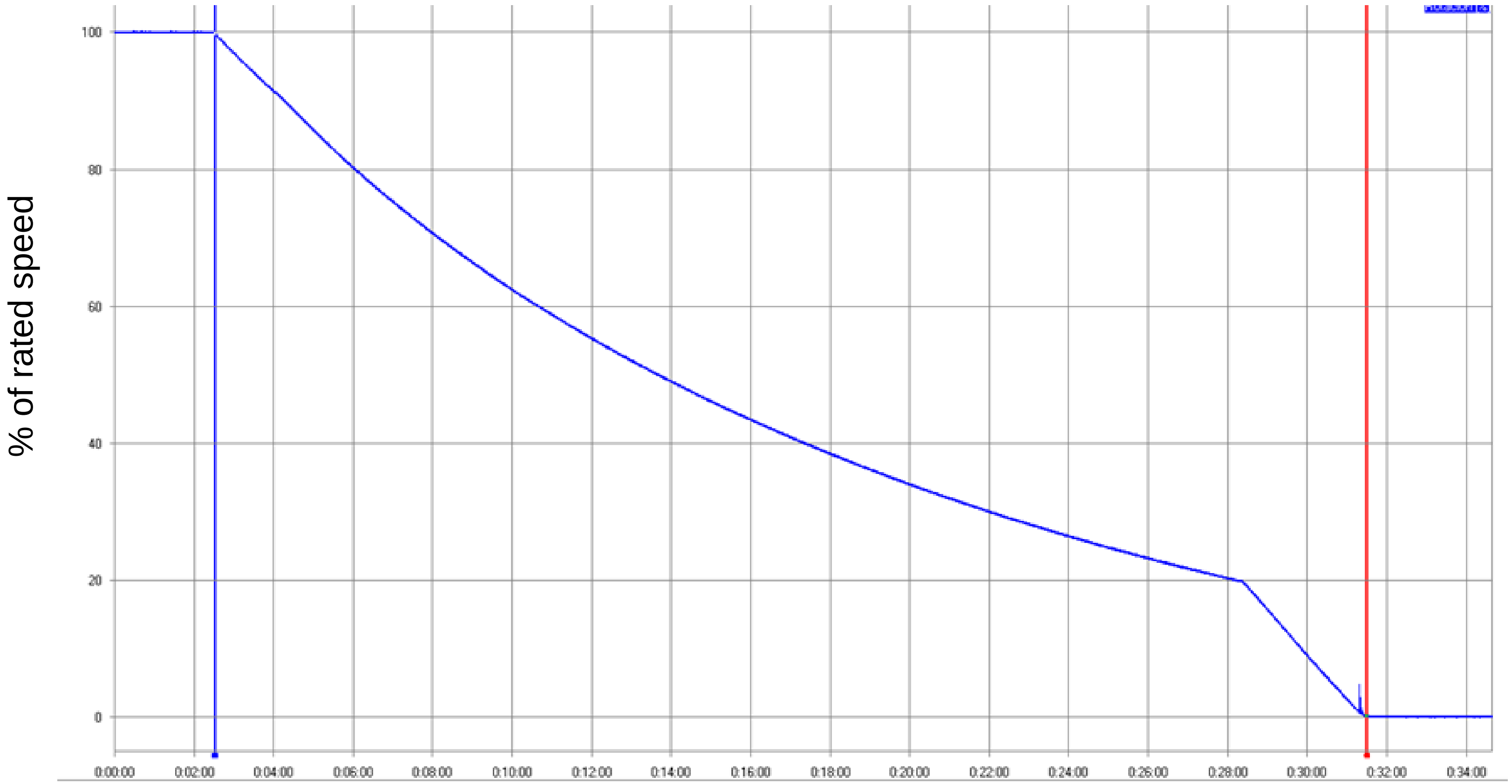
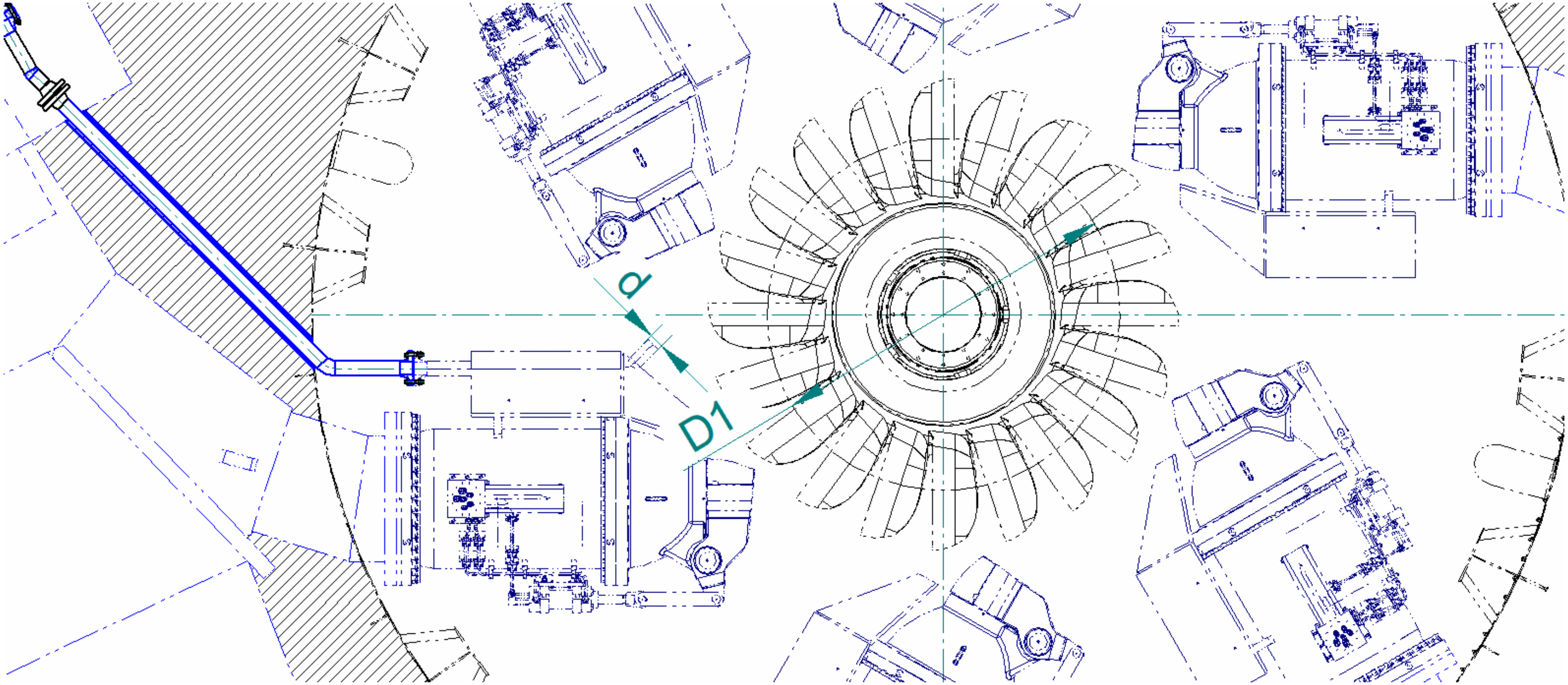
Brake jet calculation

Braking time measured at site (~29 min)

Guaranteed value = 12 min



Sketch



Motivation

Understand the assumptions of the following equation used to determine the diameter of the brake jet (d) in [m].

$$d = \frac{10^{-2}}{\sqrt{z_d}} \sqrt{\frac{0.011 \times GD^2 \times n \times 0.85}{\left(0.189H + 0.00109\sqrt{H}D_1 n\right) D_1 t_f}}$$

Where:

z_d is the number of brake jets [-], GD^2 is 4 × the rotating parts moment of inertia (J) [kg.m^2],

n is the rotational speed which the brake jet is activated [rpm],

H is the head available for the brake jet [mWC],

D_1 the runner bucket center diameter [m],

t_f is the time required to stop the rotating parts after the brake jet is activated [s].

Deceleration of rotating parts

If the moment of inertia of the rotating parts is constant.

$$T = J\frac{d\omega}{dt}$$

Where:

T is the total torque. For this mathematical model, just the torque due to the brake jet [N.m],

ω is the angular velocity [rad/s]

t is the time [s].

If ω is zero at the final instant t_f, $\int_0^{t_f} T dt = J\omega_i$

Where ω_i is the initial angular velocity.

For more details see: Angular momentum - Wikipedia

Torque due to the brake jet

$$T = z_d \eta \rho Q D_1 (V + u)$$

η is the efficiency of the brake jet [-],
ρ is the water specific mass [kg/m^3],
Q is the flow through the brake jet [m^3/s],
V is the brake jet velocity [m/s],
u is the Pelton runner tangential speed at D_1 [m/s].

And $u = \omega \frac{D_1}{2}$, therefore:

$$z_d \eta \rho Q D_1 \int_0^{t_f} \left(V + \omega \frac{D_1}{2} \right) dt = J \omega_i$$

For more details see: Pelton wheel - Wikipedia

Torque due to the brake jet

$$z_d \eta \rho Q D_1 V \int_0^{t_f} dt + z_d \eta \rho Q D_1 \frac{D_1}{2} \int_0^{t_f} \omega dt = J\omega_i$$

The $\int_0^{t_f} \omega dt$ depends on how the rotating parts speed varies with the time (see two next slides). If a linear variation is assumed

$\int_0^{t_f} \omega dt = \frac{\omega_i}{2} t_f$.

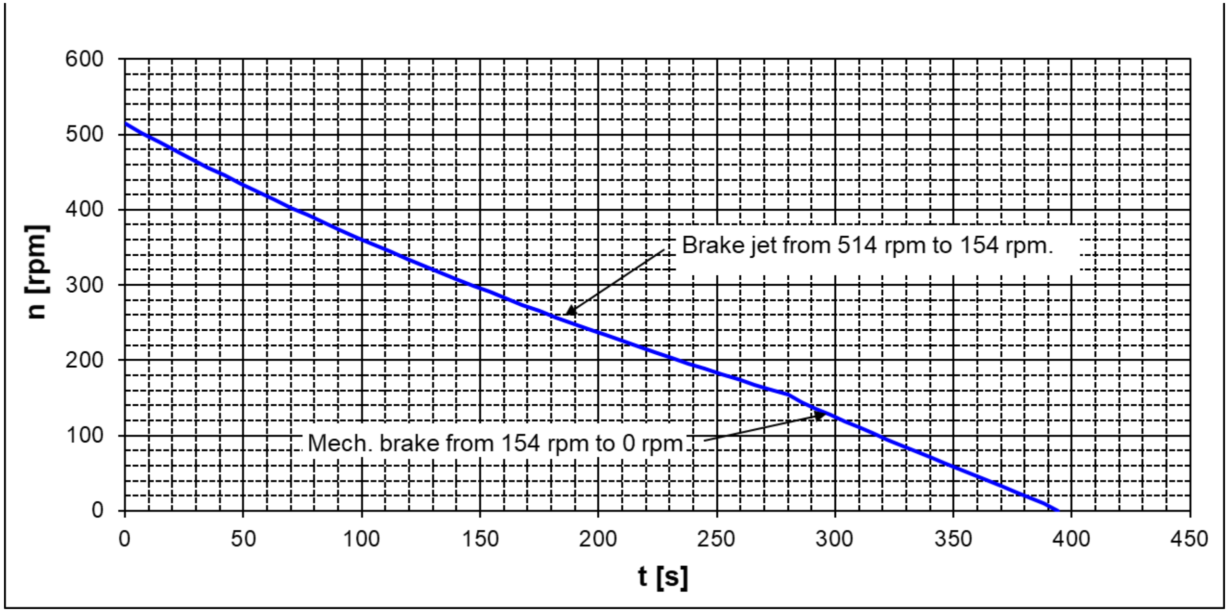
And

$$z_d \eta \rho Q D_1 V t_f + z_d \eta \rho Q D_1 \frac{D_1}{2} \frac{\omega_i}{2} t_f = J\omega_i$$

$$\left(z_d \eta \rho Q V + z_d \eta \rho Q \frac{D_1}{2} \frac{\omega_i}{2} \right) D_1 t_f = J\omega_i$$

Deceleration curve

Example from Project A calculation – Rated speed



Obs. If the brake jet is not deactivated at 154 rpm and the mechanical brake is not used, braking time becomes ~465 s.

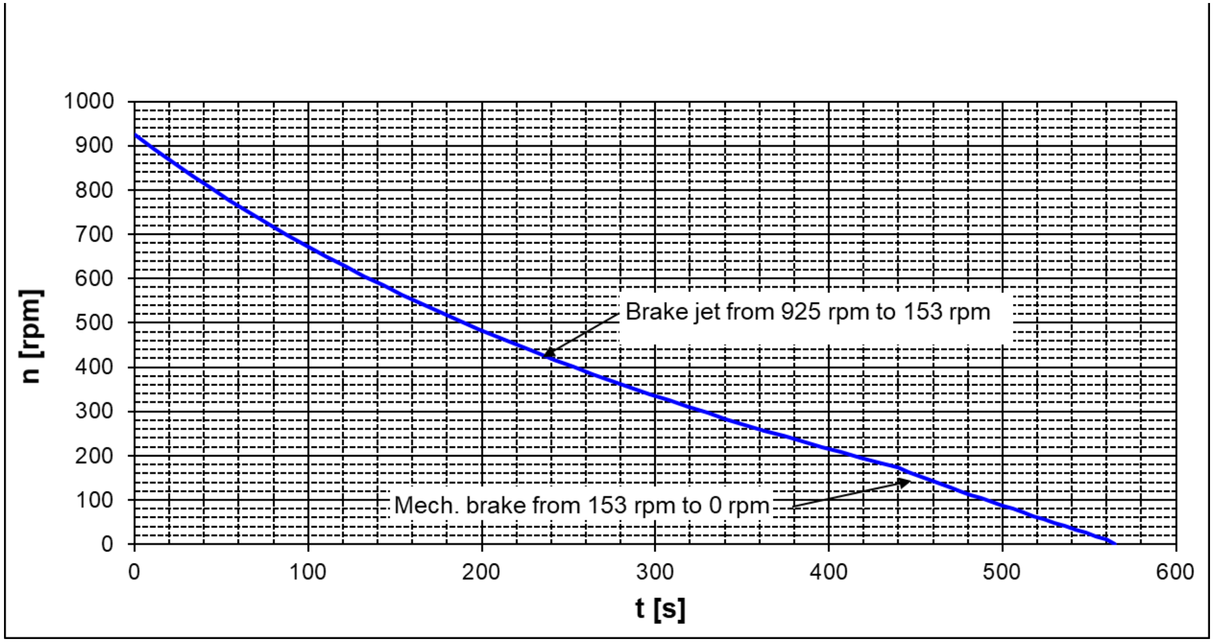
Using the formula on slide 12, calculated braking time is 643 s.

Difference is due to ventilation and bearing losses which are neglected on this mathematical model.

Formula on slide 4 yields 279 s.

Deceleration curve

Example from Project A calculation – Runaway speed



Obs. If the brake jet is not deactivated at 153 rpm and the mechanical brake is not used, braking time becomes ~635 s.

Using the formula on slide 12, calculated braking time is 995 s.

Difference is due to ventilation and bearing losses which are neglected on this mathematical model.

Formula on slide 4 yields 435 s.

Torque due to the brake jet

$V = \alpha\sqrt{2gH}$, where:

α is the brake jet coefficient of velocity [-],
g is the acceleration of gravity [m/s^2].

$$Q = \alpha\sqrt{2gH}\frac{\pi d^2}{4}$$

$$\left(z_d \eta \rho \alpha^2 2gH \frac{\pi d^2}{4} + z_d \eta \rho \alpha \sqrt{2gH}\frac{\pi d^2}{4}\frac{D_1}{2}\frac{\omega_i}{2}\right) D_1 t_f = J\omega_i$$

$$d^2 z_d = \frac{J\omega_i}{\left[\left(\eta\rho\alpha^2 2g\frac{\pi}{4}\right)H + \left(\eta\rho\alpha\sqrt{2g}\frac{\pi}{4}\frac{1}{4}\right)\sqrt{H}D_1\omega_i\right]D_1 t_f}$$

Final formula for brake jet diameter

Constants from Project A calculation:

η = 16%

α = 0.96

$$\omega_i = \frac{2\pi n}{60} = \frac{\pi n}{30}$$

$$d^2 z_d = \frac{\frac{\pi}{30} J n}{\left[\left(\frac{\pi}{2}\eta\rho\alpha^2 g\right) H + \left(\sqrt{2}\,\frac{\pi^2}{480}\eta\rho\alpha\sqrt{g}\right)\sqrt{H} D_1 n\right] D_1 t_f}$$

$$d = \frac{1}{\sqrt{z_d}}\sqrt{\frac{\frac{\pi}{30} J n}{\left[\left(\frac{\pi}{2}\eta\rho\alpha^2 g\right) H + \left(\sqrt{2}\,\frac{\pi^2}{480}\eta\rho\alpha\sqrt{g}\right)\sqrt{H} D_1 n\right] D_1 t_f}}$$

Obs. This formula gives the same numerical results as the formula on slide 4 only if η = 37%.

Final formula for braking time

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For a given d, t_f can be calculated as:

$$t_f = \frac{\frac{\pi}{30} J n}{\left[\left(\frac{\pi}{2} \eta \rho \alpha^2 g \right) H + \left(\sqrt{2} \frac{\pi^2}{480} \eta \rho \alpha \sqrt{g} \right) \sqrt{H} D_1 n \right] D_1 d^2 z_d}$$

Dúvidas?

Obrigado.

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