Experiment No. 6.

THERMODYNAMIC STUDY OF A RECIPROCATING AIR COMPRESSOR

I. OBJECTIVE

To study the operating cycle of a small, air-cooled, single stage, reciprocating air compressor and the effects on its performance of varying the compressor discharge pressure and the addition of increased clearance volume.

II. BACKGROUND

The reciprocating air compressor is widely used for various industrial applications. It is particularly advantageous when low flow capacities and high pressures are required. It is a piston displacement pump and functions by first raising the pressure of a gas and then discharging it, as the piston returns.

Physically, it is characterized by a maximum and a minimum volume contained between the piston and the head. The difference in these is termed the Displacement Volume while the minimum volume itself is termed the Clearance Volume. The value of the ratio of the Clearance Volume to the Displacement Volume strongly affects the performance of the compressor. The valves in most small compressors operate by pressure differential. The discharge valve will not open until the force due to the difference in internal pressure and the pressure in the discharge region exceeds the spring force in the discharge valve.

Similarly, the intake valve will not open until the internal pressure drops below the intake pressure, permitting the induction of a new supply of gas. Since a finite quantity of gas remains in the clearance volume at the end of the discharge, it must expand until its pressure drops sufficiently to permit the inlet valve to open, requiring a finite portion of the travel of the piston. This leads to less gas actually admitted than the maximum amount theoretically possible, which is associated with the displacement volume. The ratio of the actual volume inducted at inlet pressure and temperature, to the displacement volume is termed the Volumetric Efficiency.

It the pressure-volume relationship throughout the thermodynamic cycle can be determined and displayed graphically, the resulting diagram is called an Indicator Diagram. The area enclosed by this diagram is called the Indicated Work and the rate at which this diagram is traversed is the Indicated Power. Directing attention to the compression process only, it is noted that the process is neither adiabatic (the compressor is air-cooled) nor isothermal (not enough heat is removed during air-cooling) nor is the process reversible (friction is certainly present). However, the actual compression process curve very often follows a shape represented by the polytropic relation:

\[ P v^n = \text{constant} \]  

(6.1)

However, this is not a reversible polytropic process. Often, for small compressors, the amount of friction is small and not too much error is incurred in neglecting it. At least this assumption will
thermodynamic texts show the work done per pound in reversible processes to be

\[
\text{ISENTRIC} \quad w = kRT_1 \left[ \frac{(P_2/P_1)^{(k-1)/k} - 1}{1 - k} \right]
\]

\[
\text{POLYTROPIC} \quad w = \eta RT_1 \left[ \frac{(P_2/P_1)^{(n-1)/n} - 1}{1 - n} \right]
\]

\[
\text{ISOTHERMAL} \quad w = RT_1 \ln \left( \frac{P_1}{P_2} \right)
\]

(6.2)

We can also estimate the Heat Transfer per pound in each case to be:

\[
\text{ISENTRIC} \quad Q = 0
\]

\[
\text{POLYTROPIC} \quad Q = c_v (k - n) T_1 \left[ \frac{(P_2/P_1)^{(n-1)/n} - 1}{1 - n} \right]
\]

\[
\text{ISOTHERMAL} \quad Q = W
\]

(6.3)

Thermodynamic texts show that for an ideal compressor, the volumetric efficiency can be expressed by

\[
\eta_v = 1 - C_l \left[ \left( \frac{P_2}{P_1} \right)^{1/n} - 1 \right]
\]

\[
C_l = \frac{\text{clearance volume}}{\text{displacement volume}}
\]

(6.4)

Thus, it can be predicted that as the clearance volume increases, the volumetric efficiency goes down.

Finally, consideration of discharge pressure increase would infer a higher pressure at the end of the discharge, resulting in more of the stroke being used up and less flow passing through the compressor. The extreme case would be a discharge pressure high enough to consume the entire stroke in compression and no gas actually discharged, resulting in zero flow and zero Volumetric Efficiency.

III. EQUIPMENT

Two identical compressors are utilized in the experiment. They are Saylor - Beall Model A114F, having 2-inch bore diameter, 2-inch stroke, and a design clearance volume of 0.396 cubic inches. One compressor has a shim placed under the head to increase this clearance volume. The compressors are motor driven and use a Wattmeter for measuring input power. Rotational Speed is measured using a stroboscope. Each Rotational Speed is measured using a Stroboscope. Each compressor has a piezoelectric transducer for measuring air pressure and a sine-wave signal generator for reproducing volume information. These signals are fed into the X and Y channels of a Tektronix Engine Analyzer so that a PV diagram can be formed and photographed on the
face of the scope. The calibration factors for the charge amplifiers are 1.02 for transducer # 242 and 1.09 for transducer # 262. Insertion of the proper calibration factors permits the charge amplifiers to read directly in mv/psi. The compressor discharge into tanks which are fitted with a flow control outlet valve and thermocouple. The discharge from the outlet valve passes through a flow meter calibrated to read 2.2 ACFM full scale. The thermocouples are chromel-alumel.

IV. PROCEDURE

a) Start compressor and establish a pressure of about 40 psig in the tank. Connect the piezoelectric transducer and the sine-wave generator to the scope to establish a PV diagram. Check to make sure all instrumentation is functioning. When you feel secure in the equipment behavior, adjust the tank outlet valve to a maximum tank pressure specified by the lab instructor. Wait for equilibrium. Photograph the PV diagram and record all data.

Repeat this procedure for a total of five tank pressures in descending order (lowest about 15-20 psig). In each case be sure to wait for equilibrium.

b) Repeat the above for the other compressor.

V. ANALYSIS

Enlarge the Polaroid photos of the PV diagram by using the projector available in the stock room and tracing the projections on 8.5 by 11 paper. Be sure to include the grid line. You may choose any acceptable method of enlargement. The area can be determined by a planimeter.

For each test point determine:

- Discharge Pressure from the PV diagram (intake pressure is only slightly below atmospheric and inlet temperature is approximately that of the room air)
- Flow Rate of the air
- Volumetric Efficiency
- Indicated Horsepower
- Overall Efficiency - ratio of indicated power to input power

Plot the above variables vs. tank pressure (psig).

Each lab member is to take a different PV diagram and determine the polytropic exponent, n. They will approximate, for the compression process, the work per pound and heat transfer per pound for isentropic, polytropic and isothermal compression.