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Lumped Modelling of Vocal Fold

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Mathematical Model

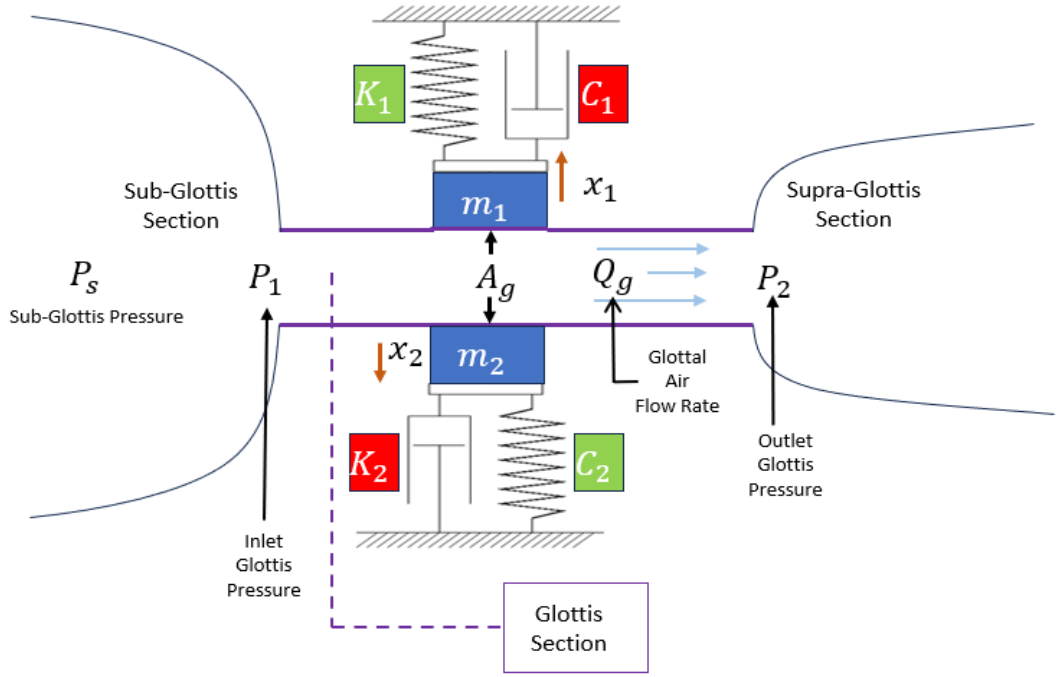

Fig: Schematic of lumped modelling of vocal folds with single mass-spring-damper system to represent each vocal fold.

- Two vocal folds are modelled.
- Each vocal fold is modelled with single mass-spring-damper system.

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Glottal Area

$$Ag = Ag_0 + lx_1 + lx_2$$

$$@\ x = x_0, Ag = Ag_0$$

$$x_0 = \frac{-Ag_0}{2l}$$

Ag = Glottal Area

x_0= Critical Displacement (displacement at which glottal area is 0)

Ag_0= Glottal Area when both vocal folds are at neutral position

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Flow Resistance and Flow Rate

$$R^2 - \frac{12\mu dl^2}{Ag^3}R - \frac{0.875\rho P_{sub-glottis}}{Ag^2} = 0$$

$$\frac{0.875\rho Q_g^2}{2Ag^2} + \frac{12\mu dl^2 Q_g}{Ag^3} - P_{sub-glottis} = 0$$

$$Q_g = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

$$R = \frac{P_{sub-glottis}}{Q_g}$$

$$a = \frac{0.875\rho}{2Ag^2}$$

$$b = \frac{12\mu dl^2}{Ag^3}$$

$$c = -P_{sub-glottis}$$

Aerodynamic Force

$$P_1 = P_{sub-glottis} - 1.37P_b$$

$$P_2 = -\frac{1}{2}P_b$$

$$P_{avg} = \frac{(P_1+P_2)}{2}$$

$$F_{aero} = P_{avg}A$$

$$F_{aero} = \frac{(P_1+P_2)ld}{2}$$

P_1 = Inlet Glottis Pressure

P_2 = Outlet Glottis Pressure

F_{aero} = Aerodynamic Force

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Total Force

$$F_{total} = F_{aero} + F_{add.aero\ resistance} + Spring\ Force + Damper\ Force$$

$F_{add.aero\ resistance}$ is additional aerodynamic resistance during closing phase to simulate flow separation

Phases of Glottal-Cycle

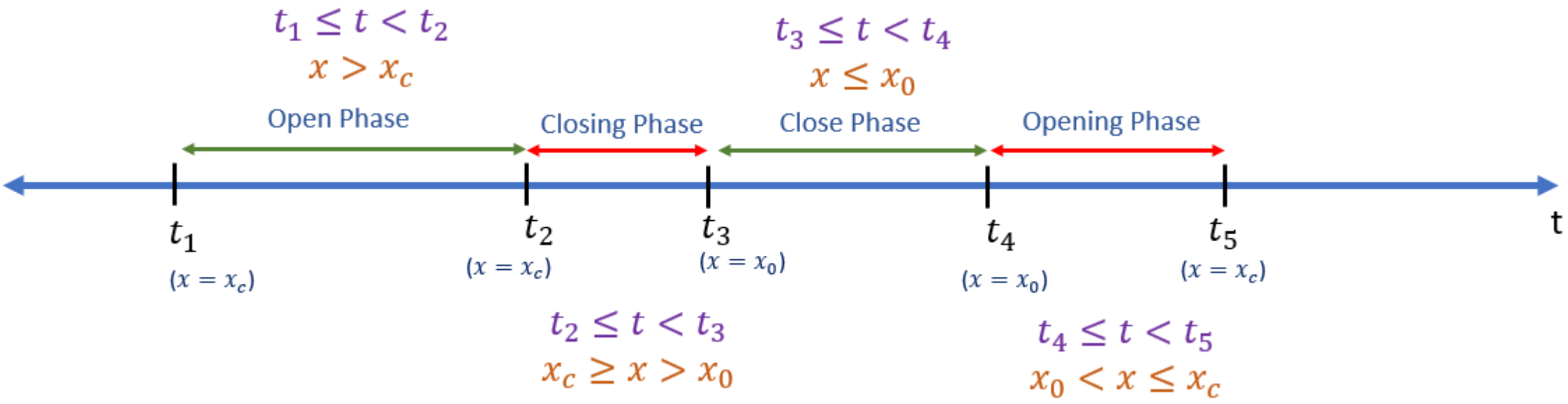

Fig: Distinct Phases of Glottal Cycle.

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Phases of Glottal-Cycle

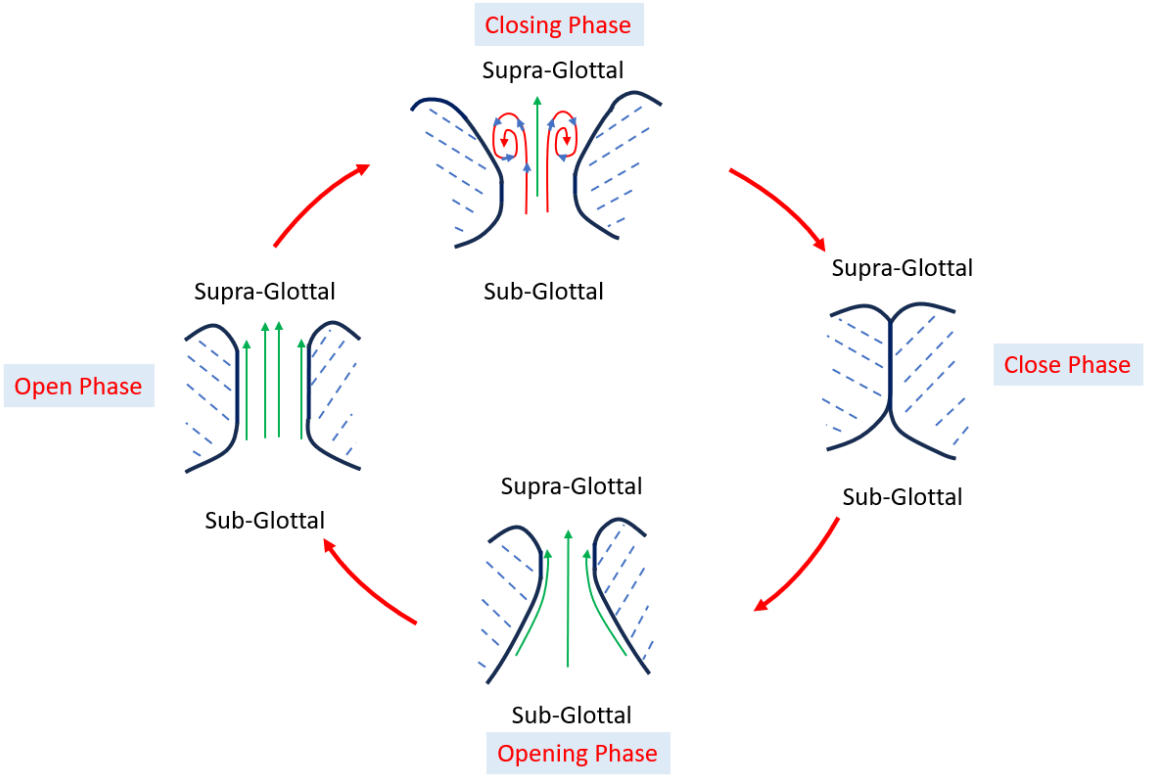

Fig: Schematic of vocal fold shapes at different phases of the glottal cycle.

Open Phase

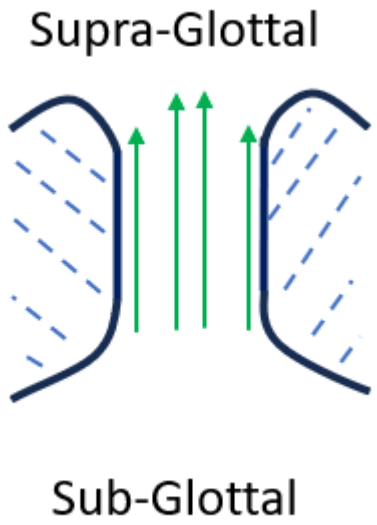

Fig: Open phase of the glottal cycle.

- Resistance is lowest.
- Pressure build-up is lowest.

Closing Phase

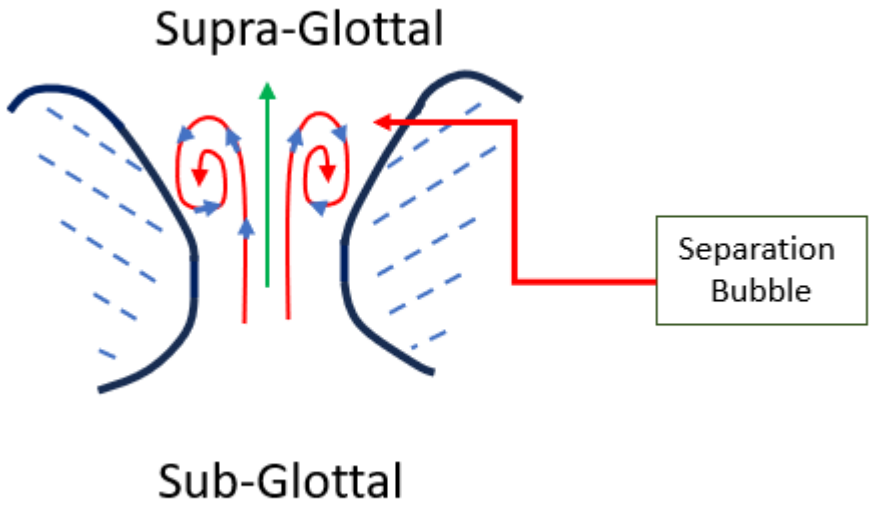

Fig: Closing phase of the glottal cycle.

- Resistance is getting higher.
- Pressure build-up is increasing.
- Additional aerodynamic resistance cancels aerodynamic force in order to simulate flow separation.

Close Phase

Fig: Close phase of the glottal cycle.

- Resistance is highest.
- Pressure build-up is highest.

Opening Phase

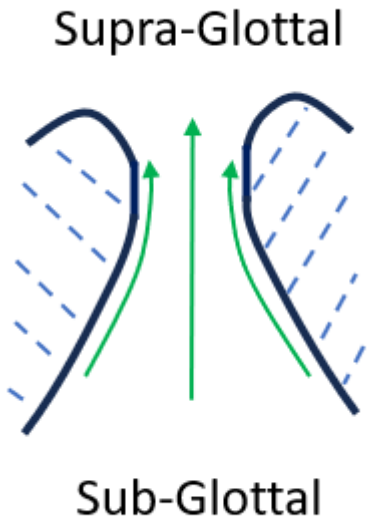

Fig: Opening phase of the glottal cycle.

- Resistance is getting lower.
- Pressure build-up is decreasing.

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Numerical Scheme

Forward Euler Method

$$\frac{dx}{dt} = \dot{x} = V = f_1(t,x,v) \quad \text{.....(1)}$$

$$\frac{dV}{dt} = \dot{V} = \frac{1}{m}(-cV - kx + F_{total}) = f_2(t,x,v) \quad \text{.....(2)}$$

$$x_{1,new} = x_{1,old} + dt \times V_{1,old} \quad \text{.....(3)}$$

$$x_{2,new} = x_{2,old} + dt \times V_{12old} \quad \text{.....(4)}$$

$$V_{1,new} = V_{1,old} + dt \times f_2\left(t, x_{1,old}, V_{1,old}\right) \quad \text{.....(5)}$$

$$V_{2,new} = V_{2,old} + dt \times f_2\left(t, x_{2,old}, V_{2,old}\right) \quad \text{.....(6)}$$

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End

Thank You!!!