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Operating principle of an active lift turbine with controlled displacement

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Abstract

The purpose of this article is to present in a simple principle of the turbine 'active lift turbine' and to realize a calculation approximation of the couple produces by this turbine. For a calculation more elaborate, it is necessary to read the preprint.[6]
The active lift turbine which has been the subject of several patent[2, 3, 7].

1 List of symbols

O : turbine center.

A : central gear center.

B : satellite gear center.

C : pivot connection between rod and crank.

D : pivot connection between rod and slide.

E : fixation point of the blade.

Ex : central gear eccentricity ($\overline{OA} = -Ex$).

R_b : radius of the crank ($\overline{BC} = Rb$).

R_g : radius of the central gear or satellite gear ($\overline{AB} = 2Rg$).

R : radius of the turbine.

C : blade cord.

H : blade height.

Sl : length of the slide.

Ro : length of the rod.

λ : tip speed ratio.

ρ : fluid density.

σ : blade solidity.

i : angle of incidence.

C_p : power coefficient.

C_{Betz} : Betz coefficient ($C_{Betz} = \frac{16}{27} \approx 60\%$). [1]

C_d : sectional drag coefficient.

C_l : sectional lift coefficient.

V_{fluid} : fluid speed.

V_f : fluid velocity at the turbine $V_f = \frac{2}{3}V_{fluid}$. [1]

2 The calculation of power coefficient

2.1 Geometry of the Active Lift Turbine :

The point O is the main axis of the turbine. The central gear (center A) is not coincident with the main axis O . The central gear is fixed relative to the direction of flow. The satellite gear (center B) is turning without sliding around the central gear (center A). The slide support (DE) is one of the turbine's arm and turns around the axis O . The profile (blade) is fixed with the slide bar in E . The slide bar has a reciprocating translatory motion with a low speed of movement. The rod is connected to the slide bar by a pivot connection in D and is connected to the satellite gear by a pivot connection in C . The slide bar is driven in rotation by the slide support.

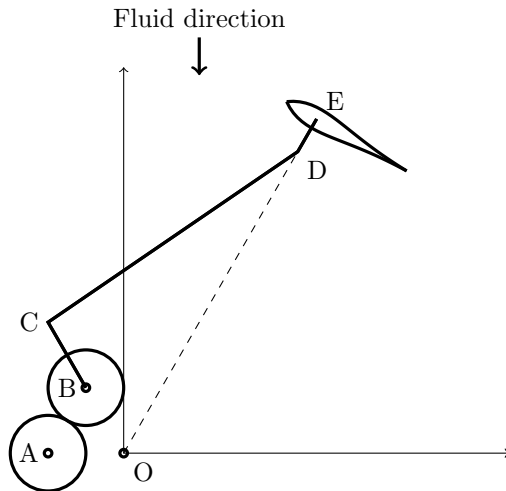


Figure 1: geometry

2.1.1 Purpose of the central gear eccentricity

A car engine is a "rod-crank" system for which the piston has an alternating translational movement. When the piston is at the top dead, the force is maximum and the torque produced is zero(5). The turbine is also a rotating rod-crank system for which the rotation center of the crank has an alternating translational movement. When the force is maximum and the torque produced is optimized(figure 4). With the eccentricity of the central gear, The trajectory of the blade follows almost the trajectory of a circle(figure 2), as for a Darrieus turbine [5]. The radial velocity of the profile is practically zero. Without eccentricity, this velocity isn't zero and it is no longer negligible(figure 3).

R_{maxi} for $\beta = 0$ ou 180 degrees

$$\begin{aligned}
 R_{maxi}(0 \text{ degrees}) &= -E_x + 2R_g + R_b + R_o + S_l \\
 R_{maxi}(180 \text{ degrees}) &= -E_x - 2R_g + R_b - R_o - S_l \\
 |R_{maxi}(0 \text{ degrees})| &= |R_{maxi}(180 \text{ degrees})| \Rightarrow E_x = R_b \quad (1)
 \end{aligned}$$

With a mathematical approach

$$\begin{aligned}
 R(\beta) &= (R_b - E_x) \cos(\beta) + 2R_g + \sqrt{R_o^2 - ((R_b + E_x) \sin(\beta))^2} + S_l \\
 \frac{dR(\beta)}{d\beta} &= (R_b - E_x) \sin(\beta) - \frac{(R_b + E_x) \sin(\beta)}{\sqrt{R_o^2 - ((R_b + E_x) \sin(\beta))^2}} \\
 \frac{dR(\beta)}{d\beta} &\rightarrow 0 \quad \text{when} \\
 R_b &= E_x \quad (2) \\
 \text{and} \quad \frac{(R_b + E_x)}{R_o} &\rightarrow 0 \quad R_o \gg (R_b + E_x)
 \end{aligned}$$

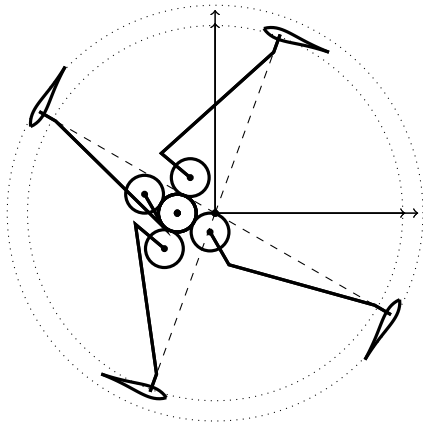


Figure 2: With the eccentricity

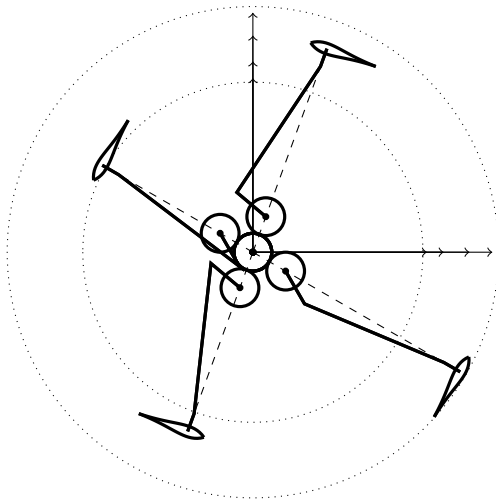


Figure 3: Without eccentricity

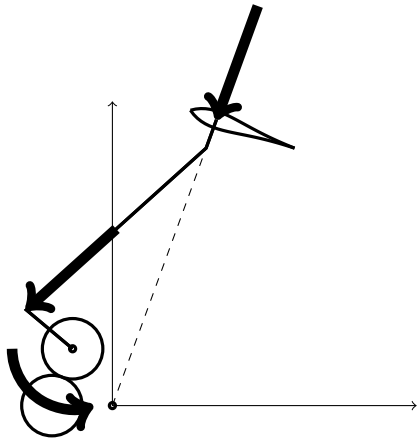


Figure 4: Active lift turbine : torque optimized

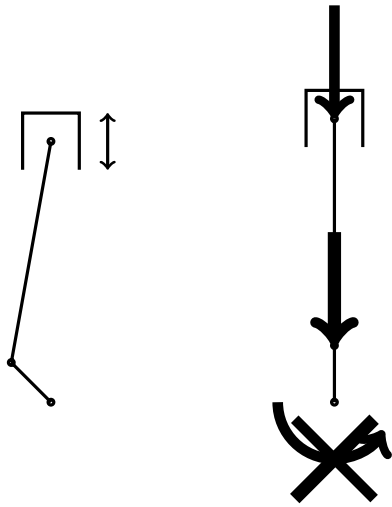


Figure 5: motor system "rod-crank": no torque

2.1.2 rapid and simplified calcul

Lift force : Tunnel tests of the tunel profiles define the lift and drag coefficient. For symmetric naca profiles type naca0012, with angles less than 13 degrees, the drag coefficient C_d is negligible and one can make an approximation of the lift coefficient by this formula $C_l \approx 0.1i$ (i : incidence angle in degrees).

For angles less than 13 degrees, it is considered that the force created by the fluid on the profil is perpendicular to the direction of the fluid and its value is:

$$F = 0.1i \frac{1}{2} \rho H C V_{fluid}^2$$

i : angle of incidence in degrees ρ : fluid density
 C : cord profil H : height profil V_{fluid} : fluid velocity

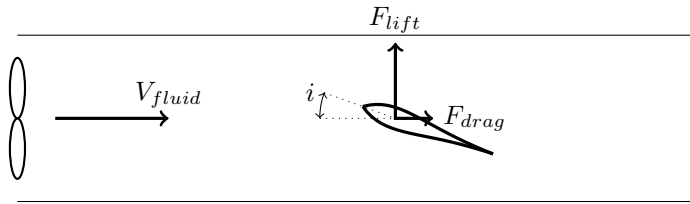


Figure 6: profil test

chord : According to the Betz theory, the fluid velocity at the turbine is $V_f = \frac{2}{3}V_{fluid}$. [1]

The coefficient ' λ : tip speed ratio' verify that the angle of incidence remains less than the maximum angle of incidence (13 degrees)

$$\lambda = \frac{\omega R}{V_f} \quad \omega = 2 \pi \cdot 60 \text{ rpm} \quad \frac{1}{\lambda} \leq \tan(10 \text{ degrees})$$

σ is the stiffness coefficient. $\sigma = \frac{\text{number}_{blade} C}{R}$

In principle, the product $\sigma \lambda$ must be less than 0.75. ($\sigma \leq \frac{0.75}{\lambda}$) [6] [4]

The chord of the profile is $C \leq \frac{0.75 R}{\lambda \text{ number}_{blade}}$



Figure 7: blade chord

Velocity relative W :

$$W \cos(i) = \omega R + V_f \cos(\beta) \quad W \sin(i) = V_f \sin(\beta)$$

$$\tan(i) = \frac{V_f \sin(\beta)}{\omega R + V_f \cos(\beta)} \quad i_{\text{approximate}} = \frac{1}{\lambda} \sin(\beta) \frac{180}{\pi} \text{ degrees}$$

$$W^2 = (\omega R + V_f \cos(\beta))^2 + (V_f \sin(\beta))^2 \quad W_{\text{approximate}} = \lambda V_f \left(1 + \frac{\cos(\beta)}{\lambda}\right)$$

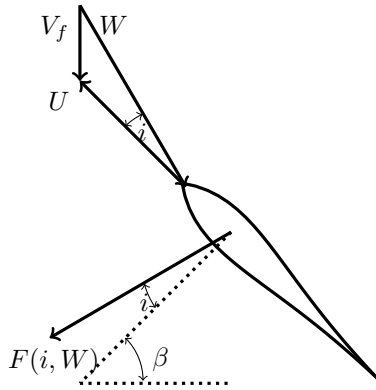


Figure 8: Velocity triangle

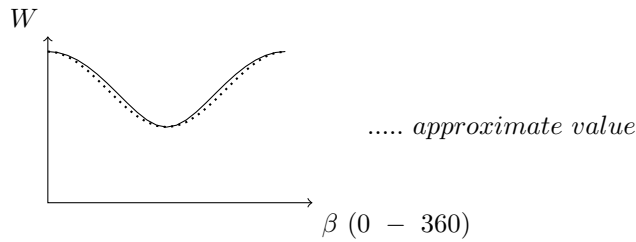


Figure 9: Relative velocity

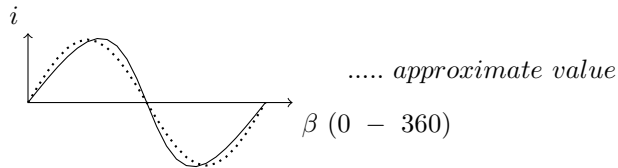


Figure 10: Angle of incidence

Force created by the fluid on the profil :

$$F(i, W) = 0.1i \frac{1}{2} \rho H C W^2 \quad i \text{ in degrees}$$

$$F_{\text{approximate}}(i, W) = 0.1 \frac{180}{\pi} \left(\frac{1}{\lambda} \sin(\beta)\right) \frac{1}{2} \rho H C \left[\lambda V_f \left(1 + \frac{\cos(\beta)}{\lambda}\right)\right]^2$$

This force can be decomposed into an axial force and a normal force.

$$F_{\text{axial}}(i, W) = F(i, W) \sin(i) \approx F(i, W) i \quad F_{\text{normal}}(i, W) = F(i, W) \cos(i) \approx F(i, W)$$

$$F_{\text{axial-approximate}}(\beta, V_f) = 0.1 \frac{180}{\pi} \rho H C V_f^2 \left(\frac{1}{\lambda} \sin(\beta)\right)^2 \left(\lambda \left(1 + \frac{\cos(\beta)}{\lambda}\right)\right)^2 \quad (3)$$

$$\left(\frac{1}{\lambda} \sin(\beta)\right)^2 \left(\lambda \left(1 + \frac{\cos(\beta)}{\lambda}\right)\right)^2 \approx (\sin(\beta))^2$$

$$F_{\text{axial-approximate}}(\beta, V_f) \approx 0.1 \frac{180}{\pi} \rho H C V_f^2 (\sin(\beta))^2 \quad (4)$$

$$F_{\text{normal-approximate}}(i, W) = 0.1 \frac{180}{\pi} \rho H C V_f^2 \left(\frac{1}{\lambda} \sin(\beta)\right) \left(\lambda \left(1 + \frac{\cos(\beta)}{\lambda}\right)\right)^2$$

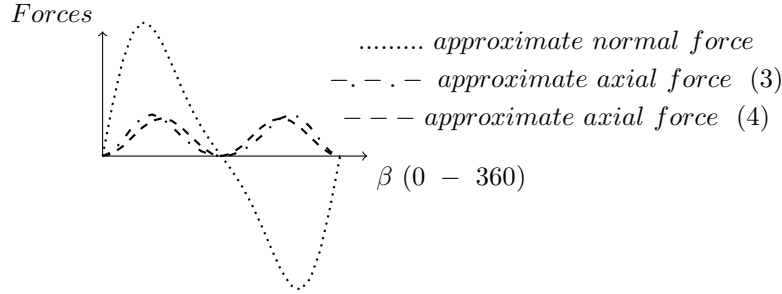


Figure 11: Axial and normal force

Torque creates by the axial force : The axial couple is similar to the torque generated by a typical Darrieus turbine.

$$T_{\text{axial}} = \frac{\text{numberblade}}{2 \pi} \int_0^{2 \pi} F_{\text{axial}}(i, W) R d\beta$$

$$R \approx -E_x + 2R_g + R_b + R_o + S_l \quad \int_0^{2 \pi} (\sin(\beta))^2 d\beta = \pi$$

$$T_{\text{axial}} = T_{\text{Darrieus}} = \frac{0.1 \text{ numberblade}}{2} \frac{180}{\pi} \rho H C V_f^2 R \quad V_f = \frac{2}{3} V_{\text{fluid}}$$

Torque creates by the normal force : System crank rod

$$y = R_b \cos(\beta) + R_o \cos(\alpha) \quad \cos(\alpha) \approx 1$$

$$Power = T\dot{\beta} = F\dot{y} \quad \dot{y} \approx \dot{\beta}R_b \sin(\beta) \quad T \approx F R_b \sin(\beta)$$

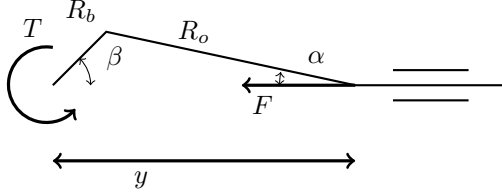


Figure 12: Crank rod

$$T_{normal} = \frac{number_{blade}}{2 \pi} \int_0^{2 \pi} F_{normal}(i, W) R_b \sin(\beta) d\beta$$

$$\frac{1}{\lambda} \sin(\beta)^2 \left(\lambda \left(1 + \frac{\cos(\beta)}{\lambda} \right) \right)^2 \approx \lambda (\sin(\beta))^2$$

$$T_{normal} = \frac{number_{blade}}{2 \pi} \int_0^{2 \pi} \frac{0.1}{2} \frac{180}{\pi} \rho H C V_f^2 \lambda R_b \sin(\beta)^2 d\beta$$

$$T_{normal} = \frac{0.1 number_{blade}}{2} \frac{180}{\pi} \rho H C V_f^2 \lambda R_b \quad V_f = \frac{2}{3} V_{fluid}$$

Rate increase :

$$\frac{T_{axial} + T_{normal}}{T_{axial}} = 1 + \lambda \frac{R_b}{R}$$

$$By \text{ using } 1 \text{ or } 2 \quad E_x = R_b$$

$$\Rightarrow \frac{T_{axial} + T_{normal}}{T_{axial}} = \frac{T_{Darrieus} + T_{normal}}{T_{Darrieus}} 1 + \lambda \frac{E_x}{R}$$

3 Conclusion :

Although the calculation is simplistic, we find the same earnings as in the preprint[6]. The yield of active lift turbine is clearly increased by report a Darrieus turbine.

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