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Kinetic Energy Recovery

Alternative Propulsion Systems ACHA5010

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1 Introduction

The automotive industry is increasingly shifting its focus towards improving vehicle efficiency and reducing fuel consumption in response to environmental, economical, and legislative pressures. As a result, the motorsport industries are following suit with constantly changing and increasingly challenging rules and regulations. One of the most effective methods to support these goals is the implementation of Kinetic Energy Recovery Systems (KERS). These systems capture kinetic energy that would be lost as heat during braking and convert it into a usable form, such as chemical or mechanical energy. After conversion, the energy recovered can be reused to support certain vehicle functions, including acceleration, or auxiliary loads, therefore reducing the overall demand on the internal combustion engine, lowering the overall fuel consumption, improving vehicle efficiency.

This report will investigate the potential benefits of introducing a KERS into a passenger road vehicle by analysing its energy usage during the Worldwide harmonised Light-duty Test Procedure (WLTP). The WLTP drive cycle is an internationally recognised standard for assessing vehicle performance, fuel consumption, and energy demands under realistic driving conditions. By applying this cycle to a chosen vehicle, a study can be conducted with the aim to measure both tractive and braking energy requirements, to identify periods of maximum recoverable energy, and to evaluate how much of this energy could be stored effectively and reused using a suitable KERS.

The vehicle chosen for this assignment is a 1.4 litre TSI Volkswagen Beetle produced in 2012. This will provide a realistic platform for assessing how a theoretical KERS could function alongside an aging internal combustion engine (ICE) system. In order to explore the practicality, efficiency, and potential impact of integrating a KERS into such a vehicle a spreadsheet will be utilised to analyse force and power calculations, alongside cumulative energies.

1.1 Aims

Aim 1 – To analyse the tractive, braking, and energy demands of a chosen vehicle over the Class 3 WLTP drive cycle.

Aim 2 – To use the analysis to determine the maximum recoverable braking energy and identify how much of the energy can potentially be recovered.

Aim 3 – To discover and evaluate a suitable KERS for the chosen vehicle.

1.2 Objectives

Objective 1.1 – Collect key vehicle data including mass, drag coefficient, rolling resistance, and frontal area.

Objective 1.2 – Produce a WLTP spreadsheet that calculates forces, powers, and cumulative energy values.

Objective 1.3 – Produce graphs of results

Objective 2.1 – Identify the braking events within the drive cycle.

Objective 2.2 – Investigate total braking energy available for recovery.

Objective 2.3 – Determine the maximum braking power to pinpoint power system requirements.

Objective 3.1 – Select an appropriate KERS for the braking energy profile of the vehicle.

Objective 3.2 – Size key system components based on the power and energy demands.

Objective 3.3 – Assess the practicality and potential efficiency of implementing the KERS.

2 Background Research

2.1 Kinetic Energy Recovery Systems (KERS)

As stated previously, KERS are designed to capture the heat energy that a typical ICE loses and therefore wastes during braking. The aim for KERS is to recover part of this kinetic energy and store it in another form so it can be utilised elsewhere to improve vehicle efficiency, especially in stop-start or mixed-speed driving conditions.

There are different types of KERS used in automotive applications, including electrical, and mechanical. Electrical KERS convert kinetic energy into electrical energy using a motor generator and store it in batteries or capacitors, these systems are commonly used in hybrid vehicles, whereas mechanical KERS utilise flywheels to store kinetic energy as rotational energy which can provide bursts of high power when re-engaged. However, the amount of recoverable energy these systems can utilise depends on the resistive forces acting on the vehicle, the weight of the vehicle, the tyre characteristics, and whether the system is matched correctly to the vehicle's braking patterns.

Skill-Lync(2025) states that KERS can not only be found in road vehicles but also commonly implemented within Formula 1 vehicles as they boost the vehicles' performance and acceleration,

along side improving their fuel efficiency which not only allows cars to stay on the track longer but it also reduces their carbon footprint which aligns with F1's push towards sustainability.

However, as explained by Skill-Lync(2025), KERS come with their complications because they can affect the weight distribution of vehicles due to the extra components, they may require advanced cooling systems as the conversion of energy generates copious amounts of heat, and developing and maintaining these systems can be expensive.

2.2 Worldwide harmonised Light-duty Test Procedure (WLTP)

The WLTP is a realistic and repeatable driving cycle that includes a range of speeds, accelerations, and decelerations to test the fuel consumption and emissions of vehicles, it is also suitable for investigating braking data and energy flows. This cycle was developed to replace the previous NEDC cycle as it was outdated and did not accurately reflect real world driving conditions.

3 Methodology

To conduct this analysis a Microsoft Excel spreadsheet, displayed in Figure 1, was used to calculate and evaluate both tractive and braking demands of a Volkswagen Beetle over the WLTP Class 3 driving cycle. Key parameters needed to conduct the investigation, shown in Table 1, were researched and presented in a separate parameter table on the spreadsheet, shown in Figure 2.

Phase	Total elapsed time	Phase elapsed time	WLTC class 3, version 5, vehicle speed	WLTC class 3, version 5, acceleration	WLTC class 3, version 5, vehicle speed	Acceleration Force	Rolling Resistance	Aerodynamic Drag	Total Resistance	Total Power	Tractive Power	Braking Power	Cumulative Traction Energy	Cumulative Braking Energy
Phase	s	s	km/h	m/s ²	m/s	N	N	N	N	W	W	W	J	J
Low	0	0	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	1	1	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	2	2	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	3	3	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	4	4	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	5	5	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	6	6	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	7	7	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	8	8	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	9	9	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	10	10	0.0	0.00	0.00	0	211.0	0	211.0	0	0	0	0	0
Low	11	11	0.0	0.03	0.00	39.83333333	211.0	0	250.8	0	0	0	0	0
Low	12	12	0.2	0.24	0.06	338.5833333	211.0	0.001878749	549.6	30.53323956	30.53323956	0	30.53323956	0
Low	13	13	1.7	0.72	0.47	1035.666667	211.0	0.135729632	1246.8	588.7739891	588.7739891	0	619.3072266	0
Low	14	14	5.4	1.14	1.50	1633.166667	211.0	1.369600188	1845.5	2768.324062	2768.324062	0	3387.631291	0
Low	15	15	3.3	1.07	2.75	1533.583333	211.0	4.603405297	1749.2	4810.299556	4810.299556	0	8197.930847	0
Low	16	16	13.1	0.97	3.64	1394.166667	211.0	8.063038777	1613.2	5870.401368	5870.401368	0	14068.33221	0
Low	17	17	36.5	1.19	4.69	1712.833333	211.0	13.41473918	1937.3	9094.364949	9094.364949	0	23162.69716	0
Low	18	18	21.7	1.26	6.03	1812.416667	211.0	22.11710566	2045.5	12330.10198	12330.10198	0	35492.79914	0
Low	19	19	26.0	0.81	7.22	1155.166667	211.0	31.75086196	1397.9	10096.16565	10096.16565	0	45588.96479	0
Low	20	20	27.5	0.29	7.64	418.25	211.0	35.5201026	664.8	5078.20502	5078.20502	0	50667.16981	0
Low	21	21	28.1	0.11	7.81	159.3333333	211.0	37.08697946	407.4	3180.244139	3180.244139	0	53847.41395	0
Low	22	22	28.3	0.10	7.86	139.4166667	211.0	37.61678874	388.0	3050.477073	3050.477073	0	56897.89103	0
Low	23	23	28.8	0.11	8.00	159.3333333	211.0	38.957744	409.3	3274.433419	3274.433419	0	60172.32444	0
Low	24	24	23.1	0.28	8.08	386.3333333	211.0	39.73590805	649.1	5247.053529	5247.053529	0	65419.37797	0
Low	25	25	30.8	0.39	8.56	557.6666667	211.0	44.5564167	813.2	6957.687347	6957.687347	0	72377.06532	0
Low	26	26	31.9	0.46	8.86	657.25	211.0	47.79585006	916.1	8117.300141	8117.300141	0	80494.36544	0
Low	27	27	34.1	0.65	9.47	936.0833333	211.0	54.61570976	1201.7	11382.88447	11382.88447	0	91877.24993	0
Low	28	28	36.6	0.69	10.17	995.8333333	211.0	62.91743291	1269.8	12909.26597	12909.26597	0	104786.51519	0
Low	29	29	33.1	0.65	10.86	936.0833333	211.0	71.8062652	1218.9	13238.63764	13238.63764	0	118025.1535	0
Low	30	30	41.3	0.47	11.47	677.1666667	211.0	80.11409428	968.3	11108.48235	11108.48235	0	129133.6359	0
Low	31	31	42.5	0.28	11.81	398.3333333	211.0	84.83726984	694.2	8195.224274	8195.224274	0	137328.8602	0
Low	32	32	43.3	0.19	12.03	278.8333333	211.0	88.06120352	577.9	6950.944632	6950.944632	0	144279.8048	0
Low	33	33	43.3	0.15	12.19	219.0833333	211.0	90.51860751	520.6	6348.611193	6348.611193	0	150628.416	0
Low	34	34	44.4	0.08	12.33	115.5	211.0	92.59227697	423.1	5218.299649	5218.299649	0	155846.7156	0
Low	35	35	44.5	-0.03	12.36	-39.83333333	211.0	93.00982899	264.2	3265.676946	3265.676946	0	159112.3926	0
Low	36	36	44.2	-0.25	12.28	-358.5	211.0	91.75999106	-55.7	-684.2026042	0	684.2026042	159112.3926	684.2026042
Low	37	37	42.7	-0.60	11.86	-858.4166667	211.0	85.63761702	-559.8	-6639.446125	0	6639.446125	159112.3926	7323.640729
Low	38	38	38.3	-0.79	11.06	-1135.25	211.0	74.77468898	-849.5	-9414.872839	0	9414.872839	159112.3926	16738.52157
Low	39	39	37.0	-0.74	10.13	-1055.583333	211.0	64.30019234	-780.3	-8015.442088	0	8015.442088	159112.3926	24757.96366
Low	40	40	34.8	-0.65	9.61	-936.0833333	211.0	56.22908566	-668.8	-6428.306586	0	6428.306586	159112.3926	31186.27024
Low	41	41	32.3	-0.78	8.97	-1115.333333	211.0	49.0200706	-855.3	-7674.105197	0	7674.105197	159112.3926	38860.37544
Low	42	42	23.0	-1.00	8.06	-1434	211.0	39.50070253	-1183.5	-9533.638813	0	9533.638813	159112.3926	48394.01425

Figure 1: Section of Excel Table.

Table 1: Table of Key Parameters.

Parameter	Value	Source
Curb Mass	1434kg	UltimateSpecs.com(2025)
Drag Coefficient	0.37	2012 Beetle Technical Specifications(n.d)
Frontal Area	2.686m ²	UltimateSpecs.com(2025)
Rolling Resistance Coefficient	0.015	N/A
Air Density	1.225kg/m ³	N/A

Curb Mass	Rolling Resistance Coefficient	Drag Coefficient	Frontal Area	Air Density
kg			m/s ²	kg/m ³
1434	0.015	0.37	2.686	1.225

Figure 2: Key Parameters Table in Excel.

Firstly, vehicle speed had to be converted from km/h into m/s, combined with the acceleration of the vehicle at each second of the cycle, the main resistive forces acting on the vehicle could be calculated.

. Acceleration Force (N) =

$$\text{Mass (kg)} \times \text{Acceleration (m/s}^2\text{)}$$

. Rolling Resistance (N) =

$$\text{Mass (kg)} \times \text{Gravity} \times \text{Rolling Resistance Coefficient}$$

. Aerodynamic Drag (N) =

$$\frac{1}{2} \times \text{Air Density} \left(\frac{\text{kg}}{\text{m}^3} \right) \times \text{Drag Coefficient} \times \text{Frontal Area (m}^2\text{)} \times \text{Vehicle Speed (m/s)}$$

. Total Resistance (N) =

$$\text{Acceleration Force (N)} + \text{Rolling Resistance (N)} + \text{Aerodynamic Drag (N)}$$

. Total Power (W) =

$$\text{Total Resistance (N)} \times \text{Vehicle Speed (m/s)}$$

. Tractive Power (W) & Braking Power (W):

To distinguish these phases more clearly two columns were created so that only negative or positive values of Total Power were isolated where appropriate, meaning the positive values under Tractive Power and Negative values under Braking Power.

. Cumulative Traction Energy (J) =

$$(\text{Traction Power (W)} \times 1) + \text{Previous Cumulative Traction Energy (J)}$$

. Cumulative Braking Energy (J) =

$$(\text{Braking Power (W)} \times 1) + \text{Previous Cumulative Braking Energy (J)}$$

4 Results and Analysis

4.1 Vehicle Speed vs Time

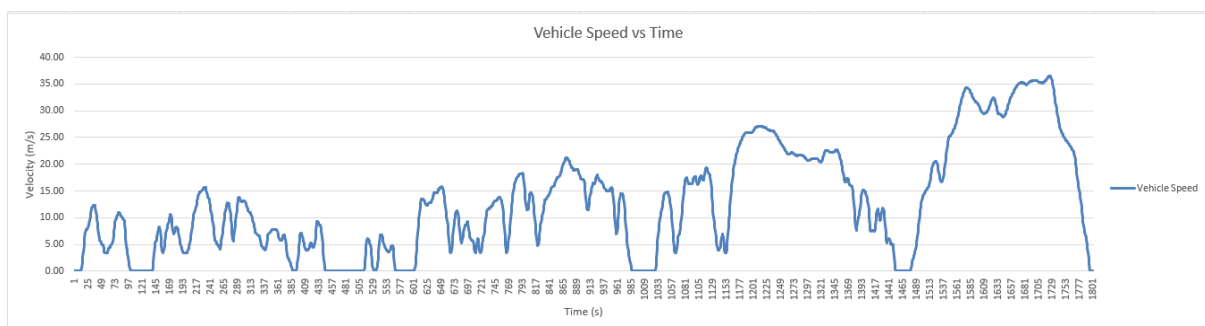


Figure 3: Graph of Vehicle Speed vs Time.

The graph in Figure 3 perfectly demonstrates the dynamic driving cycle of the WLTP, with repeated accelerations, decelerations, and phases of steadier speeds. This variation in speeds directly

influences aerodynamic drag, acceleration and braking forces, which can be seen in the plotted graphs.

4.2 Tractive Forces Analysis

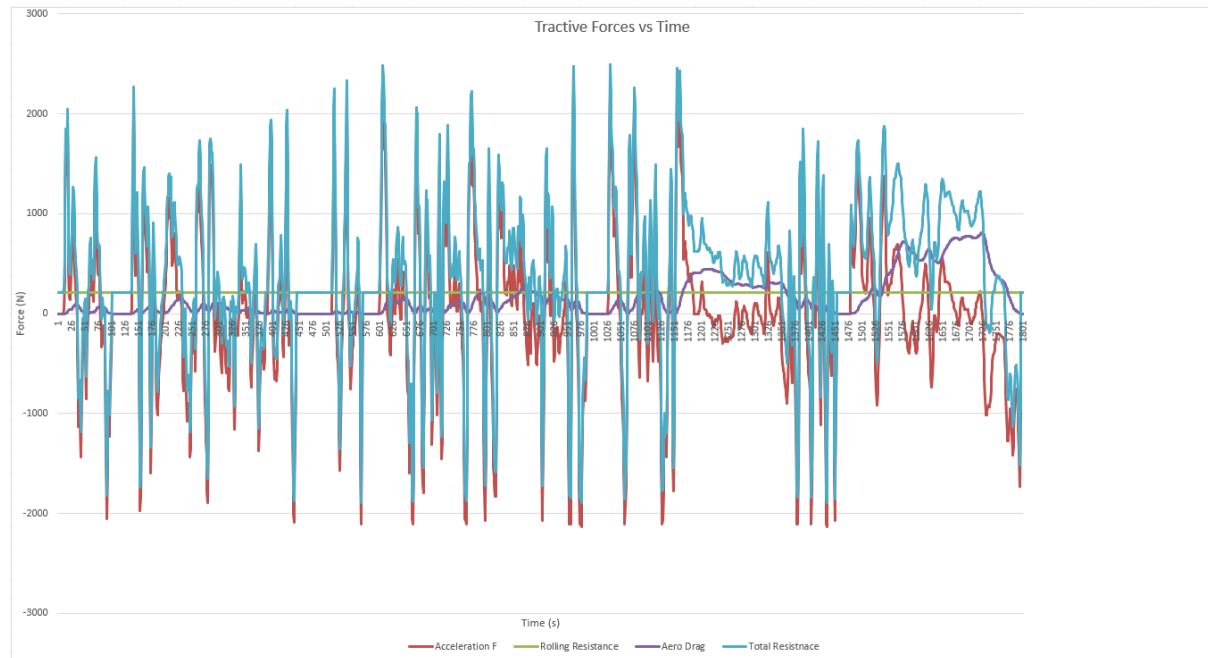


Figure 4: Graph of Tractive Forces vs Time.

The graph shown in Figure 4 shows four components including, Acceleration force, Rolling Resistance, Aerodynamic drag, and Total Resistance. Acceleration force displays some of the largest fluctuations ranging from approximately -2000N to over 2500N, which correspond with moments of heavy braking and strong acceleration. Furthermore, the spikes seen align with the steep changes in the speed graph in Figure 3 and highlights where the vehicle demands high torque. Additionally, the Total Resistance closely follows the Acceleration force because it is a combination of all the forces shown.

Rolling Resistance remains constant at 211N throughout the entire cycle, this is due to the fixed vehicle mass and tyre coefficient. On the other hand, the Aerodynamic Drag noticeably increases during the moments of high speeds particularly after the 1400s mark where the values exceed 600N due to the effects of the increasing velocity of the vehicle.

4.3 Total Power Analysis

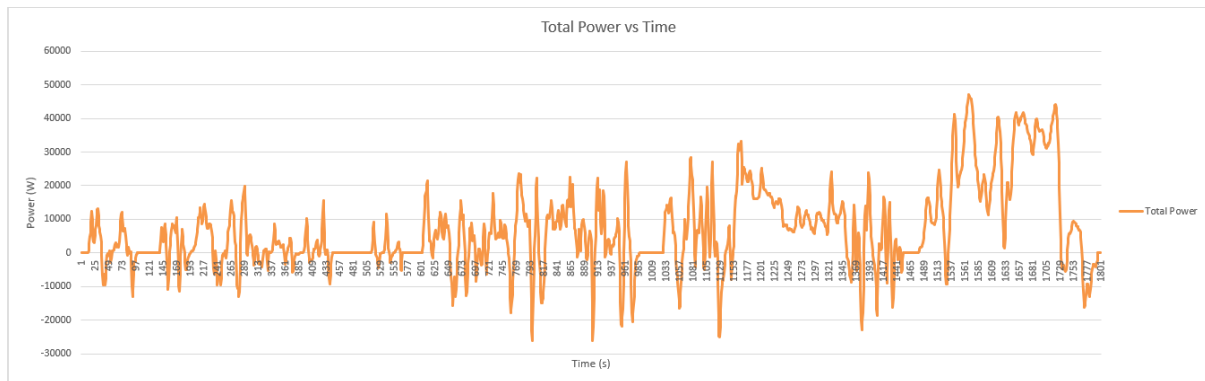


Figure 5: Graph of Total Power vs Time.

In Figure 5 the graph shows how the Total Power over the WLTP cycle fluctuates between roughly -25kW during strong braking, and 50kW during acceleration. In addition, the highest of these values are observed in the 1400-1700s range which aligns with the faster sections of the drive cycle in Figure 3, whereas the negative power spikes earlier in the cycle demonstrate frequent stopping and starting behaviour, which also corresponds to Figure 3. Moreover, the negative power spikes can be used to decipher areas where kinetic energy is available for recovery and can be utilised for calculating braking energy and estimating the amount of recoverable energy available for a KERS.

4.4 Cumulative Energy Analysis

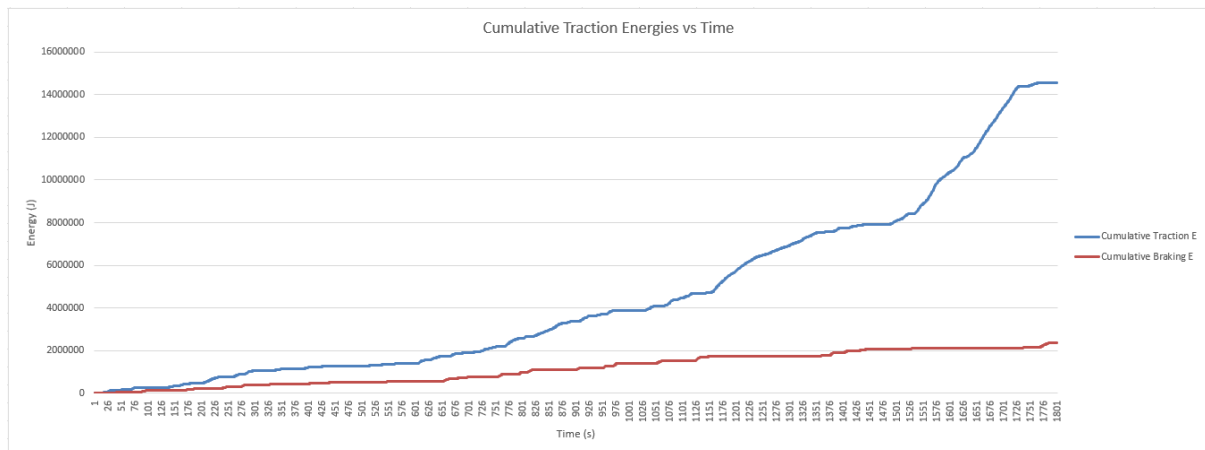


Figure 6: Graph of Cumulative Energies vs Time.

The graph in Figure 6 demonstrates how Tractive Energy increases at an increasing rate, reaching approximately 14-15MJ by the end of the drive cycle, which indicates the upper limit of how much energy could be recovered by a KERS. The scale of this energy requirement also reflects the amount of mechanical work delivered by the engine to overcome resistive forces in order to accelerate. In

contrast, the graph shows how Braking Energy increases at a more gradual pace, reaching around 2MJ by the end of the test, and shows the total amount of energy dissipated through braking, which represents the theoretical maximum amount of energy that can be recovered by a KERS, if it was 100% efficient.

5 KERS Analysis

5.1 Chosen KERS

The KERS selected as suitable for this vehicle is a flywheel KERS because it can accept and deliver high power over short durations, ideal for making a road vehicle more efficient and therefore more environmentally friendly. This system contains a high-speed flywheel, 0.5m in diameter, in a vacuum housing, a motor generator connected to the driveshaft via the gearbox, and a variable transmission. As explained by Volvo Cars (2025), this system operates by using the energy produced from braking, transferred via the motor generator to the flywheel to make it spin at high speeds and when the car begins to move again, the rotational energy of the flywheel is transferred to the wheels by the transmission.

Although the graph in Figure 6 suggests that approximately 2MJ of kinetic Energy is produced and therefore can be saved, not all of it can be. This is due to the losses that would be seen into the motor generator, transmission and flywheel bearings meaning that only a fraction of this energy can actually be utilised, and as stated by RoyalAcademy(2019), the system can be 70% efficient, although this may vary between vehicles and system setups. This means that roughly 1.3MJ of energy can be returned to the driveshaft.

5.2 KERS Sizing

To determine the rough requirements of such a system, inspection of the Total Power graph in Figure 5 shows that braking power spikes up to roughly 25kW, with most significant braking events only lasting a few seconds. Therefore, a sensible design target would be a flywheel capable of withstanding 30kW of power, rotating between 10,000rpm and 30,000rpm, and an energy capacity of roughly 500kJ to sufficiently absorb several seconds of high-power braking so it can be repeatedly charged and discharged throughout the cycle. Over the full WLTP, this allows the system to process a large fraction of the 2MJ of braking energy, even though the flywheel's energy storage capacity is substantially lower.

5.2.1 Calculating Mass of Flywheel

Rad/s =

$$\frac{30,000}{\frac{2 \times \pi}{60}} = 3141.59 \text{ rad/s}$$

Inertia =

$$\frac{E}{\frac{1}{2} \times \omega^2} = \frac{500000}{\frac{1}{2} \times 3141.59^2} = 0.101 \text{ kg/m}^2$$

Mass =

$$\frac{I}{\frac{1}{2} \times r^2} = \frac{0.101}{\frac{1}{2} \times 0.25^2} = 3.232 \text{ kg}$$

5.3 Investigating Wheel Lock

. Assuming Tyre Coefficient of friction on dry tarmac = 0.8

. Mass = vehicle mass

. Wheel Lock (m/s) =

$$\frac{P}{\mu mg} = \frac{30000}{0.8 \times 1434 \times 9.81} = 2.67 \text{ m/s}$$

. Wheel Lock (km/h) =

$$2.67 \times 3.6 = 9.6 \text{ km/h}$$

5.4 Practical viability

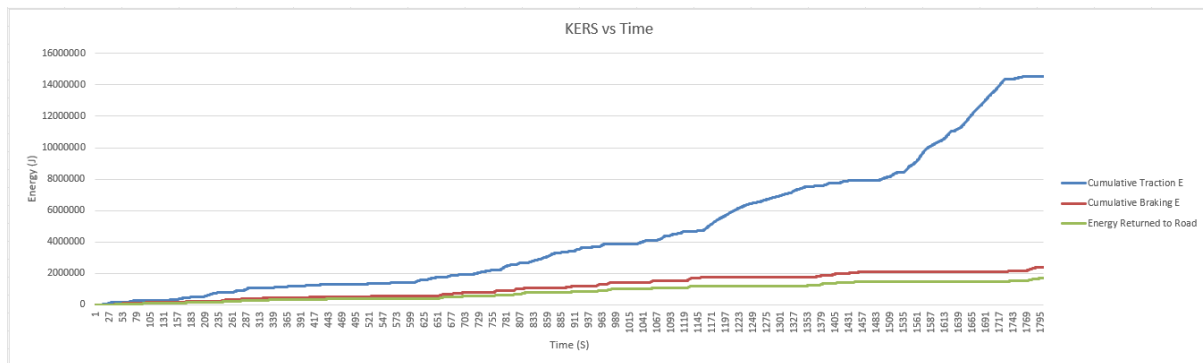


Figure 7: Graph showing Energy returned to road after KERS implemented.

The graph in Figure 7 allows the viability of implementing such a system into a Volkswagen Beetle to be analysed. It shows that the original 2MJ of braking energy lost can be reduced by approximately 1.2MJ, as shown by the green curve, meaning this much energy is being returned to the wheels. As a result, considering the maximum energy demand is around 15MJ, the potential engine load is reduced by roughly 8%.

However, the limited amount of braking means that the vehicle cannot completely run off this system, which is not the goal, but it does mean that the system will not benefit from a reduction in fuel consumption at high speeds as these conditions present few braking opportunities.

Furthermore, with the flywheel only having a storage capacity of 500kJ, some braking energy will be lost once the flywheel reaches its maximum rotational speed of 30,000rpm. Additionally, at speeds below 9.6km/h the wheel lock calculation shows that the KERS is unfit to use, requiring the friction brakes to complete the stop. Moreover, integrating this system, into such a vehicle would present challenges relating to packaging, safe containment of the flywheel, and added mass which may affect the vehicle's centre of gravity, not to mention the cost of components to make the system.

Nevertheless, this graph does suggest that this system is indeed suitable for this type of vehicle as it would provide the greatest benefit in improving efficiency in city driving with stop-start conditions where braking events are frequent.

6 Comparison

6.1 Efficiency Comparison

To compare, the standard vehicle analysed in this investigation relies solely on friction brakes to stop, which as a result dissipates kinetic energy as heat, which is approximately 2MJ as shown in the cumulative braking energy curve in Figure 7. On the other hand, the proposed flywheel KERS

provides a way of recovering roughly 1.2MJ of energy and returning it to the wheels, which represents around 8% of the total tractive energy demand of the cycle.

Moreover, friction braking provides immediate and unrestricted braking, whereas the KERS introduces certain operational constraints. This includes taking the wheel lock speed into consideration as the calculation shows that below 9.6km/h, the KERS contribution must be reduced, and the friction brakes must complete the final phase of deceleration. However, this limitation primarily affects low speed braking and so has little impact on the total energy recovery across the cycle.

Overall, the results demonstrate that this KERS is an effective way to capture and reuse otherwise wasted energy to reduce fuel consumption, engine load, and emissions in realistic driving conditions for a road vehicle. Therefore, displaying that the proposed flywheel KERS offers clear advantages over the existing system.

6.2 Driver Experience

From the driver's perspective the flywheel KERS system would feel almost seamless. During normal driving conditions, the main noticeable effect would be smoother and more responsive acceleration, particularly after braking or during stop-starting conditions, where the system reduces the need for sudden throttle input, making the vehicle feel more responsive. During braking it is possible to notice an initial firmer deceleration when the flywheel is absorbing energy, whereas at very low speeds where the KERS tapers off to avoid wheel lock, the braking sensation becomes identical to a standard friction brake system. Lastly, gear changes may feel more stable and fluent.

7 Conclusion

To conclude, this study explored the use of KERS as a method of improving vehicle efficiency using the WLTP driving cycle. The results showed that in a typical vehicle a significant amount of braking energy is wasted, and that a KERS can successfully capture a useful portion of this energy and return it to the wheels during acceleration. Doing this reduces the overall load on the engine and improves efficiency in everyday driving conditions. The system would operate smoothly alongside the existing braking hardware, with the friction brakes taking over when regenerative braking is limited during low speeds.

From the driver's perspective the system would feel largely seamless, providing smoother acceleration, and slightly more responsiveness at low speeds.

Overall, the findings indicate that a KERS, more specifically a flywheel KERS, offers a practical and effective way to recover energy that would simply be wasted. Although the system has its limitations it provides a valuable improvement and a step in the right direction towards making vehicles more efficient and environmentally friendly.

8 References

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