

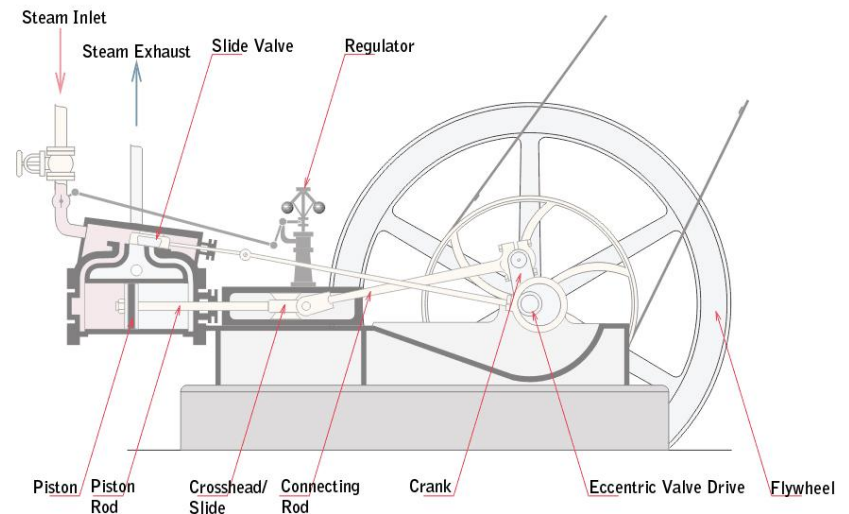
Electronic Engine Control and Optimization

GWDD Presentation: S. Chad Gibbs

5/5/2010

Introduction

- ▶ Construct a modern steam engine
 - ▶ Re-evaluate potential applications of the technology
 - ▶ Transportation
 - ▶ Energy production
- ▶ Apply modern materials and controls
 - ▶ Lightweight materials
 - ▶ Electronic controls that allow variable valve timing
 - ▶ Replace complex mechanical linkages with electronic activation methods



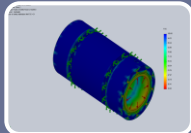
Quad Chart

Goal

- Evaluate the competitiveness of modern steam engines for power production and transportation

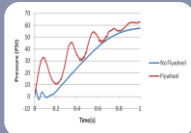
Scope

- Design and build a test rig for evaluating the applicability of camless valve control



Design Test Rig

- Define architecture and design components
- Fabricate test rig



Instrumentation and Activation

- Valve research and valve characterization testing
- Position sensor development



Collect Data

- Run the test rig with simple valve timing
- Collect and analyze running data

9/1/2009

- Research traditional steam technology
- Define scope from research

12/1/2009

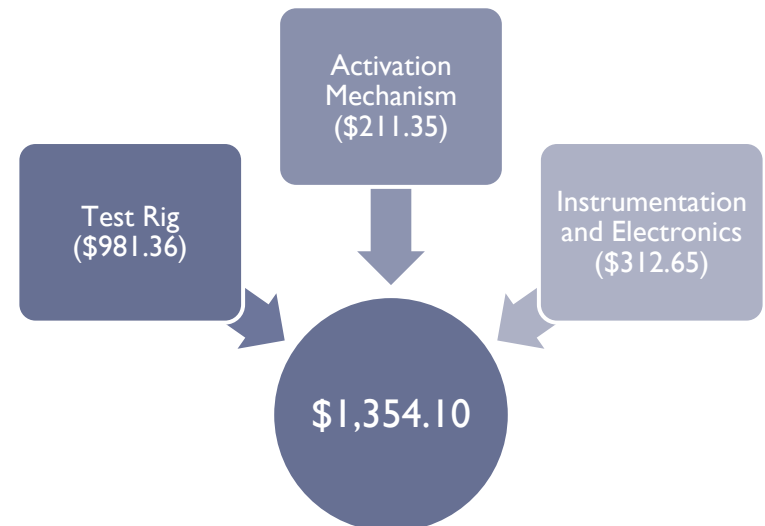
- Complete component testing
- Define architecture and design critical components

5/2/2010

- Design instrumentation and control electronics
- Run system test and analyze data

3/1/2010

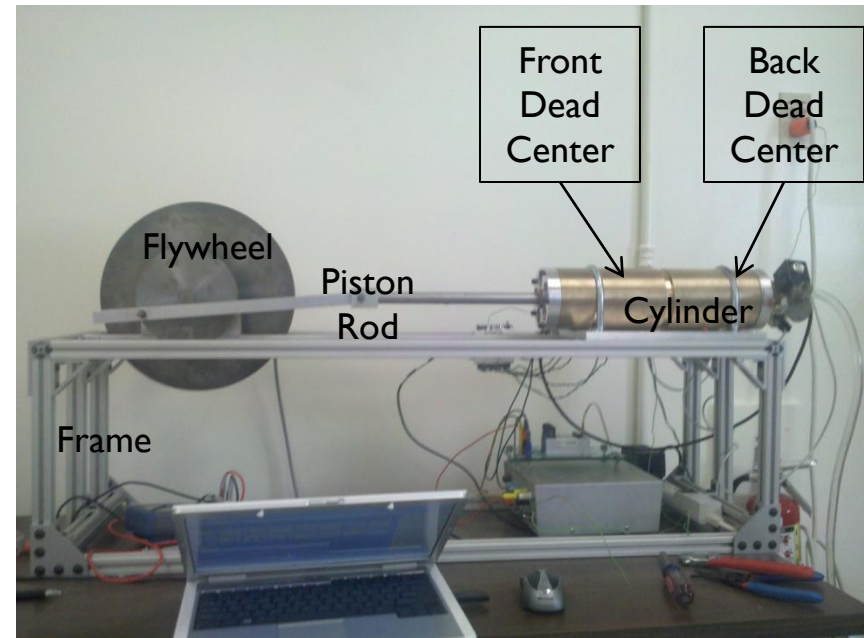
- Purchase material
- Fabricate parts and assemble test rig



Test Rig Design Analysis and Construction

System Architecture Overview

- ▶ System can be broken down into 4 parts
 - ▶ Cylinder and Piston
 - ▶ Piston Rod
 - ▶ Flywheel
 - ▶ Frame
- ▶ Terminology
 - ▶ Front/Back Dead Center



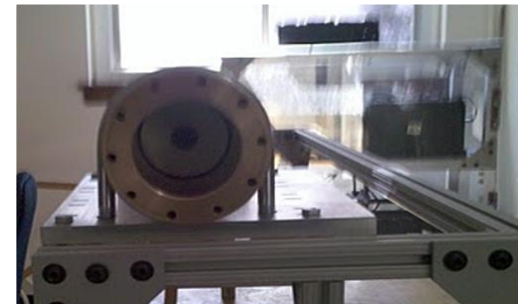
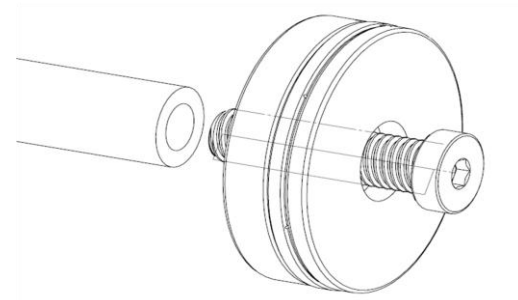
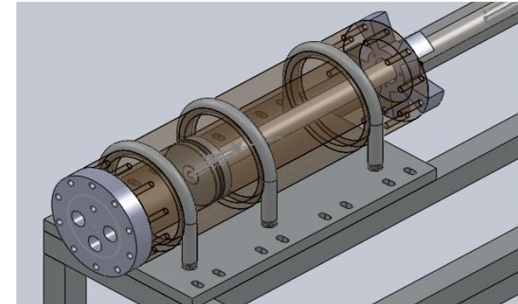
Cylinder and Piston

▶ Design Features

▶ Lubrication

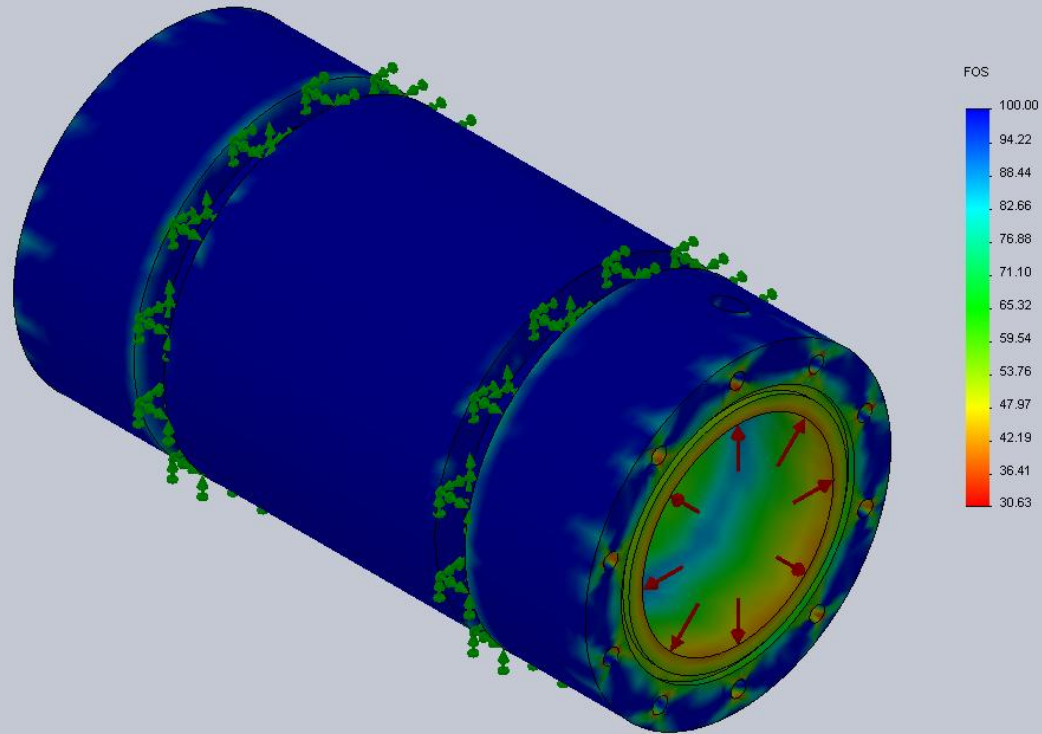
- ▶ Traditional steam engines used cast iron for cylinder.
 - required the entering steam to be injected with oil or other lubricant.
 - This process often made the outlet steam unusable
- ▶ Bronze Cylinder and PTFE piston ring makes system self lubricating

$$\begin{aligned} hp &= \frac{\text{Pressure} \times \text{Length} \times \text{Area} \times \text{RPM}}{33,000} \\ &= \frac{60 \text{psi} \times 3 \times (\pi \times 75^2) \times 100 \text{RPM}}{33,000} \\ &= .9 \text{ hp} \end{aligned}$$



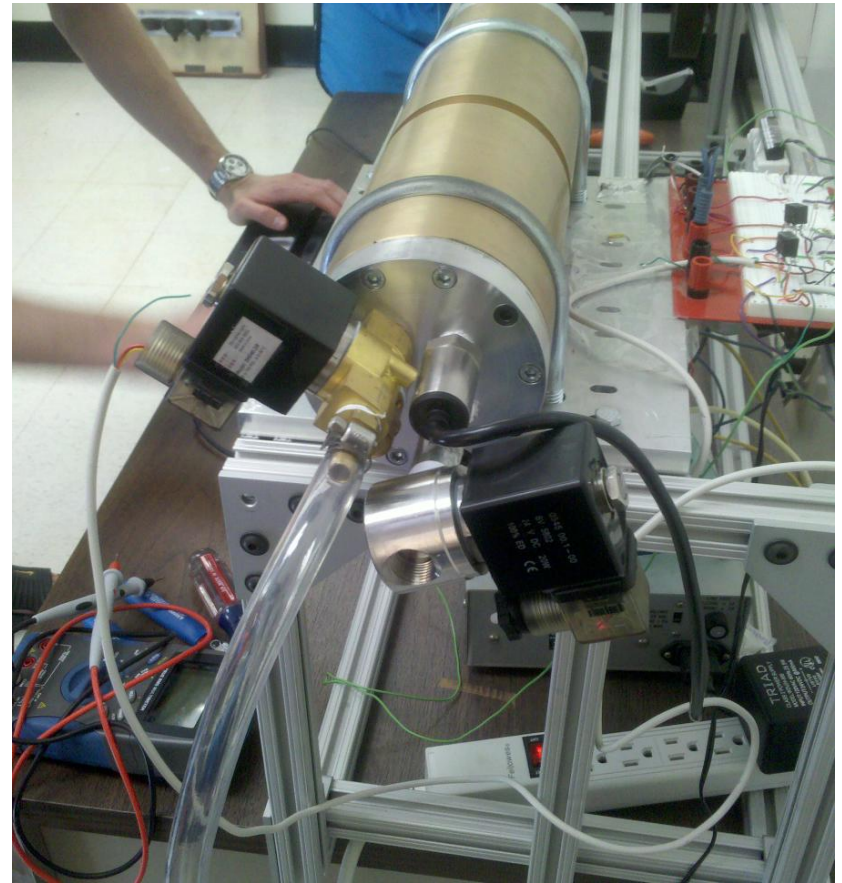
FEA for Cylinder

Model name: Cylinder 3.0-To Study2
Study name: Study 2
Plot type: Factor of Safety Factor of Safety1
Criterion : Automatic
Factor of safety distribution: Min FOS = 31



Piston Head and Instrumentation

- ▶ **Design Features**
 - ▶ All of sensors and activation mechanisms on one part
 - ▶ Modify activation and sensing without changing cylinder
- ▶ **Current Design**
 - ▶ Pressure Transducer
 - ▶ Pop-off Safety Valve
 - ▶ 2 x Solenoid Valve
 - ▶ Inlet
 - ▶ Exhaust



Flywheel

- ▶ Angular Momentum

$$L = I\omega$$

- ▶ Moment of inertia for a cylinder

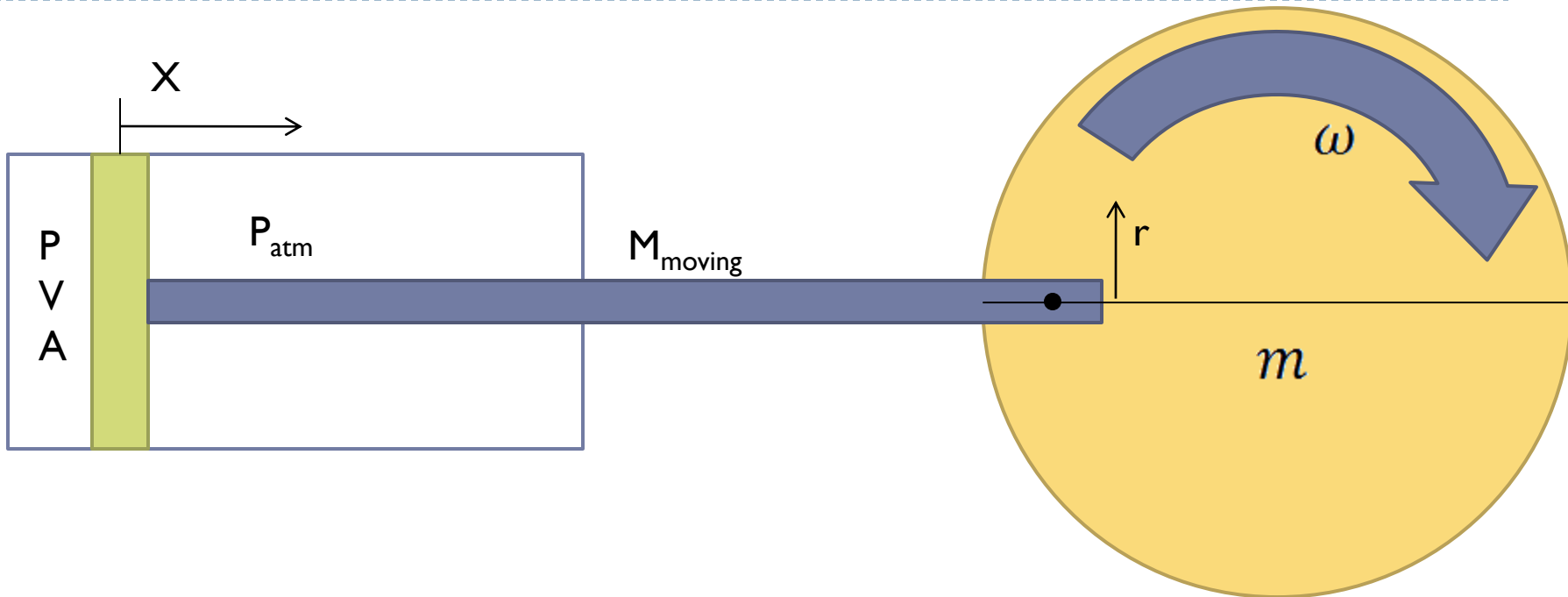
$$I = \frac{mr^2}{2}$$

- ▶ For designed setup angular momentum at 60 RPM
 - ▶ 85.53 lbf-in-s



System Characterization and Mathematical Model

Mathematical Model



Force Balance

$$M_{Moving} \ddot{x} + F_{fr} + F_{flywheel} = (P - P_{atm})(Area)$$

$$F_{flywheel} = \frac{d}{dt} [I\omega]r = I \frac{5}{\pi} \ddot{x}r$$

$$I = \frac{mr^2}{2}$$

Energy Balance

$$q_{in} - q_{out} + kc_v(\dot{m}_{in}T_{in} - \dot{m}_{out}T_{out}) - \dot{W} = \dot{U}$$

$$\dot{P} = \frac{RT}{V}(\dot{m}_{in} - \dot{m}_{out}) - \frac{P}{V}\dot{V}$$

System Characterization

- ▶ First calculation that can be made is static friction of system

$$F = (\text{Pressure})(\text{Area}) = \left(6.54 \frac{\text{lbf}}{\text{in}^2}\right) \left(\pi * \left(\frac{2.5 \text{ in}}{2}\right)^2\right) = 32.08 \text{ lbf}$$

- ▶ Represents an upper limit on the amount of energy that can be lost
 - ▶ ~25% of energy put into system

- ▶ Mass flow (.316 kg/s)

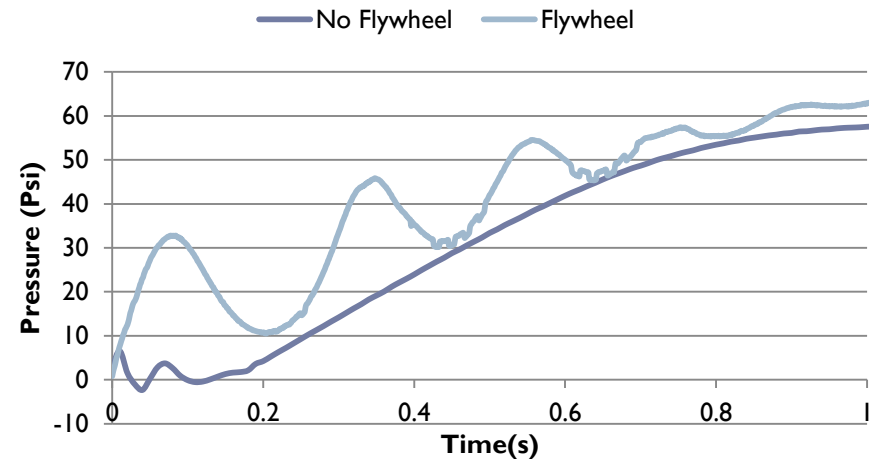
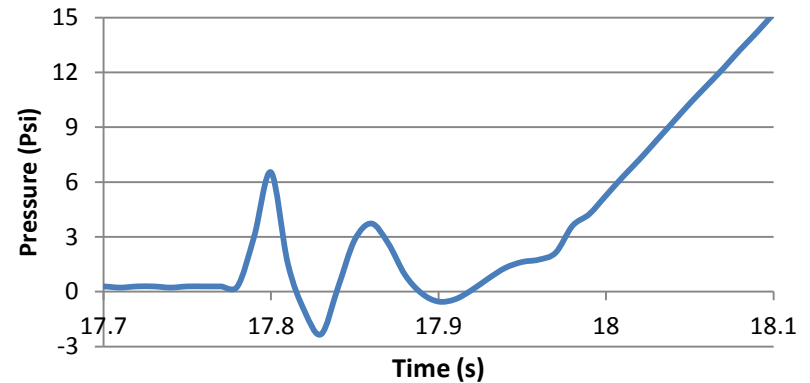
$$m_2 - m_1 = \frac{(P_2 - P_1)MV}{RT}$$

- ▶ Moment of Inertia

$$L = \int \tau dt$$

- ▶ 23.64 lbf-in-s is less than 50% of what was predicted using moment of inertia direct calculation (57.02 lbf-in-s)

No Flywheel Testing



Instrumentation and System Control

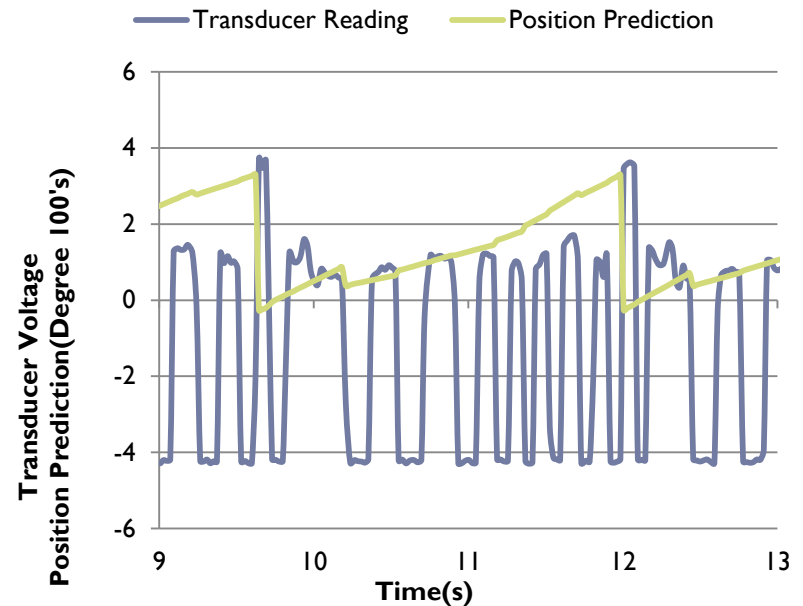
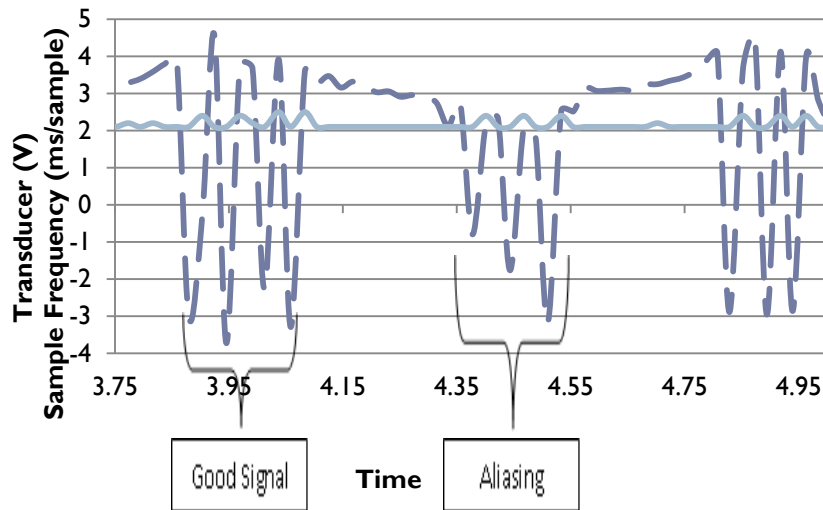
Instrumentation and Activation

- ▶ DAQ picture
- ▶ Instrumentation
 - ▶ Pressure Transducer
 - ▶ Up to 100 psi gauge pressure
 - Analog Voltage
 - ▶ Inductance probe
 - ▶ Position reading
- ▶ Activation
 - ▶ 2x 20W 3/8" NPT Solenoid Valve
 - ▶ Actuated by relay controlled by 5 VDC analog Signal
- ▶ Data Acquisition
 - ▶ NI USB 6009



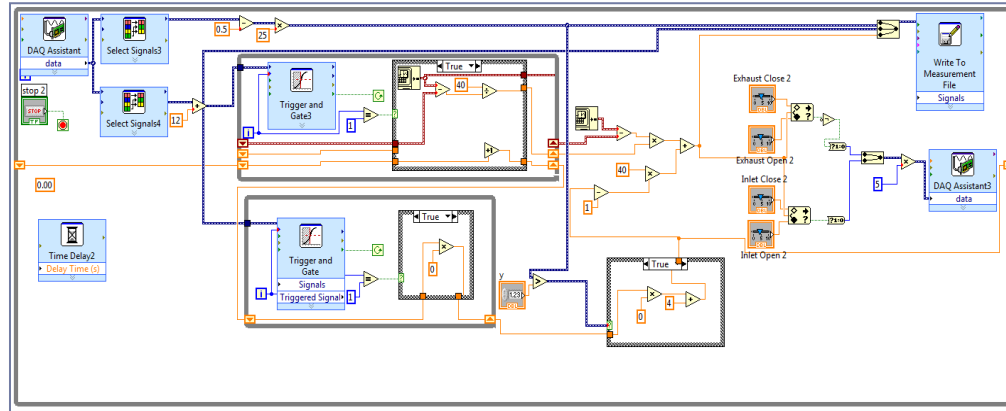
Position Sensing

Aliasing Problem Method I

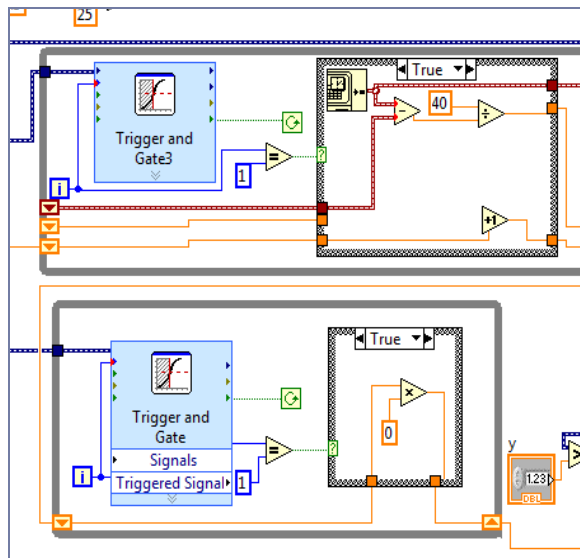


- ▶ At 120 RPM the resolution of the position sensing system is around 9 deg/sample,
 - ▶ Equally spaced 20 degree triggers with reset was implemented
- ▶ Position is determined by taking the index multiplied by 40° then adding to the previous velocity times the difference between the current time and the time of the previous trigger

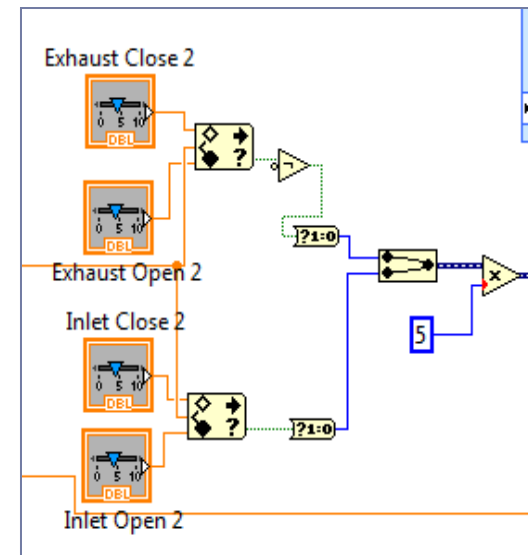
Labview VI



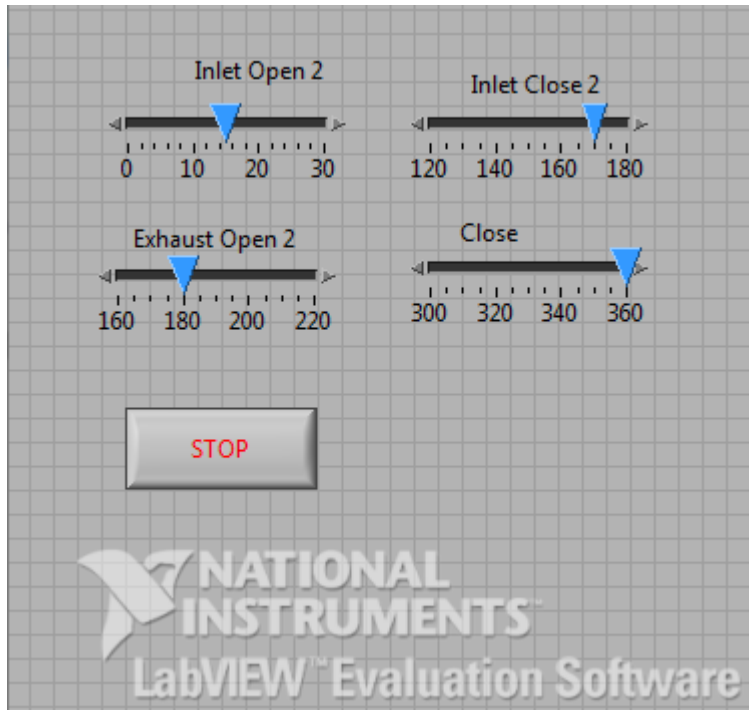
Position Sensing



Valve Control



Labview User Interface



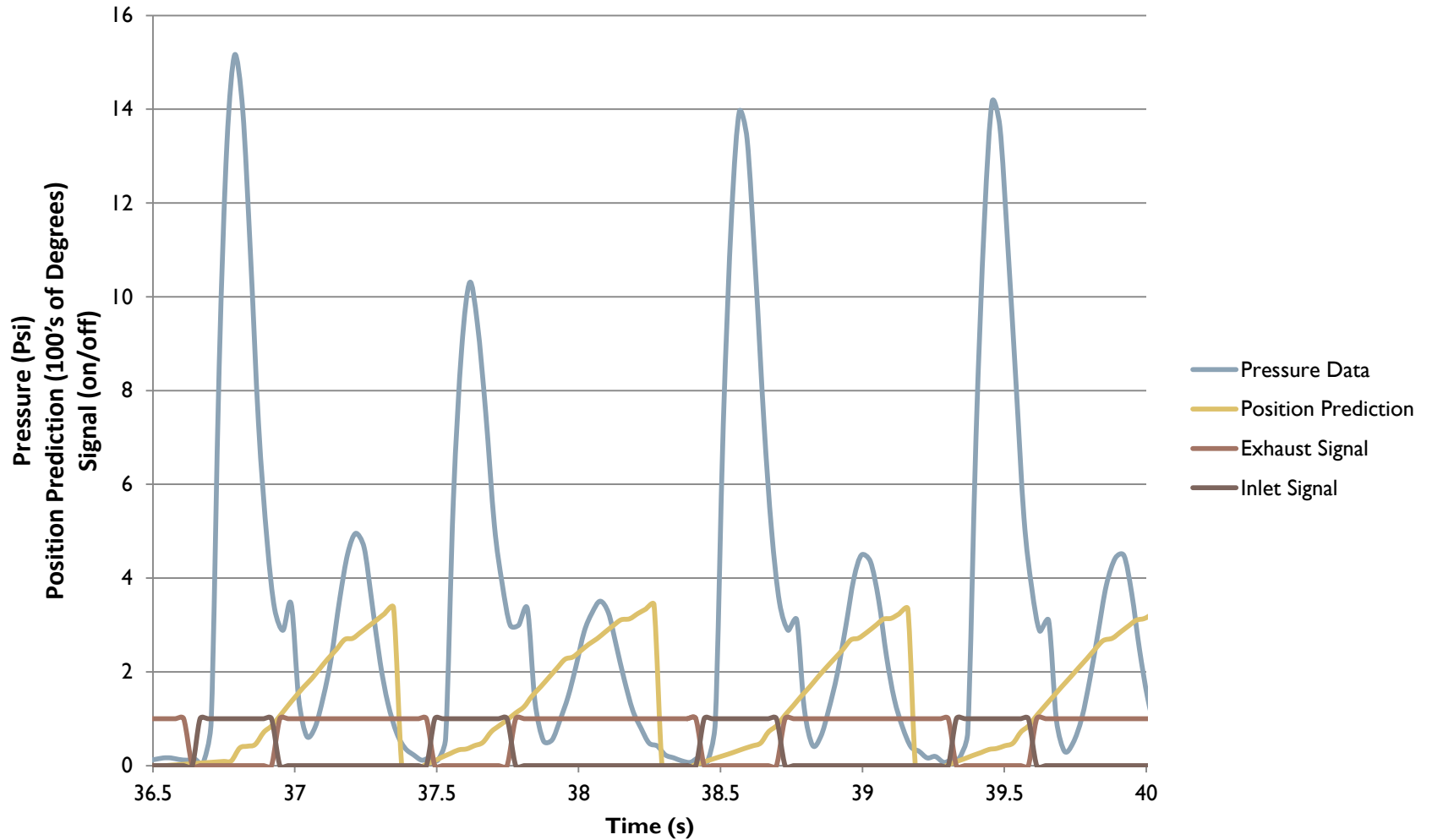
- ▶ User interface allows the user to change the valve timing with a slide valve
- ▶ Changing slide valve would be equivalent to re-machining a cam for a traditional cylinder



Video of Operation



Operation Data (60 RPM)



Preliminary Analysis

- ▶ Peak of 5 Psi on exhaust stroke is a cause for concern
 - ▶ 5 psi = 25lbf working towards stopping the flywheel.
 - ▶ Because in the middle of the return stroke this is applied at 2.5 inch radius (Lots of torque)
- ▶ Regularity of the pressure data suggests position can be determined by transducer reading
 - ▶ Ability to double check position data and add resolution
 - ▶ Application of ANN to learn pressure profile to cylinder position
 - ▶ Use just the transducer for timing.
- ▶ Velocity slows significantly when attempting to return to back dead center
 - ▶ Develop a 2 piston apparatus that is able to have two power strokes per cycle
 - ▶ Extracting energy can only be done during the power stroke because too much resistance will stop cylinder.
 - ▶ More resistance on power stroke will be a better use of supplied pressure





Conclusions

Future Work

- ▶ Improve exhaust characteristics
 - ▶ Valve with higher flow characteristics or the
 - ▶ Inclusion of more valves
- ▶ Design intelligent or optimum controller using the mathematical model and system characterization results
- ▶ Explore the performance improvements gained by applying variable valve timing based upon operating conditions
 - ▶ Torque required
 - ▶ RPM
 - ▶ Inlet pressure
- ▶ Install solenoid valves with position feedback to explore affects of varying valve profiles



Conclusions

- ▶ System is able to effectively simulate a position driven cam system without the mechanical linkages
 - ▶ Vary timing using slide bars in real time to observe performance changes
- ▶ While not able to directly evaluate whether a modern steam engine could be used for power generation and transportation
 - ▶ Good progress was made towards developing an apparatus to test and evaluate vital technologies for a modern steam/compressed air system.
- ▶ The project was great a combination of mechanical design and system testing and analysis.





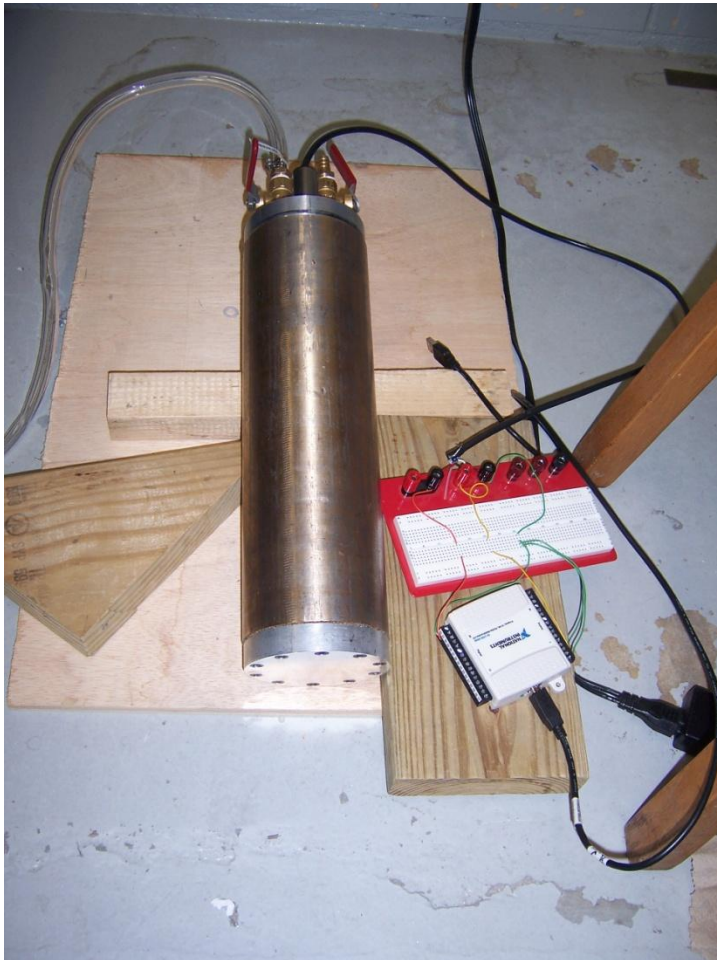
The End

A special thanks to Dr. Knight, Thomas Gallmeyer and John
Goodfellow



Backup Slides

Test Description



▶ Goals:

- ▶ Validate sealing method for end caps
- ▶ Evaluate viability of valves.
- ▶ Measure the pressure vs. time relationship

▶ Procedure

- ▶ Valve was opened to specified position by hand while pressure data was recorded.
- ▶ When filled valve closed
- ▶ Release valve opened and cylinder evacuated



Materials (Cont.)

- ▶ NI USB 6008 DAQ card
- ▶ SSI Technologies Pressure Transducer
- ▶ Shop air at 60 psi



Results Summary

File	Initial Pressure Increase Rate (Psi/s)	Time to Pressurize (s)	Average Pressure Increase Rate (Psi/sec)	Pressure Decrease Rate (Psi/sec)
PVT12-11.100.1	336.51	0.88	62.81	-249.52
PVT12-11.100.2	357.32	0.81	62.88	-271.11
PVT12-11.100.3	414.92	0.85	62.50	-240.17
PVT12-11.60.1	169.75	1.07	51.42	-231.52
PVT12-11.60.2	287.98	0.96	55.56	-146.74
PVT12-11.60.3	265.99	0.87	62.94	-242.25
PVT12-11.30.1	100.18	1.10	48.93	-60.56
PVT12-11.30.2	51.59	1.50	35.66	-42.53
PVT12-11.30.3	116.83	0.90	58.24	-92.63



Conclusion

- ▶ The data suggests that the flow rate into the cylinder was not as fast as was needed.
- ▶ Next Step:
 - ▶ Evaluate if the problem is caused by shop air
 - ▶ Test if smaller cylinder volume will allow faster pressurization
 - ▶ See if alternate valves would provide better pressurization performance

