damaged. In addition, one tooth was damaged in another position. In the damaged parts we had both color metal changing and porosity simultaneously.

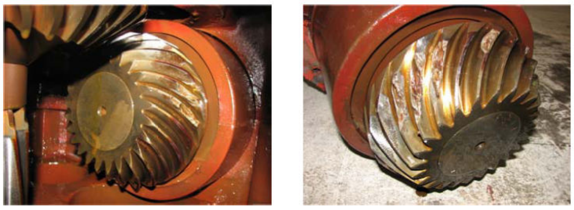

Fig. 17 Damage in gears with color metal changing and porosity

Spare mixer was in rough condition and we had to send that gearbox to machinery workshop. Then we had to continue running of this equipment. The damages developed to other gears teeth with the same mechanical and metallurgical nature and characteristics.

Fig. 18 Damage in gears in the next stage

The bevel gear engaged with pinion seemed to be ok but after checking this gear accurately, the microscopic porosities and a light changing in color was visible. That phenomenon was because of higher strength in these kinds of gears [20].

Fig. 19 Bevel gear engaged with pinion

Due to the vibration, machinery evidences, ISO 10825 and AGMA 1010 standards guidelines, the gear faults could be some kind of surface fatigue and pitting or micro pitting that sometimes could happened in bevel and spiral gears called gray staining. In this phenomenon, the cracks are developed under the surface slowly. These cracks are cut out small surface parts little by little and could cause micro pitting. The schematic of the process is shown in Fig. 20.

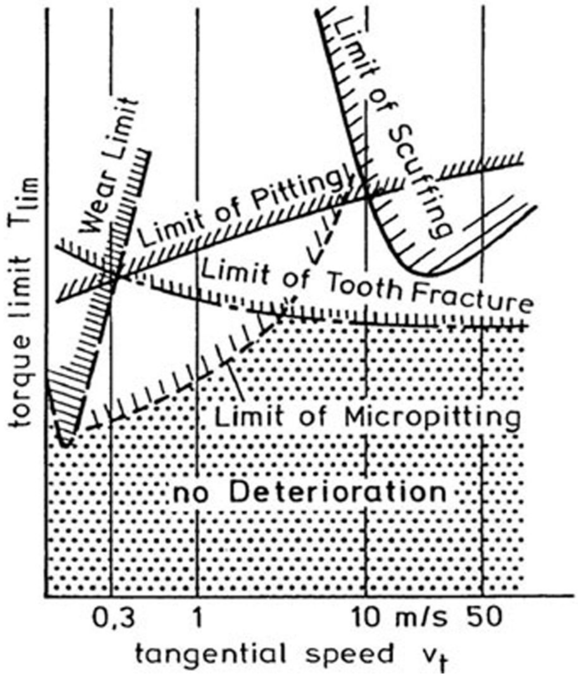


Fig. 20 Schematic of micro pitting and surface fatigue process

By continuing the micro pitting the teeth were damaged seriously in the gearbox. These micro pitting areas became some kind of center of stress concentration. Increasing load on these kinds of gears could cause bending Fatigue Failures [21].

Dou to the vibration and metallurgical observations better lubricants filtering system should be modified in gearbox. The oil analysis also confirmed this note. Besides, the cleanness of the gearbox oil should be satisfied ISO4406. In addition, the photo catalytic oxidation of Surfactant Hexadecyltrimethyl-ammonium bromide in aqueous diluted solution has been investigated. Surfactants (surface-active agents) can be anionic, amphoteric, polymeric and non-ionic. They are held in industries. Surfactants have a hydrophilic head, which attaches to water and a hydrophobic side of the molecule that avoids water. The hydrophobic part of the molecule is also free to attach to grease, fat, or oil on the surface [22].

The oil analysis should be performed more closely for this gearbox. If there is some evidences of water existence in the gearbox oil, the whole gearbox oil must be changed immediately (just a bit water in oil could amplified the micro pitting and surface fatigue seriously). Super finishing methods should be used in gear manufacturing. In addition, surface softness should be less than 10 RMS. Anti-micro pitting should be added in the gearbox oil and elastic hydrodynamic oil (EHL) could use in gear box lubrication.

Furthermore, the temperature of gearbox oil should be monitored. The higher amount of temperature could cause increasing in micro pitting rate. The machinery maintenance action Performed to this gear box by new pinion and bevel engaged gears, grinding the gear shaft, PT (there was no crack in new gears), coupling treatment, balancing all gear box rotors, shafts run out checks and treatment, measuring housing input shaft, manufacturing two spacer shims for housing bearing, Assembling bearing housing accurately, cover casing cleaning, changing the O-Rings outlet shaft and oil injection.

The vibrations decreased at a great extend after maintenance of gearbox. The mixer operated in high 1500 RPM in process full load. In addition, all GMF disappeared. Besides, there was no noise in gearbox any more. The vibration amounts remained steady during first month. Different maintenance strategies (such as corrective, time based, preventive, condition-based and predictive) could be applied for gear boxes. A new fuzzy multi criteria model is introduced recently. This model is used for the optimization decision making of the complex system maintenance strategy like most critical gearboxes [23].

The machining mechanism of gear manufacturing has a direct influence on gear characteristic and mechanical properties. Several methods are developed in recent years in modeling the gear manufacturing and optimization. These techniques could be helpful in choosing optimal machining mechanism to prevent further unnecessary maintenance [24].

In addition, the oil temperature is one of the other factors in condition monitoring systems in gearboxes. Oil viscosity can be affected by a number of external factors. The most prominent factor is due to the change in temperature during machinery operation. A lubricant viscosity will decrease with an increase in temperature and will increase with a temperature reduction. The Viscosity Index (VI) is an arbitrary scale used to measure a fluid's change in viscosity across temperature variance. Oil with high VI experiences smaller decreases in viscosity as the working temperature increases than an oil with a lower VI [25].

The process parameter optimization could be helpful to improve the gear manufacturing condition. The friction coefficient decreases with the increase in normal load. The values of friction coefficient increase with the increase in sliding velocity. Wear rate increases with the increase in normal load and sliding velocity. Besides magnitudes of friction coefficient are different for different sliding pairs, therefore, maintaining an appropriate level of normal load, sliding velocity could be an appropriate choice of sliding pair. Therefore, friction may be kept to some lower value to improve mechanical processes [26].

An environmental friendly palm-grease has already been formulated from modified RBDPO (Refined Bleach Deodorized Palm Oil) as base oil and lithium soap as thickener. Such palm-grease is dedicated for general application and or equipment working in areas like gearboxes. These kinds of lubricants could be helpful to reduce the amount of wear in gearboxes [27].

Condition base monitoring using ultra sonic signal is recently developed in gearboxes. In this method a higher frequency ultrasonic sensor used as a transducer for the data based on RPM and gear position. The soft wares simulate the shapes that show all the possible condition during the gearbox operation. Signal filtered within the ultrasonic range to avoid noise and other unnecessary interference. The signal clustered to identify the point of transient generated by any fault in the gearbox. Contributing of statistical parameter such as crest factor has a vital role in signal clustering for the gearbox operation. Crest factor showing the ratio of peak values to the average value. In other words, crest factor indicates how extreme the peaks are in a waveform [28].

$$\text{Crest factor} = C = |x|\ \text{peak}/x\ \text{rms} \qquad (1)$$

## IV. Conclusions

Surface fatigue and micro pitting could be developed in gearboxes in a few minutes. Further testing in damaged gears could be performed to achieve better understanding about the causes of the problems. These kind of testing may cause further damages in more teeth like, cutting a half micro pitting area and half healthy tooth area (wire cut method), cutting a half micro pitting area and half cracked tooth area (wire cut method) and cutting micro pitting surfaces.

Furthermore, metallography and electronic microscopic investigations could be helpful in identifying the surface fatigue and micro pitting properties. Both engaged gears should have same tolerances, surface softness quality and toughness for replacement of pinion and bevel. All mentioned parameter should be satisfied by technical document of original gears.

In addition, it is preferred to send the oil samples to parallel laboratory and compared their oil analysis reports to make sure about the quality of oil analysis.

## References

[1] Vibration School Website (2013); available online at: http://www.vibrationschool.com.
[2] I Learn Vibration-Training Website (2013); available online at: http://www.mobiusinstitute.com.
[3] Brüel&Kjær Website (2013); available online at: http://www.bksv.com.
[4] Rontu, J., Szanti, G.; and Mäsä, E. (2010). Drive Line Analysis for Tooth Contact Optimization of High Power Spiral Bevel Gears. Journal of American Gear Manufacturers Association, 4(2), 990-995.
[5] KISSsoft– Tutorial 15 Bevel Gears (2012); available online at: www.KISSsoft.AG.

[6] Fong, Z.H.; and Tsay, C.B. (2013).Kinematical Optimization of Spiral Bevel Gears. Mir Publication, Moscow.

[7] Kohaupt, L. (2013).Application of Mathematical Optimization of Spiral Bevel Gears. Mir Publication, Moscow.

[8] Brecher, C., Klocke, F., Brumm, M.; and Hardjosuwito A. (2013). Analysis and Optimization of Bevel Gear Cutting Processive by Means of Manufacturing Simulation. International Journal of Modern Mechanical Engineering, 17(2), 73-84.

[9] Methods for Designing and Manufacturing Straight Bevel Gears That Are Stronger and More Cost-Effective than Ever Before. Magazine Gear Solutions, 14(3), 23-26.

[10] Ali Zargar O.2013. Vibration Analysis of an Alstom Typhoon Gas Turbine Power Plant Related to Iran Oil Industry. World Academy of Science, Engineering and Technology. International Journal of Mechanical, Industrial Science and Engineering Vol: 7 No: 11.

[11] Howes B.C.2001. A Gearbox Vibration - Fact or Fiction. Beta Machinery Analysis Ltd. Calgary AB, Canada, T3C 0J7.

[12] Shafei A.E.2005.Gearbox Fault Diagnosis. Managing Director, RITEC Cairo, Egypt.

[13] Diwakar G. Satyanarayana M.R.S and Kumar P.R.2012. Detection of Gear Fault Using Vibration Analysis. International Journal of Emerging Technology and Advanced Engineering.2 (9):123-137.

[14] Shipley, E.E.1967. Gear Failures, How to Recognize Them? What Causes Them? How to Avoid Them? Mechanical Transmission, Mechanical Technology Inc. Latham. New York.

[15] Errichello R.L.2012. Morphology of Micro Pitting. Gear Technology. www.geartechnology.com. November/December 2012:74-81.

[16] Predki W, Nazifi K and Lutzig G.2011. Micro pitting of Big Gearboxes: Influence of Flank Modification and Surface Roughness. Gear Technology. www.geartechnology.com. May 2011:42-46.

[17] Hailiang, S., Yanyang, Z., Zhengjia, H., Jing, Y., Xiaodong, W.; and Lue C. (2013). Customized Multi Wavelets for Planetary Gearbox Fault Detection Based On Vibration Sensor Signals. Open Access Journal of Sensors (mdpi); 13(7), 1192-1200.

[18] Hariharan, V.; and Srinivasan, P.S.S, (2010).Vibrational Analysis of Flexible Coupling by Considering Unbalance. World Applied Sciences Journal, 8(4), 1022-1026.

[19] Mohamadi, S., Monavar, H., Ahmadi, H., Mohtasebi, S.S. (2008). Prediction of Defects in Roller Bearings Using Vibration Signal Analysis. World Applied Sciences Journal, 4(7), 152-153.

[20] Gopinath K.; and Mayuram, M.M. (2010). Gear Failure Machine Design II. Scientific Bulletin Indian Institute of Technology Madras, 6(2), 3-17.

[21] Yoshida, N.; and Taki, T. (2008).Micro Pitting Generation Mechanism for Gears. International journal of Automation Technology, 2(4), 1-2.

[22] Hassan, M.; Farooq, R., (2009). Photo Catalytic Oxidation of Surfactant Hexadecyltrimethyl-Ammonium Bromide in Aqueous Diluted Solutions. World Applied Sciences Journal, 7(3), 7-9.

[23] Akhshabi, M.; and New Fuzzy, A. (2010).Multi Criteria Model for Maintenance Policy. Middle-East Journal of Scientific Research, 10(6), 33-38.

[24] Kasim, M.S., CheHaron, C.H., Ghani, J.A.; Sulaiman, M.A., (2013). Prediction Surface Roughness in High-Speed Milling of Inconel 718 under Mql Using Rsm Method .Middle-East Journal of Scientific Research, 13(4), 266-268.

[25] Rasid, A.F.A., Mohamad, T.I., Ghazali, M.J.; and Mahmood, W.M.F.W. (2012). Effects of Lubricant Temperature in a Motorized Engine. World Applied Sciences Journal, 20(6), 928-929.

[26] Chowdhury, M.A., Nuruzzaman, D.M., Kumar Roy, D., KantiDey, P., Mostafa, M.G., Islam M.S.; and Rashed Mia M.D. (2013).Experimental Investigation on Friction and Wear of Stainless Steel 304 Sliding Against Different Pin Materials. World Applied Sciences Journal, 22(4), 1708-1710.

[27] Sukirno, A., Fajar R., Bismo,S.; and Nasikin, M., (2009). Bio grease Based on Palm Oil and Lithium Soap Thickener: Evaluation of Anti Wear Property. World Applied Sciences Journal, 6(7), 404-406.

[28] Nuawi, M.Z., Muhamad, T.I., Hussin, M.F.H., Abdullah, S.; and Zulkifli, R. (2010). Preliminary Study of Condition Based Monitoring on Automotive Gearbox Using Ultrasonic Signal. World Applied Sciences Journal, 9(6), 118-121.