P 76

BISTABLE MICRO ACTUATOR FOR ENERGY SAVING

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Abstract:
The article describes a linear magnetic flip-flop micro actuator, designed with FLUX software, assembled and characterised for a specific application requiring low losses at function states. The micro size allows reducing the energy required for actuation. Permanent magnets ensure bistability and suppress losses at functional states. Although the actuator is less than 1 g, the blocking force is about 0.1N and the stroke is 0.6mm. Firstly, the paper describes the main functionality of the actuator. Then are presented measured characteristics and results are compared with FLUX software computation. Finally perspectives of further miniaturisation are discussed.

Keywords: Moving magnet, flip-flop, linear magnetic actuator, energy sparing, prototype, Flux.

Introduction

Cedrat Technologies (CT) designs electromechanical devices for specific applications. After having prototyped a space compliant voice coil [1], CT has focussed its energy on development of new micro actuators. Some of them have been already published like APA XS [2] and micro stepping motor motors [3]. The article presents new works on a linear flip-flop micro actuator. Attention have been paid on this kind of devices for years, as it is shown by several publications [4],[5]. However many applications like micro valves, micro contact and Braille writer require further miniaturisation with specific constraints of forces, quickness, and operating process.

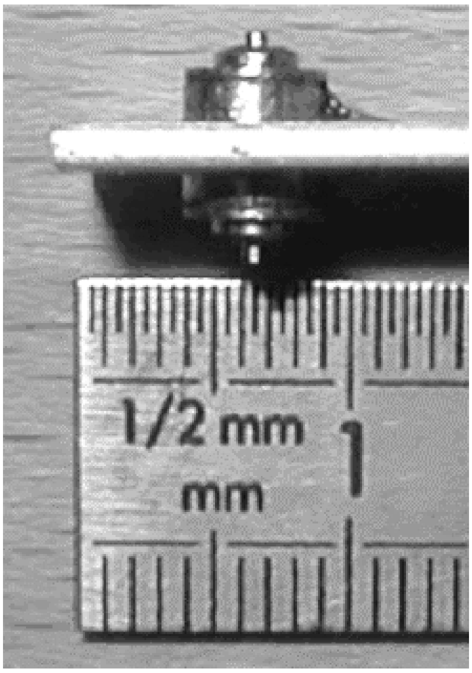


Fig. 1: *Flip-flop micro actuator*

The article presents the choice of an architecture so that the actuator is compliant to the defined set of specifications. They define an micro size actuator able to switch rapidly with a minimum of energy between two positions and to stay stable in spite of external forces. Finally the test bench is presented and actuator characterisations are sum up in a performance data sheet

Actuator specifications

The linear switch actuator that has been designed requires two functioning states, each of which corresponds to a position of the mobile part. Both positions are characterised by its constraints like external forces applied on the mobile part. For security no other static position should be allowable in normal operation. The commutation between the two states should be as rapid as possible and the energy spent by the actuator should be minimised. Furthermore severe interface ICD (Interface Control Documentation) have been set. These ones lead to the design of a very small volume actuator, hence the micro size definition.

The specifications lead to design a linear actuator with the following characteristics.

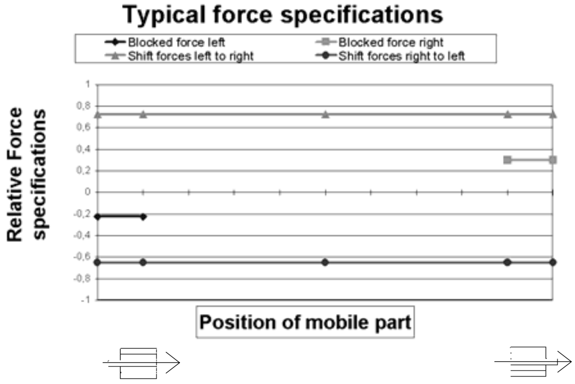


Fig. 2: *forces specifications : 4 cases*

Four cases have to be considered. Blocked forces on both positions and two switch forces between one position to an other.
When the actuator is on a fixed position on the left, a negative force is specified so that the mobile part stay on left even with an opposite force (gravity, pressure,…). Symmetrically a positive force is necessary to ensure that the mobile part stays on right. Absolute values of those positive and negative forces may not be equal according to the application constraints. Both blocked forces need to be valid only on the surrounding of the respective fixed position. There is no constraint on blocked forces for the whole actuator stroke.

When the actuator needs to be switched, a positive (resp. negative) force is required all along the stroke. (*Actually it is a little more tricky, we will see it further*). Then the required force value is significantly greater as the force should not only surpass a load, but should also overcome frictions and should ensure a rapid movement in spite of inertial masses.

Energy sparing

Two severe constraints for embedded devices are micro sized and low energy consumption. Low consumption is all the more important as it is correlated to low losses and thus low heat dissipation, which may be a necessity for micro sized devices.

Most of the time the actuator is on fixed position either left or right. Although forces are required on these positions, the best for energy saving is to avoid consumption when the actuator is in these positions. This can be achieved using a moving magnet actuator which is a bistable actuator and does not require any supply at its stable positions. Forces on fixed positions can be adjusted through the shape of magnet and other magnetic parts. Both blocked force in fig 2 can then be linked defining a characteristic of reluctant force.

The switch between two positions is performed respectively with two current conditions. The simpliest in order to be adapted to micro actuator is to use one coil with only two conductor contacts and to apply positive or negative current to switch the flip-flop actuator.
When the mobile part is at left position, the current should be sufficient to change the negative reluctant force into a positive force. The value of this force should be sufficient to overcome all resistant forces.

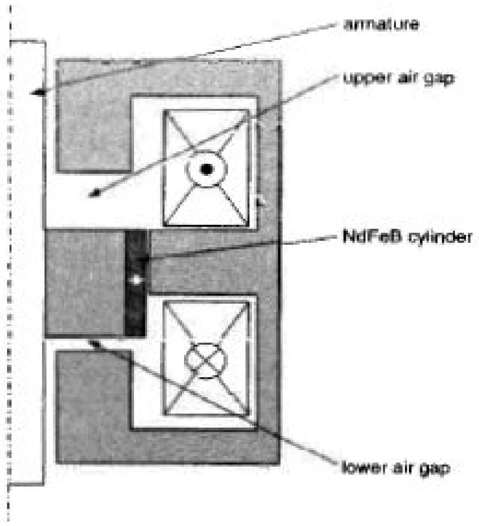


Fig. 3: *Bistable linear actuator [4]*

At constant current, and with a flip-flop moving magnet actuator, the force on the mobile part grows as the mobile part is moving. It results in a shock which may be rapidly destructive when the mobile part reaches the stroke end. The solution for reducing energy expense and reducing the mechanic constraints is to use a smarter coil command.

One should not bother on the electric time constant which for such micro size actuator is negligible (see fig 8). Considering the reluctant force characteristic one can understand easily that the current command can be cut off as soon as the reluctant force is become positive. But then the mobile part still arrive on the opposite position at high speed and degradation may be possible on the long term. One smarter command is to stop the supply when the reluctant force is still negative so that the mobile part is slowed. The remaining compromise is between the time of a complete commutation and the shock energy. If the commutation speed is essential, the shock may still be softened through a spring part.

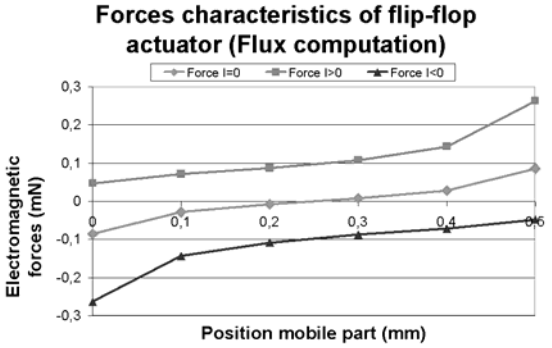


Fig. 4: *Flux Computed forces*

FLUX software has been used to select the better adapted architecture among a set of concurrent architectures, such as those shown in figures 3 and 5. Mobile coil, moving magnets, electromagnets with several configuration have been simulated and compared versus the specifications. A moving magnet architecture has been selected and optimised in dimension order to fit the specified blocked forces values and switch time. The geometry is mainly axi-symmetrical, thus most models have been realised in 2D. However, 3D models have been described in order to evaluate impact of 3D details.

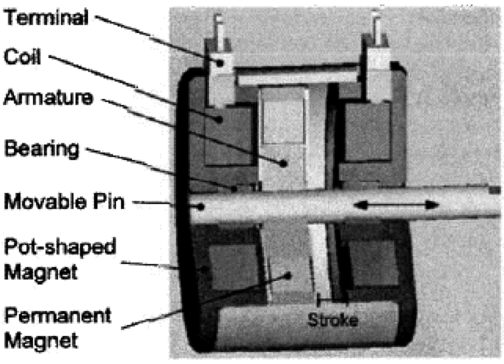


Fig. 5: *Bistable linear actuator [5]*

Prototype realisation and characterisation

A set of prototypes have been defined according to the FLUX computational model. One issue is the evaluation of frictions in such a small device. The prototypes have been assembled with different tolerance adjustments between static and moving parts.

Fig. 6: *Actuator and test support*

In order to avoid wire breaking during manipulation of tests and characterisation, actuator prototypes have been fixed on a support which maintains it either vertically or horizontally, and with the presence or not of an aluminium cooling plate.

For too thin tolerance, friction is important and the actuator behaviour is hazardous. When the bearing tolerance is greater than 50 µm, then we do not observe anymore default attributed to friction forces.

The actuator has been evaluated in a test bench presented in figure 7. The command uses a alternative pulse generator to set either a positive either a negative current into the coil. The switch motion of the mobile part is measured thanks to a laser interferometer.

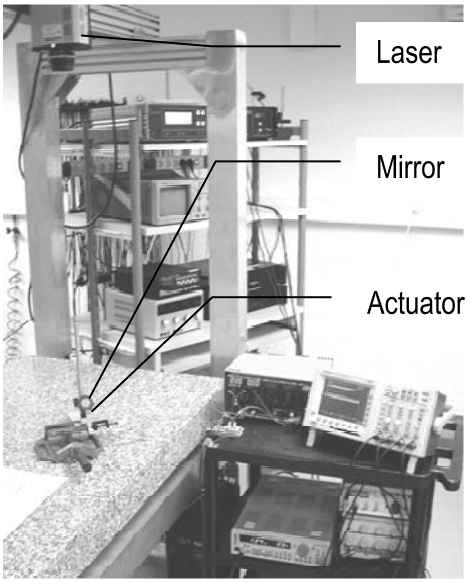


Fig. 7: *Test bench with laser interferometer*

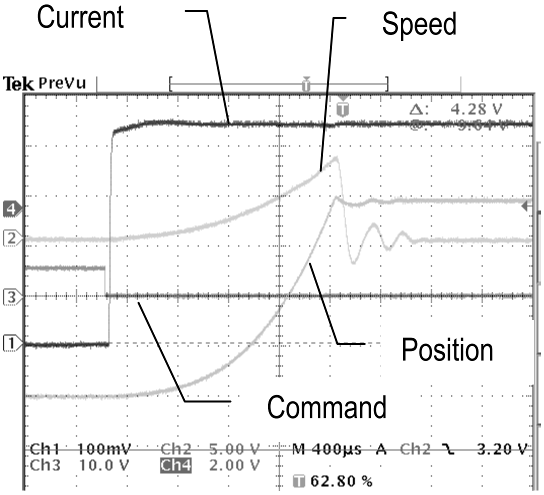
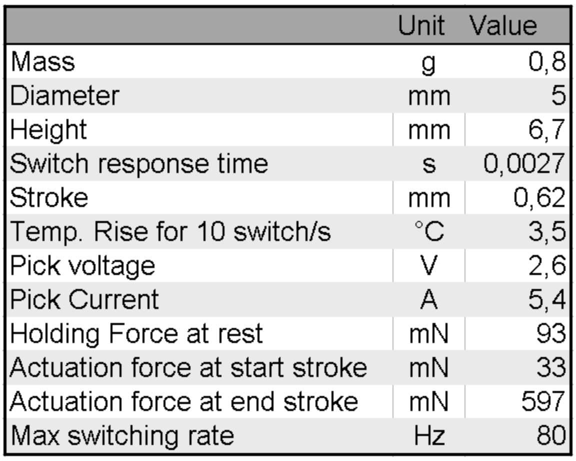


Fig. 8: *Actuator response*

Scales on figure 8 are the followings : [Current : 1A = 100mV]; [position : 80µm = 1V]; [Speed : 125mm/s = 1V];

Measurements show a commutation time of 2.7 ms for a current of 5.4A. Figure 8 shows the mobile part position and speed and the current measured in coil.

The main performances of the characterised actuator have been gathered in the table presented in figure 9.



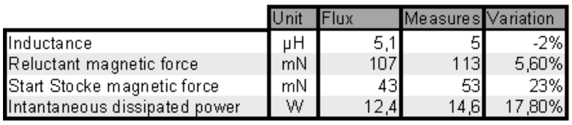
	Unit	Value
Mass	g	0,8
Diameter	mm	5
Height	mm	6,7
Switch response time	s	0,0027
Stroke	mm	0,62
Temp. Rise for 10 switch/s	°C	3,5
Pick voltage	V	2,6
Pick Current	A	5,4
Holding Force at rest	mN	93
Actuation force at start stroke	mN	33
Actuation force at end stroke	mN	597
Max switching rate	Hz	80

Fig. 9: *Actuator main characteristics*

The optimised dissipated energy for a switch is about 20 mJ for a current pulse of 0.7 ms. It allows a rate of 80 commutations per second without destruction by temperature rise.

Comparison with Flux model

The measurements performed on the prototype have been compared with the FLUX f.e.m. (Finite Element Method) software model of the actuator and has shown a good correspondence. The table in figure 10 presents the comparison for some measuring conditions. Note that the model stays slightly different from measuring conditions, which explains some discrepancy.



	Unit	Flux	Measures	Variation
Inductance	µH	5,1	5	-2%
Reluctant magnetic force	mN	107	113	5,60%
Start Stocke magnetic force	mN	43	53	23%
Intantaneous dissipated power	W	12,4	14,6	17,80%

Fig. 10: *comparison of Flux results to measurement*

Further miniaturisation

The realisation of the actuator prototype has shown that the miniaturisation limits are not yet reached. Some parts and games are still over-dimensioned and new optimisation steps should lead to a further reduction of the actuator size keeping the same force and stroke performances.

Conclusion

A flip-flop linear actuator has been designed, build and characterised. An architecture has been chosen in order to be compliant to defined specifications. The actuator has been dimensioned and optimised using the FLUX f.e.m. software and predictions of the model have been compared with the results of characterisation. Both the design of the actuator and its command have been optimised in order to minimise the energy required for a switch. It enables a switch rate of 80 Hz, a switch time of 2.7ms, a holding force at rest greater than 90mN for a 0.8g actuator mass.

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