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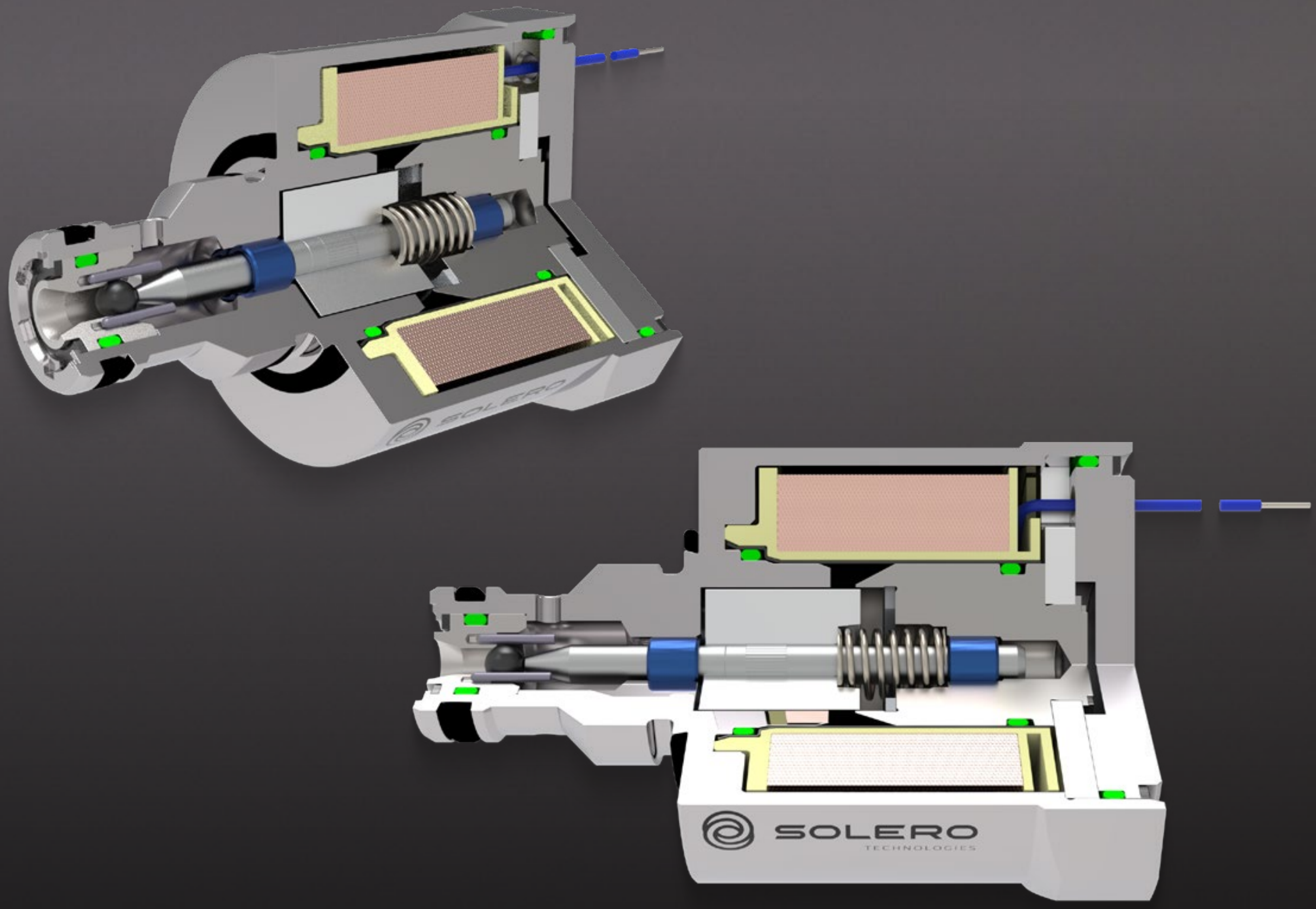

Current vs. Voltage Control in Automotive Solenoids

Comparing Performance, Efficiency, and Design Impact

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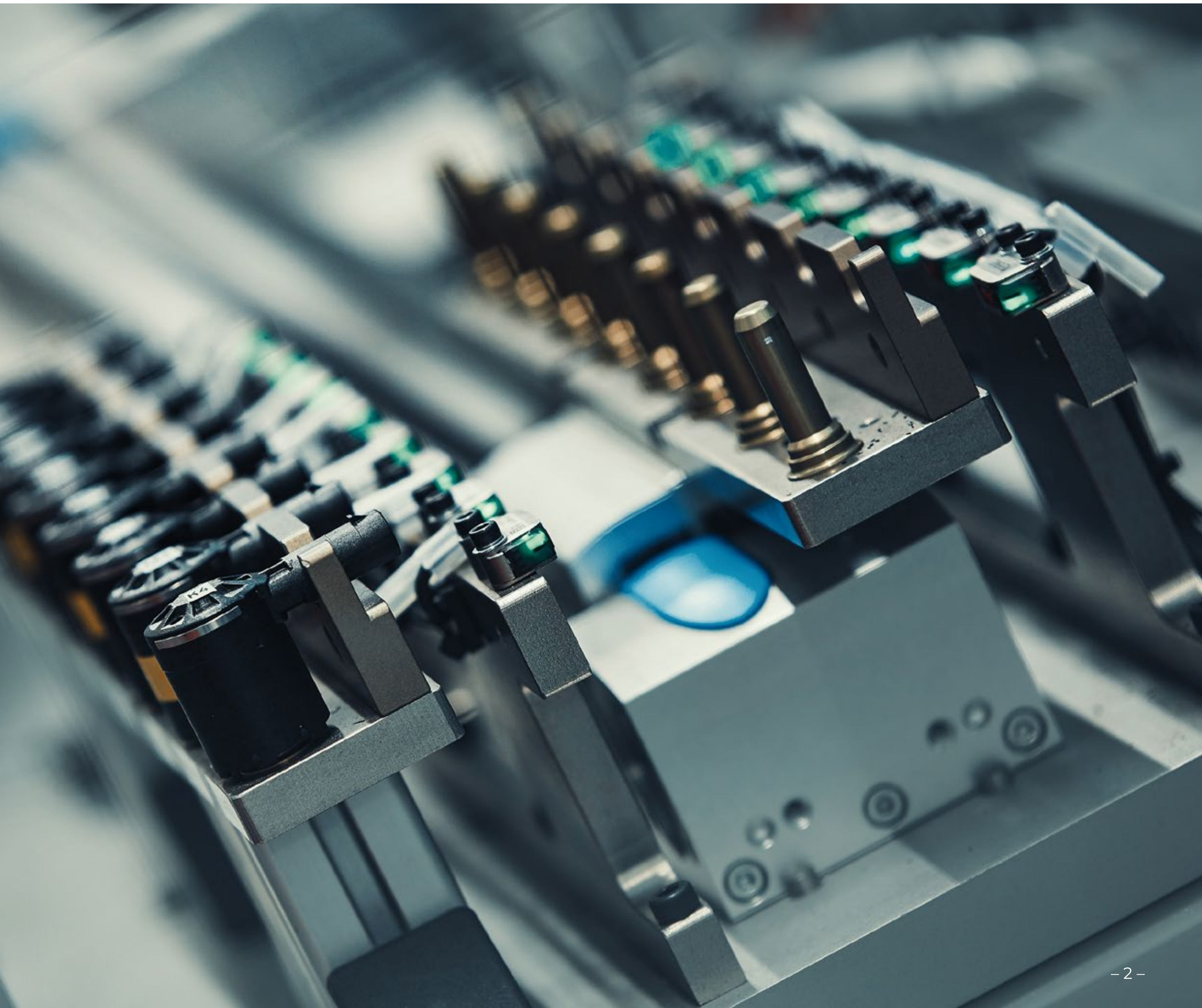


Abstract

This paper compares voltage- and current-controlled solenoids for automotive applications under varying voltage (9–16 V) and temperature (–40 °C to +95 °C) conditions. Voltage-controlled solenoids show significant force variation and require larger coils to meet performance targets, while current-controlled solenoids maintain consistent force through active current regulation. The study highlights design trade-offs in size, cost, and efficiency for both control methods in automotive environments.

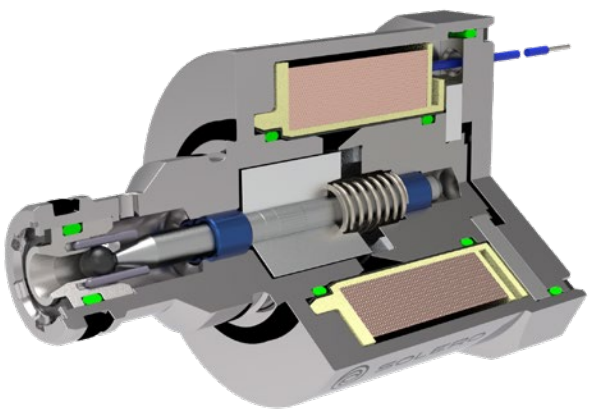
Introduction

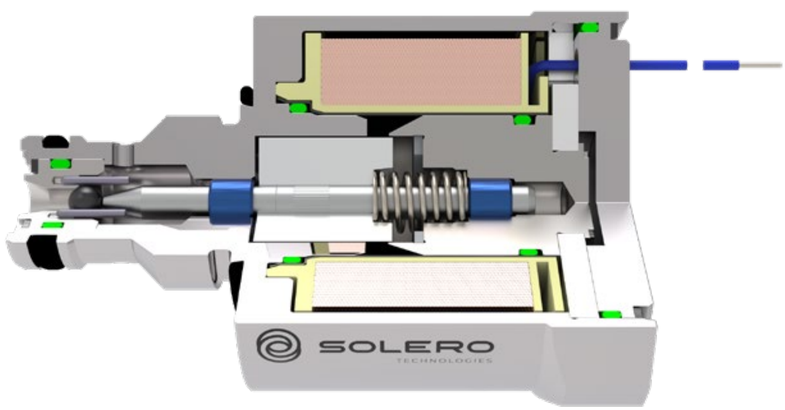
Electromagnetic actuators are a fundamental component in numerous safety- and comfort-related systems within the automotive industry, such as active suspension, fluid control or seat massage systems. A critical aspect of actuator design is the choice of control method: current-controlled or voltage-controlled. Voltage-controlled solenoids are often perceived as simpler and potentially more cost-effective in early design stages. However, practical applications—especially under compact and thermally constrained installation conditions—highlight significant challenges. Increased space requirements and elevated energy consumption can lead to higher overall system costs. This paper investigates the design implications of voltage- versus current-controlled solenoids, focusing on cost, size, and performance in automotive applications.

The force generated by an electromagnet depends primarily on the magnetomotive force (MMF), defined as the product of the coil current and the number of turns, as well as the geometry of the magnetic circuit, including the cross-sectional area and air gap dimensions.

Voltage-controlled solenoids must be designed to operate reliably within the typical vehicle electrical system voltage range of typically 9 V to 16 V for 12 V Systems and ambient temperatures ranging from –40 °C to occasionally over +120 °C. The most demanding operating conditions arise when low voltage coincides with high temperature, resulting in the lowest coil current and minimal magnetic force, and conversely when high voltage coincides with low temperature, leading to maximum coil current, while high voltage coinciding with high temperature results in increased thermal stress.

Current-controlled solenoids regulate coil current to maintain a consistent magnetic force despite variations in supply voltage and ambient temperature. This regulation compensates for changes in coil resistance due to temperature fluctuations, helping to stabilize actuator performance. Current control is typically implemented via pulse width modulation (PWM), which also enables energy savings by allowing the coil current to be reduced to a holding current once the solenoid reaches its end position, where applicable.





Comparison of voltage and current-controlled solenoids

Figure 1 depicts the force versus stroke characteristics of a voltage-controlled solenoid (Solenoid B) and a current-controlled solenoid (Solenoid A), both designed with approximately the same dimensions and copper mass.

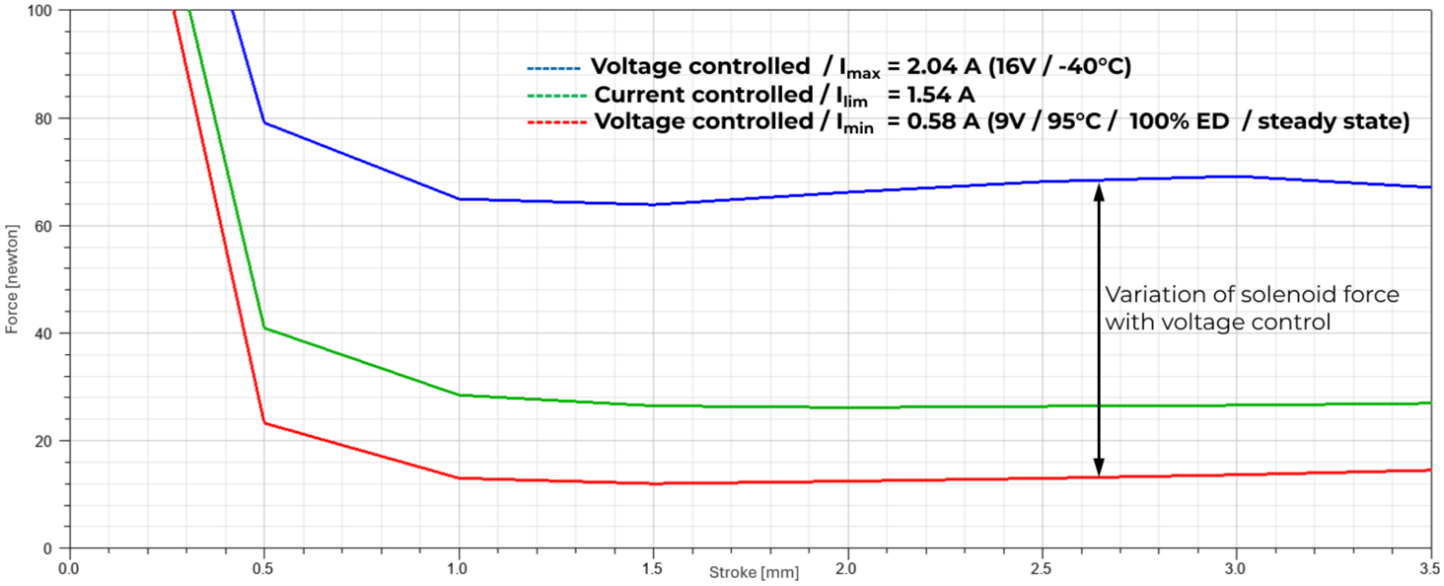


Figure 1 current and voltage-controlled solenoids with equal dimensions

It is evident that the force generated by the voltage-controlled solenoid varies significantly with temperature and supply voltage. Notably, its minimum force falls below that of the current-controlled solenoid. To achieve the same minimum force as Solenoid A, a voltage-controlled solenoid (Solenoid C) must be redesigned with an increased volume of approximately 42% and a coil requiring about 87% more copper. The corresponding force versus stroke characteristic for Solenoid C is shown in Figure 2.

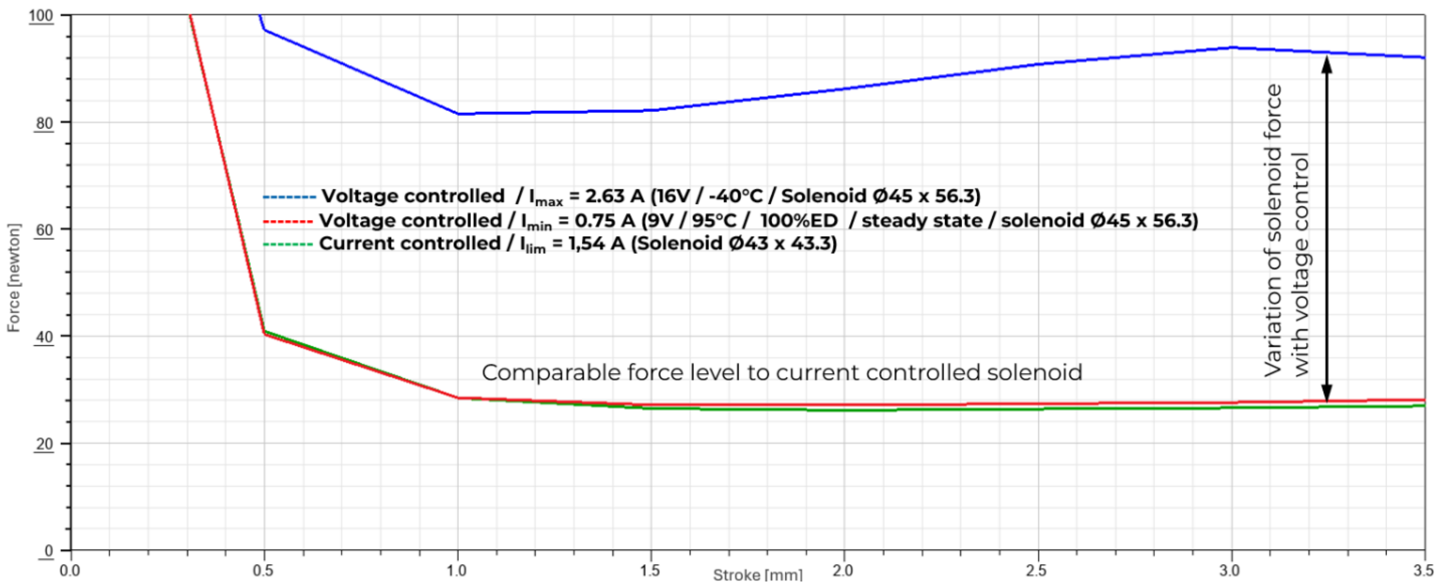


Figure 2 Voltage-controlled solenoid designed to achieve magnetomotive force comparable to current-controlled solenoid at 9 V input

The increased size and copper content of Solenoid C imply higher material costs, increased weight, and larger installation space requirements.

Conclusion

The comparison between voltage- and current-controlled solenoids shows that each control method presents specific advantages and limitations depending on application requirements. Voltage-controlled solenoids offer simpler electronics but are more sensitive to supply voltage and temperature variations, often requiring larger designs to ensure reliable operation under worst-case conditions. Current-controlled solenoids, while requiring more complex control electronics, provide more stable force output and allow for more compact and efficient designs. The choice between both approaches should consider factors such as available installation space, thermal environment, cost targets, and system complexity in the intended automotive application.

Appendix: Properties of Solenoids (Example)

	Solenoid A
Coil resistance	3.41 Ω
No. of windings	525 Wdgs.
Max. current	1.54 A
Magnetmotive force	808 AW
Needed voltage	8.99 V (steady state)
Coil temperature	202 °C (steady state)
Copper wire mass	104 g
Outer dimensions	Ø43 x 43.3 mm

	Solenoid B	Solenoid C
Coil resistance	10.24 Ω	7.94 Ω
No. of windings	891 Wdgs.	1054 Wdgs.
Voltage range	9 – 16 V	9 – 16 V
Min. current I_{min} at U_{min} 9 V / 95°C	0.58 A (steady state)	0.75 A (steady state)
Min. magnetomotive force at U_{min} 9V	517 AW (steady state)	790 AW (steady state)
Coil temperature at U_{min} / 95°C	150 °C (steady state)	151 °C (steady state)
Current at U_{max} 16 V / 95°C	0.9 A (steady state)	1.16 A (steady state)
Magnetomotive force at U_{max} 16 V	802 AW (steady state)	1223 AW (steady state)
Max. coil temperature at U_{max} / 95°C	206 °C (steady state)	207 °C (steady state)
Max. current I_{max} at U_{max} 16 V / -40°C	2.04 A (unheated)	2.63 A (unheated)
Max. magnetomotive force at U_{max} 16 V / -40°C	1818 AW (unheated)	2772 AW (unheated)
Copper wire mass	99 g	195 g
Outer dimensions	Ø43 x 43.3 mm	Ø45 x 56.3 mm

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