F2012-E14-014

A TEST BED FOR DEVELOPMENT OF LOW COST HYBRID PROPULSION

[1]Chanumolu Raviteja*; [1]Pantagani Sudhir Kumar; [2]Atluri V Prasad; [1]Ghosal Ashitava
[1]Department of Mechanical Engineering, Indian Institute of Science, India;
[2]Propulsion System Research lab, GM R&D Centre, Warren, MI

KEYWORDS – Urban mobility, Hybrid, Test bed, Parallel, Hub motor

ABSTRACT

The three-wheeled vehicle, commonly called an “auto-rickshaw” with a four-stroke petrol, LPG or CNG engine is one of the most common and affordable means of transportation(for hire) in Indian cities. It is a small, highly manoeuvrable vehicle and ideally suited for the narrow and traffic clogged streets of urban India. Electric and hybrid vehicles are particularly suited for use in urban areas since city transportation is mainly characterized by relatively short driving distances, low continuous power requirements, long idling times and high availability of regenerative braking energy. These characteristics, when carefully incorporated into the design process, create valuable opportunities for developing clean, efficient and cost effective urban vehicle propulsion systems. A novel, low cost, test-bed for experimenting with hybrid propulsion systems for urban areas is developed and presented in this work. The main objective of this work is to study the performance of a parallel hybrid configuration with DC hub motor and an IC engine. The hybrid configuration in this case adds speed to the wheel output unlike the normal power split configuration which adds torque. The addition of speed is done by connecting the output of engine and CVT to the stator of an electric hub motor. The test-bed can also be used to experiment with series hybrid configuration with inclusion of a power generating circuitry in the existing setup.

INTRODUCTION

It is almost universally accepted that the urban human population will continue to increase monotonically and significantly for the foreseeable future [1]. The population growth is expected to be more in less developed countries, as opposed to developed countries, and it is expected go up from 2.5 billion to more than 4 billion by 2025 in less developed regions. In particular, according to an UN study done in 2002, most of the new and rapid urbanization will take place in India, China, South-East Asia, Latin America, Africa and South America which are the less developed regions of the world. This increased urbanization and economic growth and the accompanying need for personal transportation and mobility is expected to lead to increased demand for energy, increased emission of CO2 and other greenhouse gasses, increased environmental impact and pollution[2], and result in increased congestion on the existing roads. One of the key questions is how we can address these challenges and develop sustainable personal mobility solutions. Some of the key requirements (in addition to many other issues) for the next generation urban vehicle must be a) high fuel efficiency, b) low or zero emissions and c) compact design to negotiate crowded roads. It is becoming increasingly clear that the future is biased towards “small, beautiful, drivable and affordable’’ vehicles. It is becoming increasingly clear that hybrid electric vehicles (HEVs) are the most promising propulsion systems [3-5].

Numerous parallel hybrid configurations have been proposed [6-9]. Parallel HEV, such as a Toyota Prius, consist of a planetary gear train with an electronic control unit to combine the power from both the IC engine and electric motors. The main disadvantage of this type of vehicle is the complexity of power train. This paper presents a test bed used for validation of novel propulsion architecture for HEV where the power addition is by adding the speeds of both IC engine and electric hub motor. The power requirements of vehicle according to modified Indian drive cycles show that the maximum power requirements for an auto-rickshaw is 80% of the time below 4KW [10], and thus two 2KW brushless DC hub motor are enough to satisfy power requirements. Hence the test bed consists of a 2KW DC hub motor and a 175cc gasoline IC engine. The test bed can operate in three different modes. a) Electric only, b) Hybrid, and c) Engine only with holding torque applied to electric motor.

KINEMATICS OF THE MECHANISM

The test bed has been designed keeping in the mind the eventual application of the technology for an auto-rickshaw. Figure 1 shows the schematic of the test bed. The crankshaft of the single cylinder IC engine has been connected to a belt driven CVT with a reduction gear at the output of CVT. The output of CVT is connected to an electromagnetic clutch which can be used to connect or disconnect the engine from DC motor while switching between different modes of hybrid configuration. The other end of the clutch is connected to the stator of electric hub motor through a spring loaded electromagnetic brake.

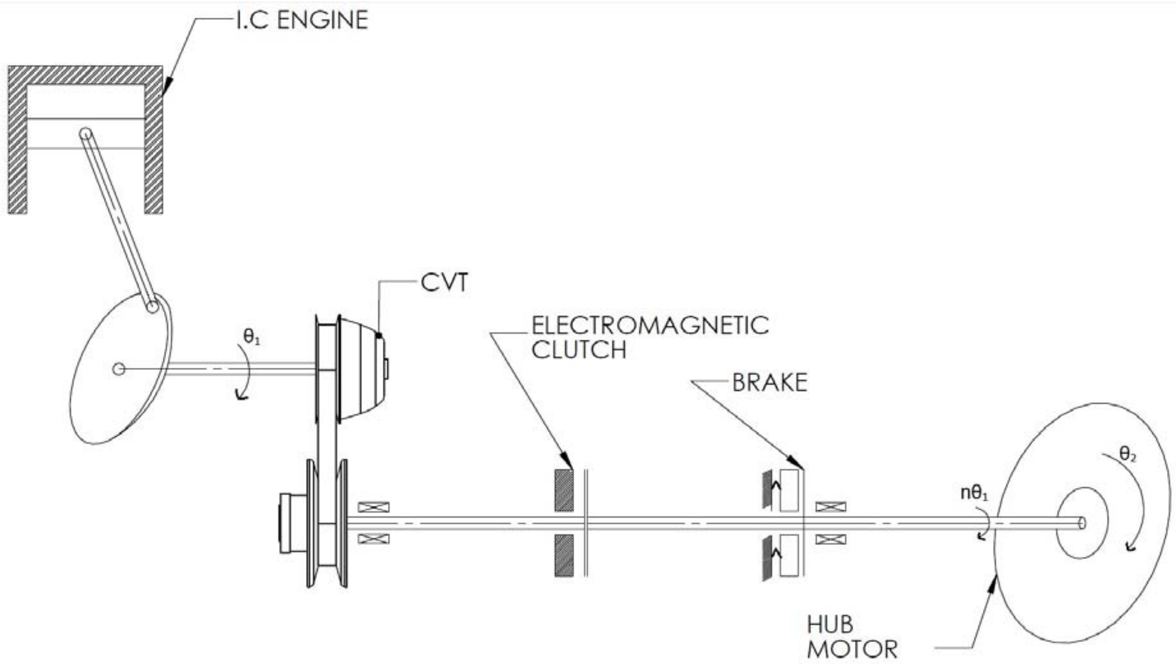

Figure 1: Kinematic diagram of test bed

Let the output speed of the CVT be denoted by ω_1 and the electric motor by ω_2, and the output of the setup be denoted by ω_3. The mechanical speed coupler can be defined by [11]

$$\omega_3 = k_1\omega_1 + k_2\omega_2 \qquad [1]$$

where k_1 and k_2 are constants associated with the structural and geometric design of the coupler which is unity in this case. Among the three speeds ω_1, ω_2 and ω_3, two of them are independent of each other and can be controlled independently. Due to the constraint of power conservation, the torques are linked together by

$$T_3 = \frac{T_1}{k_1} = \frac{T_2}{k_2} \quad [2]$$

The output of IC engine is (T_1,ω_1) and the output of motor is (T_2,ω_2), resulting in the output configuration being (T_3,ω_3). Since k_1 and k_2 are unity in our case, T_1, T_2 and T_3 are equal and the speed of the output are related as

$$\omega_3 = \omega_1 + \omega_2 \quad [3]$$

Hence the speed of the output is the sum of the speeds of IC engine and electric motor.

EXPERIMENTAL SETUP

The experimental setup consists of a 175 cc single cylinder gasoline engine coupled with a CVT. The output of CVT is connected to one end of the electromagnetic clutch. The other end of electromagnetic clutch is connected to stator of 2KW Brushless DC hub motor through a spring loaded electromagnetic brake. The hub motor is connected to the controller using the slip ring for a the main power supply and another slip ring used to connect the hall sensors used to sense the position of the hub motor. The rotor of the hub motor is connected to an eddy current dynamometer. Figure 2 shows the experimental setup used.

Figure 2: Experimental setup for low cost hybrid propulsion

EXPERIMENTAL PROCEDURE

The experiments are done in two modes -- a) electric only b) hybrid. In electric mode the power to clutch and brake is disabled. The clutch is disengaged and the brake holds the shaft from rotating due to the counter torque. The throttle of electric motor is set to the desired value and then the dynamometer is loaded by varying the torque linearly and the change in speed and torques are logged on a computer.

In the hybrid mode the power to clutch and brake is enabled. The clutch is engaged transmitting the power from IC engine to the stator of the brushless DC hub motor. The brake is disengaged allowing the shaft to rotate freely. The throttle of the IC engine is set to a defined position and the electric motor is set at the same position as in the only electric mode to compare results.

RESULTS AND DISCUSSION

The torque and speed of the engine are the main parameters which define the output power the engine. The power addition in our case is due to the addition of speed at constant torque. The figures below describe the shift in curves due to the power addition.

Figure 3 shows the torque speed curves of both electric (green) and hybrid (blue) mode. The blue curve is plotted with an initial output engine rpm (after the CVT) of 380 and the motor at an initial rpm of 800. In the electric mode the motor is supplied the same amount current, i.e. the motor rpm is kept same as that in the hybrid mode. From the above figure we can observe that there is a shift in the curve along the speed axes showing that speed addition takes place in this case. The shift in the toque also implies the increase in maximum as well as low power.

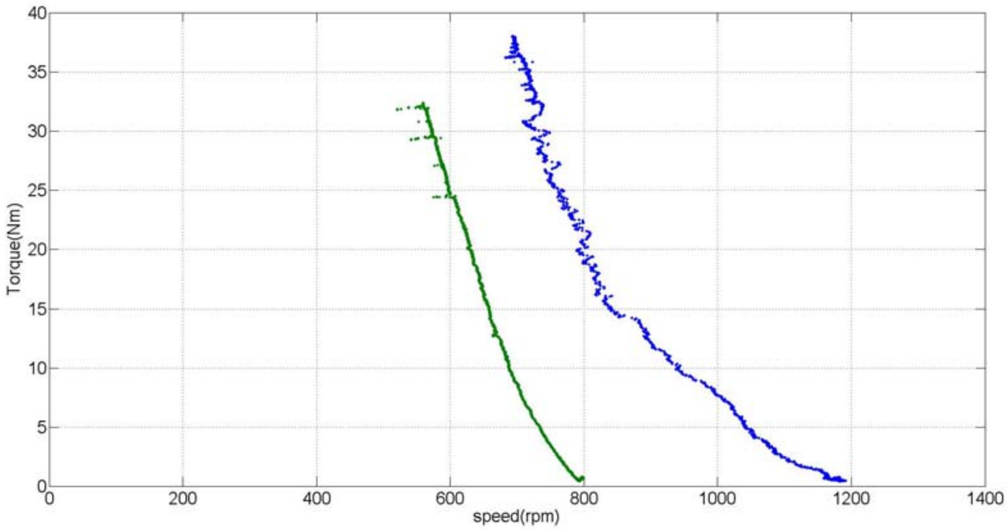

Figure 3: Torque speed curves with an initial rpm 380 of IC engine and 800 for electric motor.

As seen in figure 3, the initial difference in rpm between DC motor alone and DC motor plus IC engine is 400. As the load increases, due to the change in the ratio in the CVT, the blue and green curves come closer. After a load of 14 N, the CVT ratio do not change any more and one see that both the curves are nearly parallel to each other. *This clearly demonstrates that speed addition is taking place.*

Figure 4 shows the operation of IC engine at lower throttle levels with an initial output rpm after the CVT at a low180 rpm and the electric motor running at full throttle with initial output rpm as 800. Here also we can observe a small shift in the torque speed curves similar to the figure 3 but the shift is smaller as the throttle opening of IC engine is lower compared to the previous case.

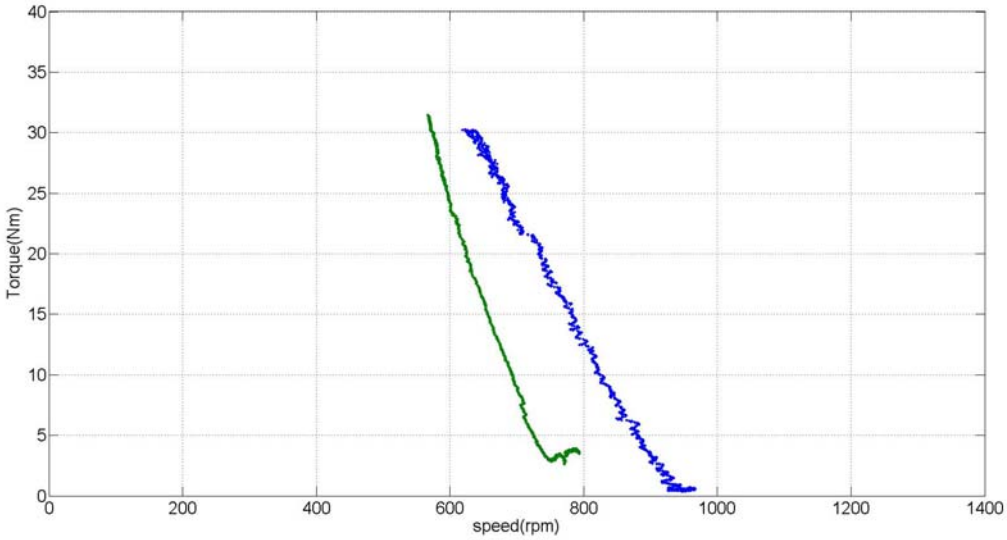

Figure 4 Torque speed curves with an initial rpm 180 of IC engine and 800 for electric motor

Figure 4 shows the operation of IC engine at approximately 50% throttle with an initial output after the CVT at 560 rpm and the electric motor running at partial throttle with initial output rpm as 640. Here also we can observe a shift in the torque speed curves similar to the figure 3 and 4 but the shift is relative to the output rpm of the engine which is dependent on the throttle opening of IC engine.

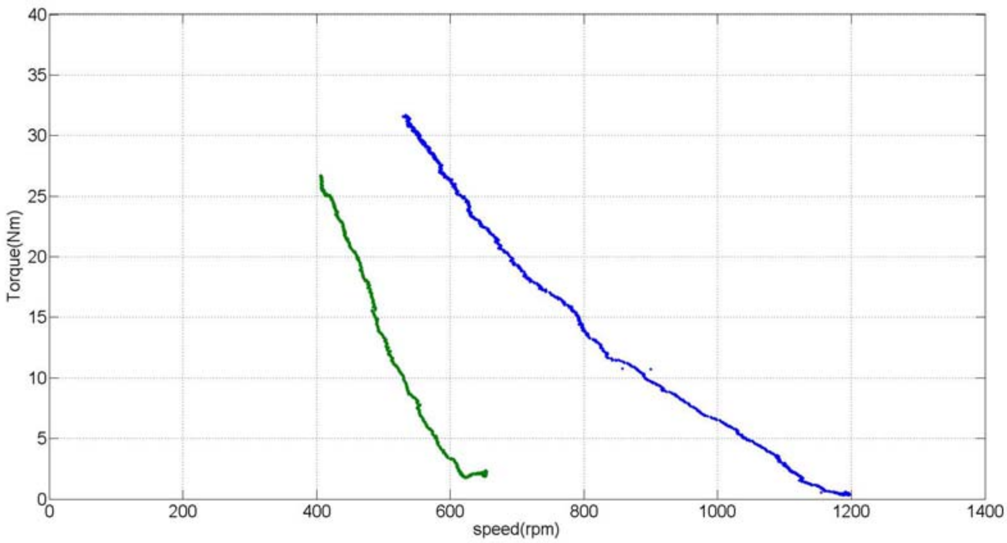

Figure 5 Torque speed curves with an initial rpm 560 of IC engine and 640 for electric motor

From the above figures 3, 4 and 5 we can observe that the shift in torque speed curve along speed axis is equal to speed output of the engine. The IC engine used in this case is controlled manually. If the IC engine is controlled by ECU to maintain a constant rpm at the output of CVT the curves are expected to be parallel to each other with an offset equal to the rpm of the engine.

CONCLUSIONS

One of the goals of an urban transport is to use the electric mode most of the time and use the hybrid mode when the power supplied by the electric motors is not enough to drive the vehicle or when the battery charge is very low. In this paper, we have demonstrated the feasibility of a concept where a DC servo motor provides power and only when necessary power is added by addition of speed as opposed to traditional addition of torque in common hybrids. The experimental results clearly show the shift in the torque-curves along the speed axis consistent with the theory. One of the main advantages of the concept is that the use of CVT and the direct coupling of the engine to the stator of the electric motor. This reduces the complexity in powertrain by avoiding planetary gears and electric control which is required in common hybrids. The absence of a gear box also reduces the cost and space requirements drastically and this type of architecture can be used in smaller vehicles such as auto-rickshaw and small cars. The developed setup can also be used to charge the batteries using IC engine by coupling the output of the IC engine to a generator and thus can be also be easily modified to demonstrate a series hybrid configuration. The main disadvantage of this setup is that the belt type CVT limits the maximum torque that can be transmitted. For further work we plan to use an ECU for a better control of the engine output.

REFERENCES

[1] http://encarta.msn.com/media_701500251/Urban_Population_Growth.html

[2] Sharma, A and Roychowdhury, A., ``Slow murder: the deadly story of vehicular pollution in India'', Centre for Science and Environment, New Delhi, 1996.

[3] Bitsche, O. and Gutmann, G., ``Systems for hybrid cars'', *Journal for Power Sources*, Vol. 127, pp. 8-15, 2004.

[4] Heather, L. M. and Lester, L. B. ``Evaluating automobile fuel/propulsion system technologies'', *Progress in Energy and Combustion Science*, Vol. 29, 2003, pp. 1-69.

[5] Tate, E. D., Hapster, Michael, O., and Peter, J. S., ``Electrification of the automobile: From conventional hybrid, to plug-in hybrids to extended-range electric vehicles'', *SAE Technical Paper Series*, 2008-01-0458.

[6] Hattori, N., Aoyama, S., Kitada, S., and Matsuo, I., 1999, "Functional design of a motor integrated CVT for a parallel hybrid HEV'', *SAE Paper No. 1999-01-0753*.

[7] Nedungadi, A., Walls, M., and Dardalis, D., 1999, "A parallel hybrid drive train'', *SAE Paper No. 1999-01-2928*.

[8] Severinsky, A. J., 1994, "Hybrid electric vehicle," United States Patent No. 5,343,970.

[9] Welke, K., Ochs, M., and Schmidt-Brucken, H., 1997, "Single shaft parallel hybrid drive system", *SAE Paper No. 970286.*

[10] Ghosal, A., Prasad Atluri, ``Architectural study of hybrid electric propulsion system for Indian cities'', IFToMM World Congress, Mexico, June 2011.

[11] Ehsani, A., Gao, Y., Emadi, A, "*Modern electric, hybrid electric and fuel cell vehicles: Fundamentals, theory and design*", CRC Press.