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Vibration Profiles of a V-belt Transmission System With a Defective Pulley

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Abstract

The study described in this paper deals with the outcomes of an experimental investigation regarding vi-bration of a V-belt transmission system with pulley abnormalities, due to a hump and a groove on pulley surface. The measurement is conducted on a test bed of a single-belt transmission system, where the drive pulley is overhung and the driven pulley is put between two supports (bearings). Data to be analyzed are taken at bearing houses of a driven pulley, along vertical, horizontal, and axial directions. The work is aimed at obtaining vibration profiles of such a system. Assessment toward the data is conducted on the frequency domain profile of vibration signals. The presence of a hump and a groove on pulley surface re-sult the followings:

- *for radial vibration, there is a significant increase in the second harmonic*
- *for axial vibration, the increase of the first and second harmonic are evident*
- *a hump gives a bigger impact than a groove*

Key words: vibration, V-belt, pulley abnormality, experimental measurement

1. Introduction

V-belt transmission systems are extensively used in industries, among others because they are easy to maintain and inexpensive. V-belt systems usually are employed to transmit power to drive other equipment, whereupon they are required to have a good operation condition for relatively long periods. But, actual practices show that abnormalities often happen during operation, that may be caused by different things, such as misalignment (parallel, angular, twisted), unbalance, defect on belts or pulleys. Unless receiving proper attention, operation abnormalities may bring failures on other components or the whole system, which in turn they may cause disturbances on a production process.

There are some parameters which could be utilized as indicators of operation abnormalities of a machine: vibration, temperature, lubrication. In condition monitoring, measurement and analysis of vibration signals are often used to detect machine operations. These because vibration signals are good indicators to assess machine condition, and can be used as an early warning toward operation abnormalities. In accordance with vibration knowledge, a certain type of abnormality will yield a specific vibration profile or response, known as a vibration signature.

The flexibility of belt material makes the transmission can withstand shock loads; but, this causes the drive is susceptible toward the emergence of belt vibration. And, because belt drives extensive use and their sensitivity toward excitation during operation, up to now study on vibration characteristics of belt transmission systems always attract many researchers, with varying focus of interests. The studies included investigation on vibration characteristics of V-belt drives with shaft misalignment (Moon and Wickert, 1999; Wonoyudo, 2006). Another form of abnormality that had been investtigated was eccentricity of a pulley (Moon and Wickert, 1997; Pellicano, Catellani, and Fregolent, 2004). Vibration due to manufacturing defects was discussed by Abrate (1992).

A study on a flat-belt drive was conducted by Leamy (2003), while investigations on serpentine belt drives were presented by Beikmann, Perkins and Ulsoy (1997), and by Di Sante and Rossi (2001). Sheng, et al. (2004) investigated a noise generated on a V-ribbed belt drive system. Implementation of a finite element method in studying a vibration response of a belt drive system was conducted by Singru and Modak (2001), and by Chen and Shieh (2003).

In light of the vast research on V-belt drives, the study described in this paper deals with an experimental investigation on a V-belt transmission system with defective pulleys. There are two kinds of defect being studied, i.e. a hump and a groove at pulley surface. The study is aimed at obtaining vibration profiles of such a system.

2. Experimental Method

The test is conducted on a single-belt transmission system, where the belt has a trapezoidal cross section and is made from rubber. The drive pulley is overhung, while the driven one is put between two supports (bearings). The pulleys are made from cast iron, where the distance between the centers of two rotating shafts is 44 cm (17.23 inches). The drive pulley is directly mounted (without a coupling) to a non-variable speed electric motor acting as a prime mover. The base of the motor can be glided to adjust belt tension, in order to have a necessary tension as required. Test bed is anchored to ground, and there are four rubber supports put between the base frame and the floor.

To simulate a lump (accumulation of debris) and a crack, a hump and a groove is made on an inner side of the driven pulley surface, where the operation speed of the driven pulley is about 18.75 Hz. Vibration data are taken for every experiment setting, that are for a normal pulley and a pulley with a hump or a groove. The data are taken after the motor is run for a particular setting, and are obtained at bearing houses of the driven pulley, along vertical, horizontal, and axial direction.

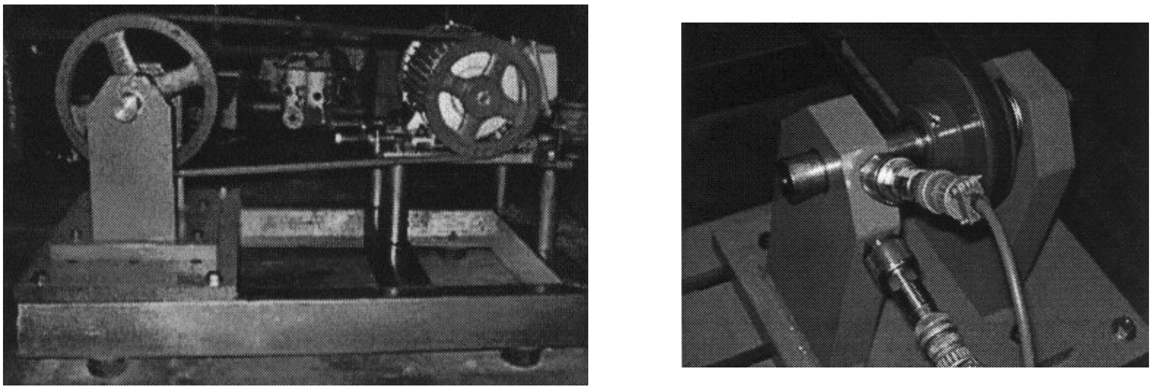

Figure 1. Test Bed and Sensor

A two-channel vibration analyzer (CSi 2120A) is employed as a measurement device, as well as a data logger. Two accelerometers, each with a magnetic base, are used as vibration sensors. The accelerometers are portable; their placement can be moved from one place to another regarding the need. Vibration data can be recorded in a displacement, velocity, or acceleration time history. They can be displayed either in a wave form (time domain) format or in a frequency domain format. The two displays are made possible because the analyzer is equipped with FFT that works based upon the Fourier expansion principle, where any function can be converted into a harmonic expression according to

$$f(x) = a_o + \sum_{n=1}^{\infty} (a_n \cos nx + b_n \sin nx) \qquad (1)$$

where a_o, a_n, and b_n are coefficients.

Using the algorithm developed based on the above formula; a time-history vibration signal can be converted into the sum of harmonic signals each of different frequency and amplitude.

3. Measurement Data and Their Analyses

The following figure shows one example of vibration measurements, presented in both a time domain graph (below) and a frequency domain graph (above). As a common practice in analyzing a condition of rotating machinery, assessment for an equipment condition mainly is done on the frequency domain profile.

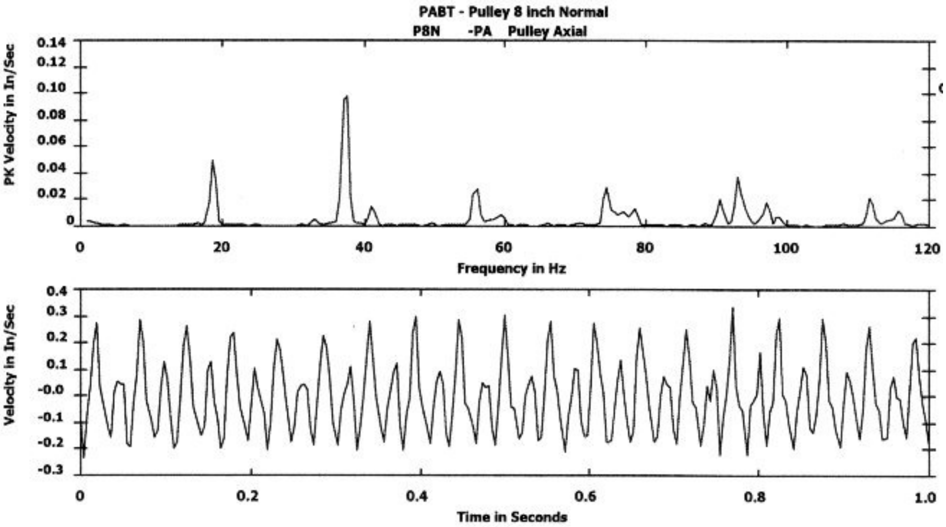

Figure 2. Frequency- and Time- Domain Graph

Amplitude data of overall vibration velocities for every experiment setting are listed in the following table.

Table I. Velocity Amplitude

Velocity Amplitude (in./sec.)			
Measurement	Normal	With Hump	With Groove
PIV	0.035	0.151	0.050
PIR	0.087	0.179	0.095
PIH	0.105	0.225	0.123
POV	0.036	0.157	0.056
POR	0.089	0.204	0.095
POH	0.108	0.244	0.126
PA	0.159	0.278	0.193

V : vertical
H : horizontal
R : radial
A : axial
I : inboard
O : outboard

Horizontal vibration levels which are higher than vertical ones are caused by the driven pulley support construction that resembles a cantilever beam, for which it is more flexible horizontally. (Radial measurements are between those two.) High axial vibration levels are attributed to the overhung construction of the drive pulley, which are enhanced by the cantilever-like construction of the driven pulley support. Axial vibration levels also indicate a less than perfect alignment between drive and driven pulleys, and an assembly problem of pulleys keyed onto the shaft. The table indicates an increase in the overall vibration level due to the presence of defects on the pulley. For the test bed used in this experiment, measurement results at outboard side (farther from the motor) are higher than results at inboard side.

In the discussion of vibration signatures, the effect of defect (a hump or a groove) is analyzed by comparing the response of a belt drive with a defective driven pulley with the response of a belt drive without defect on its driven pulley.

In analyzing the vibration of a belt transmission system it is necessary to indicate a particular frequency known as a Belt Pass Frequency (BPF) of the following formula:

$$BPF = (\pi \times PD \times rpm) / BL \qquad (2)$$

where

PD : pulley diameter
rpm : pulley rotation speed
BL : belt length

In this experiment, the BPF is about 8.4 Hz.

During vibration measurement, BPF's harmonics are identified, indicating an abnormality in transmission. This problem is diagnosed to come from an assembly process.

In addition to BPF, the occurrence of 100 Hz frequency (2 x line frequency) is identified, supposedly comes from abnormalities within the motor, where the effect is brought into an operation of the V-belt transmission. (The motor condition which is less than perfect has been verified by vibration measurement of the motor only.)

Pulley with a Hump

Figures 3 and 4 are examples of vibration response comparison between a belt drive using a normal pulley (the graph below) with a belt drive using a defective driven pulley (the graph above). The noticeable frequencies are 1x, 2x, 3x, 4x, 5x, and 6x shaft speed. The presence of a hump causes an increase in the amplitude of those harmonics, with a significant increase on 5^{th} harmonic. For axial vibration, in addition to the increase of 5^{th} harmonic, a significant increase is also recorded on 1^{st} and 2^{nd} harmonics. The axial level is much higher than the radial. This is attributed to the fact that the hump (for this experiment) is relatively large and given on the inner side of the pulley, which also brings unbalance effect to the process.

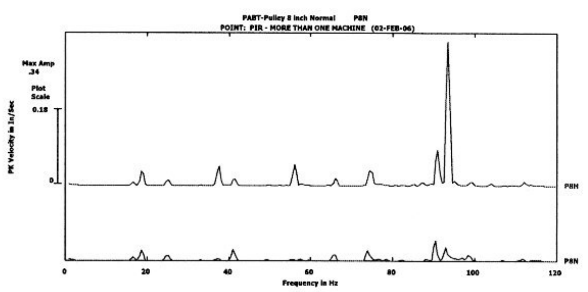

Figure 3. Effect of a Hump on Radial Vibration

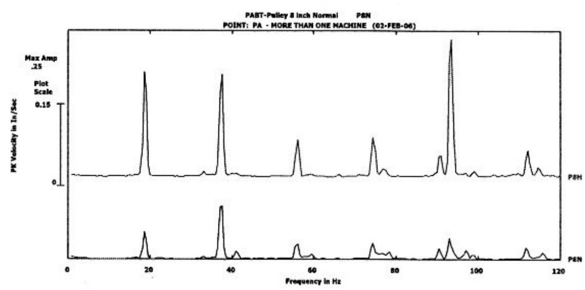

Figure 4. Effect of a Hump on Axial Vibration

Pulley with a Groove

Figure 5 shows a radial vibration spectrum of the belt drive with a groove on driven pulley surface. Within the figure there are peaks of pulley's rpm and its harmonics (1x up to 6x). Among those harmonics the highest peak is at 2x (about 37.5 Hz), while for the whole spectrum the highest peak is at around 92 Hz, which is associated with the harmonic of BPS.

As in radial vibration, the axial vibration also yields peaks at 1x up to 6 x of pulley's rpm (Figure 6), where the value of the peaks increase due to the presence of the groove. The axial measurement also records the peak around 92 Hz.

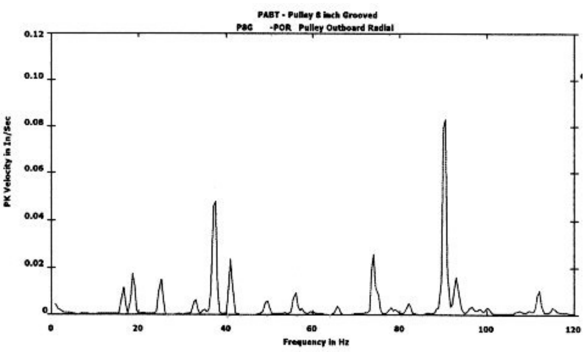

Figure 5. Radial Vibration Signature of a Pulley with a Groove

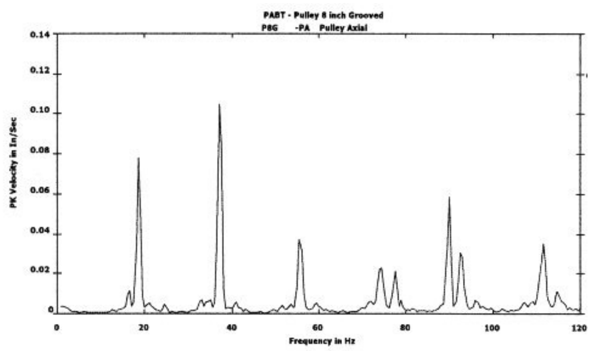

Figure 6. Axial Vibration Signature of a Pulley with a Groove

From the response it is noted that a groove (actually of a bigger size) yields a lower vibration level than a hump.

4. Conclusion

From the result of vibration measurements conducted during the test, the following assessments are noted:

- For radial vibration, the presence of a hump and a groove on a driven pulley give significant increase in the 2^{nd} harmonic (compared to the increase of the other harmonics).
- For axial vibration, the increase of the 1^{st} and 2^{nd} harmonic is evident, for cases of a driven pulley with a hump or a groove.
- A driven pulley with a hump shows the highest peak at the 5^{th} harmonic (radial and axial vibration), for which there is a significant increase due to the presence of a hump
- A driven pulley with a groove indicates a harmonic of the BFS, for radial and axial vibration, which is attributed to the less than perfect pulley-on-shaft assembly process.
- A hump on a pulley gives a bigger impact than a groove on a pulley.

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