Regenerative Braking
Hydraulic Assist Pedicab

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Summary

We did further research on the pedicab created by E. Burgett, R. Dryer, K. Jackson, K. Kysylyczyn, and J. Lai, Spring 2008, Mechanical Engineering Department, University of Minnesota. After research and testing of the individual components, we identified inefficiencies and made improvements where feasible. Based on the recommendations of the original researchers and our own curiosities, we improved the ergonomics and safety of the pedicab. We also tested the efficiency of the regenerative braking system by measuring pressures and velocity. We developed recommendations for further improvements that were not feasible due to budget and time constraints.
Initial Hydraulic Circuit
Improving the Safety and Functionality of the Pedicab

- Repaired the front manual caliper brake
- Tightened tension on chains
- Added hydraulic fluid to the reservoir
Improving the Safety and Functionality of the Pedicab

- Freed seized accumulator piston
- Repacked and secured wheel bearings
- Drilled hole, added washers and a cotter pin to secure rear left wheel
Valve Change

The original design called for a 4 way, 3 position (4/3) directional control valve (DCV), but a 4 / 2 DCV was substituted for it. They created a neutral center position by using an external spring. We were able to obtain a 4/3 DCV to fulfill the original circuit design.

Electronic Microswitches to Control Valve

- Replaced cables that operated old 4/2 valve with microswitches and wiring to operate new 4/3 electronic valve
  - Installed low voltage 12 V battery to power microswitches
Replacing the Pump/Motor

Why?
- Existing pump/motor was 4.0 CID, too difficult to pedal
- Caused accumulator to charge much too quickly (very abrupt stop)
- Also discharged too quickly and assist was minimal
New Lower Displacement Pump

- Replaced existing pump with a Char-Lynn Eaton J series pump (model number: 129-0339-02)
- It has a 0.5 CID
- Lower displacement allows longer & easier charging cycle leading to a higher attainable system pressure
- It also allows a more sustained discharge
- The only negative aspect of this pump is a lower than desired torque

http://www.eatonhydraulics.com/products/pdfs/E-MOLO-MC001-E5.pdf (pp. 36-47 of PDF file)
Changes to the Front Sprocket

- The shaft of the new pump/motor was too small for the existing sprocket
- By changing to fewer teeth on the new sprocket, we created a mechanical advantage
- Grainger part number 1L214
- Specifications: 3.45" OD, 60 pitch
- Bushing was required, Grainger 1A276
Valves

- The pressure relief valve has a cracking pressure of 1800 psi
- We removed the check valve because the pump could not produce a sufficient vacuum to open it under human power
- The vacuum pressure needed to open this check valve was found to be 4-5 psi
After our adjustments, does the system work?

The video shows how the pedicab works in the lab and three of the mechanical tests we did to measure efficiency and formulate recommendations for further research

http://www.youtube.com/watch?v=tH-rL2eZqBA
Pressure Drop Over the Valve

After repeated experimentation, the pressure drop across the valve was determined to be 50 psi.
Pump Revolutions to Charge

Using the relatively flat surface afforded by the Minneapolis parkway system, we marked out a test track to measure revolutions to charge the accumulator to 1000 psi. It took 650 feet to charge and we traveled 623 feet from a stop using the 1000 psi charge, attaining a top speed of 7 mph. System mass was 350 lbs.

Calculation:

650 ft*12 in/1 ft*1 rev of tire/70.5 in*8.085 rev of pump/5 rev of tire = 179 revolutions of the pump to achieve 1000 psi

This is equivalent to 63 revolutions of the pedals

http://www.youtube.com/watch?v=vlu6KhzDRyc
The Hill

We tested the pedicab on two hills, one a 5% grade and the other 8%. With our undersized pump, we found the regenerative braking was lacking although the hydraulic assist allowed our rider to climb a 500' long incline easily. It was on the hill shown in our video (8% grade) that the system pressure reached 1800 psi between the accumulator and the valve. At that point, our pressure relief valve held.

http://www.youtube.com/watch?v=sHL6HWSzIXM
System Efficiency Testing Using Velocity and Distance

For this experiment, we first coasted to a stop from 10 mph. It took 135 feet. We then repeated the stop test while charging the accumulator. This reduced stopping distance to 87 feet. Using the charge from this stop, we were able to travel 51 feet and attain a top speed of 3 mph. The accompanying video demonstrates.

Simple Efficiency Calculations

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\frac{V_{\text{max during discharge}}}{V_{\text{when charging initiated}}} = \frac{3 \text{ mph}}{10 \text{ mph}} = 0.3 = 30\%
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\frac{D_{\text{during discharge}}}{D_{\text{while charging}}} = \frac{51 \text{ feet}}{87 \text{ feet}} = 0.59 = 59\%
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http://www.youtube.com/watch?v=b4NbeNpHlzY
Torque

Torque = pressure*CID/2 pi

Initial torque for our system:
Torque = 1000 psi*.5 cu in/ 2 pi
= 80 in lbs

80 in lbs* 1 ft/12 in = 6.6 ft lbs
Recommendations

• Install a check valve that would open with a vacuum pressure of about 2 psi
• Replace the .5 CID pump with approximately a 1.5 CID pump to facilitate a shorter stopping distance and a greater initial torque
• Find a permanent solution to keep the back left wheel on and retain the bearings
• On a greater scale, use a variable displacement pump and a separate motor