●Duty Cycle

Duty cycle is the term used to define the heating factors of a solenoid to prevent thermal damage. Duty cycle is normally expressed as a percentage and is defined as: the solenoids "on time" divided by the sum of the "on time" plus the "off time" :

$$\text{Duty Cycle(\%)} = \frac{\text{ON Time}}{\text{ON Time} + \text{OFF Time}} \times 100$$

Duty cycle is important because a by-product of applying electrical power to the coil is heat. This excess heat can thermally damage the coil. Thus the term duty cycle is used to assure that only the safe maximum amount of electrical energy is applied to the solenoid.

As an example, if a solenoid is rated at 7 watts continuous duty, this means that the solenoid coil can operate continuously (100% on time) with an input power level of 7 watts with no thermal damage. This continuous duty rating is arrived at by lab testing. However, if increased energy output is required, then this can be accomplished by increasing the input power. However, this leads to increased temperature rise which can lead to permanent thermal damage in the coil. To prevent this, the solenoid must be operated in an "on" and "off" mode. Therefore if the input power level is increased to 14 watts (double the continuous duty rating) the solenoid's duty cycle must be dropped to 50% to prevent thermal damage. Additionally, the maximum "on" time needs to be considered.

●Maximum "On" Time

When a solenoid is actuated, current is applied to the coil. A by-product of this is temperature rise in the coil. When a solenoid is energized continuously, heating of the coil increases until a saturation level is reached which is equal to the ambient heat radiation. When a solenoid is operated in an intermittent (on-off) manner, the "on" time becomes critical if higher voltages (thus currents) are applied to the coil. These higher currents cause higher coil temperatures which can exceed the cooling capacity of the solenoid through ambient radiation. This heat rise can thermally destroy the solenoid's coil. To avoid such a catastrophic failure, there is a maximum "on" time, which is the longest time the solenoid can be energized without thermal damage. The maximum "on" time has been determined for each duty cycle, and is shown in the coil data.

●Ampere Turn

Ampere turn describes the electro-motive force that causes a solenoid to actuate. Ampere turn is the product of the applied current to the coil, multiplied by the number of turns of magnet wire, as shown in the formula below:

$$\text{Ampere Turns} = \frac{\text{Voltage}}{\text{Coil Resistance}} \times \text{Coil Number Turns}$$

Energy output of a solenoid is proportional to the number of ampere turns. The larger the number of ampere turns, the larger the mechanical energy output. However, the ampere turns should not exceed 10% duty cycle, as above this level may cause coil thermal damage. Also, since all solenoids reach magnetic saturation at 10% duty cycle, increasing ampere turns will not increase energy output.

●Heat Sink

In order to reduce coil heating and to enable a larger number of ampere turns to be employed, a heat sink is attached to a solenoid. Coil data of rotary solenoids, push-pull solenoids, and tubular solenoids are measured and tested with a standard heat sink attached. Without a heat sink, a lower voltage than specified on the coil data charts, or a lower duty cycle, must be used to avoid thermal damage to the coil. The coil data of small push-pull solenoids, self-holding solenoids, open frame solenoids and proportional/on-off solenoids, is shown without use of a heat sink.

●Safety Factor

To reduce potential problems due to energy less through temperature rise in the coil and voltage fluctuations, a safety factor of 1.5 is recommended (required output x 1.5). When using open frame solenoids and self-holding solenoids, the safety factor should be 1.3. It is possible to use a smaller safety factor, but precise application testing should be performed under all possible conditions.

●Temperature Effects on Performance

Coil and performance data shown in this catalog are measured at an ambient temperature of 20°C. When a voltage is applied to a coil, the coil temperature rises,

This temperature increase causes an increase in the coil resistance. As a result, the energy output will decrease. The relationship between the coil temperature and the coil resistance are shown in the following table.

Coil temp. (°C)	Resistance coefficient	Ampere-Turn ratio
-40	0.764	1.309
-20	0.843	1.186
0	0.921	1.086
20	1	1
40	1.079	0.927
60	1.157	0.864
80	1.236	0.809
100	1.314	0.761
120	1.393	0.718

To select the appropriate solenoid, it is necessary to consider the final temperature of the solenoid in your application. To determine the value of force or torque after the coil temperature increase, the ampere turns must be calculated from ambient temperature based on the following formula :

$$t = \frac{R_2 - R_1}{R_1} \times (234.5 + t_1) + t_1 - t_2$$

t : temperature rise (deg.)
R_1 : initial coil resistance (ohms)
R_2 : final coil resistance (ohms)
t_1 : initial ambient temperature (°C)
t_2 : final ambient temperature (°C)

●Response Time

The response time for solenoids is the time from when a voltage is applied to the coil until a given stroke has been achieved. The data in this catalog uses a coil temperature of 20°C as a reference point, without any load. Response time will become longer when a load is applied to the armature.

●Arc Suppression

The solenoid coil is an inductive load which has a high inductance. As such, caution should be taken in the form of arc suppression when energizing and de-energizing the coil.

●Pick and Hold Circuit

This circuit is used when a large energy output from the solenoid is required, but the space is limited. The circuit applies an, extremely high voltage to a coil during energizing (pick) and then applies a voltage to the coil to reduce potential coil heating problems (hold). The most frequently used method is to use a simple timing circuit that applies a high voltage signal for approximately 50 msec. and then drops off to a holding voltage. There are also dual coil designs whereby one coil is used for "pick" and the other for the "hold".

●Power Supply

All of our standard solenoids are DC type. If the power supply available is AC, then a rectifier is required to convert AC to DC. The rectifier should be a full wave rectified type. Consult the factory for recommendations.

●Relation Between Duty Cycle and Voltage

A relationship exists between duty cycle and voltage. In the table below, the relationship between ampere turn, power (watts), and voltage is shown. For example, the voltage at 25% duty, cycle is twice the voltage at 100% duty cycle.

Duty cycle	100%	50%	25%	10%
Ampere-Turn	1	$\sqrt{2}$	2	$\sqrt{10}$
Voltage	1	$\sqrt{2}$	2	$\sqrt{10}$
Watts	1	2	4	10

●How to Calculate Non-standard Duty Cycle and Voltage

The voltage of a solenoid at a duty cycle not shown in the coil data, is determined by the following formula :

$$E_2 = E_1 \frac{\sqrt{\dfrac{\alpha_1}{100}}}{\sqrt{\dfrac{\alpha_2}{100}}} = E_1 \frac{1}{\sqrt{\dfrac{\alpha_2}{100}}}$$

E_1 : Voltage at 100% duty cycle (VDC)
E_2 : Voltage at α_2 (VDC)
α_1 : 100% duty cycle
α_2 : duty cycle to be used

●**Electrolytic Corrosion of Coil**

When the solenoid is used in an environment of high temperature and high humidity, and the case is grounded, the coil may corrode and fail under electrolytic action. To eliminate this potential problem, the following precautions should be observed.

1. Ground the positive(+) lead of the power source.
2. When circumstances preclude the grounding of the positive(+) lead of the power supply, or require the grounding of the negative(−) lead of the power supply, install a switch in the positive(+) lead of the power supply and connect the negative(−) lead to the coil.
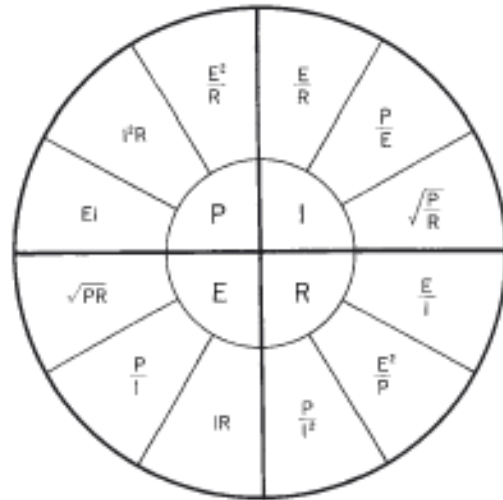
●**Use of Characteristics Tables**

Tables are provided for each size of push-pull solenoids, tubular solenoids, open frame solenoids, and self-holding solenoids, which show stroke vs. force curves at four duty cycles (100%, 50%, 25%, and 10%). For rotary solenoids, the table shows every size's duty cycle vs. torque curves for each rotation angle. Decide the size of the solenoid needed in your application, then move to the page for that size, and review details of the solenoid.

●**Conversion of Units (Reference)**

1N (Newton)	=0.102 (kgf)=102 (gf)
1kgf	=9.807 (N)
1Nm	=10.197 (kgf cm)
1MPa	=10.197 (kgf/cm²)
1kgf/cm²	=0.098 (MPa)
1N (Newton)	=0.225 (lbs)
1Nm	=8.85 (lb • in)
1MPa	=145PS1

●**Ohms Law and Power**

I=ampere
R=ohms
E=volts
P=Power