International Scientific Conference
UNITECH`2024

APPLICATION OF IMPACT DRIVE MECHANISM (IDM) ON A FLAPPING WING MECHANISM OF A MICRO AERIAL VEHICLE (MAV)

Hilmi Kuşçu[1], Ulaş Kaya[2],
[1]*Department of Mechanical Engineering, Trakya University, Edirne, TÜRKİYE*
[2] *PHD Candidate, Department of Mechanical Engineering, Trakya University, Edirne, TURKIYE*

Abstract
IDM is a method that transforms small vibrations of a piezo element into continuous linear motion as experimentally proven in our previous study [1]. Although theoretically and experimentally it is possible for IDM to move the piezo element in two directions continuously, the weight of required hardware to reverse the signal thus the direction, the fixed poles of piezo-crystal and the low velocity of piezo element during IDM application to reach the required frequency of flapping makes it difficult to use two-direction or direct sliding mechanisms for MAV applications.

In this study, a flapping wing mechanism is designed which is actuated by one-directional motion of a piezo element by applying method of IDM. For IDM to be applied in one-direction motion of piezo element a continuous surface is required. A steel fixed cylinder's outer surface selected as continuous surface to provide piezo element to move rotationally and continuously. Another lightweight cylinder with spur gear one end placed coincident with the steel fixed one. The lightweight cylinder can move rotationally around the fixed steel one while constrained to move in longitudinal direction and connected to piezo element. So, while piezo rotates around the fixed steel cylinder, it actuates the gear with the rotation of lightweight cylinder. The velocity of this gear is amplified with a gear-train. And finally, a crank-rod mechanism was employed to flap the wings of the MAV. After theoretical calculations, the two- and three-dimensional drawings, and kinematic and dynamic simulations were carried out by using "Autodesk Inventor Professional" software. All the parts of this wing mechanism are designed as manufacturable with the conventional manufacturing methods including 3d printing, machining (lathe and milling), composite resin transfer molding.

The research conducted here could be supportive when dc motors could not be used to drive MAV wing mechanisms because of environmental conditions.

Keywords*:* Micro Aerial Vehicles, Flapping Wing Mechanism, Piezoelectricity, impact drive mechanism

INTRODUCTION

The first application of IDM to actuate a micro-mechanism is back to 1990 by developing a "simple rotating arm" and a "three degree of freedom (3-DOF) joint" for a micro-positioning robot (Higuchi et al. 1990). The "simple rotating arm" was designed as one-dimensional (1-D) joint, while the "3-DOF joint" was the manipulation of a three-dimensional (3-D) ball joint as shown in Figure-1-2 [2].

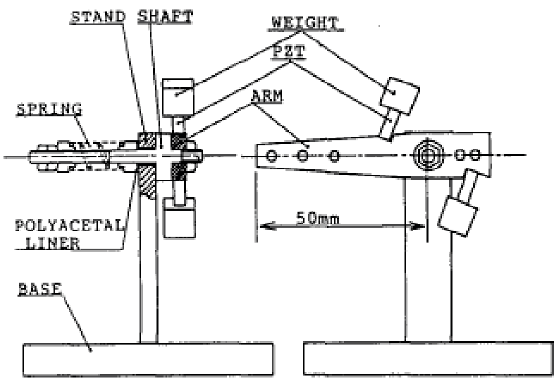

Fig.1 *Structure of IDM actuated 1-D joint.*

"UNITECH – SELECTED PAPERS" Vol. 2024
Published by Technical University of Gabrovo
ISSN 2603-378X

doi: *www.doi.org/10.70456/BVWV4055*

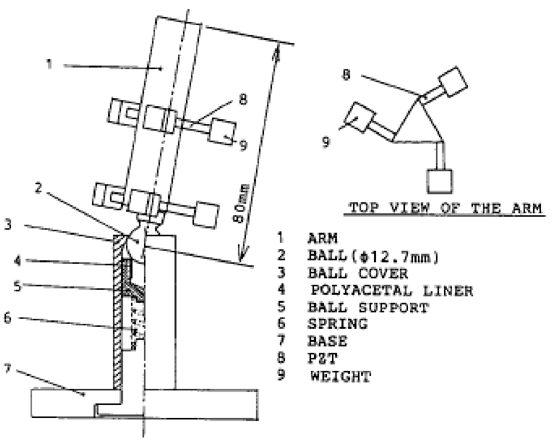

Fig.2 *Structure of IDM actuated 3-D joints.*

The categorization and qualitative comparison of MAV actuation methods including PZT-ceramics and PZT motors are summarized in 2006 (Conn et al. 2006). Two types of micro actuators are the linear and rotary types [3]. The rotary types are DC motors (brushed and brushless), PZT motors and the micro internal combustion engines, while the linear ones are the PZT-ceramics, Shape memory alloys, magnetostrictors, solenoids and the electro-active polymers. The qualitative summary of these actuators can be seen in Figure-3 [3].

Rotary Actuator	Advantages	Disadvantages
Brushed DC motor	- Simple operation, no driver electronics required.	- Size and mass may be an issue.
Brushless DC motor	- Miniature size and mass.	- Driver electronics required.
Piezoelectric motor	- Miniature size and mass. - High torque at all speeds.	- Product choice limited. - High voltage and driver electronics required.
Micro internal combustion engine	- High power density and efficiency.	- Novel technology, under development.

Linear Actuator	Advantages	Disadvantages
Piezoelectric ceramic	- Excellent performance except strain output. - Strain output can be magnified using bender arrangement.	- Require high activation voltage.
Shape memory alloy	- Excellent performance except frequency range.	- Poor fatigue life.
Magnetostrictor	- Excellent performance except strain output.	- Require high activation voltage.
Solenoid	- High strain.	- Low energy density.
Electro-active polymers	- Certain EAPs match muscle for performance. - Dielectric elastomers outperform muscle in both ss and strain output	- Only ionic EAPs operate on low voltage. - Novel technology, not widely available.

Fig.3 *Qualitative summary of rotary and linear actuators, respectively.*

The capability of piezo crystal to move in two opposite directions continuously when IDM principle is applied makes it suitable to use as a FWMAV actuator. The two-way motion of piezo, based on IDM is called smooth impact drive mechanism (SIDM) and can be actuated as a micro-mechanism in two ways as in Figure-4 [4]. The low speed, and the weight of the hardware required to change direction of piezo crystal makes it difficult to use in micro flapping wing mechanisms.

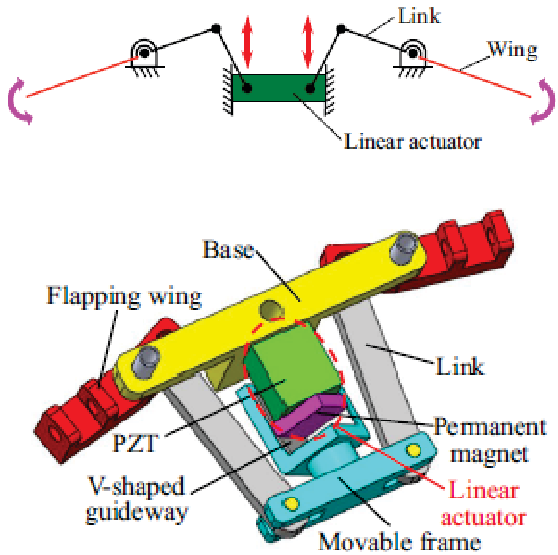

Fig.4 *Schematic design of the SIDM actuated flapping wing mechanism [4].*

To reach the required flapping speed of wings (Dragonfly: 30 Hz, bee:190 Hz, Insect: 200 Hz.), and to decrease the weight of the hardware to change the signal of PZT element a new approximation is proposed here. Instead of using a continuous flat surface, a cylindrical surface is employed for application of IDM to actuate PZT crystal.

DESIGN OF THE FLAPPING WING MECHANISM

Fig.5 shows the motion characteristics of the current design: The piezo and magnet assembly continuously rotates around the "fixed cylinder"; thus, the "rotating lightweight cylinder" rotates by push force of piezo and magnet assembly.

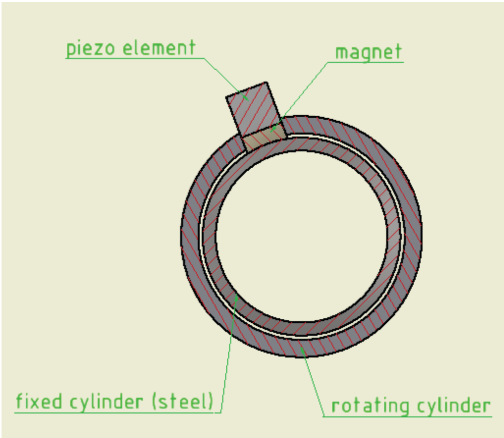

Fig.5 *Simplified model of IDM based rotary actuator.*

The complete drawing of wing flapping mechanism is drawn in Fig.6. A driving gear is connected to the rotating cylinder which drives two small gears to run the crank-rocker mechanism.

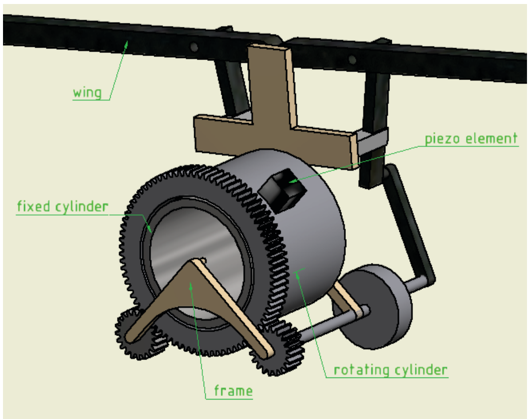

Fig.6 *Design of wing flapping mechanism (back view).*

The crank-rocker mechanisms actuate the linkage mechanism to provide the flapping of the wings as in Fig.7.

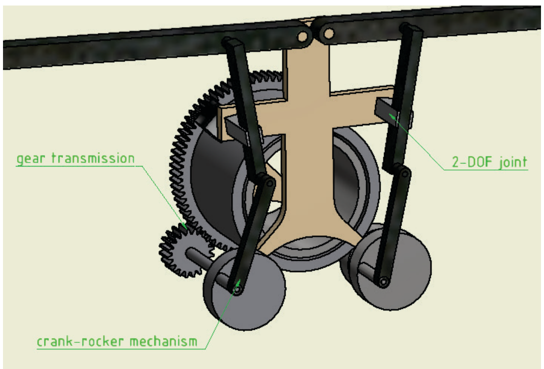

Fig.7 *Design of wing flapping mechanism (front view).*

In our previous study, the performance analysis of single and series connected PZT elements by using method of IDM is carried out [1]. The experiments showed that the velocity of double crystal test specimen can reach 20 mm/s at a resonance frequency of 22 kHz as in table.1.

Double Crystal Experimental and FEM Solutions			
Resonance Frequency (fem result-Experimental Result)	Longitudinal Deflection in x-dir. (fem result)	Transverse Deflection in z-dir. (fem result)	Linear Velocity on test rig
36 KHz-22 KHz	0.0324 mm	0.0675 µm	20 mm/s

Table.1 *Double crystal PZT element's linear velocity based on method of IDM.*

By using this measured data, the flapping frequency of the wings can be calculated:

D_d (Diameter of driving gear) =20 mm,
V_d (Velocity of driving gear) =V_{pzt},
ω_d (Angular velocity of driving gear)
D_p (Diameter of driven gears) =2 mm,
V_p (Velocity of driven gears)
ω_d (Angular velocity of driven gears)
V_{pzt} (Linear velocity of PZT) =20 mm/s.
ω_c (Angular velocity of the cranks) = ω_d

The velocity of PZT element and magnet assembly is equal to the velocity of driving gear. Thus, the angular velocity of the driving gear is

$$\omega_d = V_{pzt} \div \left(\frac{D_d}{2}\right) \qquad (1)$$

$$\omega_d = (20\,mm/s) \div \left(\frac{20\,mm}{2}\right) = 2\frac{rad}{s}$$
$$= \left(\frac{60}{2\pi}\right) \times 2\frac{rad}{s}$$
$$= 19.1\,rpm$$

The angular velocity of driven gears or the cranks can be calculated by multiplying the angular velocity of driving gear with the ratio of driving gear diameter to driven gear diameter.

$$\omega_p = \omega_c = \left(\frac{D_d}{D_p}\right) \times \omega_d \quad (2)$$

$$\omega_p = \omega_c = \left(\frac{20\,mm}{2\,mm}\right) \times 19.1\,rpm \approx 191\,rpm$$

The flapping frequency of the wing is equal to the angular velocity of crank; thus, it flaps 191 times per minute with single layer gear transmission. If a secondary gear unit with same dimensions is added to the mechanism the flapping frequency becomes

$$191\,rpm \times \left(\frac{D_d}{D_p}\right) = 1910\,rpm = 31.8\,rps$$

Which is suitable for dragonfly like MAV wing mechanisms.

CONCLUSION

In conclusion, an application of IDM principle by designing a MAV flapping mechanism which could be manufacturable with conventional methods is presented. The continuous surface of cylinder provides the PZT elements to move continuously as a rotary motor when IDM is applied.

In our next study the manufacturing of this design will be carried out and tested with different flapping speeds and number of gear units. The continuous and rotary motion characteristics of the PZT materials based on IDM when a cylinder surface is used as a guide, the micro mechanisms including micro unmanned submarines, micro vehicles to investigate planet surfaces in space, etc. could also be driven with this mechanism.

REFERENCE

[1] Kuşçu H, Kaya U. (2023) Performance analysis of continuous linear motion of single and series connected piezoelectric elements by using method of impact drive mechanism. Journal of the Technical University of Gabrovo, Vol67-2023-16, pp. 70-76

[2] Higuchi T, Yamagata Y, Furutani K, Kudoh K (1990) Precise positioning mechanism utilizing rapid deformations of piezoelectric elements. In: Micro electromechanical systems, 1990. Proceedings, an investigation of microstructures, sensors, actuators, machines and robots. IEEE, 1990. IEEE, pp 222–226

[3] Conn A, Burgess S, Hyde R, Ling CS (2006) From natural flyers to the mechanical realization of a flapping wing micro air vehicle. In: Robotics and biomimetics, 2006. ROBIO’06. IEEE International Conference on, 2006. IEEE, pp 439–444

[4] Peng Y, Cao J, Liu L, Yu H (2017) A piezo-driven flapping wing mechanism for micro