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Development of fast tool servo for advanced machining processes in turning operation

Harkaitz Urreta[1], Gorka Aguirre[1], Xabier Aranzeta[1]

[1]*IK4-IDEKO, Arriaga kalea 2, 20870 Elgoibar (Basque Country) Spain*

hurreta@ideko.es

Abstract
With the aim to increase of machining capabilities of precision turning machines, and on the other hand the trend to machine Non-Rotationally Symmetric (NRS) geometries, one Fast Tool Servo (FTS) has been designed in this project, with the objective of moving tool up to 15 mm stroke and 100 Hz frequency. Commercial standard products were not suitable as actuator for those requirements, and therefore a high force density electromagnetically driven actuator has been developed, from the magnetic field calculations to thermoelastic behaviour. The actuator has been manufactured and assembled in the mechanism, where aerostatic bearings have been used as guiding. Air bearings are based on commercial porous media bushing bearings. A proper assembly route has been defined to avoid the deformation of structure due to the very strong magnetic force in the actuator, and therefore to avoid the collapse of air bearings. To close control loop an exposed linear encoder aligned with reaction force have been used. The positioning is measured with this scale and the control is implemented in real time dSPACE hardware. Very first results of characterization in open-loop show a high bandwidth response with large stroke: 100Hz with 0.1mm/A and 4.5mm/A at 10Hz, all that with quite low thermal drift, below 10ºC at nominal current of 5A, real limit of electromagnetic actuator. The thermocouples are installed in the core of the coils; therefore a quite good control of actuator's health is monitored.

Keywords: Non-Rotationally Symmetric (NRS) part, Fast Tool Servo (FTS), Machining, Precision turning

1. Introduction and specifications

In the field of high precision manufacturing the parts with non-axisymmetric features are achieved by high dynamic actuators, or how they are known by the community, Fast Tool Servo (FTS) actuators. The research work presented in this paper summarizes the results achieved during the project of design, simulation and construction of a prototype.

First task was orientated to determine the achievable specifications for a FTS for high precision turning operations to manufacture non rotationally symmetric (NRS) geometries. The state of the art in FTS technology is plenty of solutions for parts texturing and axisymmetric lens manufacturing, where the stroke of the actuator is around microns, below one millimetre at any case. But for turning parts like presented in next Figure 1, the range is not enough and the nominal stroke have to be extended to several milimeters.

Figure 1. Parts with NRS geometries to be manufactured by FTS in turning operation in only one clamping.

After the review of bibliography around FTS systems, in the next figure there are represented the most relevant ones for our investigation, where three main groups have been defined: Large range based on linear motors or voice coil actuator, short range systems with piezoelectric actuator and finally the commercial ones available in the market.

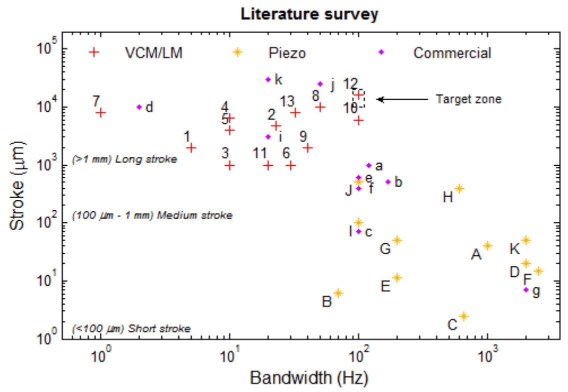

Figure 2. Characteristics (bandwidth and stroke) of analysed solution for Fast Tool Servo, the references are listed in next table.

Table 1. References showed in the figure 2.

Voice Coil or Linear actuator		Piezoelectric actuator		Commercial available model		
1	Buescher, 2005 [1]	A	Weck al. 1995	a	Precitech	FTS1000
2	Byl &Trumper 2005	B	Kouno, 1984	b	Precitech	FTS500
3	Liu et al. 2012	C	Patterson et al. 1985	c	Precitech	FTS70
4	Babinski&Tsao 1999	D	Doe et al. 1991	d	Precitech	STS
5	Zdanowicz, 2009 [3]	E	Jared, 1996	e	Kinetic	FTS600
6	Rakuff&Cuttino 2009	F	Okazaki, 1990	f	Kinetic	FTS400
7	Qingsong 2013	G	Rasmussen, 94	g	Kinetic	FTS20
8	Ludwick, 1999	H	Falter&Youden, 1995	h	Kinetic	RFTS
9	Weck et al. 1995	I	Cuttino 1999	i	NFTS6000 Nanotech	
10	Greene, 1997	J	Liu et al. 2012	j		Coburn Tech.
11	Todd&Cuttino, 1997	K	Woronko et al. 2003	k		Benz LinTec.
12	Weck, 1999 [4]					
13	Weck et al. 2003					

Three main references are highlighted, two research work from academy and an industrial application from the industry: The works from the North Carolina State University with the prototypes, FLORA I & FLORA II presented in the works [1,2] where their main specification where 4mm range up to 20Hz. On the other hand the work from IPT Aachen [3] with 16mm stroke and up to 100Hz bandwidth; both works with air bearing guiding and linear motor actuator. Finally the industrial application of WEISSER is also considered, named Hyperspeed Oval Turning (HOT), here are mentioned values up to 20g with a maximum stroke of 45mm [4, 5].

Summarizing, the FTS designed and constructed in this work is projected to achieve 25mm stroke and a maximum bandwidth of 100Hz with at least 250µm stroke.

2. Modelling, designing and first results of FTS

Following with the most extended solutions for large stroke FTS systems, the guiding technology selected was air bearing. The almost zero friction and quite high stiffness were key factor to make the decision, and comparing with other non-contact solutions without friction, like hydrostatic or magnetic bearing, the easiness to the implementation was determinant. In order to improve the standard specs of air bearings, porous media bushing bearings were selected. For the actuator, several commercial linear motors and voice coils were analysed, but any of them achieved the necessary force considering the space limitations of the design. Obviously, piezoelectric actuators, even with elastic amplifiers, have not enough stroke for this application. Therefore, it was designed an electromagnetic actuator by magnetics field simulations and structural analysis, considering the current through the coils, magnetic field from permanent magnets, generated force and induced heat. The modelling and simulations have been carried out with commercial software: FLUX for magnetics and NX Nastran for structural and thermal issues.

The overall design of the system is showed in the Figure 3, where it can note two lateral bushing bearings, an electromagnetic actuator in the middle of the guides, and an exposed linear scale at the top, aligned with cutting point to reduce Abbè error in the positioning.

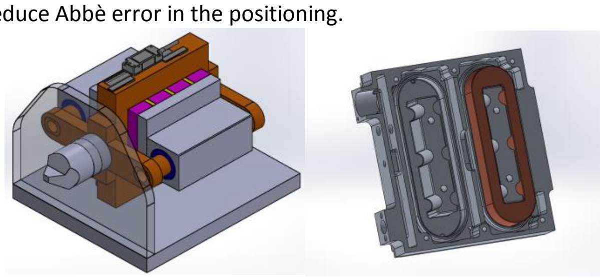

Figure 3. Schematic design of FTS with air bearings and a linear motor composed by two coils and permanent magnets.

Dynamic calculations have been conducted to determine the first vibrational modes and frequencies. The results, showed in Figure 4 indicate that in the range of interest, below 100Hz, there should not be dynamic problems due to natural modes.

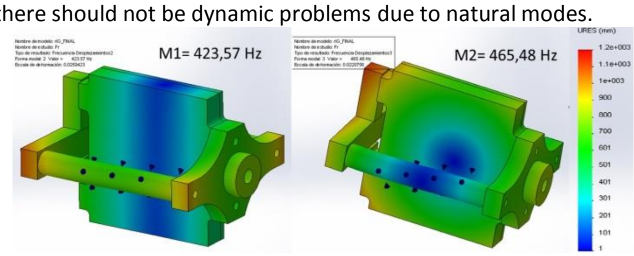

Figure 4. First two natural modes of vibration of designed structure.

Finally, the prototype has been constructed and assembled, as shown in the Figure 5, and first experimental results have been achieved like presented in the frequency response of Figure 8. A analytical model mass/damper without spring has been plotted together experimental results, with 3.5kg of moving mass and 500Nm/s damping coefficient, effect that comes from Eddy currents in the moving part.

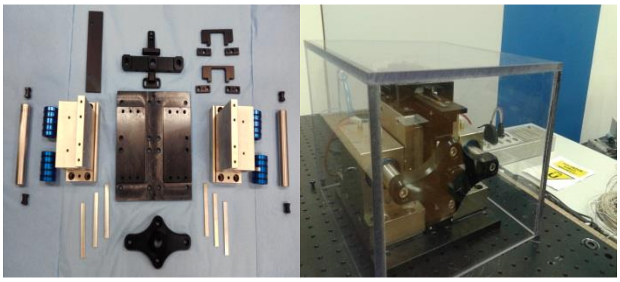

Figure 5. Prototype of FTS for large displacement, parts and assembly.

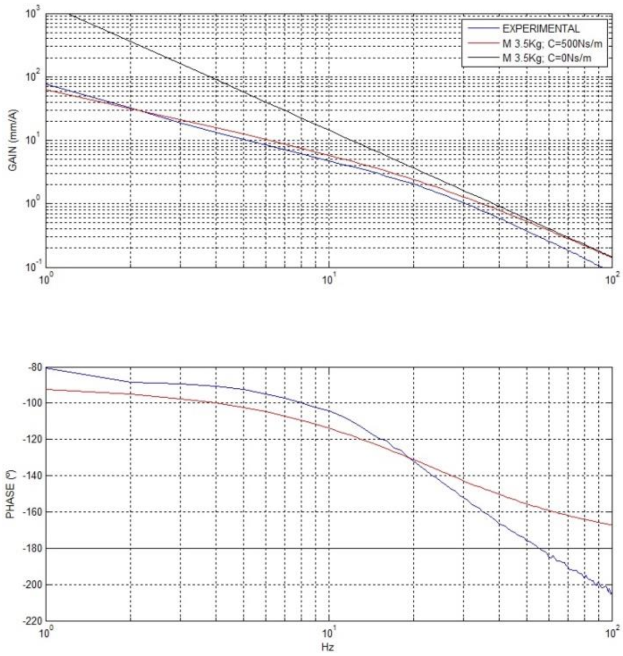

Figure 6. Experimental response of system in open-loop.

How can been noted in the figure 6, the FTS model is well adjusted to a mass and damper system with the coefficients given above. The stroke amplitude, given in mm/A, is limited by the damping at low frequencies <20Hz, meanwhile at higher ones the limit is the inertial force, moving part mass. About the precision, it will be analysed in further experiments, when control loop is closed with advanced feedfordward control strategies [6].

References

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