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ISSN: 0193-4120 Page No. 5263 - 5269

Experimental Study of Speed Range for a Hybrid Electric Powertrain System

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Article Info
Volume 83
Page Number: 5263 - 5269
Publication Issue:
March - April 2020

Article History
***Article Received**: 24 July 2019*
***Revised**: 12 September 2019*
***Accepted**: 15 February 2020*
***Publication**: 27 March 2020*

Abstract

In a hybrid drive train initial loads are taken by a motor and after a certain speed internal combustion engine starts working in tandem with the motor to provide load sharing. This transit in power from motor to engine has to be achieved in such a way that there are no vibrations experienced by the passengers and no damage is sustained by either power source or any auxiliary components. In an Internal Combustion Engine there will be an optimum specific fuel consumption range for a particular load and Engine Speed. When the engine is operating in this optimum range of specific fuel consumption, switching from a brushless DC motor to an internal combustion engine will result in a better fuel consumption rate. This paper discusses the specific fuel consumption characteristics in an internal combustion engine to determine the optimum speed range in a hybrid electric system. A four cylinder four stroke 65 hp petrol engine coupled to a hydraulic dynamometer was used to determine engine performance to understand the characteristic curve of fuel consumption at various loads from 4 kg - 8 Kg. The experimental results show a decline in specific fuel consumption characteristic curve for the speed range of 1500-2000 rpm. An interpolation model can be applied to understand the speed range for various loads. The transit in power from a brushless DC motor to an internal combustion engine during the above mentioned speed range is more viable and fuel efficient. The scope of this research extends to the transition from IC to hybrid and electric vehicle segments in current scenario of evolution in the automotive industry.

Keywords; *Hybrid Vehicles, Battery electric vehicle, Specific fuel consumption*

I. INTRODUCTION

1.1 Background

According to International Energy Agency (IEA), electric car deployment has been growing rapidly over the past ten years, with the global stock of electric passenger cars passing 5 million in 2018, an increase of 63% was observed from the preceding years. Around 45% of electric cars on the road in the year of 2018 were in China – a total of 2.3 million. In comparison, Europe accounted for 24% of the electric vehicle of the entire world whereas United States accounted for 22%.**Electric mobility is expanding at a rapid pace.** There is a high potential for electric vehicle in urban settlements [1].

Specific fuel consumption(SFC) is the amount of fuel consumed for producing a unit brake power in the engine[2].The SFC changes according to load conditions of the engine [3].In an internal combustion engine (ICE) there will be an optimum specific fuel consumption range for a particular load and engine speed [4]. Generally, SFC will decrease if we increase the load up to particular level and it will start to increase after that point.SFC acts as an indicator for the fuel economy of the vehicle irrespective of the power source [5].**Specific fuel consumption for an engine is a function of engine effective pressure and rotations per minutes [6].**

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1.2 Motivation

Technology advances are delivering substantial cost cuts. Key contributor for the development is battery chemistry and expansion of production capacity in manufacturing plants. On a well to wheel basis, greenhouse gas (GHG) emissions from hybrid electric vehicles are lower than for conventional internal combustion engine (ICE) vehicles [7].Hybrid vehicles implementation could be in terms of the fuel used in the internal combustion engine of vehicles (fuel hybridization) or the combination of motive force from an internal combustion engine and the energy stored in a storage device (drive – train hybridization). This system is known as electric – internal combustion hybrid. Battery electric vehicle and hybrid vehicles both have greatly reduced emissions while operating on electricity [8]. Growing market share and improvement in battery technology poses a threat to established automotive industries [9].The fuel consumption that originates from aggressive driving is larger in percent basis for hybrid electric vehicle [10].This signifies that the speed range has more impact on fuel consumed when it is analyzed in a hybrid system. Therefore it is the need of the hour to propose a range of speed wherein the affect on fuel consumption due to the transitioning from electric energy to an ICE is minimal.

1.3 Objective

An electro-mechanical switching system is used and power is transmitted through a dedicated transmission system. This paper discusses the specific fuel consumption characteristics in an internal combustion engine to determine the optimum speed range in a hybrid electric system. A speed range is proposed wherein the transition from electric motor to an internal combustion engine can be obtained with minimal losses. Fuel consumption when the vehicle operates at the proposed speed range should be as less as possible.

II. METHODOLOGY

The experiment was conducted by varying the load and, the fuel consumption rate was plotted. The flowchart shows the processes carried out to achieve the final output and the results were pictorially represented using a characteristics curve for specific fuel consumption.

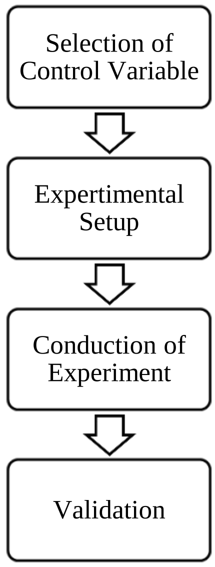

Fig 1: Flowchart of experimental procedure

2.1 Selection of Control variable

The criteria being looked into as a control variable for switching was specific fuel consumption at different rotations per minute (rpm). Specific fuel consumption relates the amount of fuel consumed per unit amount of power generated thereby providing a much conclusive relation between the amounts of fuel required.

2.2 Experimental Setup

The test rig used was coupled to a 4-cylinder 4 stroke water cooled petrol engine, Spark ignition (MPFI). Specifications of the engine are shown in table 1.

Table 1:-Engine Specifications

Make	Wagon R
Brake Horse Power	65 HP @6000 rpm

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Speed (Working RPM)	1500-2000
No of Cylinders	Four
Compression Ratio	10:1
Bore	71mm
Stroke	74mm

An engine of aforementioned dimensions and make was chosen to represent the engine category of automobile that is most widely used. Most of the automobile are using multipoint fuel injection system in petrol engines.

Table 2:-Test Rig Constants

Parameter	Constants
Orifice Diameter	20mm
Density of Air	1.193kg/m^3
Density of Water	1000kg/m^3
Density Of petrol	0.72 gm/cc
C_v of Petrol	44500 KJ/kg
C_p of Water	4.18 KJ/kg.K
Loading	Hydraulic Dynamometer

The test rig constants used for calculating power, torque and specific fuel consumption is shown in table 2.

2.3 Conduction of Experiment

The engine was operated by ensuring fuel supply, cooling water supply, with electric starter. The dynamometer was adjusted to full load (8kg) and rpm was varied and the following parameters were noted. Throttle valve was adjusted such that load remained constant over the range of working rpm of engine as specified in Table 1. The experiment was also carried out for half load (4kg) and 75% of full load (6kg) to determine the trend of the SFC characteristics curve.

- Manometer Reading
- Time for consuming 10 cubic centimeter (cc) of fuel

Figure 2:- Engine Fixture

Powertrain assembly is housed inside a fixture showed in figure 2. A throttle was mounted to control the valve opening to vary the rpm when the load was varied.

Table 3:- Recordings for Full Load

S. No.	Engine Speed	Time Required for consumption of 10 cc of fuel	Manometer Reading
	rpm	seconds	mm of Hg
1	1400	13.38	68
2	1600	12.10	75
3	1800	11.37	70
4	2000	8.84	80

Table 4:- Recordings for 75% of Full Load

S. No.	Engine Speed	Time Required for consumption of 10 cc of	Manometer Reading

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		fuel	
	rpm	seconds	mm of Hg
1	1400	14.40	36
2	1600	13.20	46
3	1800	12.10	52
4	2000	10.26	62

Table 5:- Recordings for half Load

S. No.	Engine Speed	Time Required for consumption of 10 cc of fuel	Manometer Reading
	rpm	seconds	mm of Hg
1	1400	17.20	24
2	1600	16.20	32
3	1800	15.70	39
4	2000	13.00	49

The engine was allowed to run for 5 minutes before the values were recorded so that the engine achieves equilibrium and fluctuations in load and speed values are negligible. The time required for the consumption of known quantity of fuel at the respective rpm and the differential pressure reading were tabulated. A stop watch was used to record the time taken to consume 10cc of fuel. The observations of the experiment with Full load, 75% of full load and half load are tabulated in table 3, table 4 and table 5 respectively. The rig consists of a fuel tank of 2 litre capacity connected to a measuring flask. A manometer is connected to indicate the pressure difference corresponding to the load change

Figure 3:-Hydraulic Dynamometer

A hydraulic dynamometer coupled to the test rig in figure 3. The load applied by the dynamometer was varied using the chain drive mechanism connected to the valve opening.

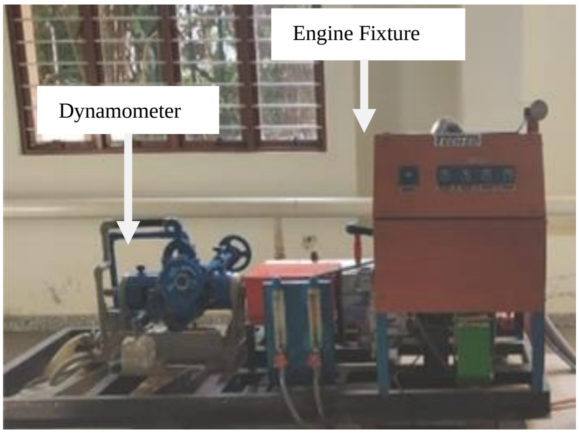

Figure 4:-Dynamometer and engine fixture

The hydraulic dynamometer is connected to the engine in figure 4.The dynamometer provides the loading for the engine.

Figure 5:-The entire assembly of the test bed

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Position of Hall Effect sensor has been highlighted in figure 5.This sensor is used to find the rotations of the shaft of dynamometer..

Figure 6:-Ignition Switch and Throttle

The position of the throttle and the ignition switch is in figure 6. The throttle of the engine and the valve opening for the application of load was continuously adjusted so as to give the constant load at varying rpm.

2.4 Validation

In order to calculate Specific fuel consumption power and total fuel consumption is determined using following formulas.

Torque on the engine (T),

$T = 0.358 * L \ \ kgm$---------------------------- (1)

The formula for torque relates the load applied by the dynamometer (L) and the dynamometer constant as shown in equation 1.

Power output (P),

$P \quad = \frac{2 * \pi * N * \ T \ * 9.81}{60000 * 0.75} \quad kW$------------------------ (2)

The formula to find brake power of an engine where "N" represents the rpm, "T" represents torque acting on the engine and mechanical transmission efficiency taken as 75% in equation 2.

Total Fuel Consumption (TFC),

$TFC = \frac{V_f * \rho * 3.6}{t} kg/hr$-------------------------- (3)

V_f = Reference Volume of fuel = 10 cc.

t= time taken for consuming 10 cc of fuel

ρ=Density of petrol= 0.72g/cc

The formula for total fuel consumption is highlighted in equation 3. The rate of mass of fuel intake provides the value for total fuel consumed

Specific Fuel Consumption (SFC),

$SFC = \frac{TFC}{BP} \ kg/kWh$-------------------------- (4)

Where; BP = Brake power, kW

TFC = Total Fuel Consumption, kg/hr

The ratio of total fuel consumed and brake power gives the specific fuel consumed calculated using equation 4.Specific fuel consumption highlights the amount of fuel per unit of power produced by the engine

III. RESULTS AND DISCUSSION

For different loads corresponding values of torque were calculated. For different torque values the brake power, total fuel consumption and specific fuel consumption values were recorded. The value of torque for full load, half load and 75% of full load is calculated using equation 1.

Table 6:-Results Table for Full load (8kg)

Torque:-2.864 kg-m				
S No.	Engine Speed	Brake Power	Total Fuel Consumption	Specific Fuel Consumption
	rpm	kW	kg/hr	kg/kW.h
1	1400	5.48	1.93	0.353
2	1600	6.27	2.14	0.341
3	1800	7.057	2.27	0.321
4	2000	7.841	2.93	0.373

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March - April 2020
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Table 7:-Results Table for 75% of Full load (6kg)

Torque:-2.15 kg–m				
S No.	Engine Speed	Brake Power	Total Fuel Consumption	Specific Fuel Consumption
	rpm	kW	kg/hr	kg/kW.h
1	1400	4.07	1.62	0.440
2	1600	4.70	1.99	0.420
3	1800	5.30	2.16	0.410
4	2000	5.89	2.59	0.440

Table 8:-Results Table for half load (4kg)

Torque:-1.43Kg-m				
S No.	Engine Speed	Brake Power	Total Fuel Consumption	Specific Fuel Consumption
	rpm	kW	kg/hr	kg/kW.h
1	1400	2.75	1.55	0.556
2	1600	3.14	1.60	0.515
3	1800	3.53	1.65	0.470
4	2000	3.92	1.99	0.510

The calculated values in table 6, table 7 and table 8 are pictorially represented in figure 8.

For full load of 8kg the torque value of 2.864Kg-m was used to calculated total fuel consumption and specific fuel consumption over the working range of engine as given in the table 6. The torque value was kept constant while varying the value of rpm in Equation 2 to calculate brake power.Time required to consume 10 cc of fuel for the selected rpm is used to calculate total fuel consumption as in Equation 3. The specific fuel consumption value at the particular speed and load, is calculated by taking the ratio of total fuel consumption and brake power.

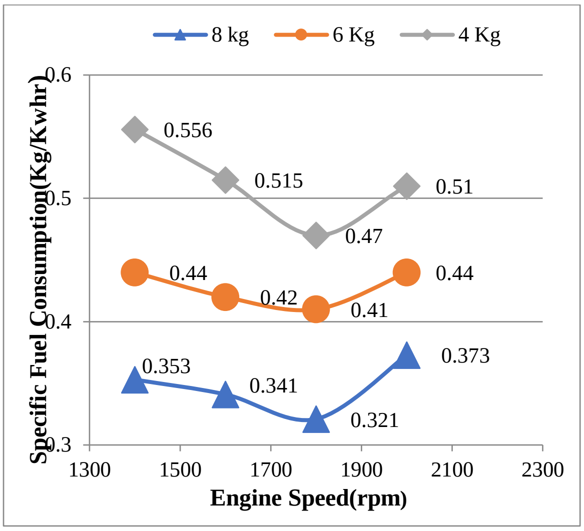

Figure 7:- Characteristic curves for the specific fuel consumption

The curves for specific fuel consumption showed a declining trend at full and partial loads as shown in the figure 7. For the curve corresponding to half the load (4kg) the least specific fuel consumption was observed to be 0.47Kg/kW.h at 1800 rpm.Similarly for the loads of 6kg and 8kg least specific fuel consumption was observed to be 0.41 kg/kW.h and 0.321 kg/kW.h respectively.

The correlation between the fuel consumption and engine speed was established. Many studies have been proposed in the past on hybrid electric systems. But, no studies have proposed using specific fuel consumption of an engine as a control variable to signify the speed range for transit in power. . On varying the load by 25%, the mathematical analysis showed no significant changes in total fuel consumption, however specific fuel consumed showed variation of 20%. The experimental results showed that specific fuel consumption reduces during the speed range of 1500 - 2000 rpm for the engine for the various loads. This speed range is ideal range for the hybrid electric powertrain system

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to switch from electric prime mover to an internal combustion engine.

IV. CONCLUSION

A four cylinder four stroke 65 hp petrol engine coupled to a hydraulic dynamometer was used to determine engine performance to understand the characteristic curve of fuel consumption at 8 kg, 6 kg and 4 kg loads. Generally the engine rpm during the city drive varies from 800-2000 rpm, during which the fuel consumption is more and reduces the efficiency of the system. An electric motor can be implemented during this speed range to reduce the fuel consumption rate in city drive. In this paper an engine was used to highlight the range of speed suitable for transition from an electric motor to an IC engine which signifies that current technology employed in automobile industry can implement such transition in power without major difficulties. The experimental results showed that specific fuel consumption reduces during the speed range of 1500 - 2000 rpm for the engine. The implementation of a hybrid system will result in mechanical losses. However the overall fuel efficiency can be improved with hybridization of the system within the proposed speed range

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