The optimum design of the flapping-wing mechanism

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Abstract: This paper presented a numerical model of flapping-wing mechanism and optimized mechanism parameters by genetic algorithm. The result of optimization shows right-and-left asymmetry of mechanism motion was greatly reduced to 17.07% of initial mechanism. The right-and-left asymmetry of wing motion of flapping-wing was greatly improved. It proves the feasibility and veracity of genetic algorithm applied on optimization design of flapping mechanism.

1. Introduction
Flapping—wing MAV is a kind of new concept aircraft that imitates the flying style of birds and insects. Flapping—wing MAV differs from the fixed—wing aircraft and rotary—wing aircraft in it draws support from the vibration of wings to produce lift, thrust and gets raise, hover and push function in a flapping—wing system. A study of bionics shows that the diversity of animal flying ability and skills originates in the diversity and the complex running mode of their wings [1-3]. So, it is significant for us to design a high efficient and reliable flapping—wing driving mechanism.

To succeed to fly the flight of flapping—wing MAV, the research institute and amateurs all over the world designed and made different kinds of flapping—wing driving mechanism. Micro-mechanical Flapping Insect developed by The University Of California uses the driving system that combines piezoelectric crystal with four-link mechanism. Robert Miles in George Asia Technology Research Center developed a flapping—wing MAV called Entomopter that used the technology of Reciprocating Chemical Muscle(RCM) to drive the flapping—wing micro air vehicle (MAV). This aircraft is designed to probe Mars in the future. Micro flapping—wing MAV developed by Anna University used the four-link mechanism to make the flight succeed In India [4-7]. As the four-link mechanism could run easily, it could actualize the ordered flapping—wing frequency, flapping—wing angle accurately to satisfy the flight of flapping—wing MAV. Micro air vehicle study group of Xijing University used the four-link mechanism to drive the flapping—wing MAV to make the control true [8-11].

But the four-link mechanism is an unsymmetrical flapping—wing system itself. This unsymmetrical flapping—wing system could cause flapping—wing phase difference between two wings when the flapping—wing system run. So, this system gets the hysteresis phenomenon and advance phenomenon. These phenomena cause the lift of left and right wings different, and lead to the transverse acting force gets different. The aircraft is on the state of swing, this state broke the flight safety and stability of aircraft. This papers is based on the four-link mechanism and uses Genetic Algorithm to optimize the mechanism control data to reduce the unsymmetry of the system at utmost and attenuate the wing swing phenomenon in flight [12-13].
2. Optimum algorithm

Genetic algorithm (GA) that is based on the algorithm evolution with survival of the fittest. Its feature is that information interchange and searching between strategy of group search and member of group are not based on information gradient. Especially, the information interchange and searching could solve the no linear problem that traditional method hardly solve. Comparing with traditional algorithm, It is a high rate to find a best answer from searching a group. We use the genetic algorithm to optimize the mechanism of flapping—wing in this papers. The flow figure 1 is as shown.

3. Example

There is a requirement that the mode of run in right and left swing arms are the same, so the aerodynamic force caused by two wings also go to be the same gradually. We are having an optimum design by the base of flapping—wing mechanism system to reduce the deviations of left and right flutter angles, and
we have an optimum design by using the data of the law that GA caused to the mechanism run. The four-link flapping wing mechanism is as figure 2 shown. \( l_2 = l_3, l_4 = l_5, l_6 = l_7 \).

### 3.1 Mathematical Model

We use the geometrical relation of the four-link mechanism to set up the left and right flutter angles \( \beta, \gamma \); the max flutter angle \( \phi \); the downwars flutter angle \( \phi_{e} \); the transmission angle \( \rho_1, \rho_2 \); mathematical model is

\[
\beta = 0.5 \cdot \pi - 2 \arctg \frac{A - \sqrt{A^2 + B^2 - C^2}}{B + C} + \theta; \quad \text{in the former equation}
\]

\[
A = \sin(\alpha + \theta); \quad B = \cos(\alpha + \theta) - \frac{l_6}{l_1}; \quad C = \frac{l_1^2 - l_2^2 + l_3^2 + l_6^2 - l_6}{2l_1l_4} \cos(\alpha + \theta);
\]

\[
\gamma = 0.5 \cdot \pi - 2 \arctg \frac{A + \sqrt{A^2 + B^2 - C^2}}{B - C} + \theta; \quad \text{in the former equation}
\]

\[
A = 2 \times l_1 \times l_4 \times \sin(\alpha - \theta);
\]

\[
B = -2 \times l_4 \times (l_1 \times \cos(\alpha - \theta) - l_6); \quad C = l_1^2 - l_2^2 + l_3^2 + l_6^2 - 2 \times \cos(\alpha - \theta) \times l_6 \times l_4 ; \quad \text{the max flutter angle } \phi: \quad \phi = \arccos \frac{l_1^2 + l_6^2 - (l_1 + l_6)^2}{2l_4l_6} - \arccos \frac{l_2^2 + l_6^2 - (l_2 - l_6)^2}{2l_4l_6}; \quad \text{the downwars flutter angle } \phi_{e} = \arccos \frac{l_3^2 + l_6^2 - (l_3 + l_6)^2}{2l_4l_6} - \frac{\pi}{2} - \theta;
\]

The size and the change of the transmission angle in the four-link mechanism are vital factors to test the transmission function of mechanism. The transmission angle is changing constantly, to ensure the transmission function good, the degree of the min transmission angle is not under 40 degree. The formula of transmission angle is as below:

\[
\text{The transmission angle: } \rho_1 = \arccos \frac{l_3^2 + l_6^2 - (l_3 - l_6)^2}{2l_4l_6}; \quad \rho_2 = \pi - \arccos \frac{l_3^2 + l_6^2 - (l_3 - l_6)^2}{2l_4l_6}.
\]

### 3.2 Objective Function

To minimum margin the flutter angle of the left and right swing arms in flapping wing system, we could use the root-mean-square deviation to set up the objective function:

\[
F(X) = \min \sqrt{\frac{1}{N} \sum_{i=0}^{N} (\beta - \gamma)^2} \quad \text{in this equation: } \beta \text{ is the instant flutter angle of right swing arm, } \gamma \text{ is the instant flutter angle of left swing arm, } N \text{ is the angle of crank spinning.}
\]

### 3.3 Design the variable quantity

The four-link mechanism’s kinematics parameters like the flutter angle, the angular speed, angular acceleration have a bearing on the mechanism’s parameters \( l_1; l_2; l_3; l_4; l_6; \theta \). We make the five parameters that decide the form of flapping mechanism, they are \( l_1; l_2; l_3; l_4; \theta \). Their design parameters and variation range is as below:

| Symbol | design parameter | variation range         | symbol  | design parameter | variation range         |
|--------|------------------|-------------------------|---------|------------------|-------------------------|
|       | crank            | [3.2mm, 13.4mm]         | \( l_1 \) | link rod 1       | [3.2mm, 25.4mm]         |
| \( l_2 \) | link rod 2       | [24mm, 30mm]            | \( l_6 \) | \( \theta \)     | Initial setting angle   |
| \( \theta \) |                  | [10°, 20°]              |         |                  |                         |
3.4 Constrained Condition

According to the condition of crank link rod system, we set these in-equations as below: 
\[ l_1 + l_2 \leq l_4 + l_6 , \]
\[ l_1 + l_4 \leq l_2 + l_6 . \]
The max flutter angle of the mechanism is invariably and it is 60 degree. To avoid coupling phenomenon of the upwards flutter angle and the downwards flutter angle caused by the changing of the max flutter angle in this mechanism. We make the downwards flutter angle a invariably, it is \[ l_1 + l_2 = 28.4 . \] To ensure the mechanism could run with a good transmission ability, the transmission could be that :
\[ \min(\rho_i, \rho_i) \geq \pi \times \frac{4}{18} . \]

4. The Optimum Result And Analyse

As the example of the flapping-wing four-link mechanism, we know that the rotation velocity of electric motor is 10000r/min. The range of the crank spinning angle is 0 degree to 360 degree. We use the GA to make an optimum design to the flapping wing four-link mechanism. We make the group scale 100, the probability of cross is 0.8, the probability of the teromorphosis is 0.02, the generation of evolution is 1000, the optimum result is as the shown in the table2.

As the optimum result shows that using the GA to have an optimum design to the flapping wing mechanism could reduce obviously the quadratic sum of swing arm flutter angle’s deviation. It captured 17.07 % of standard deviation. So, we reduce effectively the dis-symmetry of flapping wing mechanism.

| Design the variable quantity | 1 | 2 | 3 | 4 | 5 |
|-----------------------------|---|---|---|---|---|
| datum mechanism             | 4.2 | 24.2 | 8.4 | 24.86 | 15.1 |
| optimum mechanism           | 4.12 | 24.2 | 8.22 | 25.37 | 18.2 |

5. The flight test of model

According to the optimum result, we produce a new the four-link mechanism. It is as shown in figure3. As the flapping wing test flight shows that optimum mechanism reduces the vibration of left and right wings in flapping wing flight. The flight is so steady to operate easily. It is as shown in figure4.

6. Conclusions

To make the stable flight of the flapping-wing, we have an optimum design based on the flapping-wing four-link mechanism. The optimum model is the deviation of the flapping-wing mechanism right and left swing arms in the optimum process. Both the design parameter and the constraint parameter satisfy the condition of design and machining. We use the Genetic Algorithm to have a optimum design to the mechanism to get the new flapping mechanism. The test flight outdoors shows that the flapping left and right wings' vibration has been reduced. The Genetic Algorithm could offer theory and engineering instruction to the selecting of the mechanism parameter.
With the development of the study on the flapping wing and the high-need for the practicability, it is very necessary to have the equipment of the flight and the screening. The reducing asymmetry of the flapping-wing mechanism could reduce the disturbing to the flight control system, and improve the stability of the screening. These measure would offer guarantee to the practicability of flapping-wing MAV.

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