Development and Transmission of Power from Central Stations, Unwin, 1894

Action in the Compressor.—Consider for simplicity a single-acting compressor which receives and discharges a pound of air in each revolution, and let the effects of clearance and the resistances of the passages be neglected.

Let P_1, V_1, T_1 be the absolute pressure in lbs. per sq. ft., the volume of a pound in c. ft., and the absolute temperature of the air after compression;

P_a, V_a, T_a the same quantities for air before compression;

p_1 and p_a will be used for the corresponding pressures in lbs. per sq. inch;

$r = V_a / V_1$ is the ratio of compression, a quantity determined by the mechanical construction of the compressor;

$\rho = P_1 / P_a = p_1 / p_a$ may be termed the compression-pressure ratio. It depends on r, and also on the thermo-dynamic conditions of the compression.

Fig. 47 shows the indicator diagram of such a compressor. During the suction stroke a volume V_a at pressure P_a is drawn into the compressor cylinder. During compression to the volume V_1, the pressure rises according to some law expressed by the curve D C. Finally, the air is expelled into the mains at the pressure P_1. In general, the compression curve will lie between two curves D F, D G, corresponding to two limiting cases. If heat is abstracted from the air during compression, so that the temperature remains constant, the compression curve will be the isothermal D F defined by the relation

$$P V = \text{constant}$$
$$= P_a V_a = 27{,}710.$$

If no heat is added or abstracted during compression the temperature of the air will rise, and the compression curve will be the adiabatic D G defined by the relation

$$P V^{\gamma} = \text{constant},$$

where $\gamma = 1 \cdot 41$.

In ordinary compressors the curve lies between D F and D G, and approximates sufficiently to a curve defined by the relation

$$P V^{n} = \text{constant},$$

n having a value between 1 and 1·41.

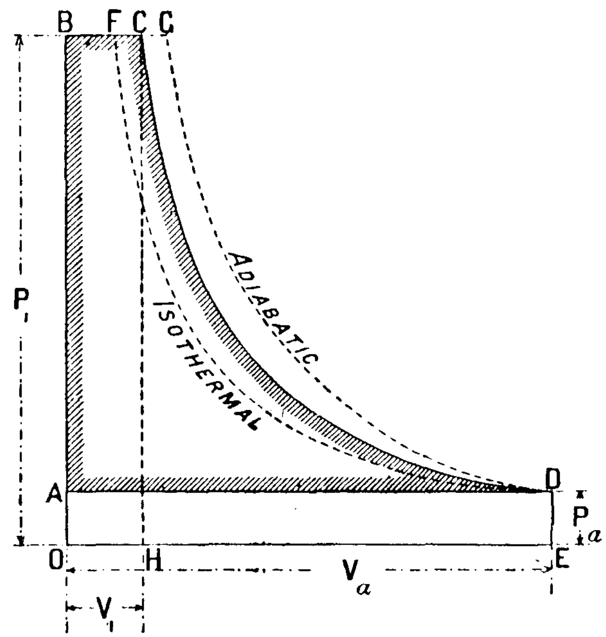

FIG. 47.

The whole work of a complete double stroke consists of three parts:—(1) The work O A D E of the atmosphere on the piston during the suction stroke; (2) the absolute work of compression E D C H; (3) the work of expulsion of the air into the mains H C B O. The effective work is the sum of these

$$- \text{OADE} + \text{EDCH} + \text{HCBO},$$

that is, the shaded area A B C D.

Case of Isothermal Compression.—It will be shown presently that the most economical compressor mechanically would be one in which heat is abstracted during compression, so that the compression is isothermal. In that case the effective work is (fig. 48), since $P V = \text{constant}$,

$$- P_a V_a + P_a V_a \log_e \frac{P_1}{P_a} + P_1 V_1$$

$$= P_a V_a \log_e \frac{P_1}{P_a},$$

or exactly equal to the absolute work of compression H F D E. But the heat abstracted during compression is equal to the same

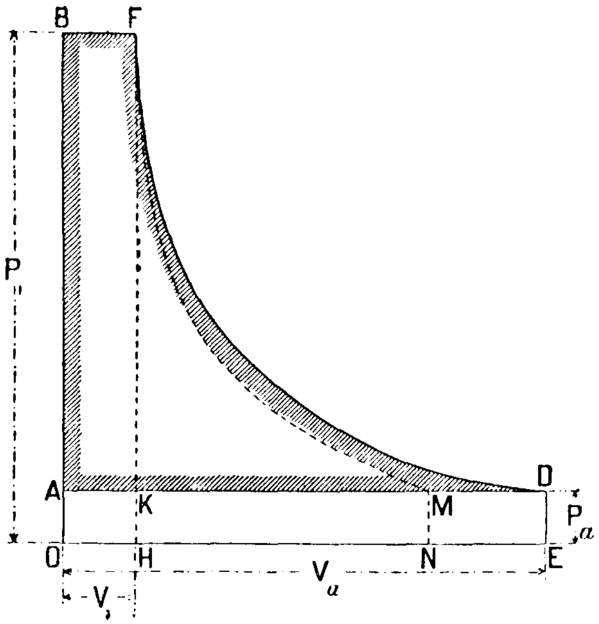

FIG. 18.

quantity. Hence the curious result is arrived at that in the most economical compression, the effective work of compression is entirely abstracted as heat and wasted. All the compression does is to put the air in a condition to do work in a motor at the expense of its intrinsic energy. In that way there is obtained an amount of work nearly equal to the work done in compression. But the work in the motor is not strictly the restoration of the energy expended in the compressor, but energy borrowed from the air. Hence the conditions of transmission of power by compressed air are different from those of transmission by pressure water.

Case of Adiabatic Compression.—The volume of one pound of air at the final pressure P_1 will be

$$V_1 = V_a \left(\frac{P_a}{P_1}\right)^{\frac{1}{\gamma}} = 13{\cdot}09 \left(\frac{P_a}{P_1}\right)^{0{\cdot}71}$$

The absolute work of adiabatic compression is per pound of air

$$\frac{P_1 V_1 - P_a V_a}{\gamma - 1}.$$

Hence the effective work in one revolution of the compressor (A B G D, fig. 47) is

$$\frac{P_1 V_1 - P_a V_a}{\gamma - 1} + P_1 V_1 - P_a V_a$$

$$= \frac{\gamma}{\gamma - 1} P_a V_a \left[\left(\frac{P_1}{P_a}\right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]$$

$$= 95630 \left[\rho^{0{\cdot}29} - 1\right] \text{ foot lbs.}$$

Case of Partially Cooled Compression.—The general equation for the work expended in compression is the same as for adiabatic compression, if n is substituted for γ.[1] If the index of the expansion curve is $n = 1{\cdot}25$, the work expended per pound of air is

$$138550 \left[\rho^{0{\cdot}2} - 1\right] \text{ foot lbs.}$$

Rise of Temperature during Compression.—For isothermal compression the temperature is constant. In any other case

$$T_1 = 521 \rho^{\frac{n-1}{n}}$$

For adiabatic compression substitute γ for n. The rise of temperature is considerable, as the following table shows:—

[1] Let P_a V_a T_a correspond to the initial, and P_1 V_1 T_1 to the final, conditions in any compressor. Then

$$n = \frac{\log (P_1/P_a)}{\log (V_a/V_1)}$$

$$= \frac{\log (P_1/P_a)}{\log (P_1/P_a) + \log (T_a/T_1)}$$

$\frac{P_1}{P_a}$	p_1 lbs. per sq. in. absolute	Temperature reached in compression		
		Isothermal $n = 1$	Partially cooled $n = 1{\cdot}25$	Adiabatic $n = 1{\cdot}41$
		°	°	°
2	29·4	60	137	176
3	44·1	60	187	255
4	58·8	60	226	318
5	73·5	60	256	370
6	88·2	60	284	415
7	102·9	60	307	455

Unnecessary Waste of Work in Heating the Air in the Compressor.—If the compressed air were used in a motor directly adjacent to the compressor, in its heated state, there would be no necessary loss due to rise of temperature during compression. Commonly the air is used at a distance, and has cooled from T_1 to atmospheric temperature T_a and shrunk in volume from B C to B F (fig. 47) before reaching the working point. The most economical compression for air transmission would be isothermal