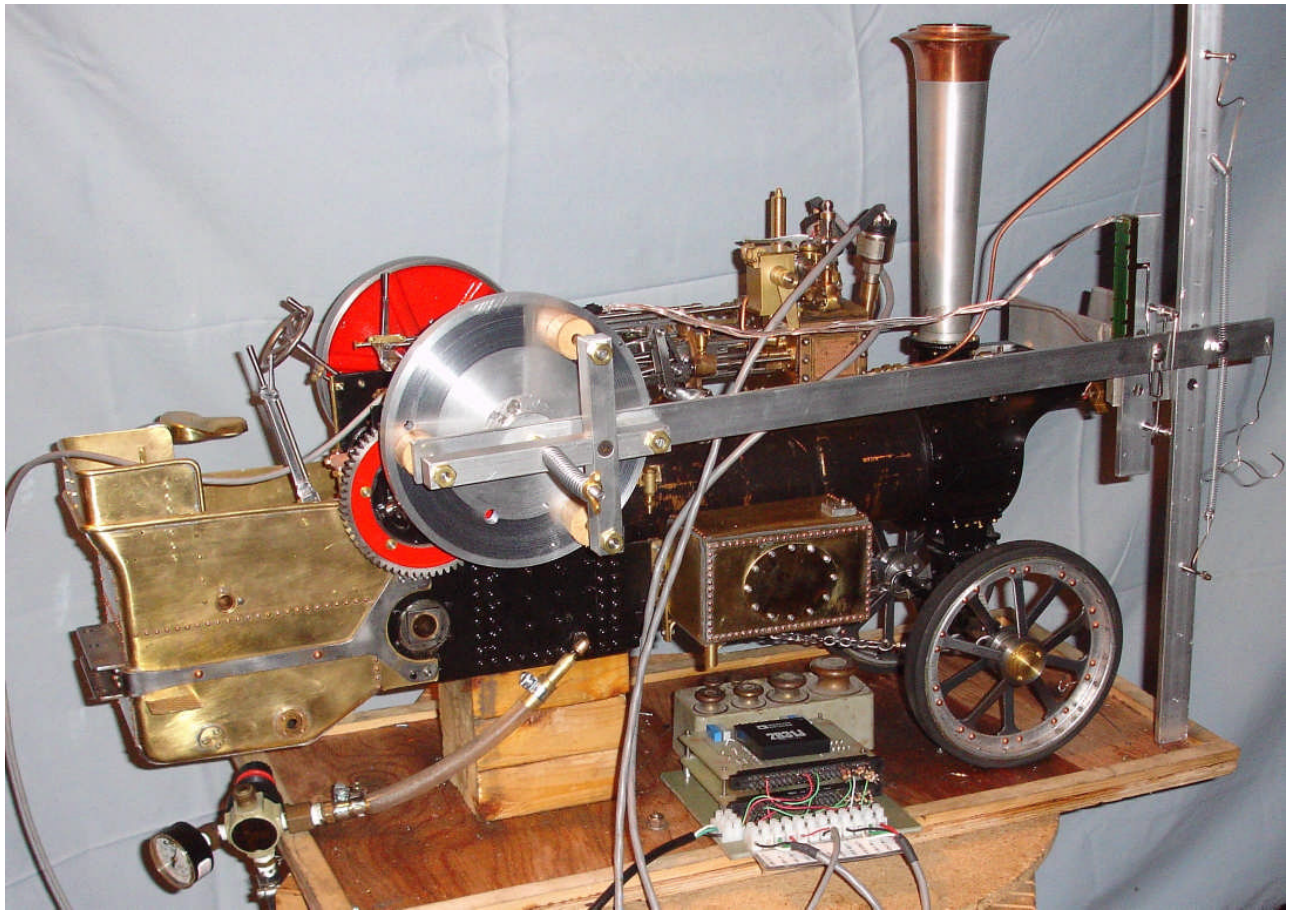
Performance Measurements on a Model Steam Engine

Bruce Murray Winchester MA



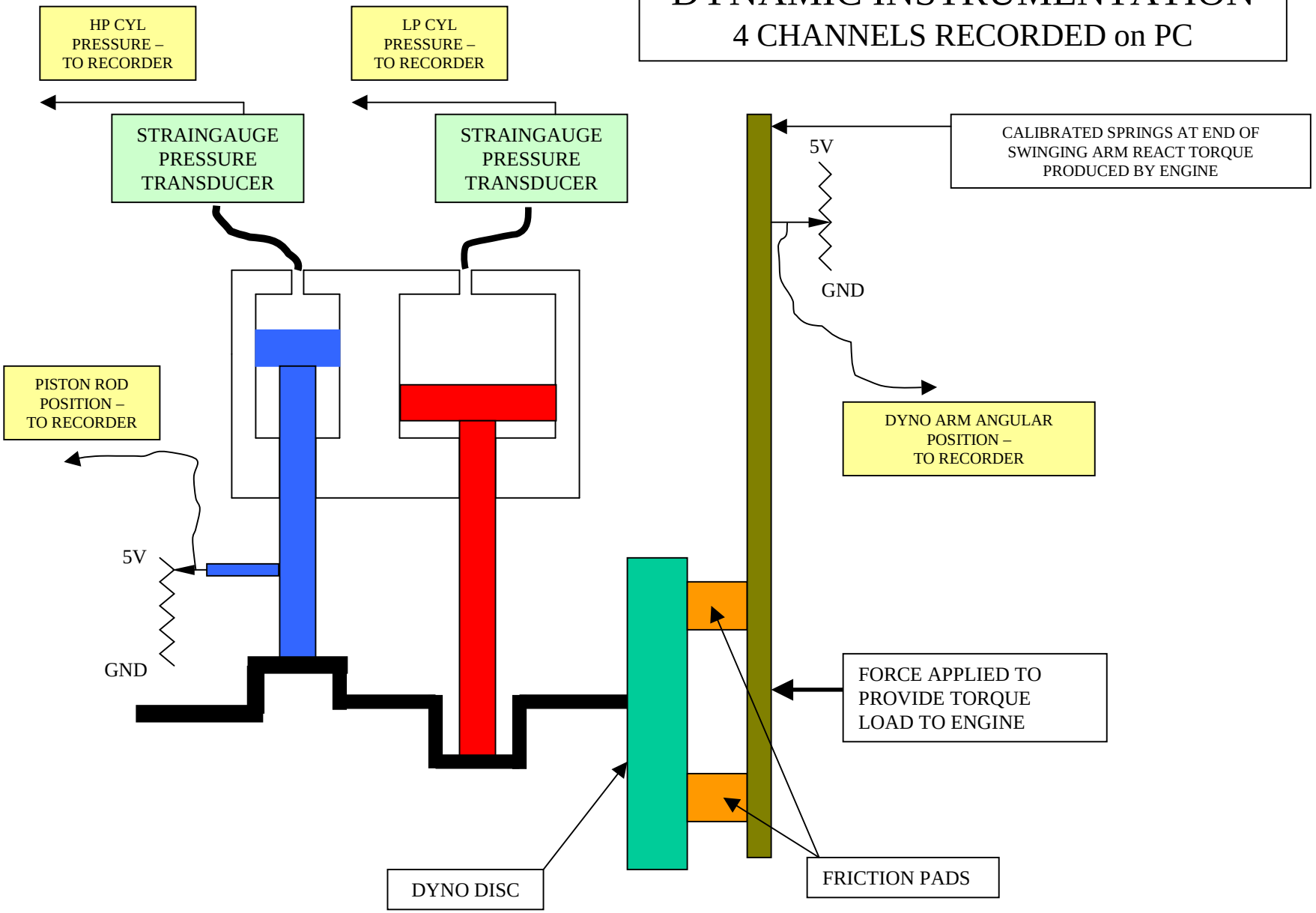
OBJECTIVES

- MEASURE THE BRAKE HORSEPOWER OF THE ENGINE
- LOOK AT THE PRESSURE TRACES IN THE CYLINDERS
- CONSTRUCT INDICATOR DIAGRAMS TO CALCULATE INDICATED HORSEPOWER
- ESTIMATE THE MECHANICAL EFFICIENCY
- MEASURE BOILER FEED PUMP DISPLACEMENT
- CHECK OUT PROPANE GAS BURNER ARRAY
- HAVE FUN

BASIC MEASUREMENT APPARATUS

- Straingauge Pressure Transducers
  - sense the HP & LP cylinder pressures
- Slider Resistances
  - measure the position of the piston rods & the spring loaded dyno arm
- Straingauge Amplifier & Filter
  - conditions the signals for the Data Acquisition System
- Data Acquisition System
  - Four Channel USB Module
    - hooked up to a PC
- Prony Brake Style Dynamometer

DYNAMIC INSTRUMENTATION
4 CHANNELS RECORDED on PC



TYPICAL SCREEN DISPLAY

TORQUE

HP PISTON POSITION

HP CYLINDER PRESSURE

LP CYLINDER PRESSURE

1 SECOND

SIGNAL VOLTAGES (–5<V<+5)

NOTE THAT THESE VOLTAGES MUST BE CONVERTED INTO ENGINEERING UNITS TO BE USEFUL

ENGINEERING UNITS

- Convert voltage readings to physical units

  Multiply voltage readings by calibration factor

Calibrations are given by manufacturers or can be determined before the test

In this test, the torque calibration was done with weights and the piston position cal. was done knowing the stroke.

The pressure sensors had a known sensitivity.

Sensor Selection

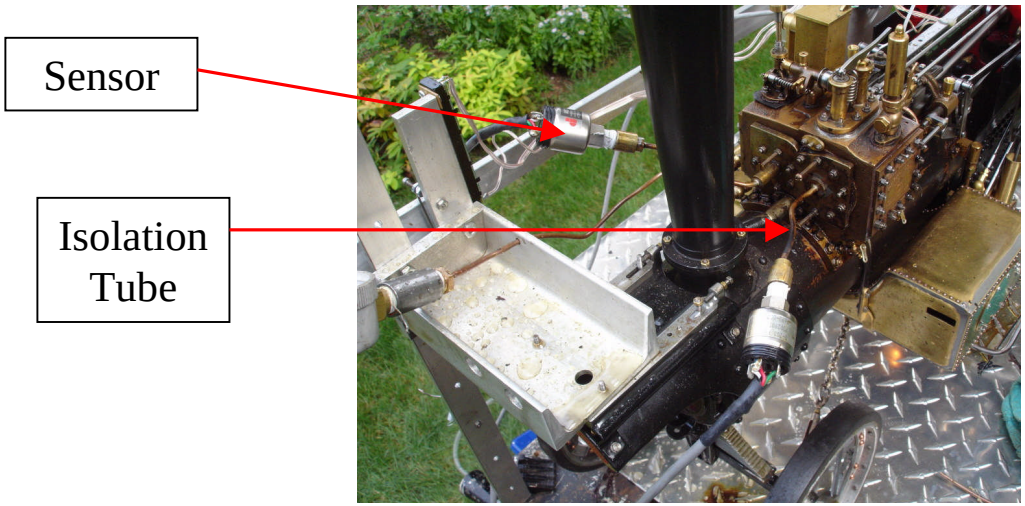
Pressure Sensor

Range, sensitivity, temperature, frequency response
Used a straingauge type diaphragm unit

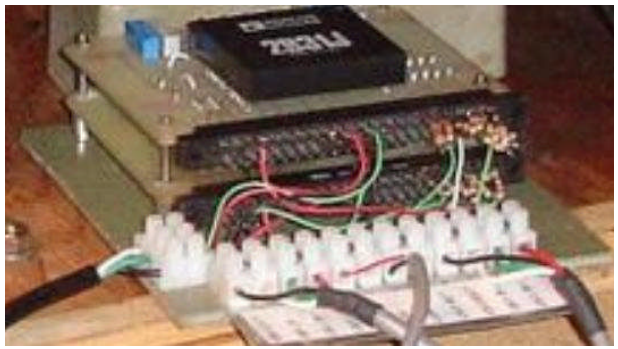
Piston Position & Torque Sensing

Amplitude of motion, frequency response
Used a slider resistor (linear fader)

Pressure Sensor Installation



FOUR CHANNEL DATA ACQUISITION SYSTEM



5V SUPPLY LINE FROM DAQ

PISTON POSITION SENSOR

TORQUE SENSOR

LAPTOP PC WINDOWS XP

USB PORT

+/- 15v SUPPLY

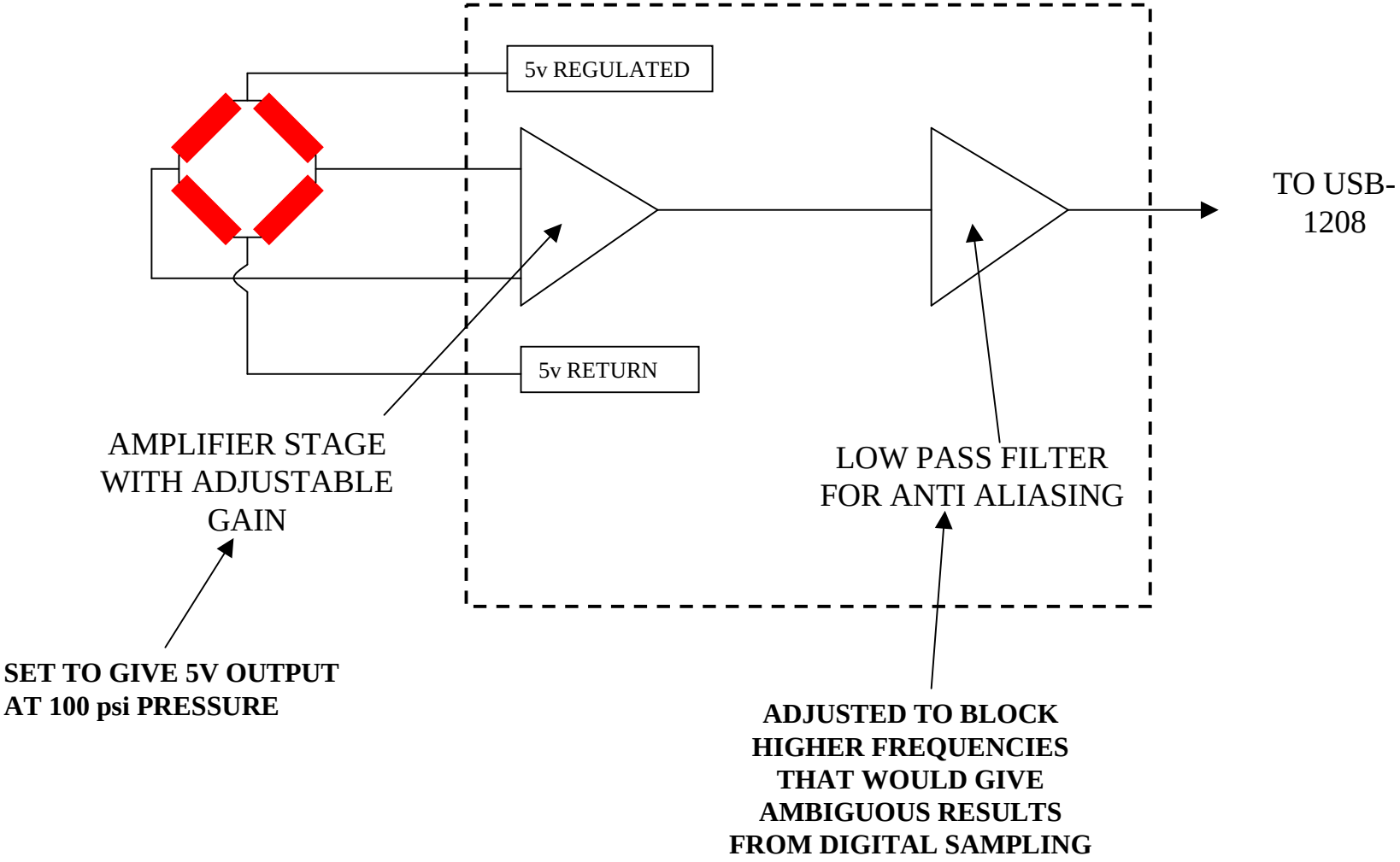
AMPLIFER/ FILTER/ 5V POWER

4 CHANNEL A/D CONVERTER USB-1208

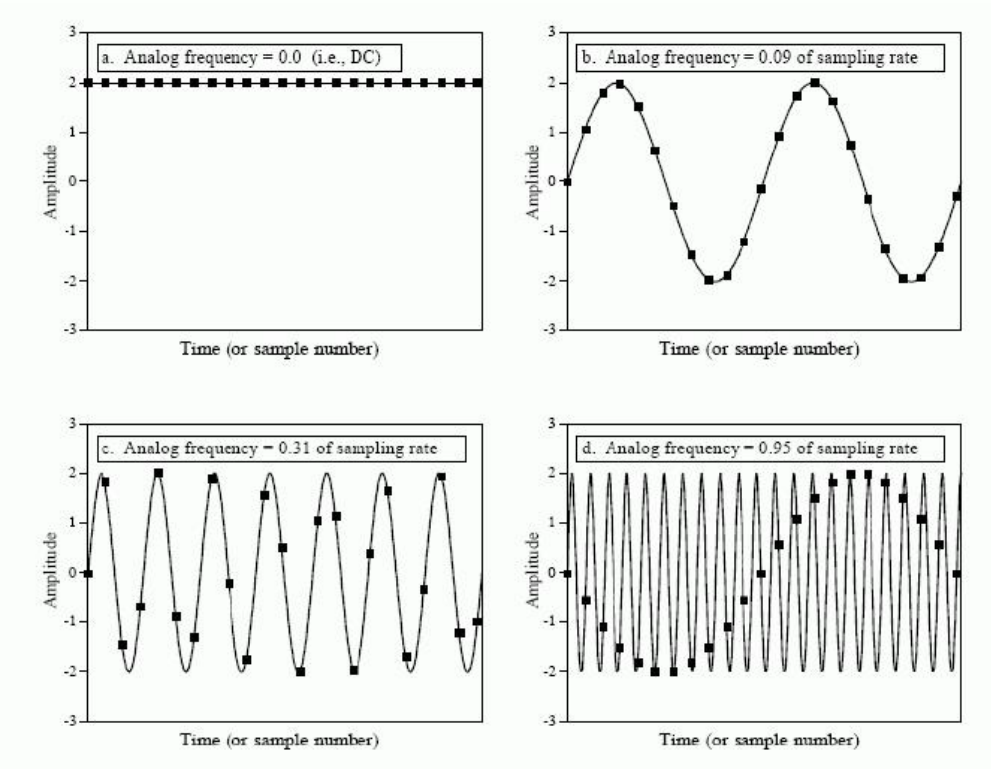
HP PRESS SENSOR

LP PRESS SENSOR

PRESSURE SENSOR SIGNAL CONDITIONING



A FEW WORDS ON DIGITAL SAMPLING



OK

SAMPLES MUST BE TAKEN AT AN ADEQUATE RATE TO CAPTURE THE TIME VARYING SIGNAL.

NOT OK

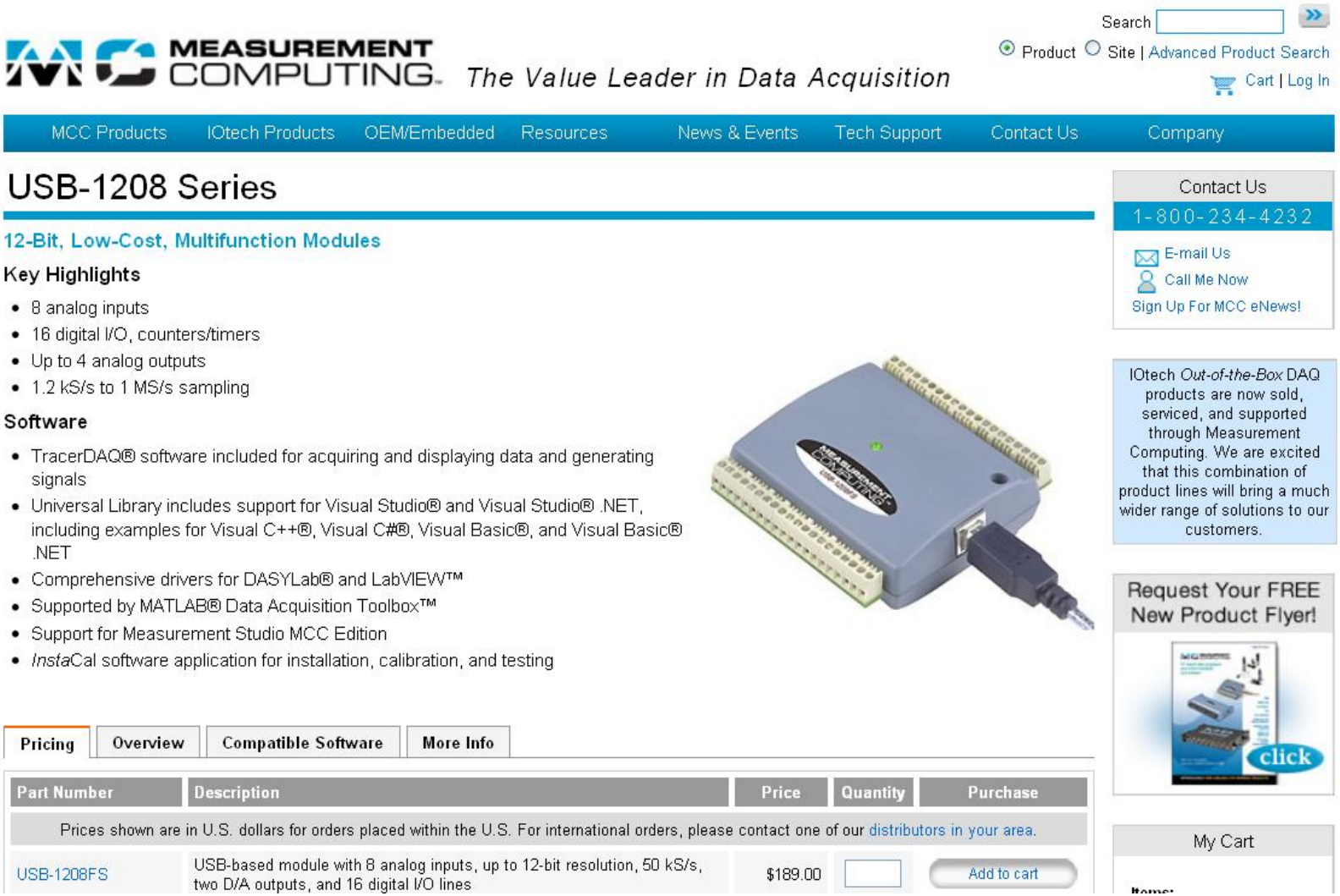
THE HIGHER THE SAMPLING RATE THE BETTER THE FIDELITY AND THE LESS EFFECT FROM UNWANTED SIGNALS

THE LOWER THE SAMPLING RATE THE SMALLER THE FILE SIZE

ANTI-ALIASING FILTERS PREVENT UNWANTED SIGNALS WITHOUT THE NEED TO USE HIGH SAMPLING RATES

THEORETICAL MINIMUM SAMPLE RATE IS SLIGHTLY MORE THAN 2X HIGHEST FREQUENCY OF INTEREST

THIS TEST USED ABOUT 40 SAMPLES PER REV (500/SEC) AND LP FILTERED AT 125Hz 2 POLE LP



Tech support contact information:
Email: info@mccdaq.com
Phone: 508-946-5100 and follow the instructions for reaching Tech Support.
Fax: 508-946-9500 to the attention of Tech Support
Users forum: http://forums.mccdaq.com

BASIC DIGITAL TEST PROCESS

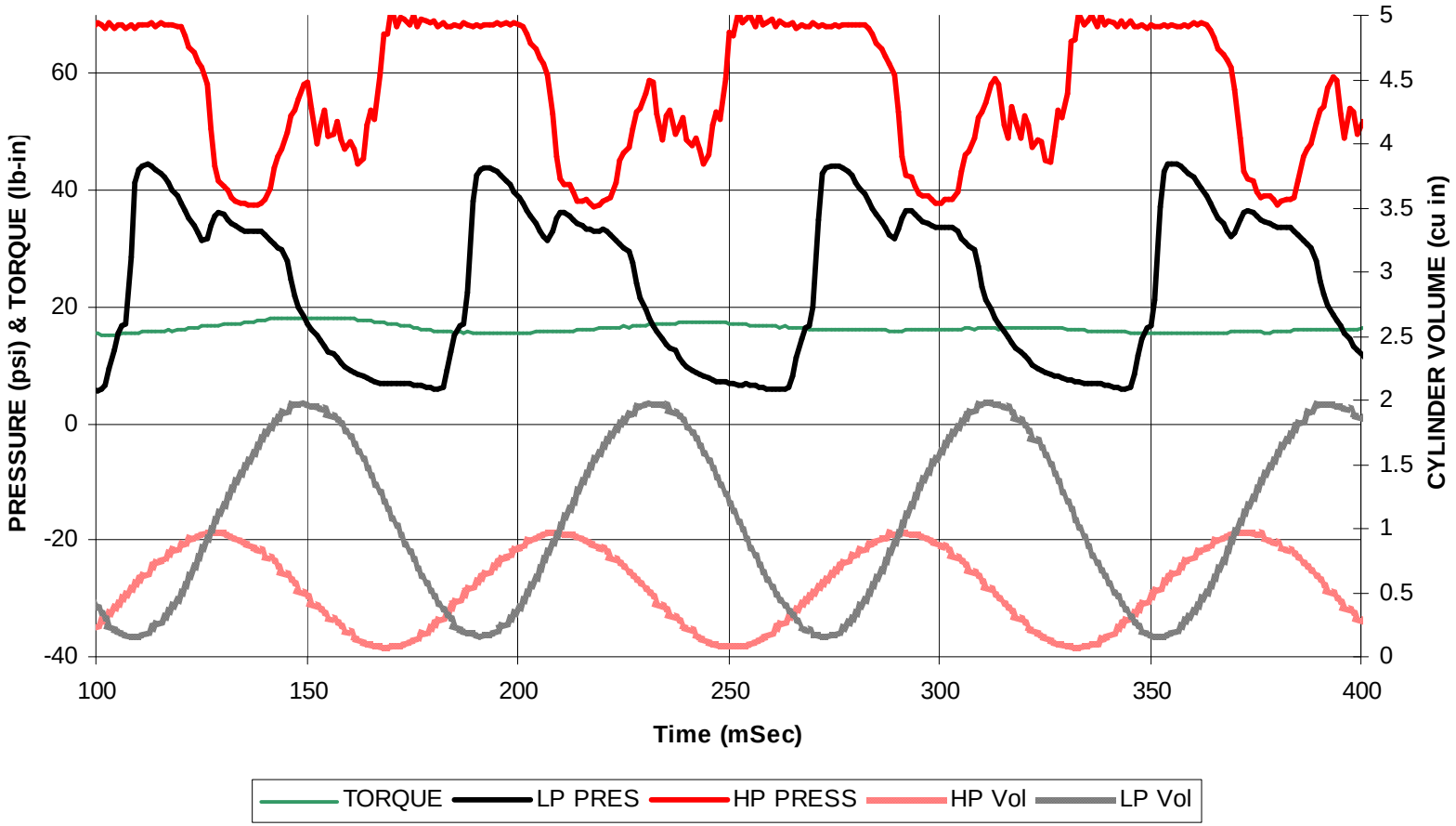
AFTER PROGRAM INSTALLATION

1. HOOK UP SIGNAL LEADS
2. SELECT INPUT DEVICES & VOLTAGE RANGES ON EACH CHANNEL
3. SELECT STRIP CHART RECORDING OPTION
4. ADJUST A/D SENSITIVITIES (+/- 5V IN THIS TEST)
5. SET SAMPLING RATE
6. SET TIME BASE
7. START RECORDING
8. SAVE DATA & EXPORT TO EXCEL AS *.csv
9. IN EXCEL APPLY CALIBRATION FACTORS, SORT DATA, PLOT GRAPHS

STEAMING TEST RUN

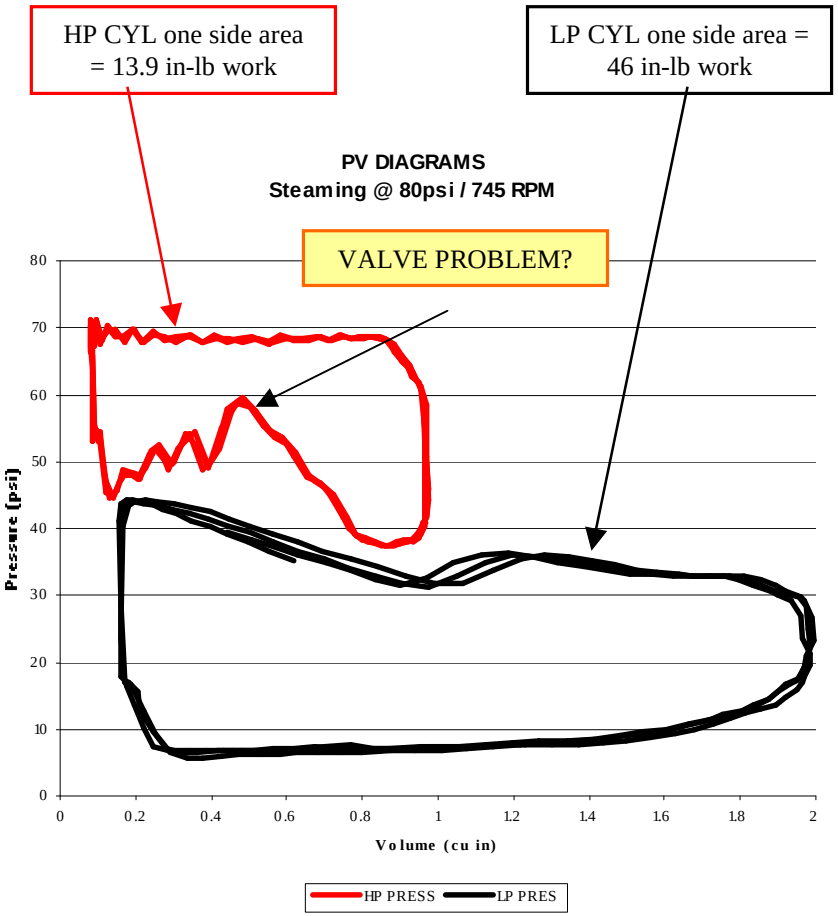
STEAMING TEST

STEAMING @ C.80psi BOILER PRESSURE
BENCH RUN Sept 8 2009
745 RPM ~ 16.4 lb in = 0.2HP



TIME TRACES EXPRESSED IN ENGINEERING UNITS

PRESSURE-VOLUME DIAGRAMS
AVERAGED OVER 10 CYCLES



1HP = 33000 ft.lb/min

Indicated HP = rate of work in the cylinders

Brake HP = rate of work at the output shaft

Efficiency = BHP/IHP

$$\mathbf{HP} := \frac{2 \cdot \pi \cdot \mathbf{N} \cdot \mathbf{T}}{33000}$$

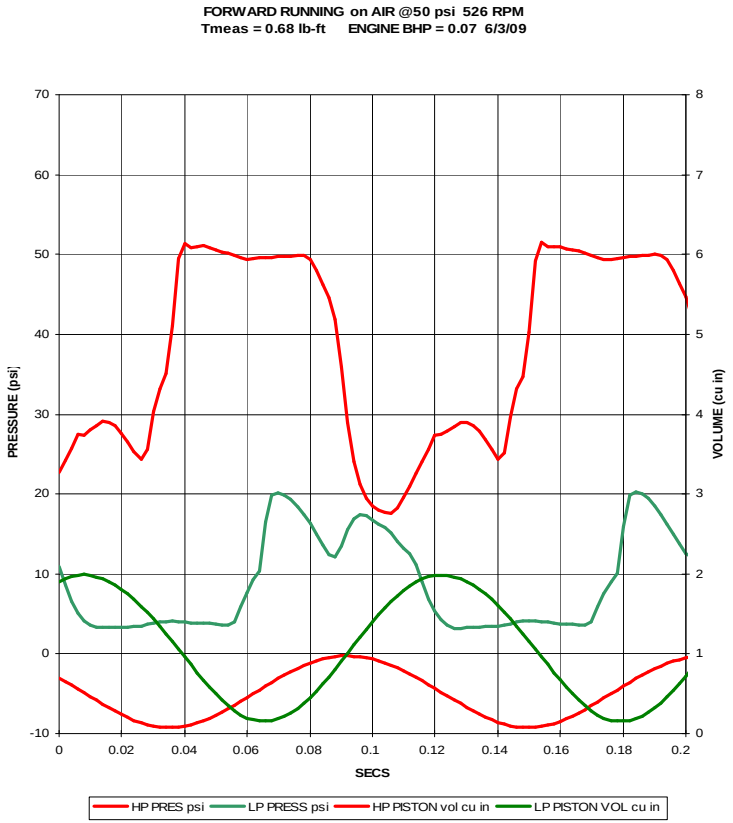
$\mathbf{HPcyl} := 13.9$ $\mathbf{LPcyl} := 46$ $\mathbf{RPM} := 746$

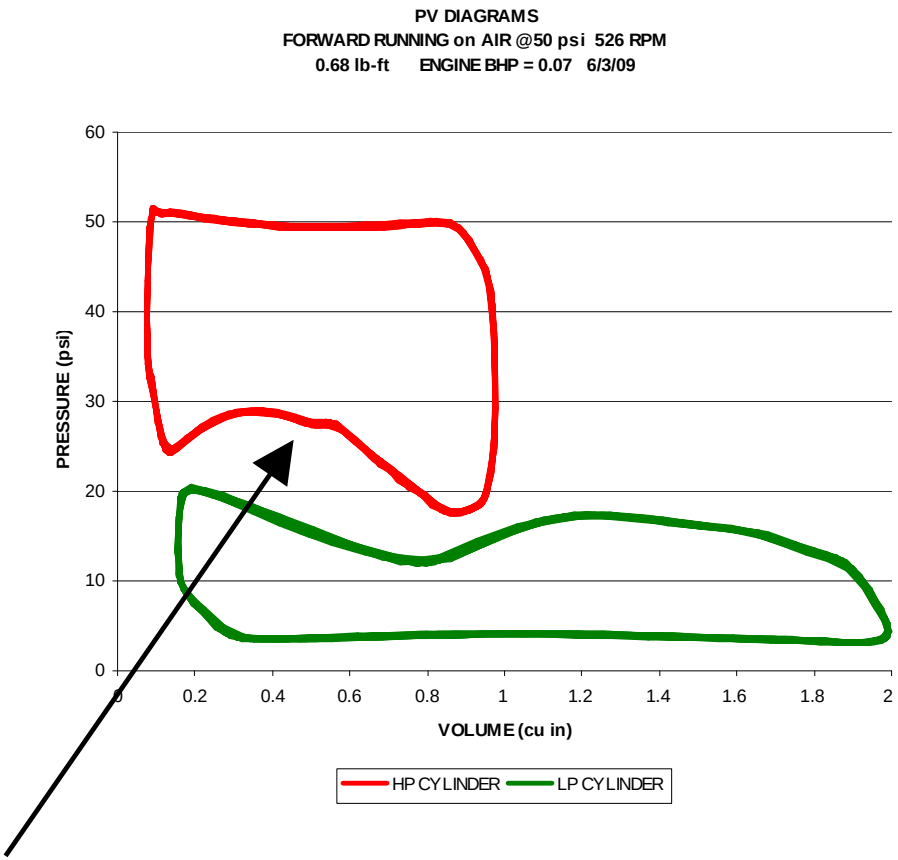
$$\mathbf{IHP} := \frac{(1.94 \cdot \mathbf{HPcyl} + 1.97 \cdot \mathbf{LPcyl}) \cdot \mathbf{RPM}}{33000 \cdot 12} \qquad \mathbf{IHP} = 0.222$$

$$\mathbf{BHP} := \frac{2 \cdot \pi \cdot 746 \cdot 16.4}{33000 \cdot 12} \qquad \mathbf{BHP} = 0.194$$

Mech effy $\mu := \frac{\mathbf{BHP}}{\mathbf{IHP}}$ $\mu = 88 \cdot \%$

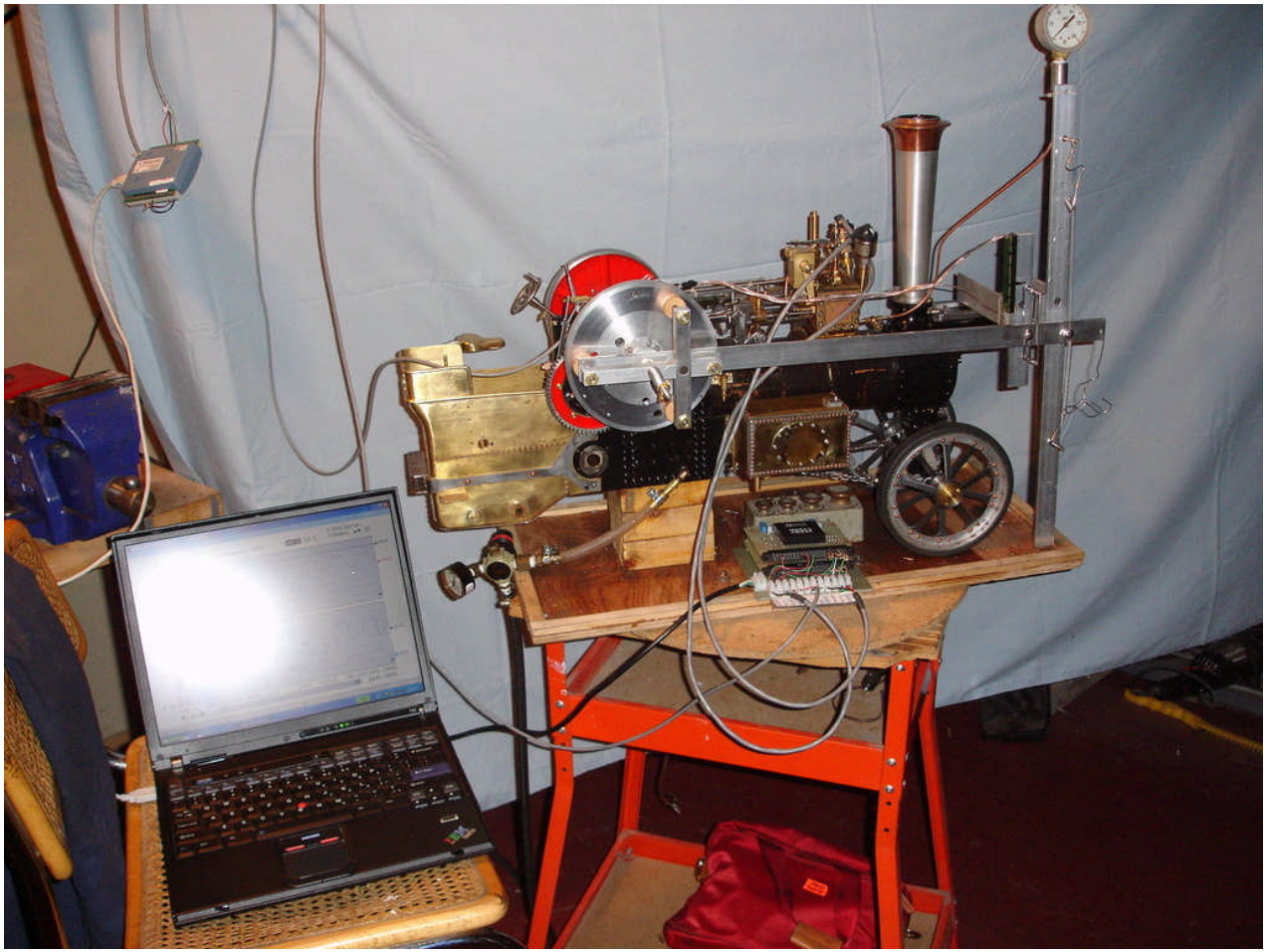
AIR TEST RUN



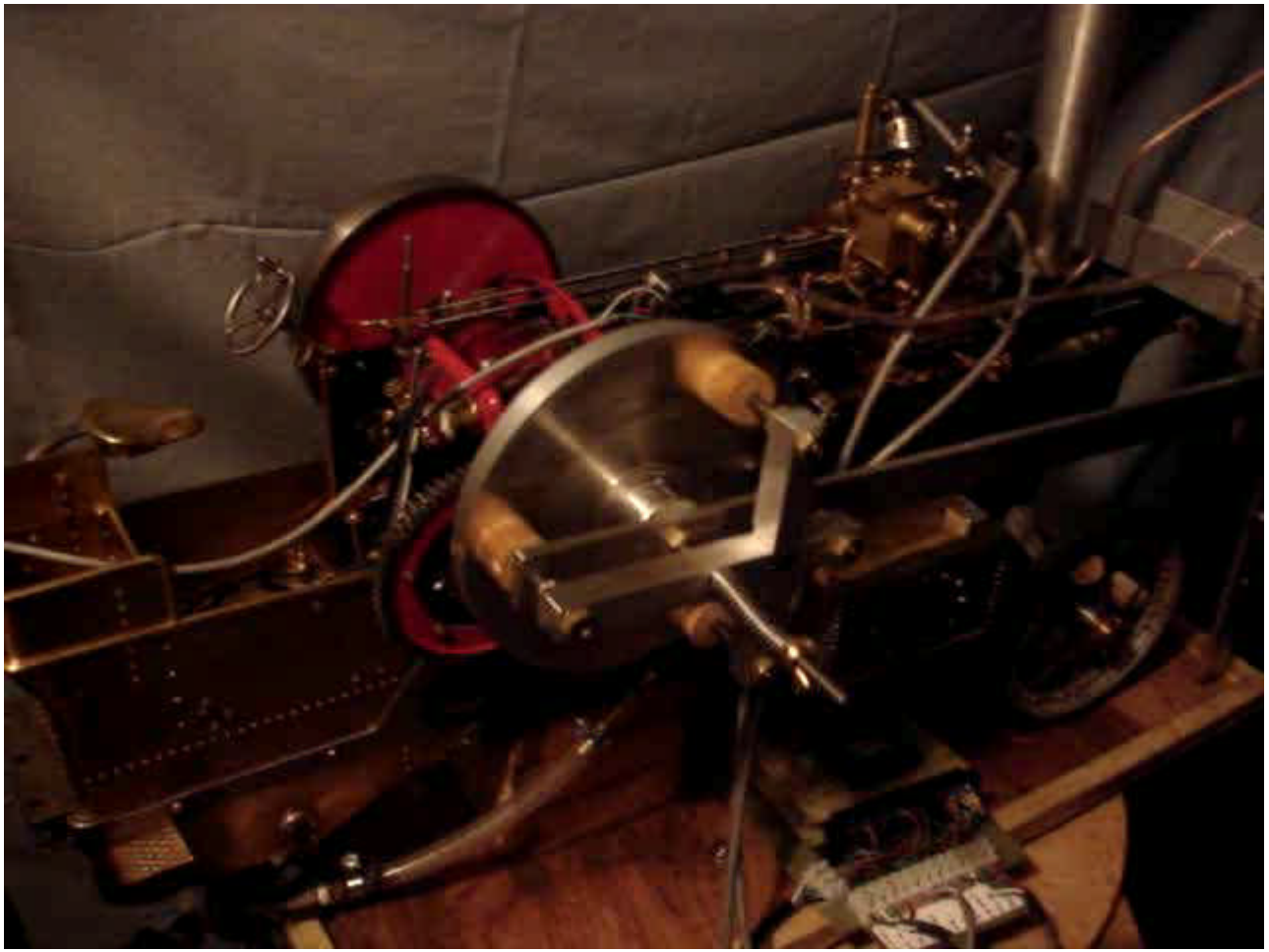


SIMILAR BEHAVIOR TO STEAMING TEST –
EXCEPT NOT SO SEVERE`
POSSIBLY DUE TO SLIDE VALVE LEAKAGE AT MID STROKE

AIR TEST ARRANGEMENT



AIR TEST RUNNING



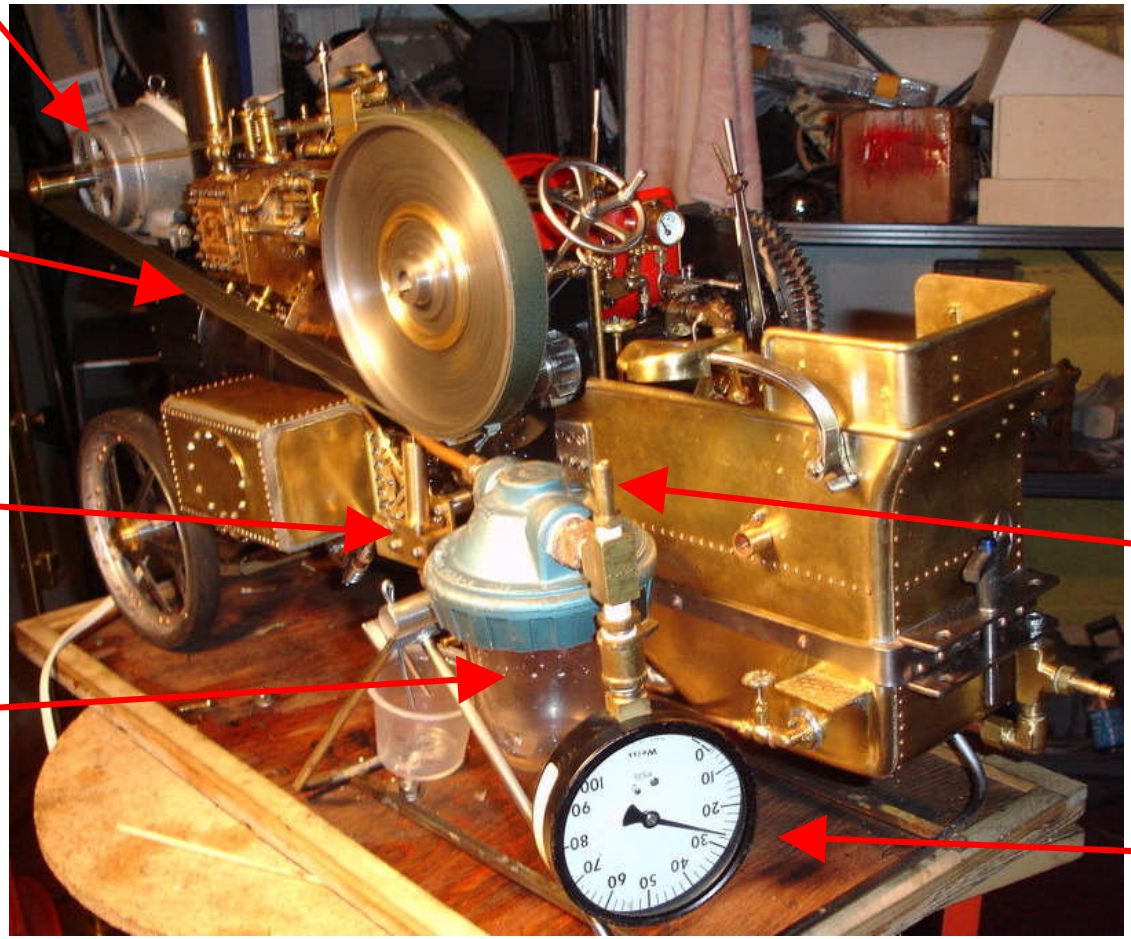
BOILER FEED PUMP TESTING

DC MOTOR

BELT

FEED PUMP

AIR LINE FILTER HOUSING used as DELIVERY CONTAINER

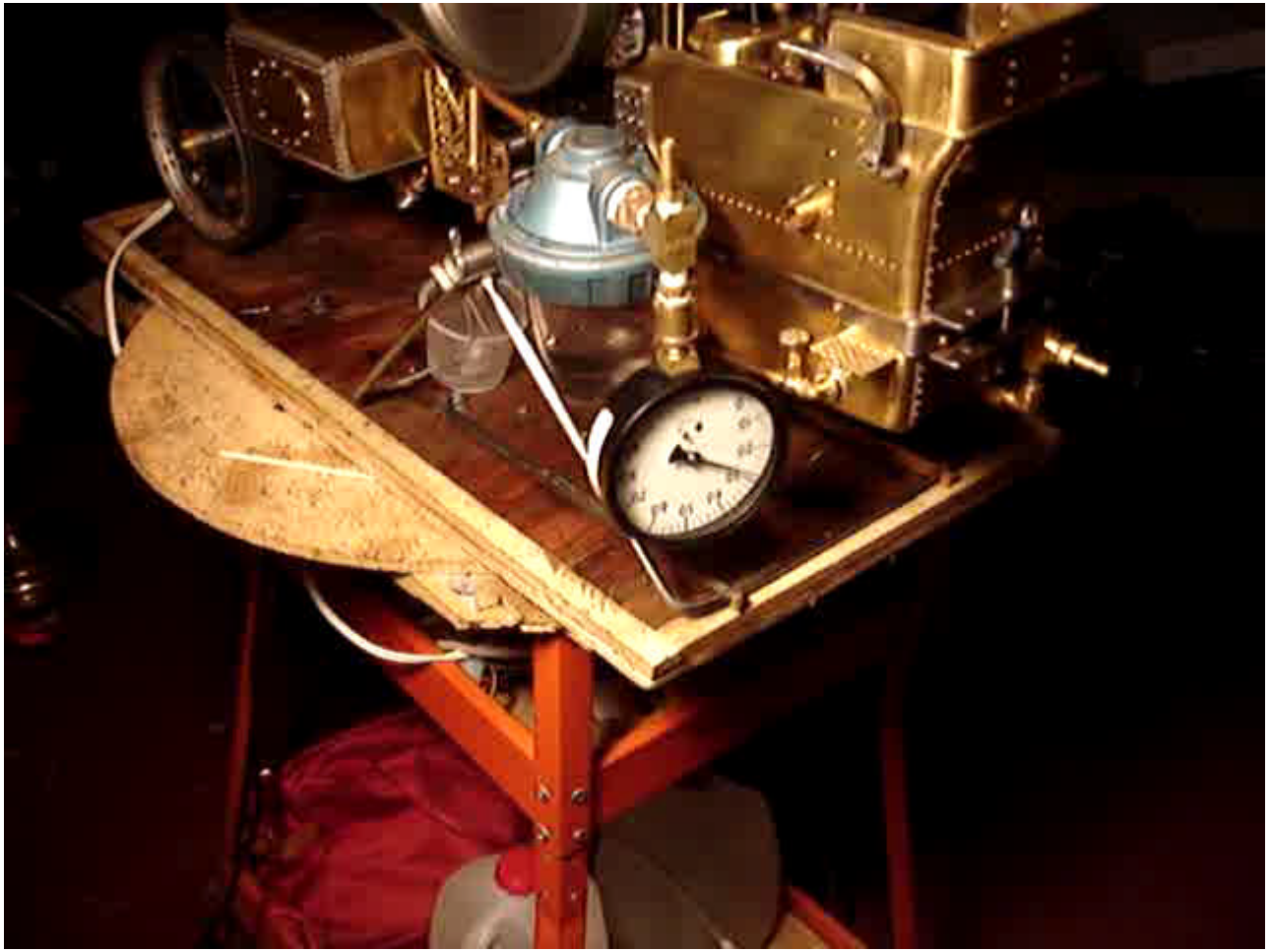


DELIVERY MEASUREMENT

TYRE VALVE for SETTING BACK PRESSURE

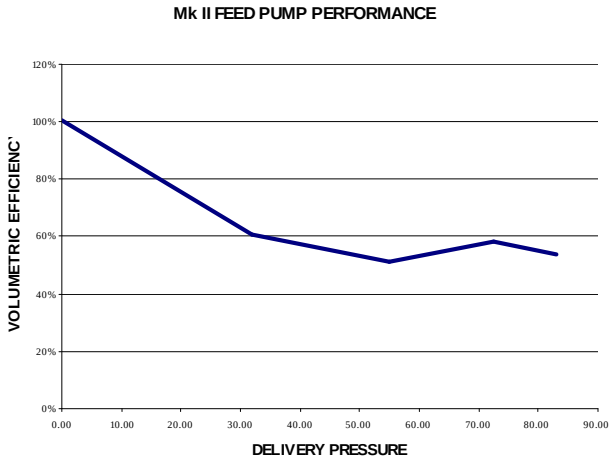
BACK PRESSURE GAUGE

FEED PUMP MOVIE



FEED PUMP TEST LOG & RESULTS

Bore	0.58					
Stroke	0.44					
Strokes per crank rev	0.44					
Crank rev per belt rot	2.40					
Volume displacement for 60 belt revs	**7.39**	**cu ins**				
Density of water	0.58	oz/cu in				
Container Tare wt (oz)	7.60					
Water delivery for 60 belt turns						
Pressure at Run Start	0	29	50	66	78	
Pressure at Run End	0	35	60	79	88	
Average pressure (psig)	**0**	**32**	**55**	**73**	**83**	
Gross Wt container (oz)	11.90	10.20	9.80	10.10	9.90	
Net wt of water (oz)	4.30	2.60	2.20	2.50	2.30	
Vol of water (cu in)	7.43	4.49	3.80	4.32	3.97	
Volumetric Efficiency %	101%	61%	51%	58%	54%	



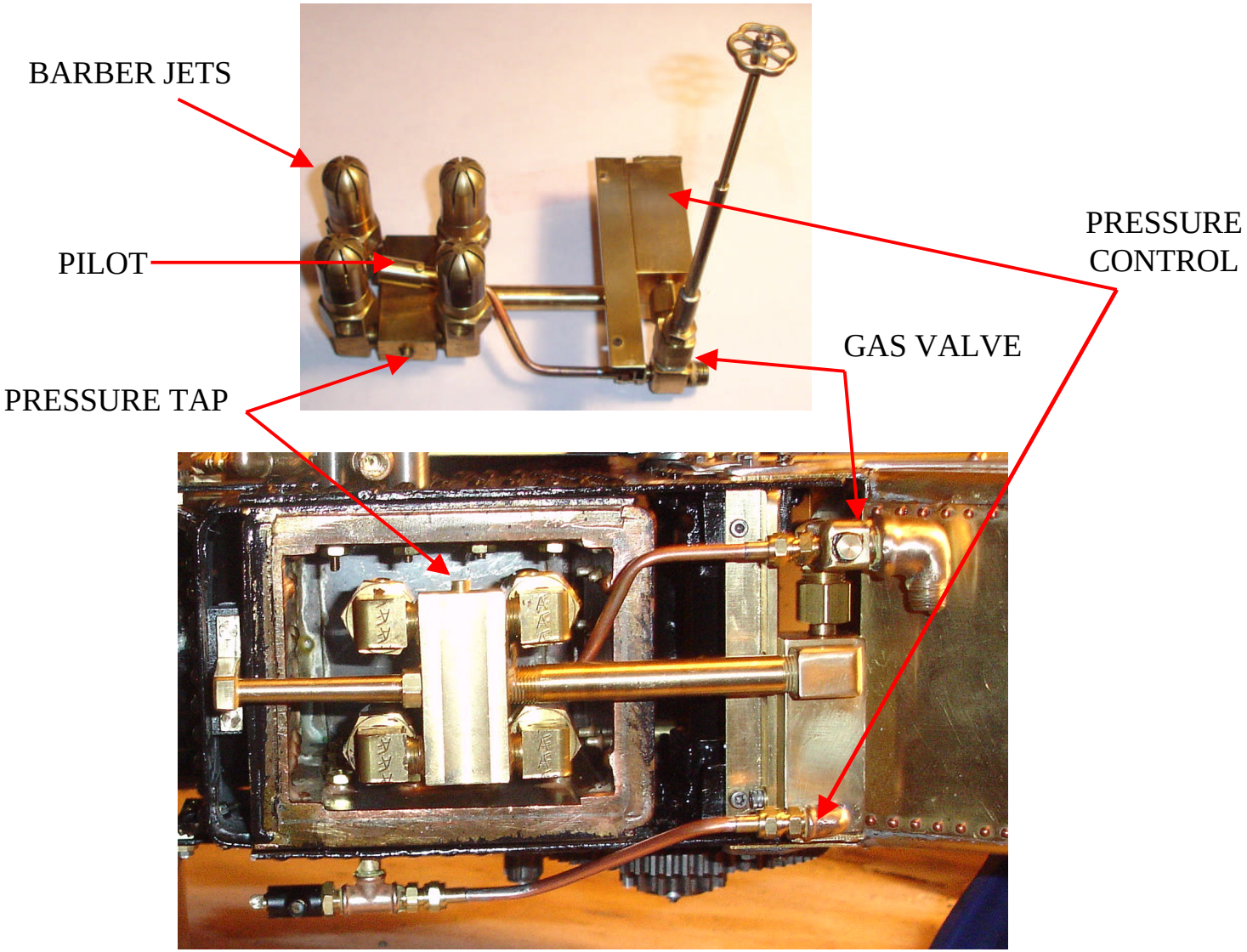
VOLUMETRIC EFFICIENCY is RATIO BETWEEN ACTUAL DISPLACEMENT and the SWEPT VOLUME of PUMP

AS BACK PRESSURE RISES, SYSTEM ELASTICITY & CHECK VALVES CAN CAUSE FLOW TO DECREASE

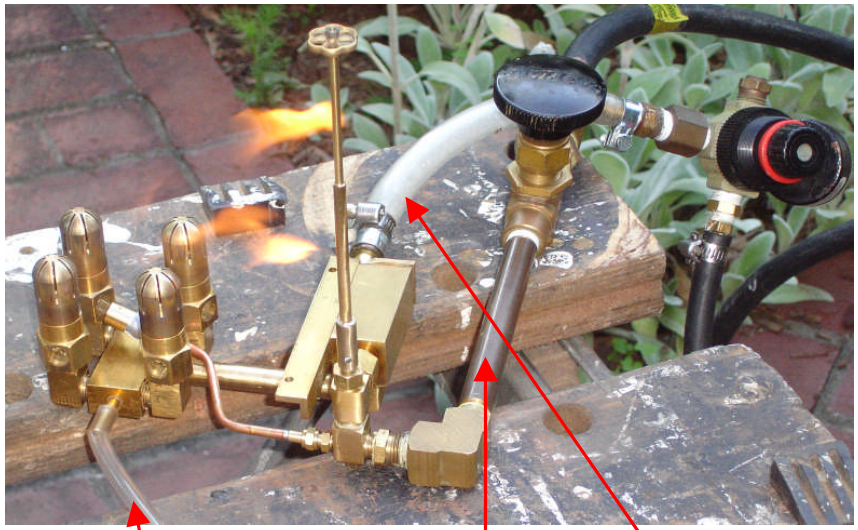
TEST CONDUCTED WITH COLD WATER so NOT ENTIRELY REPRESENTATIVE OF ACTUAL CONDITIONS

GAS BURNER

20,000 BThU/hr @ 11.5”W.C.



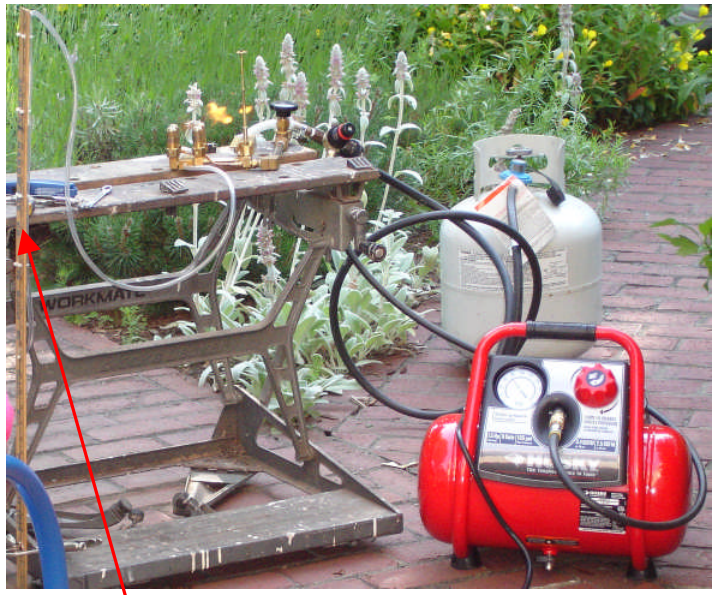
GAS BURNER CHECKOUT



PIPE to U TUBE MANOMETER

MAIN GAS LINE

"BOILER" PRESSURE LINE



U TUBE MANOMETER

COMPRESSOR to SIMULATE BOILER PRESSURE

TESTS WERE DONE

1) TO ENSURE THE PRESSURE CONTROL REDUCED THE GAS PRESSURE ABOVE 80 PSI BOILER PRESSURE

2) TO MAKE SURE PILOT WORKED

3) CHECK GAS VALVE OPERATION

First steaming run

WHAT DOES ALL THIS GOOD STUFF COST?

- USB DIGITAL DATA ACQUISITION MODULE
  - Depends on no. of channels, sampling rate, gain settings. $200 for this one. Others can be had starting at about $100
- PRESSURE SENSORS
  - Factory new c.$200 These were new from E Bay at $15 ea.
  - If you use a high output sensor (5V) then an amplifier would not be needed.
  - High output sensors can be had for $250 new
- LINEAR RESISTORS
  - Good quality low noise long life - $15 ea
- 2 ch STRAINGAUGE SIGNAL CONDITIONING SYSTEM
  - Can be built up from individual IC's for about $50. Otherwise about $200/channel new
- +/- 15V DC SUPPLY
  - $50

Omega Engineering is a good supplier of new instrumentation
www.omega.com

THE ULTIMATE TEST