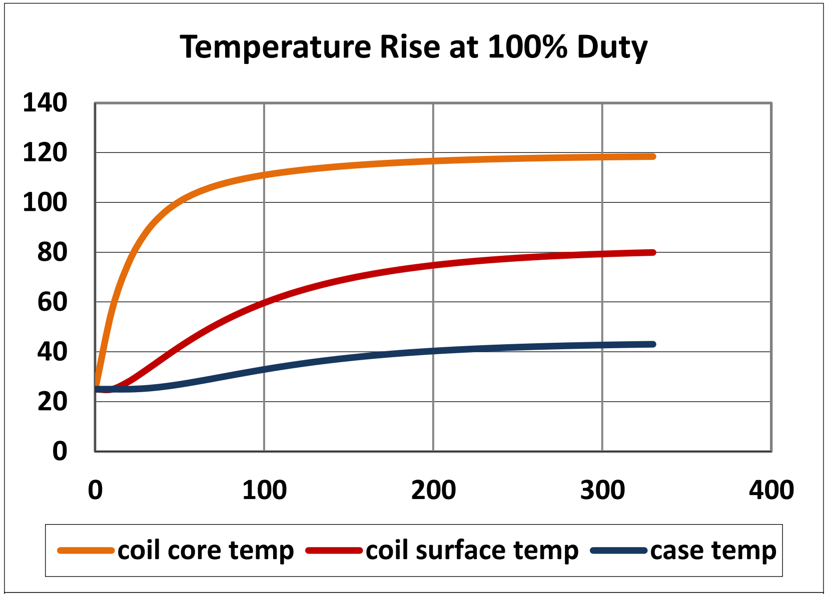
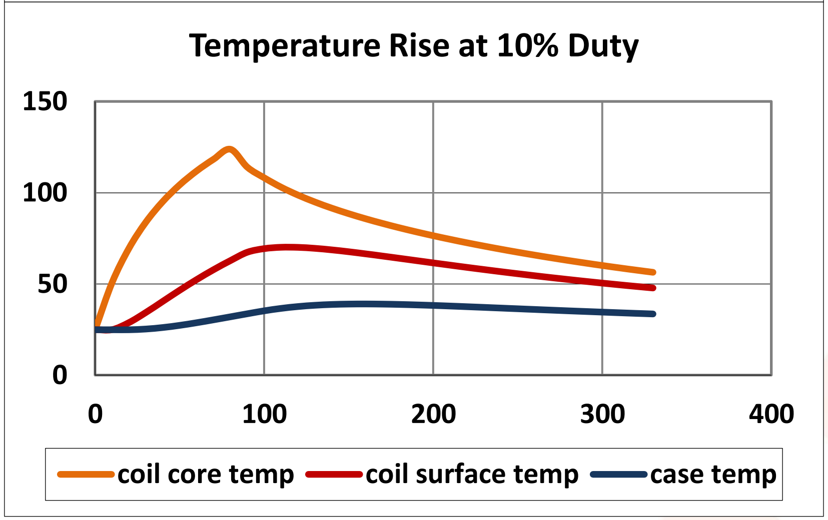
GEEPLUS

20-1002
Duty Cycle (Average Power) and Thermal Considerations

1. Introduction

- The term ‘Duty Cycle’ is widely used in describing the performance of electromechanical actuators, but is inexactly applied and subject to misinterpretation. What is really described by the term, is the excitation condition where the internal coil temperature of the device will reach the maximum temperature which can safely be endured by the insulation (or other material used in the construction).
- 100% Duty Cycle or 100%ED (ED or Effective Duty is commonly used in Europe) describes a condition where the actuator is continuously energised with constant power, and after some time will reach a stable temperature where input power (electrical), and output power (in the form of heat radiated from the surface, conducted to attached parts (heatsink requirement may be specified), and through convection) are in equilibrium, which is the limiting temperature for insulation system.
- 50% Duty Cycle, or 50%ED describes a condition where the actuator is energised with twice as much power as required to reach the temperature limit, but where the excitation is intermittent (eg 100ms ‘ON’ followed by 100ms ‘OFF’). The average power input is thus the same, however the higher current applied results in a higher Ampere-turns product being developed by the coil, and thus in higher magnetic flux and force / torque.
- Similarly for other duty cycles, as the duty cycle expressed reduces, the power applied during ‘ON’ part of cycle is assumed to increase, it is this increased excitation power which results in higher forces being developed.
- The graphs on right show the typical thermal behaviour of solenoid components with excitation at 100% duty condition, and with excitation at 10% duty condition.
- The graphs show how in the device operating at 100% duty rating, the temperature increases gradually towards a 120º equilibrium temperature, in the device operating at 10% duty cycle the coil climbs rapidly to this temperature – in the graph power is switched off at this point, the temperature of coil surface and case continue to increase for some time as heat is transferred from the coil core, before starting to cool.



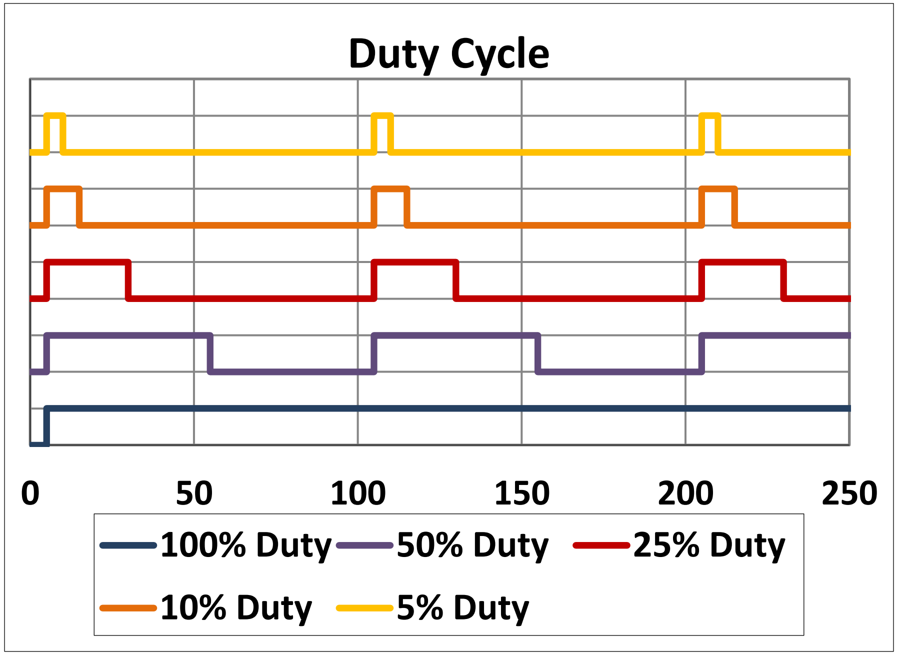


2. Duty Cycle

- The textbook definition of duty cycle, as it is understood by most engineers is :

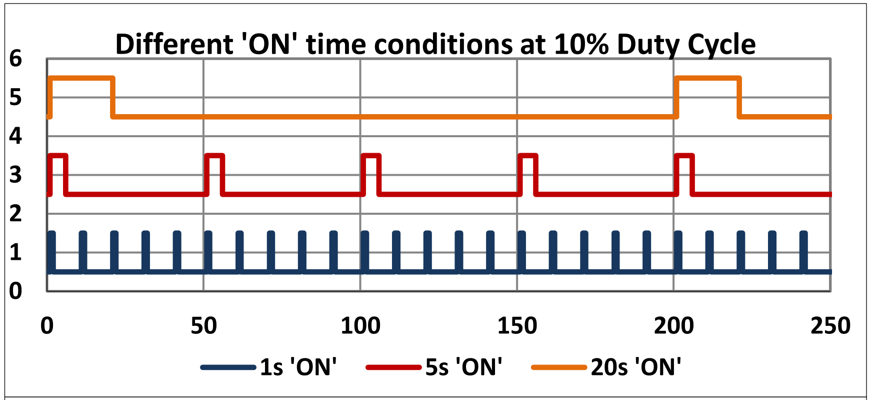
Time 'ON' / (Time 'ON' + Time 'OFF')

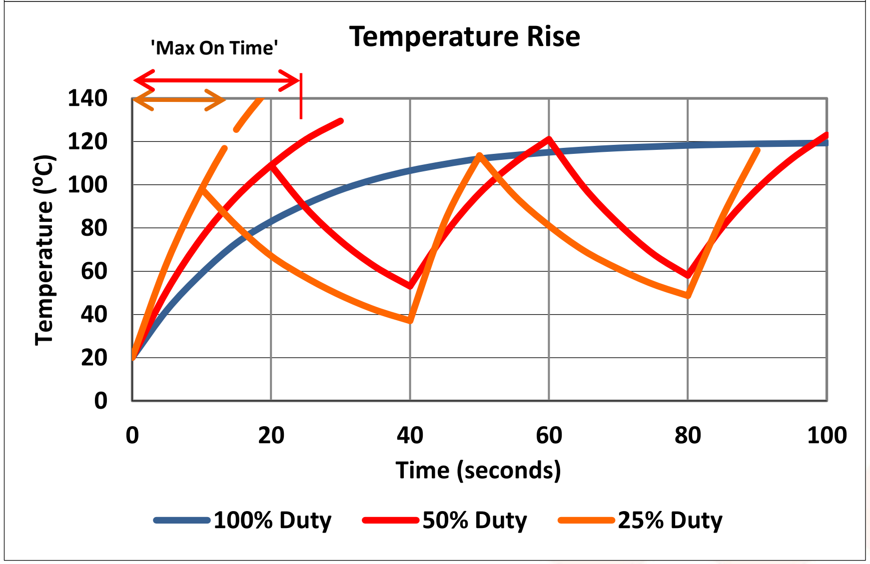
- This is illustrated graphically in the figure to the right.
- This is correct for electromechanical actuators in so far as the 'ON' and 'OFF' times are concerned, but does not take into consideration the amount of power applied to the device during the 'ON' phase.



3. Maximum 'ON' Time

- The top graph on the right illustrates several different timing diagrams representing 'ON' and 'OFF' phases of an excitation cycle. All 3 diagrams correspond to a duty cycle of 10%, however the 'ON' time is different in each case.
- Figure 4 shows what happens to coil temperature over time at different duty cycle for a M190 tubular part with maximum coil temperature rating of 120°C. Starting from 20°C, at 50% duty cycle this reaches 120° within about 24 seconds, at 25% duty cycle it reaches this temperature within about 14 seconds, this is the 'maximum on time' for the part. It should be noted that for subsequent operating cycles, if the part has not been permitted to cool fully to 20°C, then the time taken to reach this temperature will be shorter. This will normally be given for each duty cycle condition shown in data. If this 'ON' time limitation is exceeded, the device will overheat and may be destroyed. An extreme example of a bad 'ON' time condition, would be a lock which is energised for 15 minutes each day. Although the duty cycle is very small (<1%), the max 'ON' time condition is such that this is effectively a 100% duty condition.





4. Ambient Temperature and Heatsinking Conditions

- Most published data for actuator devices is based on operation in specified ambient temperature conditions, and may also specify heatsinking requirements.
- **Elevated Ambient Temperature Condition -** If a device is operating in an ambient temperature higher than the condition in which specifications are measured, the amount of power required to raise the temperature of the coil above the safe limit will be reduced. In this case the excitation power, or the duty cycle may need to be reduced to avoid overheating. Conversely in cold ambient conditions, it may be permissible to increase excitation power without risk of overheating.
- **Heatsinking Conditions -** Test data may describe heatsinking conditions under which test data has been measured. Common conditions are either an infinite heatsink (eg a massive aluminium or copper block) attached to mounting surface / bracket, or an aluminium plate of defined size (assumed equivalent to structure to which the device would be attached in use). In applications where the heatsinking conditions are poor, it may be necessary to reduce power applied to the device.

5. Coil Temperature and Temperature Co-Efficient of Resistance #1

- The maximum power which can be applied to a given device is limited by the temperature rating of insulation materials, and by the efficiency of heat dissipation from the device. It is clear from the graphs shown in section 1 that there can be big differences in temperature between the coil, and the housing of a device.
- The resistance of a metal coil increases as the temperature of the coil increases. Where the increase in temperature is expressed in °K, then the resistance changes according to the equation.

$$R(T_2) = R(T_1) * (1 + \alpha(T_2 - T_1))$$

Where:

α = temperature coefficient of resistance

T_2 = final temperature (°K)

T_1 = starting temperature (°K)

5. Coil Temperature and Temperature Co-Efficient of Resistance #2

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- The resistance of the coil of an electrical actuator can be calculated by measuring the voltage and current across the coil.
- If resistance is measured in this way at a known cold temperature [$R(T_1)$] condition, and in worst case operating condition [$R(T_2)$], the temperature in worst-case operating condition can be calculated according to the formula:

$$\mathbf{T_2 = T_1 + \frac{\frac{R(T_2)}{R(T_1)} - 1}{\alpha}}$$

Where:

T_2 = final temperature (°K)

T_1 = starting temperature (°K)

$R(T_2)$ = final resistance (worst case condition)

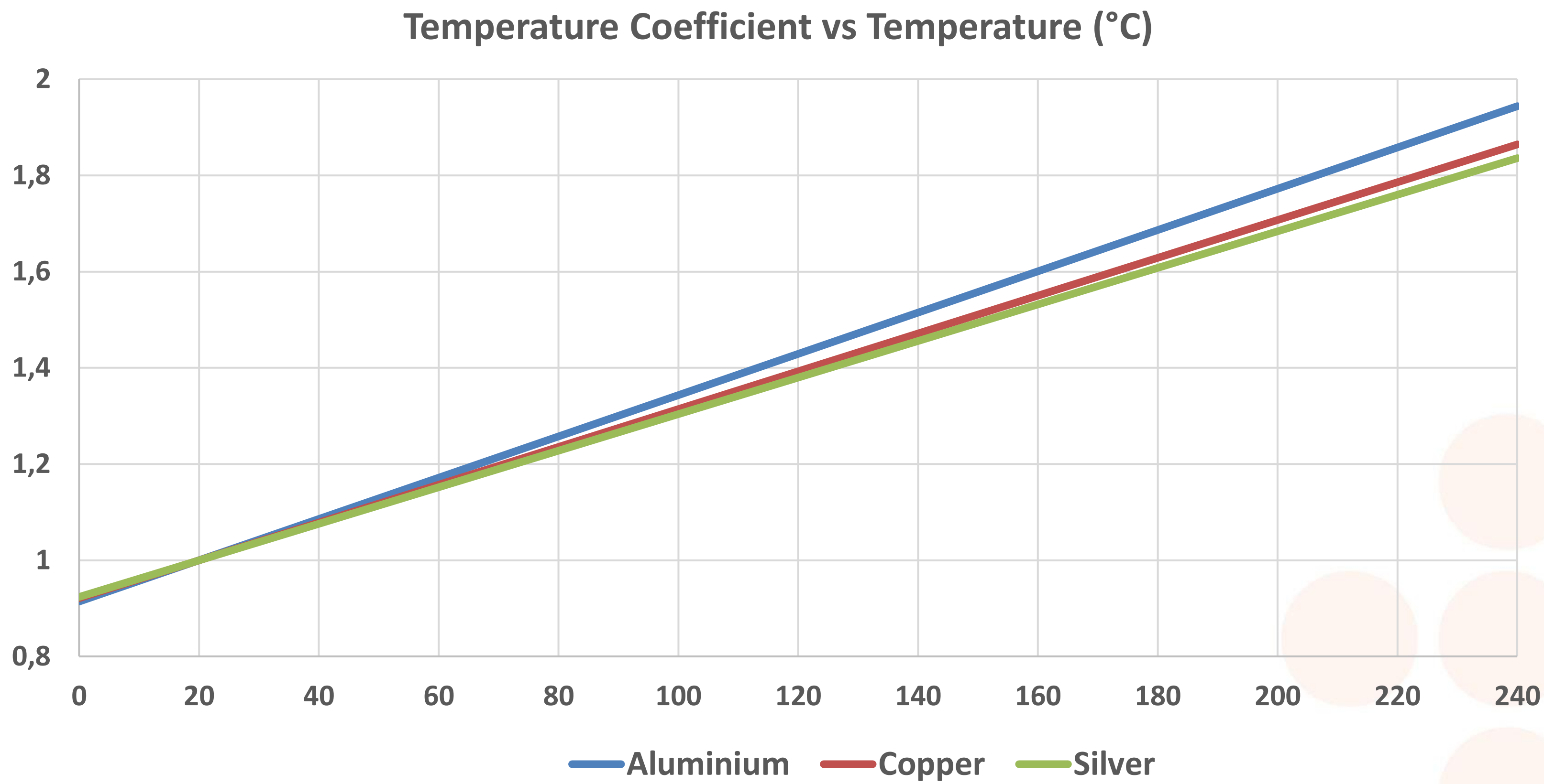
$R(T_1)$ = starting resistance at temperature T_1

α = temperature coefficient of resistance

(α for copper is 0.00393 / °K)

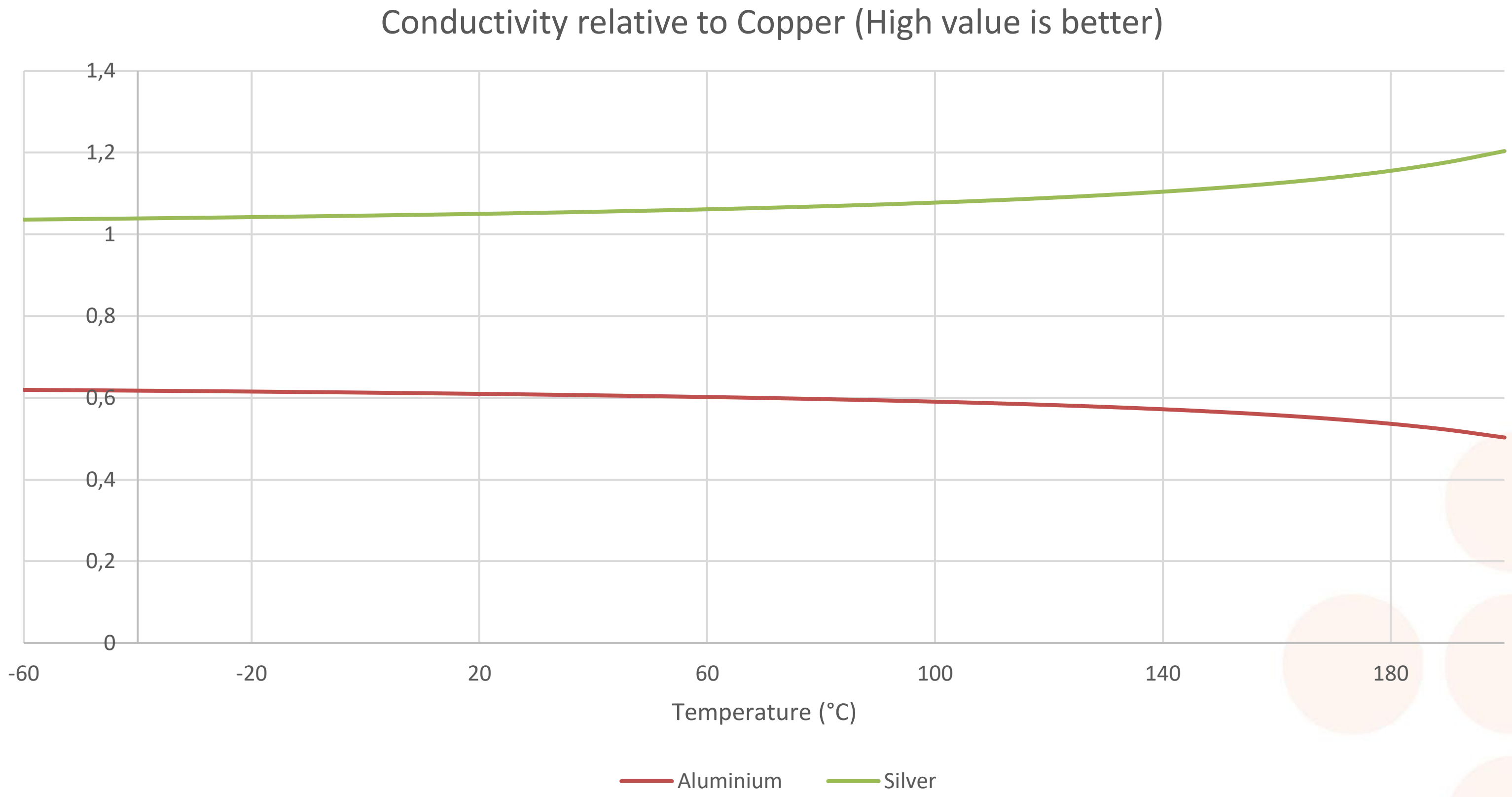
5. Coil Temperature and Temperature Co-Efficient of Resistance #3

- For a quick estimate of temperature rise, if the resistance increase factor of the coil is measured, the temperature increase can be obtained from the graph below



5. Coil Temperature and Temperature Co-Efficient of Resistance #4

- The conductivity of silver or of aluminium compared to that of copper is shown at different temperatures. The benefits of using silver wire to wind the coil become greater at elevated temperatures.



6. Heat Dissipation Mechanisms in Actuator Devices

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- The materials of an actuator have a property known as specific heat capacity, without any dissipation of energy this defines how much the temperature of 1 gramme of material will rise (in °K) when 1 Joule of energy is input to the sample. The heat capacity of the actuator is obtained by multiplying this by the component mass. Before heat is dissipated by conduction or other mechanism, energy is absorbed in raising the temperature of the coil material, this is the primary mechanism which determines the maximum 'on' time for a device.
- The primary mechanism for heat dissipation from actuator devices offered by Geeplus is conduction.
  - In VCM actuators the coil moves within an airgap in the magnetic pot assembly, a finite airgap is necessary to the operation of these devices (ferrofluid can be added to the airgap to improve heat dissipation from these devices). As the coil moves the heat dissipation may vary with changing coil position.
  - In Solenoid devices, the coil is typically wound on a plastic bobbin, and the OD wrapped with insulating tape. There is typically an airgap between the OD of the coil and case of the device
- Air is not a good conductor of heat, as can be seen from the graphs in section 1, there can be a large temperature difference between the coil and case of these devices.
- **Geeplus would always recommend that temperature rise of the coil of actuator devices should be tested in the end application under worst-case operating conditions (maximum ambient temperature, and maximum excitation power conditions).**

7. Improving Thermal Behaviour of Actuator Devices

- It may be possible to use a ‘pick and hold’ drive to reduce power consumption and dissipation. In this case a high power is applied to produce the needed pull-in force / speed, and power then reduced to hold in the energized position. This can be very beneficial for devices which show big force / torque increase in the energized position.
- In many actuator devices, the temperature rating of the device can be extended to allow operation at higher temperatures / higher power levels, through the use of higher temperature insulation materials.
  - It should be noted that as temperature increases, the coil resistance also increases and more power is wasted as heat.
- The power dissipation of actuator devices can also be extended by improving thermal conductivity between the coil and case of the device. This reduces the coil temperature for a given power input and case temperature.
  - This is technically a better way to improve performance of a device, however it can be difficult to implement requiring the coil to be over-moulded or potted with a material having better thermal conductivity than air.

8. Short Term Operation (Maximum 'ON' Time)

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- For very short-term operation with high excitation power, the removal of heat from the coil by conduction or other mechanism is not significant.
- In these conditions the main factor limiting temperature rise is the heat capacity of the coil itself, for a given amount of energy the coil temperature will rise by a fixed amount.
- The capacity of a coil to absorb energy is determined by the mass of the coil, and by the specific heat capacity of the material from which it is made. The two factors can be multiplied to obtain a heat capacity for the coil expressed in Joules per °C.