ANALYSIS OF ENERGY LOSS IN AUTOMOBILE BRAKING SYSTEM AND ITS RECOVERY

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ABSTRACT

The conventional braking (friction brake) system losses considerable amount of energy during car drive. In this paper an experiment has been made to recover this energy and make an optimization of power consumption. A model of braking system is designed and constructed to extract and store energy during the braking of a car and supply energy when it is needed. Gaseous fluid is compressed in cylinder by a high pressure liquid to store the energy of brake. A positive displacement pump driven by the extraction of energy from break is used to supply the high pressure liquid. During braking the pump is clutched with the power train of the car. The pump is utilizing the inertia energy of the car to compress the gaseous fluid. This stored energy can be used to enhance the acceleration of car and to run other accessories of the car. A performance test of the brake model is conducted and can be found that, during brake approximately 60% of inertia energy can be saved.

Keywords: Braking System, Inertia Energy Conservation, Compressed Fluid, Friction Brake.

1. INTRODUCTION

Motor vehicle is the most useful transportation system since the dawn of its creation. Many advances have been made to make the motor vehicle more desirable and friendly for the millions of users throughout the world. It is our goal to design a device that can make their commute an easily traveled one. The energy extraction from conventional braking system of automobile is a device that can do so by reducing the overall energy required to use. Brake energy is the energy that stops an engine. There are also other opposing forces such as aerodynamic drag force and rolling force. Research of Crouse[1] shows that almost 50% of the total energy is lost as brake energy although this percentage will be a bit different for different types of vehicles Wendel at al [2] described in Michigan clean fleet conference, hydraulic regenerative braking system has a good power density of 1458 W/Kg and efficiency about 85%. So this system is much better than electric energy storage device. The figure-1 shows the difference among various brake energy recovery system.

In 1996 University Wire had researched about electric regenerative braking system[3]. In 2002 a new braking system called hydraulic launch assist will make stop-and-go driving for large trucks more efficient by capturing energy that would normally be lost as heat[4]. Advanced Technology department at Eaton's Fluid Power Group in 2009 made successful testing of Rexroth
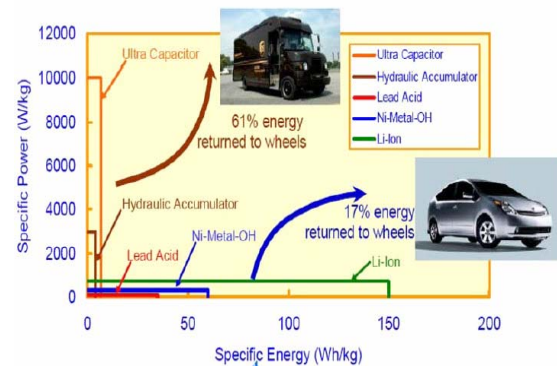

Fig 1. Various brake energy recovery system

Hydraulic Hybrid Technology in Refuse Trucks begins[4] It is sponsored by the New York State Energy Research and Development Authority (NYSERDA). This evaluation project identifies vehicle fleets which, when integrating technologies such asHydraulic Regenerative Braking system, have high potential for reducing fuel consumption and emissions. The hydraulic hybrid evaluation is part of a larger program carried out by DSNY that will demonstrate the impact of utilizing multiple alternative drive technologies. In April 2009 Artemis Intelligent Power [5] has converted a BMW 530i to mechanically capture the energy resulted from braking

(aka "regenerative braking"), and use it in an electrically-hybridized car fashion[6]

2. PRODUCT DEVELOPMENT PROCESS

A considerable effort has been made in order to produce the most desirable and affordable model to make the highest efficient and most unique device. Process have four distinct phases: the concept phase, the design phase, mathematical modeling phase and the construction phase. During the concept phase, we defined the problem of losing energy while braking on a motor vehicle. We then conceptualized different ways of using that energy with different regenerative braking systems. Through research and customer surveys, we entered the design phase knowing consumer preferences. We generated designs based on known preferences, constraints, and parameters. We then made a CAD drawing of our design. We analyzed our model from the viewpoint of the consumer and manufacturer and did mathematical analysis of the optimal designs. After reviewing our results, we hypothesized how we would enter the Construction Phase.

2.1 Methodology

Inertia energy of a car is stored as a compressed fluid energy while braking is done. A clutch is used as a brake shoe. During Braking this clutch engages the driveline of the system pump is activated and forced hydraulic fluid out of a low pressure cylinder (Reservoir) to a high pressure cylinder. This hydraulic fluid then compress the gaseous fluid in cylinder and energy is stored. This energy can also be used to run the AC compressor, lube oil motor or other hydraulic system.

Power is transmitted from the car drive train to the speed increasing gear box through the clutch. So pump is started to rotate with an increased speed which in turn moves fluid to the accumulator and energy can be stored within a short time, then car will stop.

Accumulator/High Pressure cylinder

Low Pressure Cylinder/Reservoir

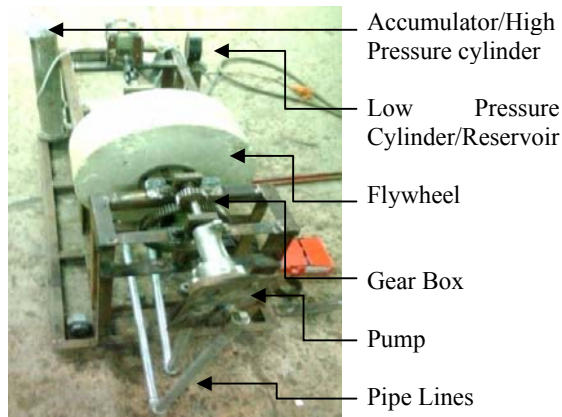Flywheel

Gear Box

Pump

Pipe Lines

Fig 2. All components in the whole system

2.2 Design Parameters

Following basic components are used in model

1. Flywheel: Diameter = 15in, Height = 6in
2. Gear box: Diameter of small gear = 1.5in, Diameter of big gear = 7in
3. Motor: 3-phase ac motor
4. Clutch : 50cc Honda clutch
5. Pump: Oil pump of medium size pick up car
6. Accumulator / high presser cylinder, Volume = 75 cubic in
7. High pressure cylinder/Reservoir, Volume = 100cubic in
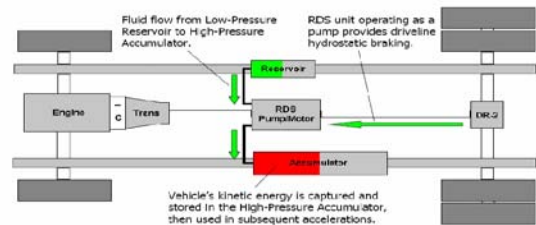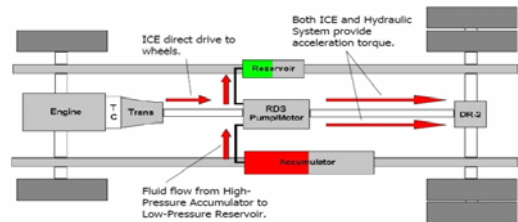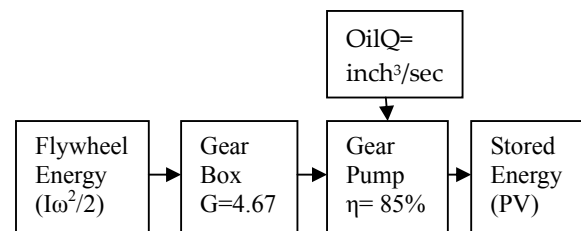
2.3 Oparation

Fig 3. Basic operation of the Model

3. MATHAMATICAL MODELING
3.1 THEORETICAL DERIVATION OF THE NECESSARY EQUATIONS

The flow diagram of energy storing system is shown below:

Power flow across the pump,
$$T_p * \omega_p = \Delta P * Q'/\eta$$
$$=> T_p * 2\pi n = \Delta P * Q * n / \eta$$

$$=> T_p = \frac{\Delta P * Q}{2\pi \eta}$$

but $T_i/T_p = G = D_1/D_2 = 7/1.5 = 4.67;$

$$\Rightarrow T_i = - I\alpha = \frac{\Delta P \cdot Q \cdot G}{2\pi \eta}$$

$$\frac{d\omega}{dt} = - \frac{Q \cdot G \cdot P_{atm} \left(\frac{V_0}{V} - 1\right)}{2\pi I \eta} \qquad (1)$$

3.2 Expression of V_O/V

$$V_O/V = e^{-\frac{(I\pi\omega_o^2)}{2\,P_{atm}\cdot V_S}\cdot\left(\frac{\omega^2}{\omega_o^2} - 1\right)} \qquad (2)$$

3.3 Time Required to Stop The Wheel

$$T = \frac{2\pi I \eta}{Q \cdot G\, P_{atm}} \int_0^1 \frac{\omega_o\, d\omega_r}{e^{(1-\omega_r^2)} - 1}$$

When $\omega = 0$ then $\omega_r = 0$
$\omega = \omega_o$ then $\omega_r = 1$

Theoretical stopping time of the fly wheel T = 6.8768 sec for N = 200 rpm

3.4 Calculation

Table 1: Theoretical final Pressure, Volume and Stored Energy

Obs No	N, rpm	P_2 psi	V_2, in^3	T sec	E_{in} (J)	E_{st} (J)	Friction Loss	% of Energy Stored
1	200	43.7	25.2	6.8	159	136	24.1	85
2	150	27.1	40.7	5.1	89.4	76.2	13.3	85

4. RESULT AND DISCUSSION
4.1 Data Collection
Flow rate and efficiency of the rotor pump are taken from J. S. Cundiff [7]
Flow Rate Q = 4.53 in^3/rev = 7.4233x10^{-5} m^3/rev
Average efficiency η_p =85%
P_{atm} = 101325 Pa, Gear Ratio = D_2/D_1 = 7/1.5= 4.67
Density of concrete, ρ = 2000 kg/m^3
Diameter of flywheel D =15in = 15*0.0254 = 0.381 m,
Width, L = 6in = 6*0.0254 = 0.1524m

Table 2: Data Collected

No of Obs	Rotation of wheel N_w (rpm)	Pressure raise in accumulator ΔP (Psi)	Time require to stop the wheel T(sec)
1	200	15.5	27
2	150	5.5	15

4.2 Results
Observation 1
Energy Input = 159.247J
Theoretical Time Required to stop the wheel= 6.8768 sec

Theoretical Energy Stored = 135.8451J
Theoretical Frictional Loss = 24.1019J
Experimental Time Required to stop the wheel = 27 sec
Experimental Energy Stored = 88.204J
Experimental Frictional Loss = 71.0429J
% of Input energy is stored (Theoretical) = 85%
% of Input energy is stored (Experimental) = 55.58%

% of Error = $\frac{(E_{st})_t - (E_{st})_e}{(E_{st})_t}$ = $\frac{135.8451 - 88.204}{135.8451}$ = 34.55%
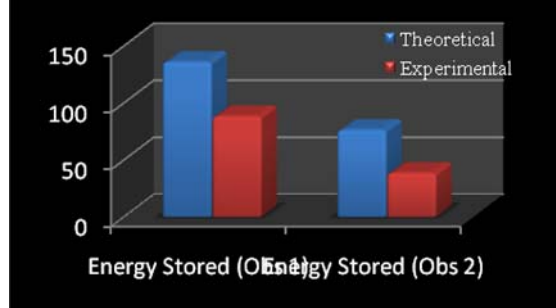

Fig. 3 Stored energy comparison
(Theoretical Vs Experimental)

Energy losses due to the friction and leakage for both observation is almost same.

Energy loss in the system for
Observation 1 = Theoretical Energy Store - Experimental Energy Stored
= 135.8451J - 88.204J
= 47.641J
Observation 2 = Theoretical Energy Store - Experimental Energy Stored
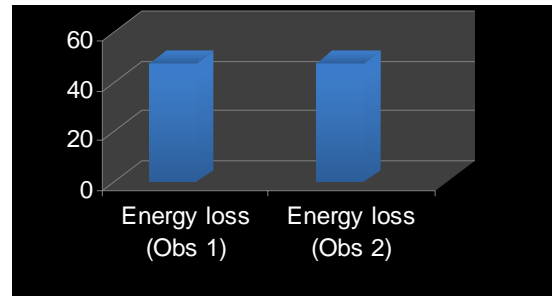= 135.8451J - 88.204J
= 47.6411J

Fig 4. Energy loss comparison for different obsevation
(Theoretical Vs Experimental)

5. DISCUSSION
Energy extraction from automobile braking system is not an easy task but we get a appriciable result. Percentage of input energy stored experimental result is 55.5% and the theoretical result is 85%. There are some deviations. These deviation occurs due o the following reasons.

- Leakage in the Pump
- Friction in the whole drive train
- Vibration in the flywheel
- Leakage in the accumulators and joints
- Unavailability of the designed components with desired rating in local market

Some unavoidable losses like friction in pipeline and leakage in pump decrease the efficiency of system. But those losses can be minimized in prototype and the deviation will be less. Because in prototype friction loss and vibration will be less and all the component will be designed and manufactured as per requirement.

6. RECOMMENDATIONS

The performance of the model can be increased through some modification. It's needs further research and this modification can be done by the future research. Some modifications are given below.

- BBy using precise molding process to manufacture pipes and pumps as per design.
- OOnly energy storage is performed and regeneration is not done. It can be done by using Hydraulic motor unit.
- BBy increasing the number of positive displacement pumps or using high pressure pumps braking could be done more rapidly.

7. REFERANCES

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3. hhttp://www.google.com/search?q=history+hydraul ic+regenerative+braking
4. WWilliam H. Crouse, "Automotive Mechanics".
5. AAdvanced Technology Department at Eaton's Fluid Power Group, Cleveland, Michigan, USA
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8. NOMENCLATURE

Symbol	Meaning
E_{st}	Energy stored in the Cylinder
E_{in}	energy in the flywheel = input energy in the device
m_w	Mass of the flywheel
D	Diameter of the flywheel
L	Height of the flywheel
I	Moment of Inertia
α	Angular Acceleration of the Flywheel
ω_o	Initial Angular velocity (velocity at the start of the braking)
ω	Instantaneous angular velocity
N_w	Rotational speed of the flywheel
N_p	Rotational speed of the pump
T_w	Torque in the Flywheel shaft
T_p	Torque in the Pump shaft
D_1	Diameter of the big gear
D_2	Diameter of the small gear
G	Gear ratio
P_o	Initial pressure in the cylinder
P	Instantaneous pressure in the cylinder
P_2	Final Pressure
Δp	Instantaneous change of pressure in the cylinder
V_o	Initial volume in the cylinder
V	Instantaneous volume in the cylinder
V_2	Final Volume
Q	Rated flow rate of pump(m^3/rev)
Q'	Flow rate (m^3/sec)
t	Time
T	Stopping time
η	Efficiency of pump

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