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CONTROL STRATEGY FOR AFTERMARKET ELECTRONIC THROTTLE CONTROL

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RESEARCH ARTICLE

ABSTRACT: This paper presents the development of electronic throttle control, provided for use in an experimental light hybrid-electric vehicle that was a final product of ongoing student project. Originally, the IC-engine throttle system was operated using mechanical linkages and cable, which was enhanced by developing a new system containing sensors and actuators. Therefore prototype of such a system had to enable the possibility of exerting control of both IC engine, powering the rear axle, and two electric hub motors, powering the front axle, by using the single accelerator pedal. This way full exploitation of hybrid drive potentials can be enabled.

KEY WORDS: throttle-by-wire, electric drive, hybrid drive, project-based learning, student project

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STRATEGIJA UPRAVLJANJA SISTEMOM ELEKTRONSKE KOMANDE GASA ZA NAKNADNU UGRADNJU

REZIME: U ovom radu dat je prikaz mehatronskog pristupa rešavanju zadatka koji je obuhvatao elektrifikaciju komande gasa električno-hibridnog vozila Hermes, nastalog iz studentskog projekta na Fakultetu Tehničkih Nauka u Novom Sadu. Hibridno vozilo prednji pogon dobija od SUS motora, dok zadnji dobija od dva elektromotora, koji se nalaze u točkovima. U cilju poboljšanja efikasnosti ovog paralelnog hibrida, kao i redukcije broja pedala gasa predložen je sistem senzora, aktuatora i mikrokontrolera koji bi bili upravljani u povratnoj sprezi, dok je, kao potencijalno rešenje, izrađen model prototipa mehanizma, koji bi u potpunosti zamenio uže, odnosno mehaničku vezu između pedale gasa i karburatora hibridnog vozila..

KLJUČNE REČI: elektrifikacija, hibridno-električno vozilo, projektno-orijentisano učenje, studentski projekat

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1. INTRODUCTION

Electronic vehicles are frequently mentioned lately, but it is not widely known that first vehicles with electronics power-train date from the late 19th century. Their development was left aside because IC engines were widely used and improved constantly. Unlike the electrical industry that was struggling to develop batteries with prolonged working hours, desired sustainability, efficiency, and capacity, the fuel industry was a step ahead by producing fuel and making it's supplying affordable and simple. But technology of today allows the electrical industry to quickly evolve and offer many new possibilities such as a modern hybrid-electric vehicles. A vehicle of that type was made by students at the Faculty of Technical Sciences on a Mechanisation and Construction Engineering Department ([1], [2]). The vehicle was named Hermes and was designed as a hybrid with parallel configuration meaning it has two different power sources (two hub motors for powering the front axle and an IC engine for powering the rear axle). This hybrid has full driveability but needs further improvement, such as reducing the number of acceleration pedals since it has two, each one for different power supply and implementing the so-called drive-by-wire (or drive-by-throttle) system as a part of hybrid's electrification. Purpose of this paper came from the desire of making such a system (or at least the prototype) that would make a better outcome in comparison with the previous, mechanical one, by achieving better engine efficiency, improving torque delivery from the engine, increasing fuel consumption, reducing environmental pollution, but at the same time maintaining similar driving experience as it was with the previous mechanical configuration.

2. ELECTRONIC THROTTLE CONTROL

Basic considerations were taken into account like:

- Which type of carburettor is implemented in the vehicle?
- Which microcontroller should be used along with the appropriate sensor(s) and actuator(s)?
- What mechanism is already within the acceleration pedal's box, whether it already has a potentiometer?
- How much space is left on the vehicle for implementing such a system?
- Are there any parts on the vehicle that are protected from vibrations and humidity that can handle parts with sensitive properties?
- What are other limitations?

Drive-by-wire throttle bodies date from the beginning of the 20th century but this vehicle's carburettor doesn't have the conventional throttle body with the butterfly, but with the needle valve.

Aftermarket ECUs with the throttle body are widely utilised systems, most commonly containing two sensors at the accelerator pedal and two sensors on the throttle body. DC motor is directly connected to the throttle body and a PID controller is used for fast, yet accurate control of drive-by-wire throttle body [3]. Three main PID parameters are its gains: proportional, integral and the derivative gain. The values of these gains are highly important since they are directly responsible for the system behavior as well as system safety. The way for getting these values accurately is by doing various tests and experiments which is done by the ECU manufacturers. Since this paper deals with a control strategy for aftermarket electronic throttle control that should be implemented in a student-made vehicle which contains rather rare type of carburettor new approaches needs to be made.

Figure 1. Hermes, hybrid-electrical vehicle [1]

Student-made electric vehicle (Figure 1) is named H.E.R.M.E.S. which is an acronym of the Hybrid Educational Recuperative Moto-Electrical Special vehicle. Its rear-drive axles are powered by a gasoline engine that was taken from the quad vehicle (named Loncin) with the cylinder capacity of approximately 220 cm3, containing one four-stroke cylinder that is fed by the carburetor. The maximum power it can achieve is 11 kW with a 17 Nm torque and has a 4-speed gearbox with the reverse gear. Additional chain transmission was made for connection of both rear axle and redesigned differential that was taken from the Yugo vehicle. Front axles are powered by two DC hub-motors with the power of approximately 1 kW per each, which was controlled by the suitable controllers. Nominal hub-motor voltage is 48 V with the power supply made out of 4 serial 12 V semi-traction batteries. Currently, Hermes'es gasoline and electrical power drives are not able to work simultaneously but this problem can be overcome by implementing control strategy that will involve appropriate microcontroller and electrification of the acceleration pedal (so-called drive-by-wire system) and automatization of both the clutch and the gearbox. Additional criteria should be taken into account like noise reduction, economic aspects (like vehicle's efficiency and environmental performance), etc.

Estimated vehicle's properties are

- Maximal velocity: 100 km/h
- Rise time: 10s (0-60 km/h)
- The maximum distance achieved by driving in the electrical regime: 20 km.

Properties of vehicle's chassis

Frame is made out of three modular segments (front, middle and rear) connected with screws so that further modifications are enabled if needed. For frame design seamless steel pipes segments Ø 21,3 mm, with a wall thickness of 2,6 mm are used.

The front axle is McPherson's type, based on the front axle Yugo's elements.

The braking system is containing two front and rare disc brakes with the main brake cylinder also from the Yugo vehicle.

Mass and dimensions

- Mass: 500 kg
- Weight distribution: approximately ’’50/50’’
- Wheelbase: 2500 mm.

3. ACCELERATION PEDAL CONFUGIRATION

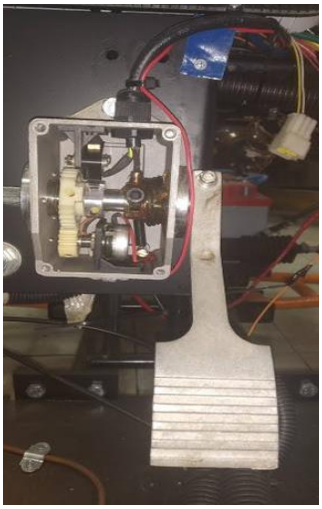

Figure 2. Acceleration pedal and it’s mechanism

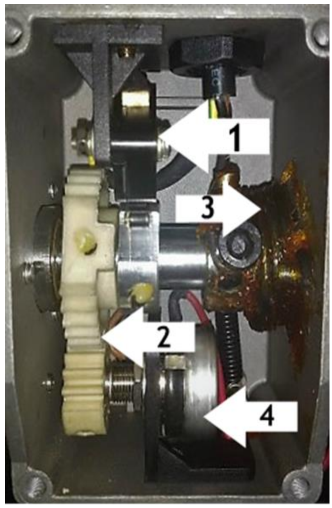

Figure 3. Main parts of acceleration pedal’s mechanism

Acceleration pedal (Figure 2) that is already implemented in the vehicle was made by the unknown manufacturer from China. Based on Figure 3 given acceleration pedal consists of:

1. Limit switch
2. Gear pair
3. Spring
4. Potentiometer.

Since all acceleration pedals used in the drive-by-wire systems have, at least two potentiometer sensors for the purpose of improving the safety strategy, those two sensors should correlate which results with the decreasing potential errors that can occur during the drive. For making the prototype of such a system one potentiometer was used, since it imitates the present state of the Hermes vehicle, although this should be improved by replacing current acceleration pedal with the more advanced one.

4. CARBURETTOR AND THE NEEDLE THROTTLE VALVE

Alike butterfly throttle, needle valve consists of a spring which is responsible for opening/closing carburettor airflow tunnel, depending on whether or not acceleration pedal is pressed. By this we want to point out the great importance of the type of the desired material needed for producing such a spring, meaning that its properties such are quality, durability and most importantly reliability is a matter of concern.

According to [8] and [9], one of the most suitable simulation methods used for design procedures, saving experimental test resources and reducing potential mistakes that could be made during diagnostics of a product is FEM (Finite element method). This method along with the theoretical an experimental approach given in [7] could be used as a model for further work on designing the most durable spring for aftermarket electronic throttle given in this paper.

Figure 4. Throttle valve inside of the carburettor

Figure 5. Complete appearance of the needle throttle valve

As it's seen from both Figures 4 and 5 needle valve motion inside of the carburetor is linear and that motion is achieved by stepping on the acceleration pedal and when the pedal is released, spring inside the valve pushes it back to the original (''natural'') position. Cable throttle system produces lagging due to inherent amount of flex [4]. This problem has been solved by implementing the drive-by-wire system, meaning that replacing throttle cable with the ECU system and tuning such a system to achieve desired goals mentioned in the introduction part of this paper.

5. DC SERVO MOTOR

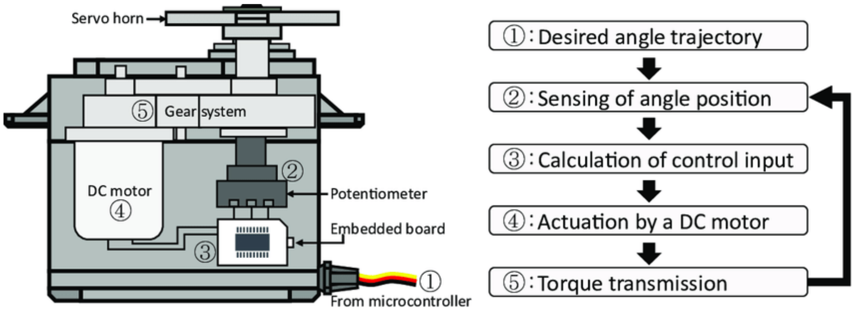

Figure 6. Basic working principle of a DC servo motor [5]

DC servo motor (Figure 6) was chosen among the diversity of potentially suitable electromotor, because of advantages it produces on the system.

Main advantages are:

- It's quick response to the given input signal (input signal is acceleration pedal position)
- Built-in potentiometer with output signal that acts as a feedback signal meaning that signal directly corresponds to the current position of a servo's shaft or in other words potentiometer acts as a servo shaft's encoder.
- Small dimensions, which make this servo motor compact and easy to install
- Compatibility with the microcontroller such as Arduino, Raspberry Pi…
- Scotch yoke mechanism (Figures 7 and 8) was considered as the best option because:
- It was easy to print (by using 3D printing technique and ABS as a filament)
- Has few moving parts
- Directly converts rotary to linear motion
- Servo motor shaft is directly connected to the mechanism, which reduces the number of additional sensors and actuators (like in a regular, throttle valve).

It produces pure sinusoidal output signal, which allows smoother operation and tuning, since the relationship between throttle position and the air flow is nonlinear.

6. 3D PRINTED SCOTCH YOKE MECHANISM

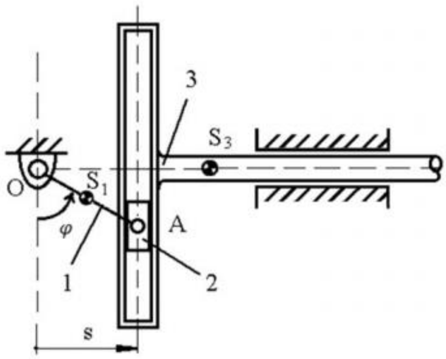

Figure 7. Working principle of a Scotch yoke mechanism [6]

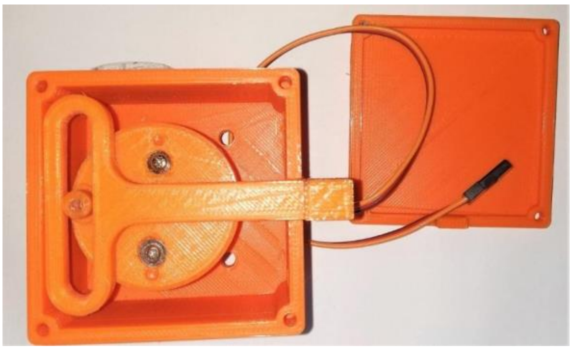

Figure 8. Servo motor and the Scotch yoke 3D printed mechanism

7. HARDWARE DESCRIPTION

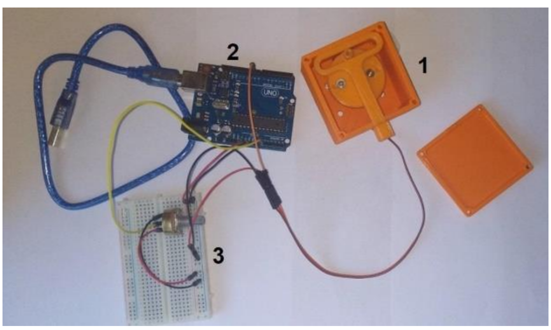

Figure 9. Prototype

Prototype (Figure 9) consists of:

1. Scotch yoke mechanism with the servo motor inside

2. Uno R3 microcontroller
3. Breadboard with the potentiometer.

8. CONCLUSION

This paper presents a mechatronics approach through developing regulation for electronic throttle control device needed for the improvement of the student-made hybrid vehicle. The vehicle is configured as a parallel hybrid with IC engine power at the rear axle and two electric hub-motors at the front axle. Originally, the IC engine throttle system was operated using mechanical linkages and cable, which is not appropriate for optimal control of the simultaneous operation of both the IC engine and electric motors. Therefore prototype of new electronic throttle control system had to be developed, exerting control of both IC engine and electric hub motors by using the single accelerator pedal. This way full exploitation of hybrid drive potentials can be enabled. Appropriate sensors, actuators, mechanisms, control algorithms and microcontroller were chosen, to achieve the first steps for desired, adequate control strategy for aftermarket electronic throttle control or so-called drive-by-wire control. The new control system also has to use a controller with the appropriate software for conversion of the control signal to the actuator displacement.

Further improvements that could be made are:

- Creating throttle maps for different working regimes, which can be implemented together with the ECU system meaning that the ECU system will switch from one map to the other according to the tuning parameters
- Additional potentiometers for gaining more accurate signals and reducing errors
- Adding more input signals like signals from the engine sensor(s) and signals with the information about vehicle velocity
- Testing prototype in various working conditions such as vibrations and higher/lower temperatures.

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