Dynamic Model Analysis for Unsteady Operating of Double V-Belt Drive System

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Abstract
Alignment issues of the transmission V-belt drive system using numerical model are one of the challenges we are trying to find ways to deal with them.Experiments and dynamic model analysis were performed to monitor and perdict of alignment issues of the transmission system.Various types of transmission system misalignment were investegated using the developed model. Using different two statistical parameters, RMS and Crest factor, the vibration level was monitored.The results obtained during the study confirmed that you have a type each type of alignment issues has an optimal way to deal with it in terms of locating the appropriate position to install the sensor.Moreover, the results displaythat it can used theRMS and CFstatistical parametersof the accelerationresponsesto detect and monitor of the transmission system misalignment.Furthermore, the mathematical model may be considered as an alternative method to detect vibration signals of the transmission system using the spring-mass system.
Keywords: Dynamic model, misalignment, V-belt, mathematical model and vibration analysis.

Introduction

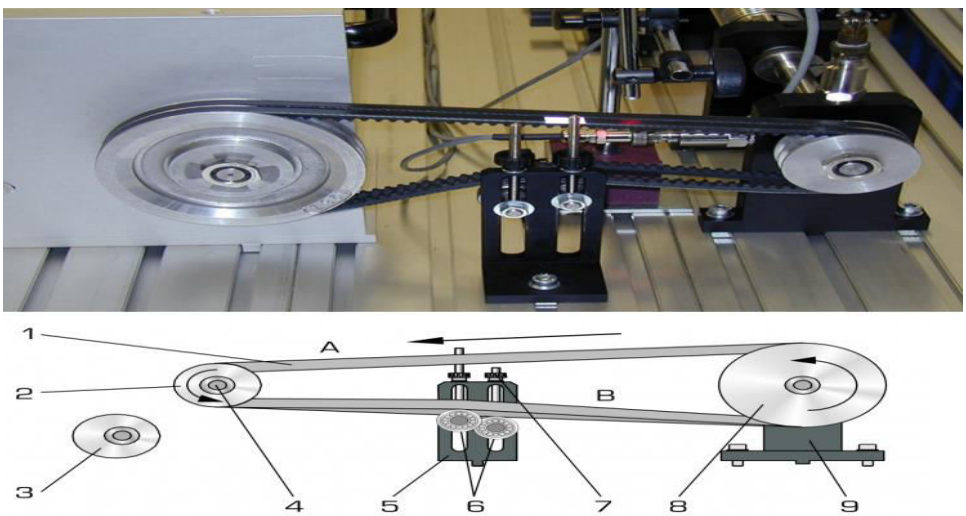
Vibration measurements and significate analyzes for transmission belt drive systems play a vital role in malfunction detection. The fault monitoring system helps to reduce downtime and prevent consequential failure, which reduces economic losses. Belt drive System generate a regular impulse during healthy condition, while the fault can be identified via note a significant signals change. Therefore, vibration analysis is usually an effective method to detect faults that facilitate maintenance and allow to be scheduled.An intelligent method is applied to detect faults in the tolerance of excitatory motors inspired by the artificial neural networks. The results showed a clear improvement due to filter the vibration signal component comparing with the traditional methods that use the vibration signal directly.The new method has proven its efficiency in detecting faults even with low-frequency vibrations [1].Vibration analysis is widely used as one of the most important maintenance methods used to treat with the malfunctions of various machine parts. This has led to an increase in the urgent need for development and the search for clear approaches to display the system oscillation [2,3]. New model based on time dependent displacement excitation is performed as a tool to obtain the vibration excitations of the bearing faults. The localized faults on the outer race with three different cases, parallel, bias and offset, is investigated. The contact stiffness parameter of the bearing is calculated using the Hertzian contact theory. A comparative study was done between the three different faults cases. Based on the results obtained, the model is considered a new approach to enhance and analyze the study of vibrations more precisely [4].Envelope analysis and Duffing oscillator is adopted to study the deep groove ball bearing with local faults presence on the races. The test rig is equipped to test the defected bearings via vibration sensors. The conclusion of this work is focused on the fact that the envelope analysis displays the vibration profile with a distinct frequency and identify bandwidth [5].Based on Hamilton's principle, a flat belt drive model is created according to nonlinear dynamic assumption. While the model controls the stationary operation and corresponds with elastic–plastic contacts, which neglects the adhesion areas. From the previous results, the stability analysis is possible to evidences that solutions with a nonlinear dynamic assumption are suitable method [6]. A statistical analysis method is utilized to study vibration impacts [7-10]. Therefore, the analytical method is performed to record the vibration responses via the frequency band [11]. The defects size presence on the outer race of the tapered roller bearing is developed using the numerical model [12].

The belt pulley system malfunctions such as unbalance, misalignment and belt worm were diagnosed using frequency band by FFT [13, 14]. Statistical parameters of vibration responses for healthy and unhealthycomponent were compared [15]. The oscillation amplitude of the belt drive system is shown to monitor the friction and rotation instability parameters under different conditions ofloading and speed [16]. The friction of the belt pulley is an obstacle to ensuring efficient power transmission. The V-shaped metal belt model was verified to estimate torque loss due to rubbing forces and the losses of the pulley deflection [17]. A belt transmissionmodel is established as a set of elements links, springs and dampers are connected each other in two-dimensional scale under assumptions of free transition and rotational stiffness [18]. Whilst in situations of multi transmission system, the problem is to find a way to define the number of points appropriate to achieve the required precision of belt bending around the individual pulleys. The mapped points make it easier to use as illustrative markers to study the oscillation of the transmission system[19]. A belt pulley drive system under steady-state operating transient is investigated using the finite element analysis. The contactareabetween the belt and pulley are determined using a penal formula with rubbing contact according to Coulomb's triple linear law of friction. Also, the drive pulley is designed in the form of circular restraints that rotate at a certain angular speed [20]. The simulated vibration pattern and experimental results have the same results characteristics [21]. The unstable belt moving process was studied assuming that the forces applied on the stick-slipregions are the samevia the perturbation solution. By checking the perturbation and numericalsolutions, it was observed that the resultsshowed an acceptable agreement[22]. A dynamic model of transmission belt drive system with different damged cases was performed to evaluate the vibration responses. Different damged cases as missing cogs, and belt alignment issueswith different anglesare diagnosis using statistical parameters [23-

24].Moreover, a new attempt to studythe pulleydurability was achieved by creating a model using a commercial software package ABAQUS.Comparing numerical and experimental results, there is a close convergence[25].

Experimental Setup

Figure 1shows the details of the device used to conduct the experiments.PT 500 (GUNT Hamburg) Machinery diagnostic system unit is used to investigate conditions that cause vibration or unsteady operating conditions.The experimental vibration signals are measured by analog accelerometers device, PCB manufactures sensors, used to record vibration data.The signals detected through from amplifier to the data acquisition card (BMC USB-AD16F) to measure and evaluate the vibration signals. The rotating speed of the belt is estimated using diffuse photoelectric sensor, Baumer.To analysis of the vibration signals, the software is used to record the vibration displacement and acceleration in the time/frequency spectrum.The belt kit is a double pulley with a roller belt tensioner for both V-belts. The pulleys are assembled using clamping sets. The experiments also include a V-belt with defect and an eccentrically small belt pulley.The vibration responses for a belt drive system is to be recorded with a different drive speeds and applied loads.



1 V-belt	2 Small belt pulley	3 Small eccentric belt pulley
4 Clamping set for belt pulley	5 Belt tensioner	6 Tension roller for V-belt
7 Adjusting screw for belt tension	8 Large belt pulley	9 Bearing block

Figure 1. Double V-belt pulley test rig.

Numerical Model Creation

The model creation is performed in Abaqus/Explicit to simulate double V-belt drive system and to carry out casestudies for various unsteady operating parameters.A three-dimensional model is required to predict the vibration oscillation and monitor the systemmalfunction. The analysis is run in many stepsto accomplish this model.The 3D model ofthe transmission system was created with SolidWorks and then imported into an Abaqus/CAE package. Thebelt material is PUrubber, which properties were listed as 70 MPa ofmodulus of elasticity, poisson's ratio is 0.4and density is 1200 kg/m^3. While the material of pulleys systemis a cast iron, which properties were listed as67×10^3 MPa of modulus of elasticity, poisson's ratio is 0.33and density is2705 kg/m^3.The transmission system analysis is run depending keeping the pulley with no movement allowed, Zero degree of freedom - Encastre, and in the other pulley is accelerated, one degree of freedom, with angular velocity about Z-coordinate VR3. The interaction between pulleys and belt can be obtained using smooth step option. 8-nodes brick elements with reduced integration were performed to mesh the model.

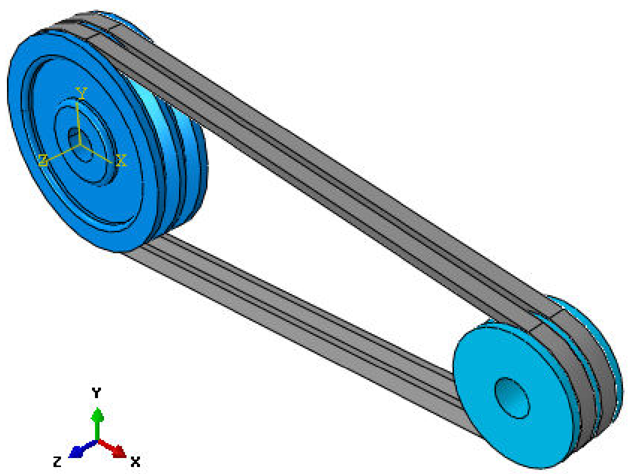


Figure 2. Schematic structure of Double V-belt pulley

The Mathematical Model of theSystem

The analysis of transmission system can be obtained by considering the spring-mass system. This system consists of a V-belt resting over two pulleys, a driver and a driven pulley, and power source, a motor.The tension roller is pressing against the V-beltin such a way that it can be used to increase the tension force.Figure 3illustrates a spring-mass system that displaysthe simplest possible oscillationtransmission system.Develop a sequence of mathematical model of the system for investigating vibration response of this system. Consider the elasticity of the belt can be analyzed by massless linear spring, while the driver and driven pulleys rotate by an θ_{DR}, θ_{DN} anglesand rotational massesJ_{DR}, J_{DN}, respectively. The motor of rotational mass J_m is rotated by an angle θ_{DR}as a result of the coupling of the motor and the driver pulley.Also, considering that the mass $M_o$is equivalent to the forcesresulting from tension roller.

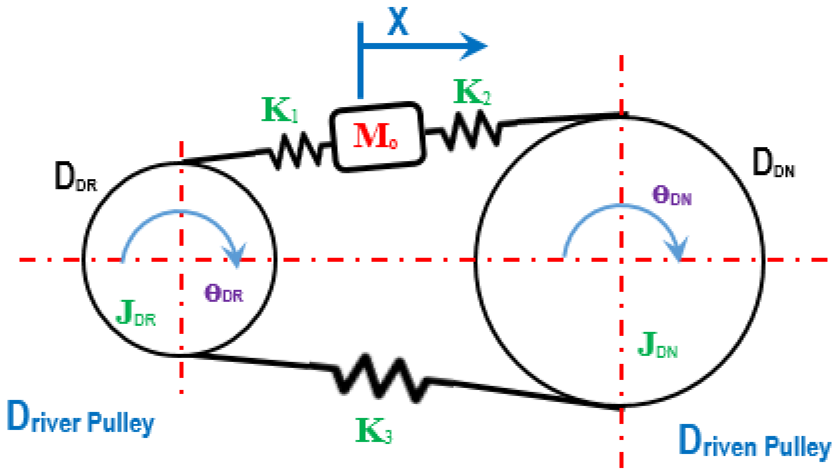


Figure 3.A spring-mass system of the belt drive.

The analyticalsolution of thistransmission equipment can be performed by applying of Newton's second law of motion [26-27]:

$$(J_{DR} + J_M)\ddot{\theta}_{DR} = R_{DR}^2 K_1(X)\theta_{DR} - R_{DR}K_1(X)X - R_{DN}^2 K_3\theta_{DN} + R_{DN}K_3R_{DR}\theta_{DR} \quad [1]$$
$$J_{DN}\ddot{\theta}_{DN} = R_{DN}\,[K_2(X)X - R_{DN}K_2(X)\theta_{DN} - R_{DN}K_3\theta_{DN} + R_{DR}K_3\theta_{DR}\,] \quad [2]$$
$$M_o\ddot{X} = K_1(X)R_{DR}\theta_{DR} - K_1(X)X + K_2(X)R_{DN}\theta_{DN} - K_2(X)X \quad [3]$$

Boundary conditions can also be applied of this equipmentto cases of friction. Both of the contact friction on the belt-pulley region and the friction concentrated in the contact area of the tension roller may be taken into account.In the present, the friction will be performed, so a mathematical solution of this equipment can be estimated by as follows:

$$(J_{DR} + J_M)\ddot{\theta}_{DR} + f_{DR} = R_{DR}^2 K_1(X)\theta_{DR} - R_{DR}K_1(X)X - R_{DN}^2 K_3\theta_{DN} + R_{DN}K_3R_{DR}\theta_{DR} \quad [4]$$
$$J_{DN}\ddot{\theta}_{DN} + f_{DN} = R_{DN}\,[K_2(X)X - R_{DN}K_2(X)\theta_{DN} - R_{DN}K_3\theta_{DN} + R_{DR}K_3\theta_{DR}\,] \quad [5]$$
$$M_o\ddot{X} + f_o = K_1(X)R_{DR}\theta_{DR} - K_1(X)X + K_2(X)R_{DN}\theta_{DN} - K_2(X)X \quad [6]$$

Where

J_M	Inertia moment of the motor;
J_{DR}, J_{DN}	Moment ofInertia of the driving and the driven pulley, respectively;
R_{DR}, R_{DN}	Radius of the driving and the driven pulley, respectively;
θ_{DR}, θ_{DN}	Angular position of the driving and the driven pulley, respectively;
K_1, K_2, K_3	Stiffness dependent elasticity coefficients of the belt;
M_o	Tension roller loading on the belt;
X	Belt elongation position;
f_{DR}, f_{DN}	Friction torque of the driving and the driven pulley, respectively;
f_o	Friction forceof the tension roller

Results and Discussion

1. Validation Between Experimental and Numerical Model

The experiments and the numerical model are examined under same operating conditions. The vibrationsignals are to be recorded for a belt drive with the parameters of pretension of the belt 130 N and shaft speed of 2500 rpm.The vibration signalsare recorded using a vertical accelerometer device. The belt speed is recorded using diffuse reflectiondevice.From the Figure 4, it is possible to see how the drive shaft speed has only meaningful effect on the vibration profile for undamaged belts where speed should result in fundamental frequency values f_{D1}in Hz and its harmonic of drive speed f_{D2}.In contrast,the vibration profile for damaged beltcan clearly be seen the Belt vibration frequencyf_{R1}(8.8 Hz) and the harmonics $f_{R2...Rn}$of the belt frequency.Frequency of the belt can be calculated using the formula;

$$f_R = (N \times C_{DR})/(60 \times L_b) \quad [7]$$

Where, N is driver speed in rpm, $L_b$is V-belt length and C_{DR} is circumference of the driver pulley. The boundary conditions of the numerical solutionhave been applied to fit the experimental set up.It can notice form the Figures 4-7 that the numerical results have approximately the same trend of the experiment results.According to the results, it can be concluded that the numerical solution can be used as a reliable method through which various malfunction can be identified and vibration responses for each case becomes available.

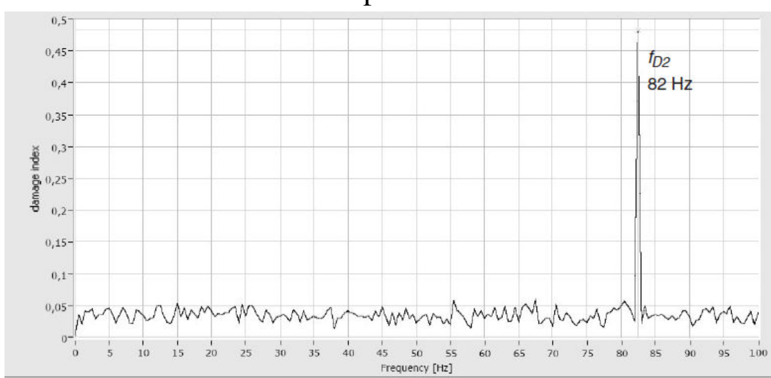


Figure 4. Vibration response for the undamaged V-beltusing envelope analysis

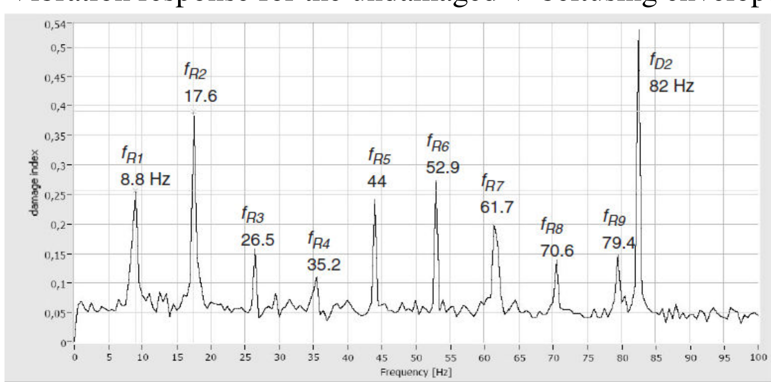


Figure 5. Vibration response for the damaged V-belt using envelope analysis

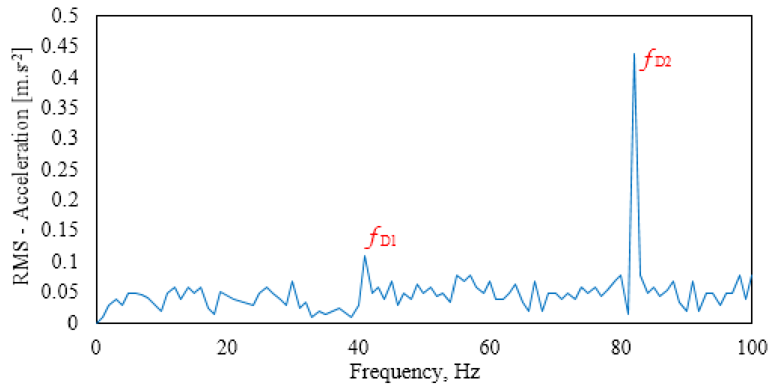


Figure 6. Vibration response for the undamaged V-belt using Numerical Model

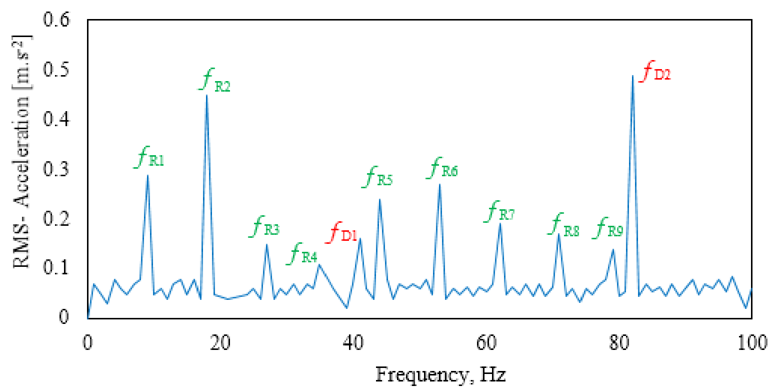


Figure 7. Vibration response for the damaged V-belt using Numerical Model

2. Transmission Drive System Alignment

Aligning the transmission belt drive system is an important maintenance task as is shaft alignment.The belt drive system alignment is also related to the friction between the belt and the pulley, which leads to increase the belt wear and loss of the motor power.There are various types of belt misalignment as illustrated in Figure 8. In practice,any error in the installation can cause of different misalignments is often encountered simultaneously.Previous validation proved that the numerical model can predict the vibration characteristics of the transmission system under different operating conditions.The analysis of system results may be performed by recordingvibrationdataof the standardoperating beltas a referencecaseto identify the signals changes ofvarious types of belt alignment issues.The statistical analysis, RMS, and CF, isapplied to monitor and controlthe vibration and noise level of the transmission system, which in turn shortens the belt's life.The acceleration signals were measured in both perpendiculardirections, horizontal [H] and vertical [V] for the co-ordinates [XYZ]. RMA and Crest factor parameters ratio, is calculated ratio of the magnitude of the damaged to the undamagedvibration values.

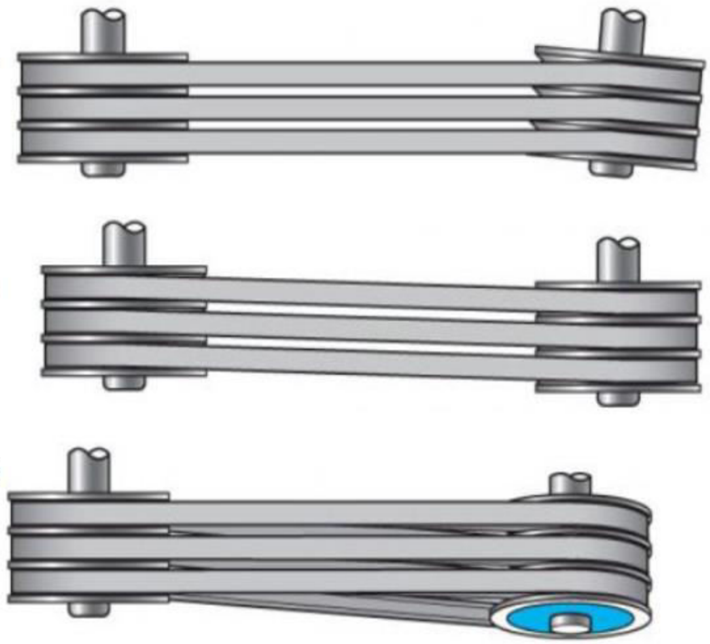


Figure 8. The three different types of transmission belt drive system misalignment (A) horizontal angle misalignment, (B) parallel misalignment, and (C) vertical angle misalignment.

2.1 Parallel Misalignment

Theoffset alignment of thetransmission belt drive system is one of the recurring issues when installing and maintaining these systems this system.The numerical model was performed to calibrate this case study. A parallel misalignment of 0.5, 1.0, 1.5, 2.0and 2.5 mmwas considered under a fundamental speed value2500 rpm [41.67 Hz]and a pretension of the belt 130 N.Figures 9 and 10 show the frequency response of the numerical signals under the aforementioned operating conditions.As shown in Figure 9, the results show that the acceleration ratio RMS values of the numerical signals are regular and are very clear to enable and facilitate the monitoring and detection of the offset alignment of the transmission belt drive system.Nevertheless, it can be noticed that the acceleration characteristic value recorded via the vertical set point is preferable compared to the signal recorded from the horizontal point. In addition, the RMS ratio collected via the vertical set point gives a high result in Y- and Z-coordinates, [A_2] and [A_3] respectively.The same observation is valid for the acceleration ratio CF values. However, the acceleration ratio CF recorded via the vertical set point for X- and Z-coordinates, [A_1] and [A_3] respectively, as illustrated in Figure 10.On the other hand, the acceleration ratio CF is distinguished more sensitivity to the values of vibration response for minor misalignment cases.It can be concluded that the sensor installed in the vertical position is appropriate for recording system malfunctions with using of the statistical parameters RMS and CF. While, that the horizontal position is not preferred to discover system malfunctions, this is a result of the vibration signals for both damaged and undamaged belt system is approximately the same.

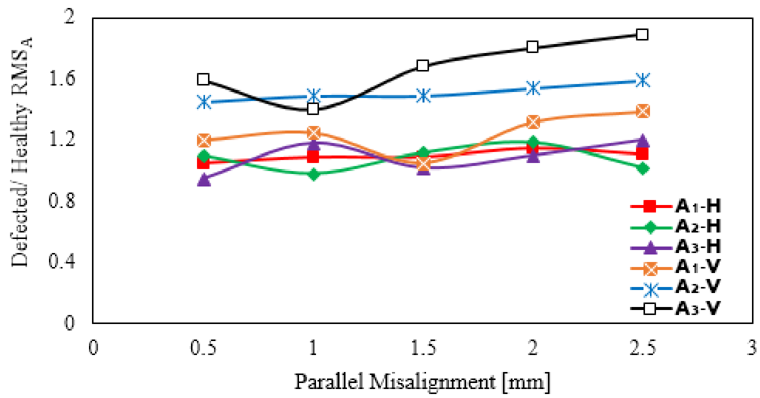


Figure 9. Acceleration ratio RMS of transmission parallel misalignment

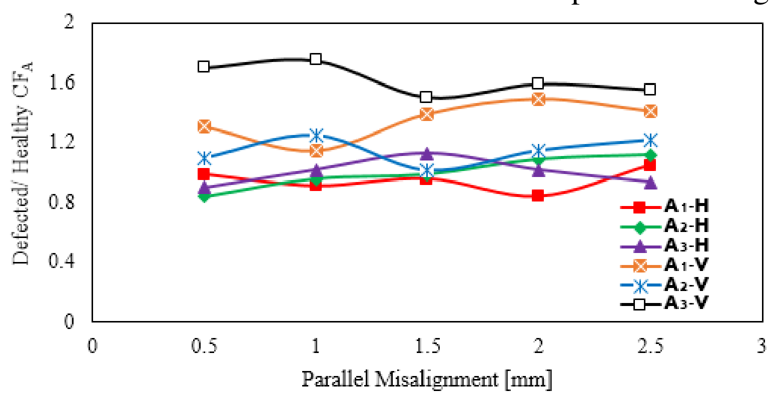


Figure 10. Acceleration ratio Crest Factor of transmission parallel misalignment

2.2 Horizontal Angle Misalignment

Horizontal angle misalignment has been investigated via the three-dimensional modeling, where the system misaligns with angles of 0.5˚, 1.0˚, 1.5˚, 2.0˚ and 2.5˚. Figure 101 shows the variation of the acceleration ratio RMS versus different misalignment angles. It can be noticed that, the accelerationsignals collected via vertical set point less than that than was recorded for the aforementioned case. On the other hand, it is clearly evident that the horizontal point is an ideal positionto detect and monitor this type ofmisalignment. This phenomenon can be related to the increase of the contact area between the belt and the pulley groove. Nevertheless, it can be predicted that, the probability of wear occurrence increases with the increase of the frictional area.Therefore, Fig. 12 illustrates the relationship between acceleration ratio CF versus different misalignment angles. The respective acceleration ratio CF can be observed for horizontal set point.The results show that, with an increase of the additional load, the vibration amplitude of the RMS acceleration signals coincides comparatively with the acceleration amplitude using CF parameter.

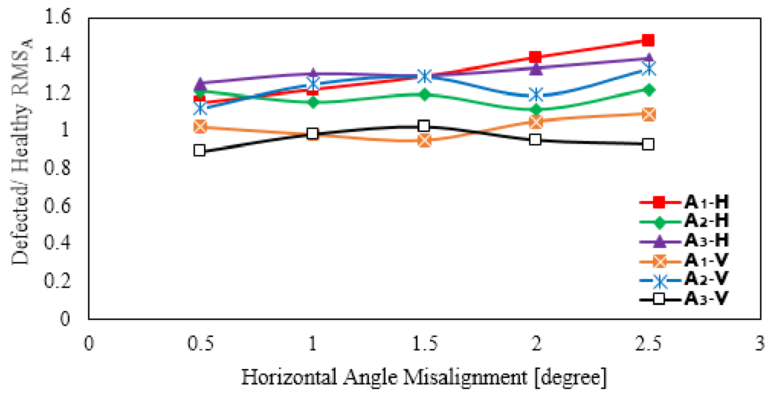


Figure 11. Acceleration ratio RMS of transmission horizontal anglemisalignment

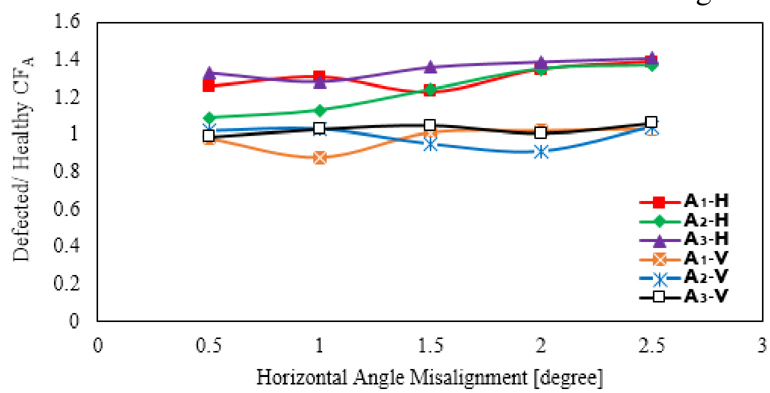


Figure 12. Acceleration ratio Crest Factor of transmission horizontal anglemisalignment

2.3 Vertical Angle Misalignment

The model is prepared to verify the last casestudy, which is the vertical angle misalignment. Where the transmission system misaligns with vertical angles of 0.5˚, 1.0˚, 1.5˚, 2.0˚ and 2.5˚. The dynamic model results present the monitoring of the acceleration ratio RMS of the vibration response for the transmission system with different vertical misalignment angles, as shown in Figure 13.It can be listed that the value RMS ratio at the horizontal and the vertical set points are greater than 1, that means both positions are suitable to monitor the system malfunctions in this case.It can also be noted a relative advantage of the data collected from the vertical set point overthe horizontal one.From Figure 14 it is possible to verify thatthe same results are achieved again using acceleration ratio CF.

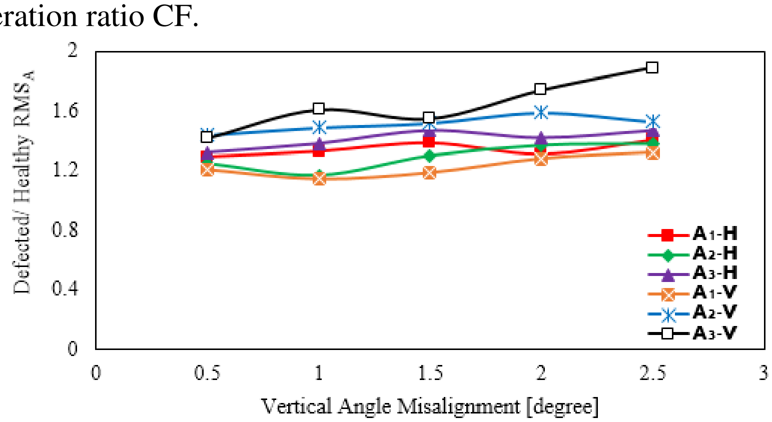


Figure 13. Acceleration ratio RMS of transmission vertical anglemisalignment

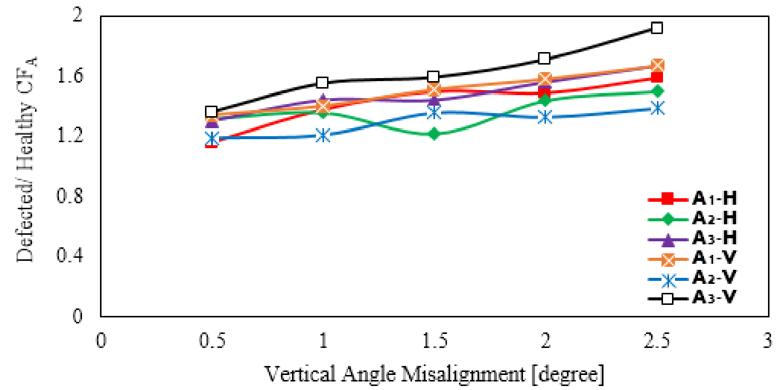


Figure 14. Acceleration ratio Crest Factor of transmission vertical anglemisalignment

3. *The Mathematical Model Analysis*

The mathematical model indicates an alternative method to study vibration behavior for the transmission system. In Figure 15 the time domain of the system position is displayed. It can be noticed that the system presents much more oscillatory than steady state case. The accelerations time domain of the two pulleys can be illustrated in Figure 16. It can be seen from that for the acceleration responses of the pulleys are not possible to evaluate the change in this system.Future work includes that, the model may be developed by increase the assumption that helps to present a good prediction and control of the vibration responses of the systemusing one of the commercial packages.

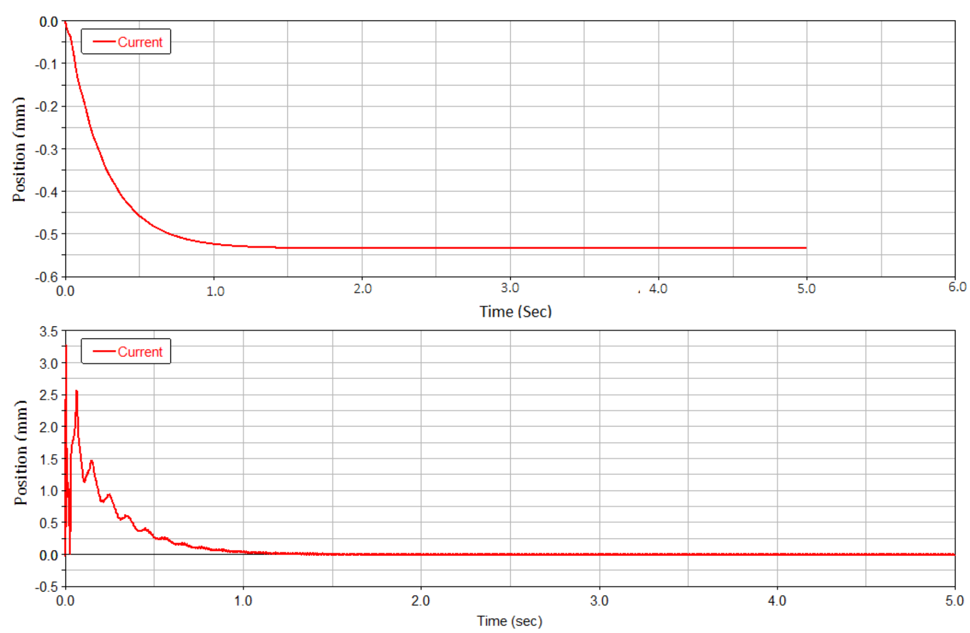


Figure 15. Time responses of system position

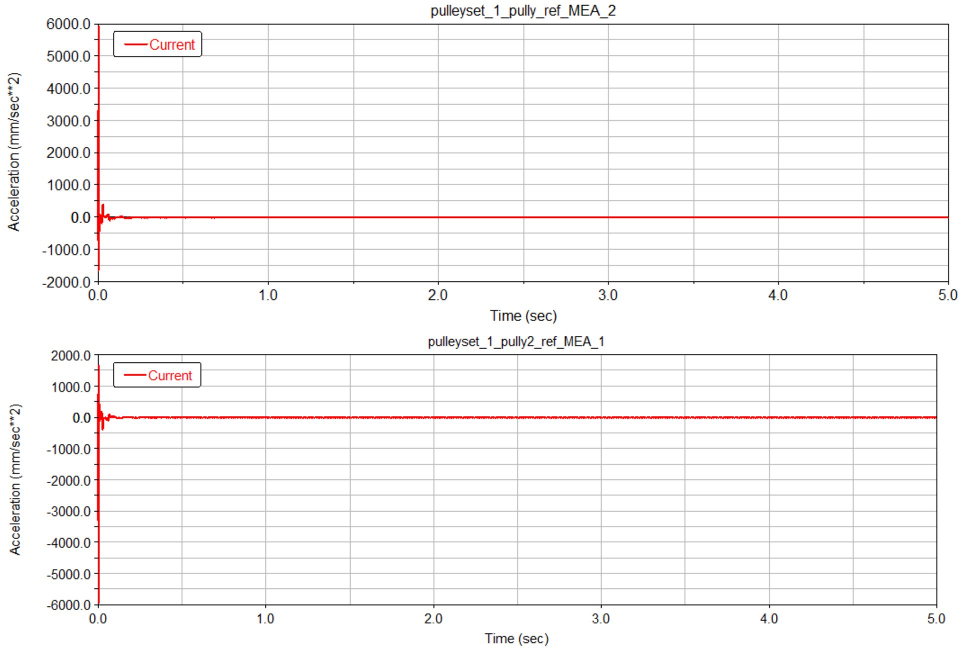


Figure 16. Time responses of system angular acceleration

Conclusions

The aim of this work is to present a solution based on finite element analysis for aligning the transmission belt drive system using vibration responses. Numericalmodel of transmission belt drive system is established and vibration behavior monitored using a commercial software package ABAQUS/CAE. Both results obtained by numericalmodel and the experimental showed a significant agreement.Based on the results, it can be found that the numericalmodel can be performed to detectand monitor the transmission belt system. By studying different alignment issues, it has been verified that both RMS and Crest Factor parameters are compatible methods to monitor and detect various conditions. For the parallel misalignment,it is listedthat the vibration signalsaredistinguishedto receive data viavertical attach point.While the set point must be installed horizontallyto detect the system malfunction with horizontal angle misalignment. Moreover, it has been found that RMS and CFparameterscan be considered as good points for collecting signals in both directions for vertical angle alignment cases.

References

1. Zarei J et al. “Vibration analysis for bearing fault detection and classification using anintelligent filter”. Mechatronics, 24 (2), pp.151-157, 2014.
2. M Amarnath, R Shrinidhi, A Ramachandra, S B Kandagal, “Prediction of Defects in Antifriction Bearings using Vibration Signal Analysis”, IE (I) Journal-MC, pp. 88-92, 2004.

3. Nabhan A.,Nouby M., Samy A. M., and Mousa, M.O.,"Bearing Fault Detection Techniques - A Review"Turkish Journal of Engineering, Sciences and Technology, 3(2), 2015.
4. Jing Liu , Zidan Xu , Yajun Xu , Xihui Liang , Ruikun Pang “An analytical method for dynamic analysis of a ball bearing with offset and bias local defects in the outer race” , Journal of Sound and Vibration 461 ,114919, 2019.
5. 4-V.N. Patel , N. Tandon, R.K. Pandey,” Defect detection in deep groove ball bearing in presence of external vibration using envelope analysis and Duffing oscillator”, Measurement 45 960–970, 2012.
6. 5- Kim D., Leamy M.J., Ferri A.A., "Dynamic Modeling and Stability Analysis of Flat Belt Drives Using an Elastic/Perfectly Plastic Friction Law" Journal of Dynamic Systems, Measurement, and Control, 133, 041009, 2011.
7. Tuncay Karacay, Nizami Akturk, “Experimental diagnostics of ball bearings using statistical and spectral methods”, Tribology International, 42, pp. 836–843, 2009.
8. Yong-Han Kim, Andy C. C. Tan, Joseph Mathew, Bo-Suk Yang, “Condition Monitoring of Low Speed Bearings: A Comparative Study of the Ultrasound Technique versus Vibration Measurements”, WCEAM, 2006.
9. Nabhan A., Nouby M., Samy A. M., Mousa, M.O.," Vibration analysis of deep groove ball bearing with outer race defect using ABAQUS “Journal of Low Frequency Noise, Vibration and Active Control, 35(4). pp. 312-325, 2016.
10. Nabhan A., Nouby M., Samy A. M., Mousa, M.O.," Multiple Defects Detection in Outer Race of Gearbox Ball Bearing Using Time Domain Statistical Parameters” International Journal of Vehicle Structures & Systems, 8(3). pp. 167-174, 2016.
11. Zahari Taha1, Nguyen Trung Dung, “Rolling Element Bearing Fault Detection with a Single Point Defect on the Outer Raceway Using FEA”, the 11th Asia Pasific Industrial Engineering & Management Systems Conference, 2010.
12. Nabhan A., Rashed A.," Experimental and Numerical Investigation of Defect Size Estimation in Taper Roller Bearing” Nosie and vibration Worldwide, 49(11), pp. 345-354, 2018.
13. Ali H.R., Khalid A.M.," Diagnosis of Pulley-Belt System Faults Using Vibration Analysis Technique “Journal of University of Babylon, Engineering Sciences, 26(2), pp. 167-180, 2018.
14. Abdulshakoor A.A., M. Lokesha G.R. Rameshkumar,” Fault Diagnosis in Belts using Time and Frequency based Signal Processing Techniques” International Journal of Recent advances in Mechanical Engineering, 6 (11), pp.11-20, 2015.
15. Kiral Z., Karagulle H., “Simulation and analysis of vibration signals generated by rolling element bearing with defects”, Tribology International, 36, pp. 667–678, 2003.
16. Wu Y., Varenberg M., Leamy M., “Schallamach wave-induced instabilities in a belt-drive system “Journal of Applied Mechanics, 86(3), 031002, 2018.

17. Akehurst S., Vaughan N.D., Parker D.A., and Simner D., "Modelling of loss mechanisms in a pushing metal V-belt continuously variable transmission. Part 2: pulley deflection losses and total torque loss validation" Proc. Instn Mech. Engrs Part D: Journal of Automobile Engineering, 218, pp. 1293-1281, 2004.
18. Kubas K., "A Model for The Dynamic Analysis of a Belt Transmission Using the Dahl Friction Model" Journal of Theoretical and Applied Mechanics, 55(4), pp. 1423-1435, 2017.
19. Kubas K., "A method of discretizing the belt in a flat model of a belt transmission" The Archives of Automotive Engineering – Archiwum Motoryzacji, 78(4), pp. 93-105, 2017.
20. Leamy M.J., Wasfy T.M., "Transient and Steady-State Dynamic Finite Element Modeling of Belt-Drives" Journal of Dynamic Systems, Measurement, and Control, 124, pp. 575-581, 2002.
21. Purwo Kadarno, Zahari Taha, “Vibration Analysis of Defected Ball Bearing using Finite Element Model Simulation”, The 9th Asia Pasific Industrial Engineering & Management Systems Conference, 2008.
22. Leamy M.J., “On a Perturbation Method for the Analysis of Unsteady Belt-Drive Operation “Transactions of the ASME, 72, pp. 570-580, 2005.
23. Nabhan A., El-Sharkawy M., Rashed A., " Monitoring of Belt-Drive Defects Using the Vibration Signals and Simulation Models", World Academy of Science, Engineering and Technology, International Journal of Aerospace and Mechanical Engineering, 13(5), pp. 332 – 339, 2019.
24. Nabhan A., Rashed A.1, Ameer A. K., Bakrey M." Diagnosing and Monitoring of Double V-Belt Drive System Under Unsteady Operating Conditions Via DMA",International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, 21 (3), pp. 1-10, 2021.
25. Kim B., Kim Y., Chun D.M., Ahn S.H., Jang J.D.," Durability Improvement of Automotive V-Belt Pulley” International Journal of Automotive Technology, 10 (1), pp. 73−77, 2009.
26. A. Hace, K. Jezernik and A.Sabanovic, “SMC with disturbance observerfor a linear belt drive”, IEEE Transactions on Industrial Electronics,54 (6), pp. 3402–3412, 2007.
27. A. G. Katsioula, Y. L. Karnavas, Y. S. Boutalis, “An Enhanced Simulation Model for DC MotorBelt Drive Conveyor System Control”,7th International Conference on Modern Circuits and Systems Technologies, 2018.