

University of Wales Trinity Saint David

Wales Institute of Science and Art



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

Alternate Power Train

ACHA 5010

Ollie Wilson 2203893

Contents

1.Introduction.....	3
2.Car Characteristics	4
3.WLTP Cycle	5
4.Cumulative Tractive and Braking Energy	6
5.KERS implementation	11
6.KERS system.....	12
7.System operation	15
8.Conclusion	16
9.References	17
10.Appendix	18
Figure 1 (Audi UK, 2009).....	4
Figure 2- WLTP test.....	5
Figure 3- different WLTP cycles within the test	5
Figure 4-Cumulative Energy graph.....	6
Figure 5-Cumulative Braking.....	7
Figure 6- Peak Braking	7
Figure 7-Cumulative Acceleration	8
Figure 8- Peak Acceleration	8
Figure 9 (Ahmed T. Hamada, 2022).....	12
Figure 10- (Ahmed T. Hamada, 2022).....	12
Figure 11- (Boretti, 2013)	13
Figure 12- (THOMAS MATHEWS, n.d.)	15
Figure 13-Price v Power of different Hybrid systems (Milica & Andrei, 2020)	18
Table 1- car characteristics.....	4
Equation 1 $u_1 - 2 = 12 * m * (v_{22} - v_{12})$	6
Equation 2- $E = 12 * I * \omega^2$	13
Equation 3- $M = 4. Er^2 * w^2$	14
Equation 4- $M = 4 * 242,864.06(0.32) * (1256.62)$	14
Equation 5- $M = 971,456.250.09 * 1,579,136.36$	14
Equation 6- $M = 971,456.225142,121.27$	14
Equation 7- $M = 6.84 KG$	14

1.Introduction

This report will be assessing the Audi A3 TDI 1.6 Sportback 2012 performance on a WLTP cycle of a class 3 cycle. The goal is to determine how much energy can be recovered and applied in a hybridisation of the car. The car already has a high efficiency but is also heavy requiring more power to accelerate forward, making it inefficient when in traffic and short journeys when starting and stopping. Urban driving for example. The goal is to improve performance and fuel efficiency around this area.

2.Car Characteristics

The Audi a3 is an efficient reliable diesel that is capable of high MPG with relative low running costs. The car is ideal for long distance driving with good utility space and build quality, as the car is older it suffers from urban aera due to low emission zones and the inherent nature of the diesel car.

Table 1- car characteristics

area m2	2.13
drag	0.31
weight + Load	1415 KG
Rolling resistance	0.012
Unladen weight	1320KG

The table highlights the key factors considered when calculating results, based on the WLTP cycle. These figures give an estimation of the total resistance encountered during acceleration, forming the basis for the power required from the powertrain to move the vehicle.

Technical Data – Audi A3 Sportback 1.6 TDI (105PS)

Status: May 2009

Model	Audi A3 Sportback 1.6 TDI
Engine / electronics	
Engine type	Inline four-cylinder diesel engine with VTG turbocharger, OHC; TDI direct injection
Valve gear / number of valves per cylinder	Hydraulic valve compensation / 4
Displacement in cc / bore x stroke in mm / compression	1598 / 79.5 x 80.5 / 16.5
Max. power output in PS / at rpm	105 / 4400
Max. torque in Nm (lb-ft) / at rpm	250 (184.39) / 1500 – 2500
Engine management / mixture preparation	Common rail direct injection, intercooler, rapid pre-heating, Simos PCR2 engine management; volume, injection-start and boost-pressure control
Exhaust emission control	Maintenance-free particulate filter (diesel particulate filter with primary oxidizing catalytic converter), regulated exhaust gas recirculation
Emissions class	EU 5
Alternator in A / battery in A/Ah	140/ 380/ 68
Start-stop system	Switches the engine off if the vehicle is stationary and no gear is engaged
Recuperation	Temporarily stores braking energy in the battery, and thus aids driving off and acceleration
Drivetrain / transmission	
Drive type	Front-wheel drive with ESP
Clutch	Hydraulically operated single-plate dry clutch
Transmission type	5-speed manual transmission, synchromesh on all gears
Gear ratio in 1st gear / 2nd gear	3.778 / 1.944
Gear ratio in 3rd gear / 4th gear	1.185 / 0.816
Gear ratio in 5th gear / reverse gear	0.625 / 3.600
Final drive ratio	3.647

Figure 1 (Audi UK, 2009)

The specs used in the excel spreadsheet reference the official Audi a3 spec sheet as much as possible for accurate data. Assumptions on rolling resistance have been made from existing data available from other cars and surfaces used during the testing cycle.

3.WLTP Cycle

The WLTP cycle (Worldwide Harmonized Light Vehicle Test Procedure) is a standardized test introduced by the European Union in 2017, to evaluate the efficiency and emissions of new vehicles. This test is based on real-world driving data collected from various vehicles and organized into multiple cycles, each representing different driving conditions, such as urban driving or long-distance journeys. The cycles also consider the type of vehicle, ranging from small cars to lorries, and are categorized by weight class. (WLTPfacts.EU, 2024)

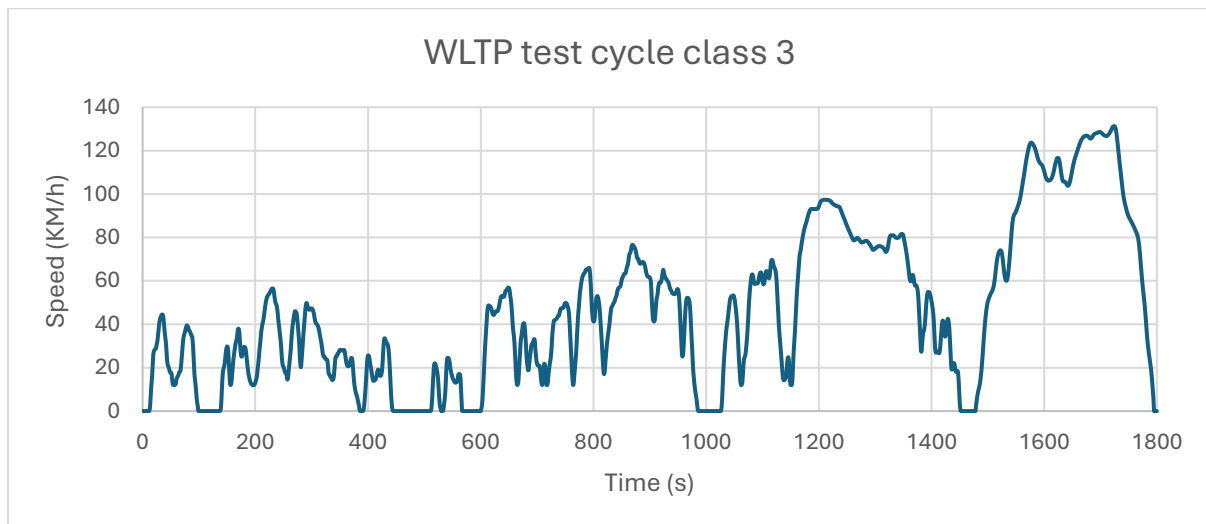


Figure 2- WLTP test

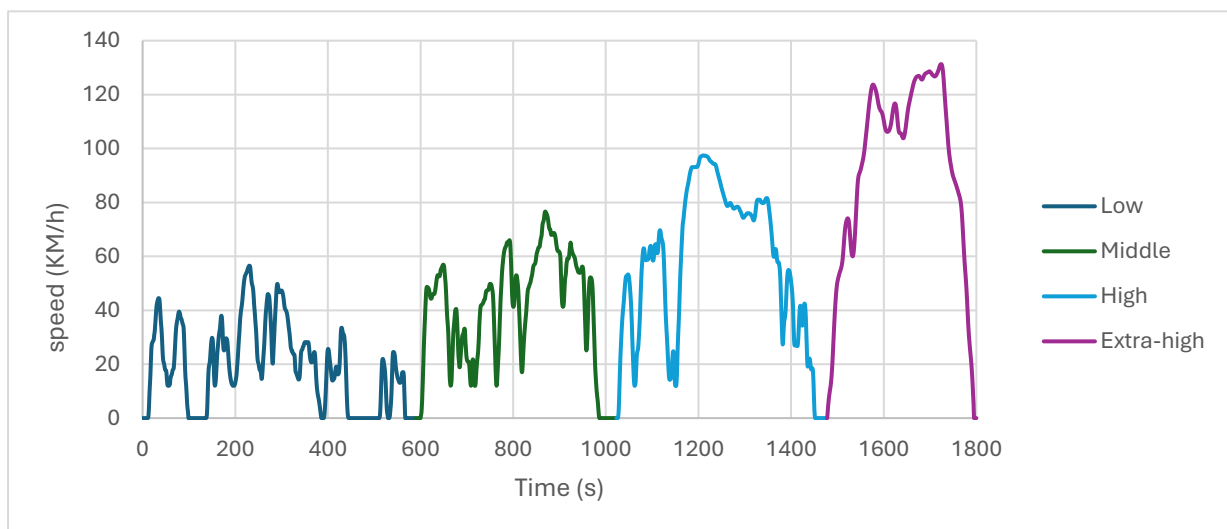


Figure 3- different WLTP cycles within the test

4.Cumulative Tractive and Braking Energy

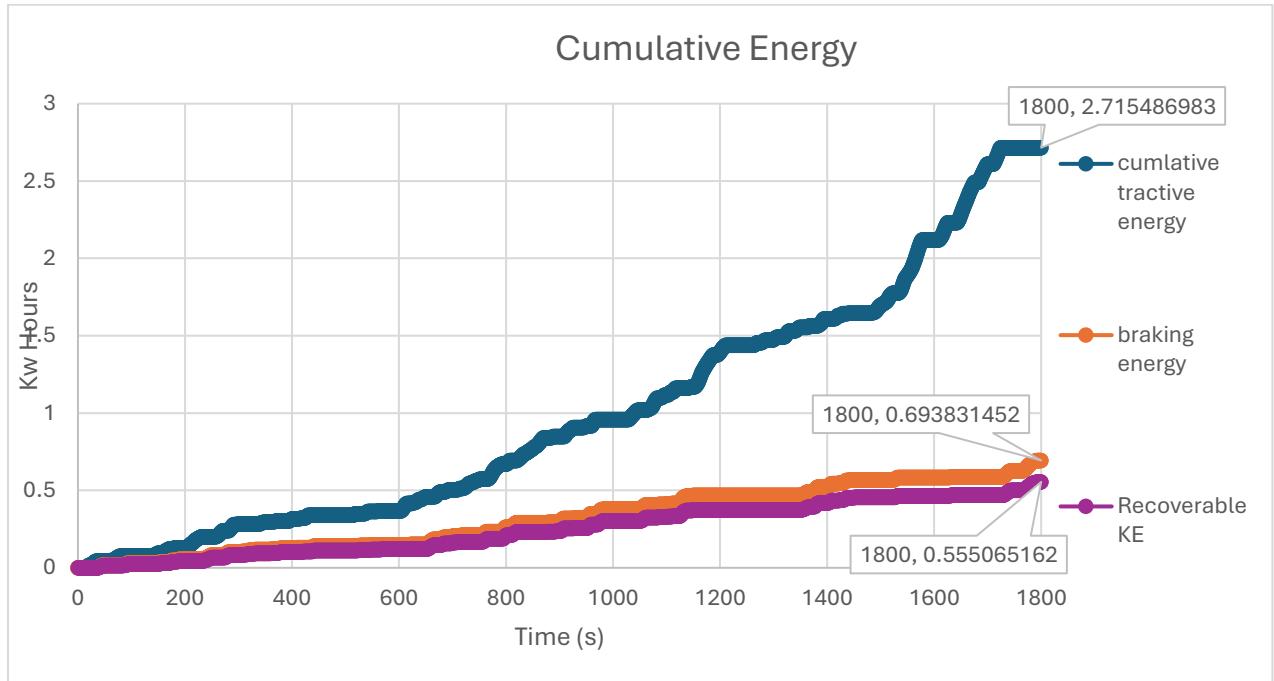


Figure 4-Cumulative Energy graph

The cumulative energy used for acceleration, braking, and the recoverable kinetic energy (KE) is illustrated in the graph, highlighting the differences in energy consumption. The recoverable KE is calculated based on the braking energy, incorporating the efficiency of the recovery system.

The total kinetic energy available during braking can be determined using the following formula:

$$\text{Equation 1 } u(1 - 2) = \frac{1}{2} * m * (v_2^2 - v_1^2)$$

However, due to inefficiencies in the recovery system, only 75% of the braking energy is typically usable. The remaining losses accounting for 25% are primarily due to driveline inefficiencies and heat dissipation during the energy conversion and storage processes. By assessing these factors, the system's practical energy recovery potential can be evaluated, which is critical for designing an effective and efficient KERS (Boretti, 2010)

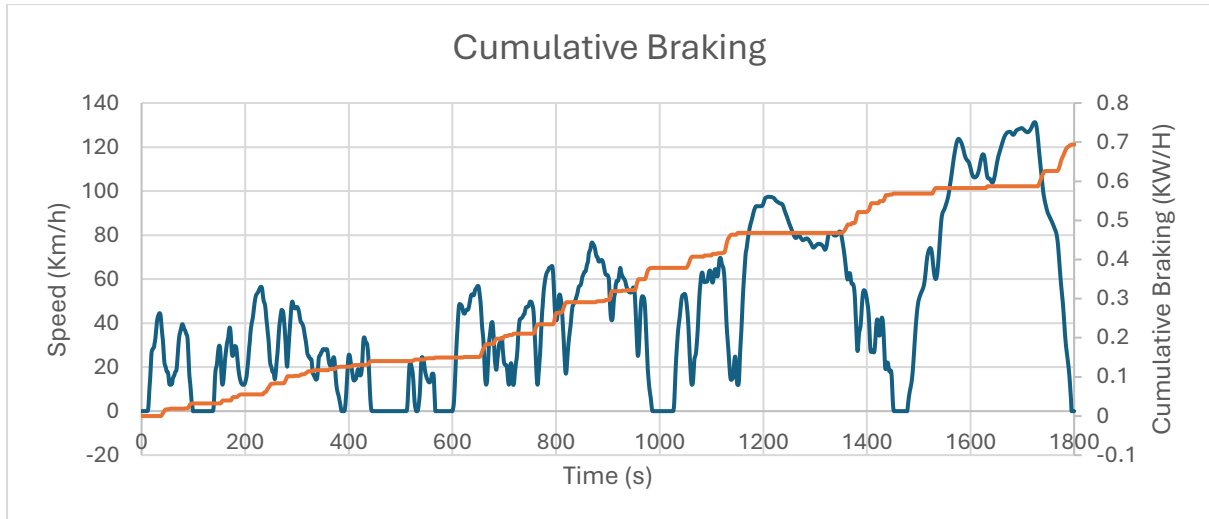


Figure 5-Cumulative Braking

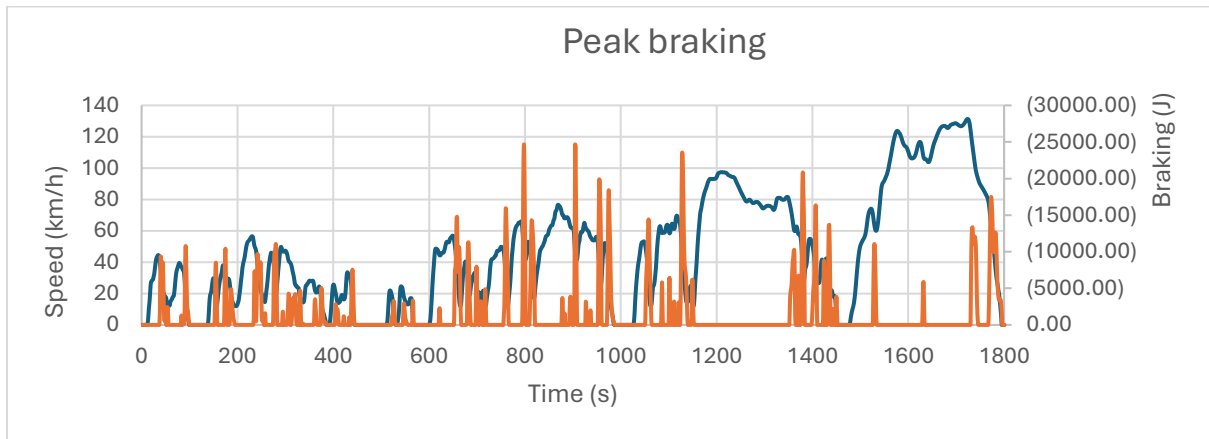


Figure 6- Peak Braking

The graph of peak braking over the WLTP cycle visualizes the braking intensity and duration during different phases of the test. By analysing this data, the total braking energy utilized, and the corresponding time intervals can be clearly observed. These braking zones are crucial for determining the sizing of the KERS system, as they indicate the maximum energy recovery requirements, and the capacity needed to store this energy efficiently. This ensures that the system is designed to handle the highest demands during peak braking periods while maintaining optimal performance.

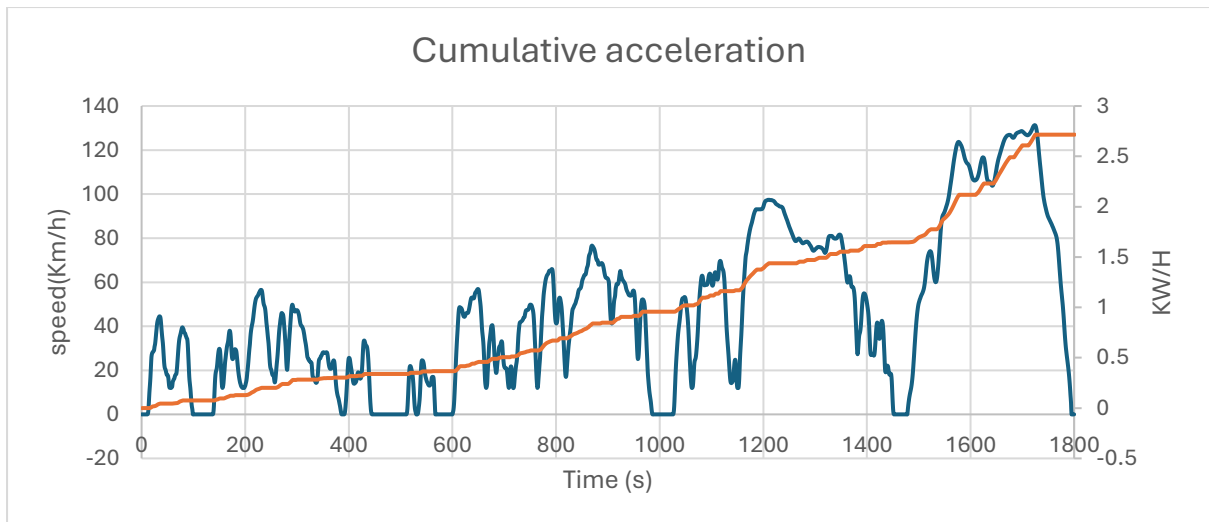


Figure 7-Cumulative Acceleration

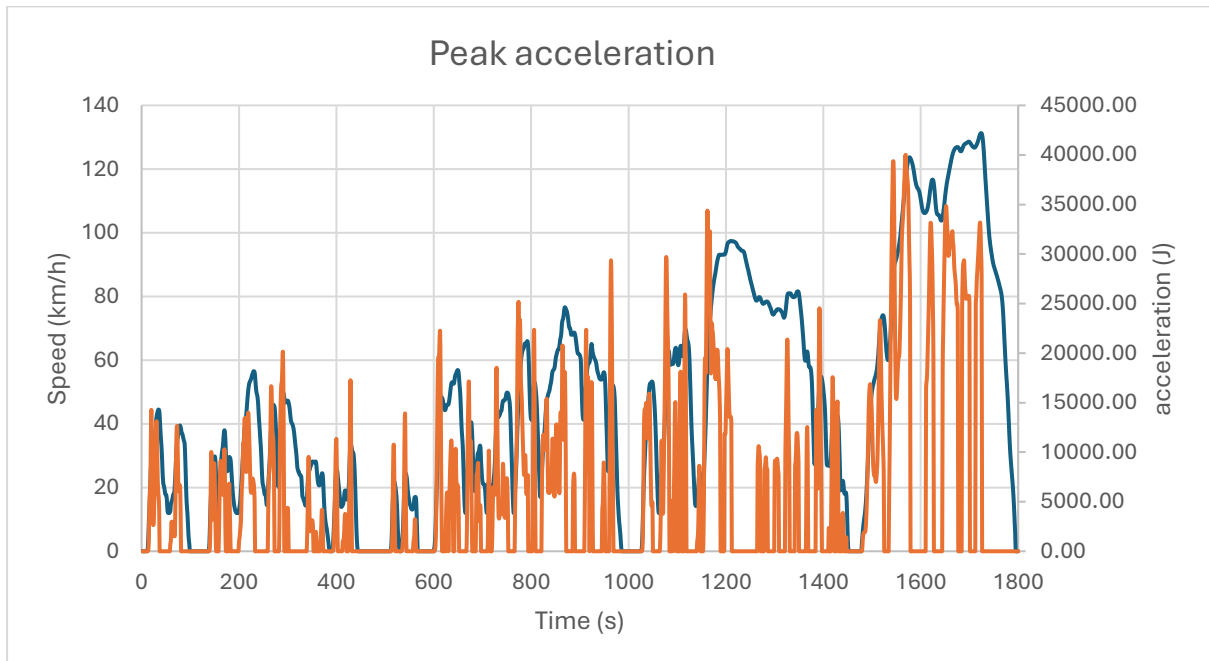
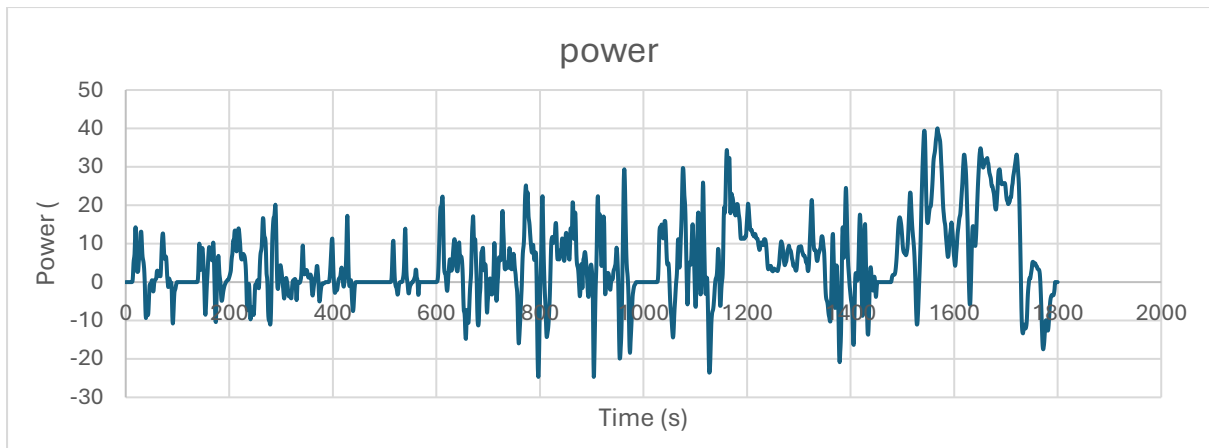
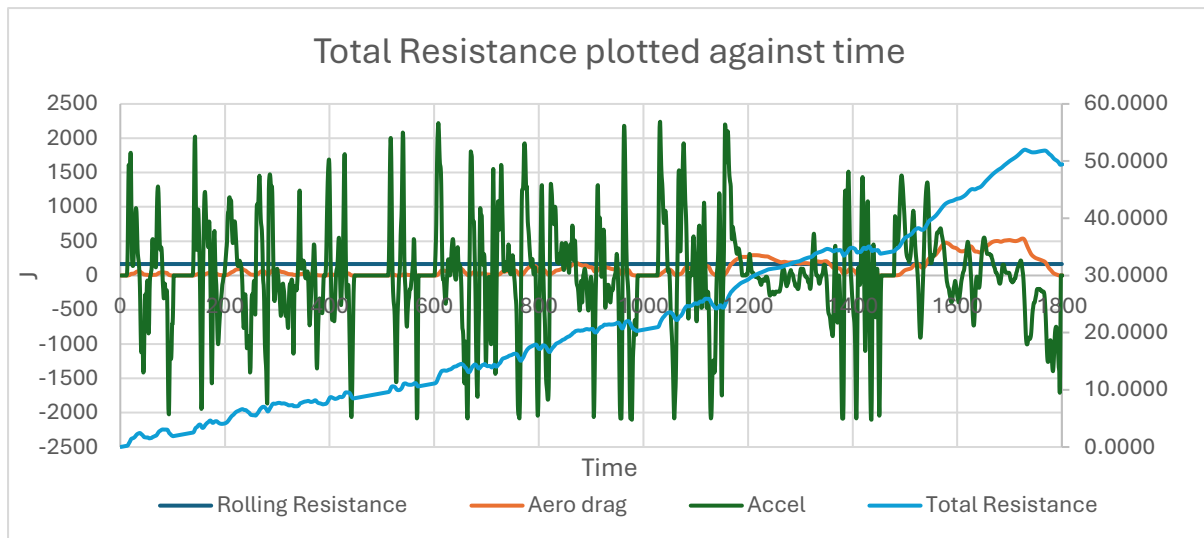


Figure 8- Peak Acceleration

Peak acceleration across the WLTP cycle helps identify critical points where energy collected by the KERS system should be redistributed to assist in vehicle acceleration. By visualizing these peaks, it highlights how much energy is required and when to deploy it most effectively. This ensures the energy storage system delivers optimal performance, contributing to smoother acceleration and reducing strain on the primary powertrain during high-demand moments.



Power distribution over the wltip cycle, shows all the positive and negative power over the cycle



The graph of total resistance over time demonstrates the cumulative impact of rolling, aerodynamic, and acceleration resistances on the vehicle. Rolling resistance remains constant due to a controlled road surface and lack of elevation changes. Aerodynamic resistance, on the other hand, increases significantly with speed, following its exponential relationship to velocity. Acceleration resistance is determined by the vehicle's mass and the force required to overcome inertia, representing the joules needed to propel the car forward during each acceleration event. Together, these forces illustrate the energy demands placed on the powertrain throughout the WLTP cycle.

5.KERS implementation

The KERS implementation will be a flywheel system that will spin up during braking, allowing short term storage of energy to then be re distributed to the wheels to assist in accelerating the vehicle. Making it more efficient.

For the sizing of the components should be big enough to allow the most amount of energy to be recovered at its peak braking during the cycle. The peak braking force on the Audi suggests 242.86 KJ and have an average braking duration of 7 seconds. Using these figures to determine the amount of power required to recover at its peak.

$$power = \frac{242860 \text{ w}}{7 \text{ s}} = 34,694W \text{ (34.69KW)}$$

Using the peak braking force the KERS can be designed to facilitate the appropriate amount of energy recovery over the peak cycle. The fly wheel is required to store a minimum of 242.86 KJ to accommodate the maximum braking.

To design the recovery system, efficiency of the train is needed to be considered. Depending on components and how they are implemented will determine how efficient the recovery of the kinetic energy is. A big area for loss is with bearings used, using standard ball bearings for the flywheel results in approximately 5% to 10 %. Magnetic bearings reduce losses to 2%-3%. Also, the actual fly wheels condition will change efficiency; by storing it in a vacuum the effects of air resistance will be nullified greatly reducing losses from 15% to 2%.

The average losses of a fly wheel system 30%, making it 70% efficient. When compared to a battery system that converts the kinetic energy to electrical energy then to the motor, is 2 times more efficient. This being achieved by keeping the energy in KE. The use of flywheel storage is good for short term power storage, but has higher losses over time compared to a battery system. By coupling a fly wheel with a small battery, a high level of efficiency can be achieved with short stops launching using the fly wheel energy and longer stops being stored in a battery to be potential used later. (Boretti, 2010)

To reduce weight the system will be purely mechanical

6.KERS system

Selecting the appropriate KERS design and method for collecting energy from the drivetrain is critical. Developing a hybrid system tailored to the desired application requires thorough research into various energy storage methods to identify the most efficient and practical option. This involves evaluating technologies such as flywheels, batteries, or capacitors, each with distinct advantages and limitations depending on the system's operational needs

Technique	Type of energy			Parameters			
	Source	Storage	Release	Efficiency gain	Space and weight	Energy recovery	Hybrid capability
Thermo electric TERS	Thermal	Chemical	Electric	2	2	3	No
Rankine cycle TERS	Thermal	Mechanical (steam)	Electric-mechanical	2	2	2	Yes
Electric turbo compound (ETC)	Kinetic	Chemical	Electric	1	2	3	No
KERS from vertical oscillations	Kinetic	Chemical	Electric	1	1	2	No
Elastomer or spring KERS	Kinetic	Mechanical (elastic)	Mechanical	2	3	1	Yes
Pneumatic/hydraulic KERS	Kinetic	Mechanical (pressure)	Mechanical-electric	3	3	1	Yes
Flywheel KERS	Kinetic	Mechanical (rotation)	Mechanical	3	3	1	Yes
Strong electric KERS	Kinetic	Chemical	Mechanical-electric	3	3	1	Yes

Figure 9 (Ahmed T. Hamada, 2022)

Table 2. Comparison of ERSs. Efficiency gain: (1) under 10%, (2) 10–25%, (3) over 25%. Weight and space: (1) no significant space or weight added, (2) moderate extra space required or weight added (typically 40kg), (3) considerable space required or weight added (440kg). Energy recovery: (1) only under deceleration, (2) depending on road surface, (3) continuously (adapted from [32]).

Figure 10- (Ahmed T. Hamada, 2022)

The desired energy recovery is based on the WLTP data and the amount of recoverable energy available from the Audi A3. Since the stopping times between braking and accelerating are short, there is no need for long-term energy storage. A flywheel configuration offers excellent energy recovery efficiency. However, factors such as the space required, and the additional weight of the flywheel must also be carefully considered.

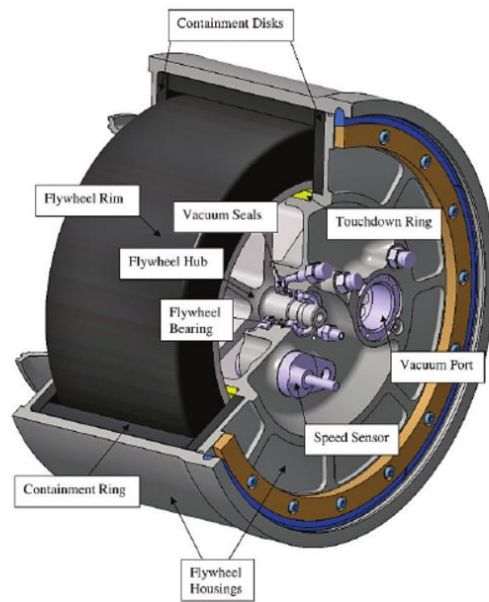


Figure 11- (Boretti, 2013)

Flywheel kers system

To determine the appropriate size of the components, several factors must be carefully considered. The flywheel must be sized to store the maximum kinetic energy available during braking and must be capable of fully discharging this energy to create the most efficient system possible.

The choice of material for the flywheel plays a critical role in its effectiveness. Metals like titanium or steel are commonly used, offering durability and cost-effectiveness. Alternatively, lightweight composites such as E-glass or graphite epoxy can be employed. These materials allow for higher rotational speeds due to their reduced weight, making them more efficient. However, they come with significantly higher costs due to the production and material used.

Figure (6) illustrates an isolated carbon fibre flywheel. While its lightweight properties enable greater efficiency through higher rotational speeds, its high cost and the complexity of its setup may make it less suitable for general use. For road cars, the cost and durability under real-world conditions often favour more traditional materials over carbon fibre, as road vehicles are subjected to more wear and potentially rough handling. (Hu Dongxu, 2023)

When selecting a material, the intended application should guide the decision. While high-performance vehicles may benefit from the advantages of advanced composites, practical considerations such as cost, maintenance, and robustness must be prioritized for everyday road vehicles.

$$\text{Equation 2- } E = \frac{1}{2} * I * \omega^2$$

Giving the fly wheel a radius of 0.3 m and a maximum rotational speed of 12,000 rpm, will be able to find the mass of the fly wheel.

$$\text{Equation 3- } M = \frac{4.E}{r^2 * \omega^2}$$

With rpm turned to radians the max speed becomes

$$\text{Equation 4- } M = \frac{4 * 242,864.06}{(0.3^2) * (1256.6^2)}$$

$$\text{Equation 5- } M = \frac{971,456.25}{0.09 * 1,579,136.36}$$

$$\text{Equation 6- } M = \frac{971,456.225}{142,121.27}$$

$$\text{Equation 7- } M = 6.84 \text{ KG}$$

Operating at 12,000 RPM falls well within the working range of materials such as steel and titanium, even with a robust safety factor. However, the flywheel's size contributes significantly to the vehicle's overall weight. This increase in weight is expected to elevate the tractive effort required for acceleration and the braking force needed to stop the vehicle.

While the added weight may slightly reduce overall efficiency, the incorporation of the KERS (Kinetic Energy Recovery System) compensates by delivering an additional 33 kW of power. This contribution has the potential to enhance both the fuel economy and performance of the Audi, outweighing the drawbacks of increased mass.

7. System operation

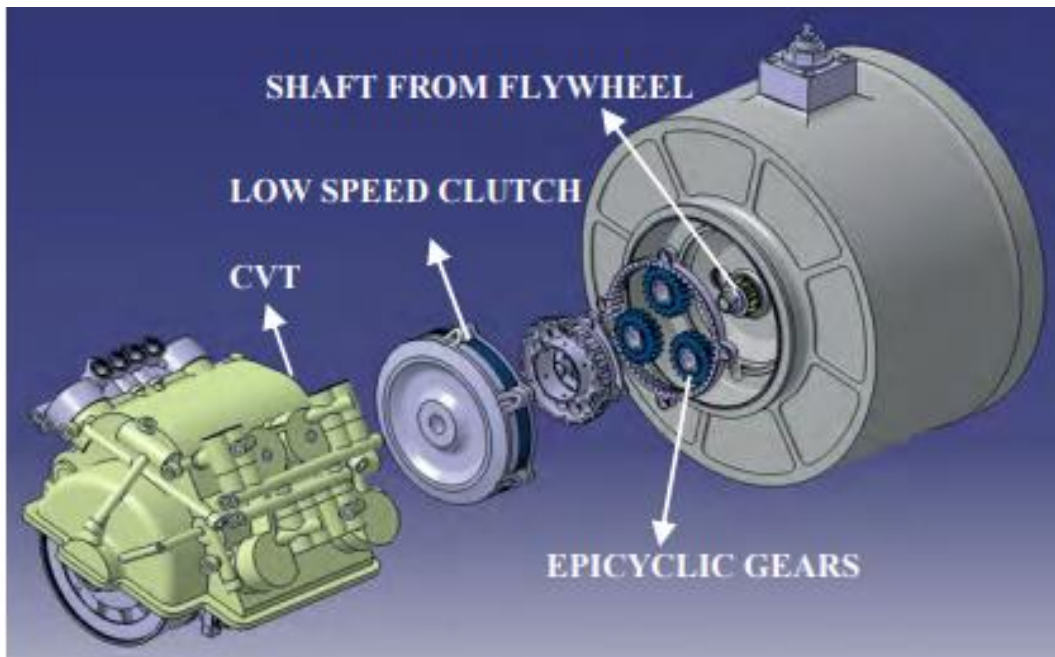


Figure 12- (THOMAS MATHEWS, n.d.)

The system will operate using the components illustrated in Figure (7). A continuously variable transmission (CVT) is central to this design. The CVT functions using two conical driveshafts connected by a belt, enabling a virtually "infinite" range of gear ratios. This allows for seamless power delivery without the interruptions that can occur in stepped gearboxes, where energy may be lost during gear changes.

In this setup, the CVT will deliver power to the KERS, ensuring efficient energy transfer between the drivetrain and the flywheel. The adaptability of the CVT is particularly advantageous, as it can optimize power output for energy recovery and redistribution, maximizing the efficiency of the system.

The low-speed clutch manages the input from the transmission to the flywheel. It disengages the flywheel when the vehicle is stationary and re-engages it when in motion. The connection to the epicyclic gear system is necessary to handle the high rotational forces from the flywheel and convert this power into a usable form for the clutch. This ensures smooth and controlled acceleration over short durations. (THOMAS MATHEWS, n.d.)

The Audi A3 is a front-wheel-drive vehicle with the engine mounted at the front. Incorporating a KERS system in the front poses significant challenges due to the size of the components calculated earlier. Additionally, the increased weight at the front could negatively impact the vehicle's dynamics, potentially making it too front-heavy and affecting handling.

A practical solution could involve using a driveshaft connected to the continuously variable transmission (CVT) to position the KERS components at the rear of the vehicle. This configuration would offset the weight distribution, improving balance while maintaining the system's performance and functionality.

8.Conclusion

This report displayed the potential integration of a flywheel-based KERS (Kinetic Energy Recovery System) in the Audi A3 TDI 1.6 Sportback 2012. Using data from the WLTP cycle, key vehicle dynamics and resistance factors were analysed to calculate the energy recovery and distribution requirements. The KERS design was tailored to the Audi's specific characteristics.

The calculations demonstrate that the KERS can recover significant kinetic energy during braking, with an estimated peak recovery of 34.69 kW and a flywheel capacity of 242.86 kJ. With a designed weight of 6.84 kg and a maximum rotational speed of 12,000 RPM, the flywheel system operates efficiently, aided by advanced components such as a CVT, magnetic bearings, and vacuum housing to minimize losses.

While the increased weight of the flywheel poses a challenge, relocating the KERS components to the rear of the vehicle effectively mitigates potential handling issues while maintaining performance. The system should improve fuel economy and acceleration without compromising the vehicle's overall efficiency.

Future developments could include integrating hybrid energy storage, combining the short-term advantages of a flywheel with a battery system for longer-term energy retention. Despite the higher losses from converting energy into battery storage the hybrid solution could further enhance performance, efficiency, and usability, particularly in urban environments where braking and acceleration are frequent.

In summary, the implementation of a flywheel-based KERS in the Audi A3 demonstrates a feasible approach to energy recovery and performance enhancement while addressing the challenges of packaging and efficiency.

9. References

- Ahmed T. Hamada, M. F. O., 2022. *An overview of regenerative braking systems*. [Online] Available at: <https://www.sciencedirect.com/science/article/pii/S2352152X22010350> [Accessed 30 November 2024].
- Audi UK, 2009. *Technical Data – Audi A3 Sportback 1.6 TDI (105PS)*. [Online] Available at: <https://www.auk-kits.co.uk/assets/documents/original/10793-AudiUK00000182A3Sportback16TDITechnical.pdf> [Accessed 30 November 2024].
- Boretti, A., 2010. *Modeling of Engine and Vehicle for a Compact Car with a Flywheel Based Kinetic Energy Recovery Systems and a High Efficiency Small Diesel Engine*, Ballarat: SAE International.
- Boretti, A., 2013. *Kinetic Energy Recover Systems for Racing Cars*, s.l.: SAE International.
- Hu Dongxu, D. X. L. W. Z. Y. Z. X. C. H. Z. Z., 2023. *A review of flywheel energy storage rotor materials and structures*, Beijing : Sciencedirect.
- Milica, L. & Andrei, G., 2020. *Influence of the flywheel profile on the energy storage capacity of the kers system*, Bristol: Pro Quest.
- THOMAS MATHEWS, N. D., n.d. *FLYWHEEL BASED KINETIC ENERGY RECOVERY SYSTEMS INTEGRATED IN VEHICLES*, Bangalore: ResearchGate.
- WLTPfacts.EU, 2024. *What is WLTP and how does it work?*. [Online] Available at: <https://www.wltpfacts.eu/what-is-wltp-how-will-it-work/#::~:~:text=Under%20conditions%20defined%20by%20EU,well%20as%20their%20pollutant%20emissions.> [Accessed 30 November 2024].

Chat gpt used for readability

10.Appendix

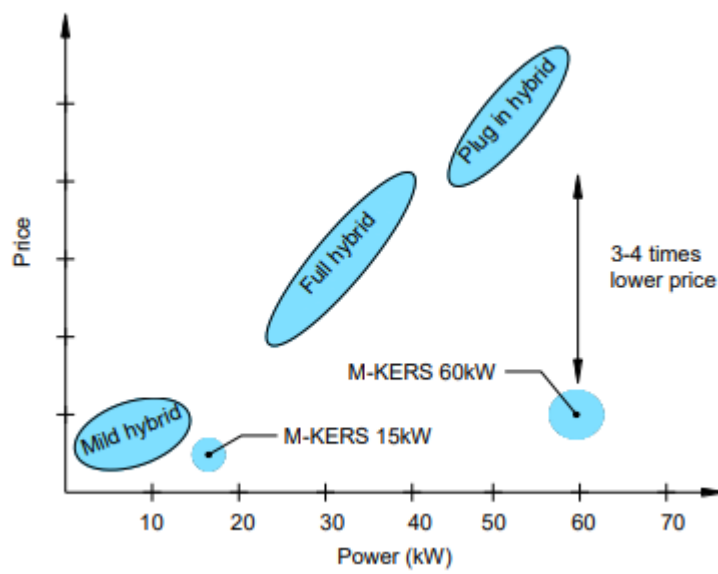


Figure 13-Price v Power of different Hybrid systems (Milica & Andrei, 2020)