

International Conference on Space Optics—ICSO 2004

Toulouse, France

30 March–2 April 2004

Edited by Josiane Costeraste and Errico Armandillo



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PIEZOELECTRIC ACTUATORS FOR ACTIVE OPTICS

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ABSTRACT

Piezoelectric actuators find their first applications in active space optics. The purpose of this paper is to describe the state of the art and some applications.

Piezo actuators display attractive features for space applications, such as precise positioning, unlubricated, non magnetic and compact features, and low power consumption. However, piezo mechanisms cannot be considered separately from their driving and control electronic. Piezo actuators, such as Amplified Piezo Actuators or Parallel Pre-stressed Actuators, initially designed under CNES contracts, shall find their first space flight applications in optics on the PHARAO Laser bench:

- fine pointing of the laser beams,
- laser cavity tuning.

Breadboard mechanisms based on piezo actuators have also been tested for refocusing purposes.

Other applications includes the improvement of the CCD resolution through an oversampling technique, such as in the SOHO/LASCO instrument, fast optical shutter operation, optical filter in combination with a Fabry - Perot interferometer, such as in future LIDAR for earth observation. The first applications shall be described and an overview of the future potential applications shall be given.

1 INTRODUCTION

Piezo actuators [1] display attractive features for space application, such as precise positioning, unlubricated and non magnetic behaviour, and leading to small mechanisms. However, the performances of piezo mechanisms cannot be considered separately from their driving and control electronic. Other aspects of concern are generally the mechanical environment (the piezo actuators may display a quality factor of 100), the thermo - mechanical behaviour and the consideration of degraded modes in case of failure.

Starting with a multilayered component, which has been space evaluated in the frame of French Space Agency (CNES) contract, it is possible to build Parallel Prestressed Actuators or Amplified Piezo Actuators.

These components can be used to build mechanisms involving one or more degrees of freedom. The purpose of this paper is to give examples of developments, and applications in space optics.

2 DESIGN OF NORMALLY CENTRED MECHANISMS

2.1 Introduction

Several normally centred mechanisms based on Amplified Piezo Actuators have been developed and qualified over the past years at CEDRAT TECHNOLOGIES. Normally centred mechanisms remains centred without any power supply or in case of failure. This characteristic offers a degraded mode and avoids the traditional Single Point of Failure (often considered for mechanisms).

Piezo actuators are not centred, because they display 90 % of their stroke in one direction and the remaining 10 % in the opposite direction. The normally centred characteristic is obtained by using the piezo actuators in a push-pull configuration (Figure 1).

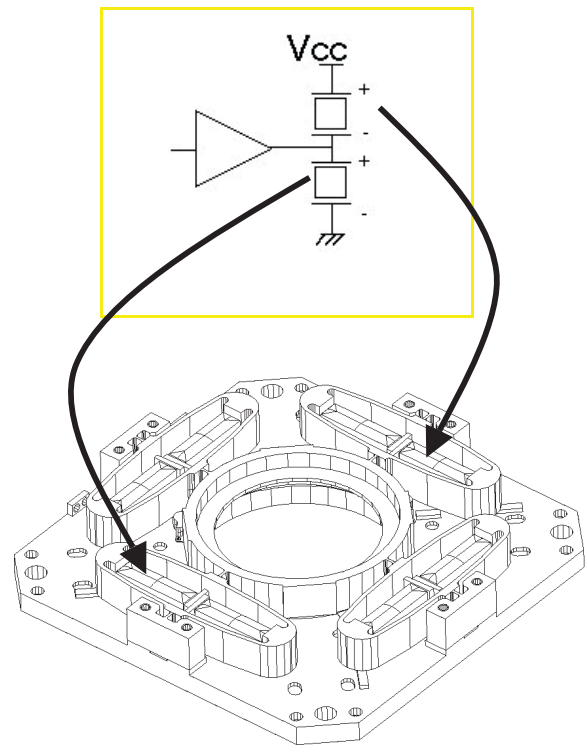


Figure 1 : Schematic of the push pull configuration

Amplified Piezo Actuators found their first flight application with a scanning mechanism (XYZ stage) for ROSETTA/MIDAS [2], qualified in 2000 and launched in 2004.

2.2 X - Y stage

A first example of normally centred mechanism is given with a XY stage, using 2 pairs of amplified piezo actuators. Since piezo actuators are driven in asymmetric mode (-20 / 150 V), obtaining a normally centred design needs a symmetric design and the driving in push – pull mode (Figure 2).



Figure 2 : Normally centred XY stage

A key advantage of this design is that the two channels display a low cross coupling and therefore allows using two independent drivers and controllers. This aspect dramatically simplifies the electronic. Moreover, a special emphasis during the design phase was taken to optimise the ratio between the payload mass and the mechanism mass. The following results are achieved and demonstrated by testing : a mass of 305 grams and a payload of 142 grams

Two kinds of sensors have been implemented:

- strain gauges sensors,
- capacitive sensors.

One typical application of this stage is the over-sampling technique (used in SOHO / LASCO [3]), to improve the CCD sensor resolution. The stage carries either a lens or the CCD itself. 4 successive pictures (n° 1 to 4) are taken (Figure 3). The distance between the 4 points correspond to one half of a pixel.

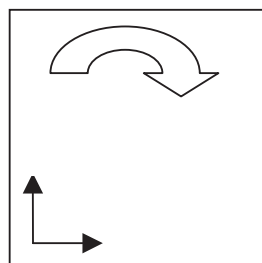


Figure 3 : Over-sampling with a piezo stage

2.3 Tip-tilt mechanisms

Fine tilting movements are also required for several tasks, such as fine pointing [4-5]. A first flight application is the management of the optical insertion power in the optical fiber. The PHARAO laser bench is using 10 tip-tilt mechanisms [6].

A double tilt tip piezo micro mechanism has been developed to solve this function. Again, a push pull driving and two independent tilt movement are the key characteristics (Figure 4). Its first application is on the laser bench of PHARAO by EADS-SODERN [6].

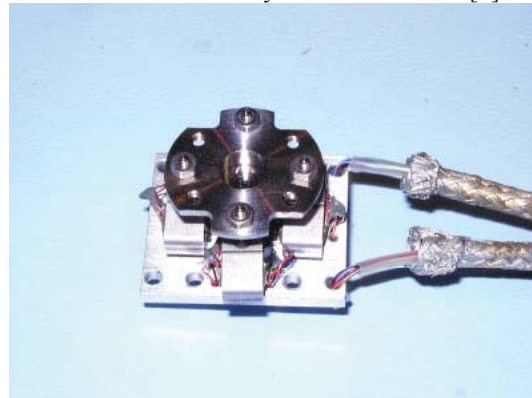


Figure 4 : View of a 3 degrees of freedom double tilt translator mechanism

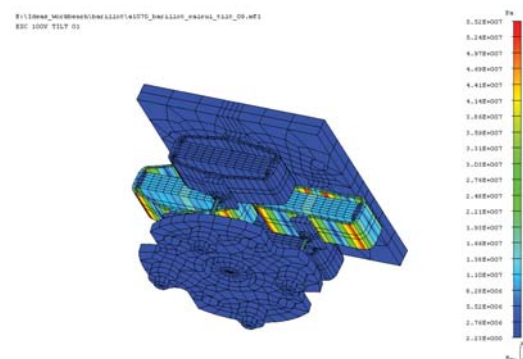


Figure 5 : Finite Element model of the tip-tilt mechanism

When decreasing the size of the mechanism, the shock requirements become more severe. The piezo solution is typically 3 to 5 times lighter than a voice coil solution.

The performances are a stroke of +/- 2 mrad, a bandwidth of 1 kHz and a stability better than 1 μ rad, which is the range of the requirements for laser intersatellite link.

2.4 Z rotation mechanism

The same methodology can be used to build a normally centred mechanism performing one rotation. This mechanism is one option to correct the spinned movement of the GAIA spacecraft on the CCD of the RVS instrument. This mechanism has been prototyped by Observatoire Paris – Meudon (Figure 6). This

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 mechanism would have to be used in a cryogenic environment. This characteristic is felt possible by a proper choice of the piezo material and would require additional testing.

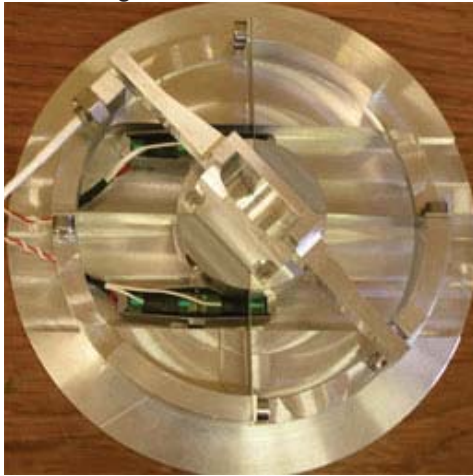


Figure 6 : View of the prototyped Z-rotation mechanism by Obs. Paris - Meudon

2.5 Drive and control electronic

Although piezo actuators have infinite resolution, other features such as accuracy, stability can only be improved by using a closed loop involving a position sensor. The performances therefore become dependent on the driving and control electronic.

A piezo driving electronic requires several features:

- a high signal to noise ratio,
- a low quiescent current,
- a protection against short circuit, ...

The electronic FB-LA75-space (Figure 7) includes:

Item	Units	Measured	Comments
Functional performances			
Stroke	mrad	+/- 2	Reduced at low temperature (below 10 °C)
Stability over 1 kHz of bandwidth	µrad	1	Obtained with Strain Gauges – limited to 25 (+/- 10) °C
Accuracy in closed loop	%	+/-1	
Bandwidth	Hz	1000	May be improved through the use of a cardanic structure
Operational performances			
Lifetime		10e8 full strokes	Designed with infinite lifetime
Environmental performances			
Storage temperatures	°C	-50 / 75	
Random vibrations	Grms	41	
Shock	G @ 500 µs	200	
Interfaces			
Mass	g	15	Excluding the housing and the connectors
Dimensions	mm		26 * 23 * 16
Driving electronic			
Primary bus connexion	V	18 - 38	Isolated
Secondary outputs	V	160, -30, 20, -20	
Linear amplifier output current	mA	+/- 30	May be increased
Linear amplifier phase margin	°	45 mini	In open loop
Capacitive load	µF	0.2 to 40	
Radiations	kRad	10	

Table 1 : Performances of a tip tilt mechanism DTT35XS and its drive and control electronics

- a DC/DC converter,
- 2 independent channels with a linear AB amplifier, a PI-filtered controller, a strain gauges conditioner.

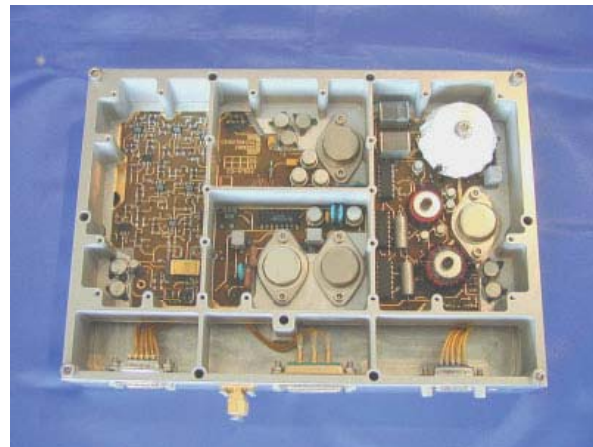


Figure 7 : View of the elegant breadboard of the driving and control electronic

This electronic has been designed according to space rules and based on a Declared Component List [7]. Its performances have been assessed through a Thermal Vacuum test. Its performances are recalled in Table 1.

2.6 Summary of typical performances

The tip – tilt mechanism DTT35XS used in the Pharao laser bench is a typical example of a normally centred mechanism, fully qualified (Table 1). Their lightweight characteristic is particularly outstanding.

Future LIDAR instruments [8], typically for earth observation use an accurate, single frequency laser source. To overcome a possible deviation of the laser source, a piezoelectric refocusing mechanism is a solution which offers a large bandwidth. Consequently, Parallel Prestressed Actuators are well suited to these applications. The prestress is essential for a dynamic operation and is realized with an external monolithic spring.

It should also be noticed that piezo active tuning filters is also a possibility in the receiving chain: piezoelectric actuators can be used to adjust the length of a Fabry – Perot cavity.

A first application is a External Cavity Laser developed by EADS SODERN for the PHARAO Laser source (Figure 8) [6].

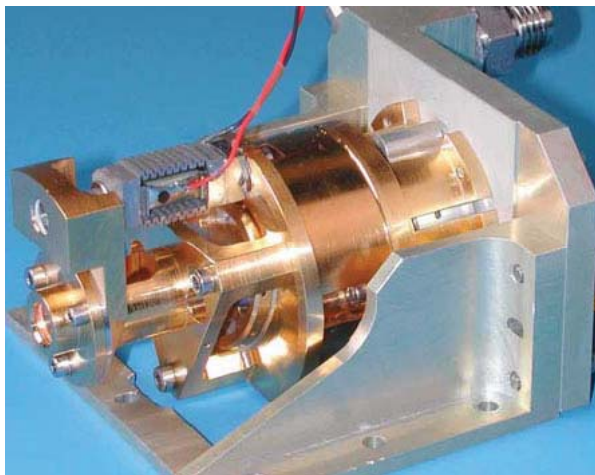


Figure 8 : View of the External Cavity Laser tuned by a piezo actuator (courtesy of EADS SODERN)

A second application is the refocusing mechanism of the laser source for the first European LIDAR ALADIN [9]. In this application, a bandwidth of 10 kHz is required.

4 CONCLUSIONS AND PERSPECTIVES

Piezoelectric mechanisms are more and more used to improve the optical characteristics. Piezoelectric normally centered mechanisms are innovative and lightweight solutions offering a centred position in degraded mode. In conclusion, Cedrat Technologies has designed a new range of normally centred space mechanisms: a XY stage and Double Tilt mechanisms without any latch mechanisms. In addition to these designs, three linked aspects have been developed:

- several position sensors (strain gauges, capacitive sensors) have been space evaluated,
- several means to increase the capability to carry a large payload within a given launch environment have been investigated,

- the driving and control electronic has been developed and tested.

The capability of the piezo mechanism to perform a positioning task (refocusing, oversampling, ...) and a cancellation of micro-vibrations at the same time has been also investigated recently in a Research and Technology program founded by the French Space agency.

An emerging use of piezo mechanisms is noticed with refocusing function of accurate single frequency laser source to be used in LIDAR.

A future trend shall be the use of piezo mechanisms in combination with cryogenic ambiances.

5 ACKNOWLEDGEMENTS

One part of this work has been carried out thanks to the financial support of the French Ministry of Research, which is greatly acknowledged. It has been technically followed by the mechanism section of the French Space Agency.

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