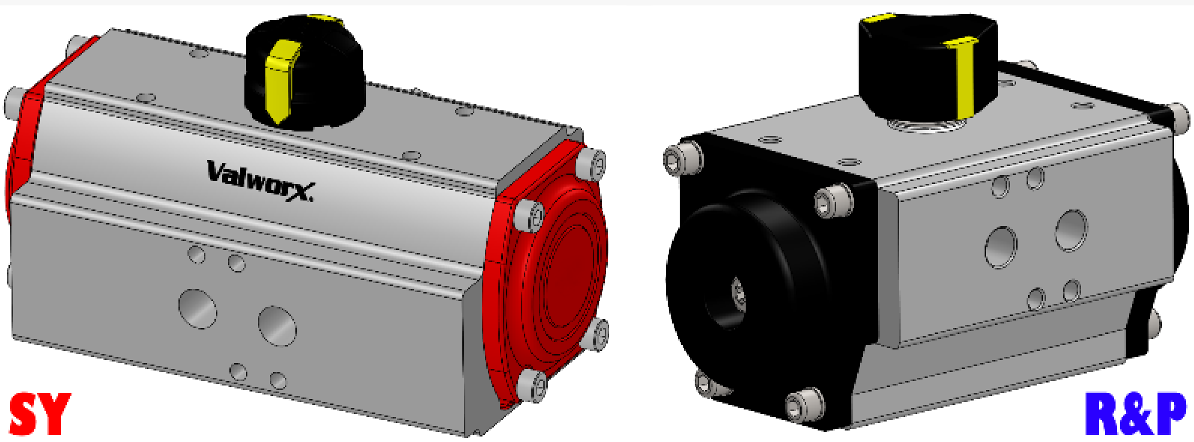
Valworx

# ProTips

## Scotch Yoke vs. Rack & Pinion Actuators:

### What's the difference?




In this ProTip, we'll discuss the differences, advantages and limitations of both types of Valworx air actuators

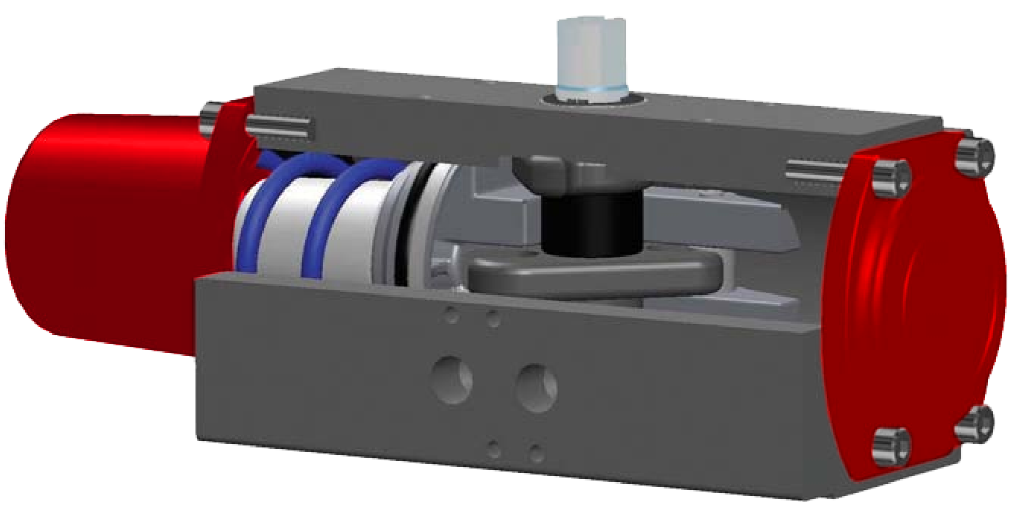
The table below gives a quick summary.

## Scotch Yoke and Rack & Pinion Comparison

| Parameter | Scotch Yoke | Rack & Pinion | Comments |
|---|---|---|---|
| **Cost** | Lower | Higher | |
| **Torque** | Higher | Lower | |
| **Lifecycle** | 1 million + | 1 million + | |
| **Frame size** | Slightly longer | Slighter shorter | |
| **Torque as function of stroke** | Non-linear | Constant | Scotch Yoke torque curve is an excellent fit for butterfly valves. |
| **Positioning (throttling) applications** | No | Yes | Rack & Pinion constant torque curve is a better fit for positioning applications. |
| **Available in spring return (SR) or double acting (DA)** | Yes | Yes | |
| **Retrofittable between SR & DA** | No | Yes | |

## Actuator Operation - Scotch Yoke

The term **scotch yoke** describes the internal design of the crank and piston system used to rotate the actuator 90° with pilot air application.



Inside scotch yoke air actuators, the application of pilot air forces pistons to move, turning a center output shaft via a crank arm.  This in turn rotates the output drive and opens/closes a valve.

**Figure 1** below shows the actuator at approximately the midpoint position while closing.

**Figure 1.**

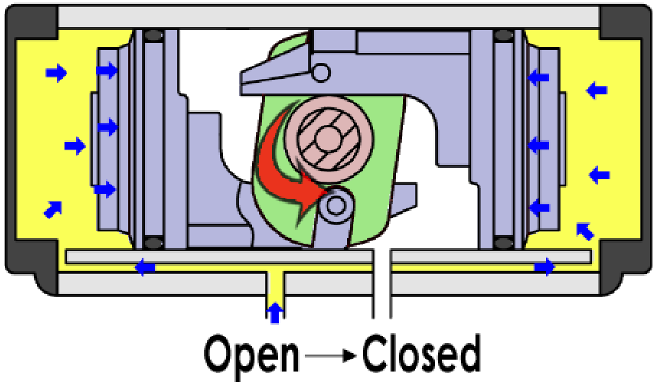
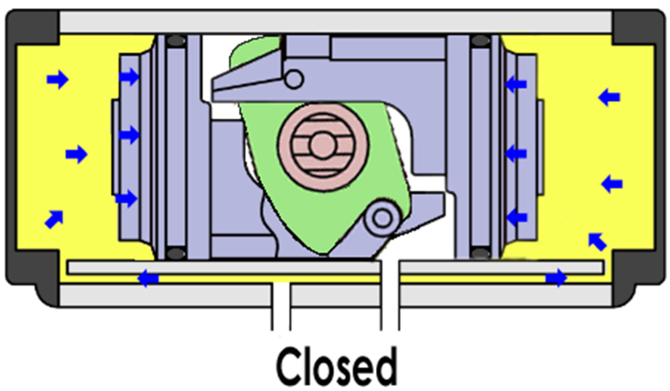



**Figure 2** shows the actuator in the closed position.

**Figure 2.**

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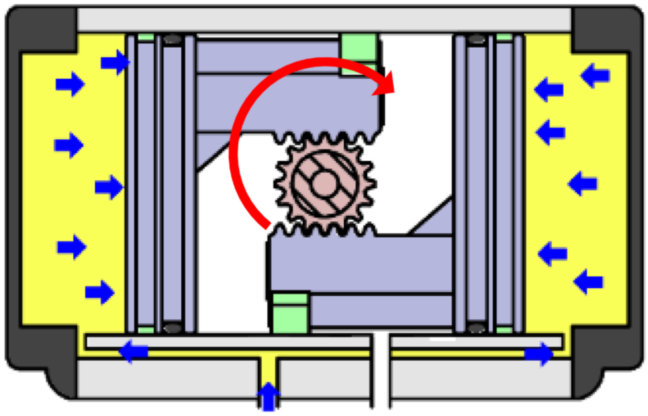
## Actuator Operation - Rack & Pinion

Inside rack and pinion actuators, the application of pilot air forces pistons to move horizontally. The pistons are connected to a toothed bar (the rack) which in turn rotates a splined shaft (the pinion). This in turn rotates the output drive and opens/closes a valve.

**Figure 3** shows the rack and pinion actuator moving from open to closed.

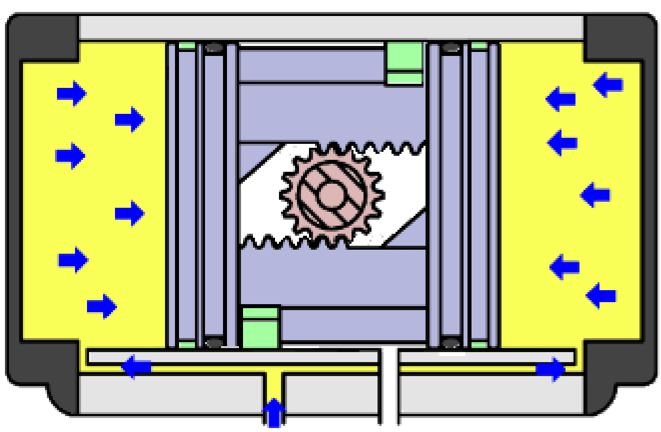
### Figure 3.




In practicality, what this means is that with a rack and pinion design, the torque is consistent throughout the entire rotation cycle.  Without a crank arm and long piston stroke, the rack and pinion actuator can be smaller and work well in tight spaces.

**Figure 4** shows the rack and pinion actuator in the closed position.

### Figure 4.

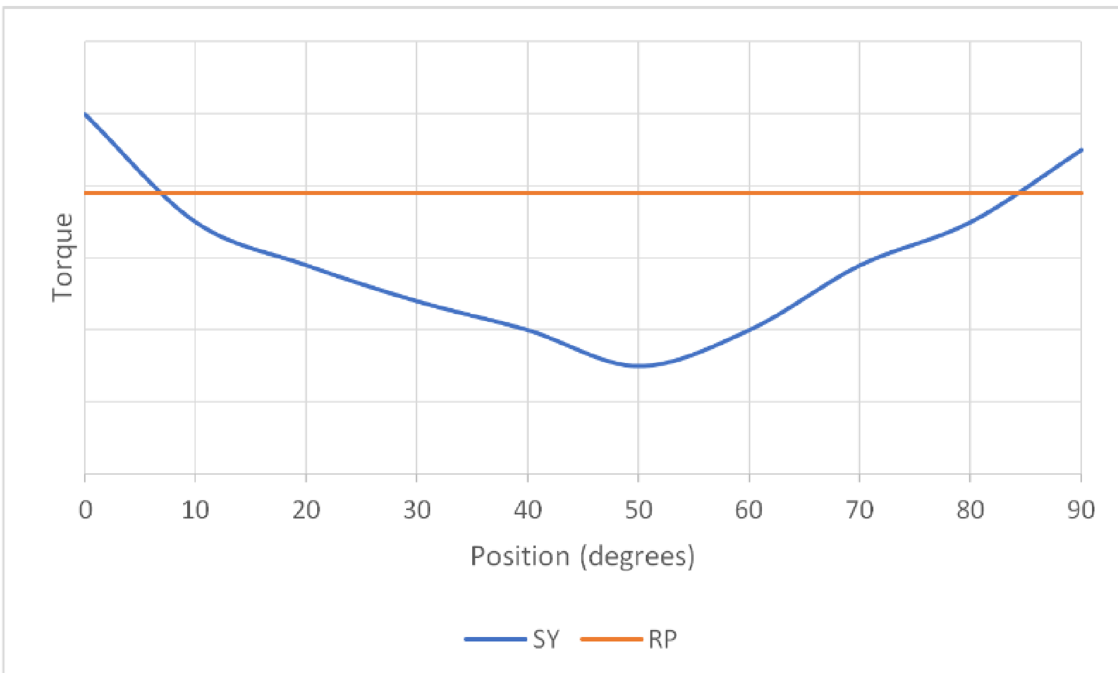



Shop for Scotch Yoke Actuators | Shop for Rack and Pinion Actuators

## Comparison - Torque

The crank arm geometry to Scotch Yoke actuators changes as a function of stroke position, resulting in higher torque at the beginning and end of the stroke (a detailed engineering discussion can be found at the end of this article). In contrast, the crank arm geometry of Rack & Pinion actuators remains constant, so the torque remains constant throughout the stroke, per **Figure 5**.

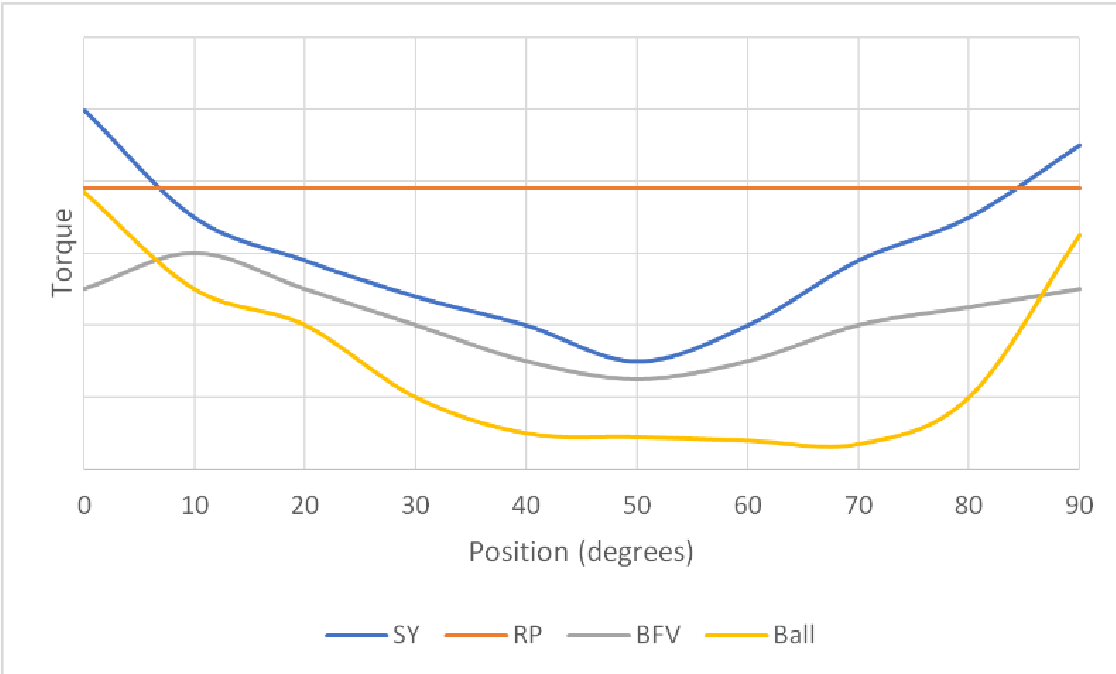
**Figure 5.**




The different torque characteristics present advantages and limitations. The torque of butterfly valves also is higher at the beginning and ending of the stroke. Scotch Yoke actuators match this, making them a good fit for this type of valve. Depending on the seal type and body material, ball valves can exhibit even more pronounced nonlinearity.

**Figure 6** depicts theoretical torque curves for the actuators and two types of valves.

**Figure 6.**




However, for positioning applications (i.e. throttling), the non-linear torque of Scotch Yokes can pose a problem, as positioners rely on feedback to converge on the input signal. Near the beginning and end of the stroke, the positioner may end up "hunting" for the desired position.

The relatively constant torque of Rack & Pinion actuators makes them better suited for positioning applications.

The crank arm of Scotch Yoke actuators is usually longer than Rack & Pinion actuators. The net result is that Scotch Yokes have higher torque for the same frame size.

## Comparison - Cost

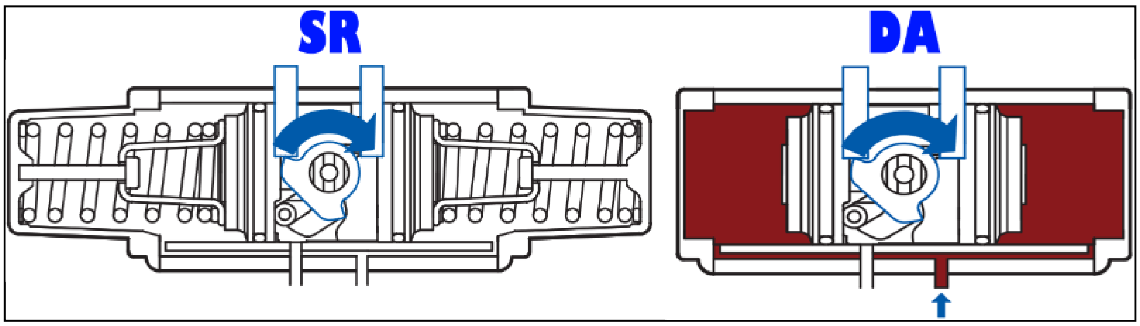
Rack & Pinion actuators have a machined (or hobbed) bar for the "rack" and a splined shaft for the "pinion". These machined parts are relatively more expensive than Scotch Yoke components, which are composed of stamped or forged parts.

In general, then, Scotch Yoke actuators tend to cost less for the same frame size. This gives Scotch Yoke actuators a double advantage of higher torque (for the same frame size) and lower cost.

## Comparison - Spring Return and Double Acting

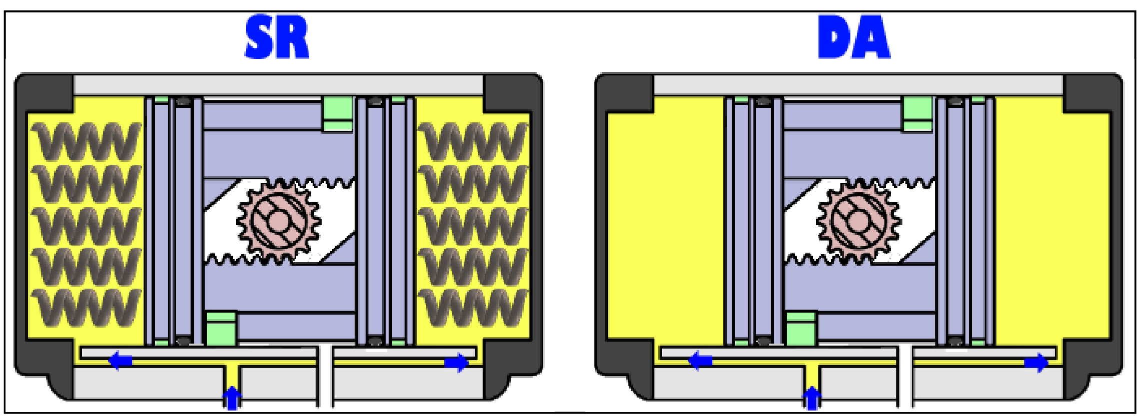
Scotch Yoke's longer crank arm means the actuator tends to be longer overall as well. This is especially true for Spring Return actuators, where the springs are basically housed external to the pistons:

**Figure 7.**




Rack & Pinions are more compact, and the same frame size can be used for both spring return and double acting.

**Figure 8.**




Rack & Pinion can therefore be converted from spring return to double acting and vice versa, whereas Scotch Yokes cannot.

## Comparison - Durability

Rack & Pinion and Scotch Yoke actuators have been used in tens of thousands of installations worldwide for decades. Both are proven, reliable designs. Durability, then, depends on the build quality of the particular brand of actuator.

Valworx air actuators are tested to over 1 million cycles. Both designs are CE listed and feature a hard anodized aluminum frame with polyester-covered end covers.

Valworx Scotch Yoke actuators have an IP weatherproof rating of IP66 and IP68. Our Rack & Pinion actuators are type IP67. For a detailed discussion of protections provided by the various IP ratings, click here.

## Comparison - Cycle Time

Cycle time is primarily determined by the time it takes air to fill and energize the actuator body. Since the port size (and therefore airflow) is the same across a range of actuators, larger actuators have a longer cycle time.

Nominal cycle times for smaller actuators are less than one second. Larger actuators may take up to 3-4 seconds.

Another consideration is the torque characteristics of the individual valve. Breakaway torque at the beginning of the stroke is higher than running torque. Therefore, Scotch Yoke actuators have a slightly shorter cycle time due to their higher torque at the beginning of the stroke.

In general, however, the differences in cycle time between the two designs are not significant.

## Comparison - Summary

Both designs offer a robust, durable solution to air actuated valve automation.

Rack & Pinion actuators are more compact and provide a constant torque output. They can be re-configured to either double acting or spring return designs.

Scotch Yoke actuators are lower cost and feature a higher torque output for the same frame size. They tend to be longer, have a variable torque output and are not interchangeable between double acting and spring return models.

Each design offers advantages and limitations. A better understanding of these enable the customer to select an actuator that meets the performance requirements while minimizing cost.

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## Shop For Air Actuated Valves:

**SCOTCH YOKE**

- 2-Way Stainless Ball Valves
- 3-Way Stainless Ball Valves
- 2-Way Brass Ball Valves
- 3-Pc. Sanitary Ball Valves
- Iron Lug Butterfly Valves
- 2-Way PVC Valves

**RACK & PINION**

- 2-Way Stainless Ball Valves
- 3-Way Stainless Ball Valves
- 2-Way Brass Ball Valves
- 3 Pc. Sanitary Ball Valves
- Iron Lug Butterfly Valves
- 2-Way PVC Valves

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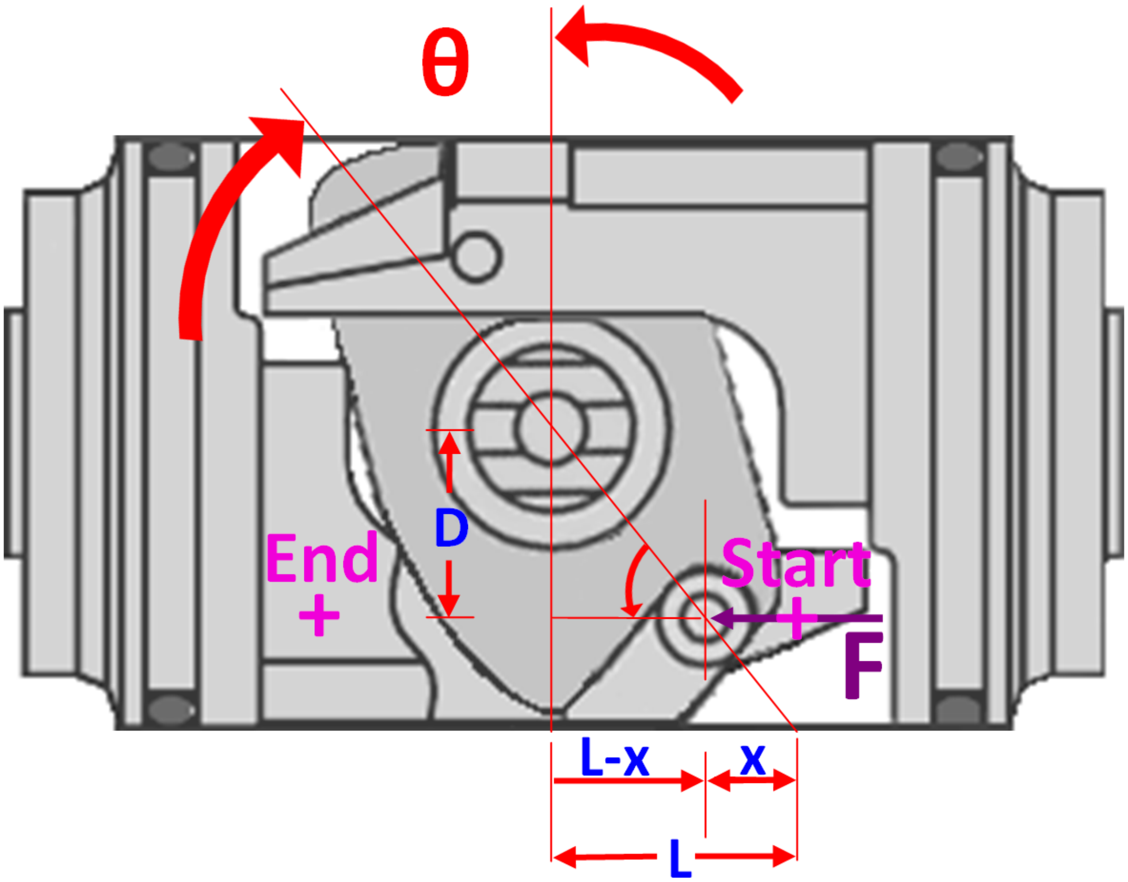
## Appendix - Scotch Yoke Torque Curve
## Engineering Discussion




To understand why the torque of a Scotch Yoke varies with stroke, we need to apply conservation of energy principles.

Let:

**L** = stroke length to mid position
**x** = stroke position
**F** = Force applied by the actuator piston (always in the X direction)
**D** = Vertical distance between the pin and shaft

Then:

$\tan\theta = (L-x)/D$

Taking the first derivative and solving for dx: $dx = -\sec^2\theta \cdot d\theta \cdot D$

Recalling conservation of energy, the work done by horizontal movement plus the work done by angular movement sums to zero:

$\Sigma W = 0$

$F \cdot \Delta x + T \cdot \Delta\theta = 0$, or $F \cdot \Delta x = -T \cdot \Delta\theta$.

For the instantaneous movement,

$F \cdot dx = -T \cdot d\theta$

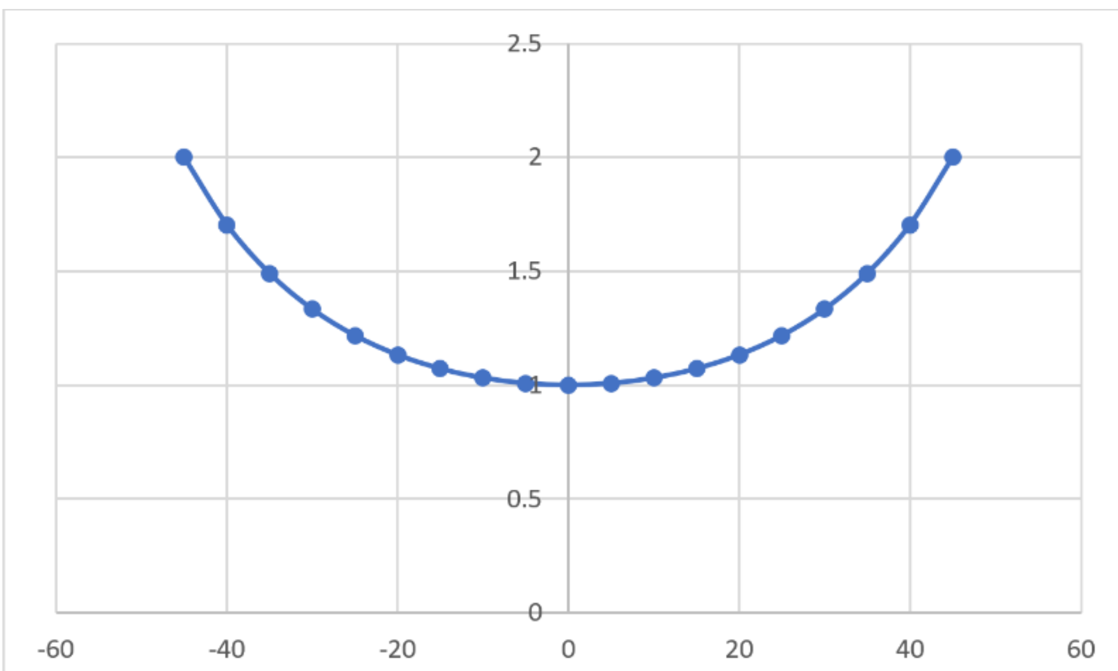
Substituting $d\theta$ for $dx$ gives:

$F(-D \cdot \sec^2\theta \cdot d\theta) = -T \cdot d\theta$

Solving for torque,

$T = F \cdot D\sec^2\theta$ where $\theta$ varies between 0 and 45°

Plotting this (and the mirror geometry to -45°) yields the familiar torque curve for scotch yoke actuators:




Variations from this are the result of differing mechanical linkages between actuator designs.

## Detailed Product Comparison:

**Scotch Yoke vs. Rack and Pinion**