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Kinetic Energy Recovery

Alternative Propulsion Systems (ACHA5010)

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1 Introduction

In this assignment we explore the integration of a Kinetic Energy Recovery System (KERS) in vehicles to enhance fuel efficiency. KERS in automotive vehicles are systems designed to recover a car's kinetic energy during braking and convert it into a form that can be either used immediately or stored for later use. Typically, this energy is stored in a flywheel, battery, or supercapacitor. When the car accelerates, the stored energy is released back into the drivetrain, providing a boost to the engine and thus improving the vehicle's overall efficiency. This technology is particularly beneficial in reducing fuel consumption and emissions, especially in stop-and-go traffic scenarios.

The focus is on selecting an appropriate vehicle and analysing its dynamic characteristics in line with the Worldwide harmonised Light vehicle Test Procedure (WLTP). Through this project, we aim to understand the potential of KERS in reducing fuel consumption and its impact on vehicle performance. The assignment involves a detailed analysis of energy recovery during braking, component sizing, and system efficiency, closing with an exploration of how KERS changes the driving experience. This comprehensive study not only deepens our understanding of alternative propulsion systems but also contributes to the development of more sustainable automotive technologies.

2 Research

In conducting research into Kinetic Energy Recovery Systems (KERS) technology, a study aimed at understanding the applications of KERS in automotive engineering was conducted. The study began with an extensive review of existing literature, looking at the technological evolution, various types of KERS (mechanical, electrical, and hydraulic), and their respective operational principles.

Focus was put on the processes of energy loss during standard vehicle operation, and how KERS technology can be utilized to recuperate a portion of this lost energy. Central to this analysis was the examination of kinetic energy generation during braking and the efficiency of different KERS in capturing and converting this energy into a usable form.

The findings of the research highlighted the potential of KERS to significantly enhance vehicle efficiency, reduce fuel consumption, and lower emissions. The study also identified key areas for future development, particularly in improving the efficiency of energy storage and conversion, and in integrating KERS technology more seamlessly into a wider range of vehicle types.

3 System Specification and Discussion

For this assignment I decided on a vehicle that had cabin space, was more practical, lower in overall mass with a moderate fuel consumption. I have chosen the Mazda CX-3 which is considered a small sports utility vehicle (SUV) specifically the 2-litre petrol which produces 89kW (120HP).

3.1 Test Mass

Assuming that the vehicle is at the minimum curb weight specified for the vehicle 1291kg, including two passengers weighing 70kg each, the total mass of the vehicle will be 1431kg. This will be the value used to calculate other parameters of this assignment excluding the WLTP cycle.

3.2 Frontal Area

To minimize the drag effect and improve a vehicle's fuel efficiency and overall performance, automotive engineers strive to design cars with lower drag coefficients and optimize the frontal area. This involves shaping the car's body to reduce turbulence and streamline airflow, which can result in a more efficient and eco-friendlier vehicle. (Jie, Xinjian and Chao, 2021)

Assuming the height of the Mazda CX-3 is 1.54m with a width of 1.77m we can calculate the Frontal area to an approximate value excluding side mirrors and also compensating for area that is unobstructed between the wheelbase, using the following equation:

$$A = W * H - 0.5$$

Where:

- A is the Area
- W is the Width
- H is the Height
- 0.5 is the unobstructed area between the wheels.

This gives us a frontal area of 2.23m²

3.3 Coefficient of Aerodynamic Drag

The coefficient of drag (Cd) quantifies how aerodynamic a vehicle is. It represents the ratio of the drag force acting on the vehicle to the dynamic pressure and the reference area. The Coefficient of drag attributed to the Mazda CX-3 is 0.33. (https://www.automobile-catalog.com/car/2019/2771075/mazda_cx-3_grand_touring_fwd.html#gsc.tab=0)

3.4 Rolling Resistance Coefficient

Rolling resistance refers to the force that opposes the motion of a rolling object, such as a vehicle's tire, as it moves along a surface, it is one of the components of the total resistance a vehicle encounters when in motion, with the other major component being aerodynamic drag, this will have an overall negative effect on the fuel efficiency (Rykov et al., 2018). Typically, the Coefficient of Rolling Resistance (Crr) value for a standard road tire on a car falls within the range of 0.007 to 0.012 (Wargula, Wieczorek and Kukla, 2019). Important to note that Crr values can vary significantly between different tyres. Assuming a value of 0.013 for our road tyre which is slightly higher.

3.5 Accelerative Resistance

Accelerative resistance refers to the resistance a vehicle needs to overcome to accelerate from a state of rest or to increase its speed while in motion. Overcoming accelerative resistance requires energy, and thus power, from the vehicle's engine or motor. The faster the acceleration or the heavier the vehicle, the more power is needed. This is why larger or heavier vehicles require more powerful engines to achieve similar acceleration to smaller, lighter vehicles. It's also why accelerating a vehicle consumes more fuel or battery power compared to maintaining a constant speed.

In summary, accelerative resistance is the force that must be overcome for a vehicle to accelerate. It's a key factor in vehicle performance, fuel efficiency, and the design of propulsion systems.

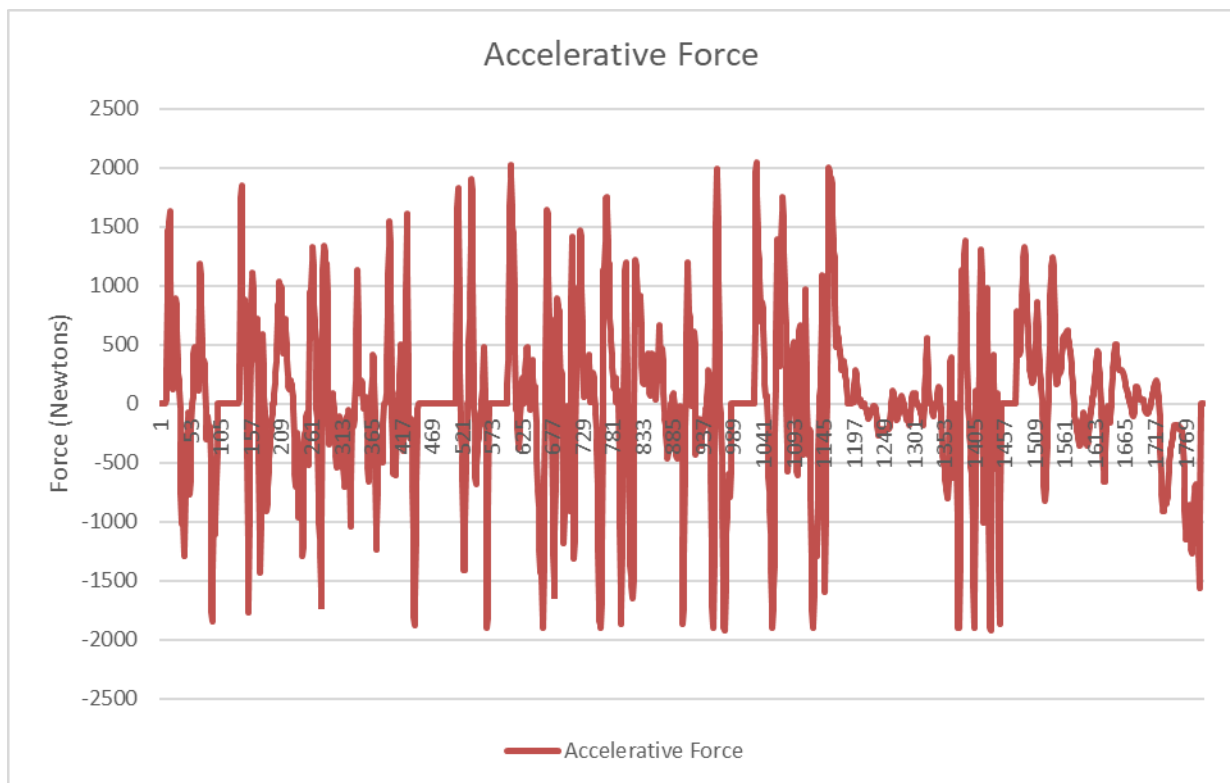


Figure 1 - Accelerative Force WLPT

Figure 1 above shows us the Accelerative force acting upon the vehicle through the WLPT cycle. As the acceleration of the vehicle increases, so does the force acting upon the vehicle meaning more power is required to continue accelerating.

4 WLPT

The Worldwide Harmonized Light Vehicles Test Procedure (WLTP) is a global standard for measuring and certifying the fuel efficiency and emissions of cars, including light commercial vehicles. It was developed to provide more accurate and consistent data on vehicle fuel consumption and emissions, as well as to better reflect real-world driving conditions compared to the previous New European Driving Cycle (NEDC) test procedure (Pavlovic, Marotta and Ciuffo, 2016). It includes four phases with varying speeds, accelerations, and decelerations to better simulate driving patterns.

Using the values for engine power and unladen mass of the vehicle we can calculate the power to ratio to select the appropriate WLPT cycle.

$$PWR = \frac{Power}{Weight}$$

Where:

- PWR is the power-to-weight ratio (W/Kg).
- Power is the power output of the object (Watts).
- Weight is the weight of the vehicle (Kg)

$$\frac{89000W}{1291Kg} = 69W/Kg$$

This means that the most suitable test cycle for this vehicle would be the Class 3 test as the vehicle has a power to weight ratio over 34W/Kg.

5 Results

Vehicles that are fitted with regenerative braking systems, typically found in hybrid and electric models, have the capability to reclaim kinetic energy during the phases of deceleration and braking. In such systems, when the vehicle decelerates - either because the brakes are applied or the accelerator is released - the kinetic energy, which is the energy due to motion, reaches its maximum potential. Usually within an Internal Combustion Engine (ICE) this energy is lost as heat in traditional braking systems. However, with regenerative braking, this kinetic energy is stored (Armenta-Déu and Cortés, 2023).

The process involves the vehicle's electric motor functioning in reverse as a generator during slowing down. This action converts the kinetic energy into electrical energy, which is then efficiently stored in the vehicle's battery. The stored electrical energy can later be used to power the electric motor. This not only aids in the vehicle's propulsion but also enhances its overall energy efficiency.

In situations where the vehicle resumes acceleration, this stored energy plays a critical role. It supports the propulsion system, thereby lessening the load on the ICE in hybrid vehicles or decreasing the rate of battery consumption in fully electric vehicles. Consequently, this mechanism not only conserves energy but also extends the vehicle's range and efficiency.

5.1 Total Resistance to Motion

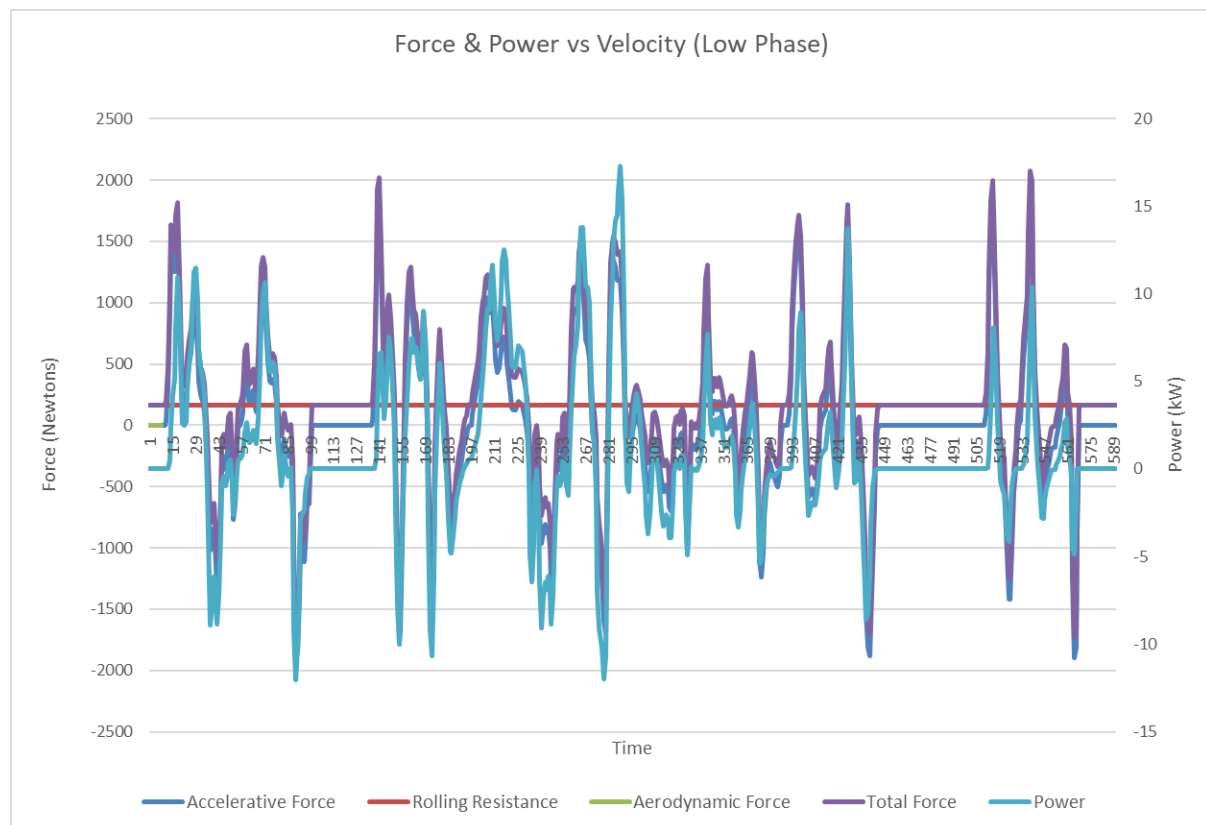


Figure 2 - Low Phase Total Force Graph

Figure 2 above gives us the resultant forces acting upon the vehicle across the first (low) phase of the WLPT cycle. It shows us that as the velocity of the vehicle increases so do the forces acting

against it. The rolling resistance caused by the friction between the tyre and road surface however will not increase only decrease to 0 when the vehicle is static. It's important to note that while rolling resistance itself does not significantly change with velocity, the total resistance (including air resistance and other factors) a vehicle faces does increase with speed, affecting overall fuel efficiency and energy consumption.

6 KERS power input and Energy storage requirements

Determining the Kinetic Energy Recovery System (KERS) power input and energy storage requirements for a vehicle involves several steps, focusing on the amount of kinetic energy that can be recovered during braking and the system's efficiency (Milica and Andrei, no date). This can be done by determining the typical or maximum speed at which every recover will occur, this would be during times of no acceleration or maximum acceleration.

$$KE = 1/2MV^2$$

This equation gives us the maximum Kinetic Energy available for recovery when the vehicle is at speed 'V'. KERS systems are not 100% efficient. Determine the efficiency (η) of the system, which includes the efficiency of energy conversion and storage.

To determine the power input, knowing the duration of each braking event will allow me to understand the regularity and extent of energy recovery opportunities. A critical aspect of this process is selecting the type of KERS appropriate for the vehicle – mechanical, electrical, or hydraulic – and determining its efficiency. (Pipitone and Vitale, 2020) The power input required for the KERS is calculated by dividing the recoverable energy by the duration of a typical braking event. Additionally, the total energy storage requirement is estimated based on the frequency of braking events and the amount of energy recoverable per event.

7 Conclusions

This assignment embarked to unravel the potential of Kinetic Energy Recovery Systems (KERS) within the application of automotive technology, particularly focusing on a Mazda CX-3 model as a case study. Through meticulous research and analysis, this study has illuminated the dynamic interplay between vehicle performance and energy efficiency, highlighting the substantial benefits offered by KERS in the broader context of alternative propulsion systems. The investigation has methodically quantified the resistive forces a vehicle encounters, namely rolling resistance and aerodynamic drag, and meticulously calculated the tractive forces required to overcome these resistances at varying accelerations. The application of the Worldwide harmonised Light vehicle Test Procedure (WLTP) provided a rigorous standard for assessing vehicle performance, ensuring that our findings are both relevant and applicable to real-world scenarios.

Key findings from this work include the affirmation that KERS can significantly enhance fuel efficiency, especially in stop-and-go traffic conditions prevalent in urban environments. Additionally, the potential energy recovered during braking phases, which is conventionally lost in internal combustion engines, can be harnessed effectively to supplement the vehicle's propulsion, thereby reducing the overall energy demand and emissions output.

8 References

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