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Analysis and Design Optimization of Axial Fan Test Rig

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Abstract:
This Project on 'Analysis and Design Optimization of Axial Fan Test Rig' is an attempt in which can be used to perform various tests on an axial fan as required in the M.E. Mechanical engineering curriculum. The main objective of the research paper is the designing of the Inlet Duct for the test rig, which can provide the requirements and also performing tests on the same to The use of the standard IS 4894(1987) — variable mass flow rate as per obtain its performance characteristics. 'Specification for Centrifugal Fans' has been referred closely throughout the design process. Use of the CAD Software Catia and Fusion 360 has been done in the modelling and drafting of the necessary components. After conducting the tests, the efficiency of the axial fan has been determined and required performance characteristics have been plotted.
Keyword: ***Fluide Flow, Axial Fan, Test Rig, CFD , Fluide Dyanamic***

INTRODUCTION :

Fans and Blowers are turbo-machines that are used to create flow within a fluid,such as air, Often, the terms fan and blower are used interchangeably and are considered synonyms of each other, Although, both are similar in terms of circulating and supplying air, technically they are quite different from each other. The main difference between a fan and a blower is based on how the air is circulated.Generally, a fan is an electrical device that moves air, whereas a blower is a mechanical device that consists of a fan, and which channels the air from the fan and directs it to a specific location or point. Also, a fan circulates the air around an entire room or a large area, while a blower is only positioned to a specific direction or point.Normally, fans and blowers are widely used in the industrial process, to provide. Air for ventilation; they are used for cooling purposes in the industries. Also, both are widely used in other electrical appliances such as air conditioners, microwaves, furnaces etc. Though, based on the amount of pressure they need in order to produce air, both are used accordingly. Blowers can move volumes of gas at a moderate pressure while fans move large amounts of gas at a low pressure.By definition, a fan is machine that is used to create flow within a fluid, such As air. It consists of vanes or blades that rotate and act on air. This rotating assembly of Blades and hub is known as an impeller, a rotor, or a runner. The impellers help in directing the air flow, and producing air at low pressure. Most fans are powered by electric motors, but other sources such as hydraulic motors and internal combustion engines can also be used.

It includes: Scope, Calculation, Modelling and Drafting, Manufacturing, Assembly, Testing.

OBJECTIVE:

- To design, analyses and manufacture axial fan test rig according to BIS standards.
- To plot axial fan characteristics and find relation between different parameters like discharge, fan total pressure and fan total efficiency at various speeds.
- To establish relationship between flow, speed, pressure and power.

VARIOUS COMPONENTS AND THEIR FUNCTIONS:

- **Inlet Duet** — To provide inlet air Passage to the axial fan with a provision to vary inlet mass flow rate.

Fig.1. INLET DUCT

- **Standard Nets** — To allow variable mass flow rates through the inlet air duct.
- **Pressure Blocks** — Since the pressure across a cross-section might not be uniform due to surface irregularities that may be present in the pipe, so a provision for measuring uniform pressure across a cross-section is made possible with the help of pressure blocks. For this, four tapped holes along the duct surface at a particular cross-section are made at equal angular intervals (90°). There are two pressure blocks connected at two different cross-sections along the duct.
- **Manometers** — A manometer is used to measure the pressure of liquids or gases.This type of pressure measuring tool typically is used to measure relative pressure or absolute pressure. Relative pressure references external air pressure or atmospheric pressure.

1. **Well type manometer:**The well type monometer is widely used because of having only one leg. The main difference between a U-tube manometer and a well type manometer is that the U-tube is substituted by a large well such that the variation in the level in the well will be negligible and instead of measuring a differential height, a single height in the remaining column is measured. Accuracy is achieved by setting zero level of well at zero level of scale before each reading of table. The sensitivity of such monometer is good.
2. **Inclined manometer:** As the name suggests, an inclined manometer involves a gradual incline in the design. This allows for the measurement of minuscule pressure to extremely high levels of accuracy. It is used where the manometric properties of liquids are similar. Again, it is the simplicity, lack of maintenance and no moving parts make it extremely efficient and easy to use.

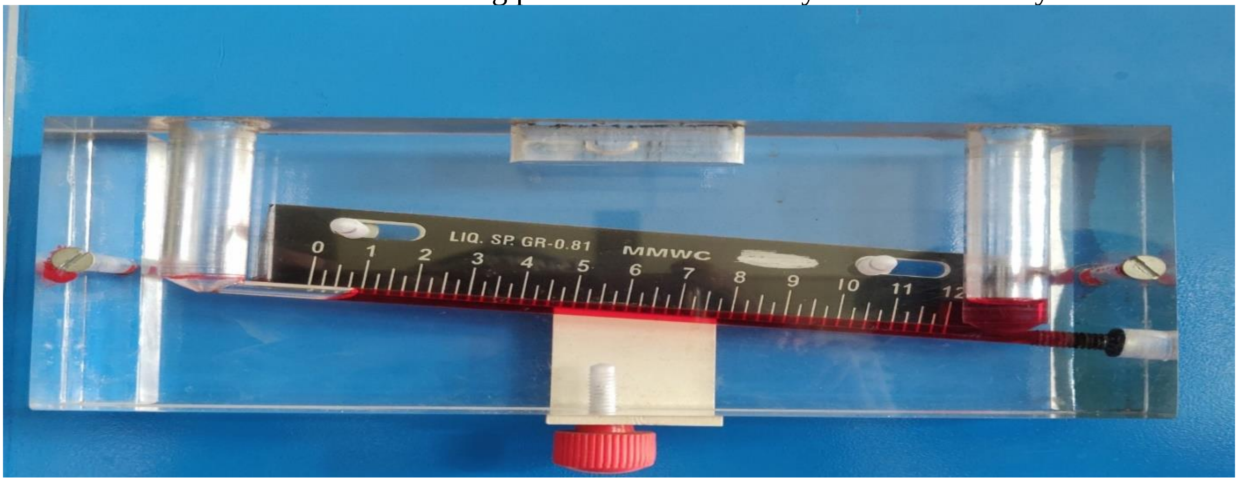

Fig.2 INCLINED MANOMETER

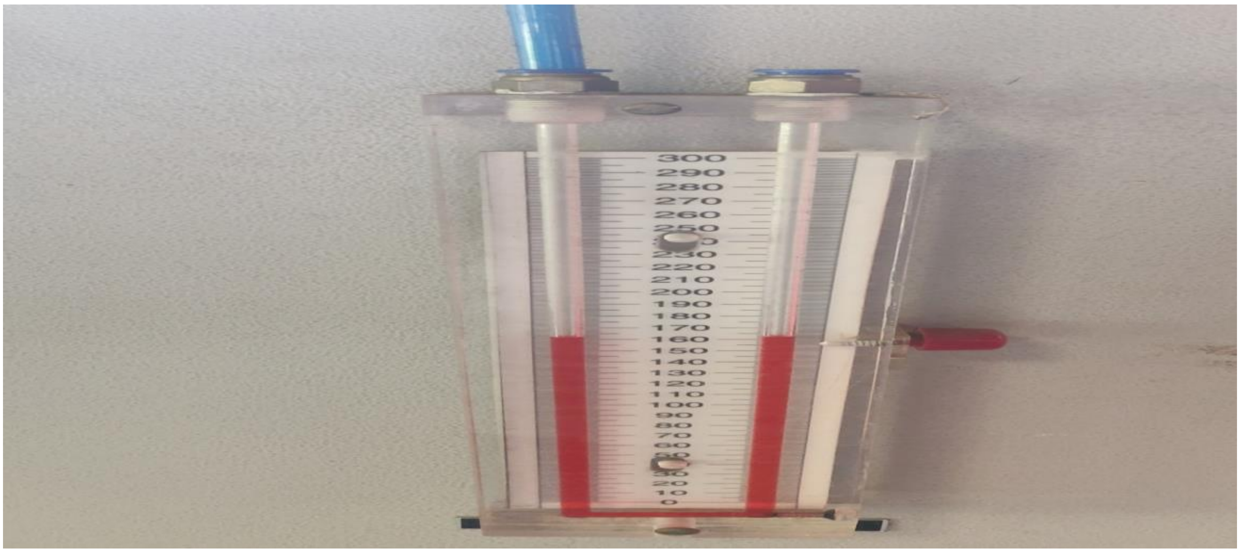

Fig 3. U TUBE MANOMETER

3. **Motor :** It is directly coupled to the impeller and provides necessary shaft power.

Fig.4. MOTOR

4. **Wattmeter :** The wattmeter is an instrument for measuring the electric active power (or the average of the rate of flow of electrical energy) in watts of any given circuit. Electromagnetic wattmeter are used for measurement of utility frequency and audio frequency power; other types are required for radio frequency measurements. Modern digital wattmeter samples the voltage and current thousands of times a second. For each sample, the voltage is multiplied by the current at the same instant; the average over at least one cycle is the real power.Wattmeter vary considerably in correctly calculating energy consumption, especially when real power is much lower than VA (highly reactive loads, e.g. electric motors).

Fig 5. TONG TESTER

5. **Tachometer (RPM indicator) :**The tachometer is a measuring instrument that is used to measure the operating speed of motor in revolutions per minute. It is also known as a revolution counter. The device can measure the rotational speed of the shaft or disc when the machine is in motion. It also indicates the angular speed of a rotating shaft. This instrument is usually used to estimate traffic speed and volume/flow. It is used in cars, aircraft or other vehicles. It shows the rate of rotation of engine crankshaft along with the marking that displays the safe range of rotational speed.An Electric Tachometer works on the principle of relative motion between the magnetic field and shaft of the coupled device. The motor of tachometer works as a generator, i.e. it produces the voltage based on the velocity of the shaft. It counts the number of rotations the crankshaft is making per minute. It is essential for the user to know the RPM of the engine and its operating range to avoid unnecessary damages. The device works on either an alternating or direct current.

- Contact type – This type of tachometer is usually fixed to the machine or electric motor. It works by bringing a freely spinning wheel in contact with a rotating shaft or disc. The shaft drives the wheel to generate the pulses. These pulses are then read by a tachometer and measured in revolution per minute. It can also calculate the linear speed and distance.
- Non-contact type – It is also known as photo tachometer or non-touch tachometer. This type of device doesn't need any physical contact with the rotating shaft. It uses a laser, infrared light, or other light sources to take the measurements. The device sends out the beam of light. This beam reflects each time a tape makes a full rotation. The receiver needs to count these reflections during the process to measure the rotational speed in RPM. This type of tachometer is efficient, durable, accurate, and compact.
    1. It is used to measure rotational speed.

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2. It can measure the flow of liquid with the help of an attached wheel with an inclined angle.
3. It is applicable for the medical sector to measure the blood flow rate of the patients.
4. It is used in vehicles to display the rate of engine crankshaft rotation.

Fig 6. RPM INDICATOR

Fig 7. TACHOMETER

CONSTRUCTION OF INLET AIR DUCT

6. The fan inlet is attached with a straight cylindrical airway of diameter D and minimum length 4D, To the inlet end of the test airway a conical inlet and four side tapping in accordance with Fig. 9 are fitted.

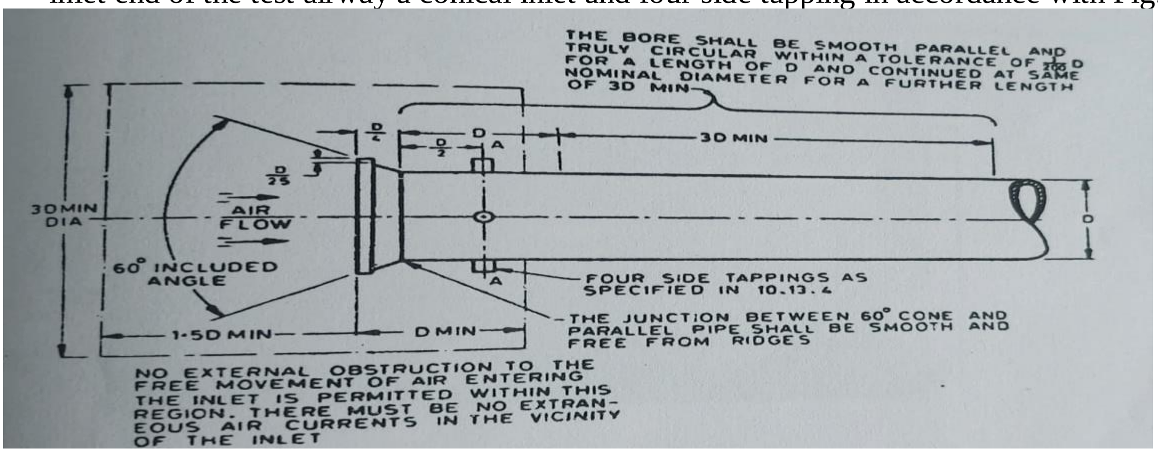

Fig 8.

7. The four side tapping at plane- AA are equally spaced at 90° on the cylindrical duct. The four side tapping are connected to one limb of the manometer. The other limbs of the manometer are opened to the ambient atmosphere and the manometer reading is taken as equal to the average static pressure in the airway.
8. A resistance comprising a screen having evenly spaced aperture of uniform size, not exceeding D/20 is fitted at a distance D from the commencement of the cylindrical portion of the inlet. The screen may be composed of one or more layers of even wire or fabric supported by a wire guard, the various static pressure data may be obtained by changing the screen or adding additional screens in the test duct.
9. At plane BB, distant 2D downstream from the resistance screen, there are four side tapping (fig. 10), similar to those in plane AA, and connected to the low pressure limb of 'a manometer, the other limb being connected to the ambient pressure in the vicinity of the fan discharge.

TERMINOLOGY

For the purpose of this standard, the necessary definitions are given below:
1. Centrifugal Fan - A fan in which the air leaves the impeller in a direction substantially at right angles to its axis.
2. Fan - A rotary machine which maintains a continuous flow of air at a pressure ratio not normally exceeding 1.3.
3. Air - The term air has been used as an abbreviation for 'air or any other gas' except where referred to as 'atmospheric air'.
4. Standard Air - Atmospheric air having a specified weight of 1.2 kg/m which is dry air at 20°C with a barometric pressure of 760 mm Hg.
5. Absolute Pressure - That pressure which is exerted equally in all directions at a point. The absolute pressure of the ambient atmosphere is the barometric pressure.
6. Static Pressure - The difference between the absolute pressure at a point and absolute pressure of the ambient atmosphere. It is positive when above and negative when below the ambient pressure.
7. Velocity Pressure - The pressure equivalent of the air velocity at any particular point. It is always positive.
8. Total Pressure - The algebraic sum of the static pressure and velocity pressure at any particular point.
9. Fan Total Pressure (Pt) - The algebraic difference between the total pressure at the fan outlet and the total pressure at the fan inlet (see also Fig. 1).
10. Fan Velocity Pressure (Pv) - The velocity pressure corresponding to the average velocity at the fan outlet based on the total outlet area.
11. Fan Static Pressure (Ps) - The difference between the fan total pressure and the fan velocity pressure at the fan outlet.
12. Inlet Volume - The volume per unit time of air entering the fan (Q) expressed in m^3/h.
13. Air Power (Total) - That part of the energy, per unit time, imparted by the fan to the air in increasing its total pressure from that at the inlet to that at the outlet.
14. Fan Duty (Total) - The inlet volume dealt with by the fan stated fan total pressure.
15. Fan Duty (Static) - The inlet volume dealt with by the fan at a stated fan static pressure.
16. Fan Total Efficiency - The ratio of the air power (total) to the impeller power,
17. Fan Static Efficiency - The ratio of the air power (static) to the impeller power.
18. Average Fan Total Efficiency - The ratio of the air power (total) to the shaft power.
19. Average Fan Static Efficiency - The ratio of the air power (static) to the shaft power.
20. Side Tube or Static Pressure Tube - A tube which allows air to flow without disturbance past one or more small orifices having their axis at right angles to the direction of air stream in which it is placed.
21. Side Tapping or Static Pressure Tapping - A small opening in the wall of an airway, having its axis at right angles to the wall and so constructed as to allow the air to flow past without disturbance.
22. Facing Tube or Total Pressure Tube - An open-ended tube, the axis of which is coincident with the direction of the air stream in which it is placed. The open-end facing upstream, that is, against the direction of flow.
23. Pitot Tube - A combination of side tube and facing tube as one unit.
24. Size of Fan - The blade sweep in millimetres, the blade sweep being the diameter of the circle traced by the periphery of the impeller. This is also commonly known as wheel diameter.
25. Cooling Air Temperature - The temperature of the surrounding atmosphere in which the fan operates.

Fig 9. TEST RIG ASSEMBLY

MODELLING AND DRAFTING

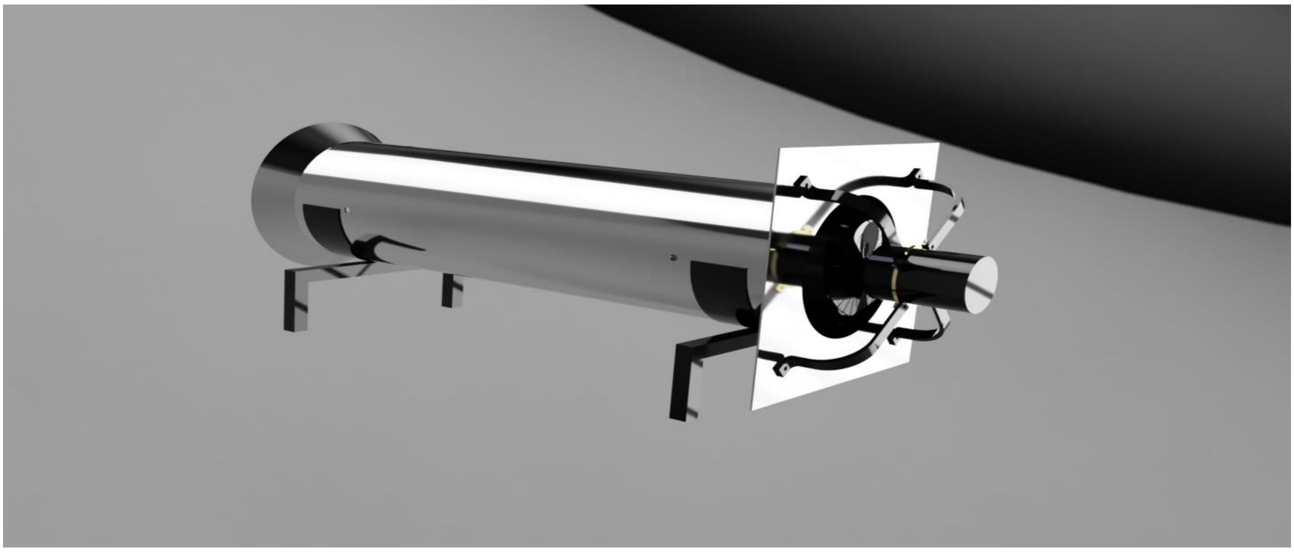

Fig 10. CAD ASSEMBLY

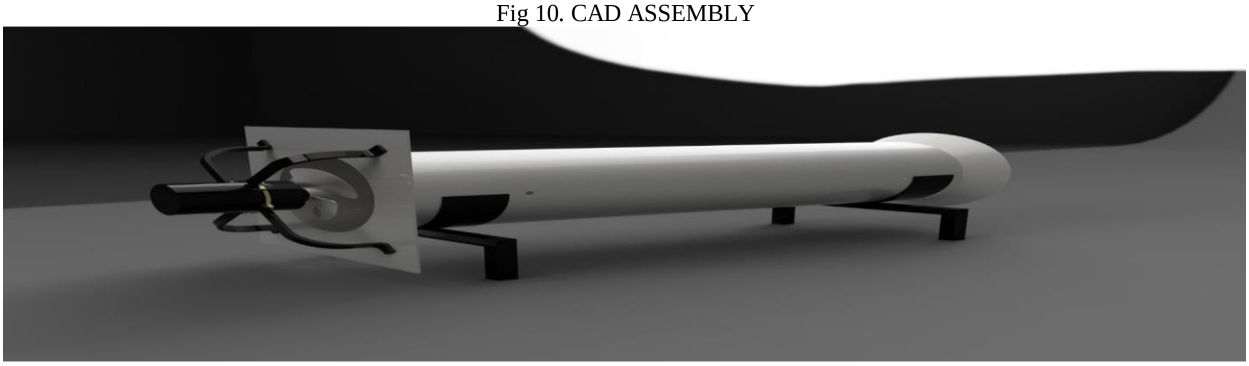

Fig 11. RENDERED IMAGE OF INLET DUCT

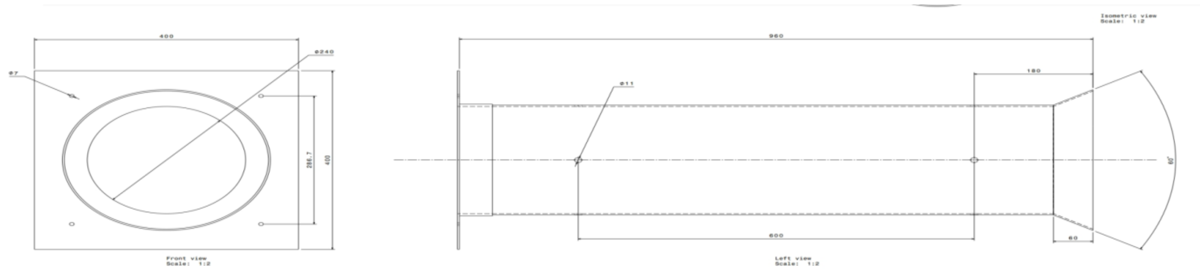

Fig 12. DRAFTING OF INLET DUCT

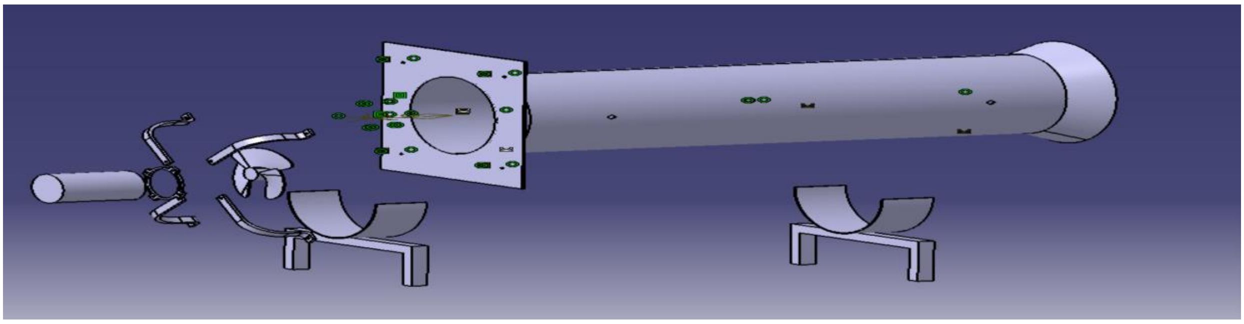

Fig 13. EXPLODED VIEW OF INLET DUCT

MANUFACTURING

Fig 14.

FIG 20.

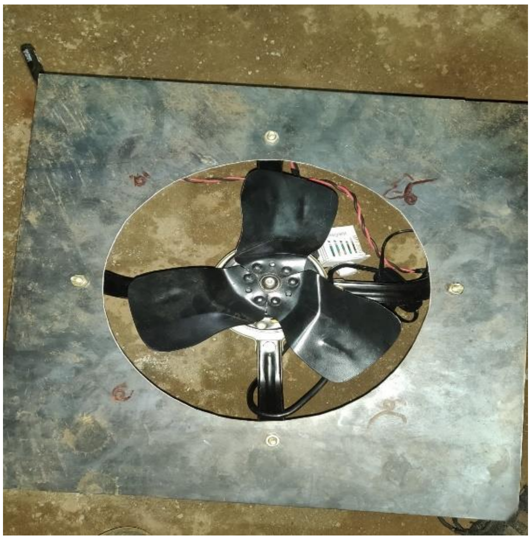

FIG 21.

ASSEMBLY

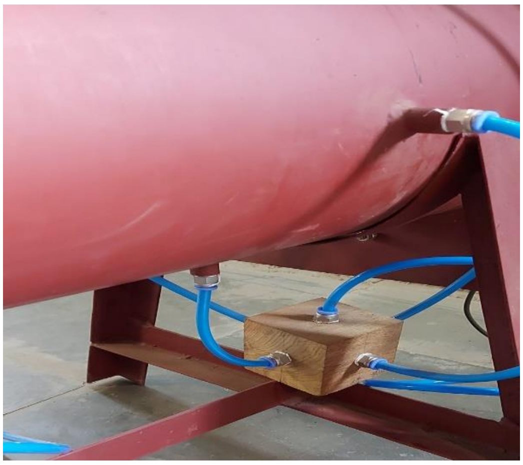

FIG 23.

ASSEMBLY OF SETUP

- The rest of the necessary dimensions of the duct are shown in the above drafting.
  The Standard dimensions are as follows-
  1. Length of Duct = 4D
  2. Position of tapping's = 0.75D from inlet
  3, Distance between tapping positions = 2.5D
  4, Length of conical part = 0.25D mm
  5. Conical inlet angle = 60°
  6. Position of welded mesh = 1.25D
  7. Size of Tapped Holes = 11 mm
  Where D = diameter of the Inlet Duct = 240 mm.

MATERIAL SELECTION

1. **Inlet suction duct:** Mild steel has good malleability, good ductility, and weldability. Its life can be easily increased by using corrosion resistant paint. It is much cheaper than other material with same properties.
2. **Pressure blocks:** wood is used as the material for manufacturing pressure blocks basically due to the properties such as low cost, light in weight, easy availability, stiffness, good strength, corrosion resistant. It is also easily machinable.
3. **Mesh (nets):** Stainless steel and nylon nets are used in the experiment since stainless steel is wear resistant, indestructible. Nylon has light weight, it can be cut and also flexes effortlessly. Also nylon meshes easily and is wear resistant.

TEST PROCEDURE

- The fan is switched ON and run at a constant speed without any obstruction in the inlet airway.
- The time required for a particular number of pulses (say 5) on the energy meter is recorded in order to obtain the power input to motor, Pr, Air static pressure readings are taken at the sections A-A and B-B.
- Now the flow of air is obstructed by placing a number of Terylon nets (say 5) in the airway and the new pressure readings are noted.
- This is repeated by subsequently increasing the number of nets (in sets of 5) and lastly a final reading is taken where the airway is totally blocked, not allowing any air to enter the air duct.
- The above procedure is repeated for a number of constant speeds.
- The Axial Fan is switched OFF.
- The required test results are obtained by computations as given in section I 1.
- The curve between fan total pressure and the inlet volume flow rate is plotted for all these speeds.
- Finally the total efficiencies at particular speeds and volume flow rates are determined.

CALCULATIONS

- D= diameter of air duct=0.24 m.
- A= area of cross section of air duct= 0.0452 sq.m.
- T= temperature of air at test section in celcius.(27 degree celcius).

1. $Q= 12500 \times D^2 \times \sqrt{(\Delta P/W_t)}$ m^3/hr.
2. Weight density of air at test section,

   $W_t= 1.205 \times (B + 0.0737\ P_s)/760 \times 293/(273+T)$ (kg/m^3)
3. Velocity of air in the airway,

   $V = 16000 \times \sqrt{(\Delta P/W_t)}$ (m/h)
4. Volume flow rate of air,

   $Q = A \times V$ (m^3/h)
5. Reynold's number,

   $R_e = (23.58 x Q)$

Reynold's number	20000	40000	60000	100000	200000	300000	400000 & above
Discharge coefficient	0.930	0.940	0.945	0.953	0.967	0.973	0.975

Calculate the value of discharge coefficient of conical inlet from table below by interpolation,

6. Velocity pressure of air at test-section:
   Pv = (Wt x v2)/2g (mm of water)
7. Friction loss in airway:
   $P_f = 0.02 \times (L/D) \times P_v$ (mm of water)
8. Fan total pressure at test conditions:
   $P_t = P_s - P_v + P_f$ (mm of water)
9. Fan total pressure at standard conditions:
   $P'_t = (760/B) \times P_t$ (mm of water)
10. Total air power :
   $P_{total} = 2.725 \times 10^{-3} \times Q \times P_t \times K_p$ (watts)
11. Shaft power:
   $P_{shaft} = [P_L - (\text{fixed losses+copper losses+stray load losses})]$ (watts)
   $P_L = (1/3200) \times (n/t) \times 3600$ (kW)
12. Total efficiency:
   $\eta_t = P_{total}/P_{shaft}$

OBSERVATION TABLE

1. 1200 RPM:

SR.NO.	NO. OF NETS	ΔP (mm of water)	Ps (mm of water)	t (sec)
1.	0	2.5	5	35.9
2.	5	2.1	9.5	37.2
3.	10	1.9	13.5	38.2
4.	15	1.8	16.5	39.3
5.	20	1.5	18	41.9
6.	25	1.2	20	42
7.	30	1	22	42.5
8.	35	0.7	23.5	42.9
9.	40	0.4	24.5	43.6
10.	BLOCKED	32	29.5	49.1

RESULT

1. 1200 RPM:

SR.NO.	Pf(mm of water)	P1(mm of water)	P2(mm of water)	Ptotal (W)	Pl	Pshaft	η
1.	0.21394	2.69695	2.87451	2.5745	156.685	155.906	1.651
2.	0.17971	7.54251	8.06254	6.60154	151.21	150.457	4.2544
3.	0.1626	11.7458	12.52658	9.75227	147.251	146.519	6.6521
4.	0.15404	14.8425	15.82654	11.9837	143.13	142.418	8.841254
5.	0.12836	16.2548	17.14582	12.2354	134.248	133.58	9.1542
6.	0.10269	18.8569	20.1401	12.4221	133.248	133.262	9.3254
7.	0.08514	21.0788	22.4632	12.6348	133.353	131.694	9.5475
8.	0.0599	22.8552	24.3615	11.4217	133.119	130.467	9.59421
9.	0.03254	24.12135	25.7222	9.07654	129.014	128.372	7.0704
10.	0	29.5	31.4446	0	114.562	113.992	0

CONCLUSION

- Axial fan test rig has been analysed, designed and manufactured according to BIS standards.
- Fan total pressure decreases as inlet volume flow increases.
- As inlet volume flow increases, the fan total efficiency first increases, reaches a maximum and then decreases. Therefore, for a particular speed, there is an optimum inlet volume flow rate at which the fan total efficiency is maximum.
- Also, the fan total efficiency increases as the speed increases.
- Flow is directly proportional to speed.
- Pressure is directly proportional to speed^2.
- Power is directly proportional to speed^3.

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