ANALYSIS OF A CONCEPT FOR PRUDENTIAL UTILISATION OF EXCESS POWER GENERATED IN IC ENGINES DURING CLUTCH ENGAGEMENT PROCESS

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Abstract— With increasing number of vehicles taking the roads, traffic congestion has become a routine problem in all major cities and towns. For a vehicle moving throughout these long queues, the engine may either be in an idling situation or the power may be drawn along with partial engagement of the clutch plates. In such cases, the engine power is not efficiently used during vehicles traction, as the engine will be operating with maximum efficiency at rated load and it will decrease with deviations from rated load condition on either direction. For a typical internal combustion engine, the fuel consumption would increase with increased brake power productions. The rate of increment in specific fuel consumption of the engine is much lesser for low brake power than for higher brake power. So when the clutch plates are fully engaged at low partial loads or partially engaged, additional rate of consumption of fuel for producing additional power will be very low compared to for producing the same amount additional power at higher loads, where it is highly needed. Hence additional (surplus) power can be produced at low load conditions such as idling or partially engaged clutch conditions, and harnessed and utilized later on when the vehicle demands high power at higher values of specific fuel consumption. The concept is validated on a typical test engine in the laboratory, and the results are normalized so that it can be applied for any engine.

Keywords-- idling, clutch, traction, internal combustion engine, brake power, specific fuel consumption, energy conservation

1. INTRODUCTION

Traffic congestion is one of the major problems faced by all metropolitan cities around the globe. Most of the major roads and intersections in and around city premises may contain long standing queues of commuter and public transportation vehicles during peak hours and this trend is most probable to increase moving on to the future.

Once the vehicle is moving through these long queues, it is obvious that using the clutch mechanism, the drivers can put the vehicle's engine at partial loads or no load depending on the power requirement. When in a partially clutched or fully disengaged engine stages, there is slippage or otherwise no literal contact between the driving and driven shafts on either sides of the clutch setup, as described in the Machine Design reference books like Shigly[1]. In both these cases it is evident that the complete power that can be produced by the engine remains underutilized for vehicular traction, instead only a fraction of the power that can be produced is drawn from the engine. Venu, [2] gives a comprehensive analysis of the transmission procedure during engagement and disengagement of the clutch plates and a relative velocity created between the pressure plate and friction plate\clutch disk, in a clutch setup, during its operation. This slippage owing to the power that can be produced not being efficiently utilized, can incur additional fuel consumption. Even though this may seem to be a small quantity, over the number of cycles and duration of time that the vehicles spend on traffic blocks, it can build up into a much bigger loss as evidenced by S. Gangopadhyay and P. Parida [3]. In such cases the no load runs of the can be analogous to idling of engine because in the long queues at the intersections and traffic blocks the idling can be due to the clutch plates being partially engaged or fully disengaged from the engine crank shaft. Gangopadhyay S. and Parida P.[3] puts forth a more general analysis in idling losses, rather than being limited to a specific data on power losses due to partial clutching or fully disengaged engine runs. Till date the scope of conserving this underutilized power is not thought about and the fuel losses during partial clutching was seen as an unavoidable one and a compulsory wastage incurred by the vehicle in its run through the busy roads and intersections. This kind of engine run can be termed as a fuel surplus condition while more fuel than what is required is burned in the engine cylinders.

On the other hand it is just the contrary, once the vehicle demands high power like in the cases of a steep slope or an overload. If the power demanded is so high, the engine fails to meet up with this demand, simply because the demanded power may just be or even over that threshold of power or torque which that engine could provide. This condition can be termed as fuel starvation since even though at full throttles the engine fails to meet up with the demanded high powers.

Even though the two problems mentioned above are the extreme conditions of an engine's run, if a balance could be struck between the two, the power deficit during the fuel starvation can be met up with the underutilized power, available in surplus during the clutch engagement/disengagement processes when the engine is left and no loads or partial loads. Surprisingly this has not been done before to satisfactory extends and thus this paper aims to throw light to the following two areas:

- The feasibility of harnessing that underutilized power present during engagement or disengagements of clutch plates, at the lower rungs of an engine's run (5-15% of rated load) when it consumes lesser fuel for unit rise in BP and then providing it to the upper rungs of its run (maximum power productions accounting roughly to 175-200% of the rated load) when unit rise in brake power consumes high quantities of fuel (section 2 and section 3).
- To substantiate this claim to a larger extend and to see if this nascent idea could stand, a case study was done on a test engine and was thereby projected to a higher powered engine of the same characteristics (section 4).

2. THE PROBLEM STATEMENT

The stages of the engine, during clutch engagement and disengagement processes, first at partial loads and then at no loads, when it is fully disengaged from transmission, are the areas of interest. Hence the situation is explained as follows:

- Engine partially loaded: By partial engagement of the clutch plates, a slippage is allowed between the driving shaft and driven shaft on either side of the clutch assembly. By doing so the complete power, which can be produced by the engine, is not passed on to the driven shaft and to the subsequent mechanical components to follow. Thereby the power drawn is only a fraction of what is produced by the engine,
- Engine fully disengaged from transmission: the aim of fully disengaging the engine is to cut off power from the driving shaft to the driven shaft. The clutch plates disengage to isolate the engine and the power flow is terminated at the clutch setup. As no power is drawn from the engine for transmission purposes, the brake power produced at the rated speed is a small fraction of the engine capacity and the engine remains underutilized.

It is interesting to note that both the above conditions tend to occur at the first 10-25% of the brake power values that can be produced by the engine because once the clutch disks are disengaged, the primary intension is to temporarily cut off the power drawn from engine and when this is done, the engine tends to attain its rated speed, provided it is at zero fuel throttling.

For a typical internal combustion engine, the mechanical efficiency curve, as shown in Fig.1 takes the peak value at rated conditions. Once the engine is partially loaded, during the engagement/disengagement process of clutch plate, the efficiency values of the engine shift to the off design conditions at either sides of the peak in fig 1. To expect a continuous and reliable performance, the engine must be operated at its rated conditions. Partial loading of the engine is most likely to fall towards the left of the peak value efficiency. Hence it is safe for any secondary power harnessing device to engage onto the engine till the rated power conditions are reached, provided the fuel consumption is in check and economical.

Let at the so called partial or full disengagement of clutch plates during the lower Brake Power regions in an engine's run, 'x' kW is the Brake power produced at a fuel consumption of y cc/sec. Since there is no full contact between the driving and driven shafts on either sides of the clutch plate, as stated by Venu [2], the whole of the 'x'kW value is not utilized for traction. Instead only a fraction of it is consumed while the other fraction is left unused. The following sections articulates the feasibility of harnessing that unused fraction of power and utilizing it later on when high power is being demanded of the engine.

2.1 THEORETICS OF THE CLAIM

When engine is disengaged by the separation of the clutch plates, the load is taken off from the engine and the engine runs at its rated speed. The power produced at this speed comes well under the earlier said low Brake Power regions of 10-25% of the rated BP.

From the principles of mechanics,

$$P \ \alpha \ T.\ \omega_{rated}$$

According to the above expression, when more power is needed for traction, the speed being constant, torque must be increased. This in turn increases the fuel consumption. Thus it can be claimed from this equation that the torque, (thereby the fuel consumption) for 10-25% of maximum BP must be much lesser than the torque (and hence fuel consumption), at a power which is 80-95% of maximum BP.

$$\text{i.e.} \quad \text{Fuel Consumption at (0.1 to 0.25) of } BP_{max} << \text{Fuel Consumption at (0.8 to 0.9) of } BP_{max}$$

The above concept is illustrated graphically in figure 2. For a typical IC engine, the fuel consumption would increase with increase in power outputs. Hence in an ideal case, the TFC vs. BP graph for an IC engine should have an increasing trend of slope as shown in Fig. 2. The left and right sides of the graph can be characterized by fuel consumptions at low BP or no loads and high BP productions respectively. On further closer analysis of the graph, it's more evident that even though throughout its range the slope is increasing, the rate of increase is gentle at the beginning stages, against the high rate of slope increase towards the end.

Consider the initial stages of the curve in fig 2. Here the curve progresses with minute increments in its slope. This trend of a gentle slope increase is evident to more than half of the curve's progress. This is the region where the engine produces low BP's and the gentle slope increments can be due to the comparatively low fuel consumption of the engine when operating in this region. The referred region is shown in fig 2 as region P. In this region, large fluctuations or variations in the BP would account to only a corresponding small variation in the fuel consumed as marked in the graph.

Once the engine is in low BP production conditions, namely when it's in Idling or partially loaded conditions, the operation of the engine would possibly be in region P. Hence it can summed up that when complete power is not drawn from the engine, as in the above working stages, the generated surplus BP is most likely to be in this region.

The Specific fuel consumption, SFC, can indicate how efficiently the engine is using the fuel supplied to produce work at that particular instant or in other words, the total fuel consumed (TFC) for a unit rise in BP produced gives the SFC as in Heywood [4].

As the slope is gentle in this region P, it can be inferred from the graph that in region P, for a unit increment of load on the engine or for a unit thrust force increase produced by the engine, it accounts for only a very small increment of fuel consumed. In other words, the SFC values would be comparatively lower in this region owing to the gentle slope.

Towards the later end stages of the curve, the vehicle demands high BP from the engine, region Q in Fig.2.The region Q is to be noted for its highly steep rise in slope of the curve, which is due to the high fuel consumption incurred by the engine for producing these high BP values. In this region, the increments in load exerted on the engine would need larger changes in of fuel consumed. Each small increment in the BP produced would get the engine to consume comparatively higher amount of fuel, i.e. the SFC is higher for the region Q.

The reason for this huge fuel consumption is very obvious because an engine's operation can only fall under region Q once high torque is demanded for the traction, like in the cases of an upward slope, sudden cruising demands etc. In all these mentioned cases the high power can be produced by increased throttling and burning more fuel and the increase in each unit of BP produced is at an expense of higher fuel consumed.

In an ideal case, the specific fuel consumption would remain unchanged throughout the engine's operations irrespective of the power outputs. But it is very evident from fig 2 and fig 5, the change in the amount of fuel consumed once the operation of the engine is shifted from region P to region Q. An economic comparison can be made between the two regions characterized by the higher SFC values in region Q to the lower values in region P, to substantiate the claim. In region P the initial values are of the order of 0.03 c.c./ kW sec (section 4, table a) and the final values in region Q are in the order of 5.4 c.c./ kW sec, implying a 180 fold increase in fuel that is being consumed in the final stages of the graph. Subsequently the cost incurred for fuel in the production of a unit BP increase in region Q is 180 times that of in region P.

Hence the claim made is that, the power which remains underused in the engine due to partial or no load conditions during clutch engagement\disengagement, can be harnessed and later on supplied when the condition demands more power from engine i.e. when each unit of Brake power is produced at a higher expense of fuel consumption.

3. METHODOLOGY

The above sections illustrated the possibility of application of a power harnessing procedure to an engine's operation. In this section the methodology of the same is explained.

Along with the vehicular traction power, other auxiliary devices also feed from the engine. Let the total power accounted for traction and the auxiliary devices be termed the primary power and the load exerted on the engine, the primary load. This primary load may vary according to the vehicles demand during its run. In a TFC vs. BP curve the primary load can range to anywhere in the graph from origin to region P or region Q, indicating an unrestricted domain for the primary load. When the vehicle is in normal run, characterized by normal throttling of the fuel pump, the complete BP generated by the engine is used up as primary power since the BP being produced is just sufficient for the primary loads.

Consider the vehicle in a wait and move mode within a queue during heavy traffic congestions. The engine will, in majority of its run, be in partial and occasional no loads, owing to continuous clutch engagements and disengagements. This may normally come under low BP production stage, the region P. Since the vehicle is made to run at a partially clutched stage, complete power that can be produced by the engine is not required as primary power and higher Brake powers could be produced than what is required for the primary loads, indicating a scope for defining a secondary power. Secondary power is that power that can be used to run a power harnessing device. Be it hydraulic, pneumatic, electric or a hybrid of any of these. The secondary load is the load that can be exerted by these devices on the engine crank shaft. The secondary loads can only be exerted on the engine when it is operating in low BP production conditions i.e. in region P in Fig 2 and below the maximum efficiency point in Fig 1. Hence the secondary power that can be harnessed from the engine strongly depends on the primary power, since only that underutilized amount of BP above the primary power, can be utilized for satisfying the secondary loads. Mathematically speaking, during partially loaded/no load stages,

Primary loads + Secondary loads + losses= BP produced

Hence the secondary loads can be applied strictly under the following two constrains:

- The engine should be operating in region P,
- Sum of primary and secondary loads must be equal to than the BP being produced

3.1 POWER EXTRACTION AND APPLICATION

When during the normal run of a vehicle there is a sudden load drop on the crank shaft due to partial loading or no loading due to clutch engagements, the primary power demanded of the engine is reduced. As said earlier an additional secondary load can be exerted on the crank shaft, provided collectively the primary and secondary loads do not exceed the BP that can be produced with the same fuel consumed. Say here, 50-55 kW as in the case of engine B, beyond which there is higher rate of fuel consumed. Or else the secondary loads will be loaded onto the engine when it is operating under high BP production conditions, i.e. in region Q. This may occur at an expense of high fuel consumption which is not economical and not desired. So the secondary loads can be engaged on the crank shaft as much as the primary load is disengaged from the engine owing to clutch disk disengagements. Further when the vehicle demands very high power from the engine. Like for the situation of a very steep slope, sudden cruising demands etc. Even if the engine produces its maximum possible value of BP, it may not be sufficient to meet these requirements in some cases. This maximum power produced would be at a very high quantity of fuel consumed and each unit rise in the BP would be at the cost of high quantities of fuel consumed. i.e. the SFC would come to very high values. So at these conditions there is a chance that the maximum power produced will be lesser than what the primary loads demand. Or in other words the primary power required is greater than BP produced.

Graphically speaking this may occur at the extreme right end of region Q in a TFC vs. BP graph. So any external boosting power available for the vehicle above the BP value, produced by engine, can be useful here. It is in this situation that the energy stored using the secondary power, that was harnessed earlier, can be put to use. If this energy can fill up the dearth in power between the primary load demand and BP produced, it can meet up with the vehicles demand of high power for that situation. Even if not fully but to a partial extend, the BP along with this energy discharge which was harnessed and stored earlier can be fed to meet up to the demand of primary loads.

Hence when each unit of BP increase consumes enormous amount of fuel, the excess power produced when unit BP rise consumed lesser fuel, can be used to give a boost up to the vehicular traction.

4. SUPPORTIVE EXPERIMENT

In order for a more practical insight to the above theoretical proposal, the engine's behavior during clutch engagement/disengagement needs to be studied. The condition can be an analogy to the state of an engine under 10-25% of its full load. The feasibility of fuel surplus and power starving conditions can be best explained if a plot between the fuel consumption and Brake Power is made. Hence a load test on an engine was conducted with a sole aim of knowing its fuel consumption at the different brake power ranges that it can produce.

4.1 NON DIMENSIONALISATION AND SCALING

The decision of selecting any engine and not a specific engine was taken up with the concept of non dimensionalisation and further scaling in mind. Hence any engine operating parameters selected can be non-dimensionalised with suitable scaling relations. These operating parameters can be correlated from the test engine and to any similar engine. Another advantage of plotting such a graph is that once a plot between the Total Fuel Consumption (TFC) and Brake Power (BP) is made, the first differential of the equation of the graph will give the specific fuel consumption, SFC. SFC is the fuel consumption for a unit brake power increase made. Hence in the expected case, the SFC at 80% full load must be much greater than the SFC at 10-20% of the full load.

4.2 EXPERIMENT

Engine A: Test Engine

Engine Type	: 4-stroke, Air Cooled Diesel Engine
Power	: 4.4kW

TFC	: 0.3749cc/sec

Engine B: Scaled Engine

Engine Type	: 4-stroke, 2.5 L Diesel Engine
Power	: 88 kW
TFC	: 5.79cc/sec

Load testing was done on Engine A. Engine B is characteristically similar to engine A but possesses higher credentials of power outputs. This engine was considered so as to analyze this claim of power harnessing in a more real time situation. This can be achieved with the concept of non-dimensionalisation using rated values and then projecting it to the higher engine. It is explained in the following paragraphs.

The values of Mean BP and Mean TFC of engine A, obtained from testing, were non dimensionalised using the rated BP and rated TFC of engine A to obtain a set of non-dimensional ratios (the values were simply divided with the corresponding rated quantities). Since engine B is of similar characteristics of that of A, these ratios when multiplied with the rated quantities of engine B, a satisfactory set of performance values of engine B can be obtained. These values are shown in Table (b).

Once a plot for TFC vs. BP was made for the engines, the first differential of the curve equation, at the particular values of BP, would give the SFC values at that point.

Fig 3 and Fig 4 shows the plots between TFC and BP for engine A and engine B respectively, with the values from Tables (a) and (b) respectively. A 6^{th} degree polynomial curve was the best fit for both the plots with the regression coefficient R^2=.9986 for both plots . The equation of the curve is shown besides the respective graphs.

Consider the equation of the TFC vs. BP curve for engine B (fig 4).

$$y_2 = 5E\text{-}09x^6 - 9E\text{-}07x^5 + 6E\text{-}05x^4 - 0.0019x^3 + 0.0267x^2 - 0.126x + 2.3318$$

Differentiating the equation with respect to x_2,

$$(dy_2/dx_2) = 3E\text{-}8x_2^5 - 4.5E\text{-}6x_2^4 + 24E\text{-}4x_2^3 - 5.7E\text{-}3x_2^2 + 0.0534x_2 - 0.126$$

Since y_2 = TFC and x_2 = BP,

(dy_2/dx_2) = Slope, which is the TFC for that unit increase in BP. This fuel consumed for unit rise in BP is known as Specific Fuel Consumption(SFC). The values of SFC also is shown in the table s (a) and (b).

Fig 5 shows the SFC vs BP graph for engine B.

4.3 OBSERVATIONS AND FURTHER ANALYSIS.

Consider Fig 4, the TFC vs. BP plot for engine B. The curve proceeds with an increasing pattern in slope when fitted with a 6^{th} degree polynomial curve. When analysed closely it can be seen that for a range of BP from 0 kW to around 50-55 kW, the mode of increase for slope is very gradual and gentle. In this region, the TFC is ranging from 0 to around 5cc/sec. So it can be said that for variations of load in this region, the consumed fuel quantity is very small. For example, in region P, for an increase of 10 kW load on the crank shaft, say from 10kW to 20kW, the additional fuel consumed is less than 0.1cc/sec.

The same can be spoken in the SFC vs. BP graph (Fig 5). For this region corresponding in the SFC vs. BP graph (fig 5), a unit thrust force increase occurs at a very small amount of fuel consumed. i.e. the SFC is comparatively smaller in this region. Hence this will be the region of operation for the engine under low power production conditions like idling or no loads and for partial loads.

Now consider the region beyond the BP values of 50-55kW. Let this region be termed as region Q for easy reference. In this region, from the TFC vs. BP graph (fig 4) it can be seen that the slope is increasing at a much chaotic rate. It implies the fuel consumption takes the upward trend of increase in this region. Once extrapolated, it can be made much obvious that the fuel consumption would further soar to very high values in a second, for higher BP production by the engine. For example, in this region Q, for an increase of 10 kW load on the crank shaft, say from 62 kW to 72 kW, the additional fuel consumed is more than 18cc/sec. Comparing the two examples, it is to be specially noted for an equal amount of BP rise of 10 kW, the difference in fuel consumption, once the region of operation of the engine changes from P to Q.

The situation of region Q is much more evident once the SFC values are analyzed (table b).For this region corresponding in the SFC vs. BP graph (fig 5), a unit brake power increase occurs at a bigger quantity of fuel consumed. i.e. the SFC is comparatively higher in this region.

5. RELATED WORK

Methodologies to improve upon the efficiency and additional systems that harness power have been a heavily researched area ever since the IC engines came into the forefront. With vehicles becoming so prominent in today's world of limited fossil fuel supplies and escalating carbon emissions into the atmosphere, this has further become a more stressed upon topic these days. Under normal driving conditions, the efficiency of an IC engine is approximately 20% as stated by Fyffe J.[5]. This value is an alarmingly low one considering the otherwise limited options onto which we can migrate from an IC engine. All these have given the term 'power harnessing' from an IC engine more weight. Hence any sort of efficient energy retrieval method is most welcome in today's world.

Hybrid engines have come to the forefront in the last decade or so owing to the need of energy savings to increase the overall efficiency and decrease emission hazards. So has efficiency and power improving methods come into prominence, like Heat Recovery from exhaust gas proposed by Jadhao J.S. and Thombare D.G. [6], mechanical supercharging, turbocharging, pressure wave supercharging of the engine as in Heywood [4], modifying specific thermodynamic processes in the basic operating power cycle of the engine as in the Thermodynamics reference book Cengel [7], an alternative thermodynamic operating cycles for the engine, like the eco cycle proposed by Postrzednik S., Zmudka Z. [8] etc. to name a few.

A hybrid electric vehicle with an electric motor aiding the IC engine, helps to keep the efficiency of the same at its peak point as proposed by Fyffe J. [5], while providing additional power as and when required by the vehicle and storing that power which is lost due to idling of the engine, when the vehicle moves through congested roads. Modern Hybrid Electric Vehicles (HEV) even reduces the energy lost due to idling of engine by shutting it off and restarting it when needed called start-stop system as proposed by Reddy S.S., Tharun K.S [9]. Electric regenerative braking in HEV's considers recovering the maximum braking energy and harnessing it .Jin L., Chen P.et al. [10] and Reddy S.S., Tharun K.S[9] puts forth regenerative braking, and [10] the same in an electric vehicle driven by in-wheel motors. This broad area of electric hybrids too does not touch upon harnessing the underutilized power during clutch engagements and disengagements in a vehicle.

A hydraulic hybrid as proposed by Rohanhatti [11] also aims to improve upon the overall efficiency of the system. It uses hydraulic accumulators and motors for the hydraulic cycle along with the IC engine. The additional power is stored as hydraulic energy to be used later on when required. A hydraulic Regenerative system by Kumar [12] converts the kinetic energy to pressure energy when a vehicle is decelerating. The energy generated due to the momentum rate change is stored in hydraulic accumulators and is later on used to aid traction. A similar concept is implemented in the Hydraulic Launch Assist (HLA) produced by Eaton Corporation to improve vehicle efficiency in its stop and go process.

In a very inspiring paper by Huang Y., Yang F. et al.[13], it is specified how engine braking can be avoided by disengaging the clutch when the vehicle is braked and slowed down, letting the engine to run on no loads. An automatic clutch then engages onto the engine, connecting it to an Integrated Starter and Generator system and the power then produced by the engine generates electricity aiding regeneration.

6. FUTURE SCOPE AND EXPANSIONS

This paper claimed a nascent idea of harnessing underutilized power during partial or no load engine runs and an engine test substantiated this claim. It is found that there is scope for considerable amount of power that can be harnessed at various operating stages of an engine during clutch engagements and disengagements. A hydraulic and an electric power tapping system may be developed to harness power from an engine during clutch engagements and disengagements without overly loading the engine so that the load exerted by the power tapping systems can be within the engine's low BP producing stage.

The hydraulic power tapping system harnesses the energy at low BP production when the engine is clutched and stores it as pressure energy of a fluid in a hydraulic accumulator setup as proposed by Gangwar G.K., Tiwari M. et al. [14]. When the vehicle demands high power, this compressed fluid at high pressure may be allowed to expand through a turbine producing work which can aid traction.

The electric power tapping is done by using the power that is harnessed from engine during clutching, to run an alternator to generate electricity which charges the main battery or feeds the auxiliary devices of the engine.

A comparative study between hydraulic power tapping and electric power tapping system will be done so as to determine which system is more efficient in using the harnessed power.

7. CONCLUSIONS

Once a vehicle is in partial or no loads due to clutch engagements and disengagements, complete power that can be produced by the engine is not utilized for vehicle traction. Only a fraction of it is used up, the rest remains underutilized. The paper provided a case study on whether this underused power could be harnessed during clutch engagements and disengagements under low BP production conditions and then used later on when the vehicle demands high power. An engine test validated the scope for this power harnessing methodology and an economic analysis gave a 180 fold increase in the cost incurred in the fuel that is consumed for higher values of brake power produced when compared to the lower brake power production conditions.

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Table A

Mean BP in kW (x)	Mean TFC in cc/sec (y)	(dy/dx) = SFC in cc/kW sec
0.1229	0.1307	-

Table B

BP in kW (x)	TFC in cc/sec (y)	(dy/dx) = SFC in cc/kW sec
2.4583	2.0186	-

0.2458	0.1522	0.03697373
0.3688	0.1539	0.06477715
0.4917	0.1548	0.06768961
0.6146	0.1581	0.05820138
0.7250	0.1634	0.04662353
0.8458	0.1698	0.03615627
0.9500	0.1736	0.03166718
1.0688	0.1794	0.03315907
1.1771	0.1868	0.04082914
1.2833	0.1909	0.05355252
1.3875	0.1960	0.06991859
1.5031	0.2048	0.09094820
1.6042	0.2135	0.11033054
1.6875	0.2203	0.12615147
1.8000	0.2297	0.14635680
1.9125	0.2358	0.16474538
2.0250	0.2532	0.18170950
2.1375	0.2672	0.19891365
2.2500	0.2791	0.21958652
2.3625	0.2900	0.24881288
2.4521	0.3100	0.28294425
2.5635	0.3312	0.34658029
2.6750	0.3646	0.44454551
2.7865	0.3922	0.59117907
2.9250	0.4505	0.86792344
2.9531	0.5263	0.94013093
3.1719	0.6494	1.74843245
3.2813	0.8621	2.36147514
3.3906	1.1494	3.15624921
3.6094	1.9231	5.44426142

4.9167	2.3507	0.02728528
7.3750	2.3774	0.05406984
9.8333	2.3908	0.07614056
12.2917	2.4412	0.11489106
14.5000	2.5236	0.18154500
16.9167	2.6221	0.30802528
19.0000	2.6814	0.47706000
21.3750	2.7711	0.75499734
23.5417	2.8852	1.10341450
25.6667	2.9477	1.54763778
27.7500	3.0263	2.09511000
30.0625	3.1627	2.84852467
32.0833	3.2977	3.64593056
33.7500	3.4020	4.41000000
36.0000	3.5479	5.60664000
38.2500	3.6417	7.00800750
40.5000	3.9103	8.63050500
42.7500	4.1264	10.49053500
45.0000	4.3105	12.60450000
47.2500	4.4785	14.98880250
49.0417	4.7871	17.09169137
51.2708	5.1158	19.97441511
53.5000	5.6312	23.16736500
55.7292	6.0566	26.68649213
58.5000	6.9568	31.53946500
59.0625	8.1285	32.59194873
63.4375	10.0286	41.59317627
65.6250	13.3139	46.66011328
67.8125	17.7519	52.12469678
72.1875	29.7002	64.30709619

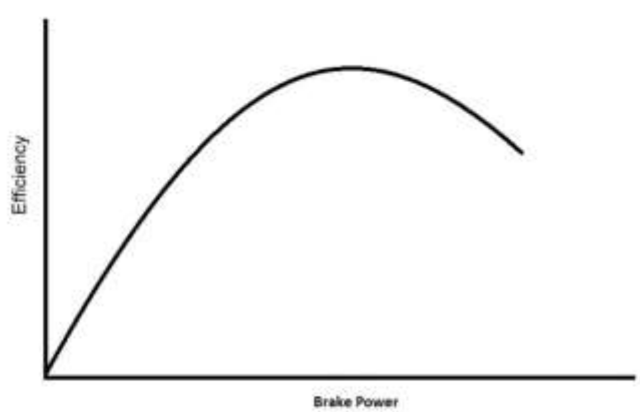

Fig. 1

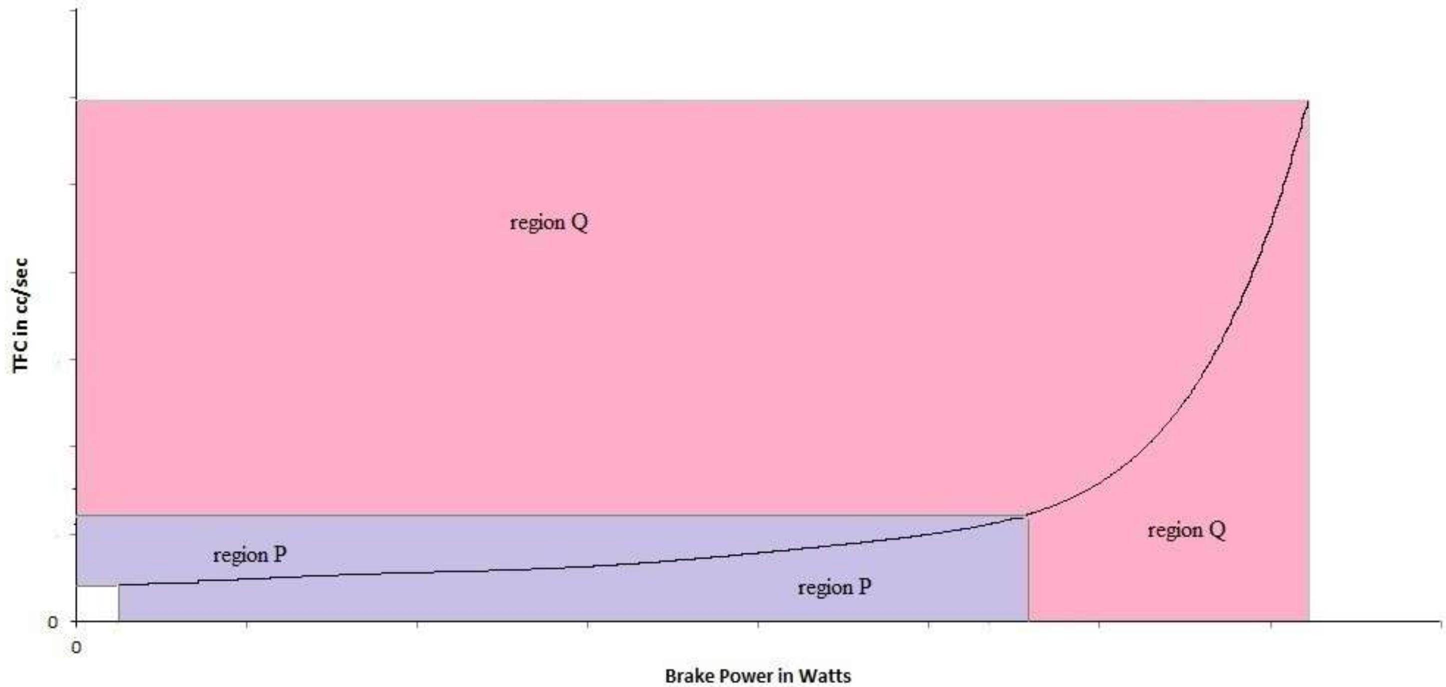

Fig 2.TFC vs. BP

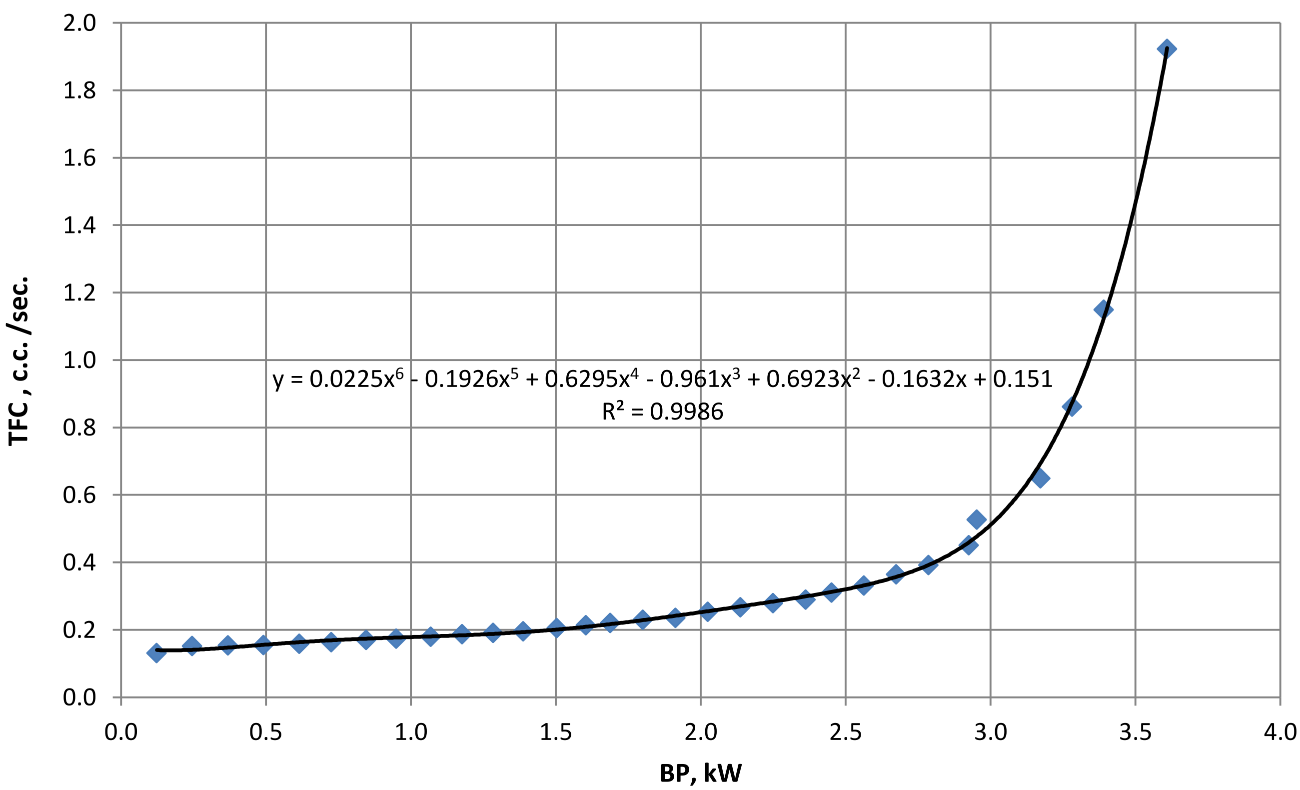

Fig.3, TFC vs BP (Engine A)

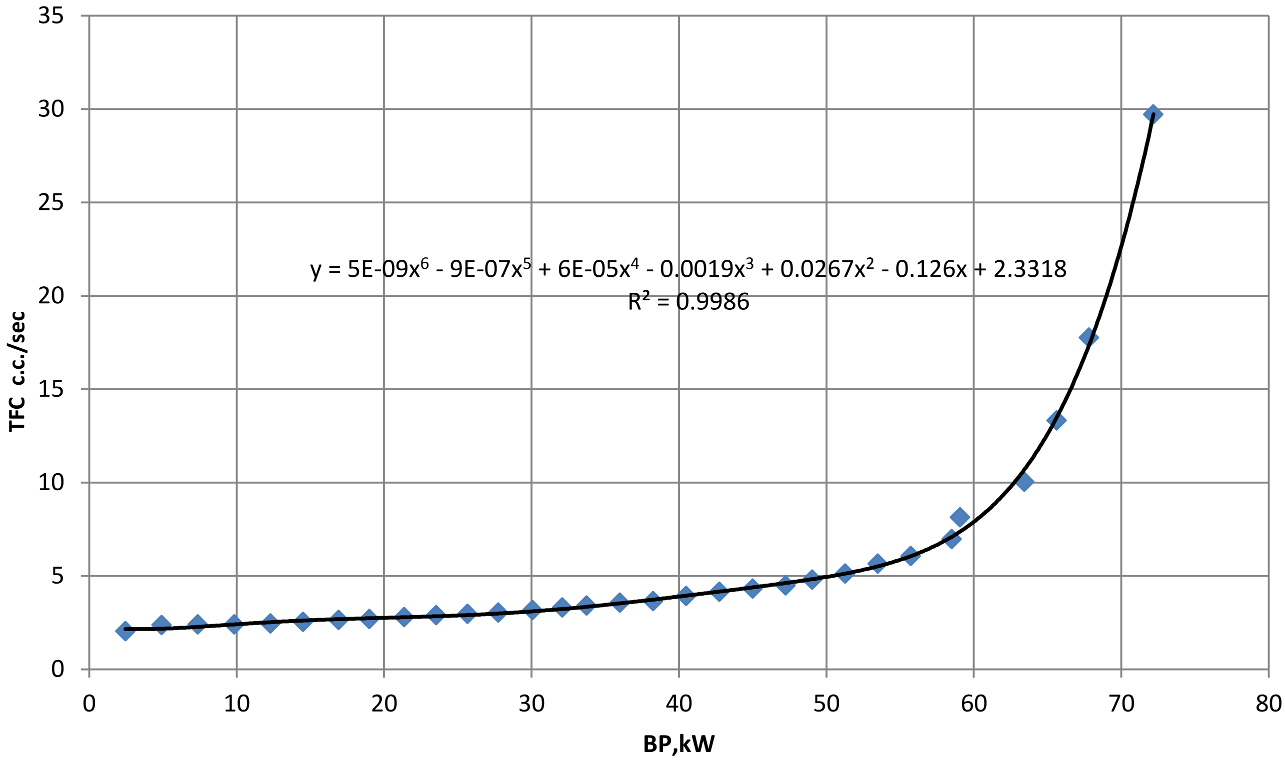

Fig. 4, TFC vs BP (Engine B)

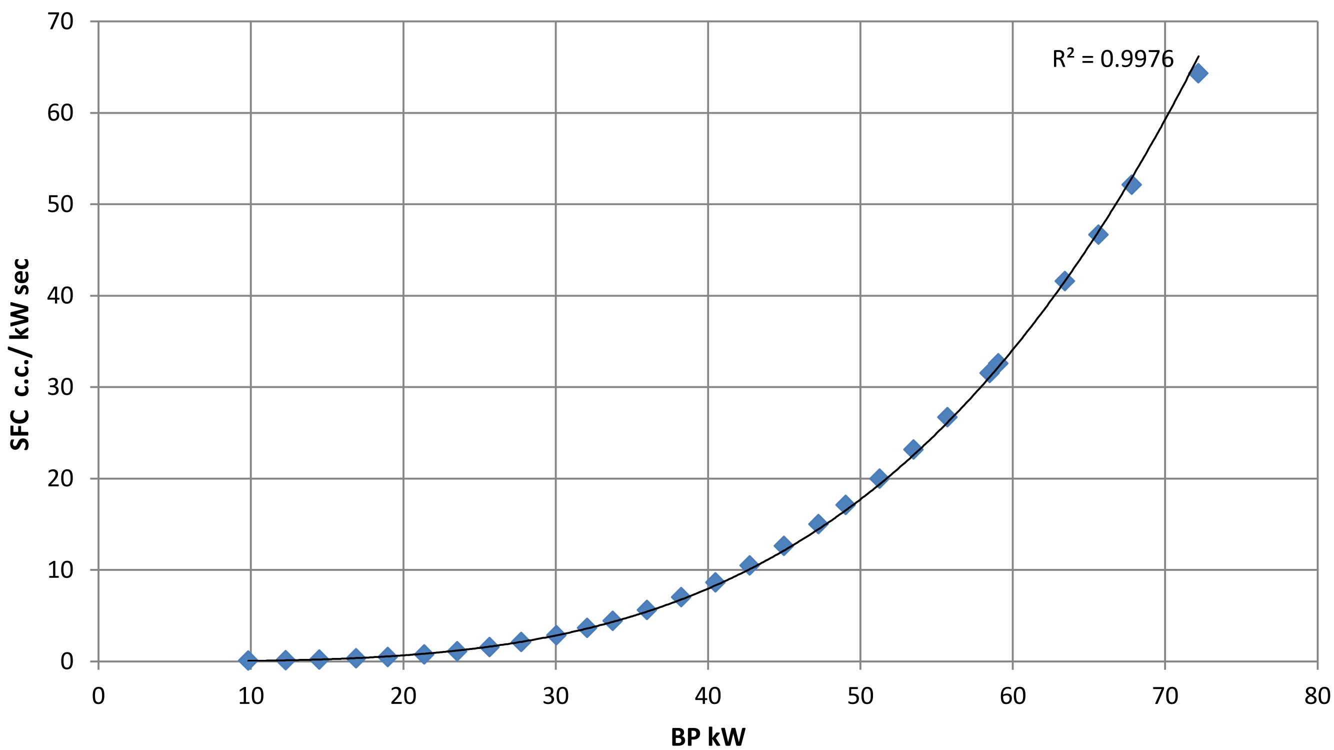

Fig. 5, SFC vs BP (Engine B)