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〈Original Paper〉

Application of Time-Frequency Analysis as a Tool for Noise Quality Control of DC Motor Systems

DC 모터계의 소음 품질관리를 위한 시간-주파수 분석의 적용

Sang-Gyu Lim* and Chang-Hwan Choi*
임 상 규 · 최 창 환

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ABSTRACT

In the quality assurance check process of DC motor systems, even though the overall sound pressure level is acceptable, there is an incident that subjective evaluation leads to failure in product quality due to annoying noise. This kind of problem may be originated from the manufacturing or assembly process. In this paper, the transient spectral analysis, or the time-frequency analysis is applied to the noise quality problem. For the case study, the cause of annoying noise in the wind shield wiper motor is experimentally analyzed in detail. It is concluded that the defect in the shaft causes the impact noise which is not detectable by steady spectral analysis. Also demonstrated is how the time-frequency analysis is effectively applied to the annoying noise identification of the rotor-gear system.

요 약

직류 모터의 생산 공정품질 확인 작업에 있어서 전체 소음레벨이 합격점에 이른다 할지라도 관능평가시의 이음으로 인해 불량판정을 받게되는 경우가 있다. 이런 종류의 문제는 가공 또는 조립 공정상에서 발생될수 있는데 본 논문에서는 과도기적 스펙트럴 분석 혹은 시간-주파수 분석 기법을 소음품질 문제에 적용해 보았다. Case Study로써 윈드쉴드 와이퍼 모터의 이음 발생원이 상세 분석되었으며, 결과적으로 정상적인 주파수 분석에서 발견되지 않았던 아마추어 축의 불량이 충격소음을 일으킨 것으로 밝혀졌다. 이를 통해 회전체-기어 시스템의 이음 원인규명을 위한 시간-주파수 분석 기법의 효과적 활용이 잘 나타났다.

1. Introduction

DC motor system is one of the widely used components in an automobile such as wind shield wipers, door actuators and seat actuators, etc. For noise quality control of motors, the inspection of the overall sound pressure level at a certain condition and the vibration level with octave filter is adopted. Unfortunately, even though the

* Members, Samsung Electro-Mechanics Co.

measurement check is passed, there is an incident that it has quality problem in terms of annoying noise which may leads to the customer complaint in vehicle. Thus, along with these objective measurements check, the subjective evaluations are also carried out in the assembly line by the experienced inspector to check if there is an abnormal sound. This kind of abnormal sound may be originated from the manufacturing and assembly process, since the overall sound pressure level and vibration characteristics are fixed in the design process and verified during test and development process. In the quality control point of view, in order to secure the quality assurance, it is necessary to find out the cause of the annoying noise and to feed back to the manufacturing and assembly process. By and large, the annoying noise in the rotating machinery has to do with the vibration due to the impact between the machine elements such as gears and bearings. However, this kind of impact noise is not clearly visible by the spectral analysis of the steady signal. This leads to the necessity of the temporal localization of signal's components. The theoretical development of the time-frequency analysis has been progressed in the various fields. Recently, its application area is extended to the noise and vibration analysis in such areas as condition monitoring, fault diagnosis, and impact noise and vibration analysis. Among the many time-frequency analysis techniques, the Wavelet transform and the Wigner-Ville transform are wall known and accessible in the commercial software. In this paper, as a case study for the quality control of DC motor systems, an annoying noise from the wind shield wiper motor system is analyzed experimentally.

2. Preliminary Investigations

2.1 Description of Wind Shield Wiper Motor

The motor system used in this study is the permanent direct current type for wind shield wiper motor system applied to passenger car, Fig. 1. It is mainly composed of rotor system with

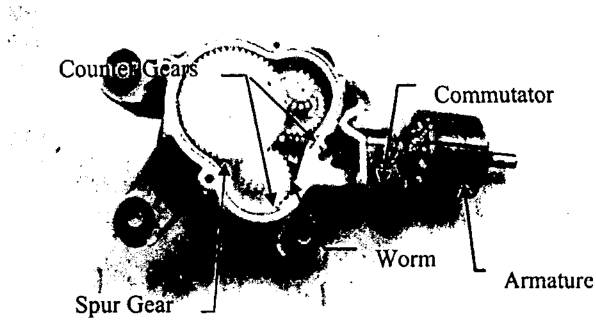


Fig. 1 Structure of the wiper motor system

brushes and commutator, and reduction gear system with a worm shaft, a spur gear and counter gears. The fundamental noise and vibration characteristics are due to the contact between the brushes and commutator, and the gear meshing. The intensity of these characteristics may be determined by the mechanical properties of the system such as unbalance, misalignment, and by the material properties of the contact in the commutators and bearings[1,2].

2.2 Preliminary Noise Test and Experimental Set-up

In order to locate the possible cause of the annoying noise problem, as a starting point, the subjective evaluations have been performed. The evaluation was proceeded step by step from the assembled motor system to the disassembled by removing elements. At first, the cover for gear reduction part was removed, and the annoying noise was there. Next, the spur gear was taken out, then the same annoying noise was remained. Finally, when the counter gears were removed, the annoying noise has disappeared. So, it is speculated that there may be defects in the meshing between the counter gears and the shaft worm gear.

The test set-up is shown in Fig. 2. The accelerometer is placed in the cage, and the rotational speed of the counter gear is measured through tachometer. For the vibration measurements, the rpm of counter gear is fixed at 120 rpm by setting the DC voltage of the power supply but, in actual test, about plus and minus 10 rpm range of fluctuations have been observed. The time signal of the vibration data are measured through synchronous averaging for the purpose of data enhancement. The number of synchronous average and the data sampling frequency used in the measurement were 10 and 16 kHz, respectively. Also the types of charge amp, accelerometer and tachometer were B&K 2635, B&K 4393 and Keyence fiberoptic sensor(FS-M1), respectively.

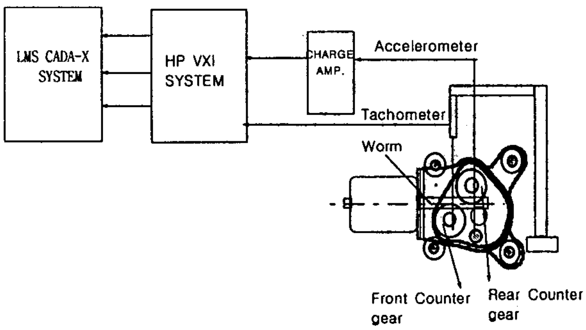


Fig. 2 Test Set-up for a wiper motor measurement

2.3 Time Signal and Spectral Characteristics

Fig. 3 shows the time data for healthy(or normal) and defect motor system for one period of 0.5 second. The reduction ratio between the shaft worm and the counter gear is 33/2. As can be seen in the time data of the normal motor system, there are 16 harmonic fluctuations in one revolution of the counter gear, resulted from the gear meshing between the counter and worm

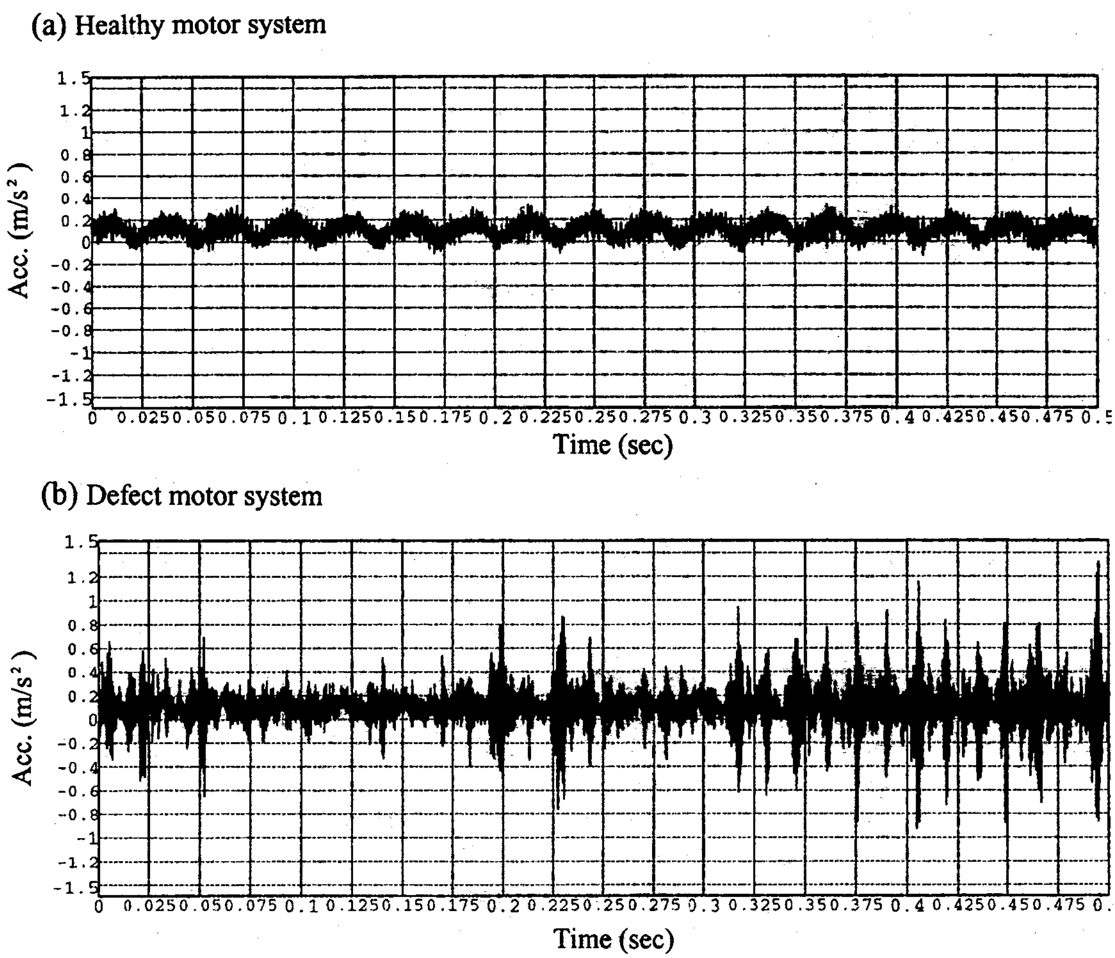


Fig. 3 Time signal for one period of the counter gear of the (a) Healthy motor system (b) Defect motor system(generating annoying noise)

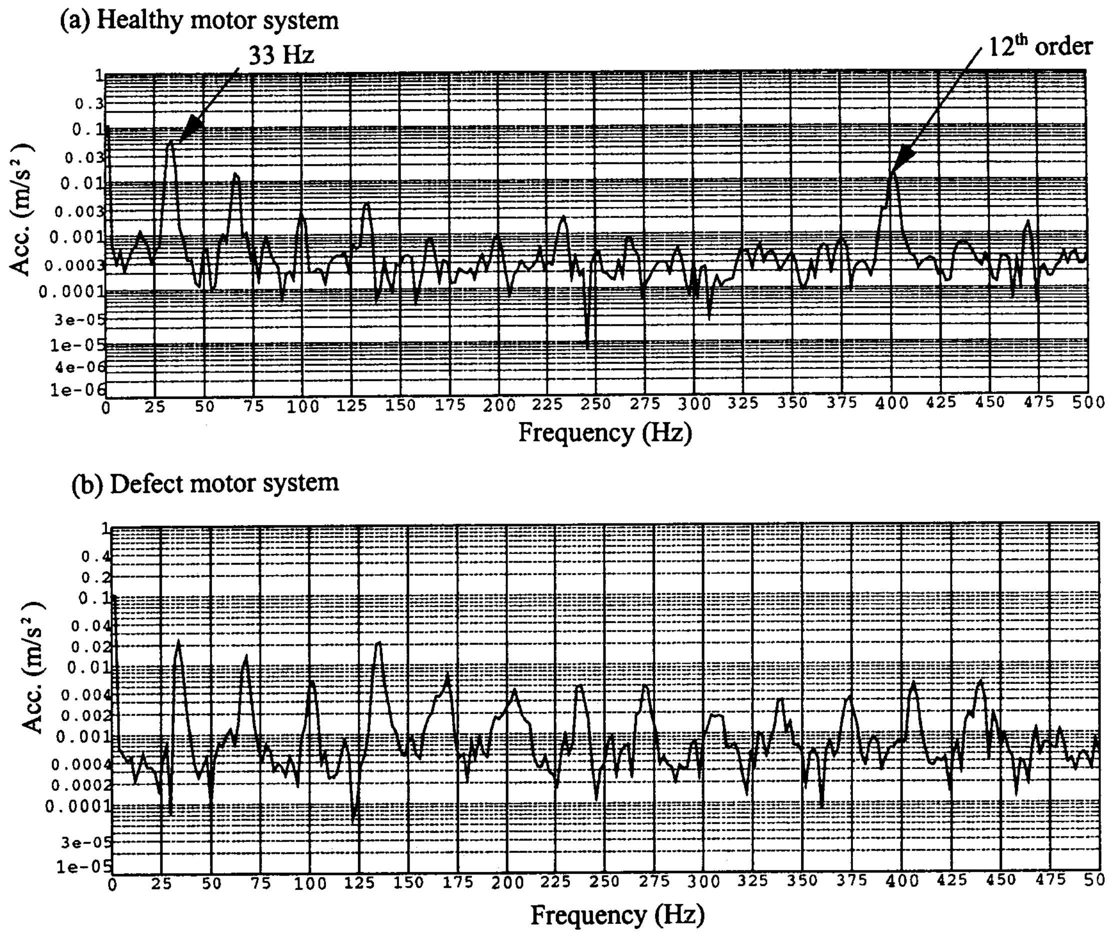


Fig. 4 Frequency spectrum (0~500 Hz) of vibration signal of (a) Healthy motor system (b) Defect motor system(The fundamental worm shaft frequency at 33Hz and its harmonics are shown. No monotonic frequency of defect motor system is visible)

gears. On the other hand, the time signal of the defect motor system contains strong non-stationary high frequency components as well as the regular harmonics.

The spectral signature of the time signal is shown in Fig. 4. As can be seen in Fig. 4(a), since the counter gear rotational frequency is 2 Hz(120 rpm) and the gear reduction ratio is 33/2, the shaft frequency is 33 Hz. The harmonics of this shaft frequency is visible and the 12th order (about 400 Hz) of this frequency is noticeable since there are 12 slots in the commutator. Comparing with the spectrum of the defect motor system in Fig. 4(b), even though the harmonics of the fundamental meshing frequency is more clearly shown, any particular attention of the monotonic frequency of the defect motor system is not payable. In Fig. 5, the spectral distributions in the range up to 5 kHz are presented, in which any particular frequency component is not noticeable except that the overall vibration level of the defect motor system is higher, in other word, the energy level is shifted upwards in the broad range (750~2500 Hz).

2.4 Kurtosis Analysis

Kurtosis is one of the statistical properties which represents the shape of the measured data distribution. It shows the peakedness of the data. According to the time data, it is expected that Kurtosis value of the defect motor system is higher than that of the healthy one. The

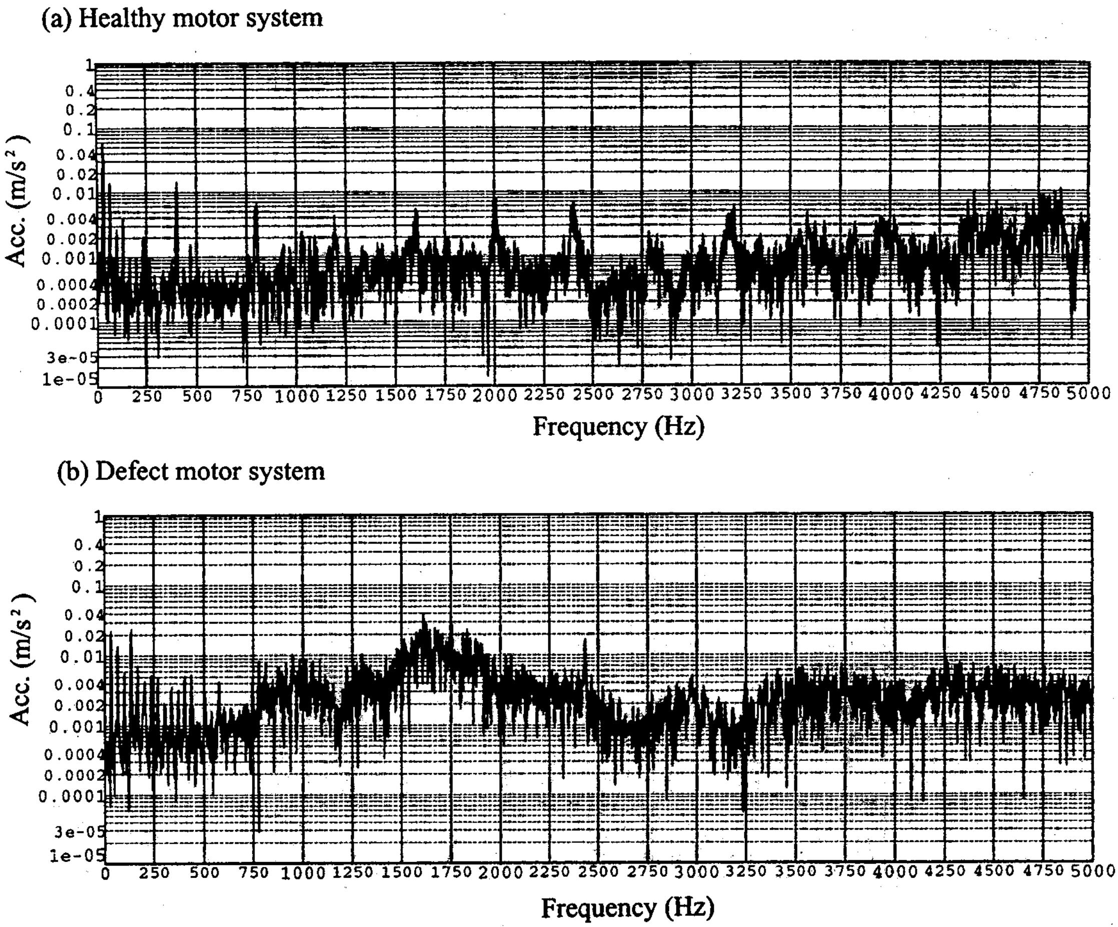


Fig. 5 Frequency Spectrum (0~5000 Hz) of vibration signal of the (a) Healthy motor (b) Defect motor (The energy level of the defect motor system increases in the broad range)

calculation was implemented using the commercial software, LMS CADA-X, and it is zero for Gaussian distribution.

Seeing the results in Fig. 6, Kurtosis value of a healthy motor system is distributed mostly below 1, while that of the defect one is as high as 4.5. This represents the fact that the defect one is very peaked even though the results of the stationary spectral analysis hardly show those differences much.

3. Time-Frequency Analysis (TFA)

The preliminary investigations reveal that the cause of the defect is not apparent by the stationary spectral analysis. Even the order tracking results(not presented here) do not give the detailed information about the cause of the abnormal vibration which leads to the annoying noise. This fact leads to the speculation that the annoying noise is due to the impact noise between the counter gear and shaft worm gear, and the detailed non-stationary analysis of the vibration signal in Fig. 3 is performed.

TFA is a tool for investigating the transient time signal in the time domain and frequency domain simultaneously. By introducing the special window function, the inherent problem with time resolution and frequency resolution is overcome. The main interests in this study is focused on the time evolution of spectral property of the meshing during one revolution of counter gear.

The detailed mathematical derivations and implementation techniques are not elaborated in

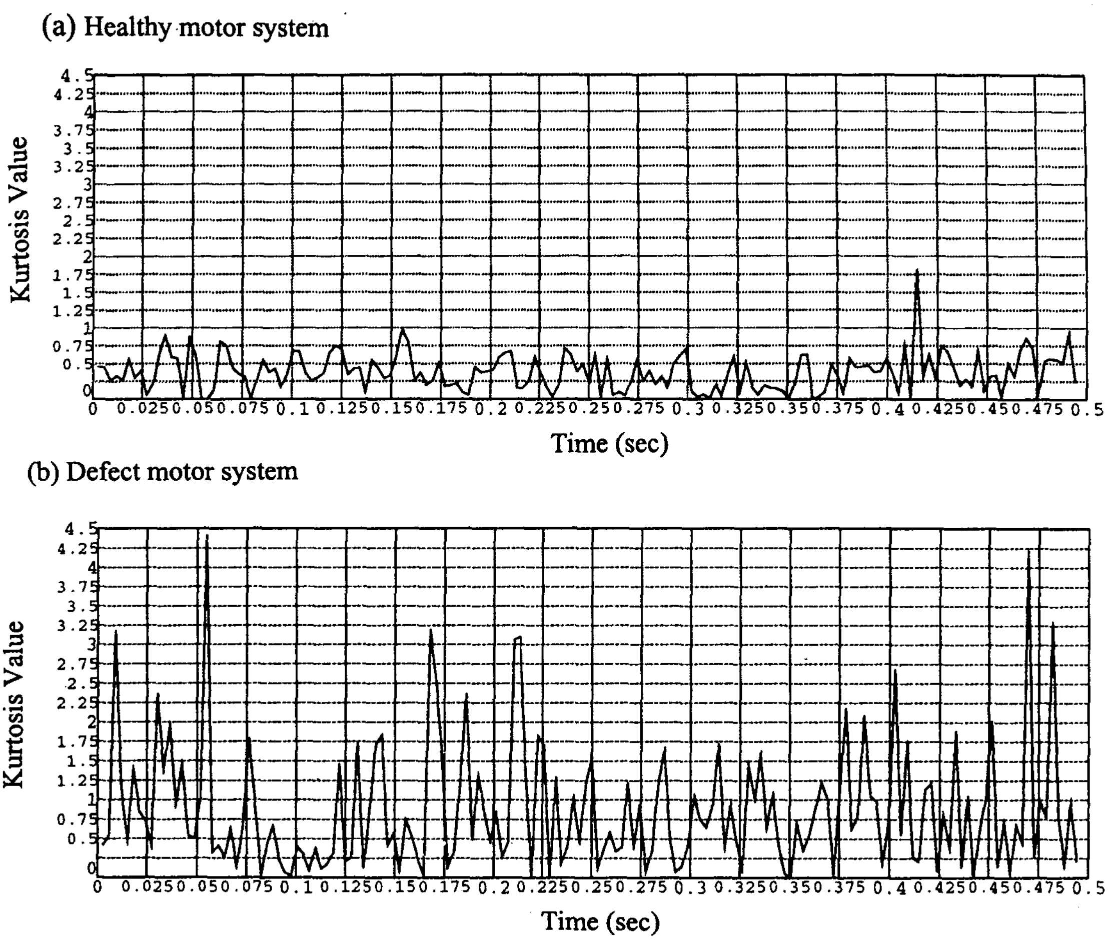


Fig. 6 Kurtosis value Distributions of (a) Healthy motor system (b) Defect motor system (generating annoying noise) (Kurtosis values represent the peakedness in the response distributions)

here. Those can be found in the references(3, 4, 5). In this paper, the TFA processing is carried out utilizing a commercial software, LMS CADA-X. Among the various analysis options, the well known Wavelet transform is used with Morlet wavelet as a transform function with 1/12 octave analysis.

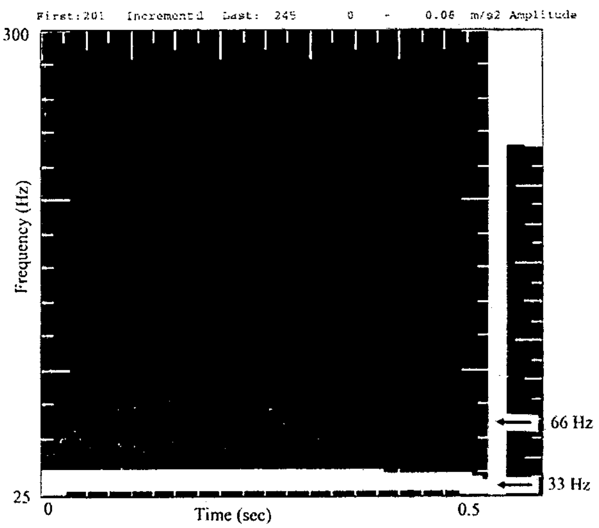
4. Results and Discussion

Fig. 7 shows the result of the TFA of the vibration data for healthy(7(a)) and defect(7(b)) motor system. In Fig.7(a), there is a strong peak at 33 Hz for entire period, which is the rotational frequency of the shaft, and are some very weak impulses near its second harmonic, 66 Hz, sporadically. However, in Fig.7(b), the strongest peaks are present near 132 Hz, in which 16 clear impulses are present.

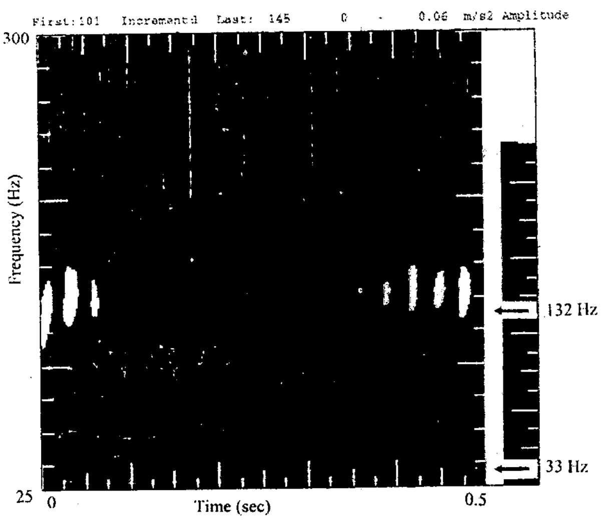
The interpretation on the TFA results of the defect motor is as follows: Since there are 16 revolutions of the shaft during one period of the counter gear and the shaft being abnormal, 16 impulses are present where the spectrum is stretched in the frequency axis. Also, because there are two gear teeth meshing for two counter gears, the 4th order(132 Hz) of shaft frequency is represented by the impulse frequency. Another attention may be paid to the fact that a half of the 16 impulses are relatively stronger than the others. This is because the rear counter gear is more susceptible to the shaft-bent induced impulse. These interpretations have been verified by looking into the worm shaft motion with very slow shaft rotational speed after removing the counter gears.

That is, lateral displacements of the worm shaft in rear counter gear position are greater than those in front. On the other hand, the shaft motion of the healthy motor system does not show any bent-induced fluctuations.

In the quality control point of view, the maximum vibration amplitude of the defect motor system is below its inspection limit, and the defect can be detectable only by the subjective evaluation. Furthermore, the remedy for this problem can not be clearly determined by the steady spectral analysis. After removing this defect in the assembly line, the annoying noise problem has been corrected.



(a) Healthy motor system



(b) Defect motor system

Fig. 7 (a) Time-Frequency (Wavelet Transform) Analysis of the vibration signal for Healthy motor system, (b) Time-Frequency(Wavelet Transform) Analysis of the vibration signal for Defect motor system. (Defect motor system shows strong impulses at 132 Hz that is the fourth harmonic of the worm shaft meshing frequency, which represents the abnormal contacts between the shaft and the counter gears)

5. Conclusion

As the NVH refinement of the vehicle is getting more attention, the annoying noise originated from the component level should be removed as much as possible. One of the potential annoying noise in vehicle is DC motor system applications such as wind shield wipers. Even though the quality assurance check is executed in the final stage of the assembly line, the annoying noise can not be fully detected by conventional FFT measurement. Furthermore, the cause of abnormal noise originated from the impact vibration can hardly be analyzed by stationary signal processing.

The time-frequency analysis technique is applied to find the cause of the annoying noise in the DC motor systems for the automobile applications, in which the rotor and gear reduction mechanism are involved. The time evolution of the spectral data reveals the detailed impact phenomena caused by the gear meshing defects and annoying noise generation mechanism.

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