Noise Analysis of Truck Crane Drive Axle by Using Continuous Wavelet Transform

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Abstract: To identify the noise sources of truck crane drive axle, noise signal was analysed by improved continuous wavelet transform (ICWT).The results indicate that the noise of the drive axle is directly caused by its surface radiation, which is due to the various dynamic stresses produced by gear meshing. Drive axle's noise energy mainly distributes in the gear meshing frequency or its octave, and the main resources of excitation and noise is the gear meshing. The results of the non-stationary noise signal transformed by ICWT can properly show not only their frequency characteristics, but also their time characteristics. ICWT is more appropriated for time-frequency analysis.

Introduction

As a primary component of vehicle power train, drive axle becomes one of the main parts which affect on the vehicle life and running safety. Because of the complicated structure and the influence of unbalance forces such as torsional vibration, bearing deformation and ground interference, drive axle becomes one of the main vibration and noise sources of vehicle power train [1]. There are many factors like gear meshing principle, materials, heat treatment, machining process and assembly precision which affect the vibration and noise and make the mechanism research and reduction difficult. The meshing impact of spiral bevel, planetary, cylindrical gear pair and bearing rolling impact in main reducer are transmitted to the axle housing through the bearing outer ring, and then the noise is produced. Especially gear face machining of main reducer is difficult, and tooth surface deformation caused by the assembly error and load affect the noise directly. Coupling vibration occurs in the working process of the drive axle system and the vibration pattern is very complicated. The dynamic characteristic of the vibration is largely affected by the time-varying stiffness, nonlinear contact impact, manufacturing and assembly errors, and intersecting of all the factors makes it difficult to grasp the central issue[2][3]. Noise signal is generally non-stationary, and FFT is no longer fit for its analysis[4]. Time-frequency methods are gradually applied in non-stationary signal analysis, in which wavelet analysis is the most efficient. Wavelet analysis has been widely applied in vibration and noise processing and the recognition results can meet the needs of practical engineering better [5].

The noise signal of the drive axle was analysed using improved continuous wavelet transform (ICWT) [5] in this paper, and the main noise source was recognized. The research can provide reliable basis for vibration and noise reduction of the drive axle.

Basic theory of wavelet analysis

Set signal $f(t) \in L^2(R)$, and $\phi(t)$ is the basic or mother wavelet, then the continuous wavelet transform of $f(t)$ can be defined as

$$T_f(a,\tau) = \left\langle f(t), \phi_{a,\tau}(t) \right\rangle = \frac{1}{\sqrt{a}} \int_R f(t) \overline{\phi(\frac{t-\tau}{a})} dt \qquad (1)$$

In the equation, a 、 τ are scale parameter and translation parameter, $\langle f(t), \phi_{a,\tau}(t) \rangle$ is the inner product of $f(t)$ and $\phi_{a,\tau}(t)$, and $\phi_{a,\tau}(t)$ is the wavelet basis function after translation and scale transform $\phi_{a,\tau}(t) = \frac{1}{\sqrt{a}}\phi(\frac{t-\tau}{a})$ (2)

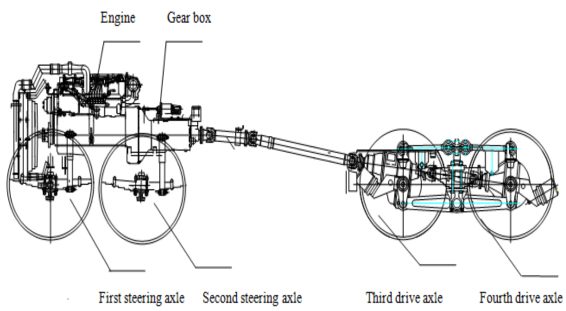

Fig.1 Drive system of truck crane

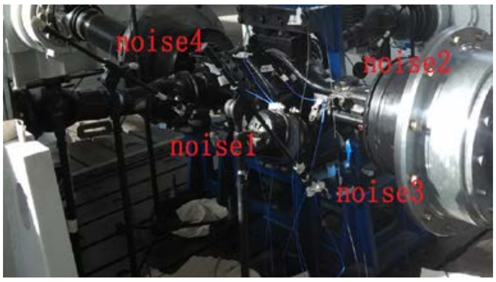

Fig.2 Test point arrangement

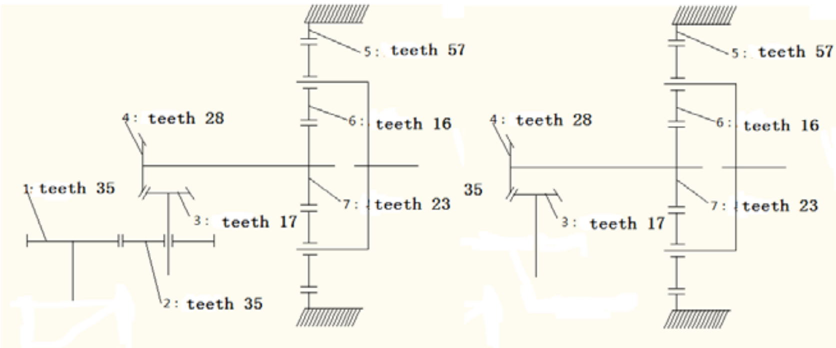

Fig.3 Steyr drive axle

The wavelet transform coefficients of the function $f(t)$ at scale a and translation point τ actually show that when the frequency component size in the window whose center frequency is ω_0 / a and bent width is $\Delta\omega / a$ at position τ and time quantum $a\Delta t$ changes, the corresponding window center frequency ω_0 / a and window width $\Delta\omega / a$ change too. Wavelet transform is generated and developed on the basis of the introduction of time-frequency localization to window Fourier transform. Wavelet transform has higher time resolution at high frequency and higher frequency resolution at low frequency. The zoom feature of wavelet transform makes it very fit for non-stationary signal analysis and different needs.

Wavelet coefficients will decrease along with the increase of the frequency. To identify the various components in noise signal more reasonably and accurately using continuous wavelet transform, each frequency component of the wavelet transform result must be multiplied by correction factors to compensate the amplitude attenuation and show the correct amplitude characteristic of the signal [4].

Noise test of the drive axle

The noise test of truck crane according to GB1495-2002 shows that the engine is the first noise source but the noise of the drive axle will increase along with the increase of the speed. When the speed is big enough, the influence of the drive axle to the vehicle is as important as the engine. The arrangement of the power train is shown in Fig. 1. The first and second axles are steering axles and the third and fourth axles are drive axles. To identify the noise source of the drive axle itself, a bench test was done. As shown in Fig.2, two test points were arranged before and after the main reducer. Other two test points were arranged around the two wheel axle housings, 300mm far away from the axle housing. The drive axles are typical Steyr tandem axles, and their structure and the number of teeth are illustrated in Fig. 3.

Noise analysis of the drive axle

The bench test was done at the input speed according to the vehicle speed requirement in GB1495-2002. The test data at 1150rpm(the vehicle speed 60km/h) was analyzed in this paper. The meshing frequency of each gear pair was listed in Tab.1. Fig. 4 to Fig. 9 showed the A-weighed original signals, frequency spectrums and wavelet transform spectrums of the noise of the third and the fourth axles. According to Fig. 5 and Fig. 8, Tab. 2 listed the frequencies and sound pressure levels in the top five.

Tab.1 Gears meshing frequency of drive axle at 1150rpm

octave / Meshing frequency(Hz)	1	2	3	5	7
The first and second gears	670.83	1341.67	2012.49		
The third and fourth gears	325.83	651.67	977.49	1629.15	
The fifth, sixth and seventh gears	190.70	381.40	572.10	953.50	1334.9

Tab.2 Sound pressure level and frequency of drive axle noise

The third axle	**Sound pressure level （dBA）**	92.24	89.7	87.06	85.73	82.04
	Frequency(Hz)	670.9	996.7	651.8	1342	325.8
The fourth axle	**Sound pressure level （dBA）**	86.68	85.99	80.89	80.75	79.78
	Frequency(Hz)	325.8	568.8	1338	1629	977.5

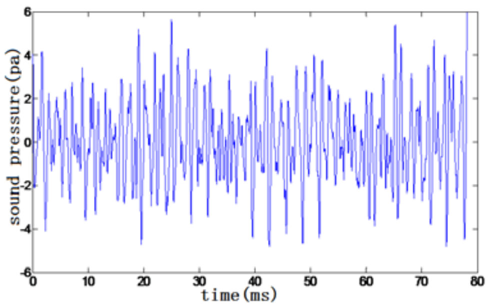

Fig.4 Noise signal of the third drive axle

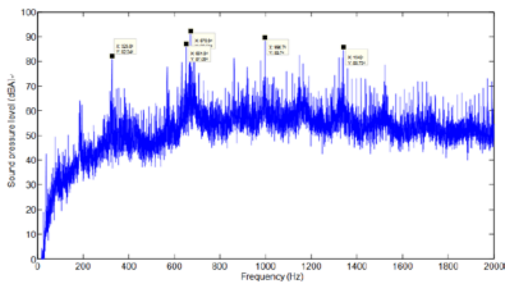
Fig.5 A-weighted sound pressure level frequency spectrum of the third drive axle

From Tab.1 and Tab.2 we can see that for the third axle, the sound pressure level of the meshing frequency of the first gear pair (the first and second gears) is the strongest, the compositive meshing frequency of the first gear pair (the first and second gears) and the second gear pair (the third and fourth gears) comes next, followed by the double-frequency of the second gear pair, end with the doubled frequency of the first gear pair and the meshing frequency of the second gear pair. From the tables we can also see that for the fourth axle, the sound pressure level of the meshing frequency of the first gear pair (the third and fourth gears) is the strongest, followed by the triple-frequency and septuple-frequency of the second gear pair(the fifth, sixth and seventh gears), ended with triple-frequency and quintuple-frequency of the first gear pair.

From Fig.6 and Fig. 9 we can see that the energy of the third axle is mainly concentrated around 600-800Hz, followed by 900-1300Hz, ended with 300Hz, and the energy of the fourth axle is mainly concentrated around 300Hz, followed by 1300-1600Hz, ended with 1000Hz. The energy of the third axle is obviously stronger than that of the fourth axle. The meshing frequency of the first gear pair (the first and second gears) of the third axle and the double-frequency of the second pair (the third and fourth gears) are approximate, indicating the existence of the resonance of the meshing frequency or the double-frequency. The ICWT result shows stationary time intervals between bright fringes, and the intervals of the main reducer are smaller but these of the wheel gears are bigger. The phenomenon indicates that rattling is produced in the gears meshing process and lead to gear howling. There are no obvious continuous bright fringes, indicating that the noise caused by the nature frequency vibration is not the primary noise source.

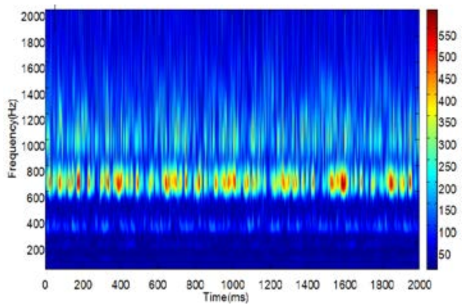

Fig.6 A-weighted sound pressure level wavelet transform of the third drive axle

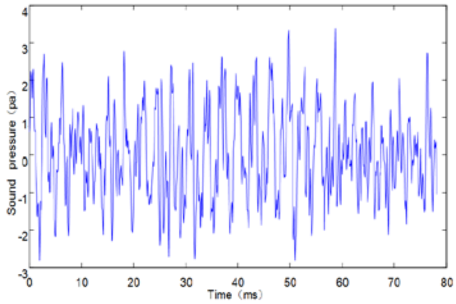

Fig.7 Noise signal of the fourth drive axle

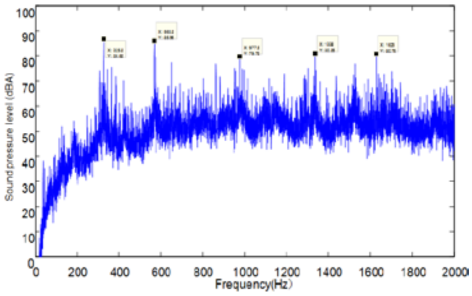

Fig.8 A-weighted sound pressure level frequency spectrum of the fourth drive axle

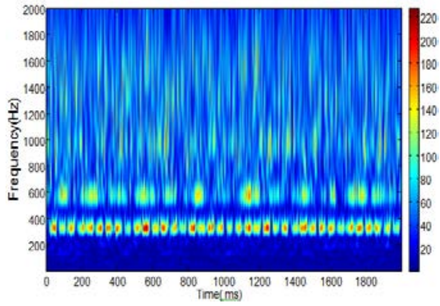

Fig.9 A-weighted sound pressure level wavelet transform of the fourth drive axle

Conclusion

(1) The noise of the drive axle is directly caused by its surface radiation, which is due to the various dynamic stresses produced by gear meshing. Drive axle's noise energy mainly distributes in the gear meshing frequency or its octave, and the main resources of excitation and noise is the gear meshing.

(2)For the third axle, the meshing frequency of the first gear pair (the first and second gears) and the double-frequency of the second gear pair (the third and the fourth gears) are approximate, indicating the existence of the resonance of the meshing frequency or the double-frequency.

(3)The ICWT result of the non-stationary drive axle noise signal can not only indicate the frequency characteristic (the meshing frequency) but also the time characteristic (gear whine). It also indicates the applicability of ICWT in signal analysis with evitable time-frequency characteristic.

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