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Design and Application of D.C. Vacuum Cleaner using Axial Flow Fan

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Abstract:

Use of Fossil Fuels in Power Generation has its adverse environmental impact. And due to growing population there is a scarcity of Fossil Fuels in today's world. To cope up with this problem this paper suggests the Design of D. C. Operated Vacuum Cleaner using Axial Flow Fan, which is capable of producing a Suction Pressure of 0.17 Bar. And it is more efficient in Cleaning and has less D. C. Power Consumption. This Vacuum Cleaner is wireless leading to better approach in cleaning the floor. As this Vacuum Cleaner is Eco-Friendly, looking forward to use a cleaner source of energy for the betterment of mankind, planet earth and environment.

Keywords — **D. C. Operated, Axial Flow Fan, Vacuum Cleaner, Suction Pressure**

. INTRODUCTION

There are various types of Vacuum Cleaners such as Upright Vacuum Cleaners, Stick Vacuum Cleaners and Hand-held Vacuum Cleaners. And all these Vacuum Cleaners generally use Electrical Energy as a source of Power. This paper suggests the use of Battery Operated Vacuum Cleaner using Axial Flow Fan for Suction Pressure generation.

An Axial Flow Fan is used to generate the Suction Pressure to suck the garbage, dust or dirt [1]. As the outward flow of Axial Flow Fan creates a low pressure than the ambient pressure inside the Vacuum Cleaner, results in the suction of the garbage.

It consists of the following parts:

i. Brush
ii. Brush Motor
iii. Suction Mouth
iv. Dust Collecting Hose
v. Axial Flow Fan
vi. Suction Cylinder
vii. Battery
viii. Gear
ix. Chain

A powered horizontal brush is used to accumulate garbage in the suction mouth area. It is a hand driven type vacuum cleaner, which has a handle to steer the vacuum cleaner and to move it at the desired position with the help of wheels.

. LITERATURE REVIEW

Reference [1], [2] show a method to set up the market position of the product through the image scale and subsequently by 5W1H and tree diagram method, and clarifies the problems and the direction of the design goals. The following step, according to Morphological Analysis and Finite Structure method (FSM), arranges the positions of the major components of the product, and shapes the forms for developing the possible alternatives. Then, it is the most suitable for the consumers that using PUGH several times to choose the final solution.

Reference [3] demonstrates the predicted performance for power, flow rate, pressure, and efficiency using the present method agreed well with the experimental results obtained for an equivalent system within 2% difference at best efficiency point. Three models of the fan-motor assembly (S1, S2 and S3) were analyzed at the component level and the decrease in efficiency produced by flow resistance was estimated to be 1% (S1 and S3 models) or 4.7% (S2 model) using the developed method.

Reference [4] shows the Pro-EnDurAncE indicators are applicable to investigate the durability of products in several different scenarios and they are robust and flexible since the assessment based on a large number of parameters and different scenarios. These indicators can be used to assess product at the design stage or to support policy measures to promote more durable products.

Reference [5], [6] and [7] show the developed robot can perform sweeping and mopping task. RF modules have been used for wireless communication between remote (manual mode) and robot and having range 50m. From the results of experiments, it is found that a cleaning robot system which works through interaction with equipment in the home and does not disturb humans can become a reality.

□. WORKING

When the Vacuum Cleaner is switched ON, the Fan blades turn, the air is forced forward towards the exhaust port. As the air moves forward, the density of air increases in front side of the Fan and density decreases behind the Fan.

There is Pressure drop behind the Fan. Thus Pressure level in the area behind the fan drops below the Pressure level outside the Ambient Air Pressure.

This creates suction, a partial Vacuum inside the Vacuum Cleaner. The Ambient Air pushes itself into the Vacuum Cleaner through the Suction Mouth as air pressure inside the Vacuum Cleaner is lower than the outside Pressure.

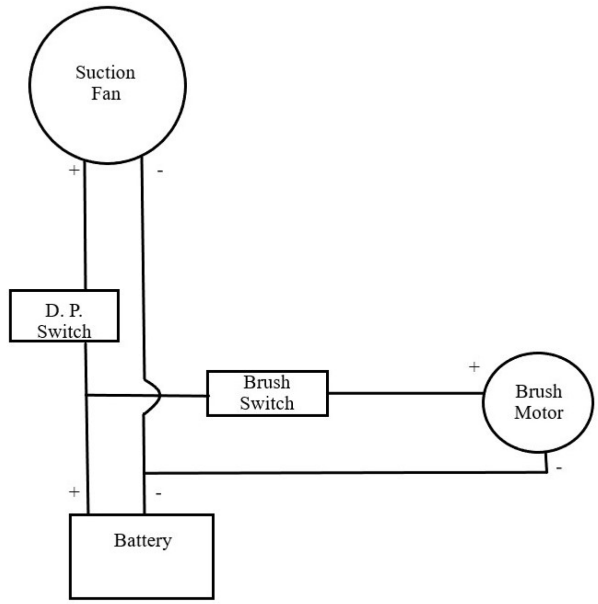

Fig. 1: Circuit diagram

□. COMPONENTS OF VACUUM CLEANER

A. Brush

The brush is a tool with filaments of Nylon used for cleaning or accumulating the dirt. This Brush is fitted in the Suction Mouth. Here the Horizontal type of rotary Brush is used. The brush is rotated by the Brush Motor. While rotating in a clockwise direction the brush carries the dirt with its filaments. Due to this the dirt gets carried towards the Dust Collecting Hose. Like this the Brush works

Fig. 2: Brush

TABLE □
SPECIFICATIONS OF BRUSH

Sr. No.	PARTICULARS	Details
1	Filament material	Nylon
2	Brush width	30 cm
3	Filament diameter	0.3 cm

B. Brush Motor

The Brush Motor is a D.C. operated motor, providing the rotary motion of the Brush. This Brush Motor has a rotary motion which is coupled to the Brush through the chain drive mechanism. This chain drive gives rotary motion to the Brush shaft, hereby rotating the brush.

Fig. 3: Brush Motor

TABLE □
SPECIFICATIONS OF BRUSH MOTOR

Sr. No.	Particulars	Details
1	Current rating	2 Amp
2	Voltage rating	12 Volts
3	Power consumption	24 Watts
4	Speed of motor	35 rpm

C. Suction Mouth

The Suction Mouth is a part which provides Suction Surface Area and covers the required surface of the floor which is to be cleaned, to create the desired Suction Pressure. The Suction Mouth has two components connected to it: Brush and Dust Collecting Hose. This Suction Mouth is a combination of two Geometries: Half Cylinder and Rectangular Cross-section. The Suction Mouth is employed to cover Suction surface to make the suction effective.

Fig. 4: Suction Mouth

TABLE □
SPECIFICATION OF SUCTION MOUTH

Sr. No.	Particulars	Details
1	Material	Tin
2	Gauge size	22
3	Width	30 cm
4	Cylinder radius	15cm

D. Dust Collecting Hose

The Dust Collecting Hose is an important part as it is the only medium through which the Sucked dirt is sent to the Suction Cylinder. The Dust Collecting Hose is a flexible part whose length can be adjusted according to the desire.

Fig. 5: Dust Collecting Hose

TABLE
SPECIFICATIONS OF DUST COLLECTING HOSE

Sr. No.	Particulars	Details
1	Material	PVC
2	Diameter	15.24 cm
3	Length	91.44 cm

E. Axial Flow Fan

The Axial Flow Fan is the main motor which creates lower pressure inside the Suction Cylinder resulting in Suction of the dirt. This Fan is fitted into the Suction Cylinder top. As the Fan rotates it produces Suction Pressure in the Suction Cylinder [1]. This Fan is also a D.C. operated Fan, operated by Battery.

Fig. 6: Axial Flow Fan

TABLE
SPECIFICATIONS OF AXIAL FLOW FAN

Sr. No.	Particulars	Details
1	Current rating	10 Amp
2	Voltage rating	12 Volts
3	Power consumption	120 Watts
4	Speed of Axial flow fan	3000 rpm

F. Suction Cylinder

The Suction Cylinder consists of the Axial Flow Fan fitted inside it. Half of the Suction Cylinder acts as the storage tank. As the Suction Pressure is produced in the Cylinder due to the Axial Flow Fan rotation, the Dirt or Garbage is sucked inside the Cylinder and gets stored into the Cylinder bottom due to self weight of the Garbage.

The storage capacity of the storage tank is of 79 litres, which makes it able to store more Garbage. And also the number of times of removing dust bag reduces due to more storage capacity.

Fig. 7: Suction Cylinder

TABLE □□
SPECIFICATIONS OF SUCTION CYLINDER

Sr. No.	Particulars	Details
1	Material	Mild Steel
2	Gauge size	21
3	Diameter	45 cm
4	Height	90 cm

G. Battery

The Battery used in this project is the main source of Power to run the Axial Flow Fan which is responsible for the production of Suction Pressure. The Battery used is of 12V/26Ah rating.

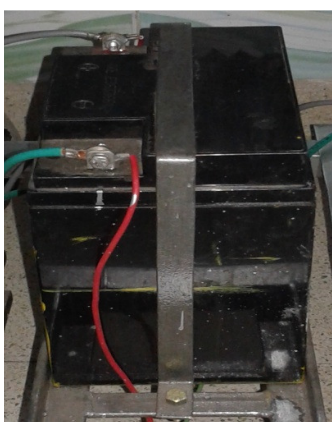

Fig. 8: Battery

TABLE □
SPECIFICATIONS OF BATTERY

Sr. No.	Particulars	Details
1	Current rating	26 Ah
2	Voltage rating	12 Volts

□. DESIGN

A. Volumetric Flow Rate of Suction Fan

Volumetric flow rate
of suction fan (Q) = $\pi \times D \times L \times N$
$= \pi \times 0.4572 \times 0.0762 \times 300$
(Q) = $328.34 m^3/min$

B. Storage Capacity of Cylinder

Storage capacity of cylinder= $\pi \times R^2 \times L$
$= 3.14 \times (0.225)^2 \times 0.45$
= 79 lit

C. Total Power Consumption(P_T)

1) ***Power consumed by suction fan(P_F)***= 12×10
= 120 Watts

2) ***Power consumed by brush motor (P_M)***= 12×2
= 24 Watts

3) ***Total power consumption (P_T)*** = 120 + 24
= 144 Watts

D. Design of gear [12]

Rated power of brush motor (P_R) = 24 Watts

1) ***Design Power to drive the gear (P_d)***,

$P_d = P_R \times K_L$
where,
K_L = Load Factor
Type of Load = Light Shock (intermittent or 3 hrs/day)
$K_L = 1$
$P_d = P_R \times K_L$
$= 24 \times 1$
P_d = 24 Watts

2) ***Static Condition***,

$F_t \leq F_B$
where,
F_t = Tangential Tooth Load
F_B= Bending Tooth Load

a) $F_t = P_d / V_p$
where,
V_p = Pitch line velocity of gear

$V_p = (\pi \times D_p \times N_p) / 60$
where,
D_p = Pitch diameter
$D_p = m_o \times T_p$
where,
m_o = Module
T_p = Number of teeth on pinion
$\underline{T_p = 28}$

$D_p = 28\ m_o$
$V_p = (\pi \times 28\ m_o \times 40) / 60$
Speed of pinion (N_p) = 40 rpm
$V_p = 58.64 \times m_o$
$\underline{V_p = 0.0586\ m_o\ m/sec}$

b) Bending Load
$F_B = S_o \times C_v \times b \times Y_m$

Selecting SAE 2320 Case Hardened Alloy Steel as the material for Pinion and Gear [12]

Basic strength (S_o) = 350 MPa
Assuming
Velocity factor (C_v) = 0.4
Face Width (b) = $10 \times m_o$
Modified Lewis Factor,
$Y_p = 0.485 - 2.87 / T_p$
$Y_p = 0.485 - 2.87 / 28$
$\underline{Y_p = 0.382}$
$F_B = 350 \times 0.4 \times 10\ m_o \times 0.382\ m_o$
$F_B = 534.8\ m_o^2$
Therefore from Strength Criteria,
$F_t = F_B$
$(24 / 0.0586\ m_o) = 534.8\ m_o^2$
$m_o = 0.914$
Hence selecting Standard Module,
$\underline{m_o = 1.125\ mm}$
$D_p = 28\ m_o$
$\underline{D_p = 35\ mm}$
$V_p = 0.0586 \times m_o$
$V_p = 0.0586 \times 1.125$
$\underline{V_p = 0.065\ m/sec}$
$F_t = F_d / V_p$
$= 24 / (0.0586 \times 1.125)$
$\underline{F_t = 364.05\ N}$

Velocity Factor,
$C_v = 3 / (3 + V_p)$
$= 3 / (3 + 0.065)$
$\underline{C_v = 0.978}$
$b = 10 \times 1.125$
$b = 11.25$

$F_t = F_B$
$364.05 = S_o \times C_v \times b \times Y \times m_o$
$364.05 = 350 \times 0.4 \times b \times 0.382 \times 1.125$
b = 6.05 mm

Check,
$8.5\ m_o < b < 12.5$
$9.56\ m_o < b < 14.06$ mm
Hence Face Width,
b = 6.05 mm is not within the range
Hence selecting Face Width,
$\underline{b = 11.25\ mm}$
Therefore, $F_t < F_B$

Hence Design is Safe.

TABLE
SPECIFICATIONS OF GEAR DESIGN

Sr. No.	Particulars	Details	
		Pinion	**Gear**
1	Module (M_o)	1.125	1.125
2	Face width (b)	11.25 mm	11.25 mm
3	Number of teeth	$T_p = 28$	$T_g = 28$
4	Velocity (V_p)	0.065 m/sec	0.065 m/sec
5	Velocity factor (C_v)	0.978	0.978
6	Lewis factor (Y)	0.382	0.382
7	Pitch diameter (D_p)	35 mm	35 mm

E. Design of Chain[13]

1) Design Power,

$P_d = P_R \times K_l$
Where,
K_l = Load Factor

K_l=1
$P_d = 24 \times 1$

$P_d = 24$ Watts
$P_d = 24 / 746$
$P_d = 0.032$ HP
Chain No.25
Pitch = 6.25 mm
$T_1 = 25$

$$D_{p1} = \frac{p}{\sin(\frac{180}{T1})}$$

$$= \frac{6.25}{\sin(\frac{180}{25})}$$

$D_{p1} = 49.86$ mm
$V_p = \pi \times D_{p1} \times N_1$
$= \pi \times 49.86 \times 40 \times 10^{-3}$
$V_p = 6.25$ m/min

$$\frac{N1}{N2} = \frac{T2}{T1}$$

$$\frac{40}{40} = \frac{T2}{25}$$

$T_2 = 25$

$$D_{p2} = \frac{p}{\sin(\frac{180}{T2})}$$

$D_{p2} = 49.86$ mm

2) Power Capacity (P),

$$P=p^2 [\frac{V}{104} - \frac{V}{526} (26 – 25 \cos (\frac{180}{T1}))]$$

where,
p = Chain pitch in mm
T = Number of teeth on smaller sprocket
V = Pitch line velocity
P = 6.25 mm
V = 0.104 m/sec
$T_1 = 25$

$$P = (6.25)^2 [\frac{0.104}{104} – \frac{0.104}{526} (26 – 25 \cos(\frac{180}{25})]$$

P = 0.035 KW
P = 35.4 Watts

3) Number of strands,

$$\text{Number of Strand} = \frac{Pd}{\text{Power Capacity}}$$

$$= \frac{24}{35.4}$$

$= 0.67$
$\cong 1$

4) Length of Chain in Pitches,

$$L_p = \frac{T1+T2}{2} + \frac{2C}{p} + p\frac{(T1-T2)^2}{40\, C}$$

where,

$$C = D_{p2} + \frac{Dp1}{2}$$

$$= 49.86 + \frac{49.86}{2}$$

C = 74.79 mm

$$L_p = \frac{25+25}{2} + \frac{2\times74.79}{6.25} + \frac{6.25\,(25-25)^2}{40\times74.79}$$

$L_p = 48.93$ mm
$L_p \cong 49$ mm

F. Calculations of suction pressure

$$\frac{\gamma}{\gamma-1} \times \frac{P1}{\rho\, g} + \frac{V1\times V1}{2\, g} = \frac{\gamma}{\gamma-1} \times \frac{P2}{\rho\, g} + \frac{V2\times V2}{2\, g}$$

$3.5(P_2 - P_1) = 50434.57$
$\{V_1 = 71.82$ m/sec, $V_2 = 298.69$ m/sec$\}$
$P_2 - P_1 = 17409.87$ N/m^2
$P_2 - P_1 = 0.174$ Bar (Vacuum pressure)

. EXPERIMENTATION

When the developed vacuum cleaner was applied for the cleaning the floor, it successfully created the required suction pressure and the following results were obtained as mentioned in table [8], [9].

Therefore, the developed vacuum cleaner is effectively applicable in the workshop of an engineering college, railway station platforms, premises of college for cleaning the floors. With due generation of suction pressure of 0.17 Bar, it can be successfully employed in the above mentioned places for cleaning purpose.

TABLE
RESULTS OF THE PROJECT MODEL

Sr. No.	Particulars	Details
1	Suction pressure	17 KPa or 0.17 Bar
2	Time required to suck 0.15 kg of Garbage	25 sec
3	Surface area cleaned in 1 second	0.073 m^2

Fig. 9: Project model

CONCLUSION

The developed vacuum cleaner has wheels and can be moved from one position to desired position manually, by applying push force to move it. It has a handle to steer the vacuum cleaner. With regard of references taken into consideration the developed vacuum cleaner works satisfactorily.

The developed vacuum cleaner generates the suction pressure of 17 KPa and this generated suction pressure is within the range of suction pressure of the available vacuum cleaners according to our research and analysis [2], [4].

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