ANALYSIS ON TURBO AIR-CONDITIONER: AN INNOVATIVE CONCEPT

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Abstract: The conventional automobile air conditioning system draws power from the engine. The air conditioning system consumes quite a reasonable amount of fuel energy. This project aims at introducing a turbocharger in order to transform the kinetic energy of the exhaust gas into useful power to run the compressor of the AC system. This avoids the extraction of power from the engine, exempting the use of belts and pulleys. This paper validates the use of gas turbines as a power input for AC compressor using Computational Fluid Dynamics (CFD). The use of magnetic gears helps to transfer the torque at the required rpm. This brings out better use of exhaust gas.

Keywords: Exhaust Gas Recovery, Regenerative Refrigeration, Magnetic Gears, Exhaust Energy Recovery.

I. INTRODUCTION

Today, energy crisis and environmental pollution have become two primary problems which are concerned by the countries all over the world. Energy crisis and environmental pollution have become two primary problems which are concerned by the countries all over the world. As one of the largest consumers of oil and also the largest pollutant emission sources, IC (Internal Combustion) engine becomes an important object for energy saving and emission reduction. At present researchers mainly focus on following two aspects for reducing energy crisis and relieving polluting gases. One is the research on IC engine alternative fuels owing to the shortage of petroleum resources and the soaring oil prices; the other is to explore new technologies for IC engine energy saving, including the technologies for IC engine waste heat recovery.

Nowadays climate changes are becoming unpredictable. Average atmospheric temperature is increasing at a significant rate. We find it difficult to cope up with the sudden changes in the weather conditions. Hence the need for an efficient air conditioning system is increasing. So, the present day automobile AC system is hence more often put to use. This situation demands for an improvement in the contemporary system. The increasing fuel prices are also one of our main concerns. The power required for the working of the AC system is usually drawn from the automobile engine, which in turn results in increased fuel consumption. A recent comprehensive study of fuel consumption for vehicle air-conditioning (AC) on a state-by-state basis using thermal comfort based approach shows that US uses an estimated 7 billion gallons of gasoline every year for air conditioning vehicles. This is equivalent to 6% of domestic petroleum consumption, or 10% of US imported crude oil. The study further shows that vehicle air conditioning loads are the most significant auxiliary loads and outweighs even other significant loads such as rolling resistance, aerodynamic drag or driveline losses. The fuel economy of a vehicle drops substantially when the AC compressor load is added to the engine. The AC increases the fuel consumption of a conventional gas-fueled car by approximately 35% and significantly higher for hybrids. So energy efficient air-conditioning systems are getting significant attention from the automotive industry to improve fuel economy of their vehicles. These situations led us in a search for an alternative powering solution for the automobile air conditioning system, which does not extract engine power directly.

II. CONCEPT OF TURBO-AIRCONDITIONING

In the engine after developing the brake power (i.e., only about 20-30% of fuel energy supplied).about 70-80% of the energy is wasted in the exhaust gas as shown in Fig.1.

Exhaust gas contains two main forms of energy.

1. **Pressure energy**
2. **Thermal energy**

The outline of turbo-Air conditioning system shown in Fig.2, the pressure energy of the exhaust gas is recovered by using a gas turbine. The power produced by the gas turbine is transmitted to the AC compressor by a new type of contactless speed reduction mechanism called magnetic gearing. The power produced by the gas turbine is transmitted to the AC compressor by a new type of contactless speed reduction mechanism called magnetic gearing.

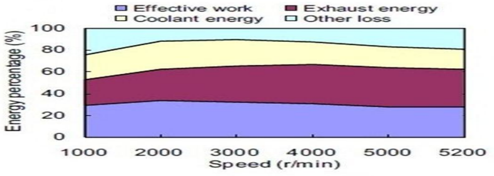

Fig.1 Energy distribution of a turbocharged gasoline engine

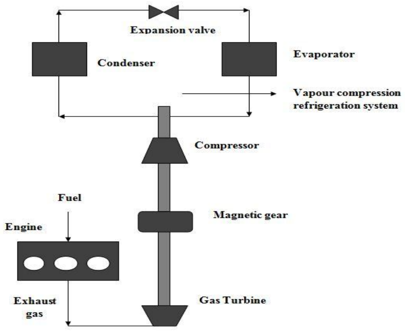

Fig.2. Concept of turbo-air conditioner

Output power from magnetic gear is used to run the compressor of a vapor compression refrigeration cycle. So that automobile air conditioner can be operated by using waste energy with a greater COP.

III. CALCULATION EQUATION AND DESIGN

2.1 The effectiveness of a vapor compressor refrigeration cycle is represented by the Coefficient of performance (COP) which can be calculated by the following equation

$$COP = \frac{\text{Refrigeration Effect (RE)}}{\text{Work requirement on compressor (W)}}$$

2.2. Compressor work required for the refrigeration system can be calculated by using the following equation

Compressor work W = $\frac{RE}{COP}$

Where, RE is the refrigeration effect produced and COP is the coefficient of performance.

2.3. In the exhaust manifold a gas turbine is coupled and the work done by the exhaust gas turbine can be obtained by the following equation

Work done by the exhaust gas turbine,

$W_g = m \quad x\ C_p\ x\ (T_2 - T_1)$

For isentropic expansion, $\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$

Therefore, Work done $W_g = m \quad x\ C_p\ x\ T_2\ x \left[1 - \left(\frac{T1}{T2}\right)\right]$

$= m \quad x\ C_p\ x\ T_2\ x \left[1 - \left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}}\right]$

Where, m is the mass flow rate of exhaust gas from engine, C_p is the specific heat of gas; T_2 is the turbine inlet temperature p_2 is the Inlet pressure of turbine,p_1 is the outlet pressure of turbine.

Table I. Air conditioning specification

Coefficient of performance (COP)	3
Cabin volume	5 m^3
Refrigeration load	3 Ton

2.4. Magnetic gear calculations: Fig. 3[17][18] shows a cross-sectional view of the prototype magnetic gear. The modulator is kept stationary while the inner high-speed (HS) and outer low-speed (LS) assemblies rotate. For this configuration, the gear ratio may be expressed as follows

$$Gear\ ratio\ Gr = \frac{ns - ph}{ph}$$

Where ns is the number of flux modulator segments and ph is the number of pole pairs on the HS rotor.

Table II. Engine specifications

Speed	1000rpm
Displacement	1700x$10^{-6}m^3$
Turbine efficiency	80%
Mean mass flow rate	0.0163 kg/s
Inlet turbine pressure	405 kPa
Outlet turbine pressure	115 kPa

Table III. Design parameters of magnetic gear

Parameters	Specifications
HS magnet pitch [fraction of pole	0.9
LS magnet pitch [fraction of pole	0.897
Modulator tooth pitch [fraction of segment pitch]	0.447
HS yoke inner diameter [mm]	41
HS yoke thickness [mm	18.8
HS magnet thickness [mm]	5
HS air-gap length [mm]	0.7
Modulator thickness [mm]	7
Modulator bridge thickness [mm]	0.5
LS air-gap length [mm]	0.5
LS magnet thickness [mm]	5
LS yoke thickness [mm]	7.5
LS yoke outer diameter [mm]	130
Stack length [mm]	40
Number of HS pole pairs	2
Number of LS pole pairs	21
Gear ratio	10.5

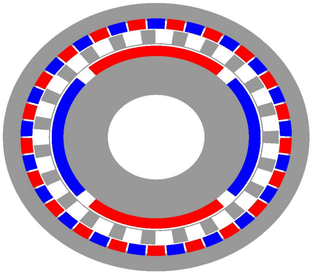

Fig.3. Cross-sectional view of the magnetic gear

The number of pole pairs on the LS rotor is given

$pl = ns - ph$

The number of flux modulator segments,

$ns = pl + ph$

2.5. Overall transmission efficiency of magnetic gear,

$\eta_0 = (\eta)^n$

Where, η_0 is the overall efficiency of transmission, η is the efficiency of each magnetic gear, and n is the number of magnetic gears connected in series

1. CFD Analysis of the exhaust gas turbine

A four cylinder, four stroke, turbocharged, spark ignition engine is used in this study. The turbocharger specifications are listed in Table. IV. Firstly we created a dummy model by using CAD software and it is imported to ANSYS 13.0 to complete the CFD analysis. CAD model is shown in fig.4. In order to provide easy access to their solving power all commercial CFD packages include sophisticated user interfaces input problem parameters and to examine the results. Hence all codes contain three main elements:

1. Pre-processing: Preprocessor consists of input of a flow problem by means of an operator friendly interface and subsequent transformation of this input into form of suitable for the use by the solver. The user activities at the Pre-processing stage involve:
i) Definition of the geometry of the region (Fig.5)
ii) Definition of fluid properties (Table V)

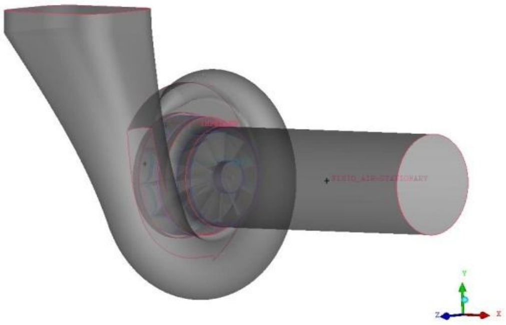

Fig 4. The assembly: multi-view of the last step modeled (CAD software)

2. Solver: These are three distinct streams of numerical solutions techniques: finite difference, finite volume& finite element methods. In outline the numerical methods that form the basis of solver performs the following steps:
i) The approximation of unknown flow variables are by means of simple functions
ii) Discretization by substitution of the approximation into the governing flow equations & subsequent mathematical manipulations

Table V. Turbocharger specifications

Property	Values
Pressure inlet(bar)	1.83
Pressure out(bar)	1.08
Temperature inlet(Kelvin)	1067
Temperature outlet(Kelvin)	945
R of exhaust gas(J/kgK)	296.93
Mass flow rate(kg/s)	0.12
Ideal torque(Nm)	1.316
Efficiency	72.6%
Real torque(Nm)	0.955
Ideal power(W)	20523
Real power(W)	14900

3. Post-processing: As in the pre-processing huge amount of development work has recently has taken place in the post processing field. Owing to increased popularity of engineering work stations, many of which has outstanding graphics capabilities, the leading CFD are now equipped with versatile data visualization tools. These include: Domain geometry & Grid display, Vector plots, Line & shaded contour plots, 2D & 3D surface plots ,Particle tracking ,View manipulation (translation, rotation, scaling etc.)

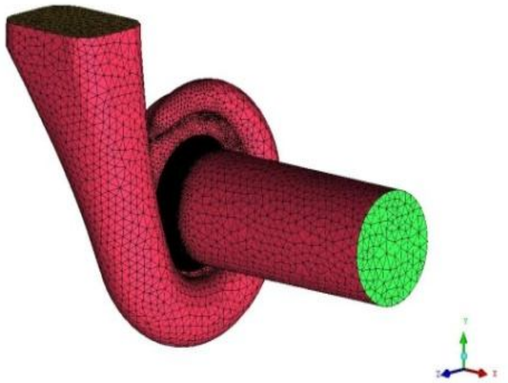

Fig.5. Discretised 3D meshed Model with the rotating region refinement & Prism layer and example applied to this work (inlet boundary).

IV. RESULTS

In the Fig.6 it shows the effect of the cell number on torque. Coarser mesh gave less numerical instability; torque has been estimated by integration of the pressure forces on the wheel surface. These two simulations were done with the same regions layout and imposing the mass flow rate at the inlet boundary (not the pressure)

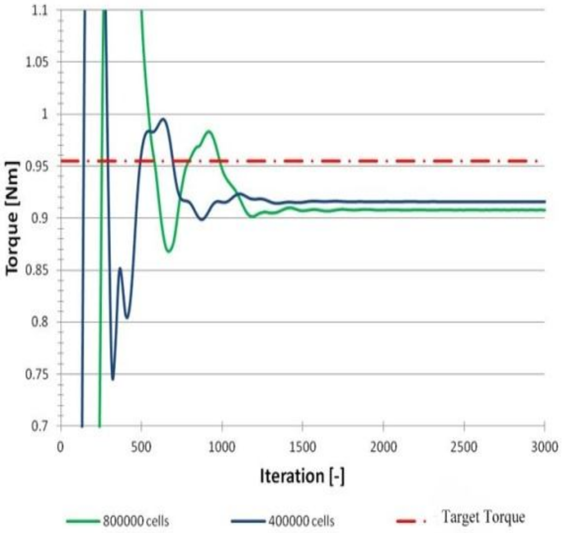

Fig. 6.Cell number influence

From Fig.7 having a farther pressure inlet generates a better numerical behavior, but the mass flow rate value decreased (as a consequence, the torque too). In a first instance, this was supposed due to the gas friction losses near to the housing wall; but since this was not retained the cause anymore.

Fig.8 shows the temperature distribution diagram in exhaust gas turbine with maximum temperature of 1058.8K at inlet surface and minimum of 924.42K at outlet surface. Fig.9 shows the pressure distribution diagram in exhaust gas turbine with maximum pressure of 2.2954bar at inlet surface and minimum of 0.73014 bar at outlet surface

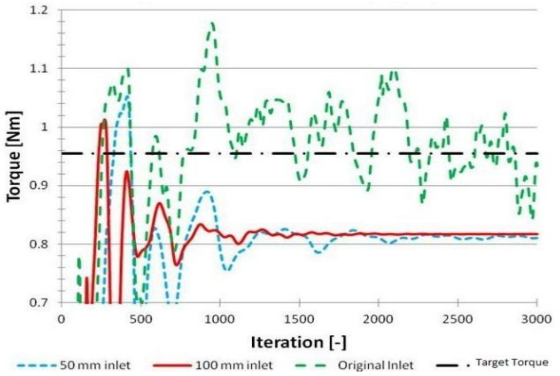

Fig.7. Inlet geometry influence

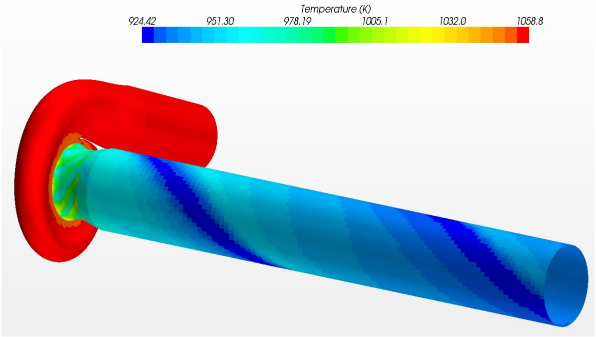

Fig. 8 Temperature distribution

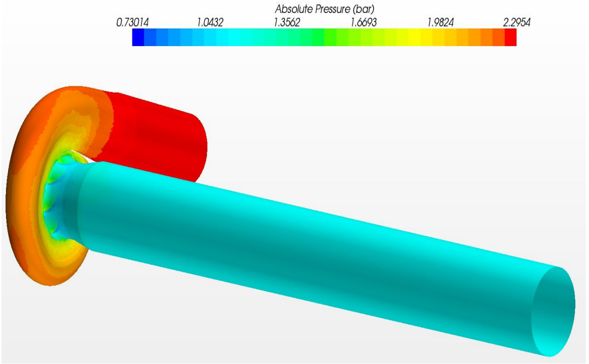

Fig. 9. Pressure distribution diagram

CONCLUSION

One of the major advantages of this concept is that it can be easily employed on low power engine and can ensure high capacity air conditioner .It offers better utilization of exhaust energy. The required torque is attained as per CFD analysis. Further the use of an eco friendly refrigerant namely HFO-1234yf can impart a greener AC system on automobiles. The use of an exhaust Rankine cycle to recover the exhaust thermal energy can further result in a best fuel utilizing engine

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