

Auto-resonant drives for insect-inspired flapping-wing micro air vehicles

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Abstract:

Many desirable traits for agile flight in confined spaces can be seen in two-winged insects such as the hover-fly and so they provide excellent inspiration for micro air vehicles designed for indoor reconnaissance and similar roles. Moreover, having a single pair of wings greatly simplifies the aerodynamic and mechanical problem.

Insects such as the Hover-fly have relatively small wings and high wing beat frequencies, the lift and control forces are thus divided over many wing beats. A consequence of the small aerodynamic force per beat is that the majority of the load on the flapping system is inertial rather than aerodynamic.

As an oscillating system the flapping wings require energy to decelerate and re-accelerate at the reversals, this energy is not used to do work but simply to maintain the oscillations. In the case of the hover-fly flight regime the drive actuators will put more energy into maintaining the oscillations than into generating flight forces, this is clearly an untenable situation if efficient flight with good duration is to be achieved.

The answer is to make the wing, its control mechanism and the driving actuator a resonant system. This means simply that the kinetic energy of the wing is converted to and stored as potential energy in order to decelerate the wing and converted back again to re-accelerate the wing. A simple example of a resonant system of this type is the pendulum which uses gravitational potential for energy storage. In a resonant system, once oscillation is initiated the only energy that needs to be input to maintain the oscillations is that which overcomes losses such as friction and that which will do useful work, which in the case of a flapping wing mechanism is producing aerodynamic lift and control forces.

The difficulty in implementing such a system is in ensuring that when this additional energy is input the natural oscillatory mode is not interfered with. If the drive does not interfere with the natural oscillation it will provide suitable driving force even as the resonant frequency changes with load. To achieve this, feedback must be employed; the resulting system comprised of energy storage, actuator, feedback sensor and control system is described as auto-resonant. A system like this monitors system characteristics such as velocity or torque as well as the overall power output requirements and aims to add the additional power in empathy with the motion and the optimal operating conditions of the actuator.

It is also possible to change the resonant frequency intentionally by changing the system "stiffness" providing two means by which the energy output may be controlled, frequency and amplitude.

This paper covers first the basic theory behind resonance and auto-resonance then presents results from an experimental apparatus demonstrating auto-resonant operation indicating the increase in efficiency and highlighting the problems in utilising current actuator technologies for AR drives. Issues relating to feedback control of an auto-resonant drive are discussed and the performance of some simple implementations are compared. Finally the viability of AR drives for flapping winged micro air vehicles is discussed.