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Fault Detection and Isolation for Paper Machinery by Vibration Monitoring Method

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Keywords：Fault detection and isolation, Vibration spectrum analysis, Rolling element bearing, Paper machinery.

ABSTRACT

Fault detection and isolation are important for preventing paper machinery from unexpected break-down during a production process. This study applied vibration monitoring technology to detect and isolate abnormal vibration occurred in paper machinery. The study made use of vibration analyzer to log overall vibration level trend of the objected machinery for a long period. This vibration spectrum was able to conduct vibration spectrum analysis to investigate whether it incurs an abnormal vibration for engineers. In this study, a case study was shown and examined for paper machinery. The study classified the correspondence of vibration spectrum with rolling element bearing and gear. This investigation was performed in a real workshop for a period of time to understand possible situations occurred in paper machinery. It showed that each vibration spectrum represented a unique problem occurred in the objected machinery. The analysis detailed the possible factors detected in the paper machinery. The obtained results can provide engineers to locate the causes of machine's breakdown to reduce economic loss for paper manufacturers.

INTRODUCTION

In these years, the development of measure instruments for vibration problem has made a great progress. This technology has been further integrated with mechanical design problem and many achievements have been also obtained. Vibration monitoring system enables an engineer to guard trend of vibration of rolling element bearing and gear to further understand the states of machine elements to prevent an unexpected breakdown occurred in the mechanical system. There are many researches have addressed the approach for vibration analysis of rolling element bearing defects. Therefore, an understanding of the measurement and analysis technology of mechanical vibration in a mechanical system will greatly help engineers improve the mechanical stability of machines.

Kiral and Karagulle (2006) presented a method based on the finite element vibration analysis for defect detection in rolling element bearings with single or multiple defects on different components of the bearing structure by using the time and frequency domain parameters. Orhan et al. (2006) investigated the defects of ball and cylindrical roller element bearing by vibration monitoring and spectral analysis as a predictive maintenance tool. Sawalhi and Randall (2008) simulated a gear-bearing model by gearbox test rig to locate a system of bearing and gear faults. A tutorial for rolling element bearing diagnostics had been introduced by Randall and Antoni (2011). Cong et al. (2013) proposed a rolling bearing fault model based on the dynamic load analysis of a rotor-bearing system. It showed that different amplitude contributions of the alternate load and determinate load can cause different envelope spectrum expressions. Zheng et al. (2013) developed an adaptive data-driven analysis approach called generalized empirical mode decomposition which can be applied to rolling element bearing fault diagnosis.

Wang et al. (2014) presented a health diagnosis that can analyze the possible damage of a bearing in different points by surveying the sampled signal spectrum, such as a single outer race defect diagnosis, a single inner race damage diagnosis, and a health diagnosis for a plurality of bearings. In this way, the study can clearly measure the magnitude of vibration frequency and effectively analyze the damage severity of the bearing. Saruhan et al. (2014) simulated the same rolling element bearing under different rolling speeds (17Hz, 25Hz, 33Hz, and 41Hz) to investigate the difference of these spectrums.

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The bearing defects resulted in harmonic, multiples of frequency, of the defected frequencies in the vibration spectrum. It demonstrated that the vibration analysis technique is a reliable and accurately detecting defect in the bearing elements.

A novel nonlinear non-stationary wavelet bicoherence technology was proposed by Gelman et al. (2014) for rolling bearing condition monitoring. This diagnostic approach applied the integrated wavelet bicoherence modulus to combine the wavelet transform and the higher order spectra by exploiting the coupling between impacts induced by bearing damage at different frequency bands. Sawalhi and Randall (2014) applied the vibration spectrum analysis to the fault information detection for wind turbine reducer. The research used harmonic cursor (with meshing frequency) in a stable speed to successfully find out the gear meshing frequency, and assess the condition of the gear operation by vibration amplitude. Jena et al. (2015) studied a method to automatically identify gear and bearing fault by using vibration and acoustic signals. Li et al. (2015) claimed a method to carry out incipient fault information detection for rolling element bearing by using synchronous averaging reassigned wavelet scalogram according to time-frequency analysis. Farina et al. (2015) proposed a two-step scheme based on two complementary data-driven techniques to investigate the fault detection problem for a drive reducer in a hot steel rolling mill. A preliminary fault detection phase was based on a computationally lightweight time-domain multivariate statistical technique. Furthermore, a frequency-domain analysis method is adopted to confirm the fault detection and on its frequency characteristics. Dong et al. (2015) performed a vibration model based on frequency-shifted bi-spectrum analysis for rolling element bearings to detect its potential faults as early as possible.

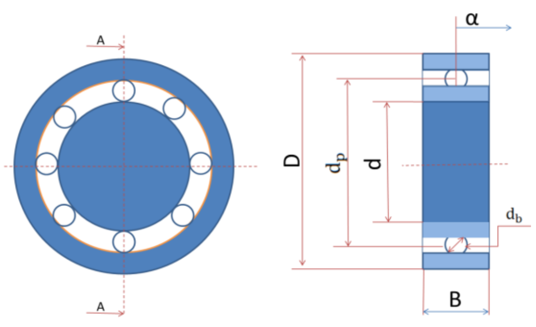
Other researches have been focusing on the failures of machine elements, such as precision locknut, incurred by vibration. Precision locknut (anti-loose nuts) usually is fitted together with bearings. It is used to lock the rotating bearing and spindle, and some other workshop tools, which are required solid locking in rotating machinery. Chen and Sun (2015) indicated that a significant wear can be generated on the surface of precision locknut while the machine system in a vibration condition. It should be noted that the performance of machine system is critically related to the rolling element bearings and its threaded fasteners.

Therefore, a detection of faulty bearing and gear conditions is greatly important for many industrial applications, especially for large scale machinery. Paper machinery is a type of large scale machinery. Its working status requires a long-time and continuous operation without any interrupt. If a mechanical failure incurred during a manufacturing process, this non-scheduled shutdown will result into seriously high production costs to the manufacturer. Therefore, fault detection and isolation are important issues in paper machinery. Now, vibration monitoring technique is a way to detect abnormal situations occurred in a machine. Vibration analysis can further find out the causes of the abnormal vibration level. It has been known that this technology has not been applied to the case of paper machinery so far. This study attempts to apply vibration monitoring technology to paper machinery to effectively promote its feasibility and reliability during a paper manufacturing process. It classifies a corresponding of vibration spectrum to a mechanical failure of paper machinery. This study makes use of spectrum analyzer to collect and analyze the data from an objective machine to investigate this problem.

BEARING AND GEAR DEFECTS

Many of rotating machineries depend on rolling element bearings (REBs). These bearings usually provide relative positioning and rotating freedom for mechanical systems. An analysis should be made to identity the potential defects of REBs before they become a serious problem to damage the mechanical system. Rotating vibration monitoring technology has been applied to many rotating machineries as predictive technology in the current production system. A vibration monitoring system supplies continuous indications of the state of balance of the machine. The indication is available on the interface of vibration monitoring system during all motor operating conditions. The vibration monitoring system helps engineers perform maintenance operations, such as the trend of vibration of rolling element bearings and the state of machine elements. Intensive researches have been done in recent years for defect diagnosis of rolling element bearings (REBs) to ensure their performances.

A REB is usually an ensemble of outer race, inner race, cage, and rolling element. Geometry and dimensions of ball bearing is illustrated in Figure 1, which shows a ball bearing is consisted of outer race, inner race and spin balls.



Section A-A

Figure 1. Geometry and dimensions of a ball bearing

Defects in the REB can generate a series of impacts which repeat periodically at a rate known as the bearing frequencies. Every bearing element defect could produce a characteristic defect frequency which is determined by its mechanical dimensions. The cause of bearing defect can be defined by identifying the type of bearing characteristic frequency. The product of multipliers with the shaft rotational speed provides the defect frequency of bearing running at given shaft speed. The bearing frequency multipliers equations can be used to determine a theoretical prediction of the frequency when the bearing element defect is occurred. These frequency multipliers for the rolling elements of a bearing in which the inner race rotates and the outer race is stationary can be defined as the following equations:

$$BPFO = (N_b / 2)(1-(N_b / d_p)\cos\alpha) \tag{1}$$

$$BPFI = (N_b / 2)(1+(N_b / d_p)\cos\alpha) \tag{2}$$

$$BSF = (d_p / 2d_b)(1-((d_b / d_p)\cos\alpha)^2) \tag{3}$$

where *BPFO* is ball pass frequency multiplier of the outer race; *BPFI* is ball pass frequency multiplier of the inner race; *BSF* is ball spin frequency multiplier. *Nb* is number of rolling elements. db is diameter of the rolling element. *dp* is pitch diameter, and a is contact angle, which is the loading angle from the radial plane. If a cage of REB has defects, a frequency is called as fundamental train frequency (*FTF*) which can be calculated by the formula as follows:

$$FTF = 0.5\omega(1 - (N_b / d_p)\cos\alpha) \tag{4}$$

Where ω is rotation speed of the axis.

A transmission system is usually consists of REB and gear element. Then, in the case of faulty gear, the fault is introduced by gear mesh with damaged teeth. A vibration frequency is introduced by gear mesh with a phase of collision, respectively. Vibration and acoustic responses from the system can be captured successively by spectrum analyzer. The vibration spectrum is called as gear mesh frequency here. A gear mesh frequency (*GMF*) can be calculated by the following equation:

$$GMF = \omega \times N_g \tag{5}$$

where ω is transmission speed and *Ng* is number of gear tooth. If a healthy gear couple is in good alignment, its gear meshing frequency is normally very low.

EXPERIMENTAL SETUP

Vibration data were gathered and processed by SKF vibration spectrum analyzer in this study. The data will be further examined to find the cause of high vibration frequency level or high noise amplitude that may be a resonance or a potential defect in the machine. The vibration spectrum analyzer provides a maximum 40 kHz bandwidth and measurement accuracy up to 12,800 resolutions for any analytical purpose. Its module of measurement function includes multiple-path data collection, non-path data collection, double-channel FFT data analysis, and three-axial synchronous measure function. The vibration signal can be transformed to spectrum by Fast Fourier Transform (FFT) method. It can be analyzed from the vibration spectrum to find out the causes of the increase of vibration frequency and amplitude in the mechanical equipment. Maintenance can be conducted by experienced personnel to replace or improve the damaged parts, thus the equipment can run in a reasonable range of vibration level.

FFT is an algorithm to compute the "discrete Fourier transform (DFT)" and its inverse function for an equation. Fourier analysis converts time (or space) to frequency (or wave number) and vice versa; FFT rapidly computes such transformations by factorizing the DFT matrix into a product of sparse (mostly zero) factors. As a result, Fast Fourier transforms are widely used for many applications in engineering, science, and mathematics. FFT computes the DFT and produces exactly the same result as evaluating the DFT definition directly; the most important difference is that an FFT is much faster.

A layout of paper machinery can be seen in Figure 2. This industrial paper machinery can produce a variety of industrial papers, such as liner board paper, corrugated paper and tube paper. The specification of the paper machinery is as follows: the width of the paper machinery is 2840mm; paper process speed is 130m/min; production rate is 105 ton/day. This type of machine is classified as a long type of paper-forming machine. The transmission system of the objected paper machinery was monitored in this case study. Its image can be seen in Figure 3.

Figure 2. A layout of paper machinery in a workshop

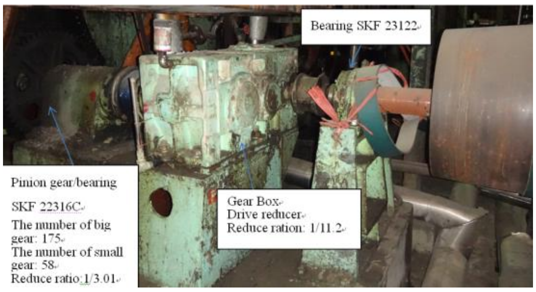


Figure 3. The transmission system of the objected paper machinery for this case study

A simplified diagram of the transmission system in the experiments is as shown in Figure 4.

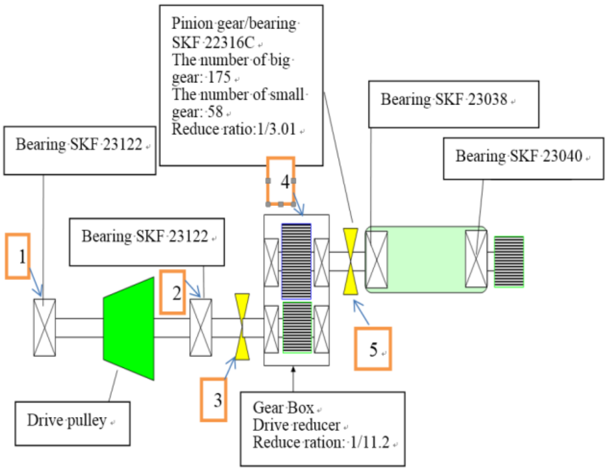


Figure 4. Simplified schematics of the transmission system (Five measurement points have been assigned)

The parameters of the spherical roller bearing used in this study are given in Table 1. The experimental procedure is as follows:

1. Planning a vibration measurement cycle for this system,
2. Conducting the management of vibration trend,
3. Finding out which bearing's vibration amplitude is increasing suddenly,
4. Retesting the signal whether it is an error signal for exclusion,
5. Confirming which bearing's vibration amplitude is in high level to carry out a spectrum analysis.

Table 1 Parameters of spherical roller bearing type SKF22316C

item	Specification
Outside dimeter, D	170 mm
Bore diameter, d	80 mm
Pitch diameter, d_p	139.914 mm
Diameter of the rolling element, d_b	26.8 mm
Contact angle, α	12.950 deg
Number of rolling elements, N_b	14

A vibration measurement was performed in axial, horizontal and vertical directions in this objected transmission system. The sensor embedded in each axis was an accelerometer. Spectrum analyzer was applied for data collection of vibration at each direction, i.e. the axial direction (as seen in Figure 5), the horizontal direction (as seen in Figure 6) and the vertical direction (as seen in Figure 7), respectively. Data obtained from the vertical direction was dominant while compared with the other two directions so that the vibration spectrum measured in the vertical direction was used to characterize the health of the machinery. It should be noted that the bearing positions, bearing specification information and rotor speeds and other related information are also required for calculation.


Figure 5. A measurement executed along an axial axis


Figure 6. A measurement executed along a horizontal axis


Figure 7. A measurement executed along a vertical axis

This analysis shall be compliant to the vibration characteristics of SKF typed-bearings to investigate the potential cause of an abnormal vibration embedded in the machinery elements. Investigator can locate an abnormal vibration frequency incurred from which section of the equipment to judge the problems where are from. After the inspection is made, investigator should call for maintenance schedule to repair these units by dismantling them. After this repair is completed, a retest should be performed to confirm its vibration spectrum trend whether it has recovered to the healthy track of the vibration frequency.

RESULTS AND DISCUSSIONS

This study applied FFT spectrum analyzer to analyze the vibration spectrum of paper machinery to effectively help maintenance engineer detect abnormal vibration problems and verify the correctness of the analysis. The analysis procedure is as shown in Figure 8. A measurement schedule was set as two months once per time. This paper machinery is divided as five systems, such as wire session, press rolls, coating, drying cylinders, and reels. Each system has five transmission systems. Each transmission system has five vibration monitoring devices. This paper machinery has a total of 125 vibration monitoring devices to monitor its vibration status.

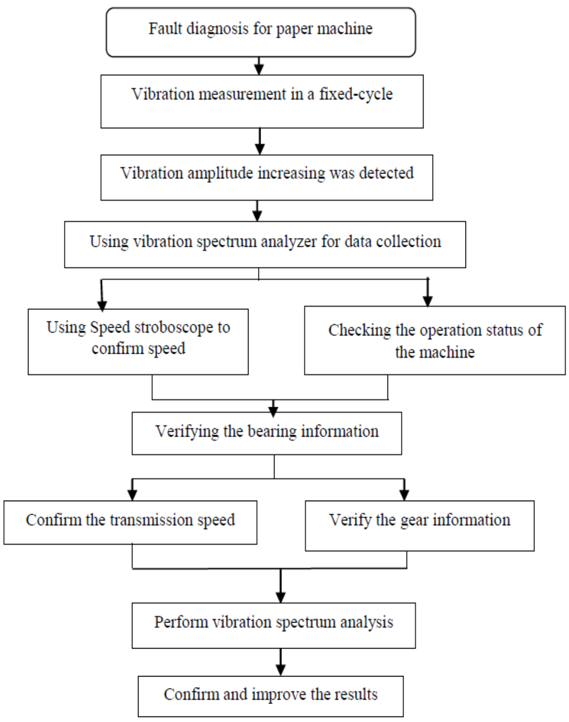


Figure 8. A process for vibration monitoring and analysis

An inspector once pushes the data acquisition button of the spectrum analyzer. Then, a vibration spectrum can be acquired from the objected system by the spectrum analyzer. A reading of value can be acquired in the monitoring equipment. This reading can be defined as a digital overall level of vibration spectrum in a period of time for a monitored system. The value is the result obtained from a vibration spectrum that has been processed by FFT algorithm embedded in the analysis system. However, how to define this vale? First, a frequency interval can be set in the analysis system, such as $F_{min} \leq F \leq F_{max}$, and please refer to Figure 9. Figure 9 shows a vibration spectrum has been digitalized.

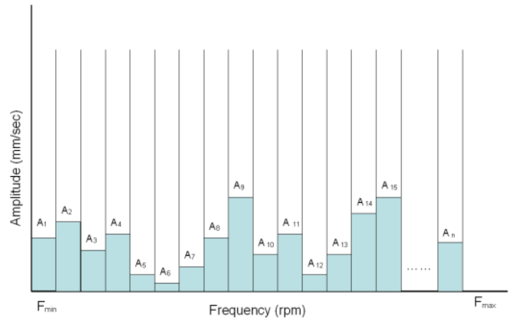


Figure 9. Digital overall level of vibration spectrum in a period of time in one measurement.

If a resolution is set as n, it means that the number of FFT lines of resolution is n, for example, n = 3200. This period of time of vibration signal can be processed further in the analysis system which defines the digital overall level of vibration spectrum, denoted as VT_{RSS}, as the following:

$$VT_{RSS} = \frac{\sqrt{\sum_{i=1}^{n}(A_i)^2}}{\sqrt{N_{bf}}} \tag{6}$$

The subscript, *RSS*, is represented as root sum square level which is the summation of energy in the spectrum from F_{min} to F_{max}; A_i is amplitude of each of the FFT lines; n is number of FFT lines of resolution. Each of A_i is a peak value from zero. N_{bf} is noise bandwidth for window chosen. In this case, N_{bf} is chosen as 1.5 for Hanning window in this analysis system. Thus,

$$VT_{RSS} = 0.8165\sqrt{\sum_{i=1}^{n}(A_i)^2} \tag{7}$$

This reading can be represented as a trend of vibration status in a sampling time for a monitored system in one measurement. Thus, the overall vibration level trend of each system in a period of time can be defined as a set of values of digital overall level of vibration spectrum obtained by taking *n* measurements to the object in the different date which the object is under a normal operation status in this case. Thus, let the set be denoted as B_{vt} where

$$B_{vt} = \{x \mid x \in VT_{RSS}\} \tag{8}$$

Let *n* be 10 in this case. By taking the mean of the elements in the set B_{vt}, a warning value, denoted as w_{vt} here, can be defined as 130% of the mean value as the following:

$$w_{vt} = 1.3 \times \left(\frac{\sum_{j=1}^{10}(VT_{RSS})}{10}\right) \tag{9}$$

In this study, abnormal vibration spectrum was found in the drying cylinders section during a certain monitoring period. One of its transmission systems was located as having potential defects. The transmission system, as shown in Figure 3 and 4, has been found that its overall vibration level trend increased significantly for a regular measurement period on the day as seen in Figure 10. A warning value, w_{vt}, is set as 5 (mm/sec) for the objected transmission system, as shown in Figure 10. The vibration amplitude exceeded 5 and continued getting higher. Then, an analysis of the vibration spectrum is required to locate the potential damage in this section. In order to more accurately identify the source of vibration, the analyst needed to acquire its vibration spectrum from three different axes.

00403-30 main transmission/BV=5=VEL, measurement point x

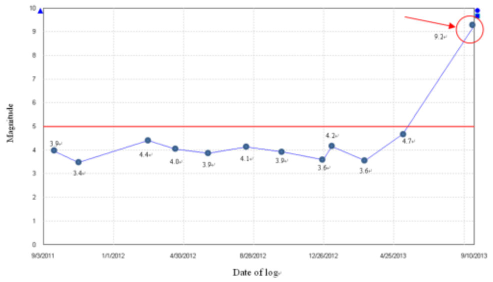


Figure 10. A log of overall vibration level trend of the objected paper machinery (From 03 Sept. 2011 to 10 Sept. 2013).

In Figure 10, a safety value should fall between 0 and 5, but the latest monitoring value has been continuing to run up to 9.2, a value significantly higher than the average value.

Using a spectrum analyzer to measure its vibration frequency of the transmission system and a stroboscope to measure its transmission speed, the results can be uploaded to SKF analysis system. From the analysis, it was compared with the schematics of the overall vibration level trend and found that this vibration spectrum occurred at the fifth measurement point of the system, as seen in Figure 4.

The fifth measurement point is a gear bearing of a dryer in this objected transmission system in the drying cylinders section. Its peripheral gear appears to connect to another gear to drive this system. As the condition had been seen, it needed to confirm which condition to cause such high vibration amplitude. These check-points are the shaft axis, the bearing, the gear and its connecting gear. These possible damages might be from all kinds of factors. From vibration spectrum analysis, it gave defect frequency 4763rpm and its harmonic frequencies such as 9441rpm, 14288rpm, and 19050rpm. A making use of harmonic cursor (SHG vernier cursor) can find out that those frequencies are a multiple of 4763rpm, i.e. a multiplier 2, 3 or 4 to the frequency 4763rpm, as shown in Figure 11. It should be noted that the damaged element had incurred a frequency spectrum with relatively large amplitude. This phenomenon was occurred while the transmission system is running at the speed 84rpm.

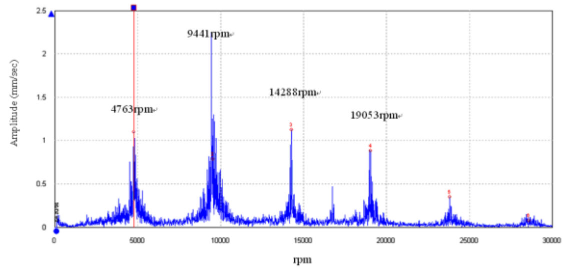


Figure 11. Damaged frequency spectrum of the transmission system was found by using a harmonic waveform cursor.

All of the frequencies with large amplitudes are multiples of the frequency 4763rpm. In order to find out which part of the transmission system caused such as frequency spectrum, all of possible situations should be examined. It can first check the damaged frequency with the bearing. It should be noted that the model number of the bearing is SKF22316C. Figure 12 shows a harmonic cursor of frequency 84rpm (represented by red dots) and a damaged frequency spectrum (represented as blue lines). This damaged device frequency 4763rpm is the base frequency which overlaps with a multiplier of the transmission speed 84rpm, such as multipliers 57, 113, 171, and 228, respectively. Since the ball bearing is freely spinning inside of cage, its rotation can't be synchronous with shaft's rotation. So, the bearing frequency would not overlap with the driving speed. This could judge that the damaged frequency is not caused by the bearing. By using a harmonic cursor, it can find that the defect frequency 4763rpm occurred in the multiple main transmission speed, as seen in Figure 12. Therefore, the evidence excludes the damage possibility of bearing because the frequency of damaged bearing and the frequency of the transmission speed don't overlap. In order to ensure the accuracy of the confirmed analysis, it needs to check the all of possibilities that incurred in the bearing.

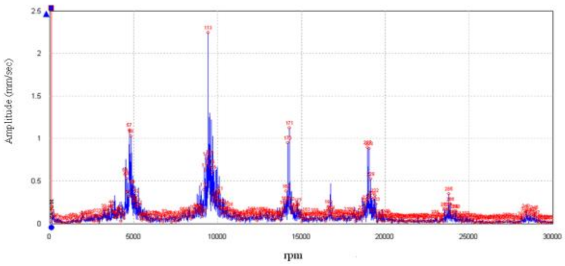


Figure 12. A comparison of the damaged frequency

with the transmission speed frequency.

In Figure 12, red dots were represented as a harmonic cursor of 84rpm. The blue lines are the vibration spectrum of the damage device. The frequency 4763rpm is the base frequency which overlaps with a multiplier of the transmission speed 84rpm, such as multipliers 57, 113, 171, and 228, respectively.

In order to confirm what caused the abnormal vibration, the damage frequency of outer race of bearing can be calculated by using Equation 1 by multiplying a rotation speed, and represented as a green line. Please refer to Figure 13 for more detailed. From the results computed by Equation 1, each green line marks a multiplier of the frequency 477.9rpm for the outer race of a bearing type SKF 22316C. The damage vibration frequency is 4763rpm, as shown a line in blue. It can be seen that each of the correspondence of the green lines and blue lines are not completely consistent. As a result, the damage was not occurred in the outer race of bearing.

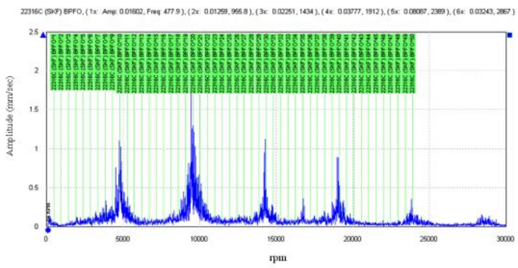


Figure 13. A comparison of damaged frequency with the ball pass frequency of outer race.

In Figure 13, each green line marks a multiplier of the frequency 477.9rpm for the outer race of a bearing type SKF 22316C. The damage vibration frequency is 4763rpm, as shown a line in blue. It can be seen that the green line and blue line are not completely consistent.

The examination of Figure 14 is similar to Figure 13. The damage frequency of inner race of bearing can be calculated by taking Equation 2 by multiplying a rotation speed.

Frequency spectrum of SKF22316C inner race: (frequency multiplier, magnitude, frequency)

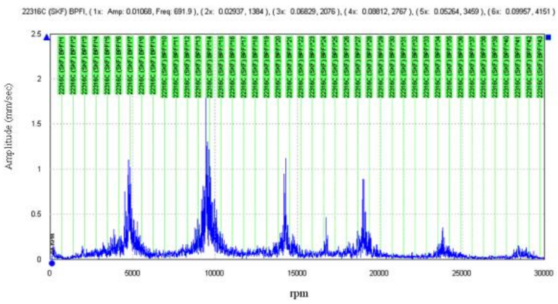


Figure 14. A comparison of the damaged frequency with the ball pass frequency of inner race.

From the results computed by Equation 2, the rotating frequency of its inner race is a multiplier of the frequency 691.9rpm, as seen in Figure 14, where each green line represents a multiple of damage frequency of the inner race of a bearing type SKF 22316C, namely 691.9rpm. The damage vibration frequency is 4763rpm, as shown a line in blue. It can be seen that the green line and blue line are not completely consistent. As a result, the damage was not occurred in the inner race of bearing.Next, the damage frequency of spinning ball of bearing can be calculated by taking Equation 3 by multiplying a rotation speed, and represented as green line. From the results computed by Equation 3, the base frequency is 217.7rpm. As seen in Figure 15, each green line represents a multiple of the damage frequency of the spinning ball. The damage vibration frequency is 4763rpm, as shown a line in blue. It can be seen that the green line and blue line are not completely consistent. As a result, the damage was not occurred in the spinning ball of bearing.

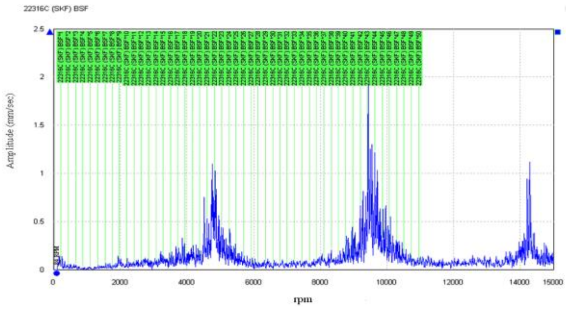


Figure 15. A comparison of the damaged frequency with the ball spin frequency.

Further, a fundamental train frequency (FTF) can be calculated by using Equation 4 if the cage of REB has defects. The computation showed that the damaged cage frequency is a multiplier of the frequency 34.43rpm. As seen in Figure 16, the green lines represented a rotating frequency spectrum of a retainer which is a number of the multiple of the frequency 34.43rpm. The damage vibration frequency is 4763rpm, as shown a line in blue. Since the base damage frequency is 4763rpm which is much higher than frequency 34.3rpm. The two frequencies are totally out of position. Therefore, the damage is not from the retainer of the bearing.

22316C(SKF) fundamental train frequency of cage : (frequency multiplier, magnitude, frequency)

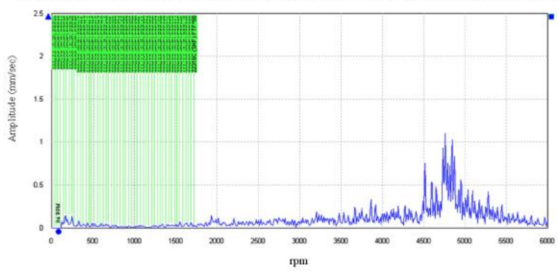


Figure 16. A comparison of the damaged frequency

with the fundamental train frequency.

From the study, it can be known that a general transmission system of paper machinery often leads to some abnormal state after a period of operation that can be classified as the following:

1. Out of alignment: This is going to happen when the vibration frequency is a set of integer multipliers, such as {1×, 2×, 3×…..}, of the transmission speed，where a multiplier b is denoted as b×, for example. It is worthy to denote that the axial displacement is usually longer than other directions when the frequency multiplier is greater than 1 in this condition.
2. A base screw or a screw fastened to the bearing is loosening. This is going to happen when the vibration frequency is a set of integer multipliers, {1×, 2×, 3×, 4×, 5×, 6×, 7×…}, of the transmission speed.
3. A dynamic friction occurs between a rotor and a bearing base. This situation will produce a vibration spectrum as a set of multipliers, such as {0.5×, 1.0×, 1.5×, 2.0×, 2.5×….}, of the transmission speed,.
4. The contact between the inner hole and the axis of the bearing is loosening. This situation will produce a vibration spectrum which is a multiplier of transmission speed, such as {3×, 6×, 9×, 12×….}.
5. The contact between the outer hole and the axis of the bearing is loosening. A vibration spectrum, a multiplier which is belonging to the set {4×, 8×, 12×, 16×} of the transmission speed.
6. Some damage occurs in the coupling. In this case, a vibration spectrum is presented as an integer multiplier, such as {1×, 2×, 3×, 4×, 5×, 6×…}, of the transmission speed. Sometime, it could generate a vibration spectrum which is one times of transmission speed in the horizontal direction of a measurement.
7. The bearing's clearance is too large. It could generate a vibration spectrum which is a multiplier of the transmission speed which is a number belonging to either of the sets, {(3×, 6×, 9×, 12×,…); (4×, 8×, 12×,….)}.

Those problems can be carefully investigated whether a multiple vibration spectrum of transmission revolution speed 84rpm is occurred. The frequency spectrum of the damaged section is not in conformity with the spectrum's feature from item 1 to 7. This is because the damaged equipment possessed a vibration frequency 4763rpm spectrum. However, the condition requires the base vibration frequency from item 1 to 7 is the multiplier of a vibration frequency as the transmission speed 84rpm. These possible vibration frequencies don't overlap with each other. After a step-by-step investigation, the above seven conditions were removed from the list of potential defects.

In order to explain this, Figure 17 shows a typical damage vibration frequency spectrum of bearings from another example. As seen in Figure 17, the green line is for a damage frequency and the blue line is the vibration frequency from some of test equipment. It can see that two spectra are completely consistent in the figure. There are not the cases as seen in the Figures 13-16. So the possibility of damage in bearing can be excluded. In general, if a bearing is in damage, these green lines should coincide with blue lines each other. However, this situation did not happen in Figure 13 to 16. In this case, the base vibration frequency (as shown lines in blue) should be a multiplier of frequency 4963rpm and coincide with a bearing damage frequency (as shown lines in green from Figure 13 to 16), but the requirement did not meet as shown in Figure 17. That's the reason the possibility of bearing damage can be excluded definitely.

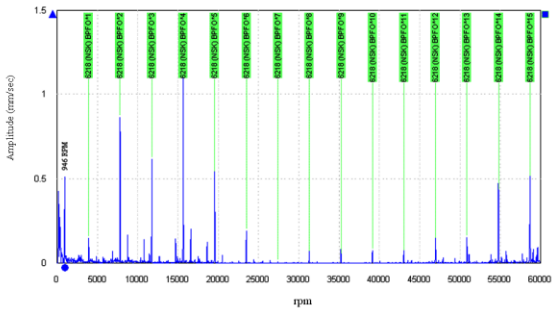


Figure 17. An example shows a frequency spectrum chart for a typical bearing during a damaged condition.

This damage frequency 4763rpm is the base frequency which overlaps with a multiplier of the transmission speed 84rpm, such as multipliers 57, 113, 171, and 228, respectively. Therefore, the defect problem could be gear engagement. Next, the status of gears should be investigated. Two gear reducers were embedded in this transmission system of the objected paper machinery. One is in the power transmission system, and another one is in the dryer. After a calculation was performed in this application, the engagement frequency of the power transmission gear reducer is 16734rpm. Another gear reducer located in the dryer had a gear engagement frequency 4763rpm. This frequency spectrum in the dryer was consistent with the waveform which induced the vibration, as seen in Figure 18.

For more information, please refer to Figure 18, the frequency 4763rpm, showed as a red line in the graph, was the gear meshing frequency detected at the fifth point in the objected section. Through the calculation of gear meshing frequency by using Equation 5, it can confirm the frequency 4763rpm is a base frequency of the gear meshing. From this, it can conclude that the damage is from gear engagement problem.

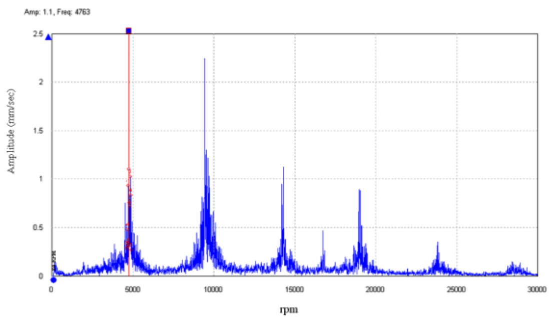


Figure 18. A comparison of the gear meshing frequency with the damaged frequency.

The diagnosis concluded that this gear reducer embedded in the dryer induced the total vibration level increasing sharply. The result of this fault diagnosis initiated a maintenance plan to repair this isolated unit. The maintenance engineer dismantled the gear system and found the contact surface existed a wearing and cracking condition, as shown in Figure 19. After the replacement was completed, the equipment was restarted to operate for a retest. It was found that the current total vibration level feel into below the average level of the total vibration frequency. Through the case analysis, it demonstrated that vibration spectrum analysis can be applied in paper machinery. Also, it can conclude that vibration monitoring can be applied for a long period to detect and isolate impending failure incurring in machinery.

Figure 19. Wearing and corrosion were found on the gear surface.

CONCLUSIONS

Paper production line is a combination of large scale machineries. Papermaking process requires a long-time and continuous process without any interrupt. In order to ensure the production process without any non-scheduled shutdown, a practical method to resolve a possibility of unexpected mechanical failures that causes a disaster shut-down is necessary. In this study, it applied vibration technology to paper machinery to effectively elevate the feasibility and reliability of paper production by examining its vibration frequency spectrum for its fault diagnosis and isolation problem. The study made use of regular vibration measurement and management technique to record the trend of vibration spectrum of paper machinery. This tracked its vibration condition and conducted a vibration spectrum monitoring for a long period of time to detect an abnormal vibration spectrum.

For further analyzing the vibration spectrum, it investigated the correspondence of a potential failure of mechanical component to a vibration spectrum. The study classified the vibration spectra of paper machinery for more industrial applications. The study successfully practiced vibration spectrum technique as fault diagnosis and isolation for paper machinery. This demonstration greatly helps paper manufactures in resolving the problem of fault diagnosis and isolation for their production facilities. This would also reduce potential financial loss for paper-manufacturing during their production process.

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運用振動監測法對製紙機械進行故障檢測與隔離

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摘 要

在生產過程中如何防止製紙機械發生意外故障所產生的損失乃是重要的課題。因此製紙機械的故障檢測和隔離成為一項重要技術手段。本研究應用振動監測技術來檢測和隔離製紙機械的傳動系統異常振動。利用振動頻譜分析儀對長週期運轉的機械設備的整體振動水準趨勢進行分析。這種被記錄下來的振動頻譜能夠經由振動頻譜分析，以調查機器是否有產生異常振動的情事。在本案例研究中，對製紙機械的傳動系統進行振動監測和分析，並將振動頻譜與滾動體軸承及傳動齒輪的對應關係進行了分類。本研究乃是在某企業工廠實際運轉的車間中進行一段時間來瞭解製紙機械可能發生的故障情形。研究顯示，經由每一個異常振動頻譜可對應一個機械結構獨特的損壞發生狀況。本研究詳細分析了製紙機械的傳動系統可能出現的故障，所得到的結果可以提供工程師找到機器的故障的原因，以減少工業紙製造商的經濟損失。