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Concept of conserving waste energy

We have seen the importance of energy, hence we should try to save and conserve by all means we have.

This can be done by:

1. Develop new processes/techniques and audit & modify the existing techniques for better and efficient use of energy. Development of more efficient machines.

2. Try to modify such processes in which energy is wasted or dissipated in some form to carry out the process.

If we laid emphasis on the second option, we come to know that there are lot of processes carried out in day-to-day domestic, industrial, mechanical applications in which a lot of energy is wasted in order to carry out the desired processes. Some examples of such processes are given below:

1. Energy dissipation in brake shoes in a vehicle during braking.
2. Energy dissipation in damping processes.
3. Energy dissipation by stopper springs.
4. Energy dissipation in elastic or rubber members acting as shock absorbers.

In all the processes listed above a part of energy is dissipated so as to lower the energy level required in a process. But this part of energy is not recoverable after the completion of process. If the process has a many cycles of such energy dissipation steps, a lot of energy would we wasted.

If somehow we adopt a novel mechanism that absorbs the energy (during energy dissipation stage) as per the process requirement, and gives back all or a fraction of that absorbed energy back to the process (when dissipation stage is over), a lot of energy could be saved.

Hence by adopting such methods, the energy which normally is "wasted", (absorption/dissipation) can be saved and supplied back to the process. Hence the process will be utilizing its energy resources in a better way.

Concept of conserving waste energy.

In previous section we have talked about mechanisms that could absorb the energy and gives off the stored energy whenever required. Such mechanisms store energy temporarily instead of dissipating them. This is achieved by using complex spring mechanisms.

Two of such energy conserving mechanisms are explained below:

1. <u>Basic spring storing mechanism.</u>

   This is a spring storage mechanism that can convert any type of linear vibrating motion into mechanical energy. It can also replace dampers or shock absorbers. It utilizes the motion during damping to store energy and convert that energy into mechanical motion energy.

<u>Principle</u>

The mechanism has a spiral spring that stores the energy. A rack-pinion arrangement converts the reciprocating damping motion into rotation of pinion. This rotating pinion winds the spiral spring. Thus the spring gets strained as it absorbs the energy. A second set of gears is connected to the second end of spiral spring. When the spiral spring uncoils, it causes rotation of gears thus transferring the stored energy. A small flywheel linked to the gears that regulated the energy outputs and also smoothens the output mechanical energy.

Continuous damping motion causes the continuous winding of spring and unwinding of springs liberates energy in mechanical form.

<u>Uses</u>

The mechanical energy available at the flywheel can be used in many ways:

1. Any generator can be linked to this flywheel for converting mechanical energy into mechanical energy.
2. Mechanical energy can be used directly by the process in any form.
3. If feasible, the mechanical energy can be used to run pumps, compressors, transfer mechanisms etc.

<u>More options</u>

If instead of rack-pinion arrangement, a rotating handle is used. Then any type of mechanical energy (involving rotation) can be conserved:

1. In Africa hand operated radios use such mechanism. A manually operated handle is used to wind a spring and this spring runs a

small motor. This rotating motor acts as a small dynamo that can run a small radio. This has emerged as a boon for such a poor nation and Africa's president Nelson Mandela has honored the inventor of this radio.

2. This mechanism is used widely in small toys in which a small ket winds a spring. And the spring when uncoils, imparts mechanical energy to the wheels.

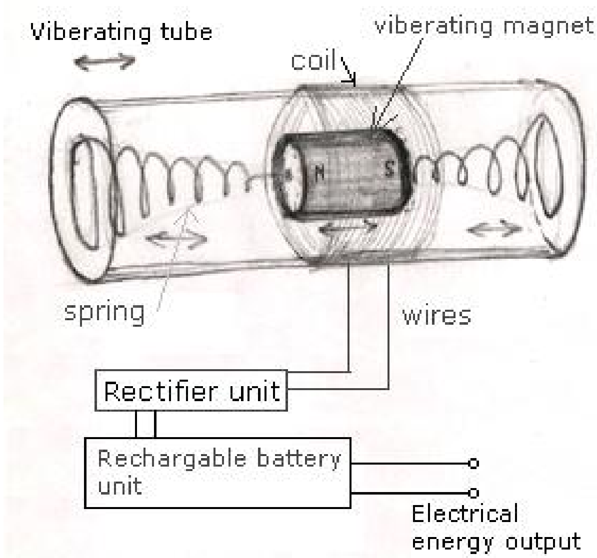
Schematic diagram of spring storage mechanism.

2. Vibrating magnetic generator mechanism.

This mechanism is use at places where a lot of energy is wasted in form of vibrations. This mechanism efficiently dampens the vibrations by converting vibrating energy into electrical energy.

Principle

A small magnet is freely suspended in a tube by two magnets. The arrangement is done such that then the tube vibrates, the magnet also moves to and fro in the tube. A small coil of copper wire is situated on the tube. When the magnet vibrates in the tube, due to magnetic induction effect, a current is induced in the coil. This current can be used in various ways as electrical energy.



Applications

This mechanism can be used on any vibrating element. It can directly convert the vibrations into electrical energy. More exploration is required to fully use the potential of this mechanism.

Uses

1. A patented technology in USA uses this mechanism in a hand-shake torch. The torch uses no batteries but rechargeable cells. Vibrating magnetic generator mechanism is used to charge the cells which in turn light a bulb. To activate the torch, just shake torch to 1-2 minutes and this produces enough electricity to light bulb for 5-10 minutes. Very good for remote areas.

Various ways of storing energy

1. Springs.
2. Height gain by weights.
3. Flywheels.
4. Pneumatic compression devices.
5. Hydraulics.
6. Elastic Rubbers members.

1. Springs

Introduction

A spring is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. The various applications of the spring are as follows:

1. To cushion, absorb or control energy due to either shock or vibration as in car springs, railway buffers, air- craft landing gears, shock absorbers and vibration dampers.
2. To apply forces, as in brakes, clutches and spring loaded valves.
3. To control motion by maintaining contact between two elements as in cams and followers.
4. To measure forces, as in spring balances and engine indicators.
5. To store energy, as in watches, toys, etc.

Types of springs

Though there are many types of springs, yet the following, according to their shape, are important from the subject pint of view:

1. **Helical springs**: The helical springs are made up of a wire coiled in the form of a helix and are primarily intended for compressive or tensile loads. The cross- section of the wire fro which the spring is made may be circular, rectangular or square.

The helical springs are said to be **closely coiled** when the spring wire is coiled so close that that the plane containing each turn is nearly at right angles to the axis of the helix and the wire is subjected to torsion. I other words, in a closely coiled helical spring, the helix angle is very small, usually less than 10°. The major stresses produced in helical springs are shear stresses due to twisting. The load applied is parallel to or along the axis of the spring.

In **open coiled helical springs**, the spring wire is coiled in such a way that there is a gap between the two consecutive turns, as a result of which the helix angle is large. Since the applications of the open coiled helical spring are limited, therefore closed coiled helical springs are mainly used.

The helical springs have the following advantages:

1. These are easy to manufacture.
2. These are available in wide range.
3. These are reliable.
4. These have constant spring rate.
5. Their performance can be predicted accurately.
6. Changing the dimensions can vary their characteristics.

2. **Conical and Volute springs**: The conical and volute springs are used in special applications where a telescoping spring or a spring with a spring rate that decreases with the load is desired. In these springs the number of active coils decreases and these leads to an increase in the spring rate. This characteristic is sometimes utilised in vibration problems where springs are used to support a body that has varying mass. The major stresses produced in conical and volute springs are also shear stresses due to twisting.

3. **Torsion springs**: These springs may be of helical or spiral type. The helical type may be used only in the applications where the load tends to wind up the spring and are used in various electrical mechanisms. The spiral type is also used where the load tends to increase the number of coils and when made of flat strip are used in ***watches and clocks.***

4. **Laminated or leaf springs**: The laminated or leaf springs consists of number of flat plates (known as leaves) of varying lengths held together by means of clamps and bolts. These are mostly used in ***automobiles***. The major stresses produced in leaf springs are tensile and compressive stresses.

5. **Special Purpose Springs**: These springs are air or liquid springs, rubber springs, ring springs etc. The fluids (air or liquid) can behave as a compression spring. These springs are used special types of applications only.

Material for helical springs

The material of the spring should have high fatigue strength; high ductility, high resilience and it should be creep resistant. It largely depends upon the service for which they are used i.e. severe service, average service or light service.

The springs are mostly made from oil-tempered carbon steel wires containing 0.60 to 0.70 percent manganese. Music wire is used for small springs. Non-ferrous materials like phosphor bronze, beryllium copper, monel metal, brass etc., may be used in special cases to increase the fatigue resistance, temperature resistance and corrosion resistance.

The helical springs are either cold formed or hot formed depending upon the size of the wire. Wires of small sizes (less than 10 mm diameter) are usually wound cold whereas larger size wires are wound hot. The strength of wires varies with size; smaller size wires have greater strength and less ductility, due to the greater degree of cold working.

Terms used in Compression springs

The following terms are used in connection with compression springs:

1. **Solid Length**: When the compression spring is compressed until the coils come in contact with each other, then the spring is said to be solid. The solid length of a spring is the product of total number of coils and the diameter of the wire. Mathematically
   Solid length of the spring,

$$L_s = n' * d$$

Where

n' = total number of coils, and
d = diameter of the wire.

2. **Free Length**: The free length of a compression spring is the length of the spring in the free or unloaded condition. It is equal to the solid length plus the maximum deflection or compression of the spring and

the clearance between the adjacent coils.
Mathematically,

Free length of the spring,

$$L_f = \text{Solid length} + \text{Maximum Compression} + \text{Clearance between adjacent coils}$$
$$= n' * d + \delta_{max} + 0.15 * \delta_{max}$$

The following relation may also be used to find the free length of the spring, i.e.,

$$L_f = n' * d + \delta_{max} + (n' - 1) * 1 \text{ mm}$$

In this expression, the clearance between the two adjacent coils is taken as 1 mm.

3. **Spring Index**: The spring index is defined as the ratio of the mean diameter of the coil to the diameter of the wire. Mathematically,

Spring Index,

$$C = D/d$$

Where

D = Mean diameter of the coil, and
d = Diameter of the wire.

4. **Spring Rate**: The spring rate may be defined as the load required per unit deflection of the spring. Mathematically,

Spring Rate,

$$K = W/\delta$$

Where

W = Load, and
δ = Deflection of the spring.

5. **Pitch**: It is define as the axial distance between adjacent coils in uncompressed rate. Mathematically,

Pitch of the coil,

$$p = \frac{\text{Free Length}}{n' - 1}$$

The pitch of the coil may also be obtained by using the following relation, i.e.,

Pitch of the coil

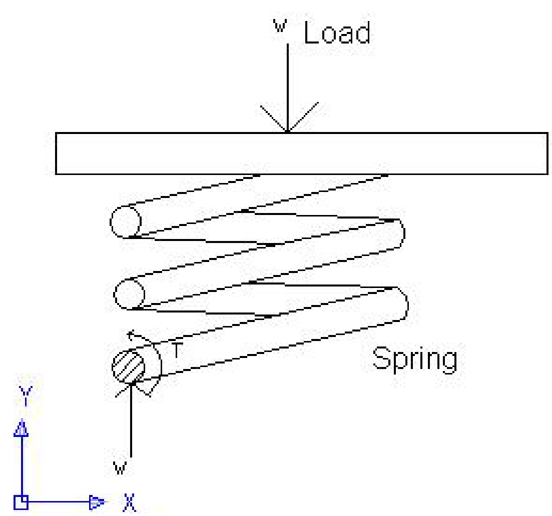
$$= \frac{Lf - Ls}{n'} + d$$

Where

Lf = Free length of the spring,
Ls = Solid length of the spring,
n' = Total number of coils, and
d = Diameter of the wire

Stresses in the Helical Springs of Circular Wire

Consider a helical compression spring made of circular wire and subjected to an axial load W,



Let

D = Mean diameter of the spring coil,

d = Diameter of the spring wire,

n = Number of active coils,

G = Modulus of rigidity,

W = Axial Load,

τ = Maximum shear stress induced in the wire,

C = Spring Index of the wire = D/d,

p = pitch of the coils, and
δ = Deflection of the spring, as a result of an axial load W.

Now the load W tends to rotate the wire due to the twisting moment (T) set up in the wire. Thus the torsional shear stress is induced in the wire.

A little consideration will show that the part of the spring is in equilibrium under the action of two forces W and the twisting moment T.

We know that the **twisting moment**,

$$T = W * D/2 = \frac{\pi}{16} * \tau 1 * d^3$$

$$\tau 1 = \frac{8 * W * D}{\pi d^3}$$

In addition to the **torsional stress (τ1) induce in the wire**; the following stresses also act on the wire:

- Direct shear stress due to the load W, and
- Stress due to curvature of the wire.

We know that **direct shear stress** due to the load W,

$$\tau 2 = \frac{\text{Load Applied (W)}}{\text{Area of Cross section}}$$

$$= \frac{4 * W}{\pi * d^2}$$

We know that the **resultant shear stress induced in the wire**,

$$\tau = \tau 1 \pm \tau 2 = \frac{8\,W\,D}{\pi\, d^3} + \frac{4\,W}{\pi\, d^2}$$

The positive sign is used for the inner edge of the wire and the negative sign is used for the outer edge of the wire. Since the stress is maximum at the inner edge of the wire, therefore

Maximum shear stress induced in the wire =

= Torsional shear stress + Direct Shear Stress

$$= \frac{8\,W\,D}{\pi\, d^3} + \frac{4\,W}{\pi\, d^2}$$

$$= \frac{8\,W\,D}{\pi\, d^3}\left(1 + \frac{d}{2D}\right)$$

$$= \frac{8\,W\,D}{\pi\, d^3}\left(1 + \frac{1}{2C}\right)$$

$$= K_s * \frac{8\,W\,D}{\pi\, d^3}$$

Where **Ks** = **Shear stress factor** = $\left(1 + \frac{1}{2C}\right)$

From the above equation it can be seen that the effect of direct shear stress is appreciable for springs of small spring index C. also we have neglected the effect of wire curvature. It may be noted that when the springs are subjected to static loads, the effect of the wire loads may be neglected, because yielding of the material will relieve the stresses.

In order to *consider the effects of both the direct as well as curvature of the wire*, a **Wahl's Stress Factor (K)** introduced by A.M. Wahl may be used.

Therefore Maximum Shear Stress induced in the wire,

$$\tau = K * \frac{8\,W\,D}{\pi\, d^3} = K * \frac{8\,W\,C}{\pi\, d^2}$$

Where

$$K = \frac{4C - 1}{4C - 4} + \frac{0.615}{C}$$

Energy Equation in Helical Springs Of Circular wire

We know that springs are used for storing energy that is equal to the work done on it by some external load.

Let W = Load applied on the spring, and
δ = Deflection produced in the spring due to the load W.

Assuming that the load is applied gradually, the **energy stored in the spring is,**

$$U = \frac{1}{2} * W * \delta$$

The **maximum shear stress** induced in the spring wire is given as:

$$\tau = K * \frac{8 W D}{\pi d^3}$$

or

$$W = \frac{\pi d^3 * \tau}{8 K D}$$

The **Deflection of the spring** is given as:

$$\delta = \frac{8 W D^3 n}{G d^4} = \frac{8 \pi d^3 * \tau}{8 K D} * \frac{D^3 n}{G d^4}$$

$$= \frac{\pi D^2 * \tau n}{K d G}$$

Substituting the values of W and δ in the equation, we have

$$U = \frac{1}{2} * \frac{\pi d^3 \tau}{8 K D} * \frac{\pi D^2 \tau n}{K d G}$$

$$= \frac{\tau^2 (\pi D n)}{4 K^2 G} \left(\frac{\pi}{4} d^2\right)$$

$$= \frac{\tau^2 * V}{4 K^2 G}$$

Where

V= Volume of the spring wire

= Length of spring wire * Cross sectional area of the spring wire

$$= (\pi D n) \left(\frac{\pi d^2}{4}\right)$$

When a load falls on a spring through a height h, then the energy absorbed in the spring is given by

$$U = P (h + \delta) = \frac{1}{2} W \delta$$

Where

W = Equivalent static load i.e. the gradually applied load which shall produce the same effect as by the falling load P, and

δ = Deflection produced in the spring.

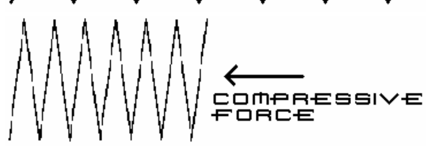
Various ways of utilising springs.

1. By direct compression and expansion.

a.) By elongation.

Normal state (uncompressed)

Compression



Elongation

b.) By twisting.

By twisting the helical spring along the axis of the spring. This method is used in our permodrive model.

2. By spiral Spring.

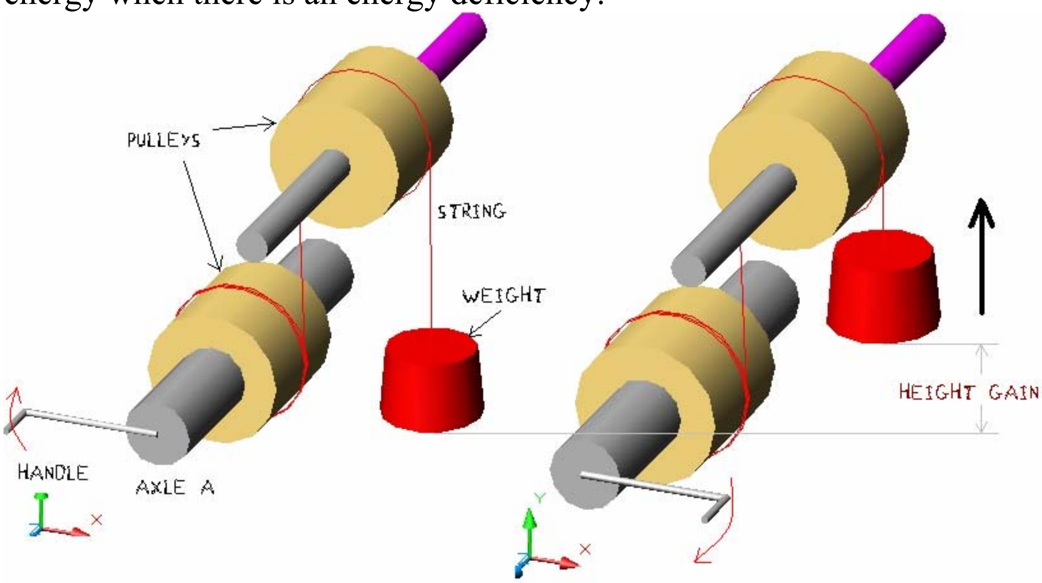
Energy can be stored in spiral springs by winding the spring. Spiral springs are widely used in manual wall clocks and small toys.

3. By Leaf Springs.

If one end of leaf spring is rigidly fixed the other end can be held forcefully perpendicular to the leaf.

2. Height gain by weights.

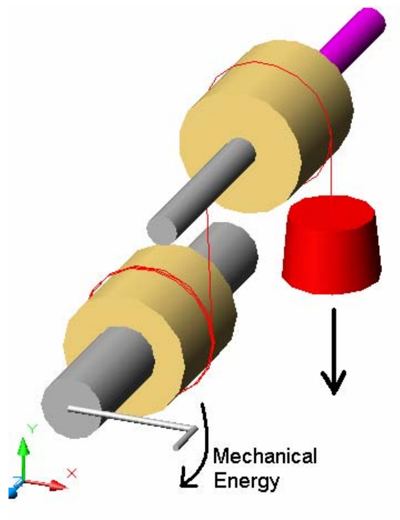
When a body gains height, it gains potential energy. This is due to the earth's gravitational force and the tendency of body is to attain a lower energy state. By using proper mechanisms we can use this principle to store energy (whenever excess) and to release the stored energy when there is an energy deficiency.



Axle A can be linked to a machine such that its rotation causes weight to lift up. The system absorbs the energy in form of increases in the potential energy of the weight and when the weight comes down, this stored energy appears as mechanical energy across Axle A.

Potential energy = MgH

Where	M	=	mass of the weight.
	g	=	acceleration due to gravity (9.8 m/sec).
	H	=	height gain by the weight.



3. Flywheels

On the Use of Flywheels in Vehicles**:**

Conservation of resources is of prime importance with regard to non-renewable forms: eg crude oil. Due Recent increase in the price of crude oil and ever depleting natural resources, the increased efficiency of vehicular transport is necessary. Energy is wasted through dissipation - friction, wind resistance etc. With most vehicles, energy is lost when it is transformed from one type to another, e.g. chemical to kinetic, or electrical to kinetic. The flywheel is a simple device that can store energy in mechanical form - the same form that is needed to propel a vehicle from rest to cruising speed.

Regenerative Braking: - All energy used to propel an automobile from rest to cruising speed is wasted when the brakes are used to stop the vehicle - the energy is liberated as heat in the brake parts. A regenerative braking system seeks to store this energy that would normally be wasted in some form (in this case, a spinning flywheel), which can be used to start the vehicle again. This is particularly important in city driving, where stop-start travelling is commonplace.

Smaller Engines Required: - In most city travel, when stop/start conditions are common, when the vehicle is stopped, the engine works to provide energy to the flywheel, which increases its rotational speed, storing the extra energy needed to propel the vehicle from rest to cruising speed. The flywheel is a more efficient form of energy storage than heavy batteries and electric motors/generators required for petrol/electric hybrid vehicles.

Some basic assessment of amount of energy in a flywheel: - A 100kg-m^2 moment of inertia flywheel spinning at 6000rpm (=100Hz) stores just under 20 Mega joules of energy, enough to accelerate a 1000 kg vehicle from rest to 60 km/h no less than 140 times! (Assuming 100% efficiency), or from rest to 100km/h no less than 52 times! As most petrol engines easily rev to 6000 rpm, this is not outside practical engineering limitations. A 50kw petrol engine would produce 20 Mega Joules in 400 seconds - less than 7 minutes to charge a spinning flywheel from 0 to 6000 rpm.

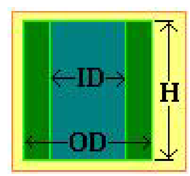
Practical Situations: - In some common vehicle uses, such as the "shopping trolley" or to pick the kids up from school, or even to commute from home to work, a flywheel powered vehicle could be charged up to maximum energy by a mains powered electric motor in the vehicles garage. A small petrol engine housed in the vehicle could be used in emergencies to charge up the flywheel to 6000 rpm maximum angular velocity.

Some Calculations on Flywheels.

For a very thin spinning hoop *(with all its material at nearly equal tensile stress*) , kinetic energy can be computed from Newton's (1642-1747) fundamental equations:

- Moment of Inertia = (Rim Density) (Rim Volume) (Rim Radius)^2
- ENERGY = (1/2) (Moment of inertia) (Spin Speed)^2

Calculations for Flywheel Energy Storage Design



Tensile stress at its outer radius, due to its spin speed, can be computed from:

- Tensile Stress = (Rim Density) (Radius)^2 (Spin Speed)^2

A flywheel cross-section is shown at right (with inner and outer diameters ID and OD, height H), which spins about a vertical axis through its centre.

Maximum stored energy, vs. weight and total volume, is usually given only for a thin hoop or solid disk. For practical aspect ratios, it is related to the rim's ID/OD ratio by slightly complicated relationships.

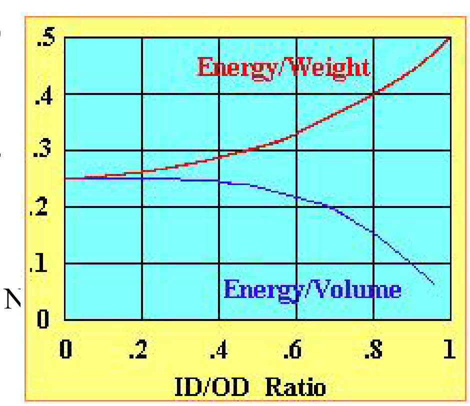
- d(Inertia) = (Radius)^2 (Rim Density) d(Volume)

This leads to the result:

- Max ENERGY = (ID/OD Factor) (Rim Volume) (Max Tensile Stress)

where:

- (ID/OD Factor) = (1/4) {1 - (ID/OD)^4} / {1 - (ID/OD)^2}



From this, we get:

- (Max ENERGY) / Weight = (ID/OD Factor) (Max Tensile Stress) / (Rim Density)

and (where Total Volume includes the space inside the rim):

- (Max ENERGY) / (Total Volume) = (1/4) $\{1 - (ID/OD)^4\}$ (Max Tensile Stress)

Normalized maximum energy-to-weight, and energy-to-volume ratios, vs. flywheel ID/OD ratio, are plotted in this figure. Note that energy-to-weight ratio increases, while energy-to-volume decreases, with increasing ID/OD. A good compromise is ID/OD = 0.75 when the space inside the rim is used for a motor/generator. Besides, it is easier to maintain a vacuum in a larger volume of space, relative to out gassing materials in the enclosure. High energy-to-weight ratio is a more important factor than energy-to-volume, particularly for a thin-wall (lightweight) vacuum enclosure.

Two significant observations can be made from these equations: Flywheel weight/energy ratio is proportional to its density (specific gravity). And energy storage is proportional to the product of tensile strength and volume of material at full tensile stress. So, to achieve high-energy storage with lightweight, rim material should be high-strength and low-density.

Practical Flywheel Batteries

With these equations (and correct unit conversions) it can be computed that. A flywheel rim having:

- Height = 1-foot
- OD = 1-foot
- ID/OD = .75
- Max Tensile Stress = 500,000 psi
- Specific Gravity = 1.1

Will store **3-kwh**, weigh 23 pounds, spin up to 100,000 rpm. Motor/generator, bearings, a vacuum enclosure, and controller electronics will have comparable weight.

Lead-acid batteries, to store 3-kwh, weigh over 250 pounds, and 5 would need to be interconnected.

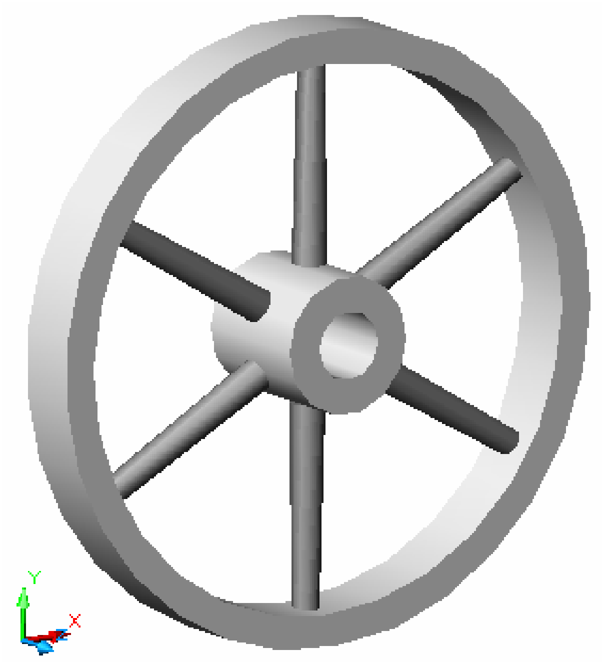
A flywheel rim having:

- Height = 2.5 feet
- OD = 2.5 feet
- ID/OD = .75
- Max Tensile Stress = 500,000 psi
- Specific Gravity = 1.1

Will store **50-kwh**, weigh 370 pounds, spin up to 44,000 rpm. Again, remaining parts will add a comparable weight.

Lead-acid batteries, to store 50-kwh, weigh over 4000 pounds, and over 80 would need to be installed and interconnected every few years. Their weight is at least 5x that now possible with flywheel batteries; and new flywheel materials described in the literature could enable flywheel batteries storing 10x more than lead-acid of comparable weight.

Energy storage/weight ratio fundamentally depends on tensile strength of lightweight composite fibers. New formulations and processing techniques have resulted in material strength that has increased steadily over the past decade. Permanent magnets like Neodymium-Iron-Boron can also help reduce weight, by allowing smaller magnet and iron components. Our thin-wall vacuum enclosure results in systems weighing considerably less than those designed to contain possible flywheel explosion in the vacuum enclosure.



A flywheel.

4 *Pneumatic compression devices.*

Any gas (like air) requires some energy to compress it under pressure. This principle can be used to manipulate a cylinder-piston arrangement, having gas in it, as a spring. Air is restricted in a closed cylinder having one piston. Energy is absorbed in air as internal energy during compression and when air expands it librates this energy as movement of ram. This action of complete assembly can be equivalent to a spring. And it can be used in place of spring where energy density required is less.

Schematic diagram.

5. Hydraulics.

Hydraulic systems is not directly employed in energy storage, but it helps in transfer of energy from source to the storage mechanism. It can transfer huge amount of energy with high efficiency and also with good control.

The permodrive system used in Australia utilizes state of the art computerized controlled hydraulics for transfer of energy. The system is highly complex and out of the scope of our study.

6. Elastic Rubbers members.

In compact systems, high-density rubbers can replace springs. Rubbers are highly elastic polymers and with the advancement in this field rubber has come out as a better alternative for springs. By selecting rubbers of proper quality, material, strength, elasticity, it can perform better than metallic springs.

There is difficulty in the design of very small spring having good amount of elongation and energy density, due to material limitations. Hence in compact systems rubbers are better alternatives than springs.

Practical case studies of some energy dissipating processes.

Given below are some practical examples in which some part of energy is wasted in dissipation in order to carry out the process. In previous section we have studied that this energy could be stored by spring mechanisms in order to use the same energy again.

Some day-to-day processes are explained below where we should try to conserve the energy instead of wasting it.

1. Braking process in locomotives.
2. Braking process in industrial machines.
3. Energy dissipation in Damper.
4. Energy dissipation in Car shock absorbers.

1. Braking process in locomotives.

When you hit the brakes, the car's kinetic energy is converted to heat through friction—throwing away the energy that was previously used to accelerate the car. In city driving, about 30 percent of a typical car's engine output is lost to braking.

Traditional brake systems grip metal disks or drums, using friction to slow or stop the rotating wheels of a vehicle. The friction of the brakes resists the forward momentum of the whole vehicle, and that friction creates heat.

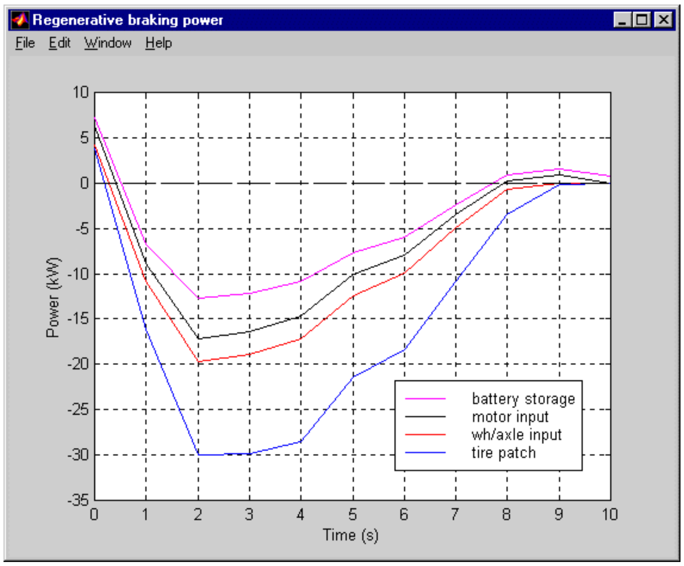
In order for something to heat up it takes energy. The energy that heats up a truck's brake system comes from its momentum, speed, and mass. Traditional brake systems, like those on large trucks, waste energy by converting forward momentum into heat.

Example – This example has been downloaded from Net. It is performed by Ford Motors to measure the amount of energy lost in braking

In this example, an electric vehicle decelerates from 17.3 m/s (38.8 mph) to 0 in 10 s.

To achieve the required deceleration, the required tractive force is negative. (Note that if the required deceleration were at the same rate as an unpowered coast down, the required tractive force would be zero because aerodynamic drag and rolling resistance would be enough to cause the required deceleration.) This indicates an opportunity for regenerative braking.

This block uses required speed and required force to determine how much braking will be done by the front-axle friction brakes, the rear-axle friction brakes, and the driveline. The braking done by the driveline is the regenerative braking. However, it is important to recognize that not all of the driveline braking energy can be stored--on its way from the wheel and axle, through the drivetrain and electric motor, and into the energy storage system (usually electrochemical batteries), this braking energy incurs losses.



The figure above shows that the regenerative braking power required into the wheel/axle assembly is whittled away by component losses as it moves up the driveline. At 2 s, the braking power required at the tire patch (computed as veh_spd_r*veh_force_r) is 30 kW, while the braking power required where the wheel/axle interfaces with the final drive (computed as wh_trq_r*wh_spd_r) is 20 kW. 10 kW is consumed by axle losses and by the friction brakes. (The variables wh_fa_fric_brake_frac, wh_fa_fric_brake_mph, wh_fa_dl_brake_frac, and wh_fa_dl_brake_mph control how much friction and driveline/regen braking is commanded as a function of speed.

About 3 kW is lost in the transmission and motor, accounting for the difference between the red and black curves at 2 s. Another 5 kW or so is lost in the energy storage system, leaving about 12.5 kW (x 1 s = 12.5 kJ) making it into storage.

In the above example we see that even in a car the energy lost in braking is of orders of 20 kW. In case of Big trucks and trains the amount of energy lost in braking is awesome. And if are able to conserve even 50% of this energy, we can decrease the external energy demand of the vehicle. This is directly linked to better fuel economy and less load on engine.

2. *Braking process in industrial machines.*

In industries, various types of band brakes, shoe brakes are employed for stopping a machine or to decrease its speed. Like in the case of automobiles a lot of energy is wasted in these types of brakes. If we could conserve this energy, the energy requirements of plant will decrease and it directly benefits the economy.

3. *Energy dissipation in Damper.*

Damper is a device that absorbs any type of vibrations and shocks. The basic principle of any damper is to absorb the vibration energy against the flow resistance of a viscous fluid. The greater the viscosity of fluid, greater is the damping effect. Energy is lost in damper in form of heating of fluid and motion of highly viscous fluid.

This energy lost in damper cannot be recovered back; hence a damper wastes a lot of energy in damping process. If we replace the damper by our energy conserving mechanisms, a lot of energy can be saved which can be feed into the existing system, thereby increasing its efficiency and economy.

4. *Energy dissipation in Car shock absorbers*.

When a car is subjected to shocks from road surface, the suspension springs absorbs these shocks. However, because springs have the characteristics to oscillate, Shock absorbers are provided to absorb these excess oscillations of the springs.

Shock absorbers employ a special fluid as the working medium. In telescopic shockers, used in automobiles, the damping force is generated by the floe resistance caused by the fluid being forced through an orifice by the movement of piston.

A shock absorber is equivalent to a damper, which creates the resistance by the viscous force of the fluid. And energy is lost in the heating and movement of viscous fluid. Replacing the shock absorber by an energy conserving mechanism, we can conserve good amount of energy.

PERMODRIVE TECHNOLOGY

The story of Permo-Drive is very much the story of Australia - ingenuity, creativity and tenacity. That concept has been developed, refined, and trialed in Australia is now the focus of international attention.

The idea is to store normally wasted energy in the heavy transport braking process and re-use this stored energy on acceleration. A simple concept that has been talked about for decades, yet until now, no commercially viable system was possible. While much recent attention has been given to hybrid electric systems, the Permo-Drive Hydraulic Hybrid concept offers even greater rewards, potential savings and could be widely available to the target market much sooner.

The hydraulic hybrid system store normally wasted braking energy, boosts performance, reduces brake maintenance costs and saves fuel energy. Irrespective of what fuel source is used to power the vehicle, diesel, LPG or CNG, our system can deliver significant fuel savings and these directly reduce harmful exhaust emissions. For the fleet operator this is truly an exciting prospect in being able to both reduce operating costs and significantly contribute to the reduction of greenhouse emissions.

Perhaps the most compelling aspect of this technology is that it can be employed in fleets of existing vehicles, as the Permo-Drive system is designed to be retro-fitted. Thus the savings can begin immediately, without waiting for new replacement vehicles to be introduced to the fleet.

We are excited about our direction and prospects as well as being proud of the groundbreaking work we are accomplishing in the transport industry. I encourage you to explore our site and read about our achievements and our global potential - a potential our team is determined to exploit to the benefit of our shareholders, our local community and Australian technology.

Pictures courtesy of Permodrive systems, Australia

TECHNOLOGY OVERVIEW

The Scope of Works originally determined for the design criteria that would form the basis of the development of the Regenerative Drive Shaft and the Energy Management System was as follows:

- Reduce the complexity of previous systems.
- Reduce the number of components of previous systems.
- Reduce the weight and thereby reduce the amount of payload sacrifice.
- Increase the available torque output over previous systems.
- Increase the retardation function and capacity over previous systems.
- Increase the energy storage capacity.
- Increase the acceleration assistance function over previous systems.
- Increase the degree of functionality.
- Increase the controllability of function.
- Institute greater interaction between vehicle performance and regeneration.
- Improve road safety.
- Reduce driver interaction.
- Reduce environmental degradation.
- Produce a genuine "Return on Investment" for end users.

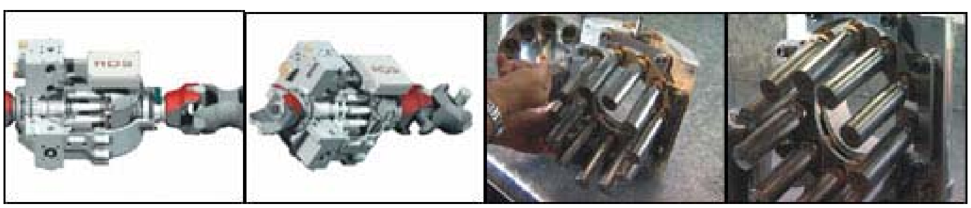
By utilizing "State of the Art" materials science, advanced computer controls, innovative design techniques and an understanding of the dynamics of vehicle performance in relation to peak demands we have been able to incorporate acceptable levels of initial design criteria into the Permo-Drive System to achieve these tremendous results.

TECHNOLOGY

Permo-Drive Technologies Limited has developed an innovative hydraulic regenerative braking and propulsion system suitable for most heavy vehicles and buses (in particular those vehicles operating in an urban driving cycle) aimed at delivering significant efficiency, economic, environmental and safety benefits.

The Permo-Drive technology has been designed to achieve the integration of vehicle dynamics, advanced hydraulics, mechanical engineering, accumulator technology, materials science, computer telemetry and electronics.

Put simply, the Permo-Drive system harnesses the previously wasted braking energy of a vehicle, stores this energy and is able to release it back into the drive shaft as required. For example a truck going down a hill or braking can store that energy for use at a later time. If the truck needs to accelerate or go up a hill, or through a gear change, the Permo-Drive system can be automatically activated to deliver additional torque to the drive shaft during periods of peak engine demand.



Pictures courtesy of Permodrive systems, Australia

<u>The Permo-Drive system features:</u>

- An innovative regenerative drive shaft,
- Composite accumulators,
- Light weight materials and
- Advanced computer telemetry.

It is anticipated that these features of the Permo-Drive Regenerative Energy Management System (PDREMS) will have a number of unique advantages. The PDREMS should significantly improve the operating and driving characteristics of the vehicle. The in-built Electronic Energy Management System (EEMS) and the unique functionality of the Regenerative Drive Shaft (RDS) means the stored energy gained through retardation can be released efficiently as a secondary power boost to deliver the following benefits:

- Significant cost savings.
- Significant reductions in fuel usage.
- Reductions in brake wear.
- Reduction in clutch, gearbox and other driveline component wear.
- Extended engine life.

Operational and Safety Benefits

- Reduction in the number of gear changes. (Less wear in automatic transmissions)
- Minimal loss of momentum during gear changes.
- Improved acceleration particularly in urban environments and in hilly terrains.
- Improved trip times.
- Reduction in driver fatigue.
- Improved traffic flows particularly in urban environments and hilly terrains.
- Provision of accurate data on the operating and mechanical performance of the vehicle.

BENEFITS

The Permo-Drive Regenerative Energy Management Systems offer a wide range of benefits to a cross section of end users, environmental groups, government legislators, air quality management districts, transport departments and the community.

The utilisation of this technology greatly assists in the improvement of road safety, driver fatigue, operator, passenger and overall community health while improving the bottom line for transport operators.

- **Mining**

  Discussions have been held with a number of manufacturers of both underground and surface mining equipment, as well as a variety of end users over the applicability of the Permo-Drive Regenerative Energy System to specific applications within the industry.

- **Marine**

  Initial developmental studies have been undertaken in marine applications where additional torque at the shaft under specific circumstances would be advantageous.

- **Agriculture**

  Agricultural applications are as many and varied as there are vehicles and there are many examples of hydraulic assistance pushers in much of the heavy tractor applications.

- **Rail**

  Regenerative braking has long been utilised in electric rail applications where the motor can be utilised as a generator and not only draw energy from the forward momentum and therefore slow the vehicle but also can feed that electricity back into the grid for credits against usage.

MINING:

Discussions have been held with a number of manufacturers of both underground and surface mining equipment, as well as a variety of end users over the applicability of the Permo-Drive Regenerative Energy System to specific applications within the industry.

Developmental considerations have been undertaken for the following equipment:

- Underground long wall.
- Underground personnel carriers.
- Belly Scrapers.
- Dump Trucks.
- Drag Lines.
- Cranes.
- Conveyors.
- Lifts.

Additionally there has been a variety of other equipment that has been considered to a lesser degree.

MARINE:

Initial developmental studies have been undertaken in marine applications where additional torque at the shaft under specific circumstances would be advantageous such as:

- Tugs and tow barges.
- Trawlers.
- Salvage vessels.

The retardation function, in these applications is negligible however the cost of additional fuel utilised to generate the stored energy is far outweighed by the selective input of additional torque during periods of peak engine demand.

Additionally there are many functions within marine applications such as cranes, drilling platforms and container lifting equipment that would benefit from the normal functionality of the Permo-Drive Energy Management System.

AGRICULTURE:

Agricultural applications are as many and varied as there are vehicles and there are many examples of hydraulic assistance pushers in much of the heavy tractor applications.

Adequate retardation has always been a concern in both function and as a safety issue, in particular where the vehicle is towing in rough conditions.

The additional controlled braking available through a regeneration system and the ability to apply increased torque on demand greatly increases the performance and safety of operations.

Energy management systems incorporated into powered trailers provide a level of performance that enables functional operation in extreme conditions.

RAIL:

Regenerative braking has long been utilised in electric rail applications where the motor can be utilised as a generator and not only draw energy from the forward momentum and therefore slow the vehicle but also can feed that electricity back into the grid for credits against usage.

However in many applications there is no electrical grid linkage and the train operates under fuel input such as diesel or coal.

Developmental work has been undertaken on the functionality of fitting flatbed rail cars with a Permo-Drive Energy Management System that can be activated automatically or at the drivers command to assist with retarding the train without brake pad activation and also to provide propulsion assistance at periods of peak engine demand.

ENVIORMENTAL BENEFITS:

The heavy automotive transport industry contributes approximately 16% of all greenhouse emissions.

Based on engineering projections and conservative market penetration forecasts by the Company the PDREMS could potentially reduce this figure by up to 3%.

The political and business environment is changing with a growing number of large corporations being held more and more responsible for pollution and emissions made by their manufacturing, distribution and business operations.

Scientific confirmation and collaboration of the hazardous effects of fine particles present in traffic pollution has been established in 1993 by the Harvard Six Cities epidemiological study. This shows a clear relationship between mortality and exposure to fine particulate matter caused by transport emissions in the atmosphere.

In August 1999 the Institute of Environmental Medicine in Stockholm released a study of the effect of fumes on 3,500 men living in areas with the heaviest traffic. This study showed that there was a 40% higher chance of contracting lung cancer for 30-year residents and 20% higher for 10-year residents.

All of these factors are contributing to the problems most industrialized countries are facing in relation to reducing emissions under the Kyoto Greenhouse Protocol and the long term damage to the health of city residents.

The PDREMS is designed to offer a solution to permanently reduce emissions from many heavy vehicles at an affordable upfront cost, which also provides a cost saving to the owners who are in low margin businesses.

The Permodrive technology is aimed at providing a completely new measure for significantly reducing vehicle fuel usage and emissions and therefore rapidly enhancing the environmental performance of the heavy automotive industry.

The Bureau of Transport Economics projects that, in the absence of further measures to limit greenhouse emissions, domestic transport emissions will increase by 42% on 1994 levels by year 2015.

In response to this, the Permodrive technology is expected to provide a realistic, cost effective way to reduce heavy vehicle fuel consumption (and therefore CO2e emissions) on articulated, rigid and bus vehicle classes.

The Permo-Drive system acts directly on the vehicle's main drive train to assist braking (store energy) and aid acceleration (release energy) and therefore leverage even greater total emission reductions when used in combination with fuel modified engines (e.g. using less greenhouse intensive fuels such as LPG, CNG, LNG and ethanol).

This project also contributes to Ecologically Sustainable Development ('ESD') because it produces substantial reductions in fuel used for heavy transport.

This slowing in the use of fossil fuels extends the availability of this natural resource for future generations.

The Permodrive technology is committed to sourcing materials that provide a product life cycle that achieves the best outcome for ESD principles.

Some other Environmental Benefits:

- Reduction in exhaust, carbon and noxious emissions.
- Reduction in engine exhaust braking noise.
- Reduction in brake dust pollutants.

Early independent tests have confirmed that utilizing the Company's experimental concept model the following results were achieved: -

- Reduction by 15% in Time to accelerate the unit from 0-100 km/hr.
- Reduction by 17% in Distance to accelerate the unit from 0-100 km/hr.
- Reduction by 20% in Fuel Used to accelerate the unit from 0-100 km/hr.
- Reduction by 17% in Time to decelerate the unit from 100-50 km/hr.
- Reduction by 15% in Distance to decelerate the unit from 100-50 km/hr.

More recent "On Road" independent tests have demonstrated a 37% reduction in fuel usage through a simulated urban drive cycle and 43% reduction in fuel usage for a simulated household waste pickup cycle. Multiple results were averaged for the simulated cycles only and do not include open highway cycles where retardation and propulsion assistance is minimally required.

Some latest news in permodrive technologies.

Lismore-based truck braking innovators Permo-Drive Technologies Ltd received a major fillip last week with institutional investors throwing the weight behind the company's revolutionary technology.

The NSW Local Government Superannuation Scheme's new $130 million Regional Development Trust has invested $1 million in the company.

NSW Treasurer Michael Egan said the $1 million added to the strong regional support for the project since the prospectus for Permo-Drive was launched in November last year.

'This new investment has brought the total investment to $4 million, which includes $2 million from Lismore and the regional community,' he said. ”The Permo-Drive system aims to boost the drive power of heavy vehicles by conserving and reusing braking energy.” He added.

Permo-Drive managing director Allan Rush said the Trust's investment was a major endorsement for the company and the technology, and established a precedent for regional investment.

'Our strategy to ‘stay regional' has been well and truly vindicated, and with the support of this Development Trust – managed by Deutsche Bank – we will be able to achieve our global potential from a regional base and deliver outstanding local, economic and employment benefits,' he said.

Mr Rush paid tribute to Lismore mayor Bob Gates, who introduced Permo-Drive to the Trust managers, as well as council.

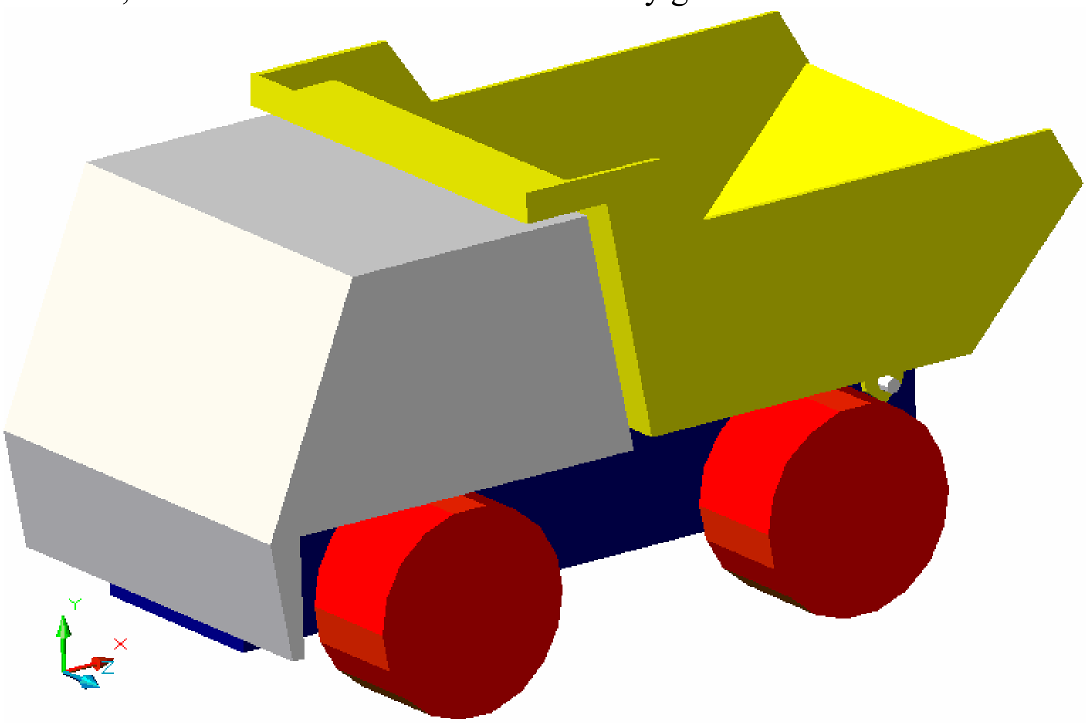
'Without the support of Council, the NSW government and Federal government via a $1 million R & D grant, this exciting project would have struggled or gone off shore.'

Mr Rush said Permo-Drive was currently involved in pre-production testing of the regenerative braking technology. But already the results are positive and he expects major scientific results soon, which he says will 'make the heavy automotive industry sit up and take notice'.

Investment opportunities still exist under the current prospectus. Contact Permo-Drive.

Working model exhibiting the working of Permodrive principle.

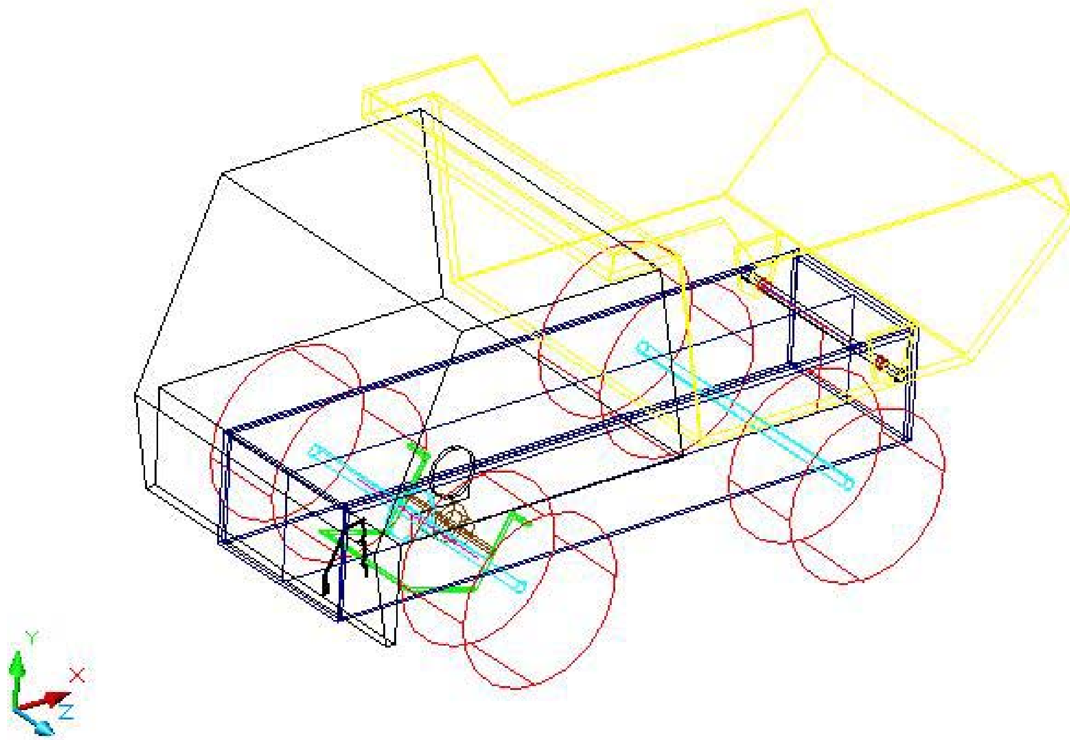
The working model is in form of a small dumper toy truck. We try to implement the Permodrive principle that is used in big trucks as regenerative braking system. But our mechanism is a little different from the actual system. In actual system the whole system is hydraulically actuated, but in our model actuation is done by gear mechanism.



WORKING PRINCIPLE OF MODEL

Working model has been made around a toy dumper truck. In the original toy the dumper is automatically opened by a helical spring, which is situated in the rear of truck. We have tried to make the dumper + spring system to form the energy storage system.

Initially the dumper will remain open (spring is in relaxed state), when brakes are applied, the gear mechanism will transfer the braking resistance to the spring. During this transfer the dumper will come down and energy will be stored in the spring (now spring is in tensed state). During the regeneration stage i.e. when the truck accelerates, the energy stored in spring is transferred back to front wheels by the gear mechanism.



VARIOUS PARTS OF PERMODRIVE MODEL

1. Rear wheel drive system.
2. Front wheel permodrive system, consisting of:
   a. Braking system.
   b. Regeneration system.
   c. Motorized Gear engagements.
   d. Energy storage in the dumper spring.
3. Wired joystick controlled remote control.

1. Rear drive system.

This mechanism acts as the engine of the model truck. It has a small motor that drives the rear wheels. The motor is a toy motor and operates at 3-6 volts.

It is linked to the driving wheels by means of small plastic gears and belt pulleys. The gear train is of reduction type. This mechanism is mainly responsible for imparting motion to the truck. The velocity ratio of motors to wheels is kept constant and after initial acceleration the truck runs at constant speed. During the applications of brakes on the front wheels the motor is switched off automatically from the hand control box.

2. Front wheel permodrive system.

This is situated at front wheels. It is the main system that stores the energy during braking and regenerates or utilizes the stored energy for the initial acceleration of vehicle via front wheels. In conventional braking, lot of energy is wasted in form of frictional heat. But we are trying to harness some amount of this energy by storing in springs by some mechanisms.

Theory:

When a vehicle is moving at certain speed and it has to stop by the application of brakes, the brakes dissipate all the momentum and kinetic energy against the frictional resistance provided by the brake shoes.

In laymen language, braking reduces the energy level of the vehicle from a higher level (high speed) to a lower level (lower speed or zero speed) by dissipating this energy as heat in the brake shoes, which provides a resistance for the braking effect. But if we provide the same resistance by a spring, we can store all the braking energy in the expansion or compression of the spring, and later this stored energy can be recovered from the spring. Hence we can save a lot of energy by this method and better utilization of energy gives us better fuel consumption and more efficient vehicles. This technique is used in Australia in big trucks and is called “Permo drive”. We try to implement the same technique in a small toy truck, but our model, energy storing medium is a spring using motorized link actuation as against the complex computerized servo controlled hydraulic systems in the original permodrive systems.

Construction:

Main components of this system as shown in figure are:

1. Front axle having 2 wheels.
2. Gear 1 on front axle.
3. Compound Gear 2 on link 1.
4. Gear 3 on link 2.
5. Motor 1 controlling link 1.
6. Motor 2 controlling link 2.

The motors 1 and 2 actuate the links 1 and 2 respectively. Links and Gears are engaged and disengaged in desired manner for getting the braking and regeneration effects. This working is explained in detail in the Main parts of front wheel permodrive system.

Main parts of front wheel permodrive system:

1. Braking system.
2. Regeneration system.
3. Motorized Gear engagements.
4. Energy storage in the dumper spring.

Braking system.

Normally when the vehicle is running, all the three gears 1,2 and 3.are disengaged with each other. At this stage all the gears are free. When brakes are applied motor 1 links the gear 1 and 2 (compound gear 2 is movable on link 1). Compound gear has teeth on half of its length; on the other half side a thread wounds, which lowers the dumper and this in turn strains the dumper spring. Hence due to straining of main (dumper) spring a resistance is produced which acts as the braking resistance. Further as the vehicle is decelerating, its excess energy is being stored in the main spring which normally dissipates in the brake shoes.

On disengaging the gear 1 and 2, braking effect is lost.

Schematic diagrams

Regeneration system.

During braking a lot of energy gets stored in main spring. At this stage the main spring is highly strained. The regeneration system enables us to use this stored energy for the initial acceleration of the vehicle via front wheels.

Actuation or Engagement - Initially all 3 gears are disengaged. To enable regeneration, motor 2 engages gear 3 both with gear 1 and 2. The gear 3 is an ideal gear used for direction change. Now when the main spring tries to restore itself it causes the dumper to move up. This upward movement rotates the compound gear 2, which further transfers the motion to the front wheel axle via gear 3 and 1. This enables the motion of vehicle without the help of prime mover (that is motor in this case).

Dis-engagement – When the main spring returns to its unstrained state or in other words when all stored energy has been transferred to the front wheels, the Motor 2 actuates link 2 such that it disengages gear 3 both from gear 1 and 2. And all 3 gears become free.

Schematic diagrams

Motorized Gear engagements.

For achieving braking and regeneration effects the action of 3 gears have to be carefully controlled. Their engagement and dis-engagement has to be achieved remotely and automatic for fast operation. 2 Small toy motors are used to achieve the desired motion of the gears by utilizing small levers and cam arrangements.

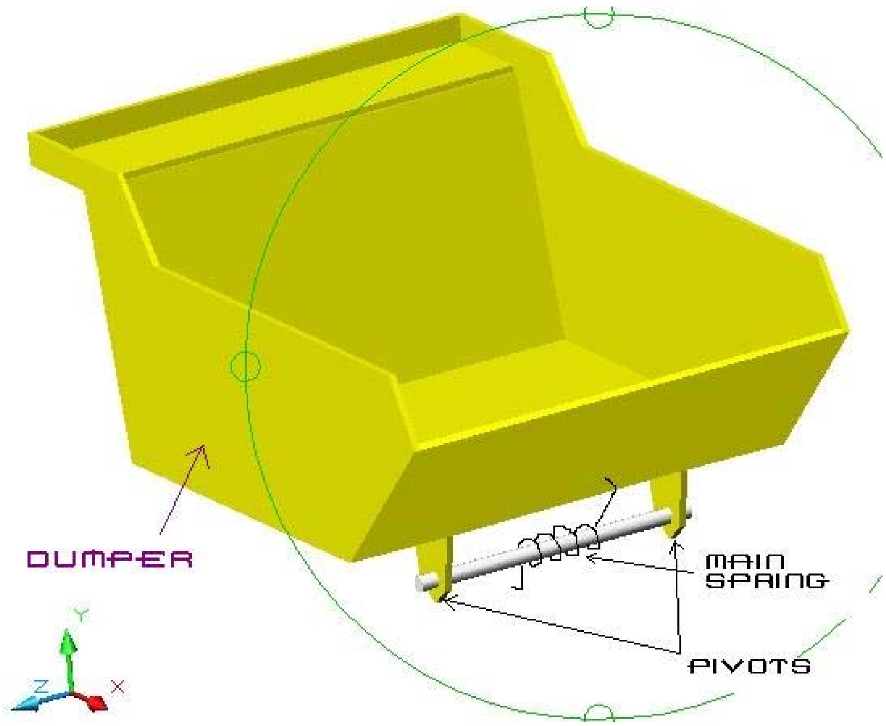
Motor 1 (as shown in figure) controls the movement of compound gear 2 by link 1. A small wheel on the motor shaft is used as a cam by which reciprocating motion of link 1 is obtained.

Motor 2 (as shown in figure) controls the movement of ideal gear 3 by link 2. A pairs of gears on the motor shaft is used as a cam by which reciprocating motion of link 2 is obtained.

Figures

Energy storage in the dumper spring.

The toy truck model that is used in this permodrive model has a dumper at its back. Two pivots and a helical spring hold the dumper. The spring has a tendency to keep the dumper upright and force has to be applied to bring it down. In fact the force required to bring it down is equal to the braking resistance provided to stop the truck during braking.



The energy absorbed during braking is stored in the spring. As a result the spring gets strained. The theory of spring is covered in detail in the section Energy storing devices.

Wired joystick controlled remote control.

Remote control controls the motors for activating the gears for obtaining braking and permodrive operations. It has two joysticks, one for each motor, for controlling the motion of motors in both directions. A separate switch is there for the rear driving motor.

The control box also contains two battery packs that provides power to the motors.

REFERANCES

1. Permodrive technologies Australia homepage, www.permo-drive.com

2. "Hot science from Australia", a science series on National Geographic.

3. "Science Frontiers", a science and technology series on Discovery Channel.

4. All figures/diagrams drawn in AutoCAD2000.