White Paper

Electro-Hydrostatic Actuation: An Attractive Energy-Efficient Option for Machine Builders

Achim Helbig, Ph.D.
Moog
Innovation Projects Manager

Key Messages

- Electro-hydrostatic actuation (EHA) is an energy-saving option for industrial machine builders
- Determining whether an EHA solution is viable requires both an economic and performance assessment
- Forward-thinking machine builders seek a "building block" approach to incorporating EHA into new designs

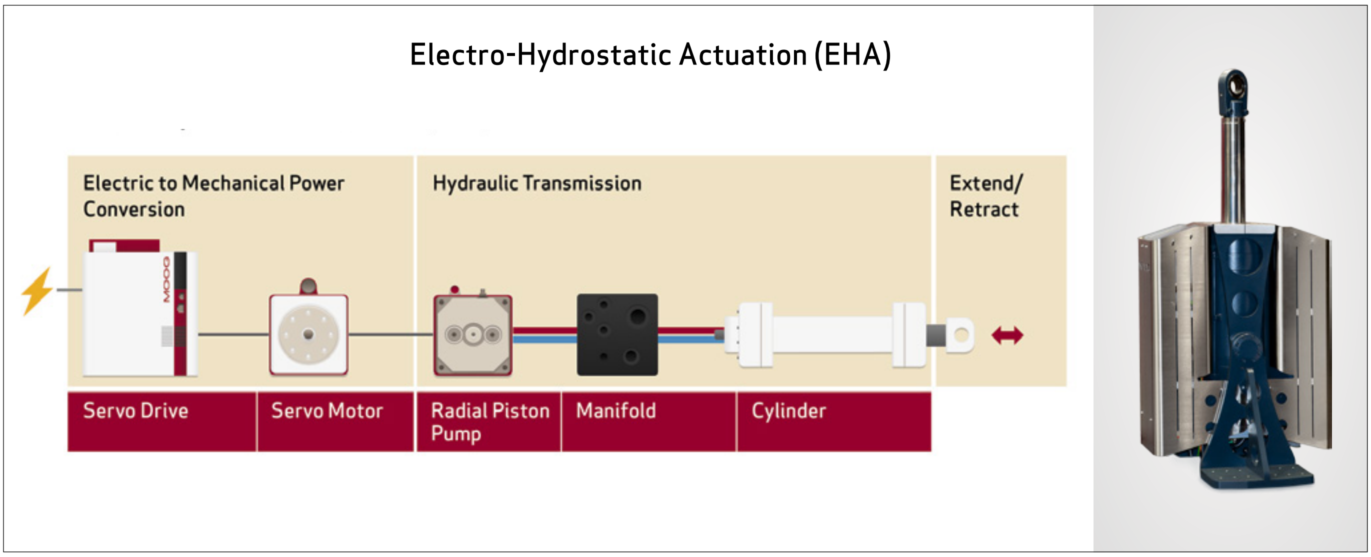


Figure 1: General layout of an electro-hydrostatic actuator (EHA) and actual image of a Moog EHA.

Executive Summary

Electro-hydrostatic actuators (EHA), widely used in the aerospace applications for linear actuation, are emerging as a viable option for industrial machine builders as the design combines the best of both electro-mechanical and electro-hydraulic technologies. The EHA is a highly integrated, compact alternative to traditional hydraulic solutions. Automation engineers moving toward electro-mechanical actuation in pursuit of energy efficiency and environmental cleanliness, will find an EHA an attractive option for high force density actuators.

This white paper will address the factors to consider when assessing an industrial machine's application suitability for this latest innovation in actuation.

1 EHA Applications and Challenges

Electro-Hydrostatic Actuator Technology

An electro-hydrostatic actuator (EHA) is a self-contained hydraulic solution that integrates a cylinder, feedback unit, variable speed pump, servo motor, electric drive and control electronics, into a compact unit requiring only an electrical connection. The integration of traditionally separate components for hydraulic actuation solutions along with the elimination of hoses and couplings are the readily apparent differences from a traditional hydraulic solution. The pump, servo motor, and servo drive are Moog building block products available in different variations and sizes which are combined with manifolds and cylinder to create an integrated EHA that can be customized in terms of speed, force, space requirements and functionality.

The EHA converts power from electric to hydraulic to mechanical. An electric servo motor drives a bidirectional, variable speed pump which is connected to the two chambers of a hydraulic cylinder. Depending on the flow, the axis is extending or retracting. In contrast to the hydraulic system, the power control is done by the pump. Varying the speed of the pump means varying the flow and thus the hydraulic power. The pressures in the chambers are load-dependent. This enables the electro-hydrostatic actuator to use energy most efficiently and deliver power on demand.

Due to the energy efficiency of the system, the hydraulic oil only absorbs little heat. Heating is typically in the range of only 40°C. Convection cooling is usually sufficient for an electro-hydrostatic actuator. This allows designers to build compact, modular units with a self-contained hydraulic system. The oil of such an actuator ages very little and does not usually need to be changed during the entire lifetime of the system. Due to the compressibility of the hydraulic fluid, it shows less stiffness than an electro-mechanical system. However, the design is highly flexible, various layouts are possible and it can be adjusted to carry out fail-safe options or serial movements of several axes.

Proven Technology in the Aerospace Industry

Industrial machines that are employing EHAs today are benefiting immediately and the worry about working with beta product releases or first generation products is no longer a concern *(See Figure 2)*. The aerospace industry has been employing EHAs for low power aircraft applications since the beginning of the new millennium. Aerospace designers gravitated to the use of EHAs from classic hydraulic solutions to improve reliability and eliminate the plumbing required for positioning of the wing flaps, landing gear, and rudder control. The aerospace industry's use of the EHA technology is a testament to its reliability.

Moog was one of the first developers of EHAs for the aerospace industry. The fact that today there are at most three to four companies in the world that can offer all the components needed is indicative of the technical expertise required to develop these self-contained solutions. After over a decade of EHA experience in aerospace, Moog launched their first EHA on the market specifically for industrial machinery applications in 2011. EHA technology in the aerospace market is a best practice by this point in time, but until recently the cost remained relatively prohibitive to the industrial machinery sector.

Figure 2: Deep Drawing Press using electro-hydrostatic actuation for the die cushion axis. Source: Dresden University

Challenges Faced in Designing an EHA for Industrial Machinery

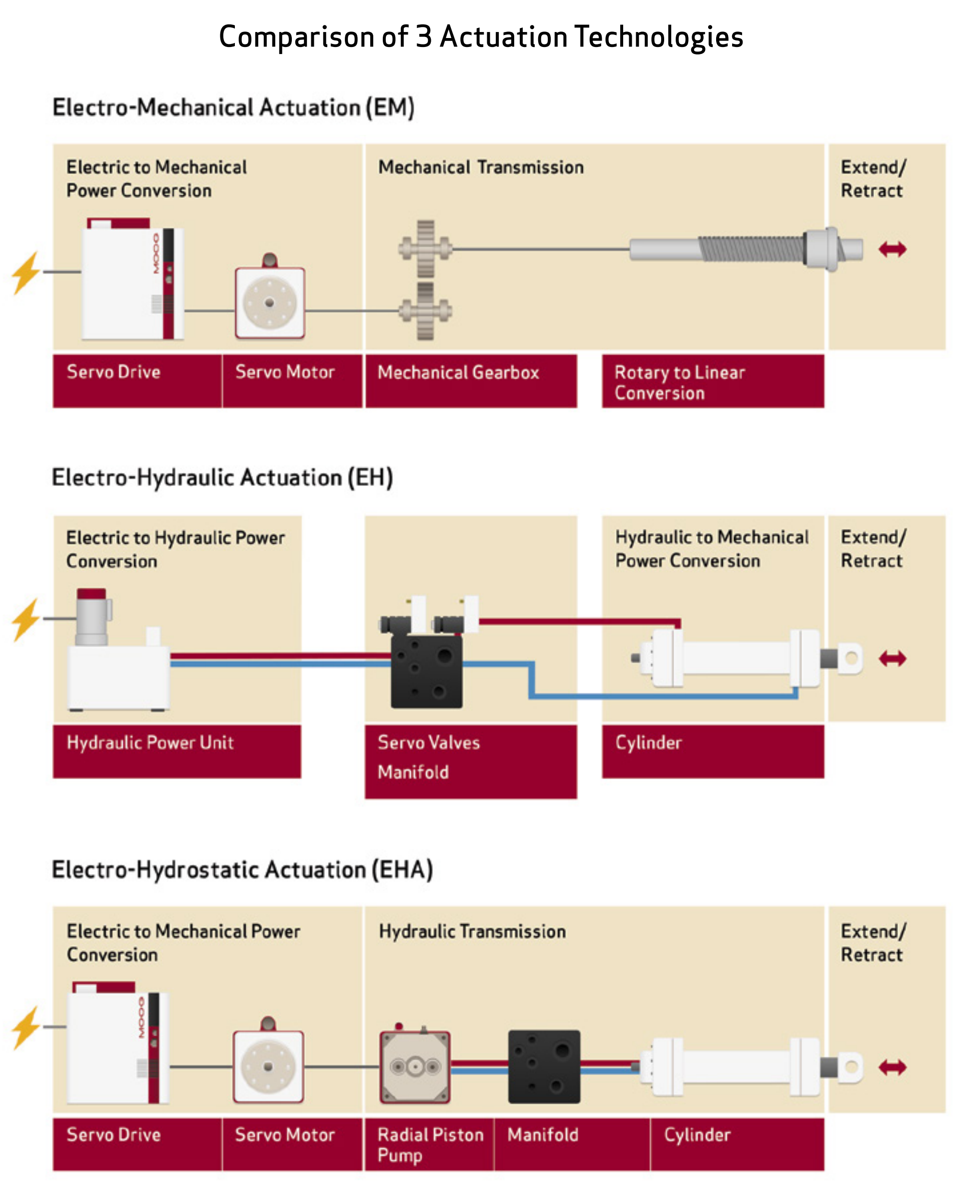
Leveraging a combination of engineering talent in hydraulics, electric servo drives and brushless servo motor design Moog formulated an EHA that is suitable for the industrial automation market requirements relative to pricing, environmental certification, and connectivity. The continual price decline in power electronics and servo motors has played a role in enabling the Moog engineering group to develop an EHA that is ideal for many industrial applications. EHAs are now at a price point where they are a competitive alternative to traditional hydraulic solutions. Factoring in the elimination of hydraulic plumbing, auxiliary pumps, servo valves, and the ongoing maintenance of filters and valves the EHA has a tremendous amount of appeal. The self-contained systems approach translates into much higher reliability as failure and maintenance associated with individual components of a traditional electro-hydraulic solutions are mitigated, if not eliminated altogether.

Reliability is not a given in all EHA systems as the integration challenges cross multiple engineering boundaries. Moog has accrued intellectual property, and extensive use of modeling tools that enable Moog to custom engineer power amplifier electronics and servo motor designs that meet unique environmental and form factor design goals specifically unique to an EHA. The packaging of a self-contained system depends upon custom engineered components that cannot be sourced off the shelf. Thus, the engineering design along with a rigorous testing and validation process that is prevalent in Moog have been key factors in the availability of EHAs for the industrial market *(See Figure 3)*.

2 The Benefits of EHA

Transition to EHA

Machine builders seeking to transition to all electric machine actuation solutions should evaluate EHA for a number of compelling reasons. For those motion control axes that require higher forces that are unattainable without resorting to large gearbox reductions with electro-mechanical solutions the EHA offers significant benefits. Furthermore, machine builders seeking designs that combine electro-mechanical (EM) actuation with hydraulic actuators will benefit from the all-electric interfaces *(See Figure 3)*.



Main Advantages and Disadvantages

	EM	EH	EHA
Energy Efficiency	✓	✗	✓
Environmental Cleanliness	✓	✗	✓
Low Noise Emission	✓	✗	✓
High Forces	✗	✓	✓
No Backlash	✗	✓	✓

Figure 3: General layout and benefits of actuation technologies.

Combining electro-mechanical and hydraulic actuation in industrial machines is now a viable option. A total cost of ownership analysis is often used to quantify both the initial savings and the ongoing benefits of an EHA in comparison to traditional hydraulics. The self-contained aspect of an EHA requires absolutely no hydraulic infrastructure to incorporate into a machine and allows machine designers to evaluate the merits of combining electric and hydraulic actuation technology without consideration of the fixed cost of the hydraulic system infrastructure.

EHA Provides Benefits of an Electro-Mechanical Solution

The trend in the industrial machinery market is a shift toward machine electrification for energy saving, lower cost of maintenance, and dynamic performance improvements. Electro-mechanical (EM) solutions cannot compete with the high forces available in hydraulic systems. To achieve the same forces it becomes impractical to use a servo motor combined with the addition of gearboxes and rotary to linear conversion. EHA, however, has a wider range of force available in a relatively compact form factor while also eliminating the need for mechanical gearing. The elimination of mechanical gearing is an important factor when considering the relative advantages of EHA over electro-mechanical solutions. The lack of ball screws or gearing is compelling to machine builders seeking to improve the simplicity in a machine design.

To an automation engineer, an EHA looks, acts, and performs like a servo motor based EM solution. There are many skills that are transferrable from EM solutions to EHA solutions from an integration perspective. An EHA is a closed loop servo system that requires the same mechatronic skills to size an actuator and tune the dynamic performance. The same tools used to determine loop gains and nonlinear compensation for electro-mechanical solutions are employed when integrating the EHA into a system. Furthermore, the control interfaces for EM and EHA are the same, particularly if the servo drives and EHA are sourced from Moog. The underlying digital servo drive technology used in the EHA is derived directly from the technology that is used in Moog's electric drives. Thus, digital interfaces such as EtherCat or alternatively a traditional analog command interface are available *(See Figures 4 and 5)*.

Maintenance Benefits/Plumbing and Hydraulic Infrastructure Eliminated

EHA solutions offer machine builders many of the benefits of EM solutions and are virtually equivalent from an integration perspective. However, when compared to traditional electro-hydraulic (EH) solutions EHA lowers the design costs of EH solutions by eliminating the design associated with routing hoses and couplings, allocating space for pumps and ensuring access to routine maintenance items such as filters, sensors and valves. Operational issues faced with the degradation and aging of oil in EH solutions are mitigated in the EHA. Filter changes in EHAs are generally two years or longer. The EHA filtering system is integrated while the oil is never exposed to the external environment which prevents many of the sources of oil contamination from bleeding or servo valve replacement, overheating and veneering associated with EH systems using external pumps. Overall, the benefits of an EHA are numerous spanning from initial design cost to annual maintenance costs.

3 EHA Application Suitability

Economic and Performance Assessment

To evaluate whether an EHA is suitable for a machine control application requires both an economic and performance assessment. As mentioned earlier, from a black box perspective an EHA functions equivalently to an EM solution. Thus, from the automation controller (PLC in most cases) perspective the interfaces are all identical where motion profiles are all planned through digital interfaces. With that in mind, there are two scenarios that characterize the ideal application for an EHA.

1. Electro-mechanical machine conversions that need the force capability or power density of hydraulics for a small number of axes.

2. All hydraulic machines that have only one or two axes of motion.

Machines that require a relatively small number of hydraulic axes are generally excellent candidates for EHA. This is simply an economic justification and doesn't factor in any of the dynamic performance issues which need to be evaluated.

Economic Analysis

From an economic perspective, there are several approaches which machine builders can use *(See Figure 3 on previous page)*. In applications with only two axes the obvious approach is to assess the differential cost of the hydraulic infrastructure which includes pumps, hoses, couplings and servo valves with the cost of an EHA. The higher price point of an EHA can be offset by the elimination of hydraulic infrastructure. However, if the inclusion of EHA proves to be more expensive an energy savings analysis is required to determine how long it takes for the solution to be price neutral. This is a break-even analysis where the duty cycle and utilization of the machine need to be estimated to determine the overall energy savings. In most cases where an energy savings analysis is applied the break-even point is about two years.

What are the Technical Parameters of the Application that Determine Suitability

A total cost of ownership analysis for an application certainly provides economic justification for the use of EHA. EHA solutions, however, do not span the entire power range of traditional EH solutions and also have limitations in dynamic performance that need to be evaluated. The upper range in flow and pressure, for Moog's line of self-contained EHA actuation systems is 450 l/min and 350 bar which is a clear demarcation point when evaluating a solution. However, the natural frequency response will vary depending upon the specific product line as the frequency response of an EHA is limited by the inertia of the internal variable speed

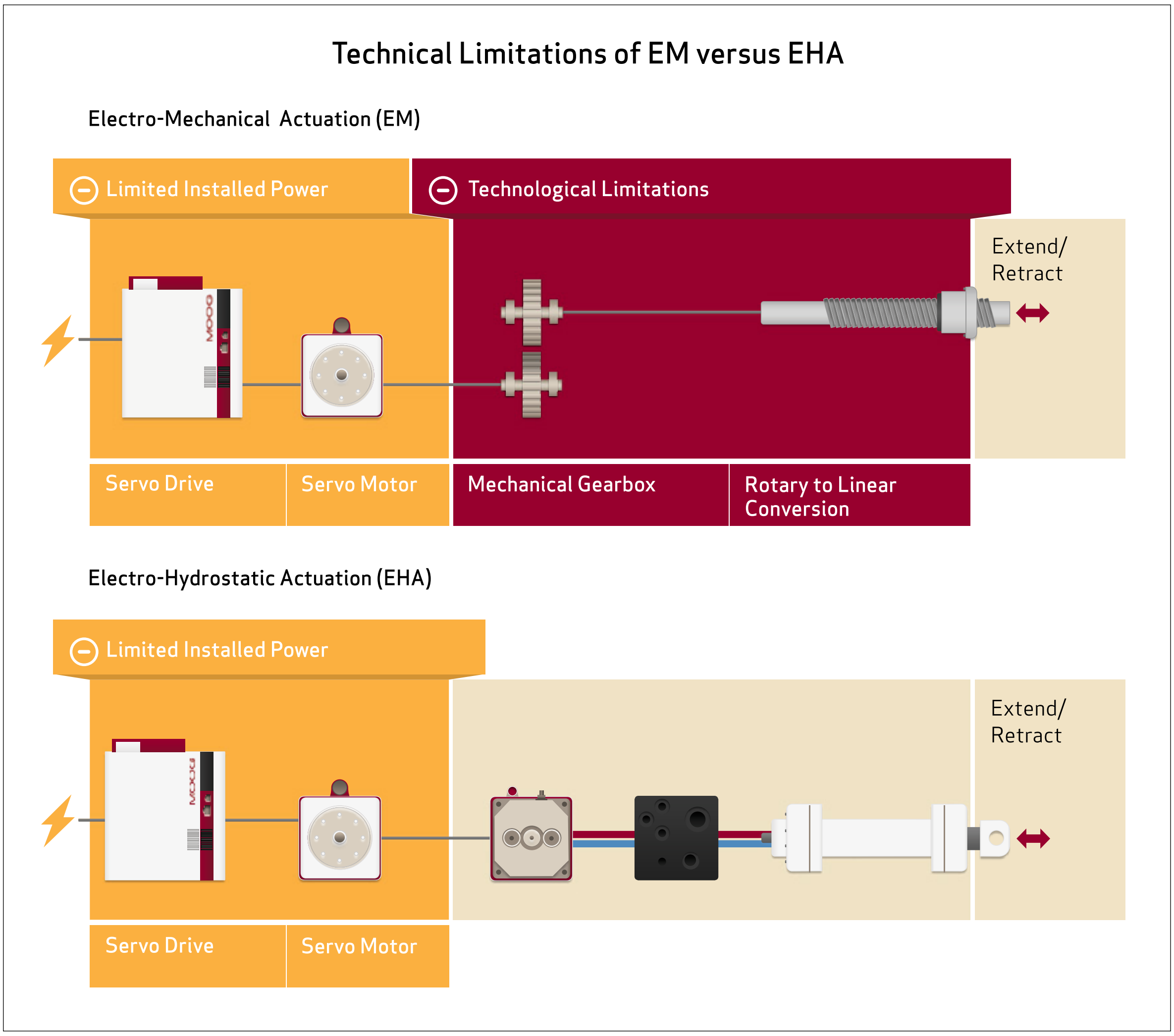


Figure 4: Limitation factor of EM and EHA technologies.

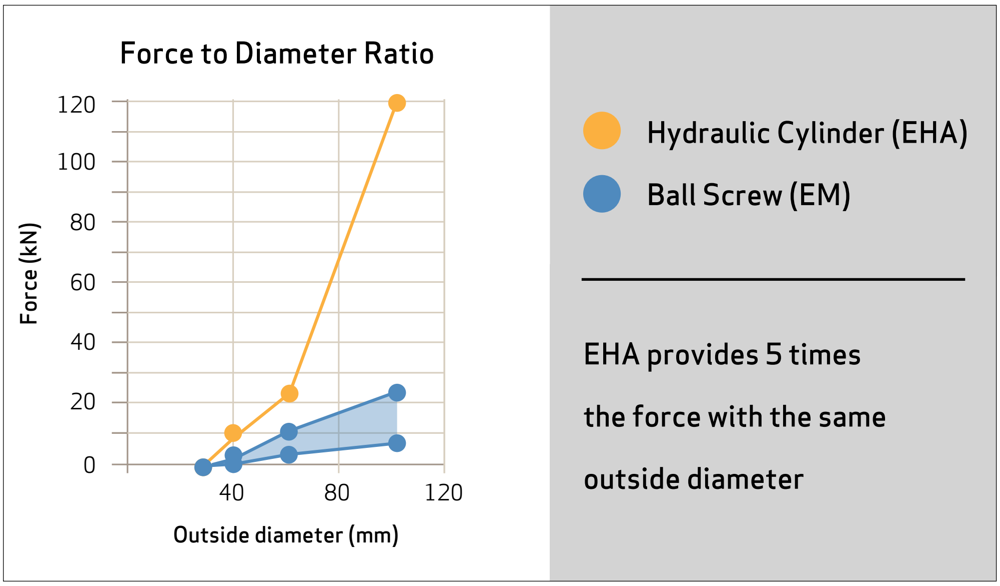


Figure 5: Force availability versus form factor.

pump motor. High accelerations can develop cavitation in the suction portion of the pump. Depending upon the characteristics of the pump and motor, the natural frequency of an EHA will be in the range of 30 to 50 Hz. For many industrial applications this is sufficient.

An example of a viable application is an injection molding machine. The clamp cylinder plus mold is typically designed to have a frequency response in the range of 5 to 10 Hz on the position loop. A servo motor/pump unit with at least 3 times higher frequency response (15 to 30 Hz) would be required in this application which can be easily accommodated by available EHA solutions *(See Figure 3)*.

4 Research Project to Improve the Energy Efficiency of Deep Drawing Presses

Moog worked with Dresden University to incorporate the EHA on a Die Cushion Press so it could be objectively compared to a traditional servo control system using servo valves *(See Figure 6)*. Die cushion presses normally have a capacity of 24 to 4,000 tons and perform a wide range of stamping operations in automotive plants including handling new materials and complex shapes such as external and internal body panels for doors, fenders, roofs and hoods. The challenge in the test performed by the professors and students at Dresden University in conjunction with Moog was to ensure the EHA could deliver the dynamics needed, but also provide higher energy efficiency than can be achieved with traditional servo-hydraulic systems.

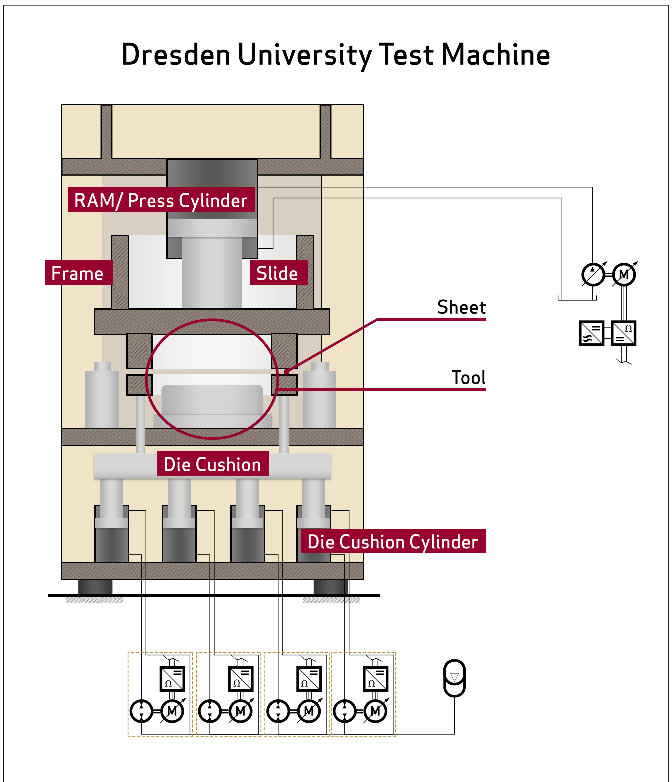


Figure 6: Deep drawing press layout using EHA for die cushion.

The conventional system was a hydraulic press machine and the architecture for the die cushion actuation was four separate cylinders, each controlled via servo valves. All of these four axes were supplied by a variable displacement pump. Next an EHA System was installed for each cylinder in the die cushion including a servo electric motor connected with a radial piston pump. All of the four axes were connected with an accumulator to support the low pressure level. During the deep drawing process the servo motor/pump unit was acting in generator mode. Via the servo drive, it was possible to feed back the recovered energy from the die cushion to the ram actuator.

According to Professor Weber at Dresden University, energy savings during a complete machine cycle of approximately 30% could be achieved during tests while maintaining comparable dynamics and pressure control functionality. A 30% energy efficiency experienced by the EHA solution is a dramatic improvement especially when you consider the large amount of energy used by these kinds of machines in a single year. A future advantage is the substantial reduction or even substitution of oil cooling due to elimination of throttle losses. This test suggests EHA technology is a viable alternative motion control system from a performance standpoint with the advantage of impressive energy efficiency *(See Figure 7)*.

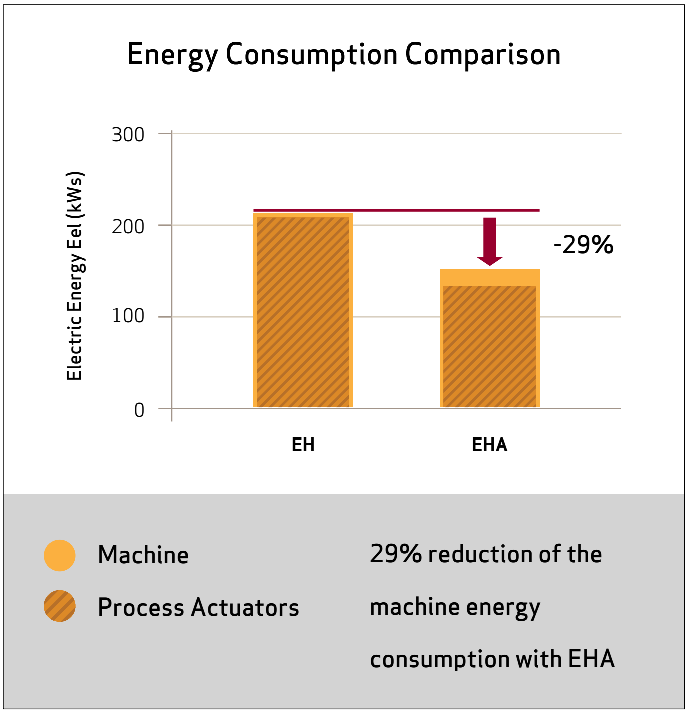


Figure 7: Energy efficiency of the test machine equipped with EHA.

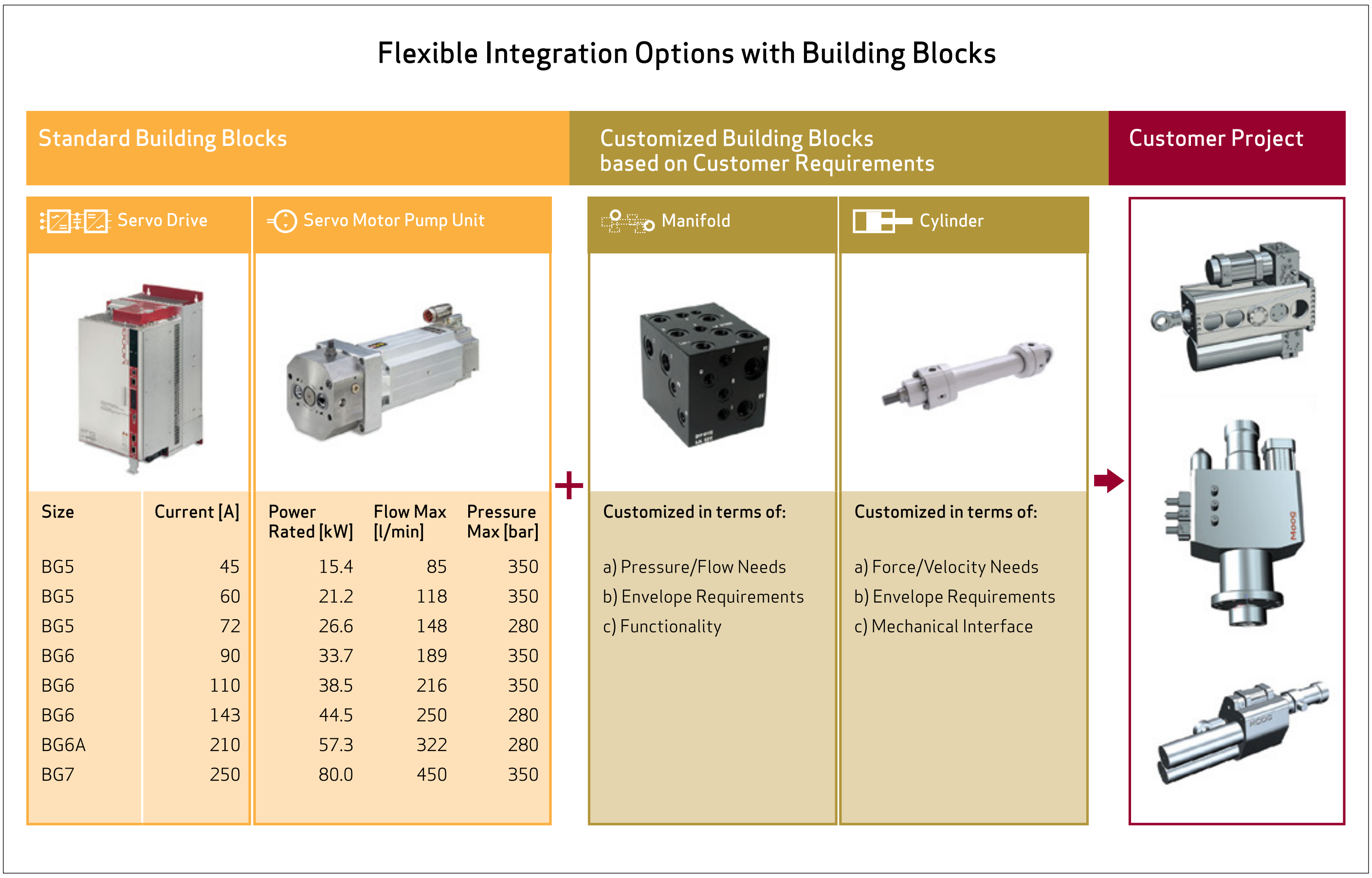
Another benefit of EHA technology is that it allows a machine builder to individualize the functionality of a machine, a process, or a movement, which is a step forward for both the hydraulic or electro-mechanical architectures. Conventional systems have a large hydraulic power supply and servo valves controlling axis movements or functions which inherently have a lot of energy losses. With the EHA these losses are eliminated by individualized axis architecture where you have an electric interface providing (via the electric servomotor pump combination) only the power you need hydraulically for specific functions and movements.

Professor Weber indicated that it is important for more industries to consider EHA as a viable, energy-efficient alternative to traditional hydraulic and electric solutions. In the future we may want to also investigate if we can improve the specification of the hydrostatic unit especially areas such as the volumetric losses for the pulsation of flow and pressure. Taking into account the pump characteristics during servo motor design may lead to increased performance. The thermal stability and the reliability are future points to investigate.

5 Conclusion

To make the EHA system accessible to more applications, Moog is adopting a modular approach combining standard building blocks such as servo drives and a servo motor/pump combination in typical sizes with a manifold and cylinder that will be customized to the exact needs of the application. This will improve the time to market for machine builders to incorporate this technology in new generation machines *(See Figure 8)*.

Using EHA technology leads to a substantial energy savings via power on demand while the dynamic performance is equal to conventional EH or EM systems. Such a self-contained axis leads to a decentralized machine axis design which allows an optimized axis performance. Moreover, it is environmentally friendly and easy to install. The interfaces are identical to today's EM solutions, the functionality is much more flexible and the achievable forces are far greater. To that end, the EHA will be functionally the same as the electro-mechanical systems that automation engineers have become familiar with over the years and the performance will be superior in many respects. This will be an enabler for machine builders to choose the right technology for the applications without incurring integration hurdles.



Size	Current [A]	Power Rated [kW]	Flow Max [l/min]	Pressure Max [bar]
BG5	45	15.4	85	350
BG5	60	21.2	118	350
BG5	72	26.6	148	280
BG6	90	33.7	189	350
BG6	110	38.5	216	350
BG6	143	44.5	250	280
BG6A	210	57.3	322	280
BG7	250	80.0	450	350

Figure 8: Moog offers a wide range of standard building block products that can be combined with other customized products to deliver electro-hydrostatic actuation solutions that fit the customer's needs.

6 Information

Moog brings years of expertise to maximize machine productivity and ensure higher performance in motion control applications. Our global team of engineers is always available to collaborate with you on designing a motion control solution that will meet your requirements.

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OR CONTACT:
Dr.-Ing. Achim Helbig
Innovation Projects Manager
Phone: +49 7031 622307
ahelbig@moog.com

For your nearest Moog location, visit
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7 Resources

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Author Biography

Achim Helbig has been with Moog since 2004 in the |position of Senior Applications Engineer, Team Manager Hydraulic Systems and Innovation Projects Manager. Prior to joining Moog, he worked at Dresden University and completed his Ph.D.

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