Mini Acceleration and Deceleration Driving Strategy to Increase the Operational Time of Flywheel Hybrid Module

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Abstract: This paper presents a new driving strategy to increase the operational time of flywheel hybrid module. The flywheel hybrid module contains low cost mechanical parts which installed on the small motorcycle. Based on normal driving cycles characteristics, the Mini-AD driving strategy is develop. It is involved a series of short or mini acceleration cycle and short deceleration cycle on top of the normal driving cycles. The new strategy is simulated for flywheel hybrid module, aimed for acceleration phase only. Simulations show that the new driving strategy can increase the operational time of flywheel hybrid module up to 62.5%.

Keywords: flywheel hybrid module, Mini-AD driving strategy, operational time.
PACS: 88.85.J-

INTRODUCTION

In an automotive technology, the research in using flywheel as a secondary power source begins as in early 70s. Nowadays some automotive manufacturer start to put this technology inside their cars even some of them uses it in high performance car. However, the reliability and performance of the flywheel hybrid is uncertain. Therefore, this technology is still on going further research and refinement. In performance aspect, the major drawback of flywheel hybrid is in the recharging and storing capability. It only can be charge using regenerative braking which exist during deceleration phase of driving cycle [1]. Although the engine can be used to recharge it, but there is no point because the main purpose of hybrid is to reduce the operation time of the engine. The harvest energy is stored inside the flywheel itself as a kinetic energy. The same flywheel transfers the energy back for propulsion. This make the flywheel is not efficient compared to electric hybrid. In an electric hybrid, the power is stored in the battery which can be use anytime as long as there is enough power in it. The purpose of this paper is to develop a new method to recharge flywheel hybrid during others phases of driving cycle which focus on the acceleration phase.

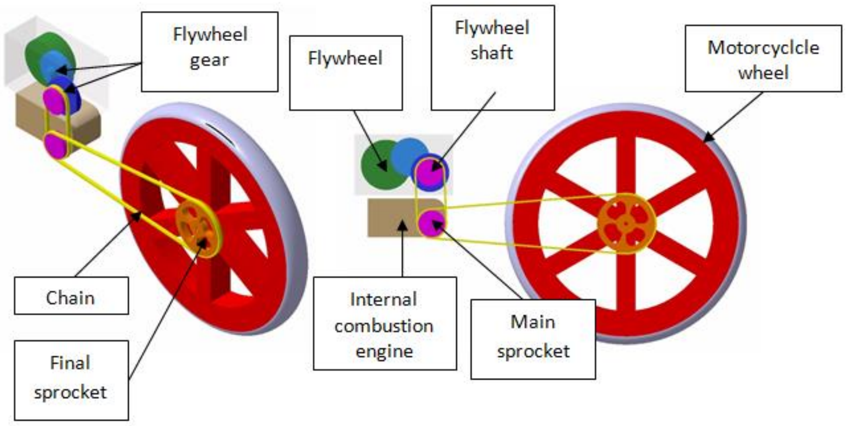


FIGURE 1. The location of flywheel hybrid module

HYBRID COMPONENTS

The flywheel hybrid module is installed inside a small size motorcycle. The reason is because in Asia region, this type of motorcycle is commonly used. In Malaysia alone, the number of small motorcycle reaching 10 million units [2]. The hybrid module is installed on top of the internal combustion engine. It is link to the main sprocket by using chain and sprocket [3]. This is shown in Figure 1 below. This system is using parallel hybrid. Flywheel and engine can work alone or work together in order to supply the power to the motorcycle. The engine is become primary power supply while the flywheel serve as secondary power supply. The connection of both power supplies is using a clutch system.

DRIVING MODE

The capability of the flywheel to charge and recharge energy make the identification of driving mode is important. The driving mode or driving cycle can be divided into three types which are the acceleration drive, steady drive and braking drive as shown in Figure 2 [4,5]. The first two drives is class as a power mode and the last drive is class as a regenerative mode. In the power mode, either engine or flywheel supplies the power to the motorcycle. During this time, energy is drawing out from the system. Energy is consumed in order to move the motorcycle forward. While in the last drive, the braking energy is transferred back to the power supply. However, in this situation, the energy is stored inside the flywheel as kinetic energy because flywheel has this capability which engine does not have it.

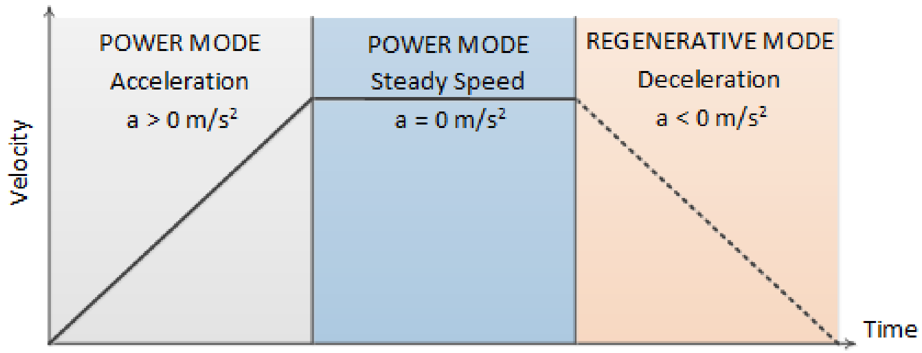


FIGURE 2. Three types of driving drive.

DRIVING STRATEGIES

In order to increase the efficiency of the flywheel hybrid, a new drive strategy is needed. Therefore the new mini acceleration and deceleration drive strategies (Mini-AD) is introduced. The concept is that the Mini-AD strategy is imposes on top of the overall drive cycle. Therefore, even during the acceleration phase, by applying this strategy, the vehicle is actually run a series of short acceleration cycle and short deceleration cycle.

There are four parameters need to be optimize. Those parameters are Mini-A acceleration value, Ma, Mini-D deceleration value, Md, Mini-A acceleration time, Ta and Mini-D deceleration time, Td. The term Mini-A refer to short acceleration cycle and term Mini-D represents the short deceleration cycle in the overall drive cycle. In this paper, the first two parameters are fixed. The focus is now to find the optimum value for Ta and Td by divide it into three types of time variation which are Ta < Td, Ta = Td and Ta > Td.

$$A/D = \frac{V}{T_{acc/dec}} \tag{1}$$

The overall drive cycle involve the acceleration of the motorcycle from 0sec, 0kph until 100sec, 100kph. The scope of this paper covers only during the acceleration phase. The acceleration of the motorcycle is set at constant value of 1m/s^2. For Mini-AD strategy, the general acceleration equation is as Equation 1.

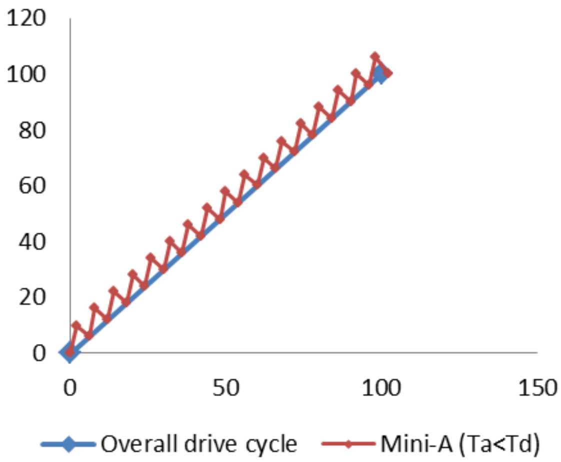
Hence, for each time variation, there are specifics acceleration and time values as shown in Table 1. Analysis of the drive cycle is using a back trace simulation method. Therefore, the Mini-AD strategy needs to impose on top of the overall drive cycle. The formulation for Mini-AD velocity is shown in Equation (2).

TABLE (1). Parameter value in Mini-AD driving strategy

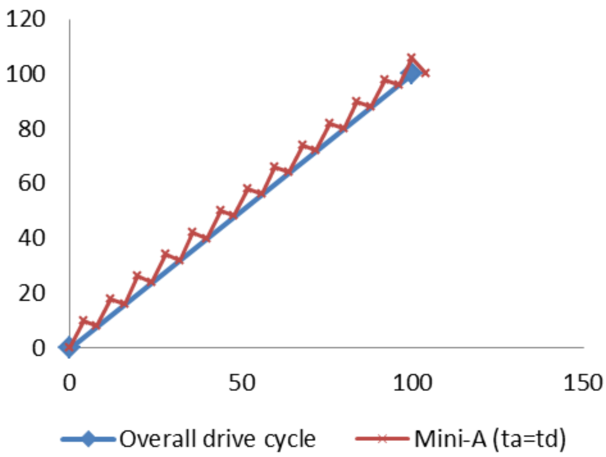
Time	$T_{acc} = T_{dec}$	$T_{acc} < T_{dec}$	$T_{acc} > T_{dec}$
Ma (m/s^2)	2.5	5	2.5
Md (m/s^2)	-0.5	-1	-2
Ta (s)	4	2	4
Td (s)	4	4	2

$$V_i = \sum_{k=0}^{n} \left(M_a . T_{a,i} + M_d . T_{d,j}\right) \tag{2}$$

Note that i is odd real number, j is even real number, and k is a real number. By using the data in Table 1 and Equation 2, the Mini-AD driving strategy for all time variations is shown in Figure 3.



(a)



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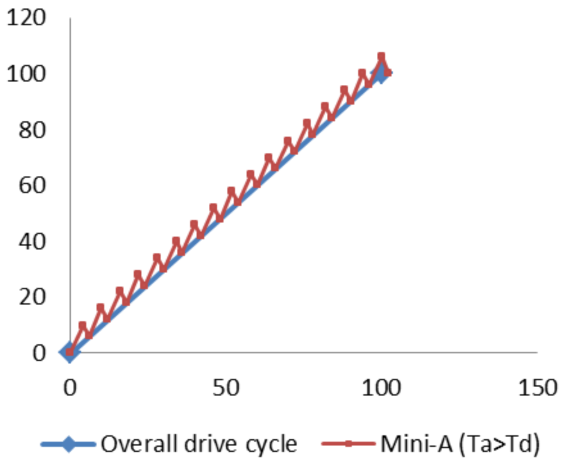

(c)

FIGURE 3. Mini-AD drive strategy on top of overall drive cycle (a) for Ta < Td (b) for Ta = Tb (c) Ta > Td

FLYWHEEL POWER

The overall simulation is involving two parts. The first part is where the motorcycle is propelled by the engine through normal acceleration phase and decelerates until full stop. These conditions recharged the energy inside the flywheel. Then by using the recharged energy, the second part of simulation begins. It involved the Mini-AD driving strategy. The charged energy stored by the flywheel became the initial energy for the Mini-AD driving strategy. The graphs of velocity against time do not show the first part of the recharging process.

The flywheel energy is calculated for each seconds of the simulation time. During Mini-A cycle, the flywheel is using it stored energy while during Mini-D, the same flywheel is stored the energy through regenerative braking. The usage energy is indicate as negative energy (energy is charged out). The recharge energy is indicate as positive power (energy is recharged in). The summation of these powers provide the total power used for specify drive cycle.

The flywheel energy is a function of flywheel inertia, I, , final velocity, v_f , , initial velocity, v_i , , motorcycle wheel radius, r and, time range, Δt. This is shown in Equation 3. ΔP_{fw} is the change of energy inside the flywheel. The Δt is the value of the time for each of Mini-A cycle and Mini-D cycle. This value is obtained by subtracting the initial time with the final time in each cycle [3].

$$\Delta P_{fw} = \frac{1}{2} \cdot \frac{I \cdot (v_f^2 - v_i^2)}{r^2 \cdot \Delta t} \tag{3}$$

The simulation of flywheel hybrid introduce a new parameter, kill time, T_{kill}. Kill time is the maximum operational time of the flywheel hybrid by using its initial energy inside the flywheel before the energy depleted (or shown as negative energy). This parameter is important as it will prove the capability of new driving strategy in increasing the operational time of flywheel hybrid.

RESULT AND DISCUSSIONS

We start with the overall drive cycle results. In the normal driving, the energy needed to propel the vehicle from 0kph to 100kph is 791.4J. This energy is either pre-stored inside the flywheel or supply by the engine. By applying the new drive strategy, the amount of energy pre-stored inside the flywheel should be lesser than 791.4J

Now the new driving strategy is applied. In time variation of Ta = Td, the flywheel hybrid lost all its stored energy at 9 seconds. This is the time where the second Mini-A happens. This is shown in Figure 4. During this time, the recharge energy at first Mini-D (this is the period where flywheel is recharge) is only 71.0J at 8 seconds. The amount of energy required for next Mini-A is 514J. The flywheel still needs 443J more to continue on the drive cycle. The remaining energy during second Mini-A cycle is only 13.8%. The simulation is halted at 9 seconds due insufficient energy stored inside the flywheel as shown in Figure 5. Therefore the kill time happens at 9 seconds. The first Mini-A is between 0 to 4 seconds and the second Mini-A is between 8 to 12 seconds.

For the time variation of Ta < Td, the kill time happens at 6.3 seconds. From Figure 7, at the 6 seconds, there is only 127J of energy available in the flywheel while the power required for the next Mini-A is 870J. The flywheel required 774J of energy to enter the next Mini-A cycle. In the second Mini-A cycle, the amount of energy is only 14.6%. Therefore, for this time variants, the flywheel hybrid can sustain its energy up to 6.3 seconds. The first Mini-A is between 0 to 2 seconds and the second Mini-A is between 6 to 8 seconds.

For this time variants (Ta > Td), the kill time happens at the 8.5 seconds where the flywheel hybrid entering Mini-A range as in Figure 8. The energy required to propel the motorcycle during this time period is 435J while the amount of energy recharged during the previous Mini-Dec is 253J. Therefore, the flywheel required 182J more energy to finish the next Mini-A cycle. There are 41.8% of energy in the flywheel during this time. It is shown in Figure 9. The flywheel hybrid can hold up to 8.5 seconds of operation in this time variants. The first Mini-A is between 0 to 4 seconds and the second Mini-A is between 6 to 10 seconds.

The result clearly shows that time variation of Ta = Td give the maximum operational time of 9 seconds. However, the variation of Ta > Td have a lower difference of 0.5 seconds only as in Figure 10. From other perspective, all time variants enter the 2nd Mini-A cycle. As shown in Table 2, the last variant spent 62.5% of its time in the 2nd Mini-A cycle. The remaining energy also point to the last variant with 41.8% remaining energy. All three time variants show that Mini-AD strategy can increase operational time of flywheel hybrid. In this case, the longer duration of Mini-A cycle compare to Mini-D cycle absolutely can give maximum operational time.

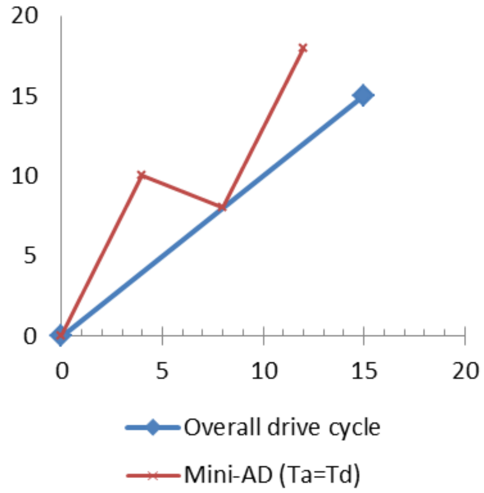

FIGURE 4. Kill time for Ta = Td.

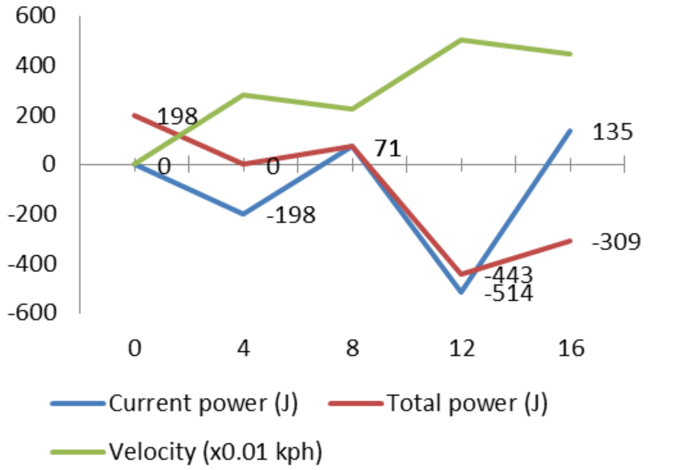

FIGURE 5. Energy and velocity vs. drive cycle time for Ta=Td.

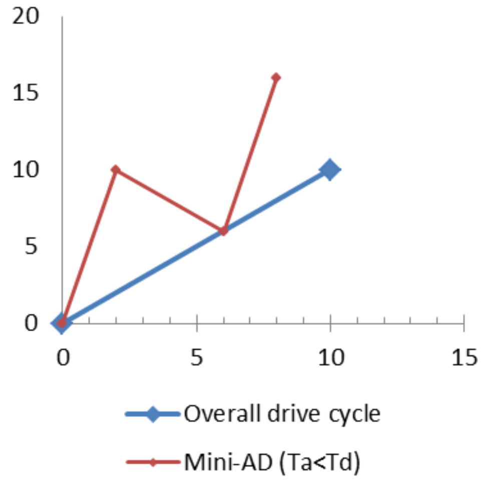

FIGURE 6. Kill time for Ta<Td.

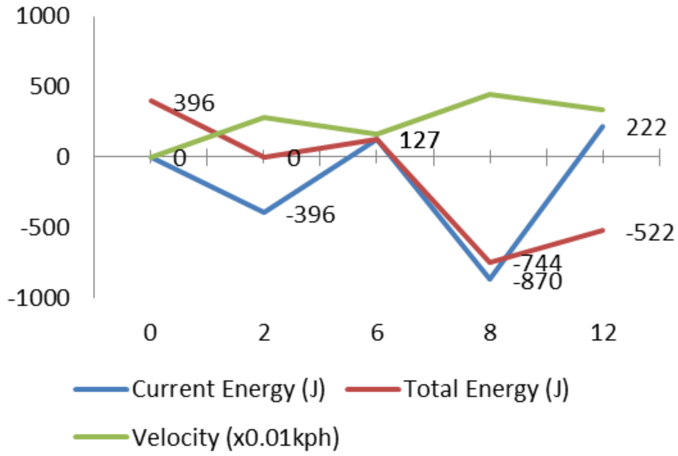

FIGURE 7. Energy and velocity vs. drive cycle time for Ta<Td.

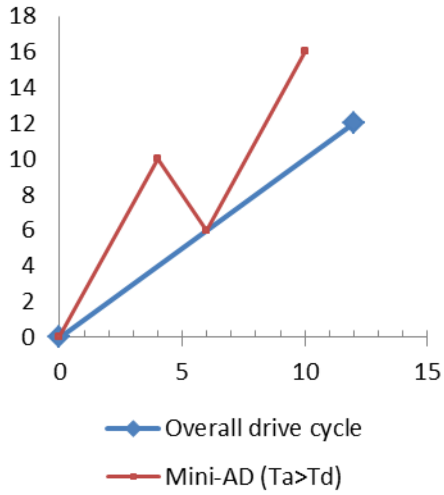

FIGURE 8. Kill time for Ta>Td.

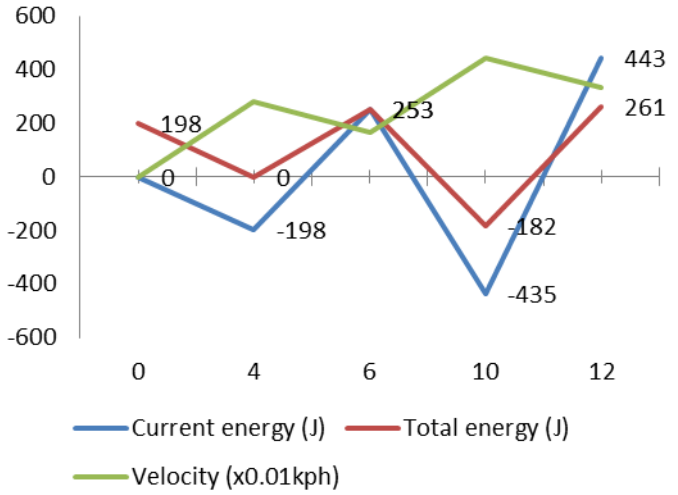

FIGURE 9. Energy and velocity vs. drive cycle time for Ta>Td.

TABLE 2. Max duration in 2nd Mini-A cycle.

Time variations	#Mini-A cycle	Kill time	Duration in 2nd Mini-A cycle	% Duration in 2nd cycle
Ta < Td	2	6.3s	0.3s	15.0%
Ta = Td	2	9.0s	1.0s	25.0%
Ta > Td	2	8.5s	2.5s	62.5%

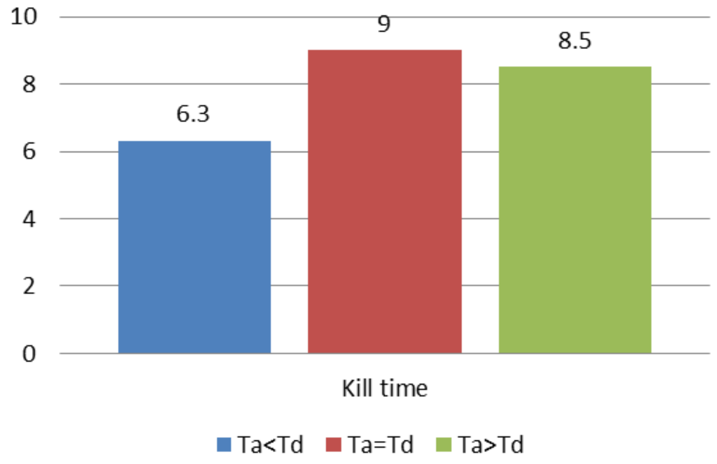

FIGURE 10. Comparison between three time variations.

CONCLUSIONS

From this research, the result show that the new driving strategy capable to increase the operational time of flywheel hybrid. Ta > Td variant increase the operational time up to 62.5% compared to nearest time is 25.0% only. The remaining energy in Ta > Td also show the maximum value with 41.8% energy remains. Therefore, to obtain the maximum kill time, the Mini-A duration must be longer than Mini-D duration. By further optimize the other two parameter, the flywheel hybrid can increase the remaining energy in second Mini-A and can enter the next Mini-A cycle.

ACKNOWLEDGEMENT

The authors would like to acknowledge Universiti Teknikal Malaysia Melaka (UTeM) under Short Term Grant Scheme (PJP/2012/FKM(17C)/S01109) and Ministry of Higher Education (MOHE) under RAGS Grant Scheme (RAGS/2013/FTK/TK07/01/B00045) for supporting and funding this research activity.

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