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ANALYSE AND SIMULATE A MECHANICAL RECOVERY SYSTEM

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2 Introduction

Flywheels are a mechanical device which use dates back thousands of years. Through this time, they have evolved from simple manual tools into sophisticated devices used in the assembly of modern energy systems. Flywheels rely on angular motion of a mass to develop and store kinetic energy. In this report the evolution of the flywheel technology will be explored. From the development of flywheels in its ancient origins to the applications it is used in today such as Kinetic Recovery Systems (KERS) in automotive engineering and off-grid energy storage systems.

The report will investigate what is meant by (KERS) in relation to automotive applications considering important design implications. Precision balancing, containment requirements and material selection will all be discussed. Additional to this, the fundamentals of mechanical batteries and the advantage they have over chemical batteries will be evaluated.

In the second part to the report an analysis of a flywheel's use in a real-world example will be undertaken. The analysis will be of the flywheels ability to store energy recovery on a high-performance hybrid vehicle (KERS System). This will be completed through a series of calculations and evaluations. In this section the effectiveness of the flywheel will be investigated in storing and reusing kinetic energy under different operating conditions. The outcomes from the analysis will offer insight into the viability of KERS in the future of automotive engineering.

3 Main Findings

3.1 Flywheel functionality

The functionality of a flywheel is to store and regulate rotational energy in mechanical systems. It plays a vital role in systems where the energy input and output are not constant by regulating these fluctuations and improve energy efficiency. The flywheel works via the principle of energy transmission, using conservation of angular momentum to store kinetic energy and distribute it in a controlled manner. When energy is applied to a flywheel (either by a motor or another external force) the flywheel accelerates and stores the energy as rotational kinetic energy, which when slowed down can be retrieved.

The kinetic energy stored in a flywheel can be expressed as:

$$E = \frac{1}{2} I \omega^2$$

Equation 1

E = Total rotational kinetic energy stored in a flywheel

I = Moment of inertia

ω = Angular velocity

This relationship shows the amount of energy a flywheel can store is a result of both its mass and rotational speed. The energy is directly proportional to half its moment of inertia and the square of its angular velocity. The result of this is why high-speed flywheels are particularly effective when used as energy storage applications, Beer (2017).

3.2 Ancient and Preindustrial Uses of the Flywheel

The principles of a flywheel (conserving angular momentum) have been understood and utilised for thousands of years. In its ancient origins as its simplest form the flywheel was a heavy disc that resists changes in angular speed due to its moment of inertia. These adaptations explained in this section are not energy storage devices as understood in the modern sense (to capture energy for later use), but as stabilisation and smoothing of mechanical input fluctuations.

Potter's wheel is one of the earliest adaptations of a device that utilises the principles of a flywheel. A potter's wheel consists of a heavy wooden wheel and was used by potters to shape clay. The wheel uses the principles of a flywheel as the wheel would keep spinning due to inertia (resisting change in speed because of its mass). A potter would utilise this when creating pottery as the wheel would smooth the input torque from the craftsman's hand or feet.

Another preindustrial use of the flywheel that was more modern than the potter's wheel was the use of flywheels with water wheels for milling. This is one of the first adaptations of a flywheel as an energy storage system. Water wheels would convert flowing water into rotational motion used to power mills. However, inconsistent energy delivery was caused by issues such as irregular water flow and start/stop movements in transition. A flywheel was attached to the rotating shaft of the water wheel to store and release rotational energy to keep the wheel running smoothly. This follows the principle of the flywheel as when the water wheel rotates, the flywheel spins (storing kinetic energy). Then when the water slows the water wheel is able to keep rotating smoothly as the stored kinetic energy of the flywheel keeps the shaft rotating smoothly. The outcome prevents any jerky motion and mechanical strain ensuring consistent operation.

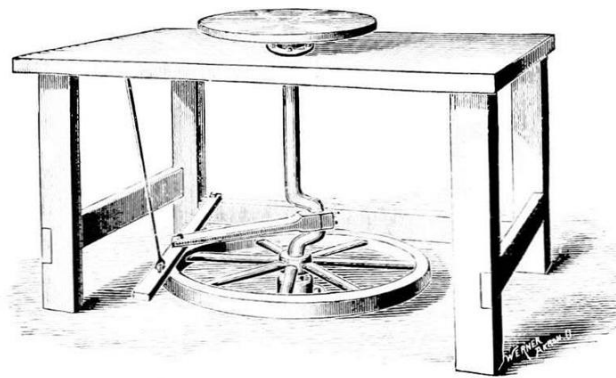


Figure 1 - Potters Wheel

3.3 Flywheels During the Industrial Revolution

The industrial revolution brought a change from a handicraft economy to one dominated by machine manufacturing with the invent of steam engines being a key characteristic of this change. Flywheels were used to help regulate speed in these engines as steam pressure that powered the engines was inconsistent which without a flywheel would cause mechanical fluctuations. As well as this, flywheels were used to distribute power around a factory in a consistent way. Flywheels would be connected to central power shafts which ran the length of factories powering multiple machinery. The flywheel would maintain momentum even if the engines lost power momentarily ensuring smooth operation. This all relates back to the principle of the flywheel resisting changes in rotational speed once rotating.

Flywheels therefore, were vital in the rise of the industrial revolution allowing factories to mass produce with industrial machines that run efficiently.

3.4 Modern Use of Flywheels

In modern industries flywheels have been adapted as crucial components in energy storage systems. These range from automotive engineering to energy storage in grid systems and renewable energy distribution.

In modern vehicles, especially electric and hybrid vehicles, regenerative braking is used to store kinetic energy and distribute it to improve performance. Regenerative braking can be done by storing the energy mechanically (use of flywheel) or chemically (use of battery or capacitors). Energy that would normally be lost during braking is instead captured and used and redistributed to support either the battery or performance depending on the system.

Flywheels store energy mechanically as when the car slows, the kinetic energy is redirected to the flywheel through a rotating shaft which rapidly accelerates it to keep angular momentum. This kinetic energy is then stored in the flywheel and when the vehicle accelerates the energy is distributed from the flywheel to the drivetrain. According to Mohd. et al. (2025) This reduces the demand on the battery as the stored energy has been transferred back to the wheels providing a short boost of power without using extra electrical energy from the battery. This is called a Kinetic Energy Recovery System.

Kinetic Energy Recovery Systems (KERS) have been implemented into road going vehicles to aid in performance and enhance battery life. However, the implementation of this technology brings engineering challenges.

Precision Engineering:

In mechanical KERS's the flywheel rotates at high speeds. According to Szumska (2025) without precision engineering there is risk of imbalance that when rotating at extreme speeds can cause vibrations and wear. These implications will eventually lead to catastrophic failure. Precision engineering with high precision tolerance can be expensive and require skilled labour and specialist equipment, which can increase costs during the manufacturing process of these systems.

Containment:

As mentioned, the flywheels in KERS systems rotate at extreme speeds. This poses a hazard as a catastrophic failure in one of these systems can turn the flywheel into one or multiple projectiles which would have the potential to cause serious harm. Therefore, the design must include containment of the system. This needs to be done with high strength materials such as carbon fibre or Kevlar which will help provide protection to any individual who may be in proximity to a failure of the system.

3.5 Mechanical and Chemical Batteries

As briefly mentioned in section 4.4, modern vehicles energy recovery systems can also store the energy chemically rather than mechanically. Chemical batteries capture the kinetic energy through rotational motion caused by braking. This kinetic energy is converted into electrical energy via electrochemical reactions to later be released as a power boost. When comparing chemical and mechanical there are similarities to the function of capturing kinetic energy to later support performance. However, there are factors which should be considered when comparing the advantages and disadvantages.

As can be seen in equation 1, the energy captured from a flywheel depends upon the rotational speed. When comparing mechanical batteries, it has to be considered that the amount of energy that can be captured relies on this as well as its moment of inertia. In KERS systems flywheels can rotate in excess of 60000 RPM, meaning that high amounts of energy can be stored and released almost instantaneously. This gives them an advantage of chemical batteries as delays can occur in release of the energy due to internal resistance, thermal constraints or limited ion diffusion (Varbanov et al., n.d.). As well as this, mechanical batteries provide higher power density. In KERS systems on road going vehicles this provides rapid acceleration.

However, in certain applications mechanical batteries have been found to be less effective than chemical batteries. This is due to chemical batteries having better use over a longer period of time with higher energy density (Li and Palazzolo, 2022). An example of this can be seen in formula 1. Williams, a team in F1 tried implementing flywheels as KERS when chemical batteries were already common in the sport. The system was limited in comparison to the chemical batteries as the races lasted for a long period of time with chemical batteries providing a higher density of power throughout the race. As well as this the packaging and safety considerations regarding the mechanical battery meant it prevented any widespread adoption (RaceCarEngineering, 2009).

In summary mechanical batteries and chemical batteries differ fundamentally in how they store kinetic energy. Mechanical batteries offer advantages in areas and chemical batteries in other. The implementation in one of these systems depends on the application and its use with all factors considered.

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