IOP Conf. Series: Materials Science and Engineering **147** (2016) 012132 doi:10.1088/1757-899X/147/1/012132

Energy recovery for a road vehicle

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Abstract. In this paper the author analyse the possibility of fluid energy recovery, generated from a road vehicle through the aerodynamic impact. The suggested dynamic recovery system use an axial wind turbine, bended with the vehicle. Also, are presented the benefits (economic and energetic) and the disadvantages (constructive and functional) in the base of a calculus statement, with original parts. The results of some numeric calculus for a concrete opportunity are hopeful, the degree of recovery (in fluid – mechanic – electric conversion) tending to 40%.

1. Introduction

This study imagines a recovery assembly, attached to the vehicle, using an axial wind turbine in a tube like in figure 1. The cylindrical tube has, in upstream, an energy concentrator with adequate form, and in downstream, a divergent nozzle. The idea is based on two examples with wind turbines for road vehicles, one a patent of Christian Stoeckert [1] and the other, a patent of Allen Park [2].

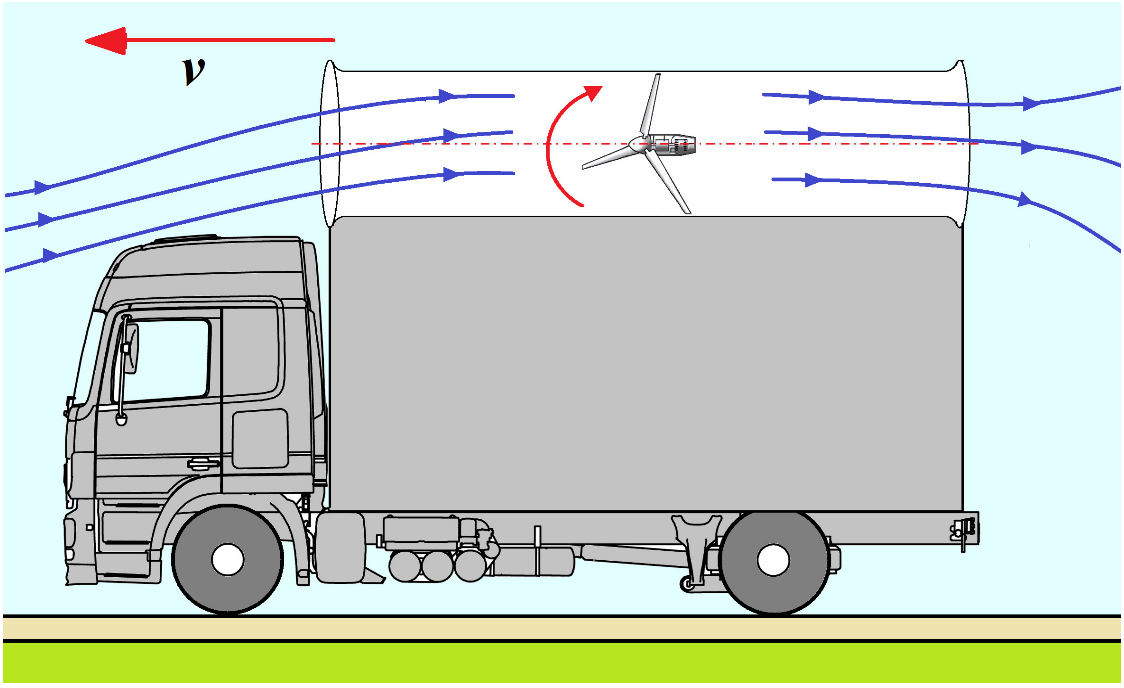

Figure 1. The recovery assembly attached to a vehicle.

On the first view are obvious some disadvantages about the weight increasing, overall size increasing (especially the length), traffic problems, manoeuvrability etc. If the energy (fuel) recovery is important, then the mentioned disadvantages can be fair solved through a technical creative effort. The mentioned disadvantages have a low importance for the big transport vehicles, which can be provided above with recovery assemblies (wind turbine).

The road vehicle disrupts an air volume (capacity), determining a flow rate Q, where A it's the cross-section of the tube and v, the vehicles speed:

$$Q = A \cdot v \ [\mathrm{m^3/s}] \tag{1}$$

The flowing power is:

$$N_f = Q \cdot p_{din} = A \cdot v \cdot \frac{\rho_{air} \cdot v^2}{2} = A \cdot \frac{\rho_{air} \cdot v^3}{2} \ [\mathrm{W}], \tag{2}$$

where ρ_{air} it's the air density and $p_{din} = \frac{\rho_{air} \cdot v^2}{2}$ it's the dynamic pressure of impact. For the flowing power will be consumed a mechanical power from the driving engine:

$$N_m = \frac{N_f}{\eta_{tr}} \ [\mathrm{W}], \tag{3}$$

where η_{tr} it's the efficiency of the mechanical power transmission from the vehicle engine to the driving wheels [3]. The incident flow power in the recovery assembly, in upstream of turbine (uniform stabilized movement) is:

$$N_i = A \cdot \frac{\rho_{air} \cdot v_r^3}{2} \ [\mathrm{W}], \tag{4}$$

where v_r it's the air speed in tube. The resulted mechanical power at the turbine axle is:

$$N_m = M \cdot \Omega \ [\mathrm{W}], \tag{5}$$

where M and Ω are torque and angular velocity of the turbine axle.

2. Views of axial turbine possibilities

For the wind turbines is defining the power coefficient:

$$C_P = \frac{M \cdot \Omega}{\frac{1}{2} \cdot \rho_{air} \cdot A \cdot v_r^3} \ [-] \tag{6}$$

According with Betz theory the ideal (maximum) value is

$$C_{P_{\max}} = \frac{16}{27}, \tag{7}$$

with $\frac{v_{rotor}}{v_{wind}} = \frac{2}{3}$ and $\frac{v_{output}}{v_{wind}} = \frac{1}{3}$.

The main source of rated power recovery is the flow rate decreasing through the turbine (factor 2/3), while the influence of the energy incomplete absorption is lower, so the factor is $\left[1 - \left(\frac{1}{3}\right)^2\right] = \frac{8}{9}$.

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Usage of the wind concentrators and turbine in-tubing gives an essential element, the important flow rate increasing through the turbine [4]. A supplementary advantage is the improvement of the efficiency through the losses elimination from the blades extremity. The fluidic power in the turbine rotor is:

$$N_t = A \cdot \frac{\rho_{air} \cdot v_{rotor}^3}{2} = \rho_{air} \cdot \frac{A}{2} \cdot \left(\frac{2}{3} \cdot v_r \right)^3 = \frac{4}{9} \cdot N_i = 0.445 \cdot N_i \tag{8}$$

It might consider that the turbine efficiency is $\eta_t = \frac{4}{9} = 0.445$, so the flow rate coefficient of the recovery assembly (real flow rate / ideal flow rate) will be:

$$\mu_r = 1 - \frac{1}{9} = \frac{8}{9} = 0.888 \tag{9}$$

The recovery assembly (tube with internal turbine) presents an equivalent hydraulic resistance to the passing of the fluid through it, a coefficient ζ_r, who results from this definition:

$$\mu_r = \frac{1}{\sqrt{\alpha + \zeta_r}} \text{ [-]}, \tag{10}$$

where $\alpha \approx 1$ is the Coriolis coefficient, for the turbulent flowing. Therefore, the coefficient ζ_r is:

$$\zeta_r = \frac{1}{\mu_r^2} - \alpha = \left(\frac{9}{8} \right)^2 - 1 = 0.267 \tag{11}$$

3. Numerical calculus

In table 1 are presented some values computed for different speeds. The mechanic and electric power have been computed for A = 0.785 m^2 (for the tube diameter d = 1 m). The air density was calculated for a spring day in Brasov city:

$$\rho_{air} = \rho_0 \cdot \frac{p_{air}}{p_0} \cdot \frac{T_0}{T_{air}} = 1.293 \cdot \frac{720}{760} \cdot \frac{273.15}{293.15} = 1.141 \text{ [kg/m}^3\text{]} \tag{12}$$

The flowing power was calculated with relation:

$$N_f = A \cdot \frac{\rho_{air} \cdot v^3}{2} \text{ [W]} \tag{13}$$

The mechanical power recovered was calculated with relation:

$$N_m = N_f \cdot \eta_t \text{ [W]}, \tag{14}$$

with $\eta_t = 0.445$. The electrical power recovered was calculated with relation:

$$N_{el} = N_m \cdot \eta_{el} \text{ [W]}, \tag{15}$$

with $\eta_{el} = 0.96$.

Looking at table 1, it can be said that the fluidic energy recovery dislocated of the vehicle is possible, using an adequate recovery assembly.

Table 1. The computed values of the recovered mechanical and electrical power

Speed	Flowing power	Mechanical power recovered	Electrical power recovered
v [km/h]	N_f [kW]	N_m [kW]	N_{el} [kW]
10	0.0096	0.0043	0.0041
20	0.0768	0.0342	0.0328
30	0.2592	0.1153	0.1107
40	0.6143	0.2734	0.2625
50	1.1998	0.5339	0.5125
60	2.0733	0.9226	0.8857
70	3.2924	1.4651	1.4065
80	4.9146	2.1869	2.0994
90	6.9975	3.1139	2.9893

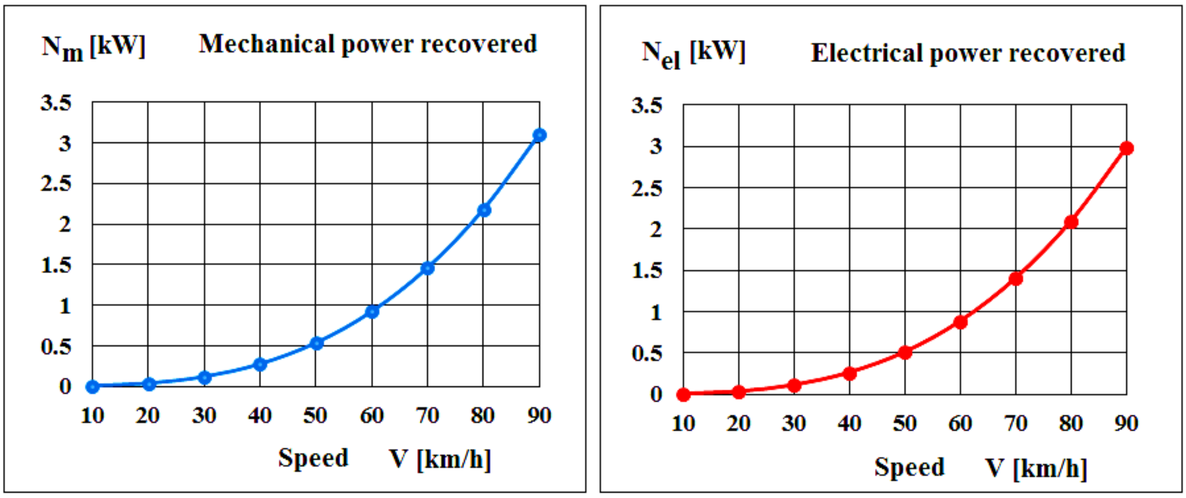

Figure 2. The mechanical and electrical power recovered in function with vehicle speed.

The recovery assembly is solider, and the consequences are analysed in the following relations. The necessary pressure for the hydraulic resistance overcame to the air passing through turbine is:

$$\Delta p_r = \zeta_r \cdot p_{din} = \zeta_r \cdot \frac{\rho_{air} \cdot v_r}{2} \text{ [Pa]} \tag{16}$$

The head resistance force, together with the vehicle, of the recovery assembly is:

$$F_r = A \cdot \Delta p_r \text{ [N]} \tag{17}$$

This force it's added to the head resistance force of the vehicle:

$$F_x = C_x \cdot A \cdot \frac{\rho_{air} \cdot v^2}{2} \text{ [N]}, \tag{18}$$

where C_x is the head resistance coefficient [4]. So, it results an increase head force:

$$\frac{F_x'}{A} = \frac{1}{A} \cdot (F_x + F_r) = C_x \cdot \frac{\rho_{air} \cdot v^2}{2} + \Delta p_r \text{ [N/m}^2\text{]} \tag{19}$$

The increasing F_x with 62% represents C_x increase with ζ_r, for the showed conditions, with speed $v = v_r$:

$$\frac{\zeta_r}{C_x}\cdot 100\% = \frac{0,267}{0,43}\cdot 100\% = 62\% \tag{20}$$

4. Conclusions
The increasing of the recovery degree of the fluidic energy can be obtained through the usage of an axial turbine more quickest (specific speed), with highest efficiency and lower gaso-dynamic resistance at the fluid passing through the rotor.

5. References
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