ELECTRICALLY DRIVEN VENTILATION BLOWERS

THESIS FOR DEGREE OF E.E.

L. C. BROOKS

1908

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GENERAL.

In discussing the subject of electrically driven blowers, the idea is to included the subject only so far as it relates to ordinary ventilation purposes, as buildings and ships, the application for forced draft for boilers, foundry blast, etc., depending upon practically the same principles, though specially designed wheels are required where excessive pressures are desired. The subject matter given has been acquired partly from personal experience and partly from collected data. Thanks are extended to the General Electric Co., for a part of the data furnished regarding fans.

A considerable amount of material has been published during the past few years regarding the uses of fans, but the average commercial fan does not take into account the possible high efficiencies necessary for economic results, and in many cases, the customer gets something that he does not want, and which is relatively expensive to operate, because the first cost is cheap.

The relative advantages of electrically driven fans over steam driven ones are as follows.

(a) Small motors are more efficient than small engines thereby allowing the use of more and smaller fans. This greatly reduces the piping and reduces the number of openings in the water tight bulkheads.

(b) Small ventilation sets are more easily installed and cared for than larger ones.

(c) The network of steam pipes from the boiler to the fans is avoided, thus reducing the losses from condensation and the spaces passed through are not heated by the radiation from the steam piping.

(d) A well built motor will run continuously for a long period of time without repairs, while a steam engine, especially of small size, requires constant overhauling, as there are a number of small wearing parts. Also a motor is much more clean in operation than an engine.

The past practice has been to use both the plenum and exhaust system of ventilation, but at present, only the plenum system is used, it being more efficient and is more satisfactory, as in a hot climate better results are obtained by driving fresh air into a compartment, and letting it get out the best way it can, rather than to exhaust the heated air and having it replaced by natural supply from an unknown source. The exhaust system is used and is best adapted for wash rooms and water closets.

The modern battleship contains quarters for 800 to 1000 men, besides magazines, store rooms, engine rooms and dynamo rooms, which must be supplied with fresh air at a rate of complete change of air varying from once in 3/4 minutes in dynamo rooms to once in 8 minutes in quarters and living spaces. To accomplish this about 100,000 cu.ft., of air must be delivered per minute, the number of fans being about 30, of various capacities to suit the requirements of the compartments ventilated.

FANS.

A sketch showing capacities and approximate sizes of fans now in use is given in plates1 and 2. The fan wheels and casings are of a built up structural steel structure, the casings being made convertible, so that in case one fan is put out of commission from any cause, it may be replaced by one from a less important location if desired. The plates should be of sufficient thickness and the reinforcement of sufficient strength to resist the pressure of the air and prevent vibration. All wheels and casings should be well galvanized to prevent corrosion. The wheel hubs should be brass bushed to prevent "freezing" on to the shaft. The inlet and outlet should be of practically the same area, the inlet being circular and the outlet rectangular in shape.

The motors should be especially well constructed as regards hard service, rigidity, commutation, and low heating requirements. They should be shunt wound and capable of about 20% speed reduction by varying the field strength. The fan wheel should be fastened to an extension of the motor shaft, and the construction of the motor and the set as a whole should be such as to permit the armature being removed from the commutator end. Open type motors should be used wherever possible, in order to reduce weight. The motor bearings to be of sufficient size to carry the required weight with the least possible wear and to have sufficient lubrication by oil rings.

Before the fans are installed on the ship, they should be given an exhaustive test(usually 2 days run) to insure that they operate satisfactorily and give the required air deliveries. In testing for air deliveries, the following procedure should be followed, the same having been found by experiment and practice to fit operating conditions.

A straight tube to be fitted to the outlet of the fan, this tube being of the size of the fan outlet, and in length equal to 20 times the average length and breadth of the outlet. A double Pitot tube designed to indicate impact pressure of moving air, also static pressure to be inserted in the center of the outlet tube. A sketch of a Pitot tube that has proven satisfactory for this work, is shown on plate 3. The two outlets of the Pitot tube to be connected to accurately reading hook gauge manometers. The velocity and pressure of the moving air in the pipe should be such that the pressure side of the Pitot tube shall not be less than 13.4 times the weight per cubic foot of air in pounds and the impact side of the Pittot tube should not be less than 17.4 times the weight per cubic foot of air in pounds. The weight of air should be corrected for barometric pressure and wet and dry bulb thermometer temperatures. Standard conditions of air being 70°F, 70% humidity and barometric height of 30 inches, the weight being 0.07465 lbs. per cu. ft.

In connection with pressures, it has been found that a pressure of 5.2 pounds per sq.ft.,(one inch of water) is the most satisfactory for ordinary ventilation purposes, the size of pipe being such as to give 2000 to 2200 ft. velocity per min. Higher velocities than this giving excessive noises in the piping due to eddies and producing circulation in the living quarters that is uncomfortable. In measuring pressures, the Pitot tube has been found to give most reliable results as all forms of anemometers have been proven entirely unreliable, care must be exercised in making the Pitot tube to prevent the aspiration effect of the current of air across the small round hole, thereby producing eratic results. In case extreme accuracy is desired, a number of Pitot tubes may be inserted in the outlet pipe, all of them being connected to one pressure recording manometer. However for practical purposes the one tube is sufficient. An increase of 10% above the minimum pressures noted above may be allowed.

In calculating the air delivered the following developed formulae are applied.

W = weight of air in lbs. per cu.ft.

V = Volume in cu.ft. per min.

v = Velocity in ft. per min.

$h1$ = impact pressure in inches of water.

$h2$ = Static " " " " ".

$h3$ = $h1 - h2$ = velocity head in " ".

A = area of outlet in square ft.

H.P. = horse power in air delivered by fan from which

$$v = 997 \sqrt{\frac{h3}{W}}$$

$$V = Av$$

$$H.P. = \frac{5.2 \times h1 \times V}{33000}$$

This will give the horse power in moving air. The average fan gives an efficiency of about 40 to 45 %, from which the required horse power of the motor may be determined. By making the outlet and inlet of the fan slightly bell mouthed with special wheels, the efficiency is increased to 50 or 55 %. In fact, fans have been constructed with an efficiency of 70 %, but these are not yet a commercial possibility. In case higher pressures were allowed, the efficiency would be increased.

PIPING.

After the question of the fan has been settled, the distributing piping should receive careful attention, for a satisfactory ventilation system may not be obtained if the piping is improperly done. It is not the intention to discuss this subject in minute detail, but rather to state a few thoughts which have been found by experience to exist.

Of course, the great obstacle to be overcome in a piping system, is friction. This may exist in the form of rough interior pipe, sharp turns, or improperly designed outlets and branches.

It is generally understood that the frictional resistance of air in pipes varies as the square of the velocity of flow, and the work of forcing the air through the pipe increases as the cube of the increase in quantity, but that the coefficient of friction does not change with the size of the pipe or velocity of air. That is if we double the quantity of air passed in the same pipe, the work lost by friction is increased 8 times, and if we double the linear dimensions of the pipe, the work lost is decreased to one fourth. The coefficient of friction for air in well constructed pipes has been found by manufacturers to be about 0.0001.

As stated above the best results are obtained with air in the mains at a pressure of about 5.2 pounds per

sq.ft., plus about 1 1/2 lbs. for velocity head and a velocity of 2000 to 2200 ft. per min.The angle at which the branches leave the mains may ~~be~~ vary from 30^{o} to 45^{o} with equally satisfactory results. But the air leaving the branches should not exceed 1000 ft. per min. velocity. This of course requires that the branch pipe be enlarged. This enlargement should be in the form of a cone (or taper) to prevent eddies, expanding at the rate of 1 1/2 inches per ft. In small pipes this may be increased to 3 inches per ft.

The accepted formula for loss in head due to friction of the piping is :

$H = 4 \times f \times \frac{l}{d} \times V_1^2$

H = loss in head.

f = Coefficient of friction.

l = length and d = diameter of pipe in inches or ft.

V_1 = velocity of air in ft. per sec. from which the size of piping required at any part of the system may be determined.

In designing the mains where branches are taken off along the mains, the size need not be changed until the velocity of the air reamining in the mains is reduced to 1500 ft. per min., then contract the main with a taper, as explained above.

Where elbows are necessary in the piping, they should be made very smooth, the radius of the centre of the pipe being not less than 1 1/2 diameters. In figuring lengths, 1 - 90^{o} elbow is equal to about 3 feet of pipe.

THEORY of FANS.

A ventilation blower may be considered to be a special type of centifugal pump. As it is sometimes erroneously supposed that the pressure developed by a blower or pump is due to the peripheral velocity of the motor as it leaves the wheel, that is

Pressure head, $H = \frac{v^2}{2\,g}$, a brief discussion may be in order, as a great portion of this peripheral velocity is spent in eddies, unless proper diffusion vanes are used.

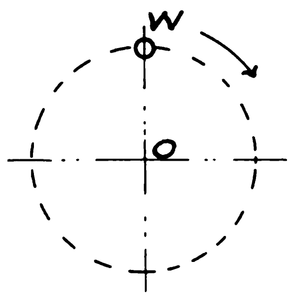


FIG. 1.

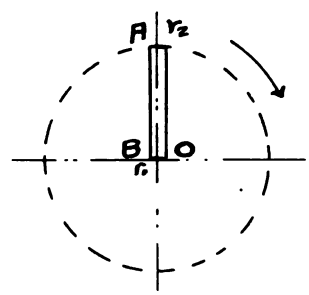


FIG. 2.

In fig. 1 let w represent a body revolving about centre O. Its mass is $\frac{w}{g}$ and centrifugal force $= \frac{WV^2}{g\,r} = \frac{MV^2}{r}$

If a tube is filled with fluid, fig. 2, and open at the inner end, each particle exerts a centrifugal force dependent upon its mass, and distance from the centre. The total centrifugal force or pressure per sq.ft. $P = \frac{MV^2}{2} = \frac{WV^2}{2\,g}$ where M = mass of unit volume, assured in air calculations to be 1 cubic foot.

If the tube does not reach the centre, $P = \frac{W}{g}\,\frac{(V_2^2 - V_1^2)}{2}$

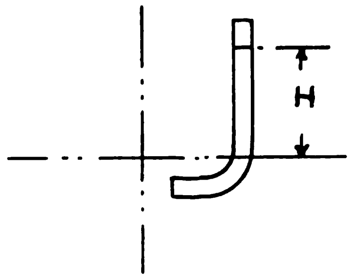
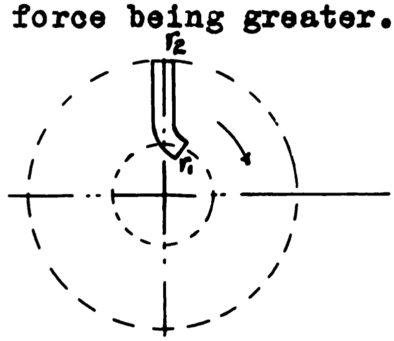


Fig. 3 . A bent tube dipping in the fluid and revolving about a vertical axis, fig.3 the centrifugal force will raise the fluid toa height H - where $H = \frac{P}{W}$, $W =$ weight of unit volume, therefore $H = \frac{V_2^2 - V_1^2}{2\,g}$

If the tube extends to the vertical axis, $V_1 = 0$ and $H = \frac{V_2^2}{2\,g}$,

the centrifugal force being greater.



If the tube is bent slightly forward, as shown in fig.4, it will act like a Pitot tube and produce a head $H = \frac{V_1^2}{2\,g}$ which makes up for the loss of centrifugal force, as the tube does not extend to the axis of rotation, the total head being produced by the centrifugal force and the Pitot tube effect.

Now if the upper end of this tube be cut-off below the head to which the fluid is raised, the fluid will flow out through the end of the tube with a velocity due to the amount that the pipe is cut off below this head, neglecting friction. Call this amount cut off $H2$ and the velocity of the fluid through the tube as C - then $C = \sqrt{2\ g\ H\ 2}$.

If no fluid is discharged, the onlywork done is overcoming friction, but if water is discharged work is done in raising a certain quantity of water per second through the height of the tube, plus the kinetic energy of the moving fluid. This static head of the fluid plus the velocity head of discharge equals the total head produced by the revolving pipe.

Assume quantity of fluid discharged per sec. = Q , and weight of one cu. ft. = K , the work done in raising the fluid is Q K H, $H = \frac{V^2}{2\ g.}$ therefore work done in raising Fluid $= \frac{Q\ K\ V^2}{2\ g}$.

The kinetic energy due to accelerating the fluid up to this velocity is $\frac{M\ V^2}{2} = \frac{Q\ K\ V^2}{2\ g}$.

Therefore the total work done on the fluid by revolving the tube is $\frac{2\ Q\ K\ V^2}{2\ g} = \frac{Q\ K\ V^2}{g}$

This is the condition under which a fan wheel acts. The wheel being considered to be made up of several tubes or channels assembled together between two guide rims, taking the fluid at the inside ends and discharging it at the outside ends, the channels being cut off at the inside ends to provide for the intake of the air. The relative velocity with which the air escapes from the wheel being much less than the relative velocity with which the inner edge of the blade appraoches the fluid. As explained above, when the fluid is drawn inuthe intake and the tubes)blades) filled, and the wheel rotated, the fluid will be drawn up the tube and discharged out through the wheel. The centrifugal force produces an outward pressure, $H = \frac{V_2^2 - V_1^2}{2g}$. The static will be equivalent to total pressure, diminished by the velocity of the outgoing air. By turning the inner edge of the blades forward toward the direction of rotation a reaction effect is produced as shown in the case of the single tube, and if the blades are bent sufficiently forward, the combined reaction and centrifugal effect is the same as the centrifugal effect of the blades extending entirely to the centre - $H = \frac{V_2^2}{2g}$, (the velocity head of the outgoing air) There is also the velocity of rotation, which is lost when

the wheel discharges freely in the air. This is in the form of kinetic energy and should be saved.

The way of doing this is by the use of a spiral shaped casing surrounding the wheel, and as the air leaves the wheel at a high velocity, it is gradually reduced in speed and leaves the outlet of the fan with a considerable reduced velocity. There is a considerable loss in eddies, the same as a small pipe discharging fluid at a high velocity into a large pipe with less velocity, the energy losses being proportional to the squares of the differences of the two velocities.

Plate 4 shows the general plan of fan construction fig. 1 showing a sketch of the wheel, fig. 2 a sketch of the wheel and casing, and fig. 3 velocity diagrams.

W = velocity in space.

U = Peripheral velocity of wheel.

C = velocity of air along the blade.

As the air comes through the inlet of the blower, it is suddenly turned and starts to enter the wheel in a radial direction. As the inner edge of the blade moves through this air, the air travels outward through the wheel with a radial velocity depending on the area of the wheel (diameter and width). As the relative velocity along the blade depends upon the angle of the blade with

the radius of the wheel and to reduce impact losses to a minimum when the air is caught up by the inner edge of the wheel, the blade is so shaped as to pick the air on edge, the inner edge of the blade being in line with the resulting relative velocity.

The velocity C2 at which the air leaves the outer end of the blade, is determined by the angle which the blade makes with the radius, which is assumed at about 20°.

The theoretical head of the air produced by the wheel, is as follows:-

(a) The static pressure at inner edge of the wheel is less than the atmospheric pressure by the velocity head.

$H = \frac{W_1^2}{2g}$, neglecting inlet losses.

(b) The reaction head produced by the wheel $H = \frac{C_1^2 - C_2^2}{2g}$

(c) The head produced by centrifugal force $H = \frac{U_2^2 - U_1^2}{2g}$

(d) The velocity head of discharged air $H = \frac{W_2^2}{2g}$

being measured above the inlet pressure which is less than the atmospheric pressure by the velocity head.

Eddy and friction losses are disregarded.

The total effect of the wheel is therefore (b) + (c) + (d) - (a) or $H = \frac{(C_1^2 - C_2^2) + (U_2^2 - U_1^2) + (W_2^2 - W_1^2)}{2g}$

The efficiency of the fan however is greatly reduced by the following losses.

(a) At the inlet where the air is suddenly turned froman axial to a radial direction.

(b) Friction of air through the wheel and along the blades.

(c) Converting the velocity head of the discharged air into static pressure.

(d) Leakage around the edge of the wheel.

(e) Friction of the wheel revolving in the air in the casing

(f) Bearing friction due to the weight of the wheel.

By applying the above elementary principles and instructions in connection with the design and constructions of the blowers and piping a satisfactory system of ventitions may be developed which is applicable to all normal conditions.

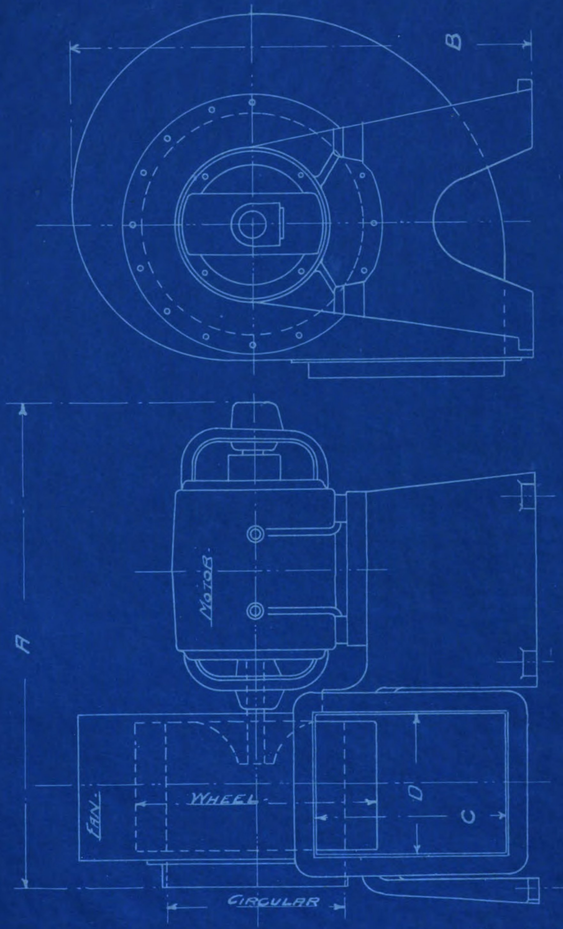


PLATE I.

Capacity cu. ft. per min.	Speed. R.P.M.	Area-Sq. Ft. of Outlet.	H.P. in Air.	A.	B.	C.	D.
2500	1150	1.25	0.5	$40\frac{3}{4}$"	$39\frac{1}{4}$"	15"	12"
4000	900	2	0.85	$46\frac{1}{4}$"	$40\frac{3}{4}$"	19"	15"
5000	810	2.5	1.0	$52\frac{3}{8}$"	$54\frac{5}{8}$"	21"	17"
8000	645	4	1.8	$52\frac{1}{2}$"	$69\frac{1}{2}$"	27"	$21\frac{1}{2}$"
10000	575	5	2.1	$54\frac{3}{4}$"	$75\frac{3}{4}$"	30"	24"
12000	525	6	2.5	$57\frac{3}{4}$"	85"	33	$26\frac{1}{4}$"

PLATE 2.

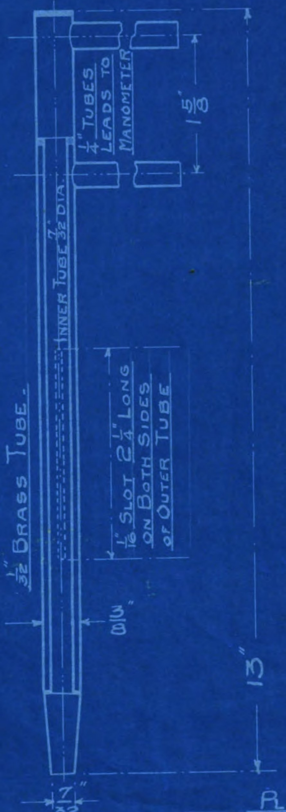

1/4" TUBES
LEADS TO
MANOMETER
1 5/8"
INNER TUBE 7/32" DIA.
1/16" SLOT 2 1/4" LONG
ON BOTH SIDES
OF OUTER TUBE
1/32" BRASS TUBE.
3/8"
13"
7/32"

PLATE 3.

FIG. 1.

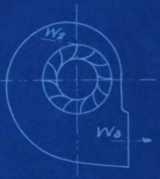


FIG. 2.

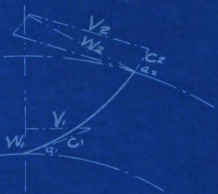


FIG. 3.

PLATE 4.

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