Abstract— Biological inspiration has been the beginning for various robotics and micro aerial Vehicle (MAV) development. Numerous studies have been undertaken on birds and insects to study about the bio-inspired design technology. The aerodynamics of the wings of birds and insects are studied for various flight mechanisms. The various wings flapping mechanism of the birds and insects provide us unbelievable aerodynamics of the fight mechanism. The objective of this paper is to study the wings flapping mechanism of the Dragonfly insect and to design a micro aerial vehicle (MAV) with the wings flapping mechanism. Linear actuator is used for the flapping mechanism of the forewings and hindwings. By using the linear actuator for the wings flapping mechanism we can perform various aerodynamics properties than the conventional motor and gear based flapping mechanism.

I. INTRODUCTION

Micro Aerial Vehicle (MAV) had gain lot of interest in aerospace and defense industries because of its small size and high aerodynamic properties. Various researches have been undertaken by many researchers and scientists to improve the performance of MAVs. Numerous technology and ideas have been implemented in various prototypes of MAVs. The emerging technology in MAV is bio-inspired flapping wing mechanism. The kinematics and aerodynamics of various birds and insects are studied to improve the flight performance of the MAVs. The flapping wing kinematics and flight performance of insects and birds are impressed lot of researchers and scientist because of its speed, efficiency and power. This paper presents the concept and design of a MAV inspired by the various aerodynamic properties of Dragonfly insect. Various studies had done to select a best mechanism to perform the flapping wing motion of the MAV to meet the flapping sequence performed by Dragonfly.

II. DRAGONFLY

Dragonfly is one of the oldest species in the world. Because of its aerodynamic properties it is differ from other insects. Dragonflies have two pair of wings namely Forewings and Hindwings. Each wing is individually controlled to achieve various flapping sequence. Due to high speed of the flapping wing sequence of dragonfly it is hard even to record it in high speed camera. Dragonflies perform various flapping sequence for thrust, lift, turns, glide and hover. In this paper we tried to perform few flapping sequence of the dragonfly.

III. DRAGONFLY FLIGHT MECHANISM

The Aerodynamic properties and the kinematics of flapping flight mechanism of the Dragonfly are studied from various biological papers. The flight mechanisms of the dragonfly are measured by few parameters, we taken in account some parameters from them [1]-[6].

The flight mechanism of the dragonfly mainly depends on the stroke plane angle $\beta$, wing flapping amplitude within stroke plane $\alpha$, and the angle of attack with respect to the stroke plane $\psi$ [2], [3], [5], [8], [9]. From various research analyses the values of these parameters are as below

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>RANGE</th>
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<tbody>
<tr>
<td>$\beta$</td>
<td>-5° to 90°</td>
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<tr>
<td>$\alpha$</td>
<td>-90° to 90°</td>
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Figure 1: Dragonfly Flight Mechanism

TABLE I: RANGE OF WING PARAMETERS
A. Lift and Trust

For lift and trust the Dragonfly uses two various sequence of wing flapping [3, 4]. The first sequence is the dragonfly uses in-phase and out-of-phase difference between forewing and hind wings for takeoff from ground. The second sequence is the amplitude of stroke angle $\alpha$ is changed in in-phase and out-of-phase flapping sequence. For heavy lift the ‘$\alpha$’ will be at maximum range (-90° to 90°) and the phase difference between the forewing and hind wing will be out-of-phase [5]. For quick lift the ‘$\alpha$’ range will be between -30 to 30° and the phase difference between both the wings will be in-phase. It this both sequence the ‘$\psi$’ angle of attack will be in range from 5°-10° [3, 4].

B. Free Flight and Hovering

In Free Flight the dragonfly mostly will use in-phase phase difference between both the wings. The ‘$\alpha$’ will be around -30° to 30°. In hovering the phase difference will be in-phase but the ‘$\psi$’ will change from range -5° to 15° [5, 6].

C. Turning

To take right and left turn during the flight dragonfly uses the complex flight mechanism. If the dragonfly want to take right turn then it will reduce the ‘$\alpha$’ to -30° to 30° at the right side wings (inner wing) and -90° to 90° at left side wings (outer wing). Which leads the dragonfly to take right turn and for left turn same principle is used for the inner and outer wings of the dragonfly.

IV. FLAPPING WING MECHANISM

Various studies and research have been undertaken to design a flapping wing mechanism for the Micro Aerial Vehicle to perform the various flapping sequence of the Dragonfly.

A. Slider-Crank Mechanism

The existing mechanism is Slider-crank based flapping mechanism. In this system DC motor is used to rotate a crank, a connecting rod is connected to the crank and the slider [10]. Because of the circular motion of the crank the slider is pulled up and down with the help of the connecting rod. The wing connected at the slider ends will perform a flapping sequence when slider moves up and down. The disadvantage of this system is we can’t perform all the flapping sequence of the Dragonfly, because we can’t change the amplitude of the stroke plane. The amplitude is fixed in this type of mechanism.

B. Linear Actuator mechanism

The proposed flapping mechanism is linear actuator based flapping mechanism. In this system dual direction linear actuator is used, when the linear actuator is forward biased it will perform pull sequence and when the reverse biased is given it perform push sequence. So when we gave correct Pulse Width Modulation (PWM) signal to the linear actuator it will perform flapping sequence. We can also rectify the drawback of the existing system just by varying the PWM input.

V. DESIGN AND DEVELOPMENT

By the research done about the biological properties and the aerodynamic properties of the Dragonfly insect, the Slider – Crank mechanism is not sufficient to perform the flapping sequence of the dragonfly. After various discussions we decide that the bi-directional linear actuator will be good enough to perform few sequence of the flapping sequence of the dragonfly wing.

A. Linear Actuator

To select the Linear Actuator for the proposed system we considered the aerodynamic properties of the dragonfly. When the dragonfly is in gliding sequence the wings will be almost in horizontal position. When the dragonfly starts to fly, the wings will move upwards above the horizontal plane and then backward below the horizontal plane. There are two types of linear actuator namely solenoid linear actuator and bidirectional linear actuator. Since the solenoid linear actuator is operate on only one direction, which will not meet the mechanism of dragonfly’s aerodynamics. So we use bidirectional linear actuator for our proposed system.
While designing the linear actuator for this proposed system, we came in the consideration of how much power we going to use. As a prototype we first planned to design a linear actuator which will operate on an operating voltage of 12v and maximum withstand current up to 20A of DC power supply. Next we consider which winding coil we going to use. We fabricated three prototypes with 36 AWG, 30AWG and 26AWG. Teflon bobbin was fabricated as per the design which helps us to wind the winding coil around it. 36AWG wire with 400 turns has been winded in the bobbin. 10mm x 10mm Neodymium rare earth magnet is used in the linear actuator. This permanent magnet will make the linear actuator to operate in both directions when the polarity is changed.

A 10mm hole is drilled at the center of the bobbin to place the permanent magnet. 4 mm diameter and 30mm long iron rod is attached to both end of the magnet. This iron rod is used to connect the wing to the linear actuator. When the linear actuator is powered by proper PWM signal this magnet and iron rod setup will be pulled up and pushed down to make the flapping sequence. We enclosed this winding and magnet arrangement inside an iron core.

B. Flapping Mechanism

Flapping Mechanism of the proposed system using bidirectional linear actuator is shown in figure.5. As shown in the figure at initial position the wing is placed 5° above the horizontal position. This 5° clearance is used to make the gliding process of the dragonfly Aerial Vehicle. The advantage of the proposed system is we can make the phase difference between the forewing and the hindwing just by changing the PWM input to the respective linear actuator. One end of the wing is connected to the linear actuator through a circular joint.

We use aluminum for the circular joint and flapping mechanism parts. This circular joint performs the major role in converting the linear motion to flapping motion.

C. Dragonfly Wing

The prototype of the dragonfly wing is design and fabricated using steel reinforcement and polythene paper. The
wing length is of 28cm and wing span is of 10cm. The steel reinforcement is used to hold the wing fit and flexible so that it won’t bend much when the flapping sequence is performed. The size of the dragonfly wing is taken as 1:10 ration from the original dragonfly.

Figure 9: Prototype of dragonfly Wing

D. Linear Actuator Driver Circuit

Linear actuator to perform various flapping sequence we have to provide a proper PWM signal through the driver circuit. We had design linear actuator to withstand 20A of continuous current so for driving the Linear Actuator at its maximum rating we use MOSFET (Metal Oxide Semiconductor Field Effect Transistor). As per our concept the linear actuator should be forward biased on T_ON time of the PWM signal and reverse biased on T_OFF time. So an H-Bridge MOSFET driver circuit was designed.

![Linear Actuator Driver Circuit](image)

To make the linear actuator forward bias MOSFET ‘Q1’ and ‘Q4’ have to be in ON state and ‘Q2’, ‘Q3’ should be in OFF state. For reverse bias ‘Q2’, ‘Q3’ should be ON and ‘Q1’, ‘Q4’ should be OFF. The working of the gate driver is when high pulse is given as input to it high terminal will be HIGH and low terminal will be LOW, if low pulse is given as input then the high terminal will be LOW and low terminal will be HIGH. So to perform forward and reverse bias of the linear actuator at high and low pulse respectively we gave same PWM signal to the gate driver just inverse with respect to each other. So at high PWM, the linear actuator will be forward biased and at low PWM, the linear actuator will be in reverse biased. This will make the linear actuator to perform the flapping sequence with respect to the PWM input. By changing the T_ON and T_OFF time duration we can change the amplitude of the stroke plane ‘α’.

VI. CONCLUSION AND FUTURE WORK

Prototype of bidirectional Linear Actuator is designed and developed. The flapping mechanism of the wing assembly was designed and developed. After the testing we came to know the size and weight of the linear actuator is little heavy so the future plan is to design a small linear actuator with less operating voltage. By the current prototype the battery and the driver circuit to energize the linear actuator became too heavy. As already we planned only to make the dragonfly aerial vehicle as a big one all the above prototype is designed in large dimension. But the resource for making this dragonfly to fly in air is heavy and expensive we planned to design and fabricate a new prototype of the dragonfly as Micro Aerial Vehicle (MAV). We going to change all the dimension and design of the flapping mechanism and wing to make this MAV very less weight and operate in low power. The length of the linear actuator is planned to be not more than 15mm and the diameter not more than 10mm and instead of iron we planned to use aluminum for all parts, by which we can reduce the weight of the linear actuator. Every parts of the flapping mechanism is minimized to make the whole mechanism very small compared to the prototype we designed now. By this new design plan, we can design a MAV with less weight and high efficiency.

REFERENCES


BIOGRAPHY

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