Research on the Strategy of Gliding in Eco-driving

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Abstract. In this paper, the study was based on the vehicle drive cycle of pulse and glide (PnG), the conversion between the kinetic energy of the vehicle and the sliding resistance power was imported. The ideal state was proposed, in which the combustion energy of the fuel is converted into the kinetic energy of the accelerating vehicle. It was derived and calculated that the efficiency of gliding in neutral is better than gliding in gear under the vehicle with the same initial sliding velocity. The kinetic energy’s transformation had been analyzed under different gliding conditions, then the strategy of economic driving is shown: gliding with gear is suggested during the vehicle travelling downhill, which plays "engine brake" and saves fuel; pulse and glide in neutral is encouraged during the vehicle automatically cruise, it makes full use of the inertia of the vehicle to improve the fuel efficiency. Gilding in neutral could be adopted when the predictable distance is long or the travelling speed is low, gilding in gear could be adopted when the predictable distance is short or the travelling speed is high, so that making use of the gliding resistance, instead of unnecessary braking, reduces the speed of the vehicle to enhance the fuel economy. The dispute has been solved which is more fuel-efficient between sliding in neutral and sliding in gear, it will provide a new base in theory for making the strategy of gliding in eco-driving.

Introduction

The fuel economy performance of automobile has attracted the concern from all over the world, and the countries which include Japan, the United States and the European Union are increasing investment on upgrading vehicle fuel economy [1]. The Republic of Korea has revised the fuel economy regulations and fuel efficiency standards to promote the improvement of vehicle fuel economy [2]. Eco-driving technology has attracted much interest through its potential of 10%~15% oil saving [3]. Although the gliding in neutral or gear can save fuel, which kind is more fuel-efficient has caused a lot of controversy which is disadvantage of standardizing the eco-driving and restricts the improvement of fuel economy. Some scholars have conducted experiments to solve this problem. In the test [4], only the fuel consumption is considered during automobiles’ gliding the same distance with the same initial speed, ignoring the final velocity’s difference which is important to the test. The test [5] had been operated on cars with different initial and different terminal velocity while ignored the influence of different kinetic energy of the vehicle, in which the rate of gliding fuel consumption was got through converting total fuel consumption into One-Hundred-Kilometer Fuel Consumption. Thus, the rationality of the experiment had been weaken.

The fuel economy of the vehicle is influenced by many factors, including road and environmental factors, traffic flow and vehicle parameters. The road and environmental factors contain: wind and weather, road grade, slope and curve and road adhesion coefficient; traffic flow factors: the density of vehicles, traffic lights, vehicle speed and other factors; vehicle parameters include engine power, transmission gear, braking performance, vehicle aerodynamic drag coefficient, vehicle speed, tire model and pressure. In general, these factors are complex and diverse, which make the problem solving difficult.
To correctly compare the fuel economy of different gliding modes, it is necessary to make these factors effect on different sliding vehicles are same. Because of the difficulty about keeping the velocity and the influence caused by wind and road factors same in the process of sliding\(^6\), it is difficult to draw accurate conclusions by road fuel economy test. In this paper, the research eliminates the difference between two automobiles for various factors, by controlling the initial and final sliding velocity invariant between the different tests, in which the final sliding velocity is the velocity at the moment that the engine recovers fuel injection. The saving effect of two kinds gliding mode could be analyzed from the view of conversion between power and energy, providing a theoretical basis for the rational choice of gliding modes in economic driving.

Economic Driving and Gliding

Economic Driving

Economic driving means that the driving of the vehicle could meet the demands of minimum emissions and high efficiency under the premise of the power structure no changing. That could be achieved through improving the driver's decision-making and behavior (especially the operation of the vehicle throttle, gear, braking), improving driving habits and relationship between “people-vehicle-road”\(^7\).

On the premise of ensuring the safety of driving, the reasonably using of vehicle gliding is one of the important economic driving strategies. Automobile gliding is that the automobile running is supported by the self-inertia instead of engine power. It is indisputable that automobile gliding can reduce fuel consumption to realize energy conservation.

Automobile Gliding Classification

The common characteristics of the vehicle gliding are: (1) the vehicle does not need the engine to provide power; (2) the accelerator pedal is in a state of relaxation.

Automobile gliding can be divided into two kinds according to the different transmission shift: gliding in gear and gliding in neutral, while it can also be divided by the working state of engine: gliding in flameout and gliding in non-flameout. The traditional vehicle flameout gliding is that the engine keeps flameout and stops working in vehicle’s gliding. Since modern vehicles are equipped with vacuum-assisted and hydraulic steering booster, which need the power from engine, the traditional vehicle flameout gliding has been banned. Modern vehicle flameout gliding is that the engine keeps rotating with no fuel injection during the vehicle gliding depending on the inertia. Due to the fact that modern electric fuel injection engine has the function of DFCO, vehicle can keep flameout automatically during the gliding with high speed in gear. Therefore, there exist two kinds of gliding for modern vehicles actually: the engine keeps idling during vehicle’s gliding in neutral, the engine is in flameout running during vehicle’s gliding in gear, which can be summarized as gliding in gear and idling gliding in neutral.

The Energy Efficiency of Gliding Comparison Between in Gear and in Neutral

Economic driving strategy is not only derived from experience summary, but also it can work better after solving the theoretical problem of the gliding model.

The Research Scheme

The tests have been designed for cars A and B which are chosen from the same model. Firstly, let car A glide in neutral with its velocity decelerating from \(v_1\) to \(v_2\) during which its deceleration is \(a_1\), and the engine keeps idling in this time whose rotation rate is \(n_1\). The distance above is recorded as \(s_1\). Secondly, let car B glide in gear with its velocity decelerating from \(v_1\) to \(v_2\) during which its deceleration is \(a_2\), and the engine’s rotation rate is \(n_2\). The distance is recorded as \(s_2\). Then, their velocities are accelerated to \(v_1\) again and repeat the test several times. The total fuel consumption of
vehicle A gliding is $Q_A$, the fuel consumption of A is $Q_1$ per $s_1$ gliding distance. Take the thermal value of gasoline $q$ is $4.6 \times 10^7 \text{J/kg}$.

**Energy Efficiency Comparison**

It is obvious that the gliding distance in neutral is longer than in gear: $s_1 = s_2 + \Delta s$ and let $\Delta s = \frac{1}{k}s_2$ where $k$ is a coefficient, and it varies with the different engine running resistance; then $s_1 = s_2 + \frac{1}{k}s_2 = \frac{1+k}{k}s_2$, and we have

\[ k s_1 = (1+k)s_2 \] (1)

So the $k$ times glide distance of A is equal to $(1+k)$ times glide distance of B, and B has once acceleration more than A. The consumption fuel of A is $Q_A = kQ_1$ after its $k$ times gliding.

In order to analyze and compare the behaviors of energy conservation, it is necessary to keep the same gliding distance between A and B. Suppose that B’s additional acceleration is in ideal state, in which supply the energy $\Delta E_k$ to B vehicle by the consuming fuel and elevating its speed from $v_2$ to $v_1$ without displacement. According to the law of conservation of energy, fuel consumption in the acceleration process is:

\[ Q_B = \frac{\Delta E_k}{4.6\eta_2 \times 10^7} \] (2)

where $\Delta E_k = \frac{1}{2}m(v_1^2 - v_2^2)$, and $\eta_2$ is the thermal efficiency of engine in the acceleration process;

Through the above analyses we could get that: during B automobile’s gliding, there is no consumption fuel for being in state of DFCO. During B automobile’s accelerating, the fuel consumption of vehicle B is $Q_B$ more than vehicle A because B accelerated one more. Thereby, it is reasonable to compare the $Q_A$ with the $Q_B$ for finding which vehicle’s Fuel-saving Performance is better.

$F_A$ represents the average resistance force of vehicle A during gliding in neutral and $F_B$ is the average resistance during B vehicle’s gliding in gear. The work done by A is $W_A = F_A s_1$ in one gliding. For its kinematic energy decrement was all transformed into the work done by gliding resistance force during A gliding, $W_A = \Delta E_k$. Plug it into formula (2) and get:

\[ Q_B = \frac{F_A s_1}{4.6\eta_2 \times 10^7} \] (3)

Get the relationship from $v_1^2 - v_2^2 = 2as$:

\[ a_1s_1 = a_2s_2 \] (4)

Plug formula (1) into formula (4) to get:

\[ \frac{a_1}{a_2} = \frac{s_2}{s_1} = \frac{k}{k+1} \] (5)

From $F = \delta ma$, it could be known that $F_A = \delta ma_1$, $F_B = \delta ma_2$, then plug them into formula (5) and get:

\[ \frac{F_A}{F_B} = \frac{a_1}{a_2} = \frac{k}{k+1} \] (6)

where $F_A = F_f + F_c$, $F_B = F_f + F_C + F_E$, $\delta = 1 + \frac{\Sigma l}{mr^2}$, $F_f$ is the rolling resistance force of automobile, $F_C$ is the air resistance force of automobile, $F_E$ is the damping force acting on the wheel from the
engine anti force while the engine is being dragged by the wheel, $\delta$ is the mass conversion coefficient of automobile, $I$ is wheel moment of inertia, $r$ is wheel radius.

Because the models of A and B are same, and the average velocity and the driving conditions are the same too, their rolling resistance and air resistance are the same. So $F_B = F_A + F_E$, plug it into formula (6) to get:

$$F_A = kF_E$$  \hfill (7)

During the gliding in gear, the engine which is dragged by the wheels keeps rotating in high speed without injecting fuel, and the damping torque of engine rotating is proportional to the engine rotational speed and produces a counter effect on wheels to impede the automobile movement [8,9], which includes the piston motion damping torque, the pump damping torque, driving auxiliary mechanical damping torque. Let $F_E = k_0n_2$, where $k_0$ is a specific coefficient, plug it into formula (7) to get:

$$F_A = k_0n_2$$  \hfill (8)

then $Q_B$ is calculated by plugging it into formula (3):

$$Q_B = \frac{kk_0n_2s_1}{4.6n_2 \times 10^7}$$  \hfill (9)

Similarly, $F_1$ is defined as the resistance force of the wheels from the engine when engine is idling under the automobile wheels drag: $F_1 = k_0n_1$; then the work that the engine idling rotation resistance has done per gliding distance $s_1$ in gear is $W_1 = F_1s_1 = k_0n_1s_1$.

According to the energy conservation principle, during the A’s per $s_1$ gliding in gear, fuel consumption of engine is:

$$Q_1 = \frac{W_1}{4.6n_1 \times 10^7} = \frac{k_0n_1s_1}{4.6n_1 \times 10^7}$$  \hfill (10)

where $\eta_1$ is the thermal efficiency of engine with idling.

From the formula (8) and (9), we have:

$$\frac{Q_1}{Q_B} = \frac{kQ_1}{Q_B} = \frac{4.6kk_0n_1s_1\eta_1}{4.6kk_0n_2s_1\eta_1 \times 10^7}$$

it can be written in the following form:

$$\frac{Q_1}{Q_B} = \frac{n_1\eta_2}{n_2\eta_1}$$  \hfill (11)

Then, which kind of gliding performs is better, it is discriminated by comparing the value of formula (11) with 1.

**Analysis of Energy Efficiency**

According to DFCO of modern automobile, the engine starts to cut off fuel when its rotating speed is more than 1800~2000 r/min, it recovers to gush fuel when its rotating speed is lower than 1200~1500r/min, which means that the average rotating speed of engine during gliding in gear is not lower than 1600 r/min, so $n_2 = 1600$ r/min; while idling speed of engine $n_1 = 800$ r/min, it could be got:

$$\frac{n_1}{n_2} \geq \frac{1}{2}$$  \hfill (12)

Combine (12) with formula (11) to get:
\[ \frac{Q_A}{Q_B} \leq \frac{\eta_B}{2\eta_i} \]  

(13)

For gasoline engine, the indicated thermal efficiency of the engine increases with the load, but the maximum thermal efficiency of the engine is less than 2 times the thermal efficiency of idling. In the derivation, the engine rotating resistance during the automobile gliding in neutral can be calculated according to engine being dragged at idling speed, at which engine’s resistance is 15%~20% more than in normal idling. On the other hand, during the automobile B additional acceleration the fuel consumption is calculated according to the ideal process in the deduction, which is less than the actual fuel consumption \( Q'_B \), therefore \( \frac{Q_A}{Q_B} < 1 \). We can draw the conclusion from formula (13) that gliding in neutral is more fuel-efficient than gliding in gear for the electro-controlled gasoline engine.

For the diesel, its thermal efficiency changes sharply with the load, and rotating speed of the diesel cut off fuel and recovers to gush fuel are low when gliding in gear. In a few cases, such as: when automobile is in less load and high gear at low speed driving, it is possible that gliding in gear saves more fuel than gliding in neutral; but in general scenarios, especially for high speed diesel ,gliding in neutral still save more fuel.

From formula (13) derivation, whose premise is that \( B \) is in the high shift, if it is in the low shift, the engine rotating resistance will be enlarged and it is more obvious for the automobile damping effect. It is visible that gliding in neutral is more fuel-efficient than gliding in gear in the fewer loads and low speed driving.

The Selection of Sliding Modes in Different Road Conditions

The common gliding ways are: ramp gliding, PnG (Pulse and Glide) and deceleration gliding. In different gliding conditions, the fuel-saving effect varies considerably. Therefore, the fuel efficiency could be improved by choosing appropriate gliding mode according to the road condition and traffic state.

The Mode of Automobile Ramp Gliding

Ramp gliding is that the automobile glides by its own gravitational potential energy on the slope top and its moving inertia in down ramp. It is applied on the long and wide straight ramp with the slope of less than 5%, and at the end of steep ramp. Gliding speed in the down ramp should be controlled in the safe speed depending on road conditions. Gliding in neutral cannot be adopted and the clutch should keep engaging to avoid the automobile gliding too fast for the brake to control the speed. During the ramp gliding, only gliding in gear can be adopt to achieve fuel-saving by DFCO function. When the road gradient is greater and there is a long distance flat road after downhill, use the engine braking during downhill, and use the gliding in neutral on flat road, it could make the fuel economy effect more significant.

For vehicles equipped with Braking Energy Recovery System, gliding in neutral could also be adopted in the case of safety speed to make full use of vehicle kinetic energy, improve fuel consumption and finally achieve economic driving.

The Mode of Pulse and Glide (PnG)

PnG (Pulse and Glide), also known as artificial glide, is one of the most typical economic driving strategies, which is fitting for proper roads in the plains or with a slope less than 2%.

First, the automobile should be accelerated steadily to the economy speed, then release accelerator pedal to keep gliding which is supported by the vehicle’s kinetic energy stored in the period of accelerating. When the speed is lower than the 80% of economy speed, the automobile is accelerated steadily again. Such accelerating and gliding are carried out alternately, which is called PnG. The engine is idling or doesn’t inject fuel during gliding, and the engine load ratio is enhanced resulting the reduction of the fuel consumption\[10\]. The performance of fuel-efficient will be better, after combining the PnG with the automobile cruise technology and controlling the velocity.
depending on automobile load and working condition \cite{11}. Compared with keeping uniform speed, 13% of fuel consumption could be saved by PnG.

Exactly as above-mentioned demonstration, PnG in neutral is more fuel-saving, but must pay attention to following conditions:

(1) Gliding in neutral is forbidden to be used on vehicles equipped with hydraulic automatic transmissions.

Because the lubrication oil pump is driven by engine, the revs of the pump becomes low which leads to the low oil pressure when the vehicle is gliding in neutral, then the planet gear and transmission shaft would be burnt in the high speed without well lubrication. For automated mechanical transmission (AMT), dual clutch transmission (DCT) and AT with electric lubrication oil pump, with which vehicles can be free from above effects.

(2) Automobile with turbo engine is not suitable for gliding in neutral. The supply of lubrication oil decreases sharply, while the turbo keeps high revs, then the turbo will suffer superhot which is caused by the same reason in (1).

(3) The reason why PnG could save fuel is that the heat efficiency of the vehicle is higher than the uniform speed during the acceleration process.

In general, the load rate is 20% while the vehicle runs on horizontal and fine road at normal speed, and it climbs to 70%~80% when the automobile accelerates \cite{12}. Enhancing the effective thermal efficiency of engine could decrease the fuel consumption, thus when the automobile is driving evenly and the engine load is low, PnG could work well. When the automobile is in full-load or in up-ramp etc., don’t do it.

**The Mode of Deceleration Gliding**

The deceleration gliding is also called predictable gliding. It works by using gliding instead of braking to reduce fuel consumption when the automobile is going to slow down or stop \cite{13}. It is supposed to choose deceleration gliding in advance when the automobile couldn’t pass the crossroads evenly for the traffic jam, red light or bridges, culverts which are predictable.

According to researches about fuel consumption in the real traffic environment, the radical acceleration and braking can lead to 30-40% increase of fuel consumption.

The basic principle of deceleration gliding is to reduce and avoid unnecessary brake by making full use of the automobile inertia. When the predictable distance is short, the gliding resistance force in the neutral is not enough to slow the vehicle during the short time which makes the vehicles have to brake and the kinetic energy will be squandered.

In conclusion, when the predictable distance is long or the vehicle speed is low, it is suggested to coast in neutral in order to avoid ‘the engine braking’ influence and make full use of the long gliding distance to realize maximizing fuel-saving. When the predictable distance is short or automobile speed is high and transmission is also in high shift, compared with gliding in neutral, gliding in gear can reduce the velocity through ‘engine braking’ instead of unnecessary braking and could make full use of DFCO, so it can benefit from the kinematic energy stored in the vehicle.

**Conclusions**

The essence of economic driving strategy is optimizing the driver's operation without changing the original vehicle powertrain hardware to meet the travel needs and reduce vehicle fuel consumption. In this paper, we analyzed the difference between these two things of gliding and the result showed that:

(1) Gliding in neutral can save more fuel than gliding in gear during the automobile PnG.

(2) Gliding in gear should be selected when automobile is driven with the short foresight distance, in the ramp gliding, or in high speed at the overdrive shift such that it is beneficial to driving safety and saving fuel by the DFCO function.

(3) Gliding in neutral should be selected when the automobile is driven at low speed in the low shift or with the long foresight distance so that it can reduce the fuel consumption by using automobile inertia.
With the development of vehicle networking technology, the data could be shared between vehicle to vehicle, vehicle to road and vehicle to internet which can give all information around to drivers to make the better choice about gliding mode [14,15], and it will avoid unnecessary braking to improve vehicle fuel economy.

In addition, it is suggested to develop a decision system through shifting gliding modes intelligently at right moment to achieve economic driving. The result of gliding in neutral saving more fuel, which will bring a positive impact on the control of hybrid vehicle power, providing a new basis for decision making.

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References


