Fault Diagnosis in Belts using Time and Frequency based Signal Processing Techniques

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***Abstract*—The main aim of this paper is to analyze belt drive using Vibration Monitoring (VM) method. A belt drive experimental setup was designed, fabricated and used for experimental work to obtain realistic vibration data for different working condition. Three different faults such as side-cut-out, side-cut-in and loose & side-cut-out were created in the belt to study and to understand the behavior of the system during healthy and fault running condition. The experiments were conducted for healthy and faulty conditions at different speeds, lower speed of 540 rpm and at higher speed of 1000 rpm. The vibration signals were acquire using NI DAQ system with LabVIEW software. The results were presented for all the cases in the comparative manner and discussed. From the results it is found that the nature of belt fault has an effect on the characteristic frequency at 1X running speed for both driver and driven shaft. At the higher speeds the intensity of vibration is more for various faults and will be increasing as the fault increases.**

***Keywords*—Rotating Machinery, Running Speed, V Belt and Vibration Monitoring**

I. INTRODUCTION

Machines are very important in our lives and it simplifies the work of people. Furthermore, now a day we use machines to the maximum extent in our daily life activities. The most important factor for the longevity of the machines is maintenance of machines to work with maximum safely and reliably. In addition, to do the maintenance it needs a professional person or mechanic who is having experience and knowledge about the equipment or the machine to keep it in good health condition. Any equipments/machines are needed to be maintained at a certain point and that depend on the behavior of the machine and health of the machine itself, otherwise it may fail. Now a day worldwide engineers are focusing on the design and the material used for developing machine and schedule the maintenance tasks to make sure the machine will work until the maximum time. Moreover, by applying the concept of Condition Monitoring (CM) techniques the running condition of the machine can be analyzed. The Vibration Monitoring (VM) is the most commonly used analysis method to analyze the running condition of machine and it may provide the clear identification of most of the faults in the machine.

Belt conveyors are the equipment widely used in coal mines and other manufacturing industries, whose main components are a number of idlers. The faults of belt conveyors can directly influence the daily production. A fault diagnosis method combining wavelet packet decomposition (WPD) and support vector machine (SVM) is proposed [1] for monitoring belt conveyors with the focus on the detection of idler faults. The proposed fault diagnosis method is firstly tested on a test bed and then an online monitoring and finally fault diagnosis system is designed for belt conveyors. A multi sensor data collection and Principal Component Analysis (PCA) are proposed [2] to develop a framework for impeller fault detection. Ahmed et al. [3] investigated the use of time domain vibration features for detection and diagnosis of different faults from a multi stage reciprocating compressor. Bajrić et al [4] made an evaluation of vibration analysis techniques as a method for the gear and gear pairs condition assessment.

In this paper an experimental investigation has been carried out on belt drive experimental setup to analyze the behavior of the system under various belt defects conditions. The results were analyzed and presented.

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II. TYPES OF BELTS

Belts are generally used in several industries for transmission of power. Subsequently, they are cheap and very easy to maintain. Belt drives are used to transfer power between machines like a fan and motor. Belts are actually subjected to push-pull and rotary motions with changeable dynamic characteristics. Transmit of power is depend on friction between pulley/sheave and belt; hence belt drives are called as friction drives [5]. The common types of belts are shown in Fig. 1.

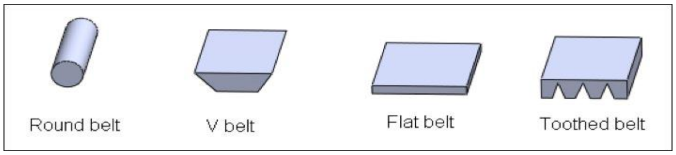

Fig. 1. Types of Belts

A. Round Belts

Round belts are made of rubber in general. Actually this type of belt is usually used for light-loads, like in a vacuum cleaner or in a sewing-machine.

B. V-Belts

V- Belt is simply a transmitter that effectively link power drive to a needed function. These belts are easy to select and simple to install and over years of reliable performance. The first V-Belt is a bared in early 1900 is cut from leather and fabric and replaces exciting drives which used brooked running in V-groups. Modern V-Belt second strutted differently are made from synthetic fiber and rubber but they still utilize the original wedge concept honest power. The wedge checked belt fixed on the wedge to create a match fed and when the drive is activated the billing power come from the action applied tension which forces the belt to wedge tightly in to the chive group. By using the wedge principle the V-Belt came the advantage of reminds ripping power.

C. Flat Belts

Flat belt is additionally utilized to send manipulation from one shaft to another. They are usually categorized as whichever tiny woven endless belts or higher manipulation flat belts. The woven endless belts are exceptionally functional whereas minimum vibration is needed at the driven pulley due to semi-elastic physical utilized in construction. The higher manipulation flat belts are frequently functional because they remove the demand to elevated belt tension utilized to grasp pulleys, which in coil reduces the burden on the shaft bearings. The physical utilized for elevated manipulation flat belts is gummy yet abrasion-resistant rubber compounds.

D. Timing/Toothed Belts

Timing belt is having toothed-belt that uses their teeth for transmission of power, as challenged to friction. This configuration outcome in no slippage, and consequently, the steering and driven shafts stay synchronized. It's extra luxurious to produce due to the intricacy of the belt and pulley shapes. V- Belts are designed to increase Strength and Flexibility, Fig. 2 represent the concept of Strength and Flexibility. Strength is provided by raw of tinsel cords. The cords service the lode carried component and made of twisted synthetic fiber (1). The comparison section is made of synthetic rubber (2). It is support the tinsel cods evenly and compresses while bending around the chips (3). Conversely, the tension section located above the cords is designed to

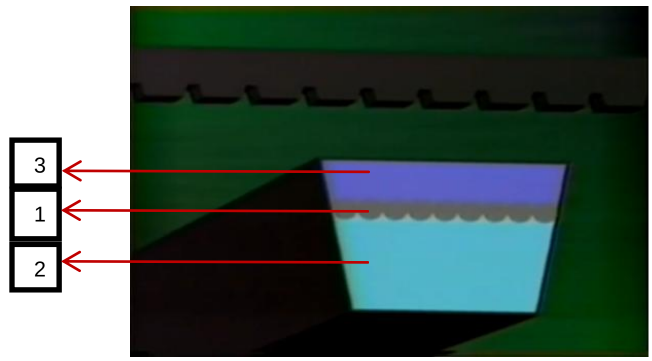

Fig. 2. Concept of Strength and Flexibility

Table 1. Industrial Power Transmission Belts

Industrial Power Transmission Belts — BANDO

Belt Type	Belt Profile	Description	Type and Dimensions			
V BELTS (Polyurethane)		Banflex	Type	Top Width	Thickness	Angle
			3M	0.12" (3.0 mm)	0.08" (2.1 mm)	60°
			5M	0.20" (5.0 mm)	0.13" (3.3 mm)	60°
			7M	0.28" (7.0 mm)	0.21" (5.3 mm)	60°
			11M	0.43" (11.0 mm)	0.27" (6.9 mm)	60°
		Polyurethane Open Ended V Belts (Bancord V Belts)	Type	Top Width	Thickness	Angle
			3L(M)	3/8" (10.0 mm)	7/32" (5.5 mm)	40°
			A	1/2" (12.7 mm)	5/16" (8.0 mm)	40°
			B	21/32" (16.7 mm)	13/32" (10.3 mm)	40°
BANDED BELTS (Rubber)		Power Scrum (Narrow V type)	See Narrow V belt for dimensions. 3V, 5V, 8V available.			
		Power Scrum (Multiple V type)	See Multiple V belt for dimensions. A. B. C. D. available.			
BANDED BELTS (Polyurethane)		Banded Banflex (Banflex Scrum)	See Banfle for dimensions. 5MS. 7MS. 11MS available.			
V RIBBED BELTS (Rubber)		V Ribbed Belts			P	b
				J	0.094" (2.4 mm)	0.16" (4.0 mm)
				L	0.189" (4.8 mm)	0.35" (9.0 mm)
				M	0.378" (9.6 mm)	0.65" (16.5 mm)
V RIBBED BELTS (Polyurethane)		Polyurethane V Ribbed Belts			P	b
				H	0.063" (1.6 mm)	0.098" (2.5 mm)
				J	0.094" (2.4 mm)	0.16" (4.0 mm)
ROUND BELTS (Polyurethane)		Polyurethane Round Belts (endless)	Available diameters: 0.08" (2.0 mm ø), 0.12" (3.0 mm ø), 0.16" (4.0 mm ø), 0.20" (5.0 mm ø)			
ROUND BELTS (Polyurethane)		Bancord Polyurethane Open End Round Belts	Available diameters: 0.06" (1.5 mm), 0.08" (2.0 mm), 0.10" (2.5 mm), 0.12" (3.0 mm), 0.16" (4.0 mm), 0.20" (5.0 mm), 0.24" (6.0 mm), 0.28" (7.0 mm), 0.31" (8.0 mm), 0.35" (9.0 mm), 0.39" (10.0 mm), 0.43" (11.0 mm), 0.47" (12.0 mm), 0.59" (15.0 mm)			
FLAT BELTS (Polyurethane)		Polyurethane Flat Belts - Cordless	Width 0.2" ~ 1.97" (5 ~ 50 mm)		Thickness 0.016" ~ 0.16" (0.4 ~ 4.0 mm)	

stretch the build around the chips. Flexibility is increased by using rubberize fabric design to provide wear resistance and increase belt flexibility. In recent years belt with the cag instruction it become popular for specific applications. The cag provided the greater flexibility and with proper usages, it is possible to get up to (25-50)% more belt life. Additionally, standard V-Belts generally have an MPN Temperature limit of 140 degree F. a cag belt can operate slightly above this limit because of its ability to minimize build up [6].

The increasing demand for a higher productivity has resulted in a wide regent V-Belt design capable to handling specific applications. Table.1 provides the specifications of industrial power transmission belts [7].

The most common V-belt type is the Classical or Conventional V-Belt also known as multiple belts because one or more belts of the same cross section can be used in one multiple drives is shown in Fig. 3(a). The application of Classical V-Belt includes industrial fans, blowers, conveyer drives, oil field equipment, and agriculture equipment. The dimensions of the Classical V-Belt are identify by prefixed A.B.C.D.E. each prefix indicate top widths for example: A-1/2", B-5/8", C-7/8", D- 1 1/4", and E- 1 1/2". The classical are available as Cog Belt of range high capacity the cog belt prefixes are AX. BX. CX. The second size diminution is length is defined as Datum Length the digits indicating the nominal size represent an approximate inside length.

Another common belt type is Fractional Horsepower (single) V-Belt is used in fractional horsepower motors or small engine is shown in Fig. 3(b). The dimensions of Fractional Horsepower are identifying by prefixed 2L. 3L. 4L. 5L and each digit are indicating outside length.

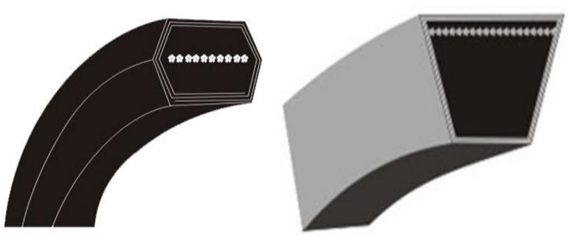

Fig. .3. a) Classical V-Belt, b) Fractional Horsepower V-Belt

Another popular belt type is Narrow (V Series) Belt is stronger than classical belt and have same application of Classical V-Belt and can use with multiple drive also and shown in Fig. 4(a). The dimensions of Narrow Belt are identifying by prefixed 3V. 5V.8V.3VX.5VX. Narrow belt are measured by effective length in a standard measure bully or by approximate Outside Length belt.

The need to resist the drive instability by Joined (Banded) belt is another type of belt shown in Fig. 4(b) that consists of two or more belt who stop fabric is joined to create one unit. This design is effective and the Id is used same tap assignation of the Classical and Narrow belt to get the part number simply as the number joined belts + standard belt Digits.

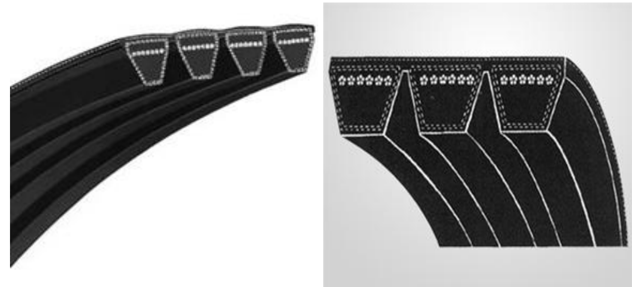

Fig. 4. a) Narrow V-Belt, b) Banded V-Belt

The Double V (Hexagonal) belt is shown in Fig. 5 used to transmit power on both sides of the belt. The construction of double V belt is similar to classical design. Therefore the id number are easy identify as AA, BB, CC.

Fig. 5. Types of Belts

III. V BELTS SYMPTOMS AND CAUSES OF FAILURE

Some of the most common V-Belt symptoms and causes of failure are discussed here to understand how to overcome these failure by taking proper troubleshoot so that failure can be minimized [8].

The Rapid Sidewall Wear symptoms depicted in Fig. 6(a) is due to main cause of Worn or Damaged Sheaves, however the other possible causes are, Belts Rubbing Guard, Sheaves Misaligned, Insufficient Tension, Wrong Belt Cross-Section or Type. Improper or Prolonged Storage, Excessive Heat, Excessive Oil or Grease, Use of Belt Dressing, Abrasive Environment, Inappropriate Sheave Material, Improper Tensioned Idler. The Worn Coven on Back depicted in Fig. 6(b) is mainly due to Belts Pried On or Misplaced Slack; however the other possible causes are defective or worn Backside Idler.

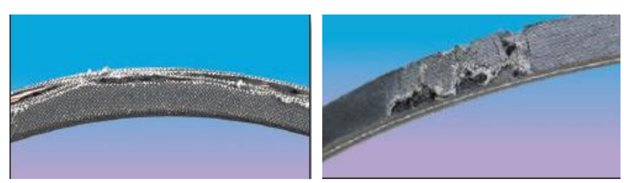

Fig. 6. a) Rapid Sidewall Wear b) Worn Cover on Back

Belt Soft, Swollen depicted in Fig. 7(a) is mainly due to excessive exposure to Oil or Grease, however the other possible cause is use of Belt dressing, Belt slips, squeals (spin burn) depicted in Fig. 7(b) is mainly due to Worn or Damaged Sheaves, Insufficient Tension, however the other possible causes are Wrong Belt Cross-Section or Type, Excessive Oil or Grease, Excessive Moisture, Overload Drive-Under belting, Insufficient Wrap on Small Sheave.

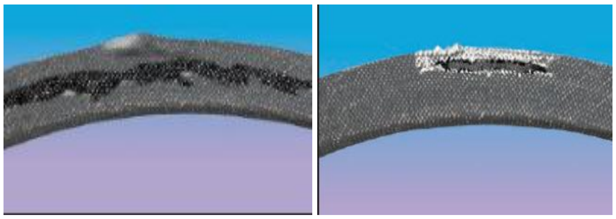

Fig. 7. a) Belt Soft, Swollen, b) Belt Slips, squeals

Belt Cover split depicted in Fig. 8(a) is mainly due to Belts Pried On or Misplaced Slack, Foreign Objects in Grooves, and Underside cracked depicted in Fig. 8(b) is due to Excessive Heat, Sheaves Too Small, Undersized Backside Idler, Improperly Positioned Backside Idler, Sheaves Misaligned, Improper or Prolonged Storage.

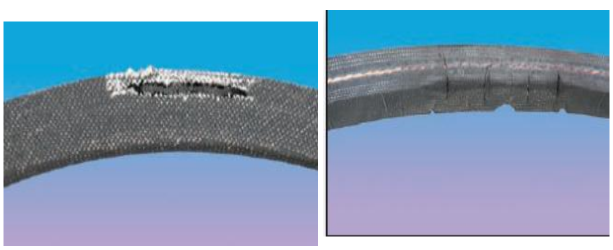

Fig. 8. a) Belt cover split, b) Underside cracked

Belt Missing Cogs depicted in Fig. 9(a) is mainly due to Excessive Heat, Sheaves Too Small, Backside Idler, Sheaves Misaligned, Improper or Prolonged Storage, and Cracked Bushing depicted in Fig. 9(b) is mainly due to Excessive Tension, Worn or Damaged Sheaves, Prying open The Split with a Screwdriver.

Fig. 9. a) Missing Cogs, b) Cracked Bushing

IV. EXPERIMENTAL SETUP

The experimental setup used for this study is designed and fabricated to collect vibration data for different working conditions. It consists of the following parts were selected and fabricated. The Motor of 1Hp and maximum speed of 1400 rev/min with power rating capacity of 0.9 KW as shown in Fig. 10(a) is selected. Bearings (No. 6302) of 20 mm diameter shown in Fig. 10(b) are used to support shaft. Two pair of pulleys (Larger with outer diameter of 127 mm and inner diameter of 20 mm and smaller with outer diameter of 87mm and inner diameter of 20 mm) shown in Fig. 11 were used. These two pairs of pulleys are mounted on a shaft diameter of 20 mm shown in Fig. 12(a). A loading system shown in Fig. 12(b) is used and a regulator shown in Fig. 13(a) is provided to control and regulate the desired speed. A V-Belt (A-838, Ld 871) shown in Fig. 13(b) is used to connect driver and driven shaft. These units are mounted on a strong base plate.

Experiments were conducted at two speeds with lower speed at 540 rpm and at higher speed of 1000 rpm. Driven pulley rotates at lesser speed than the driver pulley because the driven pulley is bigger in diameter than the driver pulley. As per speed calculation for higher speed the driver pulley rotates at 1490 rpm whereas driven pulley rotates at 1000 rpm. Similarly for the lower speed the driver pulley rotates at 790 rpm whereas driven pulley rotates at 540 rpm. The Belt drive experimental setup is depicted in Fig.14.

Fig. 10. a) Motor, b) Bearing

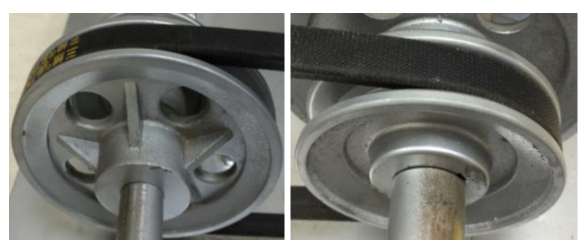

Fig. 11. Larger and Smaller Pulleys

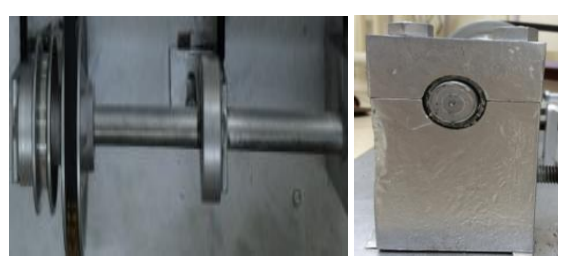

Fig. 12. a) Shaft, b) Loading system

Fig. 13. a) Speed Regulator, b) V-Belt

LabVIEW7® (Laboratory Virtual Instrument Electronic Workbench NI-National Instrument) application software model, developed (LabVIEW™ 7, 2003) with FFT analyzer is used to acquire vibration signals data through four channel sensor input module Data Acquisition Device (NI-DAQ-National Instruments-NI SCXI-1000 chassis through SCXI-1530-channel 0, SCXI-1530-channel 1 and SCXI-1530-channel 2). The photographic view of LabVIEW® software integrated with DAQ module and computer is shown in Fig. 15.

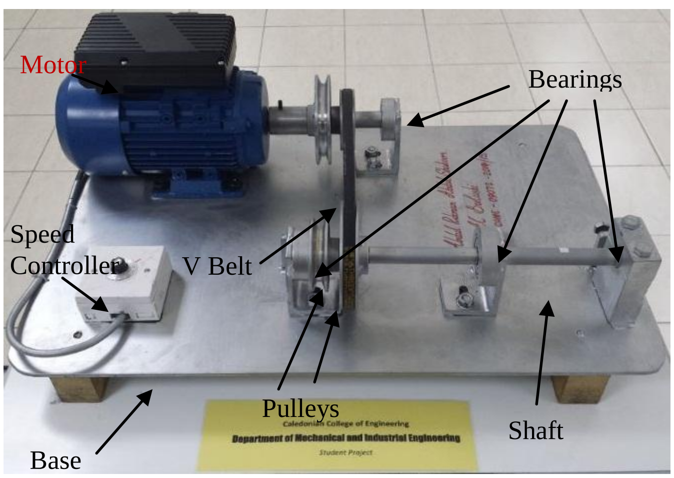

Fig. 14. Belt drive experimental setup

Fig. 15. LabVIEW® software integrated with DAQ module

The piezoelectric accelerometers (Model 621B40, IMI sensors, sensitivity is 1.02 mV/m/s^2 and frequency range up to 18 kHz) was used to acquire vibration signals in vertical, horizontal and axial directions are shown in Fig. 16. The LabVIEW7® application software displays the vibration spectrum over a range of frequencies and time scale. The front panel display of the software is shown in Fig. 16.

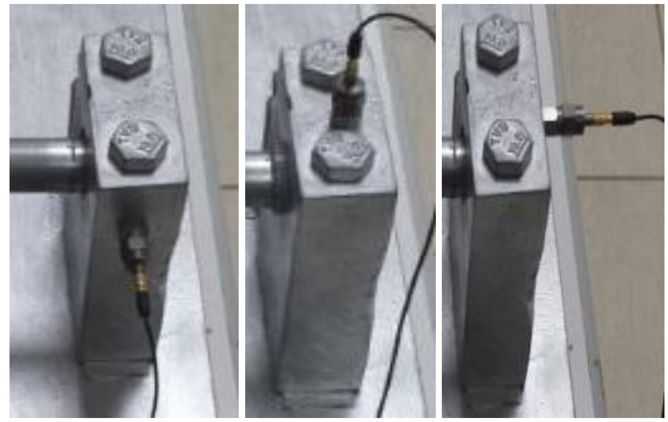

Fig. 16. Accelerometers position at bearing

A. Healthy Condition

Initially experiments were conducted for two speeds one is at lower speed of driven pulley at 540 rpm whereas driver pulley rotates at 790 rpm and other is at higher speed of driven pulley at 1000 rpm whereas driver pulley rotates at 1490 rpm under good operating condition without any faults in the belt. The required speed is attained by controlling the speed regulator and the corresponding speed is measured by tachometer. Next using LabVIEW 7.1 software the vibration signals in horizontal, vertical and in axial directions were acquired. These signals were later used to compare the signals with belts fault condition to identify the cause.

B. Faulty Conditions

Three faults condition were created in the belts to study and analyze the behavior of the rotating system under different operating speeds. The size of the belt which is used for this test is shown in Fig. 17.

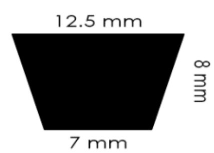

Fig. 17. Belt Size

The first Side-Cut-Out fault is induced only at outer side of the V-Belt (67mmx7mmx8mm) as shown in Fig. 18.

Fig. 18. Side Cut and removed piece

The second Side-Cut-In fault is induced only at inside portion of the V-Belt as shown in Fig. 19.

The third Loose & Side-Cut-Out fault is induced only at outer side of the V-Belt and slightly loosened the belt.

Fig. 19. Loose and Side Cut and removed piece

V. RESULTS AND DISCUSSION

The vibration signals only in the axial directions are presented here for discussion purpose. Since the amplitude of vibration is observed high in axial direction than in horizontal or in vertical direction. A typical time domain vibration signals for lower speed of 540 rpm are shown in Fig. 20. The frequency domain vibration signals for lower speed of 540 rpm are shown in Fig. 21.

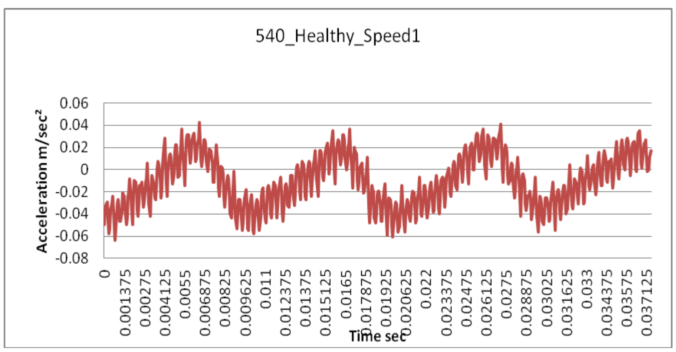

Fig. 20. Acceleration with time at speed of 540 rpm

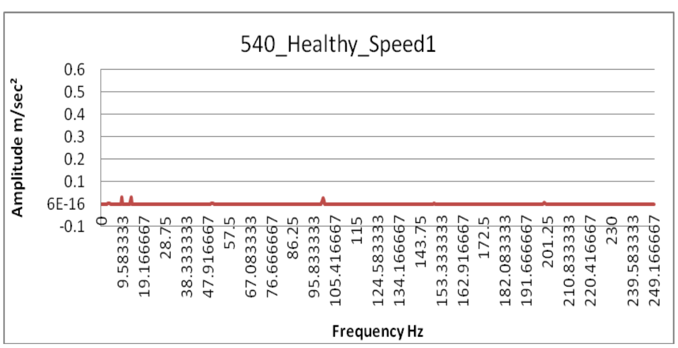

Fig. 21. Acceleration with frequency at speed of 540 rpm

Similarly the time domain vibration signals for higher speed of 1000 rpm are shown in Fig. 22. The frequency domain vibration signals for higher speed of 1000 rpm are shown in Fig. 23.

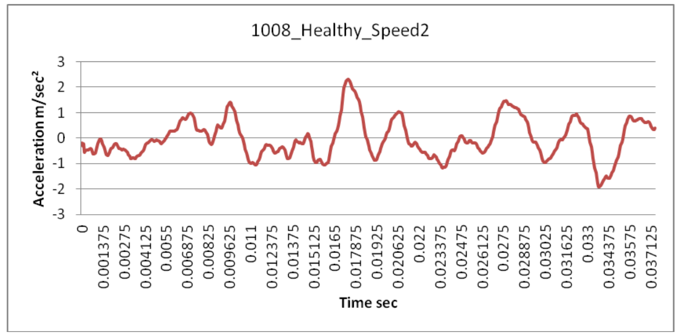

Fig. 22. Acceleration with time at speed of 1000 rpm

It is observed from the healthy running conditions that at lower speed and as well as at higher speeds of the driver and the driven, there is smooth behavior of the V-Belt. Moreover, in both speeds there is a small ignorable vibration level is observed, however this level is very low and negligible. This vibration level is used as a basic reference to compare the vibration level at various faulty conditions.

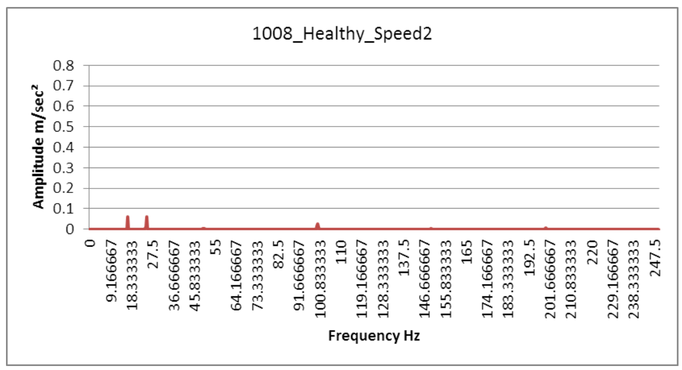

Fig. 23. Acceleration with frequency at speed of 1000 rpm

A. Side-Cut-Out Condition

The time domain and frequency domain vibration signals for Side-Cut-Out fault are represented in Fig. 24 and Fig. 25 for lower speed of 540 rpm.

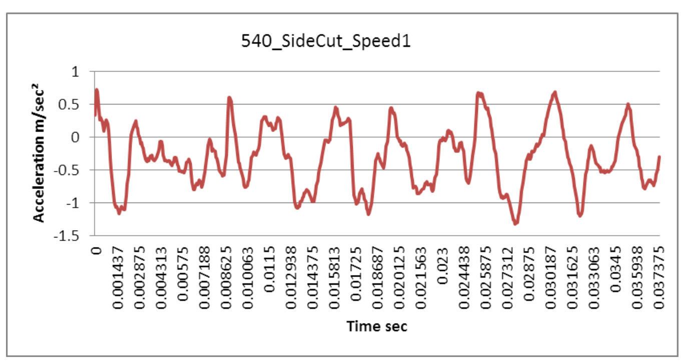

Fig. 24. Acceleration with Time for Side-Cut at 540 rpm

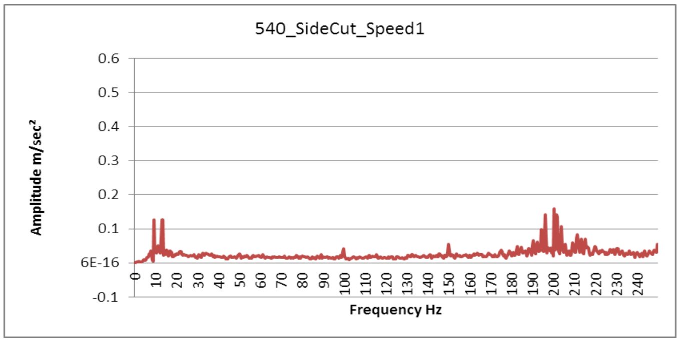

Fig. 25. Amplitude with Frequency for Side-Cut at 540 rpm

The time domain and frequency domain vibration signals for Side-Cut-Out fault are represented in Fig. 26 and Fig. 27 for higher speed of 1000 rpm.

It is observed that the Side-Cut-Out in the belt has an effect on vibration level at lower as well as at higher speed. The vibration amplitude at 1X is increasing in nature compared to healthy condition. Where, the two vibration amplitudes indicates that first one for the Driven shaft take place at the beginning and followed by the Driver shaft in the graph. But, comparing both the speeds to each other the amplitude in second speed is more.

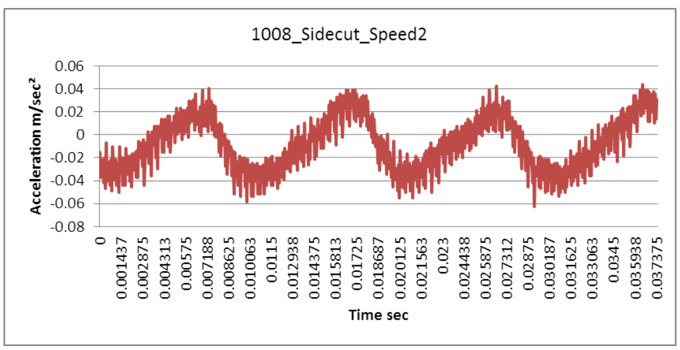

Fig. 26. Acceleration with Time for Side-Cut at 1000 rpm

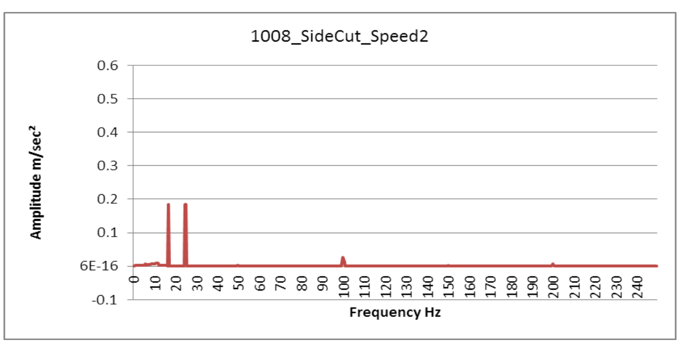

Fig. 27 Amplitude with Frequency for Side-Cut at 1000rpm

B. Side-Cur-In Condition

The time domain and frequency domain vibration signals for Side-Cut In fault are represented in Fig. 28 and Fig. 29 for lower speed of 540 rpm. It is found that in Cut-In fault condition the vibration amplitude level at 1X is more than 0.2 m/sec^2.

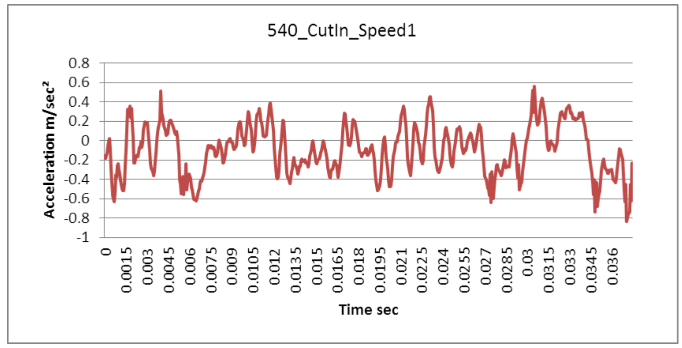

Fig. 28. Acceleration with Time for Cut-In at 540 rpm

The time domain and frequency domain vibration signals for Side-Cut In fault are represented in Fig. 30 and Fig. 31 for higher speed of 1000 rpm. It is noticed that the vibration amplitude at 1X is more than 0.2 m/sec^2. Furthermore, by observation the vibration amplitude for Side-Cut In fault is lower than Loose and Side-Cut fault.

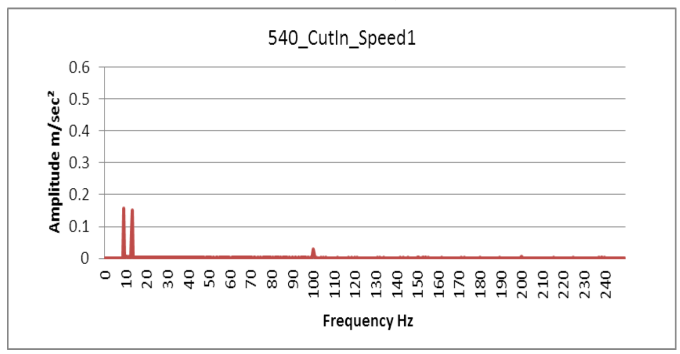

Fig. 29. Amplitude with Frequency for Cut-In at 540 rpm

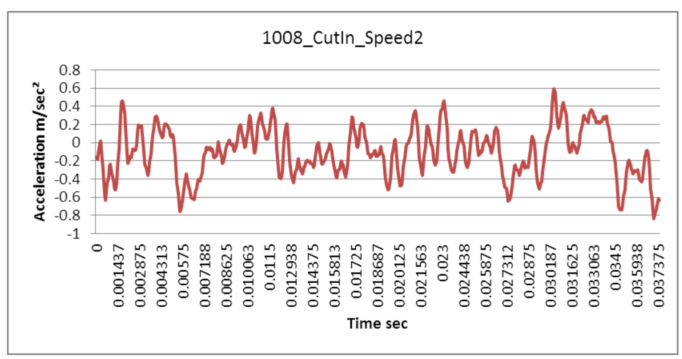

Fig. 30. Acceleration with Time for Cut-In at 1000 rpm

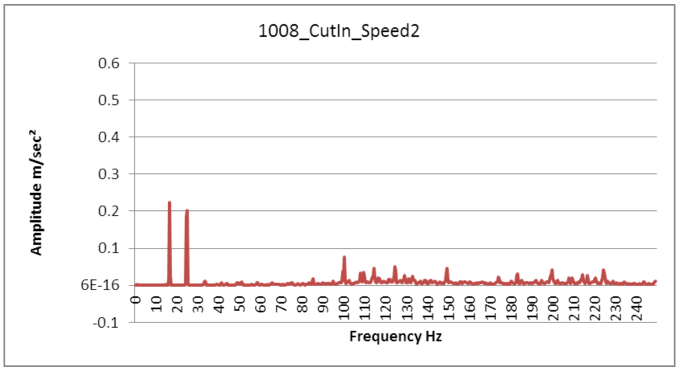

Fig. .31. Amplitude with Frequency for Cut-In at 1000 rpm

C. Loose & Side-Cut-Out Condition

The time domain and frequency domain vibration signals for Loose and Side-cut fault are represented in Fig. 32 and Fig. 33 for lower speed of 540 rpm. It is seen that, the 1X amplitude for driven shaft is nearly 0.2 m/sec^2.

The time domain and frequency domain vibration signals for Loose and Side-cut fault are represented in Fig. 34 and Fig. 35 for higher speed of 1000 rpm. As the speed increases the vibration amplitude is higher than 0.2 and nearly to 0.26 m/sec^2 at higher speed. In addition, by comparing this fault with the previous fault, it is clearly indicates that the vibration amplitude is high for Loose and Side-cut fault.

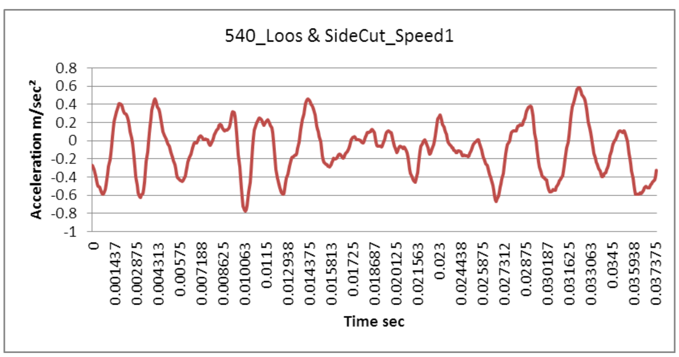

Fig. 32. Acceleration with Time for Loose & Side-Cut at 540 rpm

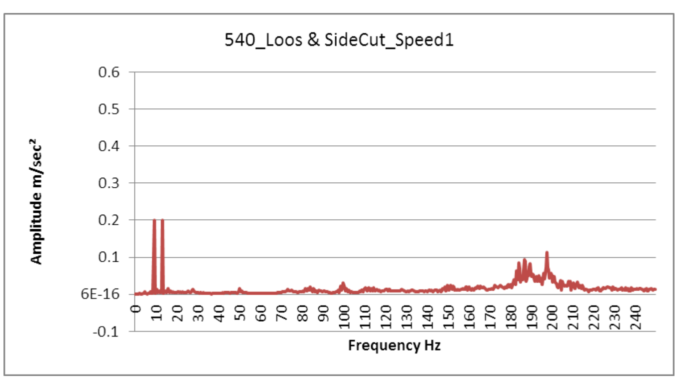

Fig. 33. Amplitude with Frequency for Loose and Side-Cut at 540 rpm

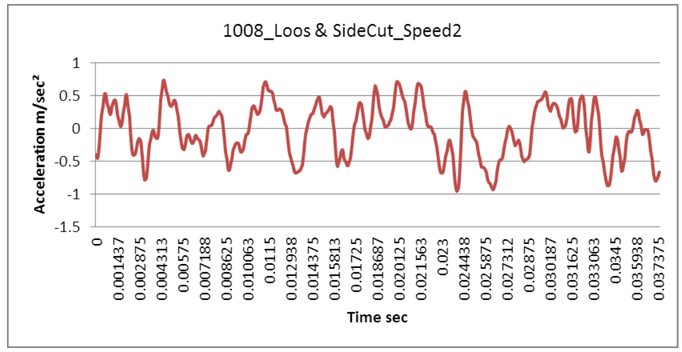

Fig. 34. Acceleration with Time for Loose & Side-Cut at 1000 rpm

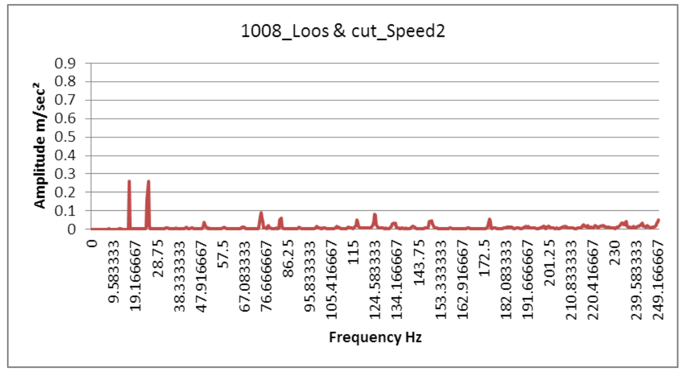

Fig. 35. Amplitude with Frequency for Loose & Side-Cut at 1000 rpm

VI. CONCLUSION

Extensive experimental investigation was carried out on the belt drive simulator experimental setup which is designed and fabricated for this study. Initially for healthy conditions the vibration signals were acquired and further used to compare the vibration signals under three faulty conditions at lower speed of driven pulley at 540 and at higher speed of driven pulley at 1000 rpm. Three faults like Side-Cut out, Side-Cut-In and Loose & Side-Cut-out induced in the belt intestinally to study the conditions. At the healthy condition it is found that the V-belt is running in smooth condition with very low vibration level. After recording the readings of the healthy condition, the three faults Side-cut-out, Side-Cut-In and Loose & Side-Cut-out induced in the belt and experiments were conducted for all the cases and corresponding vibration signals were acquired in three directions. It is found that the vibration level at 1X running speed has increased remarkably corresponding to driver and driven shaft speeds. Also the vibration level at higher speed is more compared at lower speed. The vibration amplitude level at speed 540 rpm is around 0.125 m/sec² and at 1000 rpm speed it reached 0.185 m/sec² for side-cut-out fault, for the Cut-In fault it is found that the vibration level get increased and affected more than compared to Side-Cut and health condition of the belt at the speed 540 rpm (0.156 m/sec²) and 1000 rpm (0.22 m/sec²). The other fault which was created the combination of Loose &

Side-Cut-out combined together in the V-belt and conducted experiments at the same speeds. It is observed that the vibration level is more when compared to other two fault conditions. Moreover, from the tests conducted it is concluded that the fault condition Loose & Side-Cut-out is the most affected fault in the V-belt compared with the other two faults and generates high vibration amplitude. It has high value of vibration amplitude 0.2 m/sec^2 at 1X running speed at speed 540 rpm and at speed 1000 rpm it reached to 0.26m/sec^2. Furthermore, when the speed increases the vibration amplitude increases with respect to fault created. Hence, it is found that there is a relation with severity of fault, vibration amplitude and speed.

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