GENERAL LECTURE:

**ELECTROHYDROSTATIC ACTUATION SYSTEM –
AN (ALMOST) COMPLETE SYSTEM VIEW**

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*Moog GmbH, Hanns-Klemm-Straße 28, 71034 Böblingen*Email: dbecher@moog.com**ABSTRACT**

Electro-hydrostatic Actuation Systems (EAS) successfully combine the advantages of electro-mechanical actuation - such as high-energy efficiency and low noise emission - with the benefits of electro-hydraulic technology –which include robustness and the precise handling of large forces. This paper defines keywords like EAS and Electro-hydraulic pump unit (EPU), and provides a comparison of the two technologies. Given the wide range of EAS technology topics, it is only possible to briefly introduce and discuss these in this paper. This technology has reached a level that renders it a strong mechanism for machine manufacturers to support existing and future motion control requirements.

Keywords: Electrohydrostatic Actuation System (EAS), Electrohydrostatic Pump Unit (EPU), Motion Control, Digitalization, Energy Management, Condition Monitoring

**1. DEFINITION AND TECHNOLOGY
COMPARISON**

What exactly is an Electrohydrostatic Actuation System? **Figure 1** shows the principle means of controlling flow in a hydraulic application. A common approach is to use a variable displacement pump to operate it, with constant rotational speed. The displacement of this pump is varied in order to meet the flow and/or pressure requirements of the application. This approach works successfully, but generates losses and high noise levels when in part load or idle condition. Over the last decade, there has been a growing trend toward speed controlled pumps where largely, but not exclusively, a fixed displacement pump is used. Flow control is performed by a speed variable electrical motor. The advantages of such a concept are lower losses and sound emission, especially in part load and under idle condition. As the number of controlled cylinders is typically greater than one, both systems require additional proportional or servo valves to control the movement of the cylinder. The speed variable pump (SCP) system still requires a relatively large tank to provide the appropriate flow for all machine axes.

An EAS is a system combining at least one fixed or variable displacement machine, driven by a speed controlled electrical motor controlling the movement of a cylinder in both directions, without the need for any additional control valve. Both ports of the hydrostatic machine are directly connected to the ports of the cylinder.

Figure 1: Adaption of flow by pump control

Among the many, main advantages of the EAS are:

- High energy efficiency;

- A small footprint and greater environmental cleanliness (low amount of hydraulic fluid, no or a small reservoir and less tubing);
- Low sound emission (sound only occurs under operation);
- High forces, robustness, simple overload protection as general features of hydraulics;
- Decentralized drive and control architecture;
- Easy installation and commissioning;
- Seamless integration in motion control systems with a mix of different technologies.

The EAS is a technology that will not replace existing drive and control technologies completely, but provides machine builders with an attractive, additional option that can realize a certain movement task.

Figure 2: Self-contained axis, balanced cylinder

Figure 2 shows an EAS as a self-contained design that makes use of a balanced hydraulic cylinder. The fluid volume in this case is always constant – and independent of the stroke of the cylinder. This requires only a small sized low-pressure reservoir.

The most common actuator in hydraulics is the unbalanced cylinder, as shown in **Figure 3**. The size of the low-pressure reservoir should be larger compared to a system with a balanced cylinder. Besides the function to pre-pressurize the system, the accumulator should also provide the volume difference of the unbalanced cylinder.

A brief comparison of different drive and control technologies is shown in **Figure 4**.

In electro-hydraulic actuation (EH) a hydraulic power unit (HPU) consists of a reservoir, a flow variable pump (variable displacement and/or speed variable) and auxiliary devices for filtering and cooling the fluid. The actuator's motion control is performed by means of a proportional or servo valve. The controllability and the dynamics of such an axis are outstanding. The critical points are the losses of energy due to throttle losses, the large hydraulic footprint mainly by the HPU and - if not speed controlled – the permanent noise level of the motor/pump unit.

Figure 3: Self-contained axis, unbalanced cylinder

In electro-mechanical actuation (EM), electric energy is transformed to a speed variable electrical motor that transforms its rotation, via an optional gearbox and a rotary to linear conversion (i.e. ball screw) into a linear movement. This technology delivers energy efficiency, a small footprint and low noise that only occurs if the axis is under operation. High forces are not the primary domain of EM.

The EAS combines all the benefits of both EH and EM technology. A hydraulic displacement machine can be coupled to a speed variable electrical motor, and the flow at the pump outlet directly drives and controls the movement of the attached cylinder. Robustness, long endurance and the capability to handle large forces and loads, are without doubt the DNA of the hydraulic part of such a system. Energy

efficiency and a generally smaller footprint are the key strengths that EM adds to this solution.

Figure 4: EH, EM, EAS - technology

2. DEMANDS ON THE EAS

2.1. Electrohydrostatic Pump Unit (EPU)

The EPU forms the central element of an EAS. It consists of a combination of electrical motor and hydrostatic machine, either with direct coupling or with a more traditional system with bell housing and coupling between both elements. The requirements on a speed controlled electrical motor are not special: it has to generate a certain rotational speed in combination with the torque needed, controlled by a drive. Continuous torque, maximum torque and field weakening of the motor over the rotational speed, should be designed to fit the behaviour of the hydrostatic machine and the application.

Industrial pumps are operated at constant speed, and mainly optimized for pump or motor operation. EAS requirements are different: As the cylinder speed is proportional to the rotational speed of the pump, a low cylinder speed requires low rotational speed and vice versa. Load holding requires high pump pressure with almost zero speed. To move the cylinder in and out, the hydraulic machine must be able to operate in both directions of any rotation. A pushing load requires pump operation, whereas a pulling load uses hydraulic motor operation.

Figure 5: 4Q requirements for an EAS

Depending on the application, the hydrostatic machine should be able to operate in all 4 Quadrants. To reach a high dynamic, it is preferable to remove bell housing and coupling, and to connect motor and pump in a more direct way. In general, this also leads to a more compact design. An example of such an integration is shown in Figure 6.

Figure 6: Moog EPU [8]

The Electrohydrostatic Pump Unit (EPU) is very compact. It also features a single hydraulic interface: all hydraulic ports are located in a single plane. By connecting the EPU to the manifold by 8 screws, the hydraulic connection is done in parallel.

2.2. EAS Architecture - circuits

Even though the task for an EAS seems to be clear and simple – to move a cylinder directly out of the pump in both directions – there are a couple of options that can optimize the EAS to meet the requirements of a specific application (Fig.7).

Figure 7: EAS Design options (incomplete)

The easiest option for the actuator is a balanced cylinder. In this case, the flow to and from both piston chambers is equal, and therefore so is the flow at both pump ports. A situation where the flow in and out of the pump is equal can be achieved by a single balanced cylinder, or by the combination and linking of two or three unbalanced cylinders. An example of an integrated EAS consisting of three unbalanced cylinders to create a balanced cylinder is shown in Figure 8.

Figure 8: EAS with 3 cylinders by Bucher Hydraulics

The most common option for cylinders however, is the unbalanced one. As the flows on both chambers are different, this option needs additional valves and an accumulator to handle the flow difference. A basic circuit to handle the different flows of pump and cylinder is shown in Figure 3. An adaption of different flows on both ports of the cylinder can also be achieved by

using two pump stages of different sizes. In such cases, the displacement ratio of both units should be adapted to the area ratio of the cylinder. Such a solution, which combines an integrated design with a two-pump stage solution, is shown in Figure 9.

Figure 9: CLDP by Voith [7]

In general, an EAS consists of the following parts:

- A hydrostatic machine to generate a fluid flow;
- A motor as electromechanical transformer;
- A manifold for circuit structure and auxiliary functionality (pressure relief, rapid motion/force motion switching);
- An actuator (balanced/unbalanced cylinder).

The number of components can be assembled as a motion system in various ways (Fig. 10). An integrated design is the best option wherever a solution needs to be fitted in a well-defined, small envelope on an application. The compact approach makes use of more or less standard, off the shelf components, and combines them in a way that achieves a compact solution with a lower requirement for external tubing or housing. The distributed approach allows the largest degree of freedom for an integration in a machine structure and may be the best approach for a retrofit in existing applications.

Figure 10: Integrated, compact, distributed design [9]

Many stationary hydraulic applications are featured by a movement consisting of a phase with high velocity/flow and low force/pressure

(rapid motion), and a phase with low velocity/flow and high force/pressure (force motion), for instance on metal forming and pressing applications. For such applications, it makes sense to adapt the power train components during the cycle of the machine. The main goal is to reduce the size of electrical motor and drive. The EAS offers this flexibility by way of a gearbox, which can be actuator based or pump-operated or a combination of both.

Figure 11 shows an example of an actuator-based gearbox. An actuator-based gearbox in this context means that switching between rapid and force motion is done via the interconnection of (generally) cylinders in the application. In Fig. 11, the unbalanced cylinder on the right side acts as a reservoir for the flow difference of the main (unbalanced) cylinder on the left. The upper picture represents the force movement, while the lower picture demonstrates rapid movement. Switching between both movements is performed by means of two simple switching valves.

A pump-based gearbox necessitates use of a variable displacement machine, or at least two machines with different displacements.

Figure 11: Actuator based gearbox [16]

A simple approach is the utilization of a variable displacement machine and to switch between maximum and a minimum displacement (dual displacement). With a given motor/drive, it is

now possible to achieve a force movement with maximum force, or alternatively it is possible to reduce the motor/drive size combination by at least one size. A proportional displacement machine offers the maximum degree of freedom. In such cases, the full horse- power capability, as a product of pressure and flow, can be used to apply a maximum force/velocity ratio on the machine axis.

Drive Concept	Feature
Fixed Displacement 	<ul style="list-style-type: none"> Fixed Displacement Machine Displacement adjustable
Dual Displacement 	<ul style="list-style-type: none"> Variable Displacement Machine Two Displacements adjustable Switch between V_{max} and V_{min} by switching valve
Proport. Displacement 	<ul style="list-style-type: none"> Variable Displacement Machine Proportional adjustment of displacement Control of displacement via prop. valve

Drive Concept	Hydraulic Drive	Application
Fixed Displacement 		<ul style="list-style-type: none"> Relatively constant force demand Variable actuator speed → i.e. simulation platform, deep-drawing cushions, test systems
Dual Displacement 		<ul style="list-style-type: none"> Applications with distinctive rapid and force movement → i.e. small and medium size presses
Proport. Displacement 		<ul style="list-style-type: none"> Applications with distinctive rapid and force movement Maximum utilization of drive power → i.e. medium and large size presses

Figure 12: Pump based gearbox

Another advantage of the proportional adjustment is the proportional behaviour between the transitions of both movements. In the case of dual displacement and actuator-based gearboxes, the transition is undertaken by switching elements, which also leads to unsteady control behaviour. To reach maximum dynamics with switching gearboxes, an appropriate switching strategy needs to be applied [12].

2.3. Motion Control

An EAS is a controlled system/axis. The hydraulic machine is driven by a speed controlled electrical motor. The flow at the outlet of the hydrostatic machine is – at constant displacement - almost linear to the rotational speed. The slight nonlinearity is the result of the leakage of the hydrostatic machine, which increases more or less in line with pressure. The steady state characteristic diagram in **Fig. 13** shows this

behaviour for an EAS, with an unbalanced cylinder for all 4 quadrants. This is different to a valve driven axis with a strong nonlinear, root-shaped correlation (**Figure 14**) and makes the controller design somewhat simpler.

Figure 13: Steady state characteristic of EAS

Figure 14: Steady state characteristic of valve axis [13]

The cylinder as hydraulic actuator is either position, flow/speed or pressure/force controlled or a combination of these. For this reason, an EAS consists of at least one position/speed sensor to measure the position and/or speed of the cylinder, two pressure sensors to determine the pressure in each piston chamber and a speed sensor in the motor to measure the rotational speed of the motor/pump combination.

A simple controller structure for a position controlled EAS is shown in **Figure 15**, which is in comparison to a valve driven cylinder. The inner control loop for the EAS is the current controller. Overlaid to the current controller is the speed controller of the motor, which controls the rotational speed at the shaft of the motor. Overlaid to the speed controller is the position controller of the cylinder. This controller receives the position signal from the sensor integrated in

the cylinder. The controller structure of a valve-controlled axis looks similar: the inner control loop is again a current controller, which in this case controls the current of the valve motor - in most cases a proportional solenoid or linear force motor. The current leads to a linear movement of the armature, which is connected to the spool. The motor/spool position is measured by an LVDT, and this signal is used to close the control loop of the spool position. On proportional/servo valves with integrated on-board electronics, both control loops are closed inside the valve electronics. Depending on the spool position and the difference in pressure over the valve ports, a flow streams to the cylinder and leads to a movement of the cylinder. The position signal is again used to close the cylinder position controller. The cylinder position controller is normally closed in the machine PLC. On the other hand, there are so-called axis control valves (ACV) available, which can close the external control loop inside the valve electronics.

Figure 15: Simple valve axis and EAS control loop

The general electric infrastructure of an EAS offers the opportunity to operate different controllers on different hardware platforms. The drive itself is predetermined for the internal current control and the speed control and torque limitation of the motor. Beside this basic functionality, it is also possible to integrate a basic control loop for alternating position and force in the drive. Demand values for position, speed and force are generated by the PLC (**Figure 16**).

Moog Motion Controller Customer PLC i.e. TwinCAT, S7	Moog Servo Drive	Moog EPU

Demand Value <ul style="list-style-type: none"> Position Speed Force 	Speed control Speed Limitation Torque Control Torque Limitation	
	Simple Position Control Force Control Alternating Position/Force	

Figure 16: Simple EAS control via drive.

As the drive is limited in memory and operating power, it makes sense to use a different hardware platform if seeking to achieve more sophisticated control demands. Additional functionality for the EAS could come in the form of pressure ripple compensation, fine positioning or an enhanced control loop for the axis (**Figure 17**). In cases where a synchronisation of multiple machine axes is necessary, it is more advantageous to realize this motion control on a separate hardware platform.

Moog Motion Controller Customer PLC i.e. TwinCAT, S7	Moog Servo Drive or Customer Servo Drive	Moog EPU

Position Control Force Control Alternating Position/Force Additional/hydraulic specific functionality <ul style="list-style-type: none"> Pressure Ripple Compensation Fine Positioning Accel./load pressure feedback Multi Axis Control 	Speed control Speed Limitation Torque Control Torque Limitation	

Figure 17: Enhanced EAS control

Figure 18 shows how axis control functionality for a single EAS can be achieved. The EAS in this example uses the “motion block controller (Fahrsatzregler)” functionality, which is included in the drive. With this function, it is possible to create a motion profile, which consists of a limited number of motion tasks for a single axis on a machine. Each motion block defines a motion task (for instance, moving from A to B with speed v). After the motion task is completed successfully, the PLC/drive moves onto the next motion tasks in the series. Ultimately, once the blocks of a cycle are complete, the PLC/drive starts a new cycle.

Figure 18: Motion block functionality [7]

2.4. Energy Management

The need to reduce overall energy consumption and the infeed power of machines is an ongoing concern for machine manufacturers. The use of the EAS on applications such as metal forming and pressing machines addresses this demand. On the one hand, an EAS is a ‘power on demand’ system that only consumes energy if it is operated. On the other hand, the machine’s integration in the power bus or shop floor is possible via an electrical motor and drive, and offers enhanced opportunities for energy management. An example of such an integration is shown in **Figure 19**. The die cushion is realized as an EAS. During the deep drawing process, the hydrostatic machine in the EAS works as a hydraulic motor. The hydraulic motor drives the electrical motor, which in this case functions as an electrical generator. Over the DC bus between the die cushion drives and the press cylinder, electrical energy generated by the die cushion axis is used to support the press cylinder axis. This relatively simple approach offers a potential energy reduction of up to 40% on press/die cushion machinery.

An advanced approach for the energy management of presses is described and discussed in [6]. The energy management scenarios described in this paper can be used for machines and applications where all axes are EAS, in machines with a mix between EAS and EMS (electromechanical system) or purely EMS driven machines. In order to classify how advanced any given energy management approach is, the author defines five levels of sophistication (SL):

- A common non-active front end supplies all axes. The axes exchange power over the DC bus. When the total regenerative-

power is too high, it is dissipated over a bleed resistor.

- An active front-end powers all axes, and feeds back current into the grid if power is regenerative. Axes exchange power over the DC bus. Infeed needs to cover the peak power requirement of all axes at all times.
- Infeed charges the passive capacitor storage, and both power all axes. Regenerative power is stored in the DC bus. Infeed can be significantly downsized give that peak power is provided by the capacitors.
- Controllable storage, such as active capacitor units or servo flywheels, are additionally coupled onto the DC bus. A model-based algorithm on a controller generates command values for the infeed and the storages.
- As above, but the model adapts/learns on a cyclical basis, and changes the available control outputs according to optimization criteria.

Figure 19: Press with energy management [5]

The five concepts highlighted above belong to SL1, SL2 and SL3. Beginning with a system that shares only the energy over the DC Bus (which already has the potential to save approximately 40% of all energy compared to a traditional hydraulic system), further investment in system hardware can further reduce machine energy losses in a range of additional 40-50%. Moreover, for the solutions with energy storage, the installed power could be reduced to less than 20 % of the peak power requirement of the axes. Consequently the inline elements of the infeed become much smaller and cost effective.

In components terms, the distribution of losses in almost each scenario is roughly 1/3 for pumps, 1/3 for drives and 1/3 for motors, infeed and

capacitors. Each component offers the potential for further energy reduction.

Figure 20: Description of sophistication levels

2.5. Digitalization, IoT, I40

Communication

Communication between the EAS and the PLC is provided by the drive. These components normally consist of a broad variety of digital fieldbus interfaces that offer a seamless integration with modern machine structures. Standard fieldbus interfaces such as EtherCAT, ProfiNET, Powerlink or OPC UA TSN based communication, are normally standard options.

Condition Monitoring/Predictive Maintenance

On components or at axis level - like EPU and EAS - CM and PrM becomes especially important, as they mainly influence machine performance. However, what should be monitored, and what could happen?

One answer to this question is shown in **Figure 21**. It is an approach based on two steps: First, it is necessary to collect data from an existing application/machine. For data collection, existing machine sensors can always be combined with additional sensors (e.g. vibration sensors). All data should be transferred within a cloud environment where the predictive analytics software is running. For this purpose, the installation of an IoT Gateway is necessary. The IoT gateway itself connects the machine sensors to the cloud, and transforms the data to a cloud compatible format (i.e. MQTT). In the first learning phase, the data is used to teach in a

neural network based machine model. This model describes the behaviour of the new machine. After the teaching phase, the data are used to identify anomalies that may occur while operating the machines. Any anomalies should be evaluated by an expert, who subsequently recommends any further necessary steps to the customer. This could take the form of a maintenance recommendation enabling the maintenance of the machine or/and the substitution of machine components. The service includes analytics via the ODin platform, operation of the user interface (account), monitoring, reporting, consulting and recommendations.

Figure 21: CM/PrM on system level [10]

Another approach is more focussed on single components that are part of the axis (**Fig. 22**). The hydrostatic machine is one of the most loaded parts of the EAS. High loads on tribological contacts may lead to wear over time. There are a number of approaches for dealing with this, but chiefly sensors (vibration, temperature, pressure) should be added on or near the pump.

The approach described here uses the existing sensors in an EAS. The main task of a pump is to deliver a certain flow proportional to displacement and rotational speed. However, the flow at the pump outlet – and therefore the leakage – is also influenced by the operating pressures at both ports. The fluid viscosity is a function of the fluid used, and of the temperature of the fluid.

To describe and calculate the flow at the hydrostatic machine outlet depending on these parameters (p_A , p_B , V_1 , n_1 , v), an appropriate pump/flow model is necessary. The model itself can be based either on a physical model, or a collection of equations parametrized by measurement data. Alternatively, it can be based on a neural network, which is also trained by measurement data. The main goal of the model adopted is to reach a good approximation of the

real behaviour of the hydrostatic machine, and the ability to integrate the software based algorithm on an appropriate hardware platform.

Figure 22: CM on Component Level

On the other hand, a sensor is required to measure real flow at the pump outlet. The cylinder can act as a sensor for flow: the dimensions are well known, and the position or the velocity respectively are accessible via the cylinder position/velocity sensor.

With this information, a health index acts as a ratio between delivered (measured) flow and a theoretical flow for a brand new pump, and allows the operating parameters to be derived. This value demonstrates the flow that should be delivered by the pump (out of the model), and the flow that moves the cylinder. Unfortunately, leakage does not only occur in the pump but also in the manifold, over the valves or between the chambers of the cylinder. In any case, this approach gives at least a value for the flow performance of the whole EAS. To detect the hydrostatic machine's wear a second value should be considered. As the first health index describes the volumetric efficiency of the pump (EAS), a second value considers the hydraulic/mechanical efficiency of the pump. The basis again is a model describing the torque needed on the shaft of the hydrostatic machine depending on the operating parameters. As is the case with the volumetric health index, the torque

mainly depends on the system pressures, machine displacement, speed and viscosity (p_A , p_B , V_I , n_I , v). During phases of acceleration and deceleration that torque also has to be taken into consideration. The inertia of the system (motor, hydrostatic machine) can be derived from design parameters, or by performing an appropriate test cycle on the axis.

In general, the determination of a health index does not have to occur in real time at a high sampling frequency. It is sufficient to start the algorithm for a longer period (once per hour/day/week). This provides the opportunity to place the necessary data collection in a part of the cycle where the quality of the measurement is high (i.e. constant velocity, constant load).

The implementation of such an algorithm can be realized on different hardware platforms. As the memory requirements and computing power of such an approach is less, it can run on the axis' drive, the machine PLC or it can be implemented in a cloud environment. In addition, the algorithm can also be implemented later on a constantly operational machine: as the models calculate the behaviour of a new hydrostatic machine and compare it to the actual state, they will always give a correct value for the health indexes even if installed in an already functioning machine.

Moreover, an additional expert, who analyses the CM data permanently, is not necessary: if a certain value for the health indices is fallen below a defined limit, this generates a clear signal to take action accordingly.

Tools

To fit an EAS to a certain application it needs to size the electrical and hydraulic components like hydrostatic machine, electrical motor and drive, and in case of multiple axes to consider the interaction between. **Figure 23** shows an example of such a sizing tool. Basis in this example is a commercial sizing tool (ServoSoft) which is developed for electrical drive technology originally (drives, electrical motors). The tool is enhanced by the characteristic of hydrostatic machines (size, speed and pressure range, efficiency characteristics). The sequence on the hydraulic output (flow, pressure) over the cycle forms the input parameters to size the hydrostatic machine, electrical motor and drive. A library of existing products supports to find the proper components.

Figure 23: CM on Component Level [17]

3. APPLICATIONS

A look at the application use of the EPU/EAS shows that this technology is currently used solely in the industrial sector.

Figure 24 shows a structure durability test rig equipped with Voith's CLDP (closed loop differential pump) described above. The purpose of the machine is to perform structural tests of motor vehicle springs and stabilizers. The CLDP achieves a maximum stroke of 600 mm, and can apply a load of up to 60 kN. In comparison to a traditional hydraulic axis, this technology offers energy savings of up to 70%. Energy stored in the compression of the spring can be generated back into the electrical bus/grid for use on a parallel machine working in opposite movement.

Figure 24: Test Application [11]

A similar application is shown in **Figure 25**. An EPU powered by the Moog EAS is used for the structural testing of truck axes. The EAS acts as a self-contained axis with an unbalanced cylinder. The test frequency is up to 3 Hz at a stroke of 50 mm. Other test machines have been running with up to 10 Hz.

Figure 25: Test Application with MoogEPU/EAS

Figure 26 shows a calibration press equipped with a Bosch-Rexroth self-contained SHA axis. The hydrostatic machine works with an operating pressure of up to 315 bar. It reaches a precision in position control of 1 μm . The machine itself needs up to 60% less energy, and emits less noise.

Figure 26: Axial Press [15]

A last example (**Figure 27**) shows the scalability of the EPU/EAS technology. It shows a pre-press that calibrates parts which are formed to large rings in a next step. The pre-press is equipped with 14 Moog EPU250s, achieving a maximum flow in the range of 6.000 l/min. The maximum force of the cylinder is 63.000 kN. For such an application, an open preload system is the better solution. It offers a better way to deal with fluid maintenance, such as cooling and filtering.

Figure 27: Hydraulic Press [14]

4. CONCLUSION AND OUTLOOK

EPU/EAS technology is an enhancement of drive and control technology, and combines the advantages of electro-mechanical and electro-hydrostatic actuation. It gives machine builders an attractive additional option in achieving a certain movement task. Scalability in terms of architecture and size offers a motion control solution for a broad number of markets and applications.

Certainly, there is room for optimization across all the fields outlined in this paper.

Potentially, the next step in the development of hydrostatic machines could be an increase of rotational speed as they enhance the power range of an EPU fitted with speed controlled electrical motors. In addition, it is not a mistake to keep an eye on the reduction of losses on the hydraulic side in general.

However, there is also further potential in reducing the overall energy consumption and infeed power of machines that are running as part of a network of other machines.

All in all the rapid growing number of applications show that this technology is accepted, and will play a more important role in the future.

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