THE DESIGN OF AN AIR COMPRESSOR.

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O U T L I N E.

Description.

Computations.

1. Cylinder volume.
2. Clearance.
3. Horse power.
4. Thickness of cylinder walls.
5. Size of pipes.
6. Main shaft.
7. Connecting rod.
8. Fly wheel.

The machine of which the plates herewith attached are the assembled drawings is to be a Nine horse-power, Belt-driver Air Compressor designed to discharge fifty cubic feet of free air per minute, at a maximum pressure of 100 pounds per square inch. It is to be of the vertical type, with two single acting cylinders. The machine is to be run at one hundred and twenty revolutions per minute, with an eight inch stroke. Each cylinder compresses the air to the pressure in the reservoir, and delivers directly into the discharge pipe.

In computing the cylinder volume, let V. equal the piston displacement and v equal the cylinder volume, V equal the volume of free air per minute, and N equal the revolutions per minute. Then the piston displacement will be

$$v = \frac{V}{2N} = \frac{50}{240} = .2083 \text{ cubic feet.}$$

This result furnishes a basis on which to compute the clearance. The volume of the piston displacement .2083 multuplied by the number of cubic inches in a cubic foot or 1728 gives 359.424, the number of cubic inches in the piston displacement. This divided by the stroke 8 inches, gives a piston area of 44.678. The circle whose area is the next larger than 44.678 square inches is 7 3/4 inches in diameter; but as the clearance has not been taken into account, and as this will increase the volume of the cylinder, the diameter of the cylinder will be taken at eight inches first. Then the piston displacement will be approximately 400 cubic inches.

In computing the clearance, it was assumed that the piston would approach within 1/16 of an inch of the cylinder head. The clearance volume would be 1/16 times the area of an 8 inch circle or 1/16 X 50.27 = 3.2 cubic inches. The clearance of the valves consist of the volume of one half of a 2 inch inlet valve, and the volume of one half of an inch discharge valve. The valves are respectively with thickness of the cylinder walls added 4.9 and 3.25 inches long. The inside areas are respectively 4.4 and 1.3 square inches. Then one half of the volume of the inlet valve is 4.9 X 4.4 ÷ 2 = 11.88 cubic inches. The volume of the discharge valve is 1.3 X 3.75 ÷ 2 = 2.6 cubic inches. Then the total clearance volume is the sum of all these volumes or 3.2 + 11.8 + 2.6 = 15.8 cubic inches.

Taking into account the clearance volume, and computing the cylinder volume v we proceed as follows: The clearance expressed in terms of the piston displacement would be $\frac{1}{c} = \frac{15.8}{400} = .039$. Then the compressed air which remains in the clearance space in expanding down from P_2 to P_1 will occupy a volume

$$\frac{1}{c} \left(\frac{P_2}{P_1} \right)^{\frac{1}{n}}$$

of the piston displacement. Then the total volume of the free air delivered per minute V would be

$$V = v + \frac{v}{C} - \frac{v}{C} \left(\frac{P}{P} \right)^{\frac{1}{n}} 2N$$ if N is the number of revolutions.

In these computations, the exponent n is the ratio between the specific heat of air at constant pressure C_p and the specific heat at constant volume Cv or

$$N = \frac{Cp}{Cv}$$

when Cp = .238 and Cv = .168. Then

$$N = \frac{.238}{.168} = 1.41$$

N is commonly used as 1.4. Then the cylinder volume v may be found from the above equation for V

$$V = v\left(1 + \frac{1}{C} - \frac{1}{C}\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}\right) 2N$$

or

$$v = \frac{V}{\left(1 + \frac{1}{C} - \frac{1}{C}\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}\right) 2N}$$

$$v = \frac{50}{.887 \times 240} = 0.23 \text{ cubic feet.}$$

$$v = 0.23 \times 1728 = 397.4 \text{ cubic inches}$$

which does not quite reach the volume of an 8 X 8 cylinder.

The next thing to consider will be the horse power the machine will use in doing the work required. Considering the horse power of a single acting piston working in a cylinder whose area is A square feet, and whose length of stroke is L feet. If the fly wheel makes N revolutions per minute and if the cylinder is single acting it will make N strokes per minute. If P be the mean effective pressure in pounds per square foot, acting upon the piston. Then the horse power will be represented by

$$H. P. = \frac{PLAN}{33000}$$

Now as LA is the volume of the cylinder in cubic feet, (V =.23) then the above formula becomes

$$H. P. = \frac{P V N}{33000}$$

The mean effective pressure Pm per square inch is

$$Pm = \frac{P.N}{N-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

in which P_1 is atmospheric pressure (14.7#) and P_2 is the maximum pressure per square inch to which the air is raised (100#). N is the same exponent as that used in computing the volume of the cylinder (1.4). Substituting these values in the formula, we get

$$Pm = \frac{14.7 \times 1.4}{1.4 - 1}\left[\left(\frac{100}{14.7}\right)^{\frac{1.4-1}{1.4}} - 1\right]$$

$$Pm = 51.4 \times .711 = 36.5 \text{ pounds per square inch or}$$

$$P = 36.5 \times 144.$$

Then substituting in the formula

$$H. P. = \frac{P V N}{33000}$$

we get

$$H. P. = \frac{36.5 \times 144 \times .23 \times 120}{33000}$$

$$H. P. = 4.43$$

for one cylinder only. The total horse power for both cylinders then is double this or 8.86.

The thickness of the cylinder walls of an air compressor may be computed from formulas used to compute the cylinder walls of a steam engine cylinder as both work under the same conditions. Mr. William Kent in his "Mechanical Engineer's Pocket Book" gives for small cylinders working under 100 pounds pressure the following formulas:

$$t = .003 D \sqrt{p}$$

$$t = .00028 p D$$

in which D is the diameter of the cylinder in inches and P is the maxi-

maximum pressure per square inch acting upon the piston. Then with 100 pounds per square inch acting upon a piston whose diameter is 8 inches, the solution of the above formulas are as follows:

$$t = .003 \times 8\sqrt{100}$$

$$t = .24 \text{ inches.}$$

or

$$t = .00028 \times 100 \times 8$$

$$t \quad .224 \text{ inches.}$$

These results were increased to .5 inches to make the cylinder perfectly safe.

The next part taken up will be the valves. The maximum velocity with which air should travel thru pipes is about 6000 feet per second (Kent). Then Mr. Kent gives for the diameter of the pipe in inches

$$d = 0.1161\sqrt[5]{\frac{LQ^2}{pr}}$$

In which L is the length of the pipe in feet, taken at 100, P is the pounds difference of pressure in square inches causing the flow assumed at 2 pounds, v is the atmospheres, or the ratio of absolute pressure (100 ÷ 14.7) ÷ 14.7= 7.8, and Q is the cubic feet of free air delivered in one minute (50). The above formulas applies only to flow of air in pipes under pressure; therefore, it will only apply to the discharge pipes. Then substituting

$$d = 0.1161\sqrt[5]{\frac{100 \times 2500}{2 \times 7.8}}$$

$$d = .804$$

This was increased to one inch. The formula for air transmission thru pipes not under pressure given by Mr. Kent is

$$d = \frac{L\,V^2}{363300\,P}$$

in which d is the diameter in inches, L is the length in feet taken at 100, v the velocity in feet per second, and P is the difference in pressure causing flow per square inch. With air traveling 6000 feet per second v would be 100 also. P was taken as before at 2 pounds. Then substituting

$$d = \frac{100 \times 100 \times 100}{363300 \times 2}$$

$$d = 1.38$$

which was increased to 2 inches. To verify these results the thermodynamic formula

$$\left(\frac{V_1}{V_2}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}$$

may be used, in which the v is the volume of one inch in length of the intake pipe and V is the volume in one inch in length of the discharge pipe if the lengths are unity then their volumes will be as their areas, which are v = 3.14 v = .78. Then

$$\frac{3.L4}{78} = \left(\frac{100}{14.7}\right)^{\frac{1}{1.4}}$$

or $4 = 3.93.$

These diameters make the volume ratio larger than the pressure ratio; therefore, the pipes are ample to convey the air.

In computing the strength of the main shaft the formula

$$d = a\sqrt[3]{\frac{H.\ P}{R}}$$

given by Mr. Kent for steam engine was used. d is the diameter in inches H. P. is the horse power and a is a constant computed for the torsional strength of steel at a factor of safety of from 5 to 10. For a factor of safety of 8 A is 3.5. Then if R is the revolutions per minute we have

$$d = 3.5\sqrt[3]{\frac{9}{120}}$$

$$d = 1.47$$

as a larger diameter gives better bearing surface this value was increased to 2 inches. The bearings are so arranged that there is bending of the shaft, so resistance to bending was not taken into account.

For connecting rods for steam engines Kent gives for the diameter at the middle (d)

$$d = \frac{D}{55}\sqrt{P}$$

and at the ends (d)

$$d = \frac{D}{60}\sqrt{P}$$

in which D is the diameter of the cylinder in inches and P is the maximum pressure. Substituting in these $D = 8$ and $P = 100$ we get

$$d = \frac{8}{55}\sqrt{100} = 1.45$$

$$d = \frac{8}{60}\sqrt{100} = 1.33$$

The diameter at the middle was taken at 2 inches and at the ends as 1 1/2 inches.

It is the duty of the flywheel to receive energy at one part of the stroke, and by virtue of its inertia to restore it in that part of the stroke in which the machine is doing its heaviest work, in this way keeping the speed nearly constant. Let ΔE be the excess of energy received, or the work performed above the mean during a given interval, and E_0 be the mean actual energy. Then Rankine's coefficient of fluctuation is $\frac{\Delta E}{2E_0}$. This has been found by actual experiment to vary from 1/6 to 1/4. Kent gives for the weight of the rim of a flywheel:-

$$W = \frac{mg\Delta E}{V^2}$$

in which m is the reciprocal of the intended value of the coefficient of fluctuation usually taken at 1/32; then m would be 32, g would be gravitation or 32, ΔE may be found from the above values.

$$\frac{\Delta E}{2E_0} = \frac{1}{6}$$

$$\Delta E = \frac{1}{6} \times 2E_0$$

The mean actual energy for one revolution will be

$$2E_0 = \frac{H.P \times 33000}{N}$$

if H.P. equal the horse power and N equals the number of revolutions per minute. Then

$$2E_0 = \frac{9 \times 33000}{120} = 2475$$

$$\Delta E = \frac{1}{6} \times 2475 = 412$$

Then putting these values in the formula for the weight of the fly-wheel we get

$$W = \frac{32 \times 32 \times 412}{625} = 675 \text{ pounds.}$$

The face of the wheel (b) will be taken at 8 inches and if the mean diameter is taken at 43 inches the circumference (c) will be 135 inches. The weight of a cubic inch of cast iron (w) is .26 pounds. Then if (W) be the total weight of the rim in pounds, the thickness (t) of the rim will be

$$t = \frac{W}{C\,b\,w}$$

$$t = \frac{675}{135 \times 8 \times .26}$$

$$t = 2.4 \text{ inches.}$$

The thickness was taken at 2 1/2 inches, which gives a wheel a little over 700 pounds in weight. The plans show the design of the compressor according to these general requirements, and give details of construction.