Operation with a rotary solenoid

This document supplements the open-access paper Mathias S. Fischer and Martin C. Fischer, “Cost-effective, open-source light shutters with Arduino control,” HardwareX 19, e00548 (2024); https://doi.org/10.1016/j.ohx.2024.e00548

Overview

Since publication of the HardwareX paper in June 2024 we have implemented shutters with rotary solenoids using the same Arduino controller.

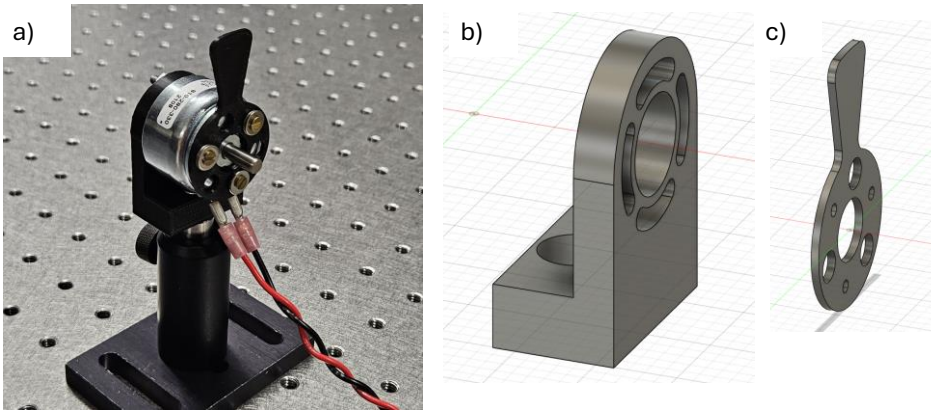

Fig. 1: a) Picture of assembled rotary solenoid shutter, b) solenoid mount, and c) shutter blade.

There are a wide range of rotary solenoids in production (see e.g. Ledex). A few of them are available through distributors (e.g. Newark). The model we tested is a Ledex 810-280-330 (price at time of purchase ~$60). This particular model has a 25-degree stroke and can operate continuously with 12 V, provided by a power supply through the motor shield already used in our design. The solenoid rotates to the “open” position when energized and returns to the default “closed” position when no voltage is applied. Thus, this solenoid provides for a fail-safe shutter operation (it closes on power failure).

Mechanical mounting

The shutter is mounted in a 3D printed holder with the threaded studs of the solenoid. The slots in the holder provide an adjustable mounting angle. A blade is attached to the rotatable plate of the solenoid with three mounting screws (in our case #3-48 screws). Please ensure that the screws do not extend through the top plate, otherwise they might impede the rotary motion (due to the ball race design, the front plate retracts during rotation). For testing purposes, we 3D-printed the blade, but for permanent operation a metal blade is preferred. The design for both the mount and blade can be found in the actuator mount directory of the Github repository. Note that due to vibrations of the shutter during repeated opening and closing, the mounting nuts can loosen. Hence, lock washers or locknuts are recommended (or epoxy the nut).

Electrical hookup

The electrical connection is identical to the case of the linear solenoid described in the HardwareX paper. The power supply voltage should be matched to the type (coil AWG) of the solenoid, but the motor shield limits supply voltage to 13.5V. For our solenoid, we used a supply voltage of 12 V.

Operation

The operation of the rotary solenoid shutter is identical to the case with a linear solenoid. A “position” value of 0 means no voltage is applied (shutter closed), a position value of “255” means the full supply voltage is applied (shutter open). Note that in the open position, the solenoid draws the full current and can get warm.

Performance

We measured the opening and closing times of the rotary solenoid shutter with a similar setup as described in the paper. Below are representative traces and average open/closing times and delays.

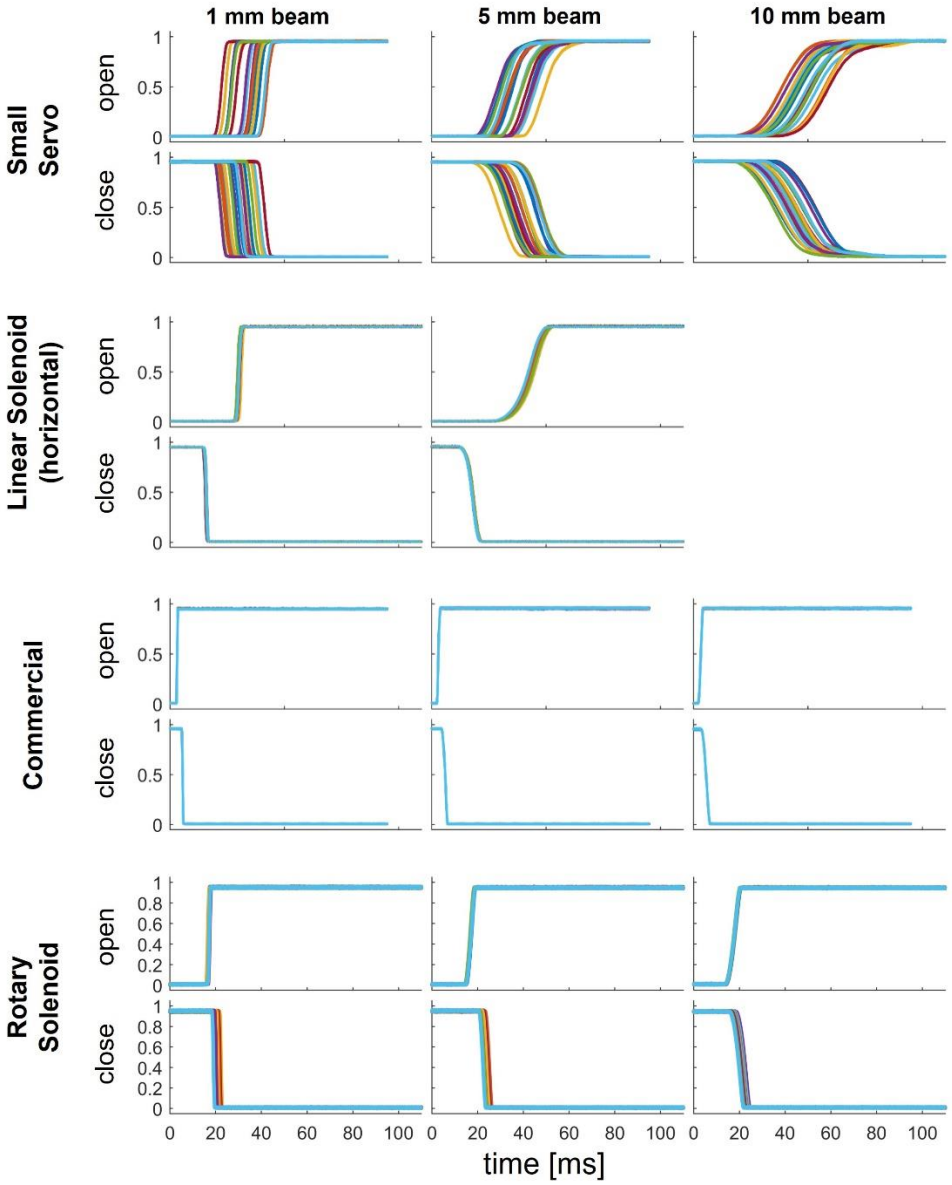

Fig. 2. Measured beam transmission during opening and closing of various shutters. The time t = 0 corresponds to the rising/falling edge of the digital control signal.

Table 1. Measured opening and closing times (τ) and delays (T).

Shutter type	Direc-tion	τ [ms] (Ø1 mm)	T [ms] (Ø1 mm)	τ [ms] (Ø5 mm)	T [ms] (Ø5 mm)	τ [ms] (Ø10 mm)	T [ms] (Ø10 mm)
Small Servo	open	2.6 ± 0.19	32 ± 5.6	8.8 ± 0.44	39 ± 5.5	15 ± 0.63	48 ± 5.8
	close	2.5 ± 0.12	30 ± 5.7	8.7 ± 0.33	40 ± 5.5	15 ± 0.36	45 ± 5.4
Solenoid (horizontal)	open	3.5 ± 0.080	74 ± 3.2	20 ± 0.92	70 ± 2.5	-	-
	close	0.95 ± 0.003	16 ± 0.18	4.3 ± 0.015	15 ± 0.17	-	-
Commer-cial	open	0.20 ± 0.001	3.1 ± 0.004	0.63 ± 0.003	2.9 ± 0.005	0.94 ± 0.003	3.2 ± 0.006
	close	0.30 ± 0.001	5.5 ± 0.006	1.2 ± 0.003	5.9 ± 0.002	1.7 ± 0.015	5.5 ± 0.013
Rotary Solenoid	open	0.52 ± 0.01	17 ± 0.3	1.9 ± 0.02	17 ± 0.2	3.0 ± 0.04	18 ± 0.2
	close	0.45 ± 0.01	20 ± 1.6	1.4 ± 0.01	22 ± 1.0	2.7 ± 0.01	20 ± 0.7

Not only are the opening/closing times of the rotary solenoid shutter shorter than the servo shutter and the linear solenoid shutter, but the timing is also more reproducible (the H-bridge on the motor shield is not limited by the PWM update rate (50 Hz) of the servo shield). Also, with a rotary solenoid a larger beam area can be achieved than with a linear solenoid (limited by the throw of the plunger).