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Kinetic Energy Recovery Alternative Propulsion Systems (ACHA5010)

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1 Introduction

The aim of this report is to research and evaluate a suitable kinetic energy recovery system for a chosen vehicle to decrease fuel consumption. I have decided to complete this on the Renault Megane RS 300 Trophy. The reason I have selected this car is because I am a personal fan of the Renault Sport range and have always aspired to own one. This car was the base for the Megane RS Trophy R, which was the fastest front-wheel drive car around the Nürburgring Nordschleife for several years. This car also has similar technology to Porsche supercars, with an all-new 4-wheel steer system. The technology is very interesting however, this may mean that the car is limited on space for adding this system, meaning that it will need to be size conscious.



Figure 1 (evo, 2020)

2 Vehicle Data

The test mass for the WLTP is calculated based on the unladen (kerb) mass of the vehicle stated by the manufacturer and the laden (gross) mass, which is the heaviest the car is permitted to weigh. Figure 2 shows the chart of the process for this calculation.

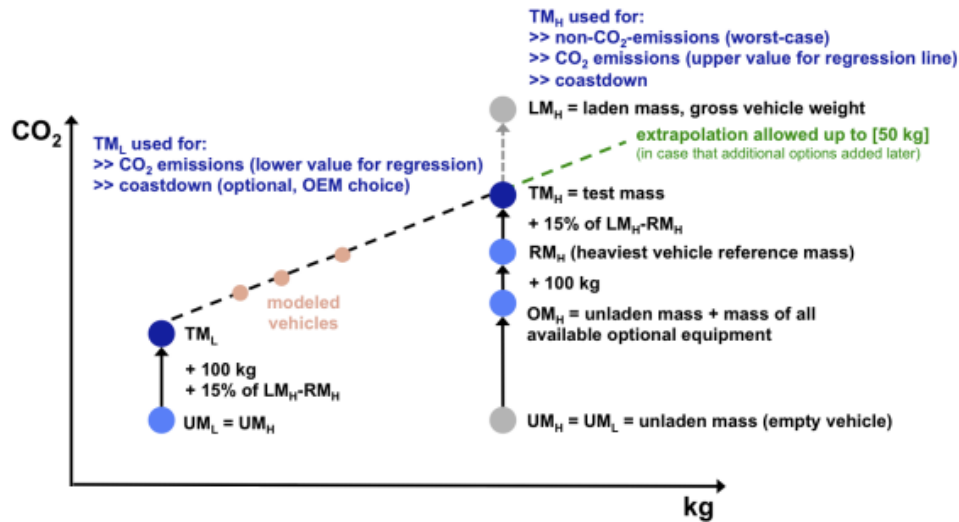


Figure 2 (Mock, P. 2011)

Renault provide a spec list for this specific model and configuration, which I have taken figures from to get accurate numbers for further calculations.

Measurements	Reference
Kerb Mass = 1419kg	(Renault Press UK, 2019)
Gross Mass = 1899kg	
Test Mass = 1576kg	Calculated using gross and kerb mass.
CdA = 0.78	(Renault Press UK, 2019)
Width = 1.87m	
Height = 1.45m	
Frontal Area = 2.27m ²	Calculated using CdA, width and height.
Coefficient of aerodynamic drag = 0.34	Calculated using CdA and frontal area.
Rolling Resistance Coefficient = 0.012	(The Engineering Toolbox, 2008)
Rolling Resistance = 185.53 N	Calculated using RRC, gravity and kerb mass.
Density of Air at Standard Conditions (ρ) = 1.29	(Rafferty, J.P. 2024)

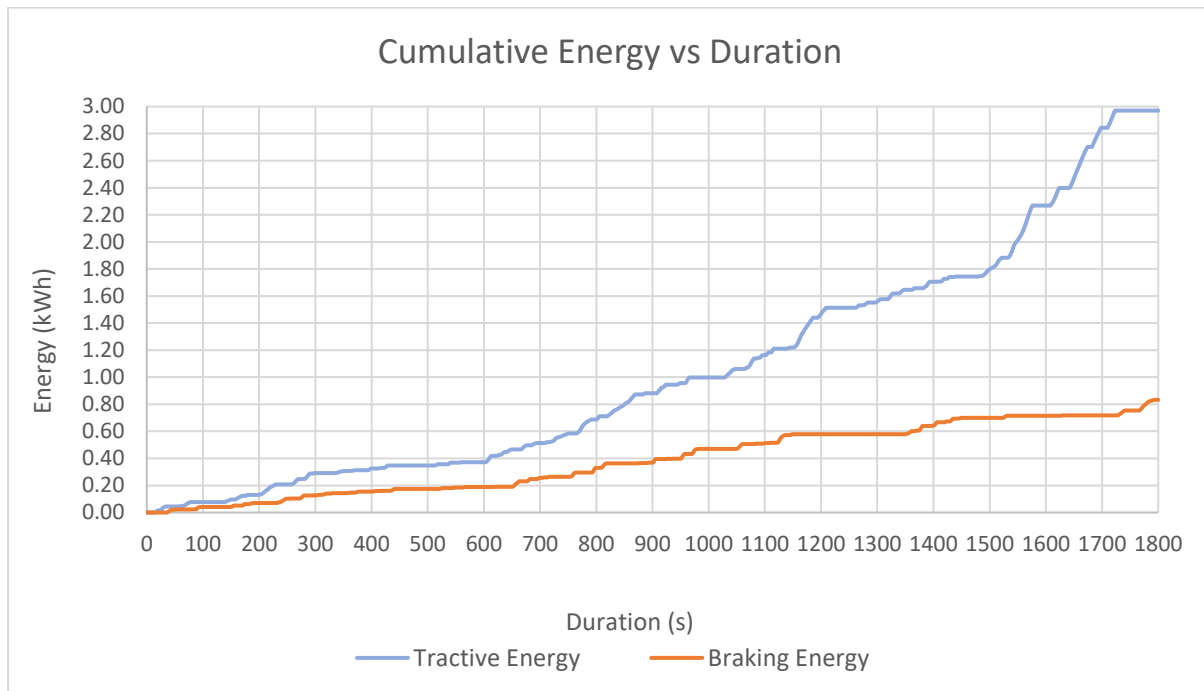
(Table 1)

Some of these values have been calculated, however, most were found through research, detailed in the reference column. The frontal area was calculated using the width and height dimensions of the car, this was then used for denoting the coefficient of aerodynamic drag, using the given CdA value. The rolling resistance coefficient is a typical value for performance tyres like the Bridgestone Potenza's fitted to this car. This was then multiplied by the test mass and gravity (9.81) to get the total rolling resistance for the car in newtons.

3 WLTP Test Procedure

This vehicle is in WLTP class 3, which is the procedure for vehicles with over 34 watts per kilogram of kerb mass. This car has 157.65 watts per kilogram, therefore is over by a large amount.

The tractive and braking energy has been calculated and plotted in the corresponding excel spreadsheet and graph 1 shows the cumulative data plotted against test duration.



(Graph 1)

4 Kinetic Energy Recovery Systems

4.1 Flywheel KERS

Flywheel KERS is one option for recovering kinetic energy. This system stores energy by increasing the angular velocity of the flywheel, then is converted through transmission devices. A diagram of this is shown in figure 3.

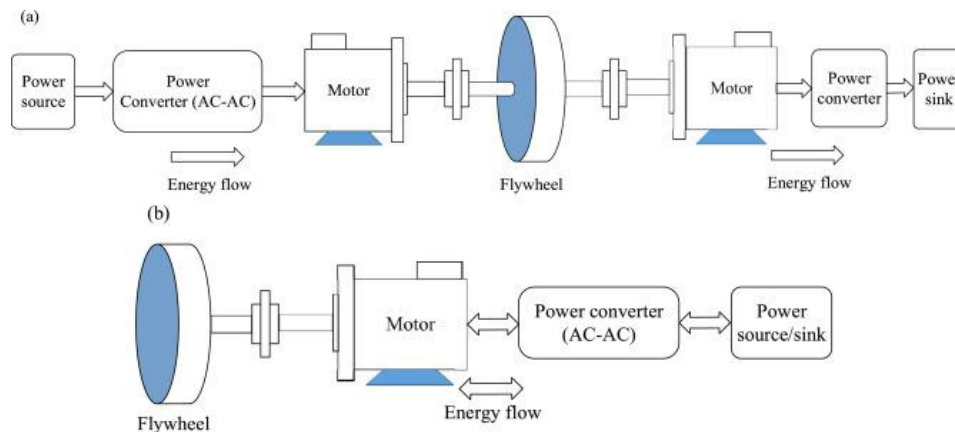


Figure 3 (Bai, S. Liu, C. 2021)

The angular velocity is increased using a continuously variable transmission (CVT) which moves the gear ratio to speed up the flywheel and store energy. The assembly is shown in figure 4:

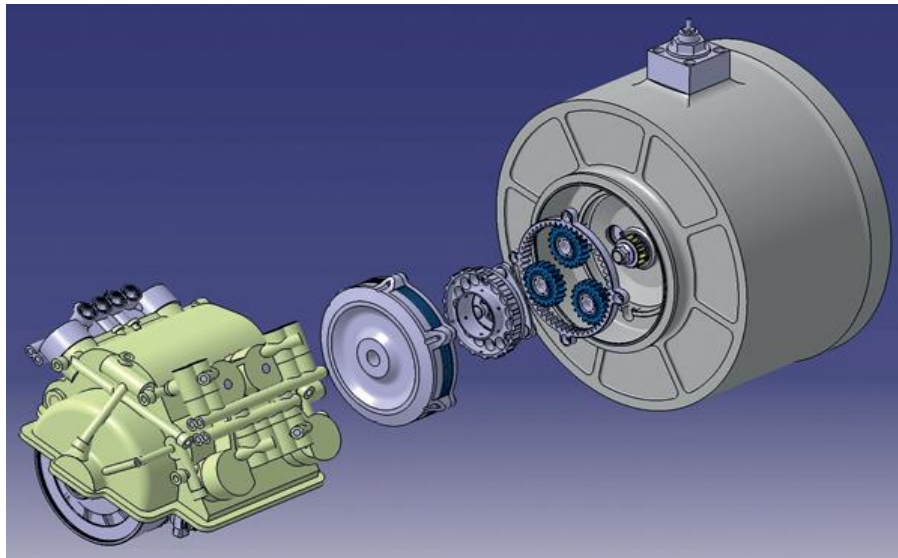


Figure 4 (S. 2018)

Using a CVT through a KER system can be more fuel inefficient as the increased rotational energy is utilised, reducing the consumption up to 30%. This system can provide a high energy density and large maximum power output. This system can offer up to 90% efficiency which is not bad for putting energy back to increase performance. However, this system may be less suitable for a performance car like this one, due to the added weight and size.

4.2 Exhaust Recovery System

Exhaust recovery system (ERS) utilises the velocity of exhaust gases to turn a turbine in the exhaust pipe, which turns an electric motor to send current into a battery for storage. This can be an advantage for a performance car as the exhaust turbine can be connected to an intake turbine which is then connected to the electric motor. The gas leaving the engine then turns the turbo forcing air through the intake quicker. Then, using the electric motor, it can keep the turbo 'spooled up' allowing intake air velocity to remain high, improving initial throttle response and power (Mitchell, S. 2022).

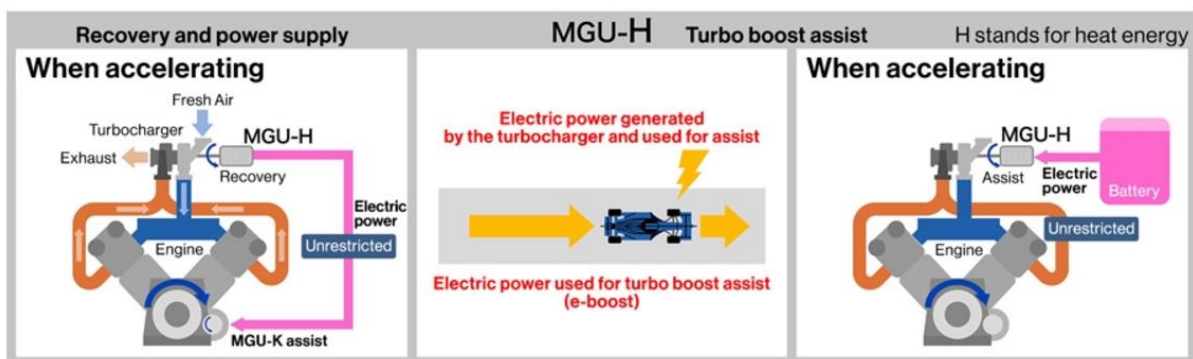


Figure 5 (Honda, 2022)

Figure 5 shows a diagram made by Honda showing the assembly of an ERS system which is used in F1. This shows how a system like this is suitable for a performance application, due to the lightweight nature of Formula 1 parts. However, this system has received criticism for being expensive and very complex, making it less suitable for a road car. Due to the complexity, it would therefore be unreliable compared to current solutions.

ERS uses a battery for storing the energy if it isn't going to be used instantaneously, therefore, this takes some further decision making and research to choose an appropriate battery type. Here are some battery options for comparison:

4.2.1 Lead Acid Batteries

Lead acid batteries have a low initial cost and are widely available, due to their use in road vehicles to store energy for startup. They have a low energy density meaning that they can't store much energy compared to the size. This can be a drawback for trying to pack a KERS system into a small space or trying to keep the car light for performance needs (Ksouksou, T. Zeraouli, Y. 2014).

4.2.2 Nickel Metal Hydride

Nickel metal hydride batteries are much more expensive than lead acid batteries, however, have current successful uses in hybrid and electric vehicles. They have a high energy density but managing the battery is important, this means that they can't be discharged to 0% often otherwise the overall capacity will begin to decrease. They also have poor low temperature performance potentially meaning the added complexity of a cooling system is required (German, J.M. 2004).

4.2.3 Lithium-ion

Lithium-ion batteries have a high energy and power density so therefore provide lots for the size and weight. However, they are known to be more dangerous with the risk of thermal runaway. This is the chance of the battery setting a light unpredictably. Therefore, a complex battery management system is required to make sure there are no risks. Unfortunately, this also raises the costs putting this technology into the more expensive bracket of energy storage (Garche, J. Moseley. 2017).

4.3 Super Capacitors

Super Capacitors are another form of transferring and capturing recoverable energy. They have advantages over batteries as they can charge and discharge much quicker, making them a good energy recovery system. They have a high power density and a wide operating range, which are some more advantages over batteries. However, they can't store large amounts of energy like batteries so therefore, it must be used in a power boost after recovery to make space for the next recovery period. On large-scale applications their cost makes them less popular as the cost per watt of energy storage is high (Goikolea, E. and Mysyk, R. 2017).

Figure 6 shows the layout of a supercapacitor KERS, showing how the power boost would be delivered through a convertor and generator.

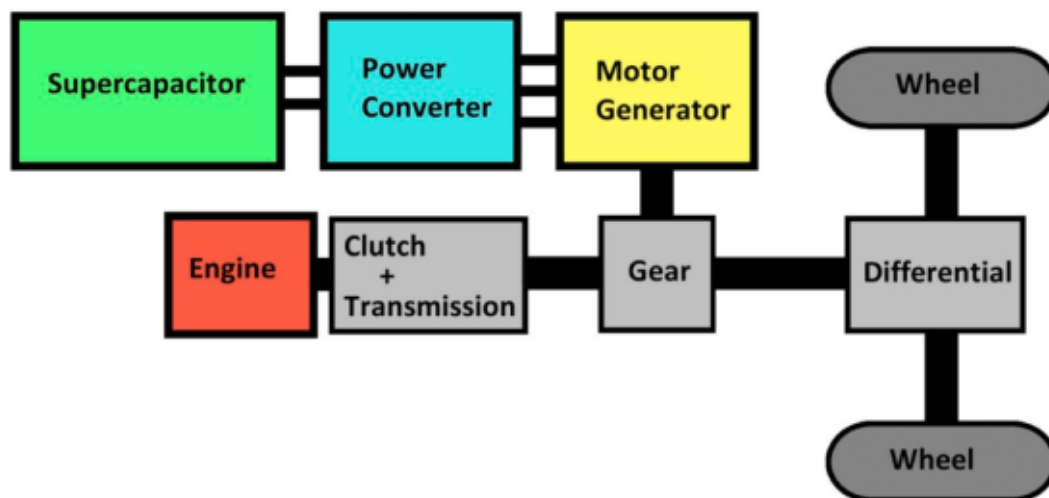
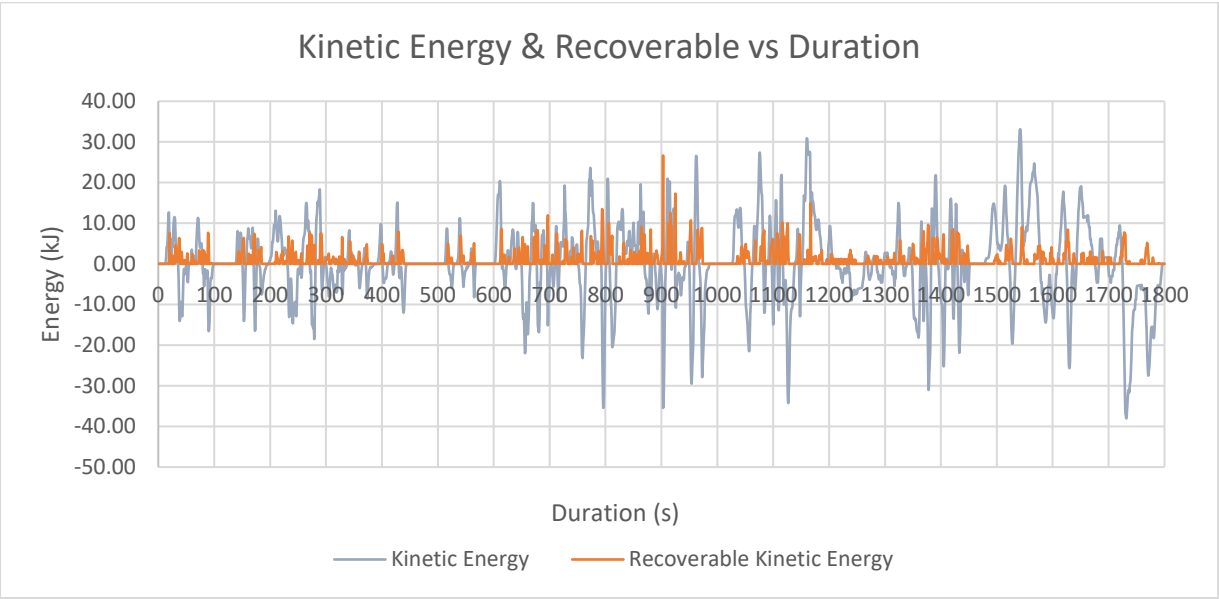


Figure 6 (Green Car Congress, 2019)

5 System Specification



(Graph 2)

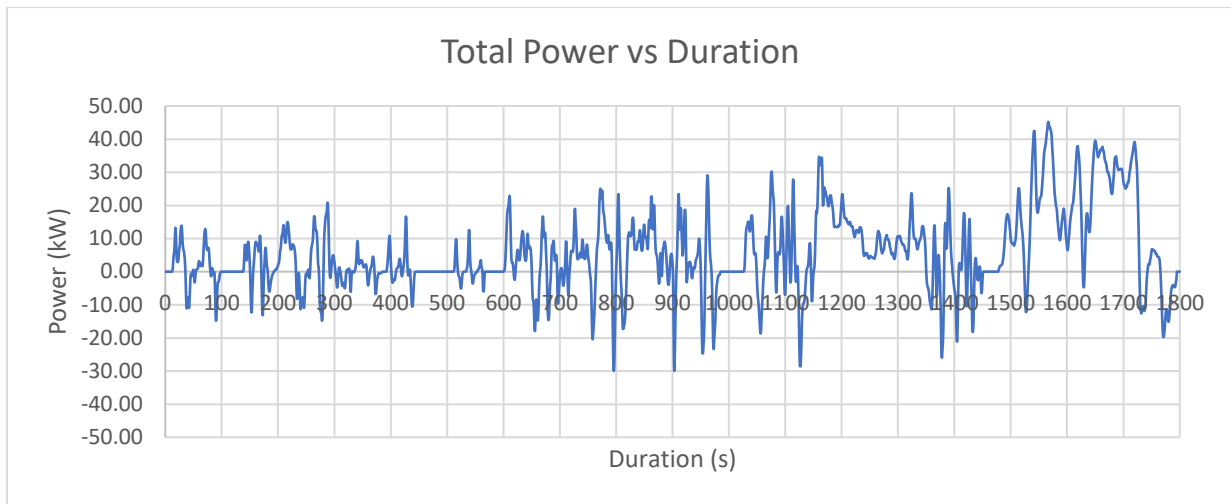
The peak energy recovery requirements can be found from graph 2, where the recoverable and actual kinetic energy has been plotted against the duration of the test. The peaks in the graph can then be found in the data to find the maximum recoverable energy. The largest peak just after 900 seconds duration was found to have 21.32kJ of energy, shown below in graph 3. This was assuming 80% efficiency therefore recovering 80% of total recoverable energy.

This spike of energy then will have to be redeployed before the next recovery period, shown in table 2. This period is 8 seconds long and the car is under acceleration during this time, meaning that there will be a boost in power.

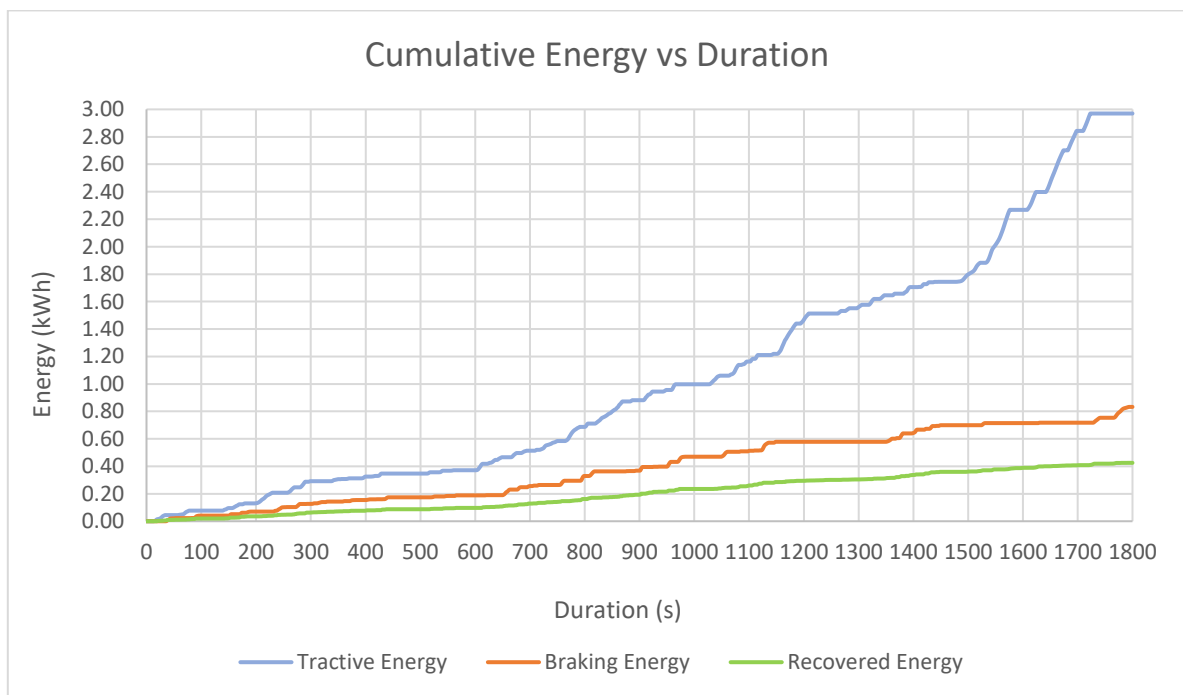
In total, over this 8 second times period, there is a demand for 53.39kW of tractive energy required, therefore it can be worked out what energy needs to be used per second to use up the charge. Each second would need a 2.67kJ boost, increasing the power to 74.75kW over this acceleration. Therefore, the system must be able to cope with a peak boost of 2.67kJ.

21.32
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
2.19
7.98

(Table 2)



(Graph 3)



(Graph 4)

Graph 4 shows the recovered energy returned to the wheel. From my calculations and mentioned earlier, this is assuming an 80% efficiency from the system, therefore, it is recovering most of the braking energy, not all. By the end of the cycle 0.43kWh of energy have been recovered, which is around half the total braking energy, showing that the system is working well to improve the cars fuel consumption.



Figure 7 (Shanghai Green Tech, 2024)

$$\text{Power (kW)} = \text{Voltage} \times \text{Current}$$

$$64V \times 2000A = 128kW$$

Figure 7 shows the supercapacitor I have specified for the recovery system. It has a power of 128kW as shown in the calculation. This will provide enough power needed for a strong surge if it has been built up under recovery.

$$\text{Energy Storage (kJ)} = \frac{1}{2} \times \text{Capacitance (F)} \times \text{Voltage (V)}^2$$

$$\frac{1}{2} \times 125 \times 64^2 = 256kJ$$

The energy storage shown in this calculation is 256kJ, which the largest recovery period does not exceed, making it large enough to hold more charge to deploy at later times or to use within its capabilities to improve reliability.

This unit is also rather small for its power capabilities, shown as specified, to be around 420mm long and 260mm wide, allowing it to be mounted easily into the tightly packed Megane.

6 System Operation

The kinetic energy recovery system I have chosen to utilise for the Renault Megane is the supercapacitor KERS. Being that it is a performance vehicle, a supercapacitor would be able to stay light but deliver larger amounts of power quickly, allowing more energy to be recovered at the next opportunity, for example, between braking zones on a track. The aim of reducing the fuel consumption would also be suited to this system. The added boost of power during acceleration would mean that the engine can work up to 28% less to achieve the speed for the WLTP test.

The difference for the driver from no KERS to this system would be that the car would feel more responsive when the accelerator is reapplied after braking. The car would also start to slow down more aggressively when off the accelerator meaning there could be less use of the friction brakes as the losses would be higher from having the recovery system.

7 Conclusion

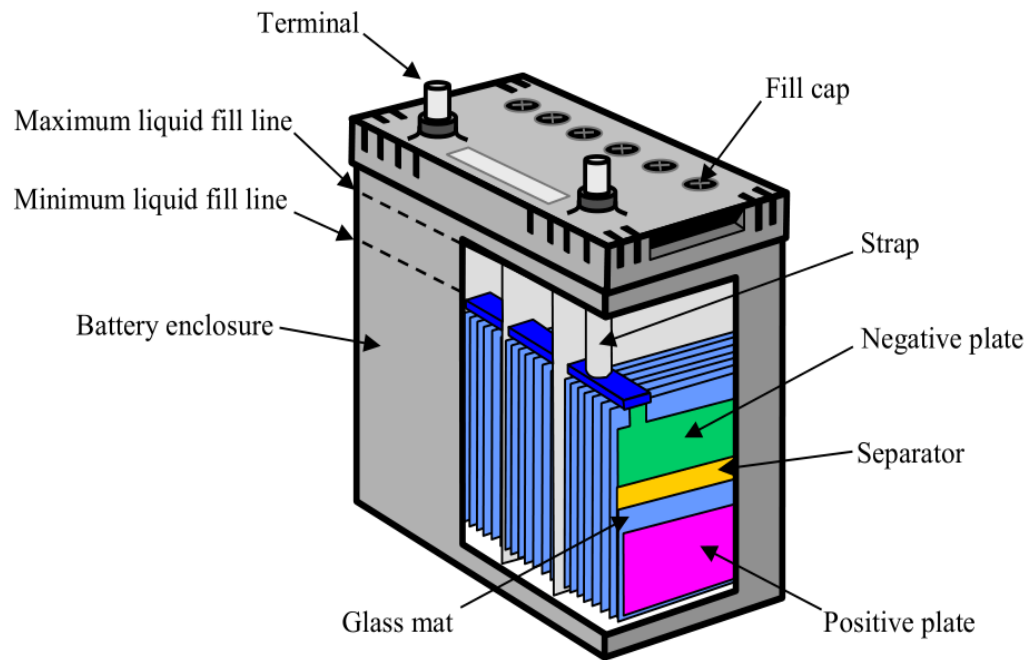
In conclusion, I feel that this system of kinetic energy recovery suits the nature and specs of this car as it is a performance focused model. This means that the system is light and easy to find somewhere to fit to the car as well as delivering good power improvements to reduce fuel consumption. The other KER systems also would have provided fuel consumption reductions, however, in my opinion, the drawbacks of having heavier batteries and complex management systems ruled out exhaust recovery systems from consideration.

The flywheel KERS would have also been a good option, being able to utilise the stored energy in a similar way to a supercapacitor system however, it would be more suitable for a large vehicle or a less tightly packed car where there is more space for stable mounting.

The specified supercapacitor may exceed the minimum requirements for the total energy recovery displayed from this test, but this means that the capacitor is well within its limits, avoiding premature failure and ensuring reliable use for a long period of time, which suits a road going vehicle.

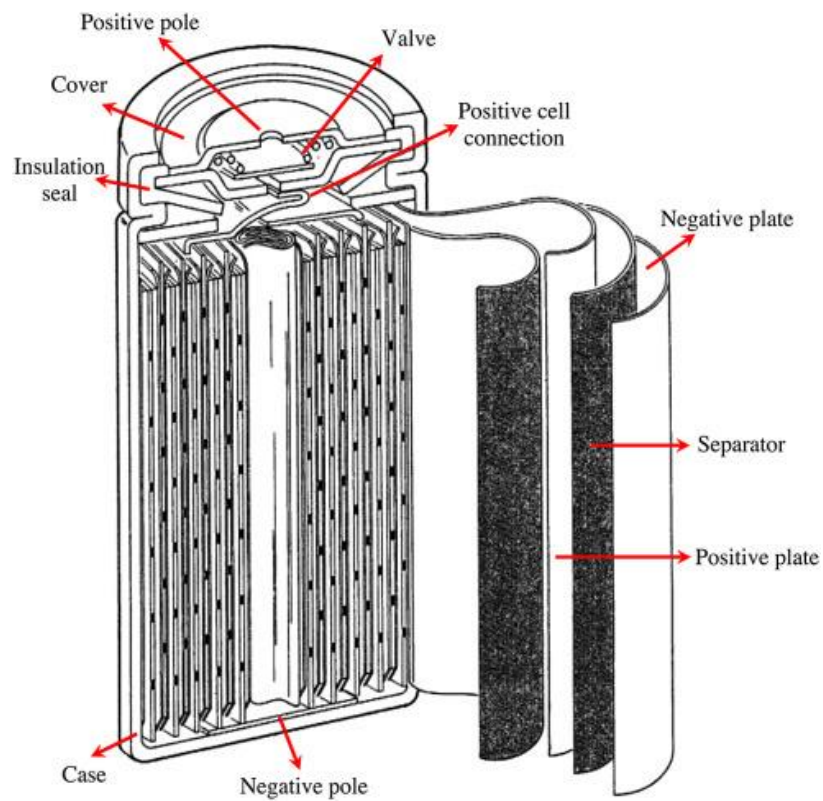
8 Appendices

Appendix A – Lead Acid Battery



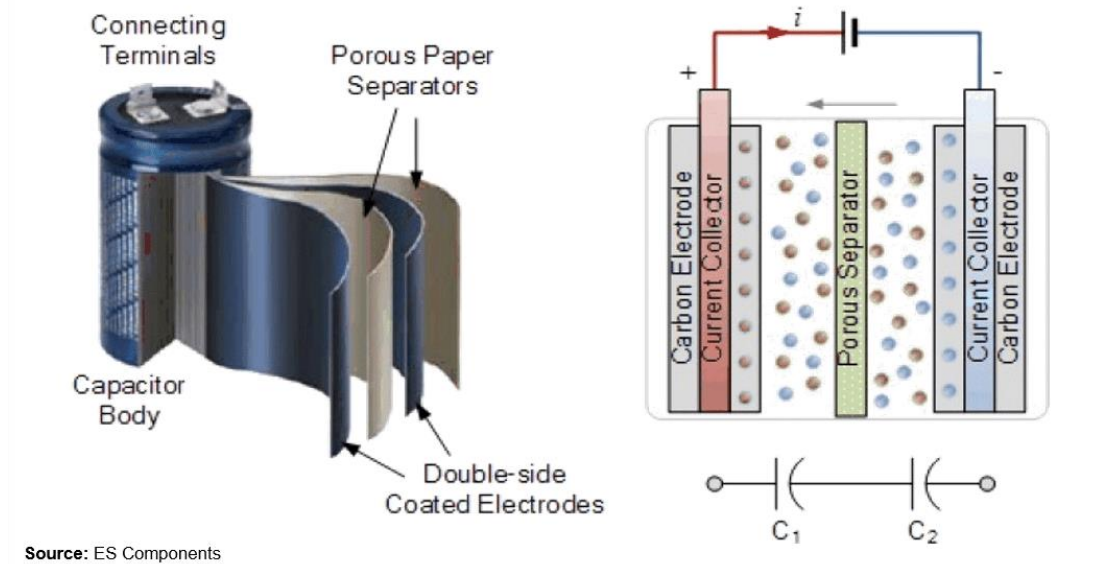
(Grankia, 2022)

Appendix B – NI-MH Battery



(Aktaş, A. Kirçiçek, Y. 2021)

EXHIBIT 2: Supercapacitor Construction



(India, P. 2024)

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