Alex Popescu — Salamander Robot Group
ECE 4011 — Advisors: L. S. Milor, P. A. Vela

# Technical Review of Micro-Servomotor Properties

## Introduction

Electric motors have a wide range of applications including commercial manufacturing, consumer products, and robotics. Servomotors are motors that have the ability to accurately control position, velocity, or acceleration for rotary or linear motion [1]. Within the field of robotics, servomotors are an indispensable part of rotary joints and other actuators [2]. For sub-human scale robots, compact servomotors, or micro-servomotors, may be used due to weight and space constraints.

## Commercial Applications of Micro-Servomotors

### Industrial

Small servomotors are used in a variety of industrial automation processes, mainly when control of valves or small-scale actuation is needed. Moog manufactures small servomotors for applications including blow molding of plastics, injection molding, packaging, labeling, and end-actuators of pick-and-place machines [3], [4]. These applications focus on high efficiency and quality [5]. Motor prices are in the range of $50-100 and up, depending on torque and size requirements.

### Consumer

Consumer electronics employ small servomotors in products such as print-head mechanisms in printers and very small servomotors for auto-focus mechanisms in cameras and older smartphones [6]. Consumer cameras can be purchased from companies including Canon and Nikon.

### Science and Research

The scientific community utilizes servo motors frequently for applications ranging from robotic manipulators and laboratory instruments [6] to photovoltaic cell positioning [7] and spacecraft fuel-trim valves [8]. Small, low-torque servomotors can be purchased from hobbyist websites such as pololu.com or robotshop.com, for prices of $5-10 and up [9]. Maximum torque can range from 0.5 to 14 kg-cm, depending on motor size and price. Maximum frame dimensions vary from 24mm to 140mm.

## Underlying Technology of Small Servomotors

A servomotor consists of a motor, a sensor, and control circuitry, to provide a closed feedback loop [1]. The motor component of the servomotor can be any electric motor, such as permanent magnet (PM) brushed or brushless, DC or AC, synchronous or non-synchronous, and/or induction or reluctance. The amount of torque PM motors can produce is proportional to the current through the motor coils as well as the number of poles of the motor. The servo sensor can be an encoder or resolver for position-control applications, or a current sensor for torque-control applications. Brushed and brushless PM servomotors are more often used for small-scale applications because the high magnetic flux-densities of rare-earth magnets allow greater torque in a smaller package.

In the case of a brushed-motor PM servomotor, current-mode or voltage-mode control can be utilized [1]. In current-mode control, the current through the motor windings is sensed and regulated to produce the desired amount of torque. In voltage-mode control, a pulse-width modulated (PWM) voltage signal is applied to the motor windings to produce an average current and thereby produce torque. PWM signals can range from 8-100kHz in frequency. Brushed motors require brushes, which can wear out easily, as well as a complex commutator.

Brushless PM servomotors utilize current- and voltage-mode control, but they avoid the problems associated with mechanical brushes [1]. Phase control, direct quadrature (DQ) control, and six-step control, are some of the control algorithms that may be utilized to modulate the voltage or current and command torque for these motors. The bandwidth of current-control loops is typically limited to 300-2.5kHz by stability requirements.

Figures of merit for servomotors include the position, velocity, and acceleration errors, maximum acceleration/torque, overshoot amount, and transient step-command response time [10]. Other metrics include settling time, maximum power, maximum speed, frame size, and rotor inertia [11].

**Building Blocks of Micro-Servomotors**

The main component of servomotors is the motor, which serves as the main determinant of the ultimate servomotor characteristics including size, power draw, torque, response time, price, and operating voltage. Brushed vs. brushless motors are a key distinction in terms of cost and performance, as brushless motors give higher performance at higher cost [12].

The control portion of the servomotor can be analog or digital, depending on performance requirements. High-end digital servos can respond to PWM position commands in excess of 300Hz, have 32-bit programmable microcontroller units (MCU), as well as 12-bit analog-digital converters (ADC) to measure current [13]. In custom servomotors, software is required to program the control algorithm in the MCU.

Power for small servos is usually input through one 4.8-8.4V DC input bus which provides power to the motor as well as control circuitry. Half-bridge circuits are used to convert this DC voltage to various average voltages and currents using PWM [1].

The sensing portion of the servomotor may take the form of a current sensor using an operational amplifier, an optical or mechanical encoder, or a resolver.

Gearing is also commonly used in servomotors to increase torque and positional accuracy [2].

References


[1] G. Ellis, "Basics of the Electric Servomotor and Drive," in *Control System Design Guide - Using Your Computer to Understand and Diagnose Feedback Controllers*, 4 ed., Elsevier, 2012, pp. 313-349.

[2] H. Eglowstein, "Introduction to Servo Motors," [Online]. Available: http://www.sciencebuddies.org/science-fair-projects/project_ideas/Robotics_ServoMotors.shtml. [Accessed 23 October 2016].

[3] Moog, "Industrial Machinery," 2016. [Online]. Available: http://www.moog.com/markets/industrial-machinery/. [Accessed 23 October 2016].

[4] LS Mecapion, "AC Servo Motor," [Online]. Available: http://bientan24h.vn/Data/upload/files/AC%20SERVO%20MOTOR.pdf. [Accessed 23 October 2016].

[5] Moog, "Blow Molding Machinery," 2016. [Online]. Available: http://www.moog.com/markets/industrial-machinery/plastics-machine-building/blow-molding-machinery/. [Accessed 23 October 2016].

[6] TigerTek Industrial Services, "Common Industrial Applications of Servo Motors," [Online]. Available: http://www.tigertek.com/servo-motor-resources/common-servo-motor-applications.html. [Accessed 23 October 2016].

[7] B. Manna, N. Saha and P. Debashis, "Optimization of solar power using servo mechanism by Perturb & Observe method," in *India Conference (INDICON), 2014 Annual IEEE*, 2014.

[8] Micromo, "Servo Motors Survive Space X Launch Conditions," [Online]. Available: http://www.micromo.com/applications/aerospace-defense/space-x-shuttle-launch. [Accessed 23 October 2016].

[9] Pololu, "RC Servos," [Online]. Available: https://www.pololu.com/category/23/rc-servos.

[10] R. H. Macmillan, "Transient and Harmonic Responses," in *An Introduction to the Theory of Control in Mechanical Engineering*, Cambridge University Press, 1955.

[11] R. Firoozian, "The Choice and Comparison of Servo Motors," in *Servo Motors and Industrial Control Theory*, 2 ed., Springer, 2014.

[12] Motion Technologies PTY LTD, "Brushed vs Brushless Servo Motors," 5 January 2012. [Online]. Available: http://www.motiontech.com.au/wp-content/uploads/2014/03/MT-Brushed-vs-Brushless-Servo-Motors-010512.pdf. [Accessed 23 October 2016].

[13] HiTEC Multiplex, "D-945TW 32-Bit, Multipurpose, Titanium Gear Servo," [Online]. Available: http://hitecrcd.com/products/servos/d-series-32-bit-programmable-servos/d-945tw-32-bit-multipurpose-titanium-gear-servo/product. [Accessed 23 October 2016].