Engineering Failure Analysis 86 (2018) 1–20

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

# Modelling of acoustic emission generated due to pitting on spur gear

Ram Bihari Sharma, Anand Parey*

*Mechanical Engineering Department, School of Engineering, Indian Institute of Technology Indore, Indore, India*

A R T I C L E I N F O

*Keywords:*
Acoustic emission
Gear
Defect
Asperity and protrusion contact
Modelling

A B S T R A C T

Acoustic emission (AE) is a non-destructive technique which is used for condition monitoring and health diagnosis of rotating machine elements such as gearboxes. Several experimental investigations have been performed which shows the capability of AE technique to fault or defect detection on gears. It has been also investigated by experimental studies that if the size of defect increases, the AE level also increases. But to the best knowledge of authors, there is lack of mathematical model to understand the physics behind the same. This study presents a theoretical model to establish a relationship between size of fault/defect and energy of AE generated during gear meshing on the bases of interaction of asperity and protrusion around the defect using Hertzian contact approach, varying sliding velocity of gear tooth mechanism, and statistical concepts with the aid of surface topography of gear tooth having the pit of different size. The model is developed by considering the influence of three phenomena during gear mesh cycle: load sharing, lubrication and dynamic load condition. The developed theoretical model is validated with experimental study performed on IAE gear lubrication testing machine and satisfactory results have been observed.

## 1. Introduction

Acoustic emission (AE) is used for non-destructive testing (NDT) of health monitoring of rotating machines. AE provides the advantage of identify the faults/defects at early stages because it is initiated at microscopic level and it is highly sensitive to detect the loss of any mechanical integrity. Hence, AE is effective technique for the defect detection in the gearboxes in comparison to other techniques such as vibration measurements, wear debris analysis, ultrasonic testing and temperature measurements etc. Several experimental studies have been performed to assess the effectiveness of AE in identifying the defect in gearboxes. The results of these studies illustrate the capability of AE to diagnosis the fault and effective condition monitoring of gearboxes. AE is defined as the transient elastic wave that is spontaneously produced by the rapid release of strain energy caused by structural change within material under the stresses [1–4]. AE is non-directional technique and the frequency range of AE takes place between 100 kHz and 1 MHz. The main concern with this technique is the attenuation of the AE signal during its propagation across the interfaces.

It has been mentioned in the researches that the presence of fault on the gears strongly influence the AE during the meshing of gears [5–14]. In addition, it is also noted that size of defect contributes to the level of AE measured. Tandon and Mata [5] performed an experimental study to investigate the presence of defect in spur gears by AE in back-to-back gearbox test rig and measured three AE parameters viz. peak amplitude, energy and ring-down counts. The defects, simulated pits, were introduced on the pitch-line of gear tooth with varying diameters using spark erosion method. They observed that the monitored AE parameters increase with

* Corresponding author.
*E-mail addresses:* phd1301203009@iiti.ac.in (R.B. Sharma), anandp@iiti.ac.in (A. Parey).

https://doi.org/10.1016/j.engfailanal.2017.12.016
Received 18 April 2017; Received in revised form 14 November 2017; Accepted 20 December 2017
Available online 21 December 2017
1350-6307/ 

**Nomenclature**

| | |
|---|---|
| $a$ | radius of Hertzian contact area |
| $d$ | separation between smooth surface of gear tooth and the reference plane in the rough surface of another gear tooth |
| $h$ | standardized separation |
| $k_v$ | dynamic factor |
| $p_a$ | load shared by asperities for respective area |
| $p_i$ | load supported by the pair of teeth at particular local contact during mesh cycle |
| $r_{1DEPSTC(1)}$ | radius of tooth surface of gear at the point of contact (at respective defect diameter) corresponding to the defect with protrusion end point of single tooth contact for the new tooth pair |
| $r_{1DSPSTC(1)}$ | radius of tooth surface of gear at the point of contact (at respective defect diameter) corresponding to the defect with protrusion start point of single tooth contact for the new tooth pair |
| $r_{1HPDTC(1)}$ | radius of tooth surface of gear at the point of contact corresponding to the highest point of double tooth contact for the new tooth pair |
| $r_{1HPDTC(2)}$ | radius of tooth surface of gear at the point of contact corresponding to the highest point of double tooth contact for the previous tooth pair |
| $r_{1HPDTC(3)}$ | radius of tooth surface of gear at the point of contact corresponding to the highest point of double tooth contact for the next tooth pair |
| $r_{1HPDTC'(1)}$ | radius of tooth surface of gear at the point of contact corresponding to the highest point of double tooth contact for the new tooth pair during the HPSTC to TD |
| $r_{1HPSTC(1)}$ | radius of tooth surface of gear at the point of contact corresponding to the highest point of single tooth contact for the new tooth pair |
| $r_{1LPSTC(1)}$ | radius of tooth surface of gear at the point of contact corresponding to the lowest point of single tooth contact for the new tooth pair |
| $r_{1TD(1)}$ | radius of tooth surface of gear at the point of contact corresponding to the tooth disengagement for the new tooth pair |
| $r_{1TD(2)}$ | radius of tooth surface of gear at the point of contact corresponding to the tooth disengagement for the previous tooth pair |
| $r_{1TE(1)}$ | radius of tooth surface of gear at the point of contact corresponding to the tooth engagement for the new tooth pair |
| $r_{1TE(3)}$ | radius of tooth surface of gear at the point of contact corresponding to the tooth engagement for the next tooth pair |
| $r'$ | reduced radius of the curvature during Hertzian contact area |
| $\bar{t}$ | mean release time of the elastic energy due to asperity deformation |
| $v$ | sliding velocity along the line of contact of the gear |
| $x$ | number of teeth in gears |
| $z(x)$ | height of the rough surface profile i.e. asperities at a distance x from the mean line |
| $z_d$ | height of the protrusions around the defect from the mean line |
| $A_c$ | total apparent contact area of one pair of teeth during meshing of gears |
| $A_d$ | the portion of contact area of gear tooth surface which is having protrusions around the produced defect as shown in Fig. 3 |
| $A_r$ | the contact area of gear tooth surface excluding the contact area $A_d$ and the area of defect (pit) as shown in Fig. 3 |
| AB | path of contact |
| AE rms | root mean square value of acoustic emission |
| AP | path of approach |
| B | face width of gear tooth |
| $C_e$ | part of the total elastic strain energy which alters into acoustic emission pulses |
| $C_m$ | part of the total elastic strain energy received by the AE sensors/AE measurement instruments |
| D | diameter of defect (pit) on the pitch line of gear tooth surface |
| $E_i$ | stored elastic energy in the contact of individual asperity |
| $\bar{E}_{ia}$ | stored mean elastic energy in the contact of individual asperity |
| $E_{AE}$ | total energy of acoustic emission converted into AE signal during the duration $\Delta T$ |
| $E_T$ | total elastic energy stored due to the asperity contacts in $N_r$ number of revolutions of gears |
| $E'$ | Hertzian contact modulus |
| $E'_{AE}$ | elastic energy rate of acoustic emission produced by total asperity contacts |
| $E'_{AE_r}$ | elastic energy rate of acoustic emission produced by total asperity contacts in contact area $A_r$ |
| $E'_{AE_d}$ | elastic energy rate of acoustic emission produced by total protrusion contacts in contact area $A_d$ |
| $E'_T$ | elastic strain energy rate released by asperity contacts |
| DEPSTC | defect with protrusion end point of single tooth contact at respective defect diameter |
| DSPSTC | defect with protrusion start point of single tooth contact at respective defect diameter |
| HPDTC | highest point of double tooth contact |
| HPDTC′ | highest point of double tooth contact during the HPSTC to TD |
| HPSTC | highest point of single tooth contact |
| LPSTC | lowest point of single tooth contact |
| LSF | load sharing factor during meshing of gears |
| $LSF_{DEPSTC(1)}$ | load sharing factor corresponding to defect with protrusion end point (at respective defect diameter) of single tooth contact for the new tooth pair |
| $LSF_{DSPSTC(1)}$ | load sharing factor corresponding to defect with protrusion start point (at respective defect diameter) of single tooth contact for the new tooth pair |
| $LSF_{HPDTC(1)}$ | load sharing factor corresponding to highest point of double tooth contact for the new tooth pair |
| $LSF_{HPDTC(2)}$ | load sharing factor corresponding to highest point of double tooth contact for the previous tooth pair |