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OPTIMIZATION DESIGN OF THE IWME

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Abstract

The IWME (Integrated Wheels of Mechanics and Electrics) includes an In-Wheel PMSM (Permanent Magnet Synchronous Motor), a reduction device, a brake device, the lubricating and cooling system, and so on in the hub of the tyre. It's the key factor to improve the performance of EV (Eletric Vehicle) and HEV (Hybird Electric Vehicle). In this paper, The IWME will be applied to a special type vehicle and mid-heavy vehicle; its integrated composition is complex. The authors have advanced the simulation analysis method of the motorized wheel based on PMSM. By the method, the main dynamic system parameters of the IWME are analyzed and simulated forward and backward with the Matlab/Simulink models of the IWME and the vehicle, in order to adapt the vehicle and to test its dynamic response. With the FEA (Finite Element Analysis), the optimization design of the IWME has been achieved. The shell structures and supporters of major components and parts have been strengthened. By evaluating the final optimization results, integrated design level has been improved according to the design method in the paper. Copyright Form of EVS25.

Keywords: IWME, EV and HEV, Simulation Analysis Method, FEA

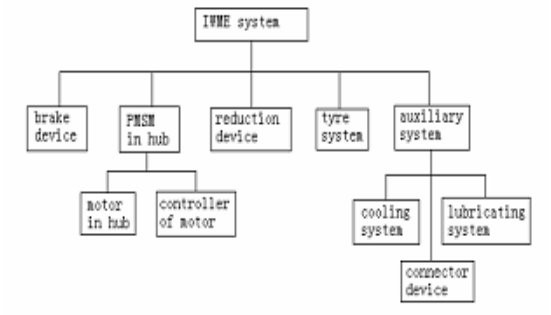
1 Introduction

The IWME (Integrated Wheels of Mechanics and Electrics) includes an In-Wheel PMSM (Permanent Magnet Synchronous Motor), a reduction device, and a brake device, the lubricating and cooling system, and so on in the hub of the tyre. It's the key factor to improve the performance of EV (Eletric Vehicle) and HEV (Hybird Electric Vehicle). Now, the more and more Motorized Wheels have been applied to the bicycle, micro car or mobile machinery shop, but the IWME applied to the special vehicle and mid-heavy vehicle is needed different dynamics performance and more rigorous structure. By working with the IWME, the advantage of the latter type EV and HEV will emerge [1, 2].

Based on the system engineer theory [3], the IWME can be divided into five systems: drive system (PMSM in hub), tyre system, brake device, reduction device, auxiliaries system, the each of five systems can be divided into several subsystems too (shown as picture1). The relations among these several subsystems is very complex, the working conditions of these subsystem are harsh too. So in the designing process, the authors have advanced the simulation analysis method and the FEA, with the system engineer theory.

Because of the driving type, the IWME can be divided into decelerate drive and direct drive [4]. According to those characteristics, the structure of IWME belongs to the decelerate drive mode with a gear case [5]. So the advantage of PMSM can be used in drive adjust. The PMSM can run in high speed, and the wheel can output high torque with the reduction device. Therefore，the IWME applies to the

special vehicle and mid-heavy vehicle, but the integrated-wheel structure is very complex.



Picture1 IWME system

2. Dynamics principle about the IWME

2.1 The dynamical performance of the vehicle with the IWME

Drive power that the vehicle needed can be gain because of the automobile principle [4] :

$$P_m \geq \frac{1}{3600\eta}\left[mgf + mgi + \frac{C_d A V^2}{21.15} + \delta m \frac{dV}{dt}\right] \cdot V \quad (1)$$

Hereinto: v—velocity of vehicle, i—gradient, A—windward acreage, η —overall efficiency, f—friction coefficient, δ —transmission moment of inertia, m—vehicle mass, g—acceleration of gravity

According to the matching relation between power and torque, the vehicle drive power can be transformed to the drive power performances of the PMSM:

$$P_m = \frac{T_m n}{9550} = \frac{K T_e n_e}{9550} \quad (2)$$

Hereinto: T_m—wheel overall torque, n—wheel speed, T_e—single PMSM torque, n_e—PMSM speed, k—drive wheel number

These are two important vehicle performances, the vehicle velocity and the max gradient; theirs calculate method is same as the traditional vehicle [4].

The vehicle velocity:

$$v_a = \frac{0.377 n_e R_r}{i_g} \quad (3)$$

Hereinto: n_e—PMSM speed, i_g—transmission ratio, R_r—dynamic radius of the wheel

The max gradient:

$$\alpha_{max} = \arcsin \frac{D_{max} - f_1\sqrt{1 - D_{max}^2 + f_1^2}}{1 + f_1^2} \quad (4)$$

Hereinto: D_{max}—max dynamic factor, f_l—rolling friction coefficient in ramp way.

2.2 Wheel dynamics

We can find the wheel torque function from vehicle dynamics principle [4]:

$$J_m \frac{d\omega_m}{dt} = T_e - T_r \quad (5)$$

Hereinto: ω_m—wheel angular velocity, T_e—PMSM output torque, T_r —PMSM resistance torque, J_m—PMSM inertia.

The PMSM performances are main factor to the IWME; we can gain the PMSM torque from the electro mechanics principle [5] :

$$T_e = \frac{P_e}{\Omega_s} = \frac{m}{\Omega_s}[E_0 I_{qM} - (X_q - X_d) I_{dM} I_{qM}] \quad (6)$$

Hereinto the first item is the permanent-magnet torque; the second item is the magnetic reluctance. Take into account the stator's number is three, m=3, and synchronization angular velocity $\Omega_s = \omega_1 / p$, $X_d = \omega_1 L_d$, $X_q = \omega_1 L_q$, the permanent-magnet is surface adhibit structure, so $L_d = L_q = L_s$, PMSM torque function can be rendered in a simpler style or form:

$$T_e = 3 p \Psi_0 I_{qM} \quad (7)$$

Therefore, we can model the PMSM and simulate its performances.

2.3 Brake performance of the IWME

The IWME have the energy feedback brake characteristic, so the optimization match with the machine brake is key factor. Based on the vehicle brake need, the IWME must provide the max brake torque and the ramp-way-stay-brake torque as the following:

The max brake torque:

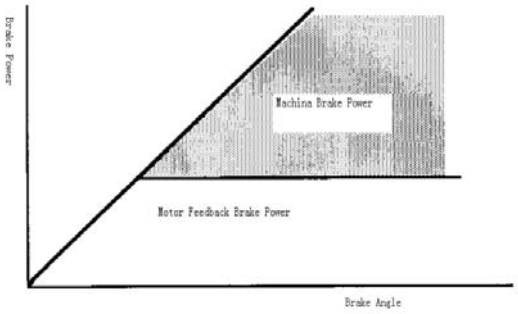
$$T_{m\,max} = \frac{Z_{max}\, g f_{max}\, R_r}{2 i_g} \quad (8)$$

The ramp-way-stay-brake torque:

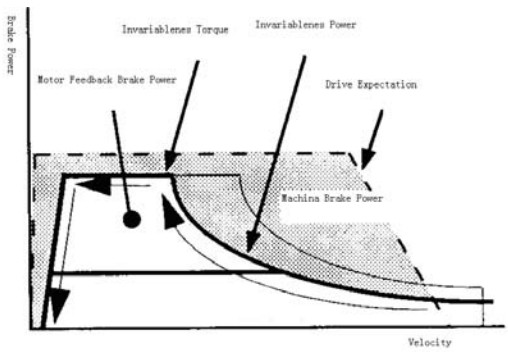
$$T_m' = \frac{mgR_r \sin arctg\ \alpha}{2 i_g} \quad (9)$$

Hereinto: Z_{max}—wheel max load, f_{max}—the max rolling friction coefficient, α —vehicle slope angle

The optimization match between feedback brake and machine brake power show as picture 2. Shown as picture 3, we can find the assign process. The PMSM feedback brake torque can be simulated with the motor torque function (shown as function 7). So we can model the brake device for simulation about the match between feedback brake and machine brake.



Picture 2 the brake power match



Picture 3 the brake power assign process

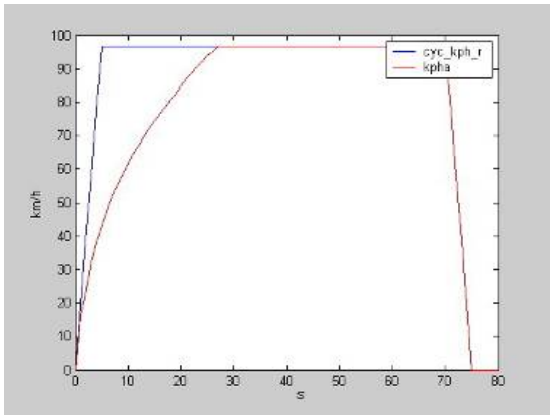
3. The simulation of the IWME

First, based on the parameters of the vehicle and the dynamic performance of the IWME, the Matlab/Simulink model was done. After optimizing the parameters of subsystem, we have obtained the result of simulation by running the model. Contrasting with the original vehicle, we can get table 1.

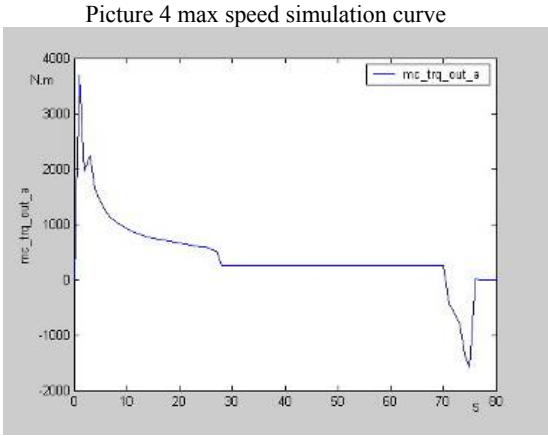
Table1: The result simulation with the IWME

	the original vehicle performance	**the result of simulation with the IWME**
Max speed(km/h)	90	96.9
0~96km/h accelerating time(s)	-	34.6
0~30km/h accelerating time(s)	9.6	4.1
Max grade ability	60%	60.3%

Contrasting with the performances of original and simulation result, we can find the drive performances were promoted. Shown as picture 4 and 5, there is the max speed simulation curve and the torque simulation curve during the course of the vehicle start, accelerate and brake.

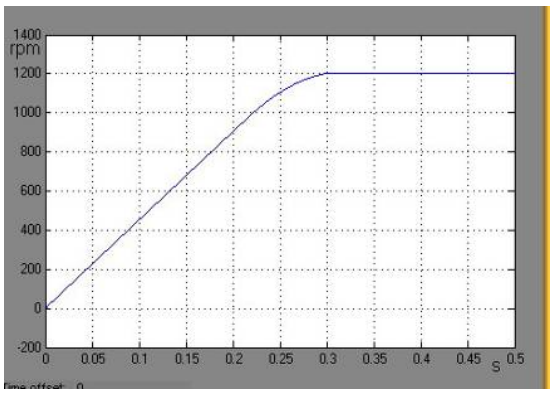


Picture 4 max speed simulation curve

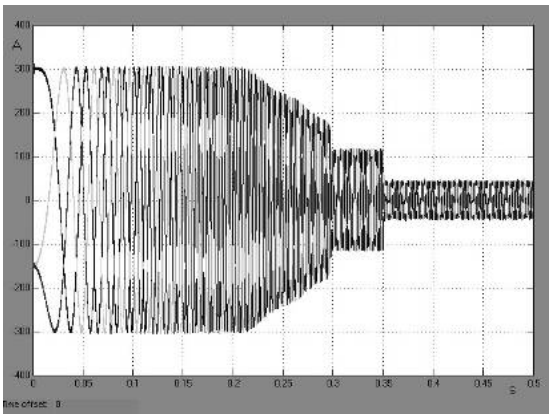


Picture 5 torque simulation curve

Second, the dynamics of the IWME was provided by the hub-drive-motor, so the performance of the motor affected the dynamic respond directly. Based on the parameter of PMSM (Permanent Magnet Synchronous Motor), we got the Matlab/Simulink model with torque ample and speed two-closed loop. Then, we had run the model, the simulate result were gain. The speed response curve and the torque ample response curve show as following (Picture 6, 7).

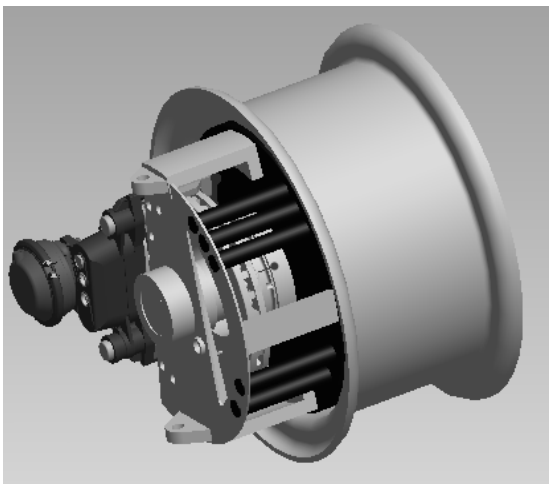


Picture 6 the speed response curve

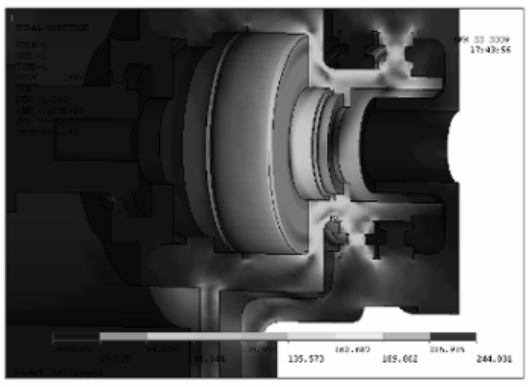


Picture 7 the torque ample response curve

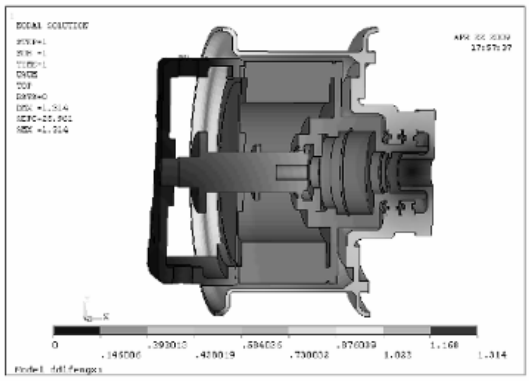
In addition, the three-dimensional structure [8] modeled by adopting the Pro/ENGINEER and Pro/Mechanical software was simulated with the ANSYS engineering analysis software. Contrasting the simulated results of several projects; we were able to optimize the structure design of the IWME [9, 10]. Shown as picture 8, there is the three-dimensional structure modeled in hub by adopting the Pro/ENGINEER and Pro/Mechanical software. With the FEA, we gained the simulation result with the vehicle load. Shown as picture 8, there is the max equivalent stress site. Shown as picture 9, we had gained the wheel total structure displacement.



Picture 8 the three-dimensional structure model of hub



Picture 9 the max equivalent stress



Picture 10 the total structure displacement

Optimizing design to the complex system, there are many contradictions among those subsystems designing. However, they have the same evaluation valve, we could evaluate these optimize results with weighted method in the general. Based on the system engineer theory, the evaluation value V_i is as following:

$$V_i = \sum_{j=1}^{5} a_j V_{ij} \qquad i = 0,1,2 \tag{10}$$

Hereinto: V_i —overall evaluation value, a_j—weighted coefficient, V_{ij}—subsystem evaluation value, i—project number, j—subsystem number.

Contrasting with the overall evaluation value of there cases, we choose the project A2 as the final optimization design. There are the max stress value and evaluation value of the main subsystems with the same vehicle load shown as table 2.

Table 2 the max stress value and evaluation value of the main subsystems

Subsystem	**Measure factor**	project A0	project A1	project A2
Main axis	**a1=0.2**	124.205	107.311	90.108
Brake support	**a2=0.2**	569.209	357.123	160.361
Reducer inner shell	**a3=0.35**	279.774	265.542	244.031
Motor shell	**a4=0.15**	104.611	84.213	84.213
hub	**a5=0.1**	42.124	42.124	42.124
overall evaluation value		256.5	202.6	152.3

4. Conclusions

In this paper, by way of dynamic response simulating and match simulating between the IWME and vehicle, we optimized the performance parameter of the IWME from forward and backward. The aim of advancing the vehicle performance was realized, because of using the advantages of the PMSM.

In structure designing aspect, the complex three-dimension structure was analyzed and simulated by running the ANSYS engineering analyses software. After synthetic evaluating these design cases, the optimizing design aim of the IWME was realized.
At last, the product of IWME had fully proved the optimizing design is right. The pictures of the product are show as following (picture11, 12).

Picture 11 the product of hub

Picture 12 the product of motor's rotor

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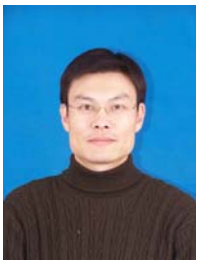

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