

FEMA CORPORATION FRICTIONLESS SOLENOID VALVES

Suspended Armature Technology

Executive Summary

FEMA Corporation's suspended armature technology and associated features have been successfully integrated into hundreds of applications in multiple markets including agriculture, construction, industrial, mining, marine and military. A combination of evolutionary and revolutionary design developments, robust engineering, and manufacturing expertise allows FEMA to maintain industry leading product performance alongside world class quality metrics.



Figure 1 – Sample of products incorporating the FEMA Frictionless Suspended Armature

Force Motor History

The FEMA force motor and electrohydraulic suspension technologies currently employed are founded on concepts first incorporated in high performance aerospace servo valves. Several types of servo valves were designed to amplify force and control systems in an aircraft. Reducing friction within the initial, or pilot stage, was a critical design goal early in the development of servo valves for this industry, as errors or performance changes are reflected and amplified through the entire control system.

One type of servo was the torque motor which utilized a rotational armature mounted to a beam style spring, which eliminated nearly all friction within the valve. When electrical commands were received from the operator or control system, a corresponding output was provided with near-zero dead band and practically infinite resolution.

The torque motor reduced threshold and hysteresis well beyond other technologies of that era. However, aerospace servo valves were too costly for the commercial market.

FEMA Proportional Pressure Control Valves - A New Approach

The advantages of the aerospace servo were readily apparent to FEMA engineers. However, it took a fundamentally different approach to introduce frictionless technology to new markets.

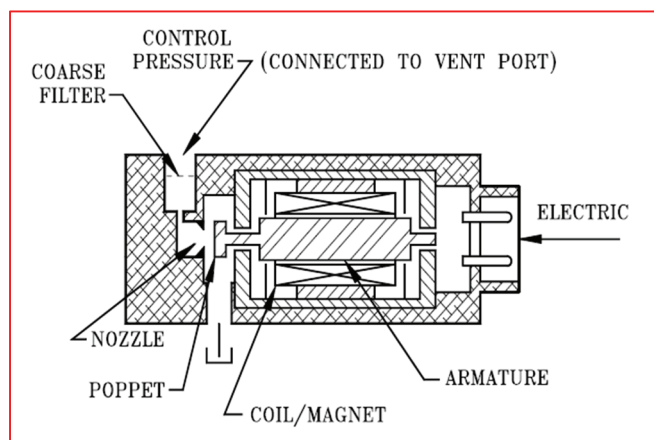


Figure 2 – Pictorial representation of a FEMA PPC (Proportional Pressure Control)

Instead of a torque motor, FEMA developed and patented a lower-cost rectilinear flat spring suspended armature force motor, which accomplished the same benefits in smaller packages with greater flexibility. Flat springs main-

tain the radial position of the armature within the assembly, preventing contact with surrounding components while allowing for precise, controlled axial motion. Much like the torque motor, static and kinetic friction are eliminated thus reducing hysteresis and eliminating threshold.

Unlike the proportional valves offered by other manufacturers, the FEMA Proportional Pressure Control (PPC) does not require a superimposed dither or low frequency PWM signal to operate. In traditional designs, an oscillating or dithered electrical command signal is required to mitigate static friction and excessive threshold. With no internal friction, FEMA's suspended armature valves can operate with high frequency or DC command signals, simplifying driver requirements and reducing development time and cost.

The FEMA Analog Valve

Initial designs were targeted to and proven successful in industrial and off-highway markets. In fact, this platform has proven so flexible, reliable and robust that it is still in production today. However, since the introduction of the original PPC, several generational design upgrades have enabled decreased cost and improved manufacturability, including automated assembly and test.

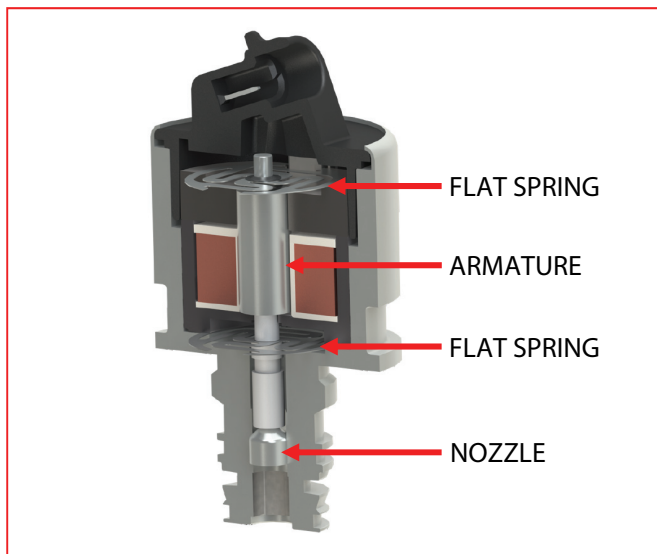


Figure 3 - Internal features of the FEMA Analog pilot

The FEMA Analog valve is the second generational update to the PPC. As displayed in Figure 3, this suspension system enables high clearances within the motor, meaning these designs handle contamination levels an order of magnitude or more beyond traditional solenoid and proportional valves. Valves incorporating FEMA suspension armature designs are rated up to -/25/20 per ISO 4406.

These high clearances and the suspension system virtually eliminate wear surfaces allowing for reliability which has resulted in not just years of service for a valve, but decades.

With tens of millions of these products in the field, FEMA has unmatched reliability and performance consistency over life. Due to its historical robustness, commanded output remains precise and repeatable; in spite of challenging applications and difficult environments.

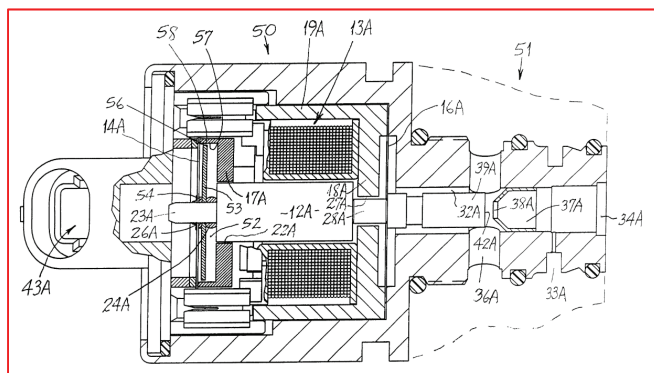


Figure 4 – Patented damping features are found in multiple FEMA proportional pressure control valves

FEMA also developed and patented a tunable hydraulic damping arrangement within these suspended armature units. This important feature enables system resonances to be attenuated or eliminated. FEMA Applications and Systems Engineering work in concert with our customers to find the optimum performance parameters via modeling, analysis, and laboratory validation. Further information on this damping configuration can be found in US Patent 6281772 – *Dynamic Damping in a Frictionless Solenoid Valve*.

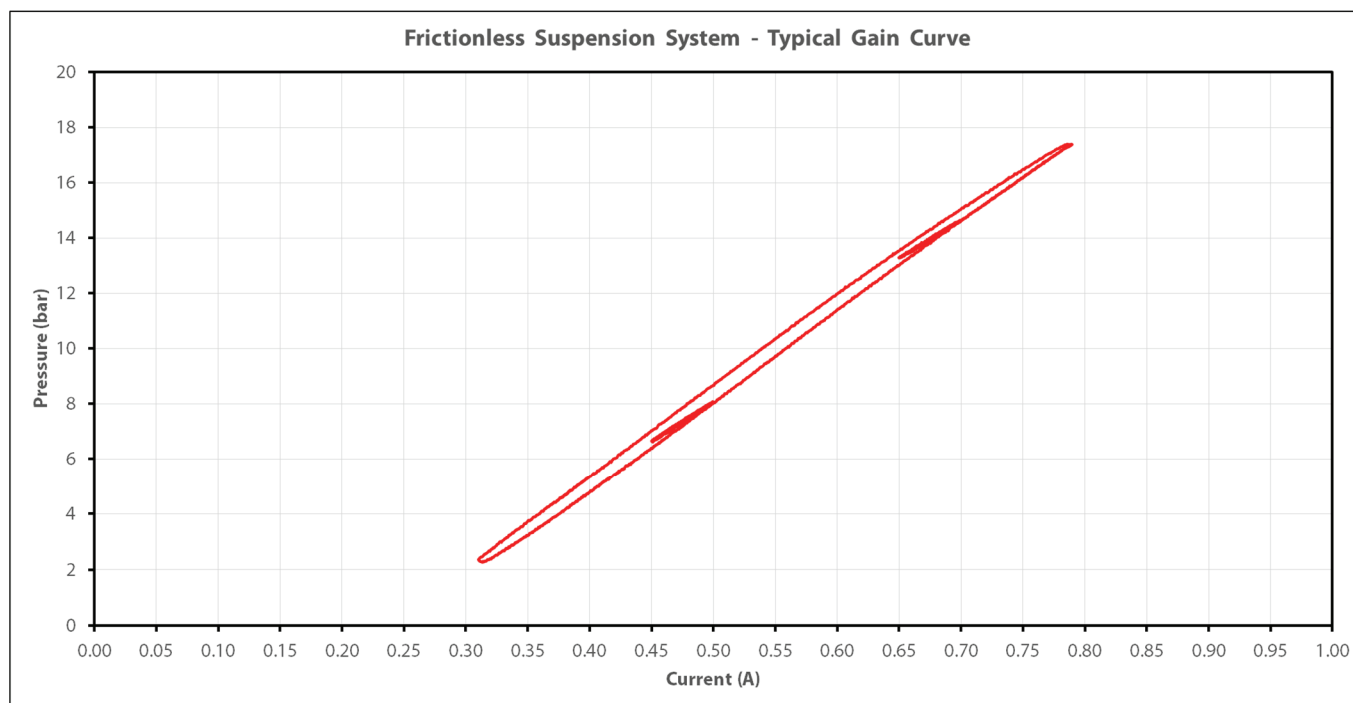


Figure 5 – Pressure gain curve of a FEMA Corporation two stage Analog valve

The majority of Analog frictionless pilots are mated to a second stage cartridge assembly. In this configuration, proportional pressure control of clutches, brakes, or other elements can be controlled precisely by the valve. Figure 5 shows an example pressure gain curve of the second stage. Note the “threshold loops” at 0.50A and 0.70A, showing exceptionally low threshold and hysteresis even as a two-stage assembly.

The Future of Frictionless Solenoids

With third and fourth generation products now currently in production, the family of valves utilizing the suspended armature continues to grow. For example, FEMA pilots have proven well suited to auto-guidance valves for agriculture and construction equipment, where the low hysteresis and robustness to contamination have proven to give the customer industry leading performance and proven reliability. These valves are even used to provide full steer-by-wire vehicle control. Patented spool damping on the FEMA L10n series of two stage proportional valves combines with a new, smaller frictionless pilot to provide an

advanced, tunable design with efficient packaging. Finally, the Lyra proportional pilot valve uses its frictionless armature to control pressure on a hydrostat based Infinitely Variable Transmission, an application that demands a repeatable, stable control valve.

FEMA continues to partner with customers on challenging applications, leveraging engineering expertise, advanced technology, and cutting-edge manufacturing to develop products that elevate our customers above the competition.

See how FEMA can assist you with any current or future challenges by contacting us via fema-corp.com