Optimization of Air Engine Power Output for Varying Design Parameter Values

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Abstract - In two-wheeler motor bikes, usually IC Engines are used and these engines have a number of shortcomings related to pollution due to emission of harmful substances directly into the atmosphere. This paper presents a novel concept of Air Engine run motorbikes which will have zero pollutant emission rates. There is a need to develop a proper design relation between the various design parameters like number of vanes, inlet pressures, shaft speed and rotor to casing diameters. This paper elucidates the variation in power output depending upon the combination of the aforementioned parameters. Expansion ratio has been defined and its significance related to air engine power output has been put forth here. The expansion ratio has been found out for the air engine design that gives the most optimum results.

Key Words: **Two-wheeler motor bikes, Air engine, Vanes, Compressed air, Rotor to casing diameter, Shaft Speed, Inlet Pressures**

1. INTRODUCTION

As per a survey, India has more than 53.2 million two wheelers registered all of which are driven by Internal Combustion (IC) Engines. About 75-80% of the air-polluting agents are being exhausted by vehicles out of which 70-80% share comes from the two-wheelers. The pollutants exhausted from two-wheelers include carbon monoxides (CO), Carbon Dioxide (CO_2) , Oxides of Nitrogen (NO_x) and unburned hydrocarbons (HC) . Surveys and recent trends show that number of two-wheelers all over India is going to increase and their number may increase as much as twice their number the year before. To curb the ever increasing air pollution it has become necessary to thwart the growth of its leading contributor i.e two-wheelers powered by IC Engines. This paper presents a new concept of using Air Engines, using compressed air as a potential power source for two-wheel motor bikes instead of IC Engines. Such a motor bike will be equipped with an Air Engine along with all its required accessories, which will transform the energy present in compressed air, into mechanical rotary motion.

The researchers all over the globe and environment scientists have predicted that in the next 2-3 decades humans would have used up all the conventional non-renewable sources of energy available. Sustainable development is thus what is required today and it would be a leap forward in this sense if we could successfully replace majority of IC Engine run motor bikes on roads into Air Engine run motor bikes with zero air pollutant emission rate. For this it is of utmost importance to increase the efficiency of these motor bikes and match its efficiency with that of traditional IC Engine powered motor bikes. One of the key factors in increasing the efficiency of Air Engines lies in developing an Air-Engine Design which will provide us with the maximum possible useable output while consuming the minimum possible energy input. This paper explains further the design parameters and dimensional relations which will help develop an efficient and economical Air Engine [1-6].

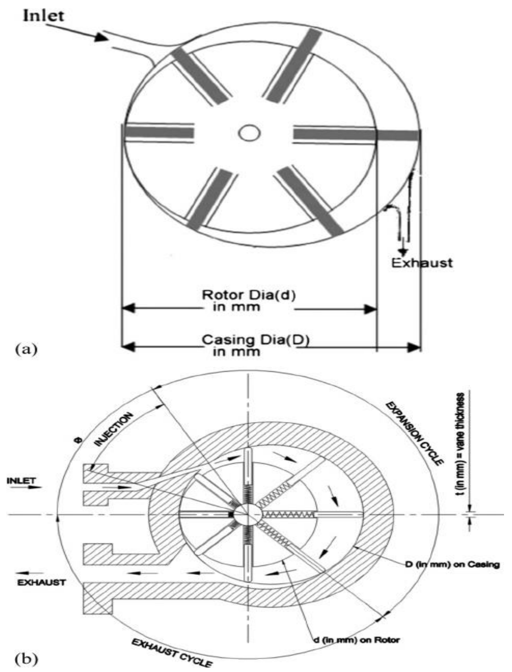

Fig -1: (a) Basic representation of the rotor and vanes[7]
(b) Detailed representation of the air engine[7]

2. CONCEPTS

This Engine basically works on the principle which is reverse in operation to that of a vane type pumping device or a vane type compressor. In this engine the prime source of power is the compressed air which is converted into a total shaft work. In this engine the compressed air at high pressure is injected into the portion enclosed between two adjacent vanes and the compressed air occupies the annular spacing between the rotor and the casing. As eccentric relation exists between the rotor and the casing the annular region between the rotor and the casing goes on increasing as the vanes rotate. As a result of this, the compressed air gradually expands as it rotates along with the vanes and this expansion process of compressed air is adiabatic in nature. Due to the expansion of compressed air an equivalent amount of work is done by the air on the vanes. This work done on the vanes results in the rotary motion of the vanes and thus the energy contained in the compressed air is converted into mechanical energy in form of rotary motion. Also the exhaust process of air is isochoric in nature and isochoric work is done on the system. This summarizes the fact that the total net shaft output in Air Engine is a cumulative of the adiabatic expansion work and the isochoric work done on the system. To minimize the leakage of compressed air without producing any meaningful work output the vanes are spring loaded so as to maintain a continuous desired contact with the casing. The Air Engine is accompanied with a storage tank containing the compressed, high pressure air which is the driving source for this type of engine. The engine is designed for maximum efficiency, considering running speeds of 2000, 2500 and 3000 RPM which are the average running speeds for motor bike.

3. ASSUMPTIONS

1) The Suction Process is perfectly isobaric.
2) The Expansion process is perfect adiabatic in nature and no loss or gain of energy occurs during this process.
3) The Frictional Losses occurring are neglected. (Assumed to be approximately equal to the energy gained during impact of compressed air on the vanes)
4) The Suction and Exhaust process are assumed to occur at atmospheric pressure and no losses occur during this process.
5) The leakage of compressed air is assumed to be negligible as the vanes are spring loaded and in continuous contact with the casing walls.
6) Scavenging process i.e. the process of exhaust of air is 100% complete and there is no energy lost in recompression of the air.

4. DESIGN MODIFICATIONS

The most important aspect in the design of Air Engine is the diameter of the rotor and the diameter of the casing. This is because the intake capacity of the engine, the adiabatic expansion process occurring and finally the exhaust all these processes are directly affected by the diameters of rotor and casing. Another important aspect in the design is the number of vanes being used. The numbers of vanes directly decide the intake angle, expansion angle and the exhaust angle which in turn affects the efficiency of the Engine. This paper elucidates the above design aspects which will result in the maximum possible efficiency of the Air Engine. The design parameters especially the diameters of rotor and casing for the engine depend upon the speed at which the Engine is desired to operate. This paper presents the optimum diameter relation that should exist between rotor and the casing of the engine, for different speeds of operation which will provide the most efficient effect at that particular speed for a given number of vanes [8-9]. In an Internal Combustion Engine, increase in the temperature and pressure of the air-fuel mixture is achieved before ignition, by compressing the gas between the piston and the cylinder head. Thus compression is a crucial process in case of IC Engines and it depends on the compression ratio used for that engine. Compression ratio is defined as the ratio of total volume to the clearance volume. Conversely, in case of Air Engine, the air is already in compressed form and the power is developed due to the expansion of high pressure compressed air. Due to this, the efficiency of Air Engine depends on the Expansion Ratio used just as it depends on the Compression Ratio for IC Engines. The Air Engine is basically a Rotary type of Engine in which the maximum volume is obtained at the end of Expansion Stroke (Adiabatic Expansion of Air) and the minimum volume is obtained at the inlet section, i.e. at entry of the air into the annular region. In this Paper, the value of Expansion Ratio is calculated for different number of vanes used and also for different rotor-casing diameter relations. From the results thus obtained, an optimum combination of total number of vanes and rotor-casing diameter ratio is obtained at which the Air Engine gives the Maximum Efficiency. The variation in Expansion Ratio for different design dimensions is as shown in the table below.

5. INPUT PARAMETERS AND CALCULATIONS

1) Exit Angle of Air (a) = 25^0
2) γ = 1.4 for air
3) Running Speed = 2000 rpm, 2500 rpm, 3000 rpm
4) Number of Vanes (n) = 4, 6, 8
5) Angle of Vanes = 360/n= 90^0, 60^0, 45^0
6) Diameter of Rotor = 100mm
7) Rotor to Casing (D/d) Ratio = 0.95, 0.90, 0.85, 0.80, 0.75, 0.70, 0.65, 0.60, 0.55, 0.50
8) Inlet Pressure (P_1) = 2bar, 3bar, 4bar, 5bar, 5bar, 6bar, 7 bar
9) Exit Pressure (P_5) = 1.013 bar (atmospheric pressure)
10) Pressure at the end of Expansion Process

    $P_4 = (V_1/V_4)^{\gamma} \cdot P_1$ (Considering Adiabatic Expansion)
11) Clearance between vane and casing wall = 0.5mm

12) Thickness of Vane (t) = 6mm

As discussed earlier, the high pressure compressed air when enters into the annular spacing between the rotor and the casing in one of the chambers formed between any two vanes, pushes the vanes and thus produces some net work on the system. This work produced on the system is assumed approximately equal to the frictional losses occurring in the entire system and thus they balance each other. Thus, the net work that is done on the system is a cumulative effect of the Adiabatic Expansion of Compressed Air and the Isochoric Work Done during exhaust of the air and is given as [10-11]:

$W_{expansion} = \{ n.(N/60).(\gamma / \gamma\text{-}1).(P_1V_1 - P_4V_4) \} = \{ n . (N/60) (\gamma / \gamma\text{-}1). (1\text{-}(P_4/P_1))^{(\gamma -1)/ \gamma} \}$

$W_{isoch\ exit} = \{n.(N/60).(P_4 - P_5)V_4\}$

Therefore;

$W_{total} = \{n.(N/60).(\gamma / \gamma\text{-}1).(1\text{-}(P_4/P_1))^{(\gamma-1)/\gamma}\}+\{n.(N/60).(P_4\text{-} P_5)V_4\}$

Expansion Ratio (E) = Volume at the end of Expansion Stroke / Volume at inlet or suction

Therefore; $E = (V4 / V_1)$

Let the vane width is t_2, Therefore the empirical relation for width is given by;

$\{t_2/t_2\text{-}(t/\sin(a))\} = 1.2$

Thus we get; t_2 = 70mm

Thus we get Length of Rotor = 70mm

6. RESULTS

Graphs of various parameters have been plotted according to the calculations done for finding out the parameters. Various unexplored aspects have been discussed with the help of the following graphs.

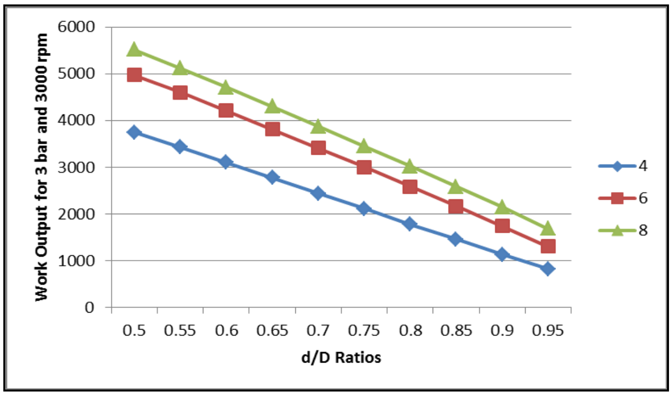

Chart -1: Work Output versus rotor/casing diameter ratios

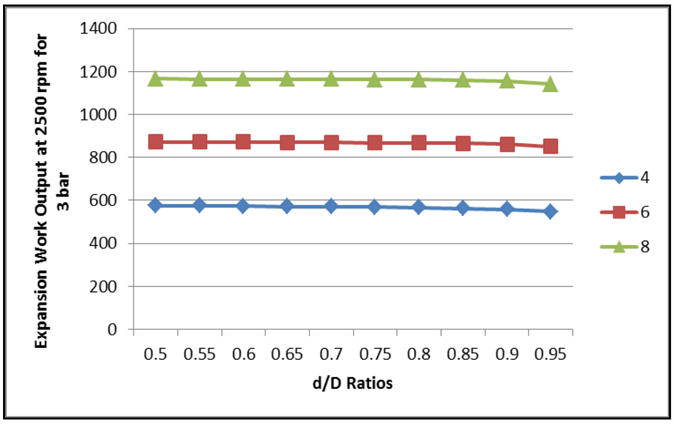

Chart -2: Expansion work output versus rotor/casing diameter ratios for different number of vanes

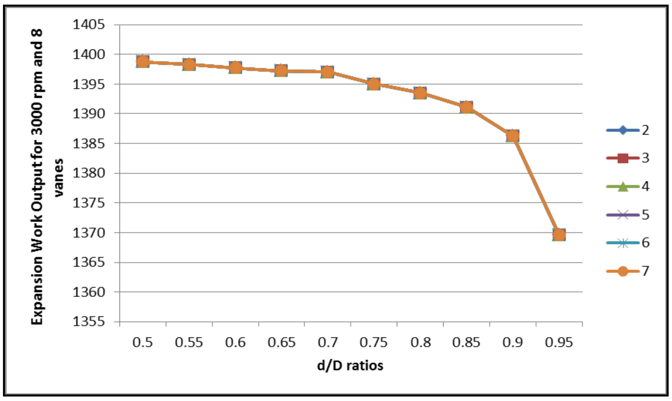

Chart -3: Work Output versus rotor/casing diameter ratios for different inlet pressures

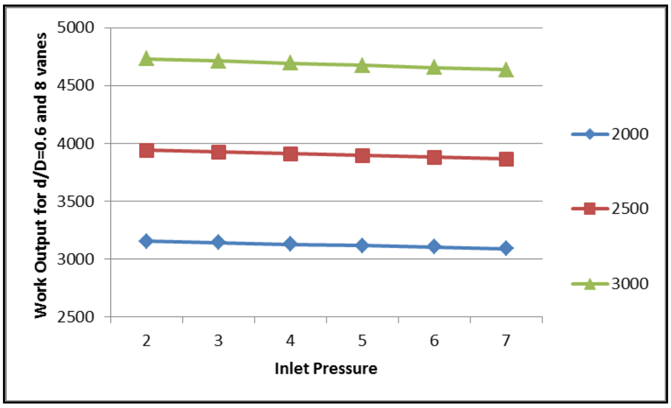

Chart -4: Work Output versus inlet pressure

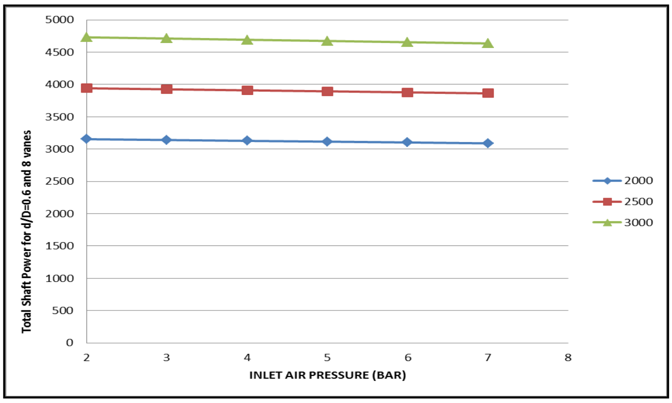

Chart -5: Total shaft power versus inlet air pressure

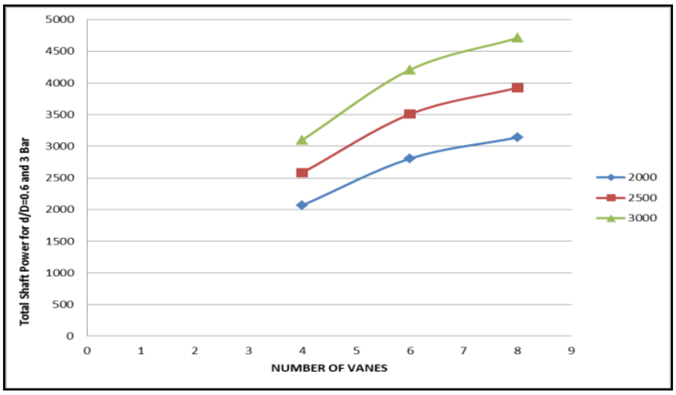

Chart -6: Shaft Power versus number of vanes

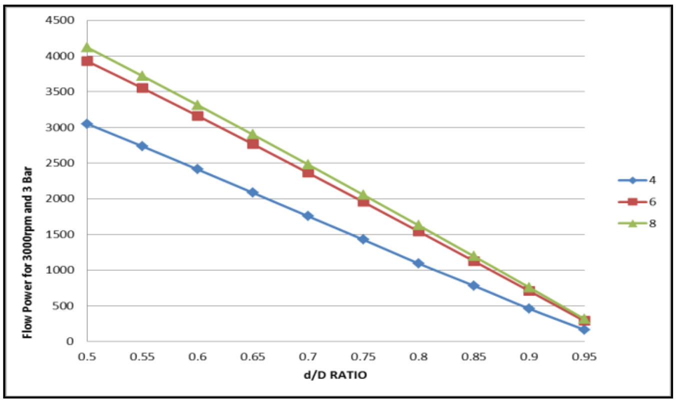

Chart -7: Flow Power versus rotor/casing diameter ratios

Chart-1 shows the variation of work output for different number of vanes for various rotor to casing diameter ratios. It is clearly understood that the work output decreases with increasing d/D ratio with maximum work output obtained at d/D equal to 0.5 for 8 vanes. The minimum work output obtained is at d/D equal to 0.95 for 4 vanes. At lower d/D ratios the difference in work output is higher for different number of vanes. The work output is higher for lower d/D ratios, but air consumption is greater. Thus, efficiency of energy conversion from compressed air to resultant work output decreases with decreasing d/D ratio. Therefore d/D ratio around 0.7 gives the optimum work output. The work outputs for 6 and 8 vanes are in the same range and thus 6 vanes will be preferred.

Chart-2 shows the variation of expansion work output at 2500 rpm and 3 bar for different d/D ratios and different number of vanes. It is evident that the work output is almost constant for particular number of vanes for varying d/D ratios. Thus the variation in work output is due to varying flow power. The variation in flow power has been discussed with another graph.

Chart-3 shows the variation of Expansion Power at 3000 rpm and 8 vanes for different inlet air pressure and rotor to casing diameter ratio. The curves of expansion work obtained for varying inlet air pressure overlap. It is thus evident that expansion work output will remain same irrespective of inlet air pressure. The expansion work output increases steeply till d/D=0.7 and increases slowly despite increase in air consumption at lower d/D ratios. Thus optimum work output will be obtained for d/D ratio of about 0.7 at any given inlet air pressure.

Chart-4 shows the variation of work output at d/D=0.6 and 8 vanes for varying inlet air pressure and different shaft speeds. The work outputs for different pressure ratios are almost constant for particular shaft speed. However, the difference in work output for different speeds is significant with maximum work output for 3000 rpm. Air consumption increases with increased shaft speed, however the work output is considerably high for 3000 rpm. Thus, shaft speed for optimum work output is around 3000rpm.

Chart-5 shows the variation of flow power for different number of vanes at constant speed of 3000rpm and inlet air pressure of 3bar. It can be clearly seen that flow power decreases with decreasing d/D ratio. Maximum flow power output is obtained for d/D ratio of 0.5 and minimum work output is obtained for d/D ratio of 0.95. The difference in obtained flow power output goes on increasing with decreasing d/D ratio. The flow power for 6 and 8 number of vanes is in the same range for a given d/D ratio. Thus 6 vanes will be desired due to comparative reduction in air consumption and ease of design. The efficiency of energy transformation from compressed air to flow power decreases as d/D ratio decreases. Thus, optimum flow power is obtained for d/D ratio of 0.7 for any number of vanes.

Chart-6 shows the variation of total shaft power with changing inlet pressure of air at three different speeds. The graph has been plotted for d/D ratio equal to 6 and number of vanes equal to eight. It is clearly evident that the shaft power decreases slightly as the inlet pressure increases. The shaft power is lowest for speed equal to 2000 rpm and highest for speed equal to 3000 rpm. It can be inferred from the graph that the inlet pressure does not have a lot of effect on the total shaft power thus for maximum shaft power the engine should be run at 3000 rpm.

Chart-7 explains the variation of total shaft for different number of vanes at d/D=0.6 and constant inlet air pressure of 3 bar. Total shaft power goes on increasing as number of vanes increases. It is evident that, shaft power increases rapidly with increase in number of vanes from 4 to 6 whereas the increase in shaft power is much slower for increase in vanes from 6 to 8. The shaft power obtained is close to each other at different shaft speeds for 4 vanes. However, the difference goes on increasing as number of vanes increases to 6 and 8 and consequently the air consumption also goes on increasing. Thus, for 4 vanes optimum selection would be a shaft speed of 2500 rpm. For 6 and 8 vanes, optimum selection is a shaft speed of 3000 rpm.

Table -1: Optimum Result for Different Number of Vanes

Number of Vanes Used	4	6	8
Shaft Speed Desired	2000RPM	2500RPM	3000RPM
Optimum d/D Ratio	0.65	0.7	0.75
Optimum Power output	2.035 KW	3.306 KW	3.4 KW
Expansion Ratio	Inlet(V1) = 0.01799m³ Outlet(V4) =0.1272m³ Expansion Ratio = 0.1414	Inlet(V1) =0.005114m³ Volume(V4) =0.082787m³ Expansion Ratio =0.062	Inlet(V1) = 0.0022848m³ Outlet(V4) =0.052682m³ Expansion Ratio =0.043

6. CONCLUSIONS

This Paper presents clear information about the combination of number of vanes and ratio of rotor diameter to casing diameter to be used in order to obtain the optimum efficiency. The information provided in this paper can prove to be highly useful when considering the design of an Air Engine which will provide optimum efficiency. For the design of an Air Engine the number of vanes and the diameter relation to be used is the most preliminary at the same time most crucial information required and thus the information provided in this paper will be very helpful in this aspect. It is possible to draw the following General Conclusions from the above analysis :

1. As the number of vanes increases from 4,6,8 ; the expansion ratio increases and the power output available at the shaft increases.
2. There exists an optimum inlet pressure value range which provides us with the maximum efficiency. Pressure values above and below this range fails to obtain the desired maximum efficiency.
3. Most optimum system design is obtained for:

   Number of Vanes = 6

   Rotor to Casing Diameter = 0.7
4. Between each two adjacent pairs of vanes we get meaningful resultant work done on the system and thus during a single revolution of the shaft, work cycles equal to number of vanes are obtained.
5. The Exhaust from this Engine contains zero air polluting elements.
6. Expansion ratio obtained for optimum design parameters= 0.062.

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