Analysis of electric vehicle extended range misalignment based on rigid-flexible dynamics

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Abstract. The safety of the extended range electric vehicle is seriously affected by the misalignment fault. Therefore, this paper analyzed the electric vehicle extended range misalignment based on rigid-flexible dynamics. Through comprehensively applied the hybrid modeling of rigid-flexible and the method of fault diagnosis of machinery and equipment comprehensively, it established a extender hybrid rigid flexible mechanical model by means of the software ADAMS and ANSYS. By setting the relevant parameters to simulate the misalignment of shafting, the failure phenomenon, the spectrum analysis and the evolution rules were analyzed. It concluded that 0.5th and 1 harmonics are considered as the characteristic parameters of misalignment diagnostics for electric vehicle extended range.

1. Introduction
Owing to the driving range of Electric Vehicles, the extended range plays an important role in the electric vehicles development. At this stage, It has been recognized as important electric vehicle products by many car companies from the prospect of the markets advance[1,2]. However, because of high degree of electrification and continuous improvement of the power system, the program of electric vehicles appear various troubles in operation[3,4]. Among them, the shaft misalignment fault of extended range device accounts for much more than 60% in mechanical fault. Meanwhile, the shaft misalignment will lead to the system radial and axial vibration and affect the system stability [5].

Nevertheless, in analysis of the traditional multi-rigid body dynamics, the simulation results can not reflect the actual crankshaft working condition. The reason maybe not considered the increase components as a continuous elastic body. In this paper, taking a diesel generator as the research subject, on the basis of virtual prototyping software ADAMS and finite element analysis software ANSYS, it established the extender hybrid rigid flexible mechanical model[6]. By setting the relevant parameters to simulate the misalignment of shafting, it conducted frequency analysis and researched the failure phenomena and evolution rules of misalignment faults. At last, it extracted the characteristic parameters of misalignment diagnostics for electric vehicle extended range.

2. Rigid-flexible hybrid dynamic model
Firstly, it imported the three dimensional CATIA model into the mechanical system simulation software MSC.ADAMS. Secondly, it regarded the key component as linear elastic body by means of the finite element method and combined with other rigid body model...
through nonlinear connection with boundary interaction. Then, it defined the material properties of each part and the connection relationship of the kinematic pairs. Finally, it obtained the multi-body dynamic rigid body model by applying external excitation and driving as shown in Figure 1.

3. Simulation analysis

3.1 Normal state

The diagnostic characteristic parameters are extracted by comparing and analyzing the normal state and fault condition based on the rigid-flexible hybrid dynamic model. The angular velocity of the crankshaft or the center angle of the flywheel is used to observe the engine transient speed fluctuation, abnormal movement or stagnation phenomenon.

Setting the simulation model in full load and 1500 rpm steady state with normal operation, it collected the X-axis torque signal of shaft coupling and extracted the spectrum signal as shown in Figure 2.

3.2 Misalignment fault in stable speed

It is obviously that the dynamic response is related to the degree of shaft misalignment. Assuming that the shaft misalignment is 1 mm or 3 mm, the misalignment force is applied in the middle part of the coupling and the shaft is in full load and 1500 rpm steady state. The shaft coupling X-axis torque signal of time domain and frequency domain are shown in Figure 3 and figure 4.
In order to research the failure phenomena and evolution rules of misalignment faults, it extracted the spectrum value in some specific frequency.

**Table 1** Spectrum value of X-axis torque signal in 1500 rpm

| Frequency(Hz) | 0     | 24.4141 | 48.8281 | 73.2422 | 97.6563 |
|---------------|-------|---------|---------|---------|---------|
| Normal state  | 5.9687E+6 | 4.3641E+10 | 1.3532E+10 | 1.5962E+8 | 3.2071E+8 |
| 1mm misalignment | 3.4068E+10 | 1.2276E+11 | 3.8199E+10 | 8.8527E+8 | 3.3344E+8 |
| 3mm misalignment | 4.3540E+10 | 1.5609E+11 | 4.6095E+10 | 8.8995E+8 | 3.7247E+8 |

As shown in figure 3, figure 4 and table 1, viewed from the above three conditions, the shaft coupling X-axis torque signal spectrum value in the frequency of 24.4141Hz appeared a peak value. It means that the power spectral density showed the first times frequency characteristic. With the degree of misalignment fault increased, the spectrum value in different frequency are all improved greatly and the growth rate becomes larger, especially in the first times and the second times frequency characteristic. Compared with the normal condition, the spectrum value of the first times is increased by 181.30% with 1 mm misalignment, 257.67% with 3 mm misalignment. It is because that the power spectral density reflects the power distribution of the torque signal in the frequency domain. When a misalignment fault occurs, the shaft motion is changed, the movement is no longer smooth, the shaft vibration and X-axis torque increased. It resulted the first times frequency characteristic becoming much more obvious.

According to the analysis above, the first times frequency characteristic maybe used as the characteristic parameters of misalignment diagnostics in stable speed. In order to further analyze the universality of the conclusion, it conducted the simulation analysis in 1000 rpm and 2000rpm with different misalignment degree.
As can be seen from figure 5, figure 6 and table 2, the amplitude of X-axis torque signal becomes larger with the increase of the rotational speed. At the same time, the first times frequency characteristic has much more significant in the power spectral density. Take the example of 1 mm misalignment, confronted with the 1000 rpm, the spectrum value of the first times is increased by 227.21% with 1500 rpm and 374.93% with 2000 rpm. It can be seen that the effect of vibration caused by misalignment is also enhanced with the increase of rotational speed. The performance in the time domain is the amplitude of the waveform up and down and the increase in performance in the frequency domain is a multiplier amplitude of the sharp increase.

### Table 2  Spectrum value of X-axis torque signal in different speed

| Speed (RPM) | 1000     | 1500     | 2000     |
|-------------|----------|----------|----------|
| Normal state| 1.2593E+10 | 4.3641E+10 | 6.7964E+10 |
| 1mm misalignment | 3.7517E+10 | 1.2276E+11 | 1.7818E+11 |
| 3mm misalignment | 4.5041E+10 | 1.5609E+11 | 2.4314E+11 |

3.3 Misalignment fault in variable speed

In order to study the influence of rotational speed with shaft misalignment, it analyzed the start-up process of a continuous linear change from 0 rpm to 2000 rpm in 2.4 s. Take the normal condition, 1 mm misalignment minor fault and 3 mm misalignment serious failure as the analysis object. The power spectral density of shaft coupling X-axis torque signal are shown in figure 7, figure 8 and figure 9.
From figure 7, figure 8 and figure 9, when the rotational speed is changed from 0 to 2000rpm, the amplitude of the torque signal spectral density are also changed and distributed in different frequency range. Firstly, in normal and 1 mm minor misalignment fault conditions, the dominant frequency of power spectral density is 0.5th times and first times in the low or medium speed, and only 1 times in high frequency range. Secondly, under the condition of 3 mm misalignment fault, the dominant frequency is mainly 0.5th times, supplemented by the frequency of first times.

The engine failure will often lead to the occurrence of other faults, such as rubbing fault, rotor loose. The deeper the failure degree, the greater the other faults possibility. In normal and 1 mm minor misalignment fault conditions, the shaft needs to overcome strong inertial and damping forces. There is a slight collision between the main shaft and the bearing, resulting in the rubbing fault of 0.5th times spectral density. As the speed increasing, the effect of rubbing fault is reduced and the first times spectral density starts to appear as a frequency multiplication characteristic. However, in the case of the 3 mm misalignment serious fault, it may cause the change of the shaft physical state and the damage to the electric...
vehicle extended range is larger. Therefore, the friction caused by the rubbing fault plays a significant role and the dominant frequency of power spectral density is 0.5th times.

In summary, the misalignment diagnostic characteristic parameters is 0.5th times in starting speed and first times in stable speed. If the 0.5th times spectrum value in stable speed is still large, it may have occurred in a large amount of misalignment and need for timely treatment.

4. Conclusion

The paper established a extender hybrid rigid flexible mechanical model by means of the software ADAMS and ANSYS. By setting the relevant parameters to simulate the misalignment of shafting, it conducted frequency analysis and researched the failure phenomena and evolution rules of misalignment faults. The following conclusions can be drawn.

Firstly, for misalignment fault in stable speed, the first times frequency characteristic maybe used as the diagnostics characteristic parameters. Secondly, for misalignment fault in variable speed, the misalignment diagnostic characteristic parameters is 0.5th times in starting speed and first times in stable speed. If the 0.5th times spectrum value in stable speed is still large, there maybe happened a serious misalignment.

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