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ME-446
SENIOR MECHANICAL ENGINEERING LAB

ENGINE GROUP

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ABSTRACT

At the beginning of this quarter we ~~were given~~ volunteered to work on a small, three cylinder Thermo King diesel engine and a Stuska model 90 dynamometer. The main purpose of this experiment was to: A) mount the engine, dyno, attach all necessary coolant lines and connect all the gauges available for the equipment we were provided with. B) Make any repairs that the engine required in order to run. C) Install a pressure transducer in one cylinder and a crank angle indicator on the crankshaft to correlate cylinder pressure with crank position.

DESCRIPTION OF TEST APPARATUS

~~Over the course of the quarter a great deal of time and energy was spent fabricating our test apparatus.~~ A sketch of the apparatus including engine, engine stand dynamometer, cooling tower and instrument panel has been included in appendix A, see fig. 1.

An itemized list of the activities and duties of each group member has also been included in appendix B. Following this generalized duty roster is a more detailed description of the duties that each member performed, these detailed descriptions were written by each member and submitted to me.

Once the engine was in working order, we went to work mounting the crank angle sensor and installing the pressure tap in the auxiliary cylinder head.

Due to the limited life span of the crank angle sensor, it was desired to make this piece of equipment removable. This was accomplished using a modification of a lovejoy type connector which attaches the sensor to the crank and a dovetail/set-screw joint that attaches the sensor to the engine frame. The lovejoy type connection can only fit together one way, this is calibrated with the top dead center position of piston number one. Thus, any time the sensor is removed from its dovetail, the correlation between crank angle and crank angle sensor is not lost. Figure 2 in appendix A gives an exploded view of this junction between the sensor, crankshaft and engine frame.

At the same time that the crank angle indicator installation was taking place, the auxiliary cylinder head was being drilled and tapped to accept the pressure transducer. The first step of this procedure was to determine the maximum length that the tube into the cylinder could be without affecting the data acquired, ie. the tube could not be so long that its inherent damping characteristics filtered out valuable information. Another design criteria of the pressure tap tube was to limit its volume. The volume of this tube would be added to the clearance volume of the cylinder. We set out to design a tube that would not increase the clearance volume of the cylinder by more than five percent. Assuming a tube diameter of .218", this maximum length was calculated to be 1.5 inches, See fig. 3. Upon drilling the pilot hole through the head, it was discovered that avoiding the water jacket would be impossible, therefore a steel sleeve was turned on the lathe and press fit into the cylinder head.

good

Calculations were made to verify that the press fit would hold under operating conditions, see fig. 3A in appendix A. Although requiring more work to install, the sleeve running through the water jacket does prove advantageous. The engine coolant will help cool the pressure transducer and maintain it at a constant temperature, this may provide more linearity in the measurements that it produces. The location of the pressure tap in the cylinder and a cross section of the transducer sleeve has been included in appendix A, see fig. 4.

EXPERIMENTAL PROCEDURE

It was desired to trace pressure vs. crank angle on the oscilloscope, with pressure on the vertical axis and crank angle on the horizontal.

The pressure transducer produces a charge signal, in pico Coulombs. This signal must first be converted into a voltage signal to be used as an input for the scope. The pressure transducer came equipped with a charge amplifier specifically for this purpose. It was desired to achieve approximately 100 psi/volt as an output signal from the charge amplifier. Therefore the "XDCR-SENS" adjustment was set to 1.13 pC/psi (as stated in the calibration data provided with the pressure transducer, see figs. 5 and 5A in appendix C) and the range switch was set at 100 psi/volt. The output signal was then sent to the oscilloscope where the sensitivity was set to 1 volt/div. The resulting pressure measurements could then be read directly from the scope where each vertical division on the screen represented a pressure of 100 psi.

The crank angle sensor is essentially a potentiometer with built in logic. The connection procedure for the crank angle indicator is as follows, a photo-copy of the specification sheet obtained from Novo Tehcnik has been included, see fig 6 in appendix C. To activate the internal op-amps in the sensor's circuitry, leads 4, and 6 are connected to +15V, while lead 5 is connected to -15V. A +5 volt reference voltage is applied to lead 3, and lead 1 is tied to ground on the oscilloscope. Leads 3 and 5 are then used as input signals o-scope. The voltage output observed at the reference leads is a linear ramp that ranges from 0 to 5 volts over the 360° rotation of the sensor's shaft. It should be noted that 0 volts represents bottom dead center and 2.5 volts represents top dead center of the reference cylinder. The scope uses this voltage ramp to sweep the horizontal axis on the view screen.

RESULTS

Since the scope output is a voltage vs. voltage plot, and we were unable to locate an oscilloscope that was capable of saving such a trace, we took photographs of the output just as we viewed it on the screen, see fig. 7, appendix D.

As mentioned earlier, the output from the oscilloscope can be interpreted as 100 psi/vertical division. All of the traces that were observed from this engine produced maximum pressures of less that 800 psi. Traces A, B, and C all have a jagged edge on the downward side of the curve. The point where the trace changes from a smooth line to a jagged line is the instant where the fuel is injected into the cylinder, and the cylinder fires. Note that trace D does not have a jagged edge as the pressure declines, this would indicate that the cylinder did not fire on this cycle, this will be referred to as a motored cycle. Interestingly, the maximum pressure on the motored cycle is not lower than on the traces where the cylinder did fire, in fact it registers a slightly higher pressure. What this would seem to indicate is that this engine is severely tuned down and/or running under a no-load situation. Actually both are true in this instance. This engine is probably downtuned because it was not designed for performance, rather, its power output was sacrificed for reliability and longevity.

Initially, the observed pressures seemed low, however, upon further research, maximum pressures in the 700 to 800 psi range do appear feasible. Figure 8 in appendix D shows a typical compression ignition engine cycle similar to the data that our engine produced (this data was found in figure 1-15, page 28 of Internal Combustion Engine Fundamentals by John B. Heywood). However the pressures reach approximately 2800 psi. This is somewhat deceiving, the small dotted line that is circled in the diagram is a trace from the very same engine on a motored cycle. Note that the pressure registers approximately 850 psi, almost identical to our data. The main difference between Heywood's data and ours is that the engine used in his experiment is either loaded down much more than ours, or is tuned to produce much more horsepower per unit of engine displacement.

Due to lack of time we were unable to obtain more data and make observations. It is quite possible that the cylinder pressures would increase if the engine loading and the throttle were both increased. When the engine is more heavily loaded, naturally the horsepower output is greater, this increase in horsepower must be viewed on the scope traces as an increase in the area under any one particular trace. If the pressures do not increase, the increased area would come from a "widening" of the trace. Here the combustion gasses would be allowed to expand at a more constant pressure, thus "widening" the shape of the trace and creating more area under the curve. Since the area under the curve is a representation of the energy dissipated by that particular cycle, the trace widening translates directly into a greater amount of energy dissipated per cycle.

There is much more that can be learned from these pressure vs. crank position traces. For instance, the work performed by each cycle can be determined by integrating over one 360° cycle. This information can in turn be used in conjunction with the dynamometer readings and a knowledge of the engine speed to determine the losses that the engine experiences per revolution. In addition, the diesel fuel's potential energy can be plotted against the engine's mechanical energy output to determine the ultimate efficiency of the engine.

SUGGESTIONS

Although this was an extremely interesting project, it would have been better suited for a two credit class had the engine and dyno already been mounted and were in working order. As it stood, we spent the vast majority of the quarter engineering and building the test set up rather than acquiring and analyzing test data. Even though a great deal was learned, there remains a large amount undone simply due to lack of time.

There still remains a number of problems with the engine that should be addressed before this piece of equipment is used in extensive laboratory testing.

First and foremost there should be a pressure release valve installed on the cooling tower. The line that supplies water from the tap has a tendency to overpressurize the coolant system and blow the coolant hoses off of their connections. In addition to the pressure release valve, the thermostat valve on the cooling tower should be replaced or repaired, currently it does not open properly. In addition, high temperature coolant lines should be installed to prevent hose blowout.

An instruction manual should be written, or at the very least be comprised of all information available regarding the engine, cooling tower, dyno and all gauges associated with these pieces of equipment.

A more appropriate throttle linkage would make regulating engine speed easier, possibly a lever type linkage. Along with the throttle linkage, a fuel pump would be helpful. Currently a gravity feed system is employed, this works, but a fuel pump would perform better.

APPENDIX A

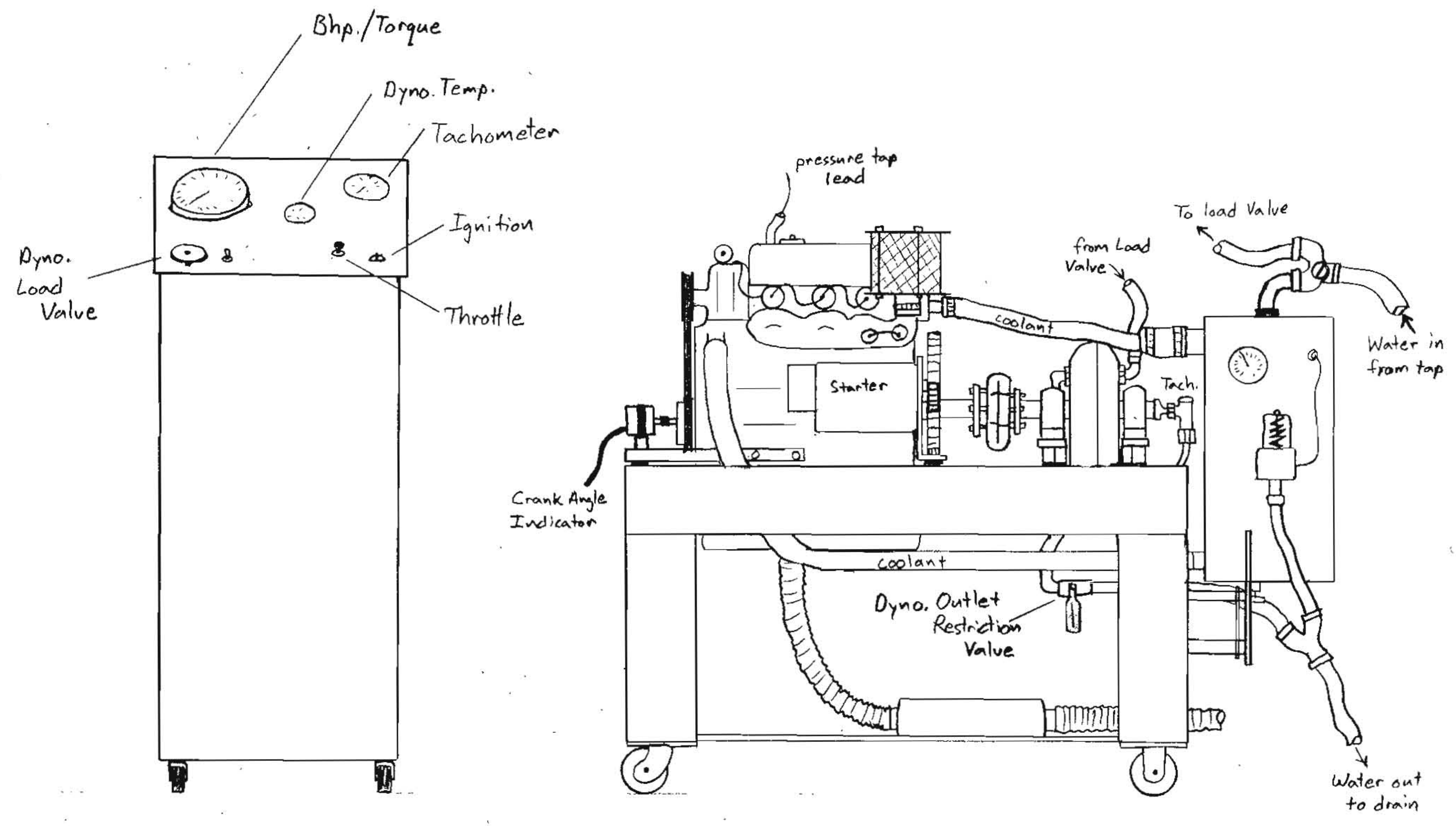

Bhp./Torque
Dyno. Temp.
Tachometer
Ignition
Dyno. Load Valve
Throttle
pressure tap lead
To load Valve
from Load Valve
coolant
Water in from tap
Starter
Tach.
Crank Angle Indicator
coolant
Dyno. Outlet Restriction Valve
Water out to drain

Fig. 1

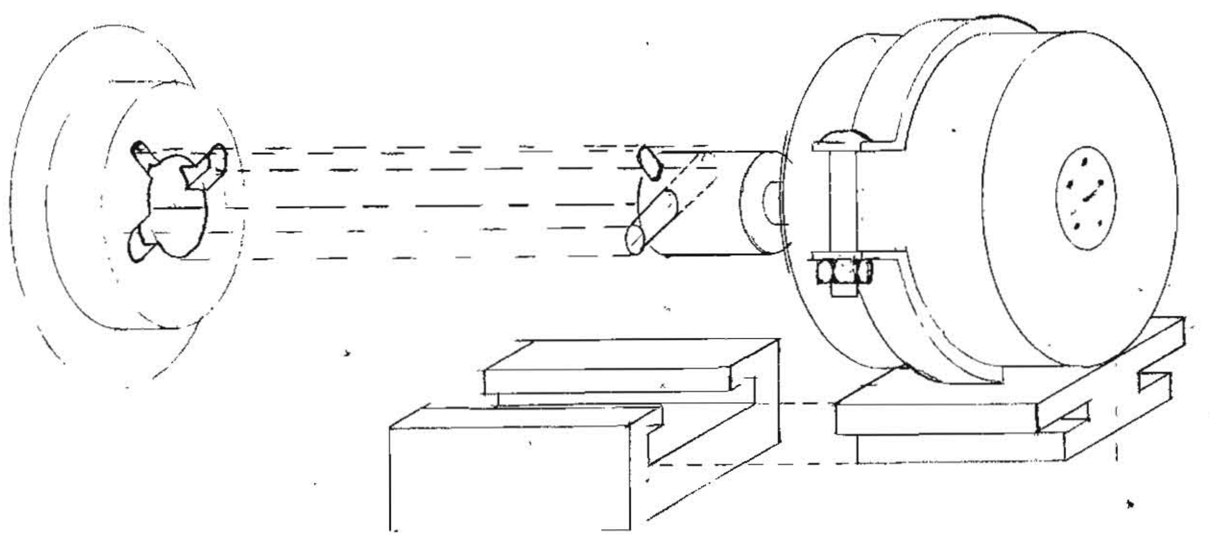
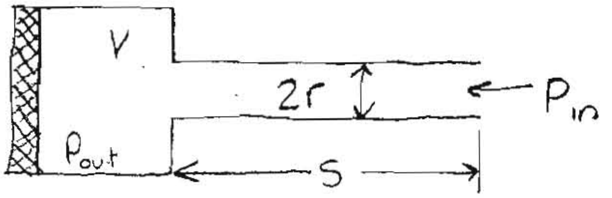


FIG. 2

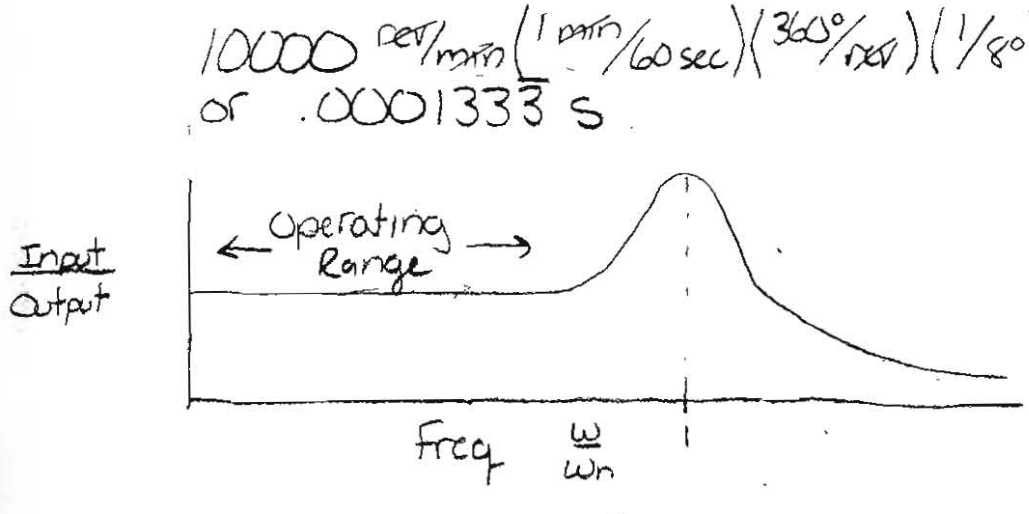


$$\omega_n = \sqrt{\frac{3\pi r^2 c^2}{4SV}}$$

$$\zeta = \frac{2\mu}{\rho c r^3}\sqrt{\frac{3SV}{\pi}}$$

Assume during test situation that crank angular velocity is 10000 rpm, therefore, the time response duration is for 8° angle

$10000\ \text{rev/min}\,(1\ \text{min}/60\ \text{sec})(360°/\text{rev})(1/8°) = 7500\ s^{-1}$
or $.000133\overline{3}$ s



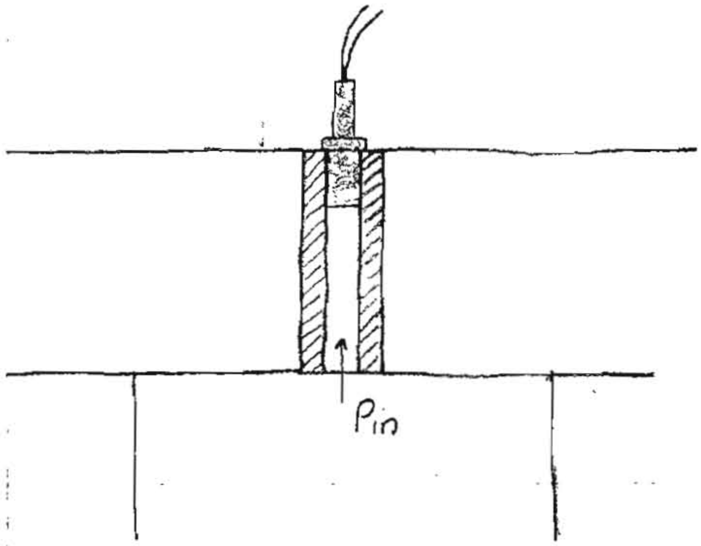
Assume $\zeta = 1$ for damped response and $\omega_n = 15000$ Hz

Therefore; $\omega = 7500$ Hz will be in operating range.

Cont. →

FIG. 3

$$\Rightarrow \omega_n = \sqrt{\frac{3\pi r^2 c^2}{4 S V}} \geq 15000\ Hz$$



Volume at T.D.C. Bore 2.83 in at 23:1
Stroke 2.83 in

$$\text{Volume (Full)} = (2.83)^2 (2.83) \pi/4 = 17.80\ in^3$$

From compression ratio

$$\text{at TDC. } \forall = \frac{17.80}{23} = .774\ in^3$$

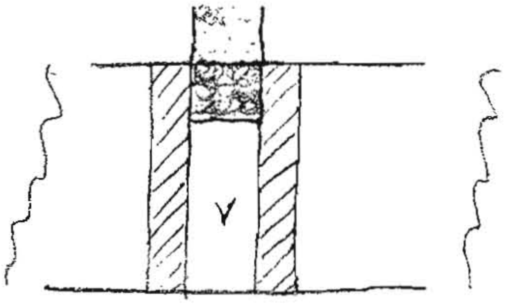
want volume to change only 3-5% ⇒ the volume of the transmitting tube must be less than $.0406\ in^3$

FIG 3 CONT

$$\omega_n = \sqrt{\frac{3\pi r^2 c^2}{4SV}}$$

It can be seen that a reduction in the volume tends the $\omega_n \rightarrow \infty$

Therefore; we will not have an air chamber before the transducer



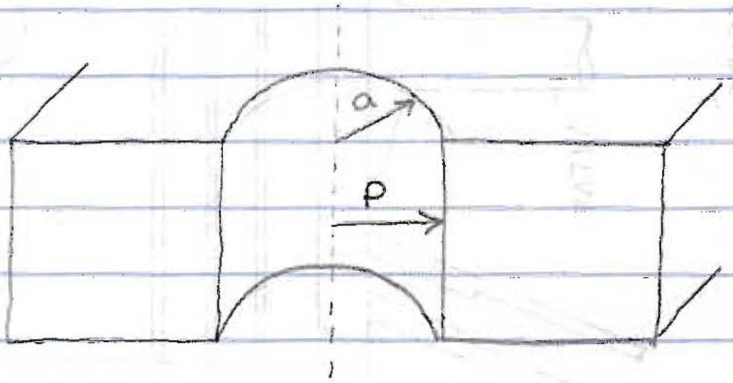
$$r_{max} = \sqrt{\frac{V_{max}}{\pi S_{max}}} = \sqrt{\frac{.0406}{\pi(1.5)}} = .093 \text{ in}$$

$\Rightarrow \phi_{max} = 3/16''$ with length at $1.5''$

FIG 3 CONT

Calculation to determine press Fit force

Poissons Ratio $\mu = \frac{E}{2G} - 1 = \frac{30\times10^6}{2(11.2\times10^6)} - 1 = .33$

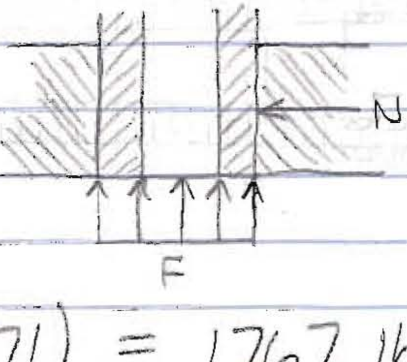


$a = .437$
$\Delta = .0015$
$b = \infty$

In radial

$$P = \frac{E\Delta}{4a}\left[1 - \frac{a^2}{b^2}\right] = \frac{30\times10^6(.0015)}{4(.437)}\left[1 - \frac{.437}{\infty}\right]$$
$$= 25743.7 \text{ psi}$$

$F = PA = 25743.7(.5\pi(.437)) = 17671$ lb (Normal)



choose $\mu_f = .1$

$F = \mu_f N = .1(17671) = 1767$ lbs to press out

FIG. 3A

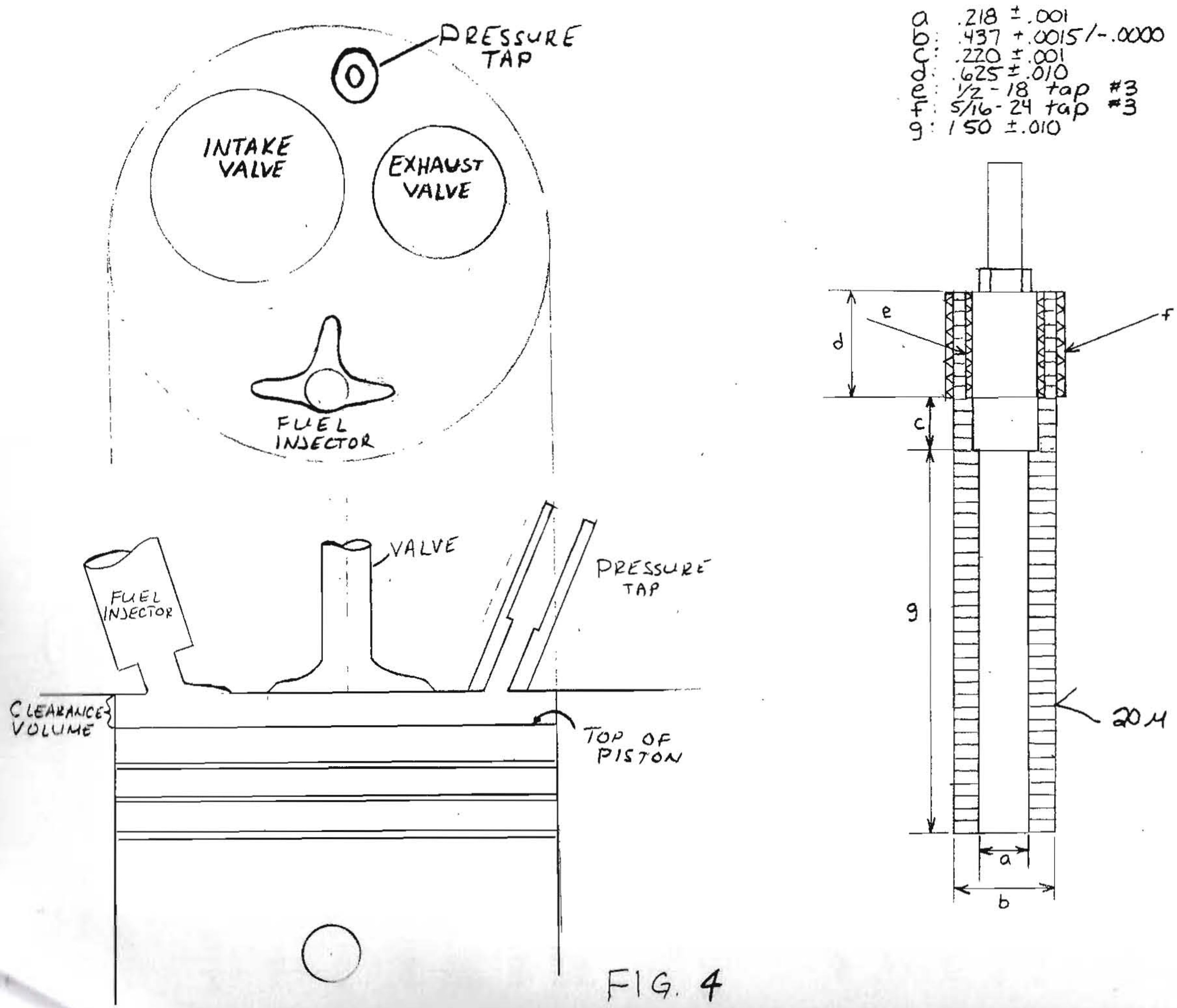

PRESSURE TAP
INTAKE VALVE
EXHAUST VALVE
FUEL INJECTOR
FUEL INJECTOR
VALVE
PRESSURE TAP
CLEARANCE VOLUME
TOP OF PISTON
a .218 ±.001
b: .437 +.0015/-.0000
c: .220 ±.001
d: .625 ±.010
e: 1/2-18 tap #3
f: 5/16-24 tap #3
g: 150 ±.010
e
f
d
c
g
a
b
20 μ

FIG. 4

APPENDIX B

The following is a list of all the tasks performed on the project over the course of the quarter as well as a breakdown of who helped with each.

BUILT STAND FOR ENGINE
- cut --Hasan
- tack --Dave
- weld --Bret

BUILT HEAT SINK FRAME
- cut, tack ------------------------------------Dave, Hasan
- weld --Bret

FABRICATED AND INSTALLED WHEELS
- cut, drill ------------------------------------Kurt
- weld --Dave

FABRICATED AND INSTALLED DYNO MOUNTS
- drill --Bret, Kurt
- weld --Kurt

PAINTED ENTIRE ENGINE STAND
- prime, paint ---------------------------------Bret, Hasan,Kurt

INQUIRE ABOUT CRANK ANGLE SENSOR -----------------Kurt

SHOPPING TRIP
- purchased engine mounts ---------------------Kurt, Hasan

INSTALLED ENGINE MOUNTS
- drill --Kurt, Bret

PRESSURE TRANSDUCER TUBE CALCULATIONS ------------Dave

SHOPPING TRIP ------------------------------------All
- flexible exhaust hose
- exhaust coupling and clamps
- starter relay
- ignition switch
- throttle cable
- battery terminals
- oil
- air filter
- fuel filter
- garden hose and fittings
- assortment of pipe fittings and couplings

COOLING SYSTEM INSTALLATION ----------------------All
- hose clamps from university stores ----------Kurt, Hasan

EXHAUST INSTALLATION
- fabrication----------------------------------Kurt
- assembly------------------------------------Dave

SHOPPING TRIP
- rubber coupling for air filter --------------Kurt, Hasan

AIR FILTER FABRICATION AND INSTALLATION
- cut, drill, assembly -------------------------Dave

DYNO HOOK-UP
- coolant lines --------------------------------All
- tachometer ----------------------------------Bret
- temperature probe ---------------------------Dave

FABRICATED MONITOR STAND
- cut --Dave
- tack ---Dave
- weld ---Dave
- install wheels -------------------------------Dave
- battery tray ---------------------------------Kurt

formed sheet metal skirt --------------------Dave
fabrication of top --------------------------Kurt
gauge layout ---------------------------------Kurt, Dave
assembly -------------------------------------Kurt, Dave,Hasan
painted ---------------------------------------Dave
installed gauges -----------------------------Dave

FABRICATED AND INSTALLED FUEL SYSTEM
cut, tack, weld ------------------------------Bret
weld nipple on fuel can ---------------------Bret
ELECTRICAL WIRING -------------------------------Bret, Hasan
consulting with John Caven to obtain materials
THROTTLE LINKAGE INSTALLATION
layout, cut, form, drill, assembly ----------Hasan, Bret,Kurt
FINAL GAUGE AND ELECTRICAL WIRING INSTALLATION ---Dave
B.H.P gauge
dyno temp gauge
load valve and switch
throttle linkage
tachometer
ignition switch
battery terminals
fuel line
SHOPPING TRIP ----------------------------------Kurt, Hasan
fuel
muffler clamp
START ENGINE AND TROUBLE SHOOT ENGINE ------------All
TROUBLE SHOOT DYNO --------------------------------All
fix leaks -----------------------------------Kurt
install flow restrictor of water outlet -----Bret
PRESSURE TAP INSTALLATION ------------------------Dave
machining
CRANK ANGLE SENSOR MOUNTING
cut --Kurt
form ---Bret
drill --Kurt
machining ------------------------------------Kurt
tack ---Kurt
weld ---Dave
paint --Dave
ENGINE TEARDOWN --------------------------------Kurt, Hasan,Bret
MODIFICATION OF ROCKER ARM STAND ----------------Dave
INSTALLATION OF NEW HEAD -------------------------All
ANALYSIS --All

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KURT KRUEGER 3-5-92

FABRICATED AND INSTALLED WHEELS

After the engine stand was fabricated, wheels were to be installed. A set of four casters were located in the shop. I assisted in the mounting of these casters by cutting and drilling the hole pattern in the shoe plates that were welded on to the bottom of each leg of the engine stand, the casters were then bolted to the shoe plates.

FABRICATED AND INSTALLED DYNO MOUNTS

The dyno had to be shimmed in order to use the existing mounting brackets that were with the engine and dyno initially. I drilled the holes in the engine stand that bolted to the mounting brackets. I also assisted in welding the shim pads to the mounting brackets and helped install the entire dyno mounting structure.

PAINTED ENTIRE ENGINE STAND

I assisted in prepping the engine stand for painting by removing the caster wheels and wiping down the frame with lacquer thinner.

INQUIRE ABOUT CRANK ANGLE SENSOR

I called Novo Technik and asked them to send me a spec sheet for our crank angle sensor.

SHOPPING TRIP

Hasan and I drove out to Eagle Lake and picked up four snowmobile engine mounts.

INSTALLED ENGINE MOUNTS

I assisted in drilling the mounting holes in the engine stand that the engine mounts bolted into, and then bolted the engine to the stand.

SHOPPING TRIP

The entire group and I acquired two purchase orders in order to buy needed materials. We went to Champion Auto, Menards and TSC and bought the following list of items needed to continue on our project.

flexible exhaust hose
exhaust coupling and clamps
starter relay
ignition switch
throttle cable
battery terminals
oil
air filter
fuel filter
garden hose and fittings
assortment of pipe fittings and couplings

COOLING SYSTEM INSTALLATION

Hasan and I went to University Stores and requisitioned several hose clamps and garden hose fittings that were needed for the cooling system and dyno connections. Upon returning from this errand, the entire group proceeded to connect the water lines from the cooling tower to the engine.

SHOPPING TRIP

Hasan and I obtained a purchase order and went to Menards to get the rubber coupling that was used to connect the air filter to the intake manifold.

DYNO HOOK-UP

The entire group worked on connecting the water lines to and from the dyno.

FABRICATED MONITOR STAND

There were several components that were fabricated separately and then assembled to form the monitor stand. I assisted in the tack welding, the squaring of the main frame. While the final welding was being done, I began work on the framework for the battery tray, later I welded the tray in place. The next step was to fabricate the top of the stand. I located a piece of 0.125" steel, cut it to size on the band saw, ground and filed the edges smooth, and welded the hinge in place. I then assisted in drilling and tapping holes in the frame, and then fastening the top to the frame. Next I assisted in the layout of the gauges, and later the installation of the gauges.

THROTTLE LINKAGE INSTALLATION

I assisted in the layout of the throttle linkage.

SHOPPING TRIP

Hasan and I went to Champion Auto and bought a Muffler clamp to attach the remaining flexible exhaust tubing to the outlet side of the muffler. After purchasing the clamp, we stopped at a gas station and filled the fuel can with diesel fuel.

START ENGINE AND TROUBLE SHOOT ENGINE

The entire group assisted in the starting of the engine.

TROUBLE SHOOT DYNO

Not all of the water lines running in and out of the dyno were water tight seals, I assisted in stopping these leaks. I also assisted in consulting with others to determine why the dyno was not applying sufficient load to the engine. The solution was that an inadequate amount of water was building up in the dyno.

CRANK ANGLE SENSOR MOUNTING

The crank angle sensor must remain oriented with one position of the crank at all times. Due to its limited life span, the sensor must also be removable. I devised a system where the sensor could be removed quickly and easily utilizing a dovetail and a set screw. The connection between the sensor and the crankshaft is made with a modification on the lovejoy type connector. The male end of the connector is attached to the stud of the sensor with a set screw. The female end of the connector is machined into a plate that is bolted to the pulley on the crankshaft that drives the water pump. To insure that the sensor is in constant relation with the crank, the male and female ends of the connector can only fit together one way. See fig. 2 for further description of the connection.

ENGINE TEARDOWN

I assisted in removing the old cylinder head.

INSTALLATION OF NEW HEAD

As soon as the set of new gaskets arrive, the entire group can begin to install the cylinder head that has the pressure tap installed.

ANALYSIS

Time permitting, we will connect the oscilloscope to the engine and observe the crank position vs. cylinder pressure relationship.

MISCELLANEOUS

This project was extremely time consuming, much of what was accomplished over the course of the quarter has not been recorded here. Things such consulting time with other professors and students cannot be accounted for. An immense amount of time was spent looking for parts around the shop and in the other labs. I spent a good deal of time running back and forth between my apartment and the lab. Any time a shopping trip was necessary, I had to trek back to my apartment and get my car. Shop clean-up is another aspect of a project like this, for every hour spent working approximately ten to fifteen minutes were spent cleaning up the mess that the particular job created.

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Bret A. Gohman
3/3/92

The following is a brief synopsis of my contributions to the diesel engine test stand project.

1) **WELDED STAND FOR ENGINE:** I was involved in the planning of the engine stand. Once the materials were cut and positioned, I MIG welded the assembly together.

2) **WELDED HEAT SINK MOUNTING FRAME:** Once the materials were cut and positioned, I again welded this assembly together and to the engine test stand frame.

3) **FABRICATED AND INSTALLED DYNO MOUNTS:** The engine dynamometer needed to be shimmed up to the same level as the engine crankshaft center. To accomplish this, the appropriate size shims were found and I assisted Kurt with welding them onto the dyno mounts. Once these mounts were welded, I drilled both the mounts and the engine test stand, located the appropriate bolts and mounted the dynamometer.

4) **PAINTED ENTIRE ENGINE STAND:** I assisted with painting the engine test stand frame. I wiped the entire frame down with lacquer thinner, and assisted with priming and two coats of paint. I also assisted with painting the engine mounting plates.

5) **INSTALLED ENGINE MOUNTS:** Once the rubber engine mounts were obtained, I assisted with drilling the holes in the engine test stand frame and subsequent mounting of the diesel engine.

6) **SHOPPING TRIP:** I compiled a preliminary list of items needed for the project. Other members of the group added to this as necessary. I went with to help select the appropriate parts listed below:

flexible exhaust hose
exhaust coupling and clamps
starter relay
ignition switch
throttle cable
battery terminals
oil
air filter
fuel filter
garden hose and fittings
assortment of pipe fittings and couplings

7) **COOLING SYSTEM INSTALLATION:** I consulted with Dr. Ready and Dr. Jones on the correct way in which to route the coolant hoses. Once the group had made the decision on the coolant system I assisted with the assembly.

8) **DYNO HOOK-UP:** Once the dynamometer hoses were understood, I assisted with the routing and installation. I also connected the mechanical

tachometer gear reduction onto the end of the dyno.

9) **FABRICATED AND INSTALLED FUEL SYSTEM:** The first obstacle regarding the fuel system pertained to the use of fuel pumps. The engine manual suggested the use of two fuel pumps in series. Professor Fiszdon informed me that he did not want to use any sort of a pressurized fuel system, therefore no pumps. A gravity feed system was the answer. I located a fuel can and a brass valve. I cut a hole near the bottom of the can and brazed the valve onto it. I assumed this would allow the fuel can to be disconnected from the system to be refilled. I then constructed a mounting frame and welded it to the control stand making sure that the fuel level would be higher than the fuel injection pump inlet.

The second obstacle was an inlet fitting on the injection pump. The fitting was an odd metric size. We were not able to locate one during the previous shopping trips. I found an over-size brass fitting, turned it down on the lathe, and cut the appropriate threads onto it. I then located some Tygon tubing for fuel line and connected the system.

10) **ELECTRICAL WIRING:** I selected the required components for the wiring system. Once the appropriate connectors were brought from John Caven, I completely wired the system. (See Figure 1)

11) **THROTTLE LINKAGE INSTALLATION:** A throttle cable mounting bracket was constructed. I redesigned this previous bracket with the new bracket fitting closer to the engine with better alignment. This new bracket was formed from aluminum and allowed for cable adjustment. I also drilled the engine throttle lever to accommodate the throttle cable and a return spring.

12) **INITIAL START OF ENGINE AND TROUBLESHOOTING:** I assisted with the initial start-up of the engine.

13) **TROUBLE SHOOT DYNO:** I assisted with the initial testing of the engine dynamometer. It had some water leaks and did not properly load the engine. After consultation it was decided that a restriction was to be placed on the outlet. I located a valve and the appropriate fittings and installed a "flow restriction valve" on the dyno outlet.

14) **CRANK ANGLE SENSOR MOUNTING:** I assisted with the preliminary design of the crank angle sensor mounting system.

Figure 1: Wiring diagram

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The following is a synopsis of what Dave Leibel did throughout the quarter.

BUILT STAND FOR ENGINE

Assisted in the layout of the frame (dimensions, material, etc.).
Squared and tacked the frame and legs together.

BUILT HEAT SINK FRAME

Complete layout and fabrication of the heat sink tower with the exception of final weld.

Installed heat sink tower and vibration isolators onto frame.

FABRICATED AND INSTALLED WHEELS

Welded the wheel pads to the legs of the frame and attached the wheels.

FABRICATED AND INSTALLED DYNO MOUNTS

PAINTED ENTIRE ENGINE STAND

INQUIRE ABOUT CRANK ANGLE SENSOR

SHOPPING TRIP

INSTALLED ENGINE MOUNTS

PRESSURE TRANSDUCER TUBE CALCULATIONS

Calculated the response characteristics of the pressure transducer and the effect that the increased volume of the tube would have on the response. Conclusion: The volumetric change will not significantly effect the response characteristics of the sensor.

SHOPPING TRIP

Assisted in the selection and purchase of the parts needed for the engine and the coolant lines. The list can be found on the abridged list of the names and tasks completed.

COOLING SYSTEM INSTALLATION

Assisted the group members in the installation of the coolant system lines which involves the hosing, connections, etc.

EXHAUST INSTALLATION

Assisted in the manufacture of the exhaust supports and complete assembly.

SHOPPING TRIP

AIR FILTER FABRICATION AND INSTALLATION

Complete layout and fabrication of air filter assembly.

DYNO HOOK-UP

Assisted in the attachment of the dyno water supply and discharge.

Installed the temperature probe.

FABRICATED MONITOR STAND

Complete layout and fabrication of monitor stand with the exception of the battery tray and gage location. The specific tasks can be found on the names and tasks completed printout.

Installed the gages in the final product.

FABRICATED AND INSTALLED FUEL SYSTEM

ELECTRICAL WIRING

THROTTLE LINKAGE INSTALLATION

FINAL GAUGE AND ELECTRICAL WIRING INSTALLATION

Complete gage and electrical integration with the engine and dyno to the monitor stand.

Wrapped wiring and cables into a single trunk for convenience.

SHOPPING TRIP

START ENGINE AND TROUBLE SHOOT ENGINE

Assisted in the starting of the engine.

TROUBLE SHOOT DYNO

Assisted in the correct operation of the dyno.

PRESSURE TAP INSTALLATION

Complete layout and manufacture of the pressure tap sleeve and engine head.

Complete layout and manufacture of the rocker arm support to seat around pressure tap post.

Specific tasks can be found on the attached printout.

CRANK ANGLE SENSOR MOUNTING

Assisted in the final alignment of the mount.

Welded and painted the assembly.

ENGINE TEARDOWN

INSTALLATION OF NEW HEAD

In progress.

ANALYSIS

15) ENGINE TEAR-DOWN: I briefly assisted with removing the existing cylinder head from the engine.

16) MISCELLANEOUS: This category encompasses a great amount of time spent on the following activities:

-consulting with other present and non-present group members
-assisting other group members with their appointed tasks
-locating the required tools and equipment to complete tasks
-clean up of tools and work areas

B+

HASAN
AKHTAR
3-5-92

BUILT STAND FOR ENGINE

Looked for appropriate size square tubing in the EPL and cut four equal size pieces to use for legs of the frame. I Assisted is squaring and welding the frame

BUILT HEAT SINK FRAME

I assisted in the building of the frame by cutting the pieces to the popper length and welding the frame together.

PAINTED ENTIRE ENGINE STAND

I Assisted, first in priming and then in the actual painting of the frame.

SHOPPING TRIP

After realizing that we needed engine mounts so that the engine would not vibrate drastically, I assisted in fulfilling the requirements to get the paper work done for purchasing the engine mounts. We then went to Dave's Auto Shop to purchase four rubber engine mounts.

SHOPPING TRIP ------------------------------------All

I assisted the rest of the group in acquiring a purchase order to buy the following list of items:

- flexible exhaust hose
- exhaust coupling and clamps
- starter relay
- ignition switch
- throttle cable
- battery terminals
- oil
- air filter
- fuel filter
- garden hose and fittings
- assortment of pipe fittings and couplings

After we were granted the requested purchase order I assisted the group in locating each item at Champion Auto, Menards, and TSC.

COOLING SYSTEM INSTALLATION

I assisted in obtaining the proper paper work from Jeff Oelke and Dr. Fiszdon to requisition supplies from University Stores, I then assisted in obtaining the needed supplies.

SHOPPING TRIP

I assisted in filling out the pater work and then went to Menards to buy a rubber coupling for air filter.

FABRICATED MONITOR STAND

I assisted in assembling the monitor stand by welding part of the battery tray to the frame and by bolting the top to the frame.

ELECTRICAL WIRING --------------------------------Bret, Hasan

I assisted in figuring out the wiring and consulting with John Caven about the different sockets which could be used.

THROTTLE LINKAGE INSTALLATION

I assisted in connecting the throttle linkage by creating and installing a bracket which would clamp the outside sleeve of the throttle cable to the engine block.

SHOPPING TRIP

Assisted in purchasing a Muffler clamp to attach the flexible exhaust tubing to the muffler. After that was accomplished, we stopped and filled the fuel can with diesel fuel.

START ENGINE AND TROUBLE SHOOT ENGINE

I assisted in connecting the necessary water lines to the faucet prior to starting the engine.

TROUBLE SHOOT DYNO

I assisted in fixing leaks in the water lines of the dyno.

ENGINE TEARDOWN

Assisted other group members in removing the head from the engine and prepared the exhaust manifold to be re-installed by removing the old gasket material that had stuck when it was removed from the cylinder head.

APPENDIX C

CHARGE CALIBRATION DATA

PCB

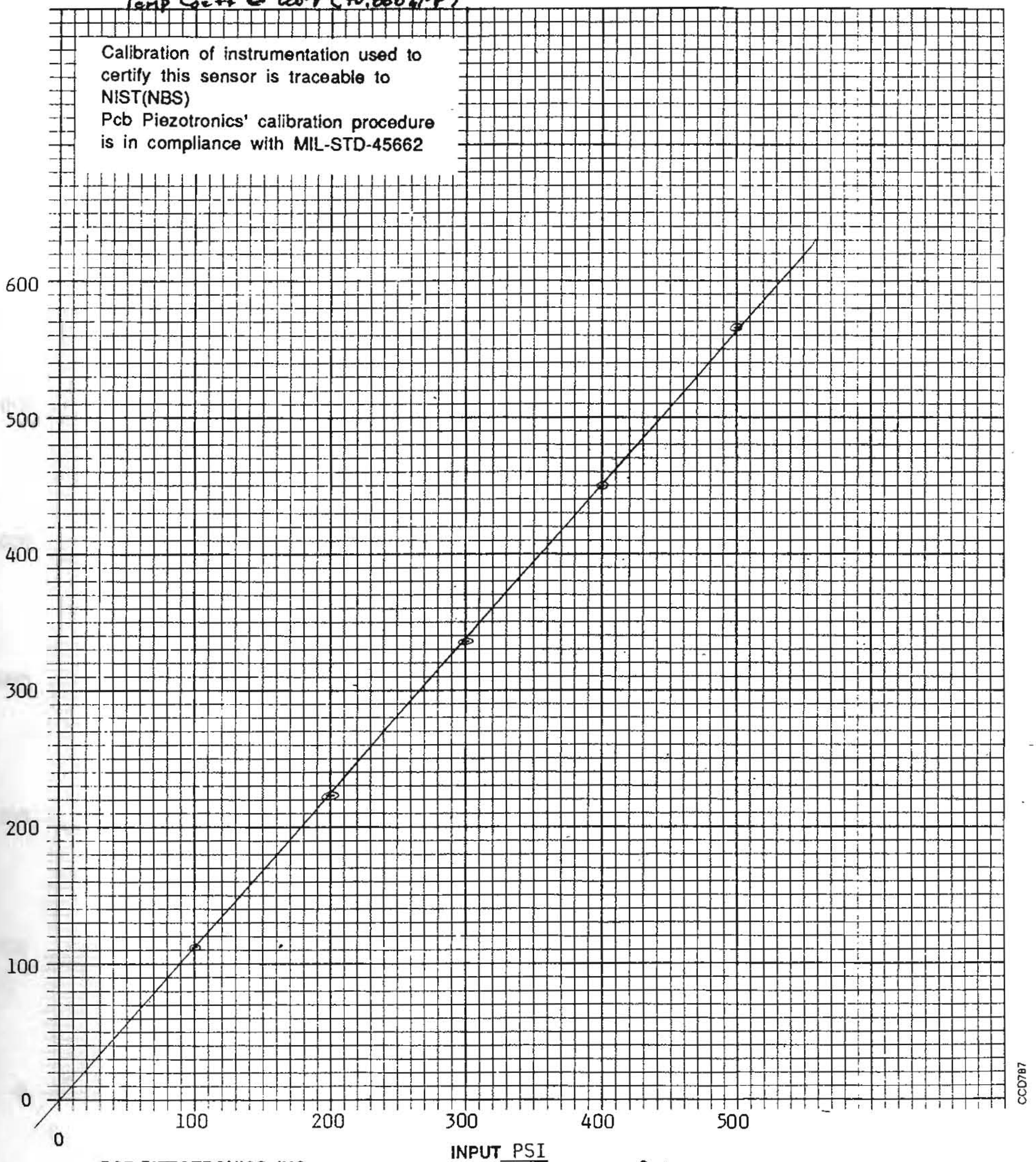
Model 112A05 Cal Range 0-500 Psi Nat'l Freq 250 kHz

S/N 8836 Sens* 1.13 pC/psi Linearity* <1.0 %FS By G. Redmond

* By comparison with reference standard per ISA S37.10. Zero based best straight line.

Capacity 21.0 pF Date 27 March 96

Temp Coeff @ 600°F (+0.008%/°F)



INPUT PSI

PCB PIEZOTRONICS, INC.
3425 Walden Avenue, Depew NY 14043
Tel: 716-684 0001 TWX: 710-263 1371

FIG 5

Customer ____________

PO Number ____________

CHARGE CALIBRATION DATA

PCB

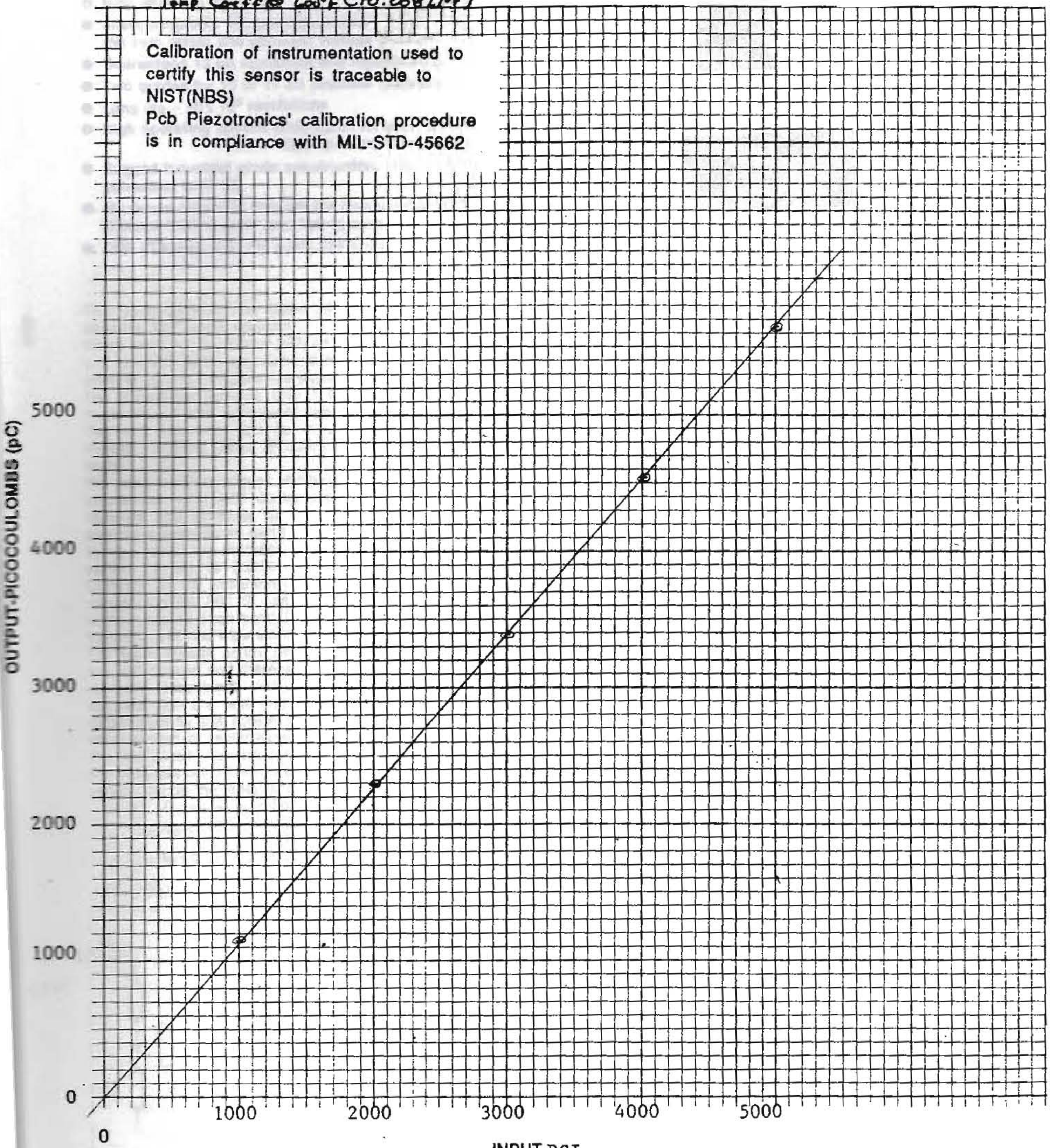
Model* 112A05 | Cal Range 0-5,000 psi | Nat'l Freq 250 kHz

S/N- 8836 | Sens* 1.13 pC/psi | Linearity* <1.0 %FS | By G. Redmond

* By comparison with reference standard per ISA S37.10. Zero based best straight line.

Capacity 21.0 pF | Date 27 March 90

Temp Coeff @ 600°F (+0.0082/°F)



CCD787

INPUT PSI

PCB PIEZOTRONICS, INC.
3425 Walden Avenue, Depew NY 14043
Tel: 716-684 0001 TWX: 710-263 1371

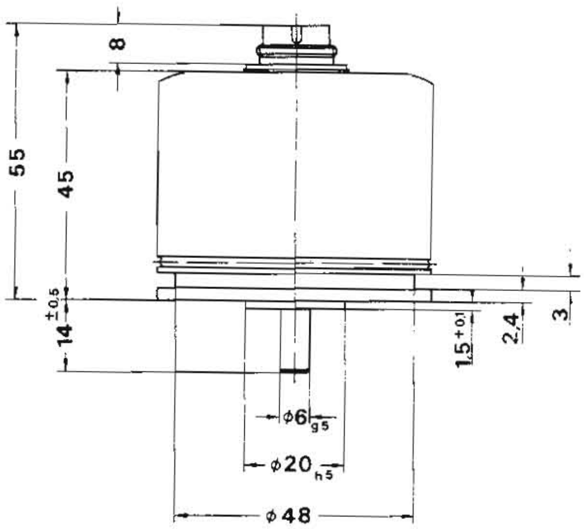
Customer ____________

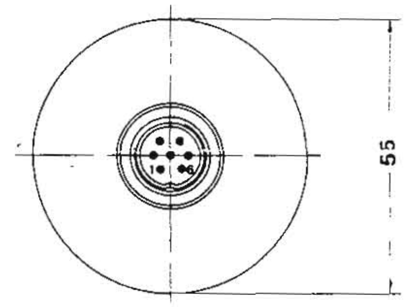
PO Number ____________

FIG 5A

Special Features:

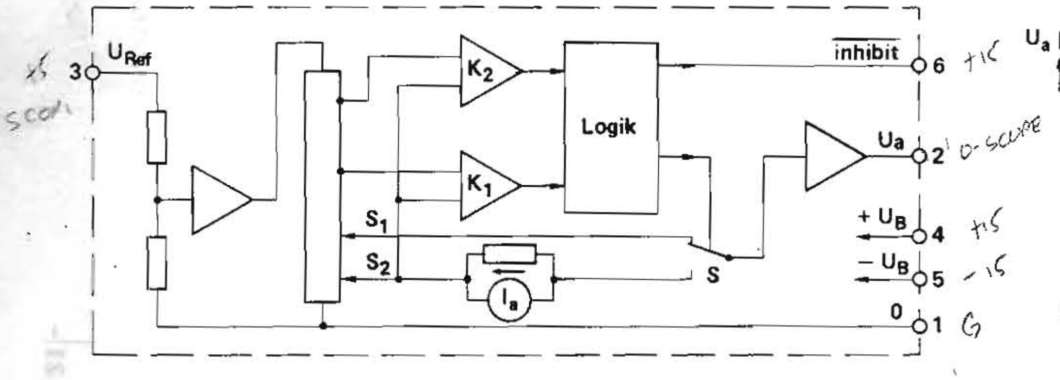
- Value-for-money Absolute Angle encoding module
- Gap-free output over all 360°
- High absolute linearity
- Interchangeable without adjustment (no zero offset and constant voltage gradient)
- Guaranteed 12 bit resolution and repeatability
- Two grades for 10 or 11 bit absolute accuracy
- Long life – 50 x 10^6 revolutions
- High operating speeds 6000 r.p.m. for short periods 1500 r.p.m. continuous use
- Rugged industrial grade construction, sealed shaft, connector to IP 65
- Maximum reliability through the combination of the Dinopot HQ5 system* and hybrid technology
- * DBP 2733949, U.S. Pat 4,203,074 and other patents





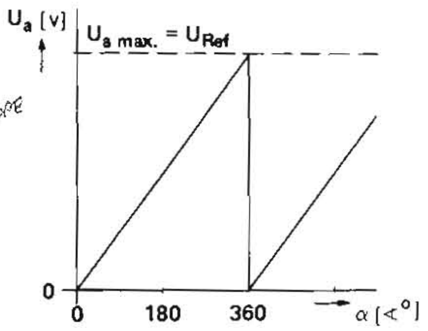
This potentiometer has been designed to be used as an absolute 360° angle encoder.
When used in conjunction with an external A/D converter, the unit operates as an angle transducer with 12 bit resolution and offering 10 or 11 bit absolute accuracy.
The transducer requires only 7 connections and these are made via a 7 pole, waterproof plug and socket.
The A/D converter can be mounted in an external rack, thereby, offering ease of connection with protection from noise.
We can provide examples of circuits where the unit is used in connection with A/D converters or analogue systems. If required and in order to allow the rapid construction of prototype systems we can supply circuit modules on standard Europa cards, the modules available would include A/D converters, Binary to B.C.D. converters and Digital Displays.
Contrary to the limitation encountered with other potentiometers, the AW 360 ZE can be used over all 360° of rotation since it has no dead band. This limitation has been overcome by the use of two wipers and a special Hybrid circuit.
The reset voltage at the beginning and end of the sawtooth are well defined and there is no function angle tolerance as is normally associated with potentiometers. These features coupled with the fact that the maximum output voltage is determined by the applied voltage means that units may be interchanged or replaced without the need to adjust or trim.
The transducer delivers a logic signal quite seperately from the analogue output which can be used to inhibit the A/D conversion during the reset period.

1.) Ground – red
2.) brown
3.) White
4.) Yellow
5.) Green
6.) Grey
7.) Orange



Connection diagram

FIG. 6



Output signal

APPENDIX D

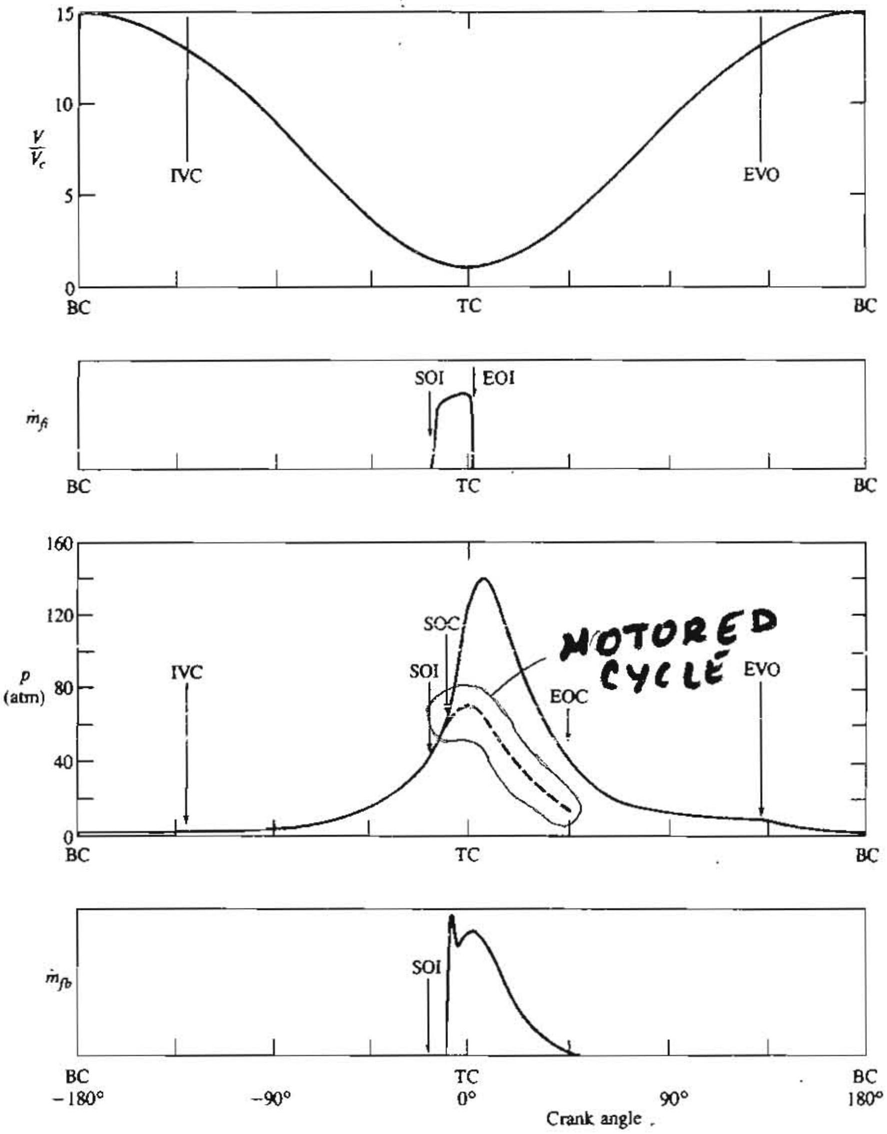
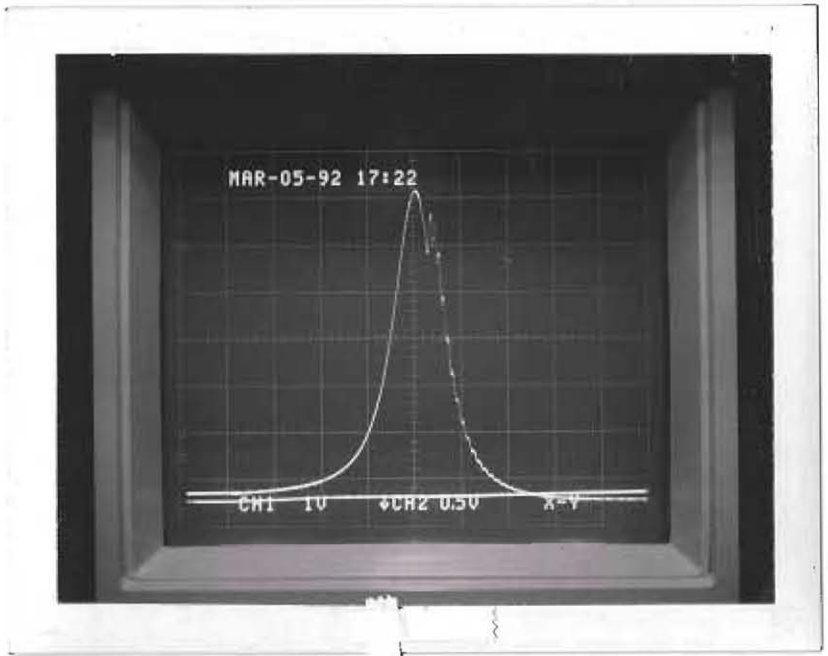
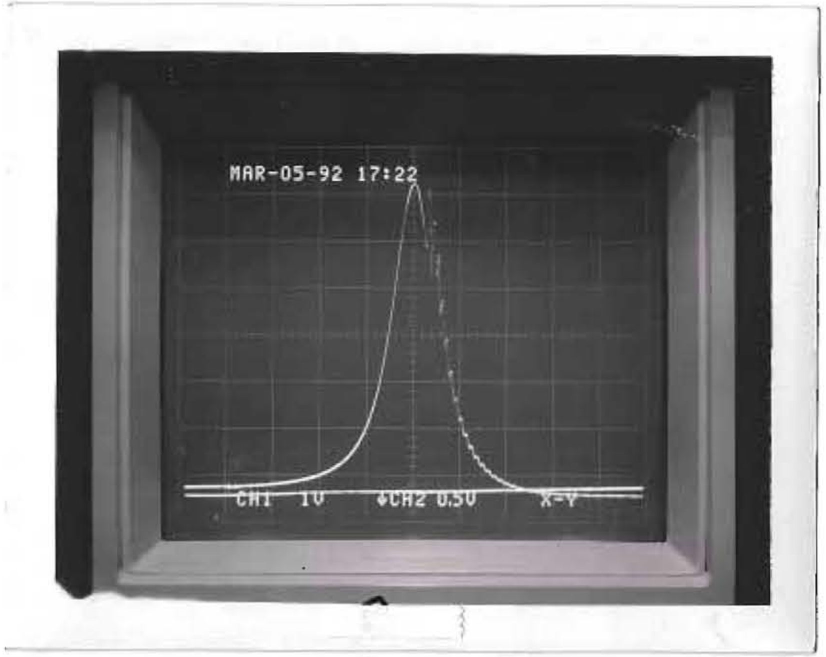


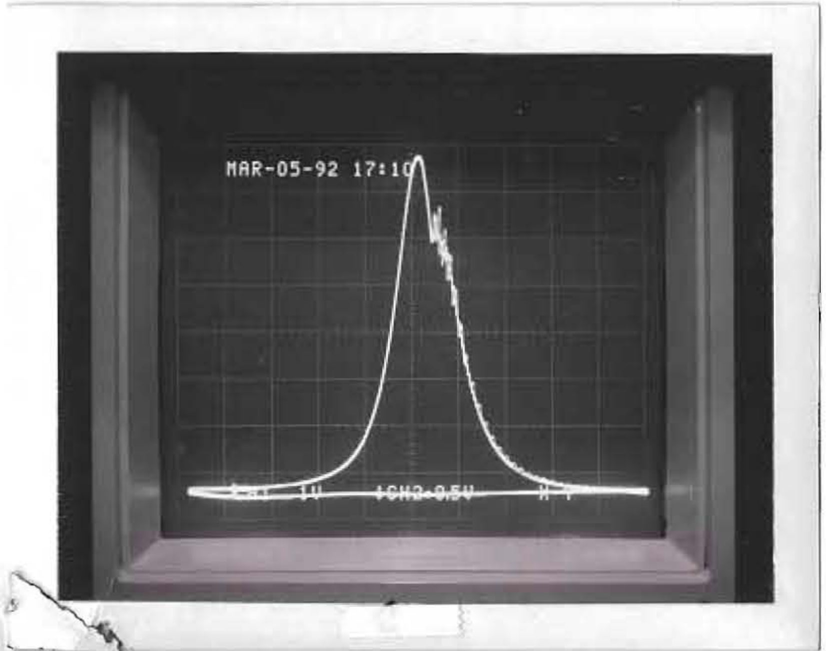
FIGURE 1-15
Sequence of events during compression, combustion, and expansion processes of a naturally aspirated compression-ignition engine operating cycle. Cylinder volume/clearance volume V/V_c, rate of fuel injection $\dot{m}_{fi}$, cylinder pressure p (solid line, firing cycle; dashed line, motored cycle), and rate of fuel burning (or fuel chemical energy release rate) $\dot{m}_{fb}$ are plotted against crank angle.

nozzles are used. In one common fuel pump (an in-line pump design shown in Fig. 1-17) a set of cam-driven plungers (one for each cylinder) operate in closely fitting barrels. Early in the stroke of the plunger, the inlet port is closed and the fuel trapped above the plunger is forced through a check valve into the injection

FIG. 8


MAR-05-92 17:22
CH1 1V ⌀CH2 0.5V X-Y


MAR-05-92 17:22
CH1 1V ⌀CH2 0.5V X-Y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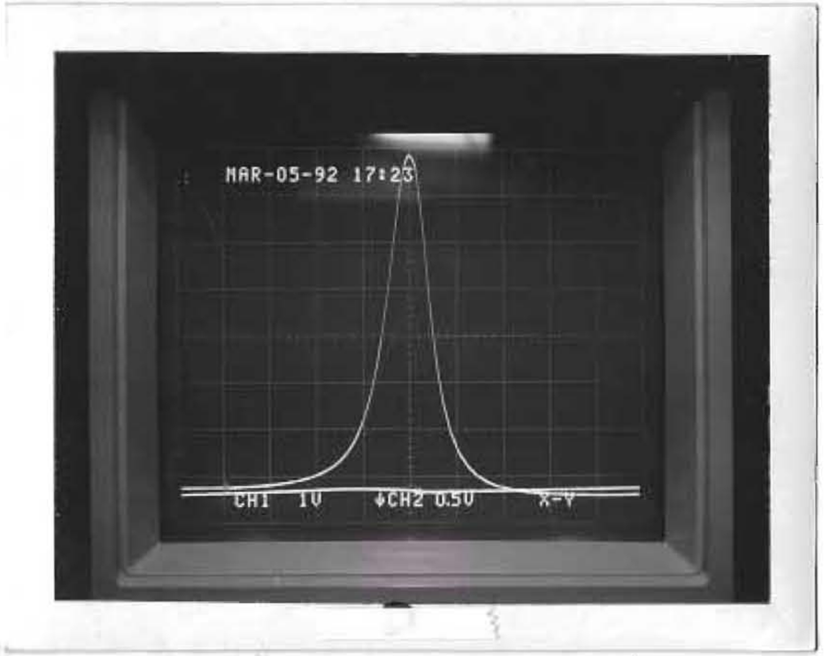
MAR-05-92 17:23
CH1 1V ⌀CH2 0.5V X-Y