Feasibility and structure analysis of gas/electric dual power vehicle power system

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Abstract. In this paper, based on the design requirements of gas/electric dual power vehicles on the basis of the completion of the experimental car power matching, including the prime movers selection and check, including: focus on the analysis of compressed air power as a gas/electric dual power vehicle power source feasibility, and the experimental vehicle power system design and selection; In this paper, the layout of two power sources of the vehicle is analyzed, and the characteristics of several forms are discussed in the test vehicle. Under this research scheme, the control strategy of the vehicle in starting, light load, heavy load, climbing and other working conditions is discussed and compared.

1. Type selection analysis of electric drive system
There are many parameters determining the performance of the motor, including the starting and accelerating performance of the motor, the heating condition at low speed, the power generation efficiency at braking, the overload bearing capacity of the motor and the reliability during the use of the motor [1]. According to the data of electric vehicle motor, brushless motor has good high torque characteristics at low speed [2], high efficiency, good speed regulation and other characteristics. As the power motor of electric vehicle, it is the most appropriate choice.FIG1 shows the characteristic curve of such brushless dc motor:
From the above graph, it can be seen that the relationship between torque load and current, rotational speed and output power at rated voltage is 0 at the torque load, the rotational speed curve and the vertical axis are delivered to a point, and the rotational speed of the rotation speed is the no-load speed, which is the maximum rotation speed of the motor, the required working current is the minimum, while the output power is almost 0; Gradually increase the torque load, the linear slope of the motor speed is negative, linear decrease, working current synchronous linear increase, increase the output power; When the torque load is about 1/2 of the stall torque value, the output power reaches the maximum [4,5] and reaches the peak power, but it has exceeded the rated power of the motor at this time, so it is not suitable to operate in this condition for a long time.

If the dc motor is used for vehicle driving, there are the following states: a. In the case of car starting or uphill, the motor speed is very low, but the torque load is very large, at this time, more current is needed to drive the motor rotor to do work, the battery needs to bear a large discharge current, will significantly reduce the service life of the battery; B. Under the condition that the vehicle is moving at a high speed and a uniform speed, the speed of the dc motor is in a high state. At this time, the vehicle needs a large power and the driving torque can be reduced.

2. Kinematics analysis of compressed air drive system
In gas/electric hybrid bicycle model (figure 2), for example, assume that the driver and the total weight of the goods for \( G = 1500 \text{N} \), according to mechanical design manual query, Friction coefficient between rubber and cement floor of vehicle tire is about \( u = 0.02 \), hybrid between bicycle wheels is about \( L = 980 \text{mm} \), the length of the two cars two rubber wheel radius \( R \) the size of 300 mm, the wheel shaft radius \( R \) is 8 mm; According to the specific situation of the vehicle, the distance between the center of the frame and the axle of the front wheel is estimated to be \( l = 637 \text{mm} \).

As shown in the figure, the rolling friction of rubber wheel is ignored at this time. The equation is obtained:

\[
\begin{align*}
\begin{cases}
\quad f_1 < f_2 \\
\quad G = N_1 + N_2
\end{cases}
\end{align*}
\]

In the formula,
\( G \)---- the gravity of the vehicle itself and the gravity of the person, the unit is N
\( N1 \)----- the force acting on the front wheels, the unit is N
\( N2 \)----- the force acting on the rear wheels, the unit is N
\( f1 \)----- friction between the front wheel and the ground, the unit is N
\( f2 \)----- friction between the rear wheel and the ground, the unit is N
Due to the presence of \( f_2 \), the momentum of the bicycle changes at the moment of starting, showing a trend of increasing. Besides, because \( f_2 \) is a kind of static friction force, the kinetic energy of the dual-vehicle itself is converted by the pneumatic engine to the pressure in the gas storage tank, and finally becomes the kinetic energy when the bicycle starts to generate the initial velocity.

![FIG2. Force analysis diagram of starting and constant speed movement of dual electric cars](image1)

Assuming that the two cars move at a uniform speed, the balance of forces can be obtained as follows:

\[
\sum F(x) = f_2 - f_1 = 0
\]

\[
\begin{align*}
\sum F(y) &= N_1 + N_2 - G = 0 \\
\sum M(O_1) &= Gl - N_2l = 0 \\
\sum M(O_2) &= N_1l - Gl - l = 0
\end{align*}
\]

\( L \)------ distance between the center of front and rear wheels in mm

\( l \)------ distance between the center of the car and the center of the front wheel, in mm

There is the following relationship between the friction \( f \) between the rubber wheel and the road surface and the supporting force \( N \) generated by the road surface on the rubber wheel:

\[
f = \mu N
\]

Substitute relevant parameters of the experimental vehicle into the formula:

\[
f_1 = \mu N_1 = 10.5N \quad f_2 = \mu N_2 = 19.5N
\]

According to theoretical mechanics, the rear wheel of the two-car is now taken as the research object for force analysis (fig.3):

![FIG 3. Force analysis of the rear wheel while driving](image2)

When the two cars are moving in a straight line and uniform speed on the road surface, the following relationship can be obtained from the balance of forces between the rear wheels as the research object:

\[
\sum M(O_2) = f_2 R - Fr = 0
\]

The relevant parameters of the experimental dual-powered vehicles were substituted into the above formula 1.5, and the torque generated by the dual-powered rear wheel drive was obtained as follows:

\[
T = Fr = 5.85N \cdot m
\]
The motor is connected with the rear wheel of the vehicle through the roller chain, and the chain transmission efficiency of the roller chain is obtained through the mechanical manual $\eta = 96\%$. In the research of this project, the transmission type of the two-car chain is ordinary roller chain. The transmission efficiency was found to be $\eta = 96\%$ from the data of chain transmission model selection in the mechanical manual.

Therefore, the torque that the pneumatic motor should generate shall not be lower than:

The above is the theoretical data. The actual torque of the 1/4HP piston motor used in this experimental vehicle is 1.37n.m, and the transmission ratio is 4:1, which is consistent with the calculation results and can meet the purpose of uniform driving of the compressed aerodynamic drive vehicle.

3. Dynamic analysis of compressed air drive system

After inquiring the theory of fluid mechanics, the mechanical energy that can be converted into external work under pressure should meet the following formula:

$$ W = \int_{V_1}^{V_2} PdV $$

(3.1)

In the formula, $W$-- total mechanical work performed by the theoretical gas; $V_1$-- total volume of gas tank; $V_2$ -- volume of high-pressure gas after expansion; $P$-- instantaneous pressure change; $V$---instantaneous volume of gas.

According to relevant literatures, the high-pressure gas in the gas storage tank does not transfer heat with the outside world during the expansion process when it is doing work. At this time, the external work done by the compressed air should be the minimum value in theory, and it is the safest to calculate the range [4]. To query the relationship between relevant gas state parameters in fluid mechanics, the following equation can be obtained:

$$ \frac{P}{P_1} = \left(\frac{V}{V_1}\right)^{\kappa} $$

(3.2)

Assuming that the constant pressure during the exhaust of the pneumatic motor in the process of gas work is, the following equations (3.1) and (3.2) can be obtained:

$$ W' = \frac{P_1V_1}{k-1} \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\kappa-1}{\kappa}}\right] $$

(3.3)

Experimental car air tank of gas charge pressure 12 million mpa, maximum volume of 0.012 cubic meters to calculate according to the insurance, the end of exhaust at atmospheric pressure is about 0.1 million mpa, gas adiabatic coefficient is 1.4, the parameter in equation (3.3) is calculated, it is concluded that the ideal gas final adiabatic work into the total mechanical work of size:

$$ W' = 1.44 \times 10^5 J $$

According to the previous analysis, the selected motor output torque of the dual-power experimental car should not be less than $T=6.094$N·m, so the power, speed and torque of the pneumatic motor under normal work should meet the following relationship:

$$ \begin{cases} 
M = 9550 \frac{P}{n} \\
T = M \\
A^T = \frac{6 \times 10^7 P}{2Zn\eta} 
\end{cases} $$

(3.4)

According to the actual situation, $Z$ is now 3,$\eta' = 0.45$. By substituting relevant data into the equation set (3.4), the following formula can be obtained: $A^T = 2.33J$. That is, when the theoretical
value of mechanical work done by compressed gas to pneumatic motor in the adiabatic process is 2.33J under ideal conditions, the starting or uniform speed of the vehicle can be guaranteed.

The above formulas and experimental parameters were simultaneously calculated to obtain that the total mechanical work generated by the compressed air energy in the gas storage tank during the whole process of energy storage and release work changing into mechanical energy if it is always in an adiabatic state: \( W = 8.4 \times 10^3 J > 2.33J \)

This shows that compressed air used to drive the vehicle has sufficient feasibility.

4. Pneumatic motor characteristic curve

According to the literature search, the mechanical characteristics of the pneumatic motor are relatively soft [5], and its characteristic curve is shown in figure 4:

The following conclusions can be drawn from the figure: when the speed of the pneumatic motor is 0, the torque \( M \) generated by it is shown as having multiple values in the curve, which is uncertain; When the speed is slightly above 0, the torque \( M \) immediately reaches its peak, but the power output is almost 0. When the speed \( n \) reaches \( N_{\text{max}} \), the torque \( M \) is almost 0, and the output power is almost 0. The maximum torque \( M \) occurs when the output speed is approximately equal to 1/2 of the peak value, and the output power is also its peak value. In addition, when the speed exceeds the rated speed, according to the data, there will be greater wear and tear due to lubrication [5].

The above analysis proves that the pneumatic motor, as the power system of the vehicle, has a certain driving capacity and can basically meet the requirements of torque and speed in running. The experimental scheme is feasible. Schematic diagram of overall scheme layout of dual power system of automobile is shown in figure 5:
FIG5. Schematic diagram of transmission structure of gas/electric dual power vehicle power system

5. Summary
By analyzing the power system and compressed air powertrains of compressed air/electrical dual-power vehicle, the feasibility of using brushless motor in the experimental scheme was determined and the use of compressed air power system can meet the requirements of vehicle kinematics and dynamics performance, at the same time according to the needs of the experimental scheme design completed the scheme layout of the power system, control scheme schematic diagram, for the next step of the experimental scheme design laid a theoretical foundation.

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