piping. This bears a definite relation to the perimeter and area of the duct, varying with the roughness of the wall surface and the velocity of flow. The other kind of loss exists where the air is turned around a corner, as in elbows, or where a change in section of the pipe causes an increase or decrease of velocity. This is a dynamic loss and varies with the degree of abruptness of the shock.

For the ordinary velocities used in duct work the flow of air is turbulent and the friction and shock losses vary substantially as the *square of the velocity* and are therefore usually expressed as a per cent of the velocity head.

STATIC, VELOCITY AND TOTAL PRESSURES

The flow of air in a duct or pipe is under the influence of three distinct pressures namely, the velocity, static, and dynamic or total pressures. The *velocity head* or *pressure* (*VP*) is defined as that pressure which is required to create the velocity of flow, that is, the pressure or head required to accelerate the mass from a state of rest to the final velocity attained. The *static head* or *pressure* (*SP*), also termed the frictional or resistance pressure or maintained resistance, is that pressure required to overcome the resistance offered to the flow. This, in reality, is the pressure tending to burst the pipe as would be measured by the ordinary pressure gage. The *dynamic head* or *pressure* (*TP*), also termed the *total* or *impact* pressure, is the sum of pressures required to overcome the resistance to flow and create the velocity of discharge. That is

$$TP = SP + VP \text{ or } VP = TP - SP$$

FUNDAMENTALS OF DUCT DESIGN

The sizes of ducts and flues for gravity or mechanical circulation of air are based on the losses due to friction, and these losses must be kept within the available pressure difference. This pressure difference in mechanical ventilation is that derived from the fan; while in gravity ventilation the aspirating effect due to the temperature and height of the column of heated air causes the pressure difference.

The general rules to be followed in the design of a duct system are:

1. The air should be conveyed as directly as possible at reasonable velocities to obtain the result desired with greatest economy of power, material, and space.
2. Sharp elbows and bends are to be avoided.
3. All ducts or flues shall have sides as nearly equal in size as possible. (In no case shall the ratio between long and short sides be greater than 10 to 1.)

The ducts for a school, theater or other public building, where freedom from noise and elimination of drafts is essential and where branch ducts serve individual rooms, present more difficult problems in design than are involved in proportioning ducts intended for heating a factory, where a main duct of decreasing dimensions extends lengthwise of the building and gives a uniform distribution of air. For public buildings air velocities must be kept low, the range being from 900 to 1,200 ft. per minute while in industrial buildings velocities may range from 1,500 to 2,000 ft. per minute or even more.

The higher velocities reduce the cost of the ducts but, of course, increase the cost of power for driving the fans.

The standard velocities of air for public buildings are as follows:

1. Through the outside air intakes 1,000 ft. per minute.
2. Through connections to and from heater 1,000 to 1,200 ft. per minute.
3. Through the main discharge duct from 900 to 1,200 ft. per minute.
4. In branch ducts 600 to 1,000 and vertical flues 400 to 800 ft. per minute.
5. In registers or grilles 200 to 400 ft. per minute depending upon the size and location.
6. If diffusers of proper design are used, 25 per cent higher air velocities may be permitted.

The general procedure for designing a duct system is as follows:

1. Study the plan of the building and draw in roughly the most convenient system of ducts, taking cognizance of the building construction, avoiding all obstructions in steel work, equipment, etc., and at the same time maintaining a simple design.
2. Arrange the positions of duct outlets to insure the proper distribution of heat.
3. Divide the building into zones and proportion the volume of air necessary to supply the heat for each zone.
4. Determine the size of each outlet based on the volume as obtained in the preceding paragraph, for the proper outlet velocity.
5. Calculate the sizes of all main and branch ducts by either of the following two methods:
   a. *Velocity Method.* Arbitrarily fix the velocity in the various sections, reducing the velocity from the point of leaving the fan to the point of discharge to the room. In this case the pressure loss of each section of the duct is calculated separately and the total loss found by adding together the losses of the various sections.
   b. *Friction Pressure Loss Method.* Proportion the duct for equal friction pressure loss per foot of length.
6. Calculate the friction for the duct offering the greatest resistance to the flow of air, which resistance represents the static pressure which must be maintained in the fan outlet or in the plenum space to insure distribution of air in the duct system. The duct having the greatest resistance, will usually be that having the longest run, although not necessarily so.

FRICTION LOSSES

The loss of head caused by friction, which is numerically equal to the pressure required to maintain a given velocity, may be most easily expressed by the modification of the Fanning formula, when, dealing with round pipe and standard air (70 deg. fahr. — 29.92 in. Barometer).

$$h = z\,\frac{L}{D}\,h_v = \frac{L}{ED}\left(\frac{V}{4005}\right)^2 \qquad (3)$$

When dealing with rectangular ducts and standard air,

$$h = z\,L\left(\frac{a+b}{2ab}\right)h_v = \frac{L}{E}\left(\frac{a+b}{2ab}\right)\left(\frac{V}{4005}\right)^2 \qquad (4)$$

where

h = loss of head in inches of water.
V = velocity of air in feet per minute.
L = length of pipe.
D = diameter of pipe.
a = one side of rectangular duct.
b = other side of rectangular duct.
(L, D, a, b: All in feet or inches.)
z = coefficient of friction which varies from about 0.01 to 0.03.
E = length of pipe in diameters for one head loss.

It will simplify calculations to consider that the values of z and E vary only with the nature of the pipe surface. Thus, E may be taken as