Preamble

When making a new design for a servo-application, having a solid understanding of the work cycle is the foundation of good engineering. Once the cycle is well understood, several results can be obtained, that give the engineer enough information to select and size the required gearbox, servo-motor and servo-drive. Some of benefits of properly calculating duty cycle derived parameters are: more reliable designs that closely adhere to the design constraints and proper sizing of all components the machine, leading to significant cost reductions.

This tool was created to provide the engineer with the following advantages:

- Increased automation leading to a reduction in man-made errors.
- Instantly provides the 3 most important parameters
  - The duty cycle (ED%) as a percentage of the total cycle time. Once the duty cycle is known, the cycle can be classified as per IEC 60034-1. Most common cycle types are S1 (Continuous duty) and S5 (Intermittent periodic duty with electric braking, ED%⩽60% and t_{Cycle}⩽20 mins). Cycle type plays a very important role in gearbox sizing.
  - The average torque absorbed by the machine during it's active periods (T_{Avg}).
  - The average input speed of the machine during it's active periods (n_{Avg})
- Works for both simple and complex cycles. It's the later case, that is common for machine tools and that showcases the tool's strengths, that was the rationale for creating this tool.

This tool requires that the user knows for each phase: duration, initial and final speeds, and absorbed torque.

Disclaimer

This tool was made to simplify selection of Servotak gearboxes, and as such, it is our best interest to make sure it outputs accurate results. However, it is possible, albeit unlikely, that your inputs fall under an edge case that makes it produce inaccurate results. It's the responsibility of the user to make sure that the results are correct and applicable to its use case. Under no circumstances shall we be held responsible to any damages to persons or property due to correct or incorrect use of this tool, or to errors in it.

Assumptions

To offer a more user friendly and simple to use tool, it was necessary to make a number of assumptions. Please make sure that your use case falls within them:

- Both input and output duty cycle parameters at the input of your machine, that is, after the motor and the eventual gearbox.
- Speed and torque are signed, meaning that one direction is chosen as positive and one direction is chosen as negative. Torque that accelerates movement in the positive direction or decelerates movement in the negative direction is positive.
- Operation is cyclical in nature, where each cycle starts and ends with no input speed.
- Each phase that has a non-zero input speed has a non-zero input torque.
- Results only take into account normal operation. Proper calculation of exceptional situations such as emergency stops falls upon the user.

Definitions and formulas

F_α: Phase

Phases during the work cycle are labeled as F_α, where α is the phase number. Each phase has a duration t_α, an average speed n_α, and a torque T_α.

t_{Cycle}: Total duration of the cycle

This is the total duration of the cycle, including any dwell times.

$$t_{cycle}=\sum t_\alpha=t_0+t_1+t_2+\ldots=t_{Work}+t_{Dwell}$$

t_{Work}: Duration of the active part of the cycle

This is the duration of the phases of the cycle where torque and speed are not zero.

$$t_{Work}=t_{Cycle}-t_{Dwell}$$

t_{Dwell}: Dwell times

This is the total duration of all phases where torque and speed are zero.

ED: Duty Cycle

The duty cycle is the ratio between t_{Work} and t_{Cycle}. It represents the percentage of time the motor is doing useful work

$$ED=\frac{t_{Work}}{t_{Cycle}} \qquad ED\%=\frac{t_{Work}}{t_{Cycle}}\cdot 100$$

Z: Cycles per Minute

Z is the number of times the cycle does repeat in a minute.

$$Z=\frac{60}{t_{Cycle}}$$

n_α: Phase Average Speed

If there is no change of direction during a phase, the average speed is calculated as the average between the final speed of the phase ($n_{\alpha e}$) and the initial speed of the phase ($n_{\alpha b}$)

$$n_\alpha=\frac{|n_{\alpha e}-n_{\alpha b}|}{2}$$

However, if the cycle includes a change of direction, that is, speed goes from negative to positive or from positive to negative, either the cycle must be split, or the following formula must be used

$$n_\alpha=\frac{n_{\alpha e}^2+n_{\alpha b}^2}{2\cdot|n_{\alpha e}-n_{\alpha b}|}$$

n_{Avg}: Cycle Average Speed

The average speed of the cycle must be calculated only for the active parts of the cycle. Dwell times must not be considered.

$$n_{avg}=\frac{\sum t_\alpha\cdot n_\alpha}{t_{Work}}=\frac{t_0\cdot n_0+t_1\cdot c_1+t_2\cdot n_2+\ldots}{t_{Work}}$$

T_{Avg}: Cycle Average Torque

Cycle average torque is calculated only during the active parts of the cycle, that is, excluding dwell times.

$$T_{Avg}=\sqrt[3]{\frac{\sum n_\alpha\cdot t_\alpha\cdot|T_\alpha^3|}{\sum n_\alpha\cdot t_\alpha}}=\sqrt[3]{\frac{n_0\cdot t_0\cdot|T_0^3|+n_1\cdot t_1\cdot|T_1^3|+n_2\cdot t_2\cdot|T_2^3|+\ldots}{n_0\cdot t_0+n_1\cdot t_1+n_2\cdot t_1+\ldots}}$$

n_{Peak}: Peak speed during the cycle.

Peak speed is the highest (or lowest, for negative speeds) cycle attained during normal operation. As listed in the initial assumptions, it's unrelated to emergency stop torque.

$$n_{Peak}=max(n_\alpha)$$

T_{Peak}: Peak torque during the cycle.

Peak torque is the highest (or lowest, for negative torques) cycle attained during normal operation. As listed in the initial assumptions, it's unrelated to emergency stop torque.

$$T_{Peak}=max(|T_\alpha|)$$

Examples

Basic Cycle

This is the most fundamental cycle, and appears in most applications. It's composed of an acceleration phase, a constant speed phase, a deceleration phase and a dwell time. It typically applies to general automation machines such as packaging machines in the food and pharmaceutical industries, robotics, etc.

Input

The following fields correspond to the input shaft of your machine

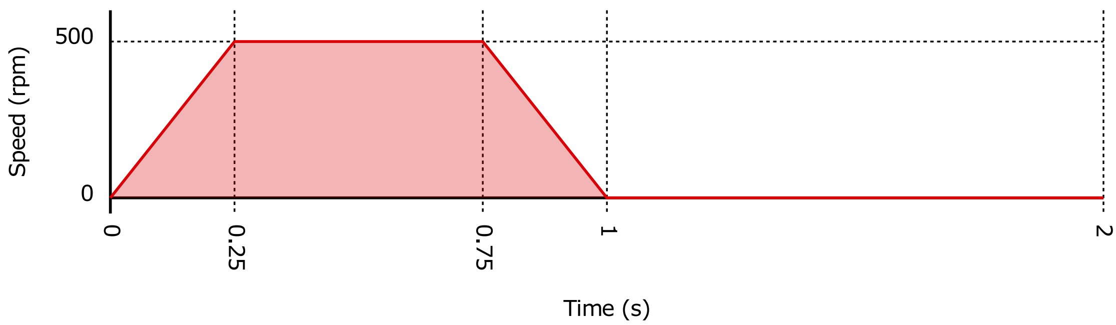
	Time			Speed				
Phase	**Start (s)**	**End (s)**	**Duration (s)**	**Initial (rpm)**	**Final (rpm)**	**Average (rpm)**	**Torque (N·m)**	
F_0	0	0.25	0.25	0	500	250	350	Delete
F_1	0.25	0.75	0.5	500	500	500	170	Delete
F_2	0.75	1	0.25	500	0	250	350	Delete
F_3	1	2	1	0	0	0	0	Delete

+ Phase

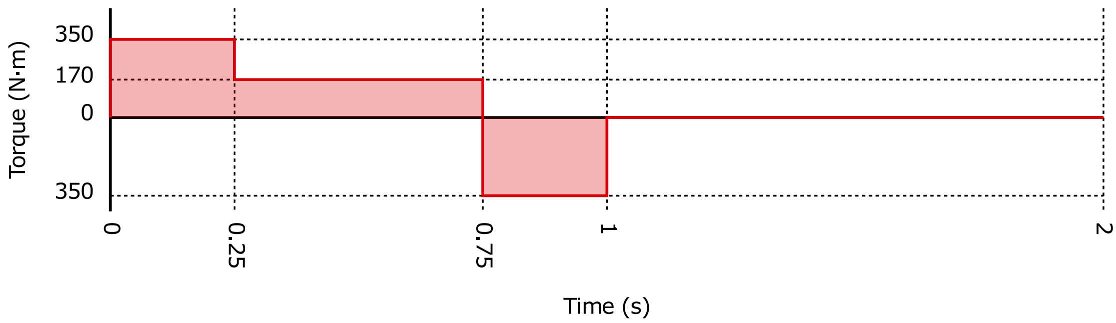
Results

Total Duration	t_{Cycle} =	2	s
Active Duration	t_{Work} =	1	s
Duty Cycle	ED =	50	%
Cycles per Minute	Z =	30	
Average Speed	n_m =	375	rpm
Peak Speed	n_m =	500	rpm
Average Torque	T_m =	260	N·m
Peak Torque	T_{Peak} =	350	N·m

Speed Chart



Torque Chart



Cycle with Multiple Dwell Times

This example is made of four simple cycles, with identical active parts, but with different dwell times, as required by the manufacturing process it automates. This cycle is typical of servo-controlled programmable rotary tables, fully automated assembly machines (both linearly operated and rotary), etc.

Input

The following fields correspond to the input shaft of your machine

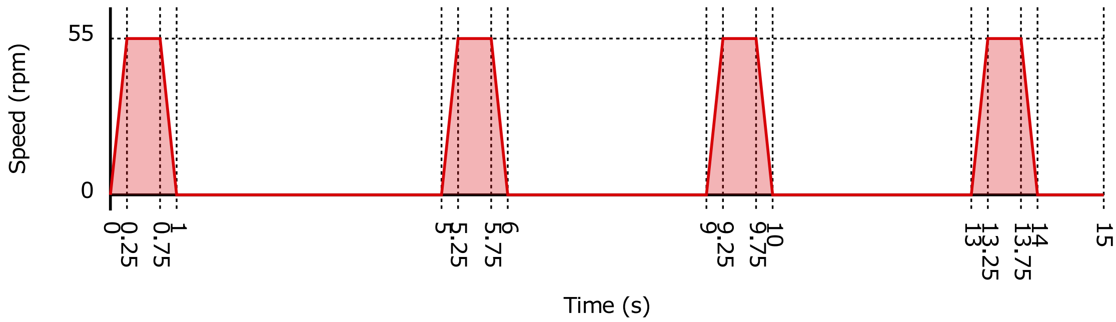
	Time			**Speed**				
Phase	**Start (s)**	**End (s)**	**Duration (s)**	**Initial (rpm)**	**Final (rpm)**	**Average (rpm)**	**Torque (N·m)**	
F_0	0	0.25	0.25	0	55	27.5	500	Delete
F_1	0.25	0.75	0.5	55	55	55	200	Delete
F_2	0.75	1	0.25	55	0	27.5	500	Delete
F_3	1	5	4	0	0	0	0	Delete
F_4	5	5.25	0.25	0	55	27.5	500	Delete
F_5	5.25	5.75	0.5	55	55	55	200	Delete
F_6	5.75	6	0.25	55	0	27.5	500	Delete
F_7	6	9	3	0	0	0	0	Delete
F_8	9	9.25	0.25	0	55	27.5	500	Delete
F_9	9.25	9.75	0.5	55	55	55	200	Delete
F_{10}	9.75	10	0.25	55	0	27.5	500	Delete
F_{11}	10	13	3	0	0	0	0	Delete
F_{12}	13	13.25	0.25	0	55	27.5	500	Delete
F_{13}	13.25	13.75	0.5	55	55	55	200	Delete
F_{14}	13.75	14	0.25	55	0	27.5	500	Delete
F_{15}	14	15	1	0	0	0	0	Delete

+ Phase

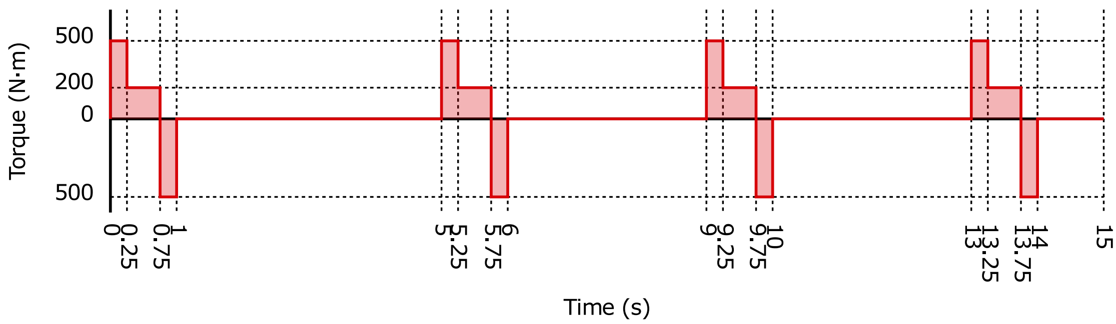
Results

Total Duration	t_{Cycle} =	15	s
Active Duration	t_{Work} =	4	s
Duty Cycle	ED =	27	%
Cycles per Minute	Z =	4	
Average Speed	n_{Avg} =	41.3	rpm
Peak Speed	n_{Peak} =	55	rpm
Average Torque	T_{Avg} =	360.9	N·m
Peak Torque	T_{Peak} =	500	N·m

Speed Chart



Torque Chart



Cycle with Alternating Directions

This cycle starts with a basic cycle with a short dwell time, and then reverses direction, with a new basic cycle that returns performs the same work in the opposite direction, followed by a long dwell time. It's most often encountered in bending machines (wire, sheet metal, etc), linear actuators (both ball screw based and belt drive based), mechanical servo presses, pick and place machines, etc.

Input

The following fields correspond to the input shaft of your machine

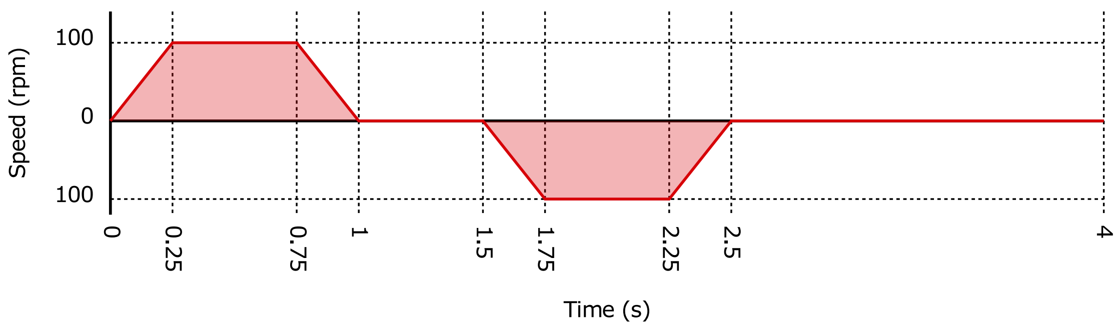
	Time			Speed				
Phase	**Start (s)**	**End (s)**	**Duration (s)**	**Initial (rpm)**	**Final (rpm)**	**Average (rpm)**	**Torque (N·m)**	
F_0	0	0.25	0.25	0	100	50	1000	Delete
F_1	0.25	0.75	0.5	100	100	100	500	Delete
F_2	0.75	1	0.25	100	0	50	1000	Delete
F_3	1	1.5	0.5	0	0	0	0	Delete
F_4	1.5	1.75	0.25	0	100	50	1000	Delete
F_5	1.75	2.25	0.5	100	100	100	500	Delete
F_6	2.25	2.5	0.25	100	0	50	1000	Delete
F_7	2.5	4	1.5	0	0	0	0	Delete

+ Phase

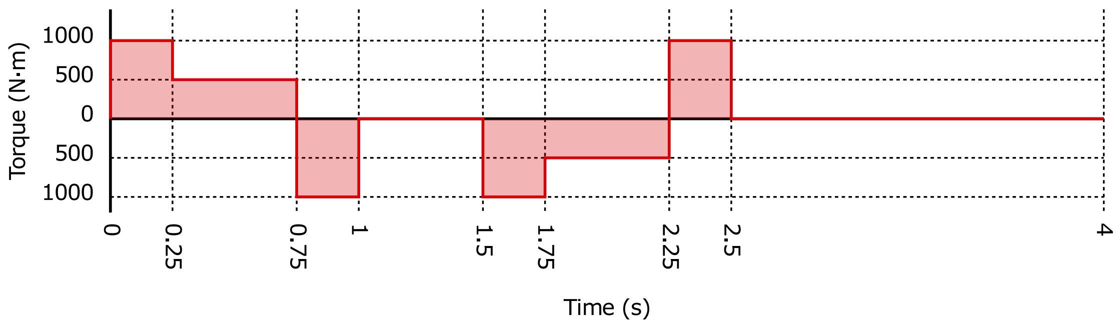
Results

Total Duration	t_{Cycle} =	4	s
Active Duration	t_{Work} =	2	s
Duty Cycle	ED =	50	%
Cycles per Minute	Z =	15	
Average Speed	n_{Avg} =	75	rpm
Peak Speed	n_{Peak} =	100	rpm
Average Torque	T_{Avg} =	746.9	N·m
Peak Torque	T_{Peak} =	1000	N·m

Speed Chart



Torque Chart



Complex cycle

Complex cycles are composed of multiple different cycles, with possibly different torques, speeds directions and times. This example is typical of machine tools such as heavy duty CNC machines, machining centers, milling machines (gantry based, traveling column based, etc.), etc. It was calculated for a 25m traveling column milling machine. Phases F_0 to F_2, and F_4 to F_6 correspond to progressively finer rough machining, while phases F_8 to F_{10} corresponds to a final precision machining step. Phases F_{12} to F_{14} correspond to the column's rapid return to the starting position.

Input

The following fields correspond to the input shaft of your machine

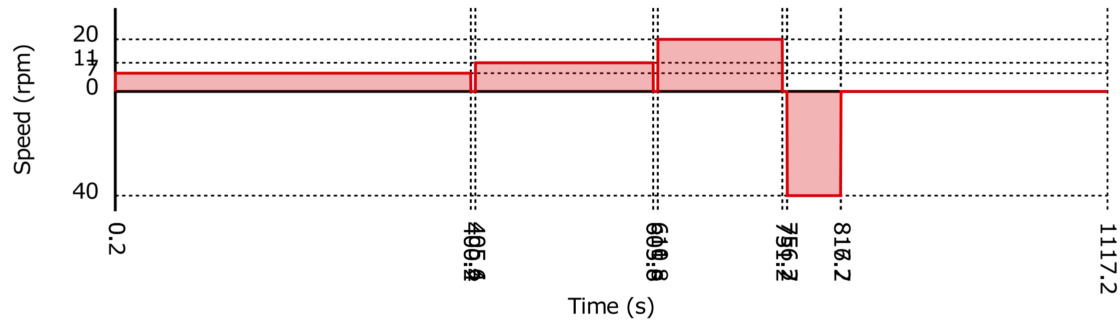
Phase	Time			Speed			Torque (N·m)	
	Start (s)	End (s)	Duration (s)	Initial (rpm)	Final (rpm)	Average (rpm)		
F_0	0	0.2	0.2	0	7	3.5	2500	Delete
F_1	0.2	400.2	400	7	7	7	2000	Delete
F_2	400.2	400.4	0.2	7	0	3.5	2500	Delete
F_3	400.4	405.4	5	0	0	0	0	Delete
F_4	405.4	405.6	0.2	0	11	5.5	2500	Delete
F_5	405.6	605.6	200	11	11	11	1300	Delete
F_6	605.6	605.8	0.2	11	0	5.5	2500	Delete
F_7	605.8	610.8	5	0	0	0	0	Delete
F_8	610.8	611	0.2	0	20	10	2500	Delete
F_9	611	751	140	20	20	20	800	Delete
F_{10}	751	751.2	0.2	20	0	10	2500	Delete
F_{11}	751.2	756.2	5	0	0	0	0	Delete
F_{12}	756.2	756.7	0.5	0	40	20	3800	Delete
F_{13}	756.7	816.7	60	40	40	40	500	Delete
F_{14}	816.7	817.2	0.5	40	0	20	3800	Delete
F_{15}	817.2	1117.2	300	0	0	0	0	Delete

+ Phase

Results

Total Duration	t_{Cycle} =	1117.2	s
Active Duration	t_{Work} =	802.2	s
Duty Cycle	ED =	72	%
Cycles per Minute	Z =	0.1	
Average Speed	n_{Avg} =	12.7	rpm
Peak Speed	n_{Peak} =	40	rpm
Average Torque	T_{Avg} =	1434.4	N·m
Peak Torque	T_{Peak} =	3800	N·m

Speed Chart



Torque Chart