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UTeM`s Amphibious Hybrid Vehicle: Development of Hybrid Electric Propulsion System

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Abstract – *This paper presents the preliminary development of hybrid electric propulsion system for amphibious hybrid vehicle (AHV). AHV is developed as a transportation vehicle that can operate both on land and water to be used by the rescue team in rescue operations. AHV is driven by motor electric on the land, while on the water, AHV is propelled by the internal combustion engine (ICE). At the same time, ICE is used as generator to generate the electricity to recharge the battery pack. The main factors that need to be considered in order to develop a hybrid electric propulsion system is the power required by batteries to transmit to the motor electric to move the vehicle. An optimum hybrid electric propulsion system should have minimum fuel consumption, simple to develop and high reliability. Matlab Simulink Analysis based on the mathematical modelling is conducted to determine the power required before the fabrication take place. The design of hybrid electric propulsion is then fabricated by combination of ICE and electric motor. Finally experimental analysis is conducted to determine its reliability and durability.*

Keywords: *Hybrid Electric Propulsion System, Amphibious Hybrid Vehicle*

Nomenclature

F_{ad}	Aerodynamic resistance force
F_{rr}	Rolling resistance force
F_{hc}	Rolling resistance force
F_{la}	Acceleration force
F_{te}	Tractive force
ρ	Air density
C_d	Coefficient of drag (depends on body design)
A	Frontal area of vehicle
v	Velocity
m_t	Total mass
g	Acceleration of gravity
θ	Angle of slope
P	Power required

I. Introduction

Hybrid vehicle means combination of two or more power source to increase the overall efficiency [1]-[16].

The types of hybrid can be classified based on driveline configuration. There are three common types of hybrid design configuration which are series, parallel, and series-parallel. Although further improvements on vehicle fuel economy since the last 40 years have been conducted, the average efficiency in the use of gasoline ICE normal operation is only at 15%. While other 85% is lost to the environment as engine heat, exhaust gas heat, aerodynamic drag, rolling resistance of the tires, losses at the driveline and during braking [2].

Addition of an electric motor and electric energy storage from ICE can increase diversity of efficiency significantly, depends on the system design.

Common features of most hybrids that improve fuel economy are:

(i) Idle stop

The average vehicle idle time is around 20% of the total driving operation. During this time, turning off the engine can reduce the fuel consumption by 5 to 8% [2].

While during others time, fuel can be saved by turning off the engine when the vehicle is under deceleration, thus CO^2 emissions is not released. The idle stop is possible because restarting the engine happen at very low engine speed. The mix of air-fuel is combust at crank speed of 400 rpm. [1].

(ii) Regenerative braking

During deceleration or braking driving phase, the system will absorb the braking energy and store it in an energy storage device such battery or other components for future use, and it is also helps in charging the battery [3].

(iii) Power-assist

The electric motor gives additional power to the ICE when the vehicle is accelerated. Assistance from the power-assist module can reduce the size of the engine and improve the fuel efficiency without reducing the overall performance of the vehicle. Application of power-assist in Toyota Prius shows that the performance of 1800cc ICE is comparable to 2400cc performance with power-assist. [4]

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(iv)Engine efficiency

The ICE efficiency is low during low speed and low load operation. Therefore, to increase the system efficiency at this condition, the electric motor can be used as alternative power supply. Hence, the fuel consumption and emission is can be set to zero at this particular time.

II. Development Process

In development of the hybrid electric propulsion system, the following considerations need to be adhered:

i. Design of hybrid configuration.
ii. Power requirement.
iii. Component selection and arrangement.
iv. Vehicle size.

The first two criteria are very important parameters in order to design a hybrid electric propulsion system. Apart from that, the following assumptions are required in conducting the analysis:

i. Vehicle moving in constant velocity without acceleration.
ii. There is no energy loss from ICE.

II.1. Design Process

Firstly, to design the hybrid electric propulsion system is to come up with a power flow planning in the AHV. A series hybrid configuration type is applicable in the vehicle as the propulsion system. The power flow plan is presented as in the Fig. 1.

II.1.1. Determining Hybrid Configuration

The AHV hybrid system in Fig. 1 consists of seven main components as correlation in the hybrid system of vehicle. When the ICE is running, the alternator that be linked to the crankshaft of ICE will generate the electricity according to the rotation of the crankshaft.

The increasing speed of the crankshaft rotation will increase the production of Alternating Current (AC).

Then, the regulator will regulate the unstable rectified AC to the steady at 12Volt of direct current (DC).

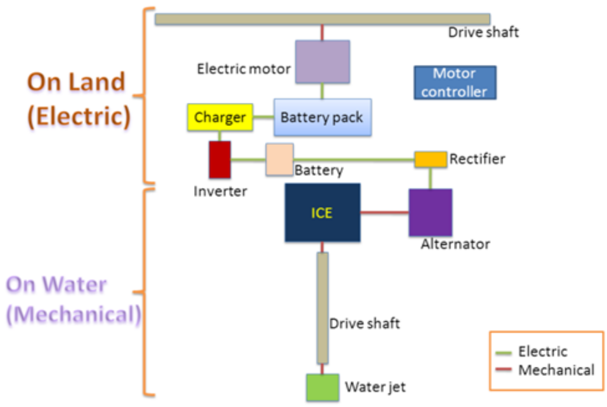

Fig. 1. Planning of the power flow in a AHV

The 12Volt DC from regulator is recharged the 12 Volt batteries which is used as a power bank. Next, the inverter will amplify the 12Volt DC to the 240Volt DC.

The amplified current is then use to run the charger. Charger is used to charge the 60 Volt DC battery packs that are required by the electric motor to operate. AHV also come with plug-in charging system to charge power bank as an alternative to ICE charging system.

Both power sources have specific operation environment. On the water surface, AHV is propelled by water jet which is connected to ICE driveshaft. While on the land, AHV is driven by the tyre which is connected to the drive shaft that powered by the electric motor.

The factors that determine the amount of the power from batteries which can transmit to motor electric are: tractive force. It is a summation of aerodynamic resistance force, rolling resistance force, hill climbing force, and acceleration force [5]. As shown in Fig. 2, the vehicle with mass, *m* moving at velocity, *v* on the slope with an angle, θ should overcome all the opposing force.

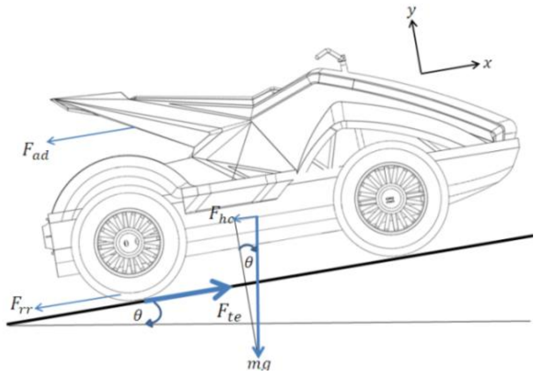

Fig. 2. Mathematical model of vehicle

II.1.2. Determining the Tractive Force

Based on the mathematical model of vehicle as shown in the Fig. 2, aerodynamics force is a friction force acting on the body surface area with the air when the vehicle is on the move. The corresponding mass density of air may be taken as $1.25\ \mathrm{kg \cdot m^{-3}}$ [6]. The common value of drag coefficient C_d is determined from the Table I [7].

Rolling resistance force is due to the friction between tyre and the road surface. The typical value of rolling coefficient μ_{rr} is 0.015 [8]. Hill climbing force is required for vehicle to move along incline road. Based on the Newton's Second law of motion, the inertia force is increasing if acceleration is increase [9].

Therefore, the tractive force is increasing proportional to inertial force [10]. As mentioned earlier in previous section, vehicle will move on constant velocity. This is to simplify the analysis as the vehicle is in equilibrium condition due to summation of all forces is zero.

II.1.3. Determining Power

Assuming that vehicle does not stop until the fully charged batteries is exhausted.

TABLE I
COMMON VALUE OF C_d

	C_d		C_d
Sport car, sloping rear	0.2-0.3	Truck	0.8-1.0
Saloon, stepped rear	0.4-0.5	Motorcycle and rider	1.8
Convertible, open top	0.6-0.7	Sphere	0.47
Bus	0.6-0.8	Long stream-lined body	1.2

The required power of batteries to operate the electric motor at any given constant velocity can be calculated using Eq. (6):

The aerodynamics resistance force:

$$F_{ad} = \frac{1}{2}\,\rho\, C_d\, A\, v^2 \quad (1)$$

The rolling resistance force:

$$F_{rr} = \mu_{rr}\, m_t\, g \quad (2)$$

Hill climbing force:

$$F_{hc} = m_t\, g\, \sin\theta \quad (3)$$

Inertial force:

$$F_{la} = m\, a \quad (4)$$

Total tractive force:

$$F_{te} = F_{ad} + F_{rr} + F_{hc} + F_{la} \quad (5)$$

Power required by batteries for motor electric:

$$P_{b-m} = (F_{te} \times gear\ ratio) + \frac{1}{\eta} \quad (6)$$

Units:

Force, F	N
Density, ρ	$kg \cdot m^{-3}$
Area, A	m^2
Velocity, v	$m \cdot s^{-1}$
Mass, m	kg
Acceleration	$m \cdot s^{-2}$
Angle	degree^o
Power, P	W

The power analysis is done for each constant velocity ranging from 0 km/h to 40 km/h with different gradient of $0^o, 5^o$, and 10^o.

II.1.4. Analysis Results

The analysis is focus only on electric motor and the result of analysis is determined by equations (1)-(6). The equation parameter is shown in Table II [11].

From Fig. 2, the frontal area of vehicle is calculated as stated in Table II. From Table I, there is no common value of drag coefficient for this type of vehicle, so the value is assumed as in Table II. Total of mass is 273.2 kg where the mass of rider is to be assumed with typical weight around 60 kg. The vehicle is assumed moving on incline road surface gradient of 0^o, $5^o$and 10^o degrees. With all parameters and assumptions, the result for analysis on power required for vehicle is shown on the graph in Fig. 3. The analysis is conducted by using Matlab Simulink Analysis and the block diagram is shown in Appendix (Figs. 1A(a) and 1(b)).

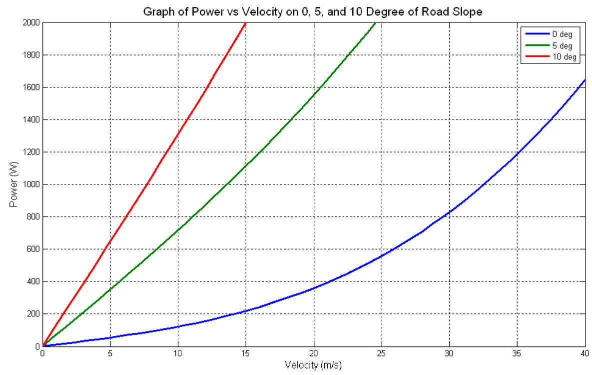

Fig. 3. Graph of Power vs. Velocity on 0, 5 and 10 Degree of Road Slope

Fig. 3 shows that the required power of the vehicle to move at different slope subjected to constant velocity. Power required by battery is proportional with the vehicle speed. Therefore, the speed of the vehicle is depends on the capacity of the power bank [12].

According to the graph, when the vehicle is move on a flat road at speed of 35 km/h, the battery need to supply the power of 1200W to the electric motor. By using the same battery power, if the vehicle move along the slope of 5^o, the vehicle can speed up is up to 16 km/h. The speed of vehicle is up to 9.2 km/h when vehicle move along $10^o$of slope.

TABLE II
ASSUMPTION AND PARAMETER

Parameter	Value	Parameter	Value
Density of air, ρ	1.25 kg. m^{-3}	*Mass of vehicle*, m_v	213.2 *kg*
Drag Coefficient, C_d	1.3	*Mass of rider*, m_r	60 kg
Surface are, A	0.98 m^2	*Efficiency*, η	0.98
Gravity acceleration, g	9.81 m. s^{-2}	*Gear ratio*	$^{14}/_{60}$
Rolling Coeffient, μ_{rr}	0.015		

The result shows that the power requires are proportional to the vehicle speed and the climb angle.

The selection of battery sizing and performance is based on the maximum power required to move the vehicle on flat surface which is 1600W.

II.2. Fabrication of the Hybrid Electric Propulsion System

The next step of this research is the fabrication of the hybrid electric propulsion system. The hybrid electric propulsion system was fabricated by installing the 150cc ICE which is used as a power source for water jet propulsion and it is also use to generate electricity by using the alternator that is built-in inside the engine.

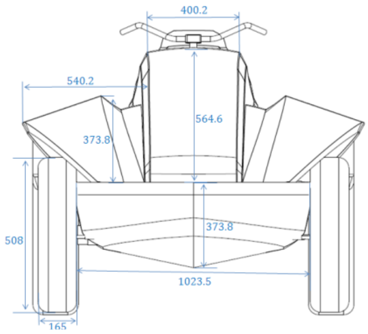

Fig. 4. Front view of the vehicle

AHV is installed with Brushless DC motor with 1kW to 3kW of rated power. Brushless DC Motor is more efficient, more compact and lightweight [2]. Lead Acid with Nano Gel technology is used as battery pack for the vehicle. Lead Acid is cheaper compared to Lithium-Ion or Nickel-Metal Hydride and this type of battery is suitable for mild level of hybrid. Five of batteries is used which is 12V, 20Ah each make the total of voltage is 60 Volt. Motor controller with 60Volt of working voltage is used to control the voltage and current supply to electric motor. Throttle voltage for motor controller is 1.2 Volt to 4.3 Volt and the maximum current through motor controller is 70 Ampere. An intelligent charger with 240V is installed into the vehicle. As shown in Fig. 2A, the components are mounted to the chassis of the vehicle.

The component placement follows the suitability of the chassis and the component function. The hybrid electric propulsion system in amphibious hybrid vehicle is completely developed as shown in Fig. 3A.

III. Conclusion

In this paper, the development process of the hybrid electric propulsion system is properly demonstrated. It started with proper power planning, then the components integration and finally system testing and analysis.

Maximum 3kW rated power of the electric motor capable to propel the vehicle more than 40 km/h. However due to safety factor, the maximum speed of the vehicle is limited to 40 km/h. The installation of electric motor really assists in reduction of fuel consumption and vehicle emission.

Appendix

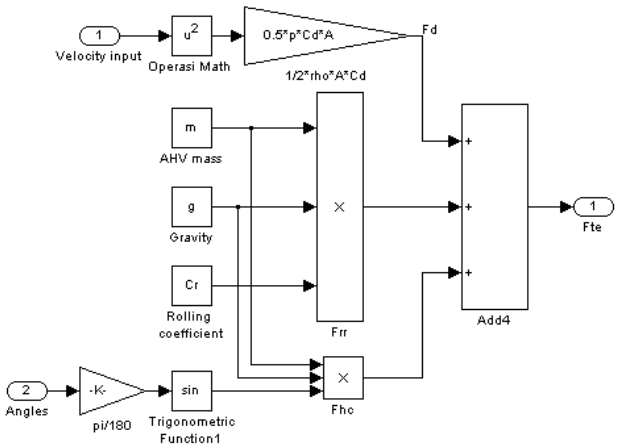

Fig. 1A(a). Block diagram for tractive force

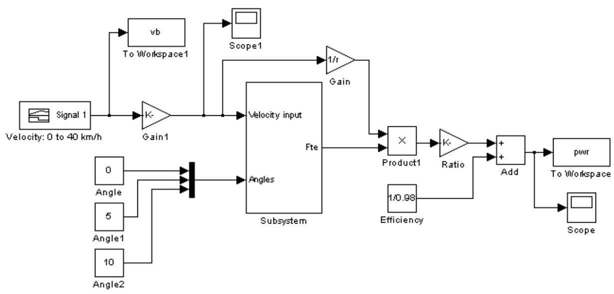

Fig. 1A(b). Block diagram for power

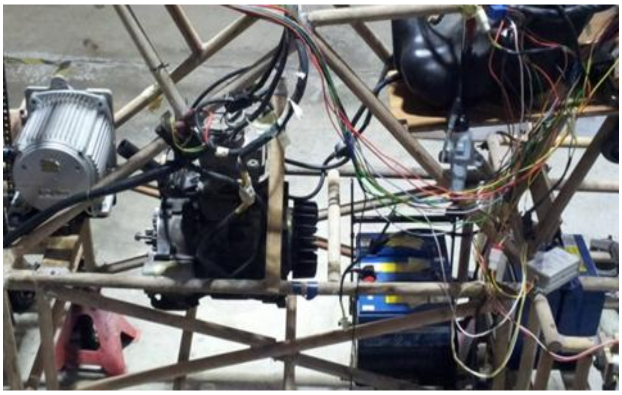

Fig. 2A. Hybrid propulsion system [12]

Fig. 3A. Complete AHV with hybrid propulsion system [12]

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