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FUNDAMENTALS OF FLUID POWER

PNEUMATICS • HYDRAULICS • MECHATRONICS

UNDERSTANDING FLUID POWER SYSTEMS

Sara Jensen,
Technical Editor,
Power & Motion

IN THIS UPDATE TO OUR *Fundamentals of Fluid Power* ebook, we've brought together some of the key principles, technologies and design techniques for creating modern fluid power systems.

Within this ebook you'll find guidance on how to select between using hydraulics and pneumatics, the basics of air compressors, how to reduce noise in a hydraulic system and more. We have also included information on mechatronic systems given the role fluid power components can play in these solutions as well as the opportunities in bringing together mechanical and electronic principles.

Fluid power systems will remain integral to many applications, necessitating a proper understanding of how and when to utilize them to ensure development of optimal motion control solutions.

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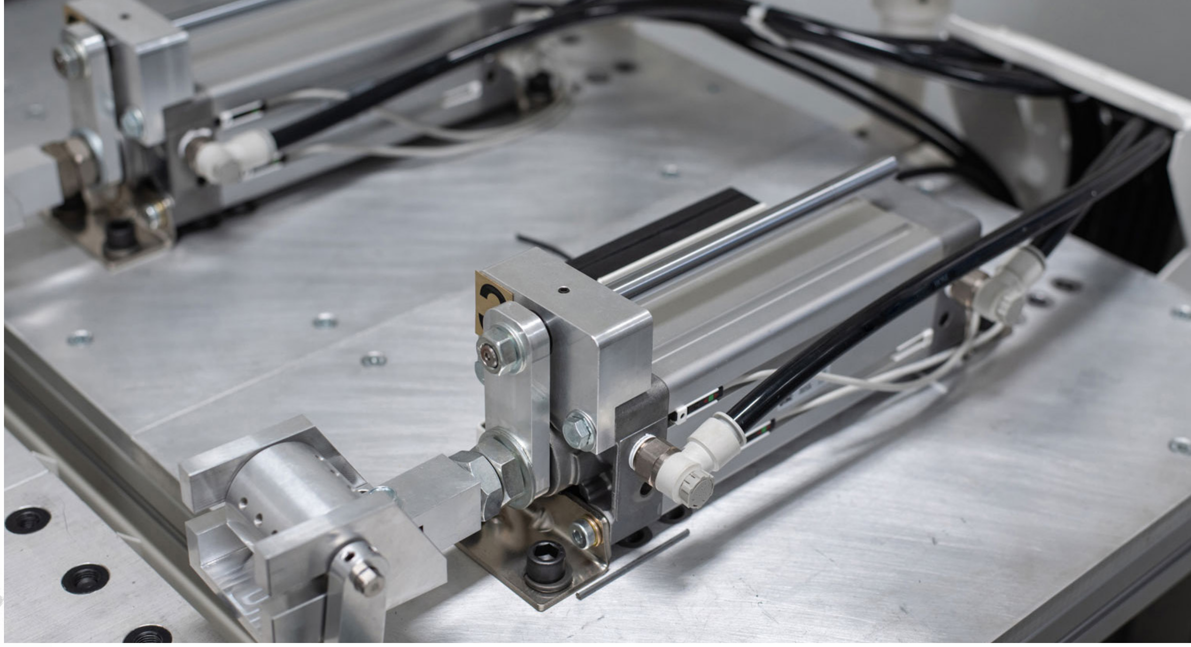


Right sizing pneumatic components and systems ensures optimal efficiency. *Dreamstime/Pakphoto*

CHAPTER 1:

When to Specify and Use Pneumatics

SARA JENSEN, Technical Editor, *Power & Motion*

Several factors should be taken into account when selecting pneumatics as a means of power transmission.

Pneumatics is one of the two methods used to transmit power within the field of fluid power. While its counterpart hydraulics uses a liquid, pneumatics utilizes gas to move power from one location to another.

Compressed air is typically used for pneumatic systems, but nitrogen and other inert gases can also be used depending on the application requirements. A typical pneumatic system uses a compressor to pump air into a receiver which is able to hold a large volume of air to then be used by the system when needed.

Although hydraulics is known for its higher power density, pneumatics offers its own benefits and is a widely used technology. “Usually, it comes down to total cost of ownership. If you don’t need the heavy loads possible with hydraulics, you can still get high speed with pneumatics but lower total cost of ownership,” explained Jon Jensen (no relation to author), CFPPS, CFPECS & CFPAI, Industry Projects Manager – Energy at SMC Corporation of America in an interview with *Power & Motion*.

When deciding whether to use pneumatics or hydraulics, there are several factors to take into consideration.

Determine Load and Speed Requirements

According to Jensen, the lower cost and longevity of pneumatic components can make them a more desirable option than hydraulic or electric actuators in many applications. The amount of force required in an application is the key determining factor for choosing pneumatics or hydraulics. “Generally, the added cost of hydraulics is not needed unless the forces are higher,” said Jensen. “If you’re moving things in the range of a few pounds then pneumatics is a good choice.”

He noted hydraulics typically come into play when loads reach several hundred pounds or more as at that point it does not work well to move something pneumatically. Control

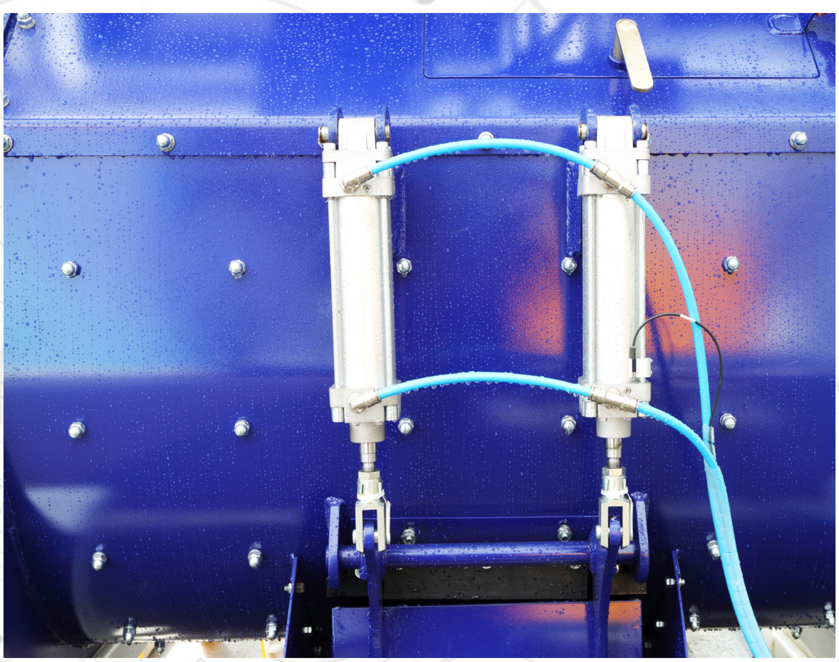
Pneumatic components are an appropriate choice for applications with lower load requirements. *Dreamstime/Boy Driessen*

is better within hydraulic systems because the fluid does not compress which is beneficial when moving something heavy as it prevents jerking or bouncing while moving.

Pneumatics are an appropriate choice for applications with lower load requirements. Again, they can provide a cost-effective solution, among other benefits. Because pneumatics components are designed to operate at lower pressures they are not as expensive to manufacture as hydraulic components.

Industrial pneumatics use a centralized compressor to supply a whole facility whereas hydraulic systems feature individual pumps and motors and are set up on a machine-by-machine basis which factors into operational costs. "You have the cost of multiple motors and pumps, or engines in the case of mobile hydraulics," said Jensen. This can lead to more time spent on maintenance, repair parts and other operational costs.

When looking at other options available today such as electric actuation or electric motors, he said the up-front costs are generally higher. Loads and speeds are a factor to consider with these options as well because there comes a point with electric actuators at which making them larger becomes cost prohibitive and it would make more sense to instead use hydraulics.



The lower cost and longevity of pneumatic components can make them a more desirable option than hydraulic or electric actuators in many applications. ***Dreamstime/Serjlogrus***

Weigh the Pros and Cons

Durability is another key benefit offered by pneumatics as they do not break down very often. Jensen said they tend to fail gradually and can start leaking but still work for years. When they do leak, it is usually not as much of an issue as with hydraulics as air will not contaminate the environment like oil does. The one caveat is if the pneumatics system is being used in a cleanroom; then the leaking of air could cause a contamination issue in these sensitive environments. But in general, he said the use of air makes pneumatics a clean technology.

Like any technology, pneumatics is not without its challenges one of which is the fact these systems use compressed air which Jensen said can make them "a little more interesting to deal with." A common issue is low pressure or the perception there is low pressure. If there is not enough pressure moving through the system performance issues can arise. But it is important to determine the actual cause of that lower pressure so the appropriate fix can be made.

Another challenge Jensen noted is the fact system leaks may be ignored. “Because leakage is not usually a catastrophe or environmental hazard, it is often ignored.” While this may not impact productivity it can negatively affect efficiency and ultimately operational costs. This is an issue the industry attempts to address through technology developments and use of monitoring systems.

Additional factors which should be kept in mind with pneumatics is the cost of compressed air as it is costly, said Jensen, as well as a less efficient means of transmitting power than hydraulics or direct mechanical systems such as electric motors.

However, despite some of these challenges, he said the various benefits pneumatics provide makes them an attractive option in many cases. “It’s still a widely used and accepted means of transmitting power, especially in factory automation, packaging and other applications like that where speeds are high, but forces and loads are comparatively low,” said Jensen. “If you added it all up, total cost of ownership is still attractive even though efficiency is [lower].”

Right Size the System

If choosing to use pneumatics, what are some considerations design teams should keep in mind? According to Jensen, right sizing the pneumatic system is vital to ensuring its efficiency. All components in the system need to be sized correctly, he said.

A common practice has been oversizing components “just in case” but Jensen said that leads to larger volumes to fill which makes a system less efficient. Even the size of tubing and hoses needs to be considered because the more volume that needs to be filled the higher the operating costs. As such, it is important to be “very particular about sizing things correctly,” he said.

Another suggested best practice is to not run everything at the same pressure. This means designing the system so the correct pressure for each part of the machine is adjusted and maintained. If something is moving it does not usually need the same force in both directions. “Usually, it’s pushing something and then pulling back and not doing any work,” said Jensen. “We can adjust the pressure and often reduce the cost of the air by 50% for that application. There are a lot of little things you can do that add up to real efficiencies.”

In general, he said it is important to get pressure and flow in the right place and for end users to monitor them both to ensure efficient operation.

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CHAPTER 2:

A Technical Comparison: Pneumatic Cylinders and Electric Rod Actuators

RYAN KLEMETSON, Business Development Manager, Tolomatic Inc.

Here's a look at the performance criteria of electric and pneumatic sources of automated linear motion.

When it comes to designing applications that need linear motion, engineers are often drawn into the debate about which is better for automation: pneumatic cylinders or electric linear actuators.

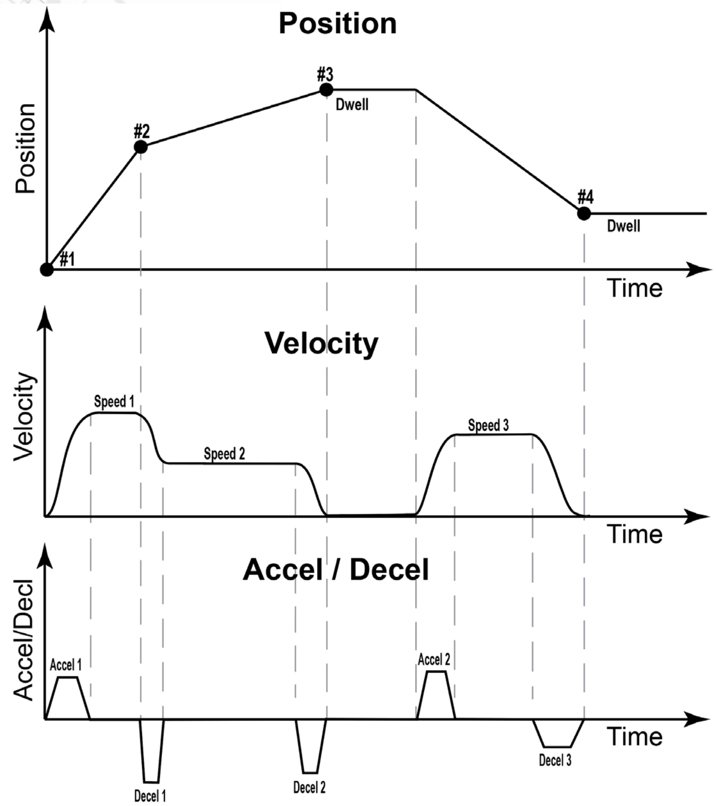
Pneumatic cylinders have long been used as an economical source of linear motion across a broad spectrum of manufacturing processes. They are durable and simple to install, and they provide a low-cost method of providing what's needed for linear motion and forces. But electric rod actuators have become an economical alternative for linear motion. They can provide control and reliability advantages while meeting an application's requirements.

Here's a technical comparison of the performance of the two when it comes to critical criteria such as motion control; force; velocity, acceleration and deceleration; system components and footprint; reliability, life and maintenance; data collection; efficiency and utility costs; and shock and side loads. It should help design teams choose the best approach.

Motion Control

Pneumatic cylinders easily accomplish basic end-to-end positioning. Mid-stroke positioning, however, requires adding hardware to hit that third position, which results in positional performance that is not very accurate or repeatable. Servo-pneumatics can address these positioning issues, but they complicate the design and add costs which make their cost structure similar to that of electric actuators.

In addition to positional accuracy and flexibility deficiencies of pneumatic cylinders, speed control can also be a challenge and requires fine-tuning. In pneumatics, speed



Motion profiles graphed at different velocities with varying accel/decel rates, all under full and precise control.

control is monitored through flow controls. Operators must manually dial in an application's speed, which can be difficult to meet. Once the speed setting is adjusted, the valve regulates the pressure output required from the cylinder. Again, operators must fine-tune the cylinder to get the desired force.

Finally, a pneumatic cylinder's repeatability of position, speed and force can be diminished by worn seals, leaks, pressure drops and spikes in the compressed air, as well as other maintenance factors. These factors often make it difficult for pneumatic cylinders to provide repeatable performance in demanding industrial environments.

Electric actuators are often chosen by designers to get control over multiple positions, accuracy, repeatability, output force, acceleration, deceleration and velocity at any time during the motion.

Electric actuators, coupled with a servo drive and motor, offer infinite control over position, as well as positional accuracy and repeatability far beyond that of pneumatic systems. Additionally, multi-axis servo controllers are readily available off-the-shelf for most modern control systems and can be easily used with several linear and rotary axes to run even the most complex motion profiles. This motion control and flexibility can be programmed into PLCs, HMIs and other controllers.

With these added capabilities, machine start-up and change-over times are fast and repeatable. This lets OEMs easily boost performance and that translates into more productive processes.

Force

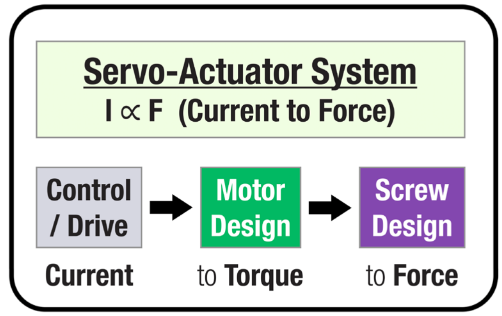
Pneumatic cylinders typically operate at pressures from 80-100 psi or 5.5-7 Bar. They follow the Force = Pressure x Area fluid power principle, so the forces they can generate are easy to calculate.

However, pneumatic cylinders are typically not used at their full output force and are often oversized to improve control and ensure system operation. With pneumatic cylinders, system rigidity can be viewed as low due to the compressibility of air. This can lead to slight system delays and process variability due to the time lag needed for pressure to build.

Electric actuators can precisely control the power going to the servo motor that drives the mechanical components to create both linear movement and force. Force is generated almost instantaneously and is essentially "on demand."

The servo controller's closed-loop control enables precise, repeatable speeds and forces. This ensures processes are consistent cycle after cycle while preventing damage to the product or system.

When selecting electric actuators, designers should match the motor's rpm and torque to the actuator's screw lead and gearing. Although this step may appear to complicate the process, many companies that make actuator and servo components provide easy-to-use sizing software that takes all these variables into consideration.



Electric actuators precisely regulate current through the servo motor to achieve accurate and repeatable force.

Velocity, Acceleration and Deceleration

Pneumatic cylinders can generate high velocities if compressed air volume and pressure are readily available. With sufficient volume and flow, pneumatic cylinders operate at high cycle rates in basic end-to-end positioning applications without the need for detailed sizing or application engineering.

A common challenge of pneumatic systems is that the velocity of commanded motion is difficult to accurately and repeatedly control. Engineers designing pneumatic systems that will operate at high linear speeds, or with high acceleration and deceleration rates, must typically consider shock absorbers or design for the shocks and impacts that may be present. If they don't, the resulting shocks and impacts can shorten the service life of air cylinders and associated components.

Electric actuators can precisely and accurately control velocity and the acceleration/deceleration profiles throughout the motion profile. They can also be easily changed from one speed to another without stopping or over-running position. Velocity control improves overall performance, minimizes move times, and increases cycle rates and overall productivity. And the smooth motion eliminates the potential for shocks and impacts, which improves the machine's overall reliability and reduces risk of downtime.

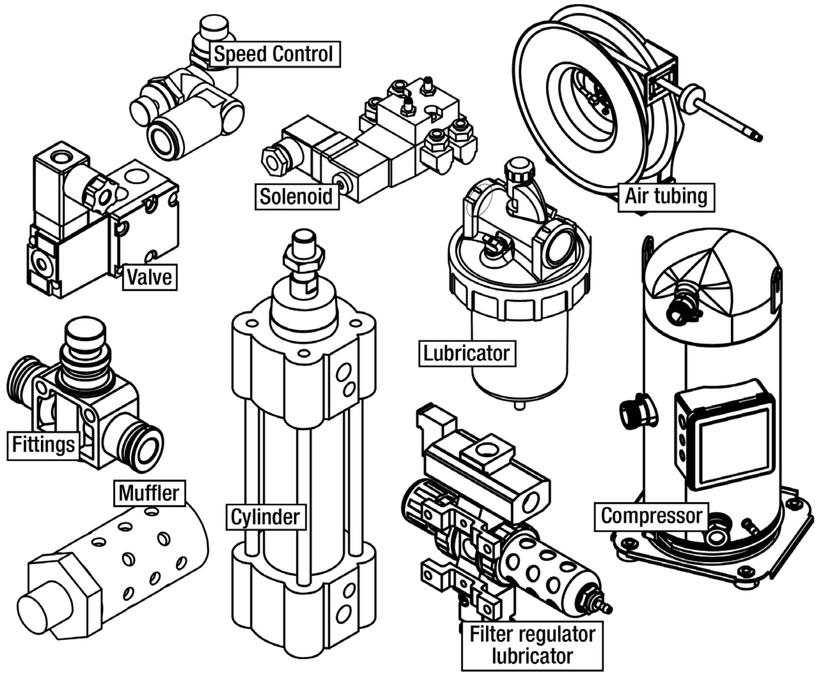
Providing high speeds and forces simultaneously requires a more involved sizing process. Designers will need to assess various screw leads, gearing and servo motors that have the range of rpm and torque capabilities to meet their requirements. The combined limitations of these may restrict the actuator's maximum velocity or thrust capabilities. In some cases, pneumatic cylinder systems offer higher overall linear velocities. However, overall cycle time can often be reduced when using electric actuators operating at similar, but lower, velocities. This is achieved by moving only the minimum amount of distance necessary instead of running end to end as is required when using air cylinders.

System Components and Footprint

Pneumatic cylinders require a cylinder, compressor or compressed air supply, valves, filters, regulators, tubing and fittings, as well as ancillary components. This results in an increased component count compared to electric actuators.

The compressor or compressed air supply takes up additional floor space at the machine, or requires a compressor room, which consumes significant plant space. When factoring the compressor into the overall footprint, pneumatics have a larger total footprint in the plant than electric actuators.

Most compressed air supplies also need overhead air hoses and air drop lines to bring compressed air to the workstation. These long hoses mean there's more air to compress,



Pneumatic systems consist of several components and accessories.

an increase in potential leaks and a decrease in overall efficiency.

Electric actuators are physically larger than pneumatic cylinders and are rarely if ever a drop-in replacement, so they need more space. However, electric actuators have fewer components: a mechanical actuator; a motor (servo or other); an optional gearbox; cables; and a drive/amplifier, which is usually housed in a control cabinet.

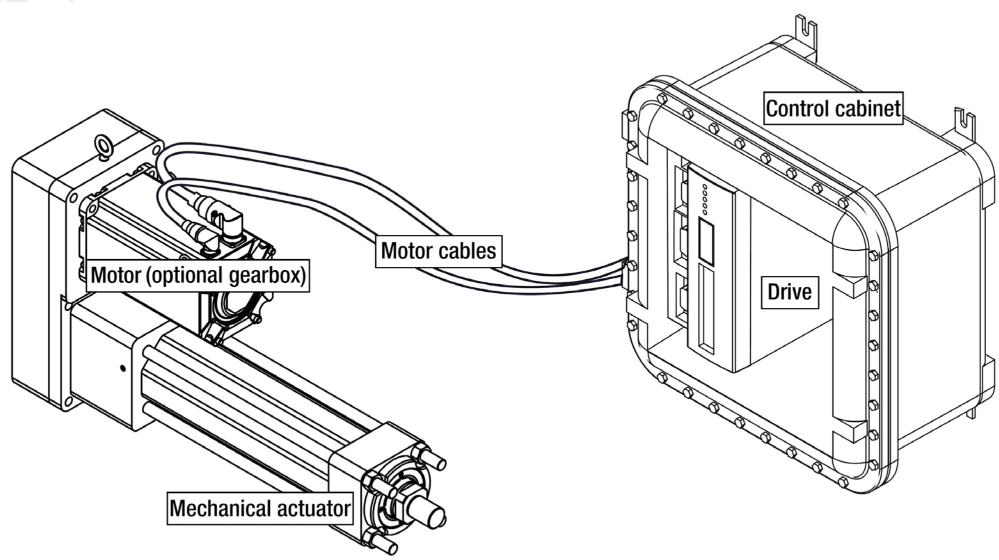
Electric actuators, due to having powertrain components (power screws, bearings, etc.) inside the assembly, are longer than pneumatic cylinders. But this additional length is more than compensated for by the actuator's much smaller overall footprint.

Reliability, Service Life and Maintenance

Pneumatic cylinders can provide rugged performance and have a long service life if properly maintained. One key element necessary for long service life is durable rod and piston seals. They must maintain proper engagement with their sealing surfaces to contain the pressure required for the given motion and force.

As the cylinder cycles back and forth, seal wear is inevitable. Any leaks decrease the cylinder's efficiency, force, speed and responsiveness.

Predicting when seals may fail and when to carry out timely maintenance can be almost impossible. As seals wear, operators must manually adjust air flow rates and pressures on



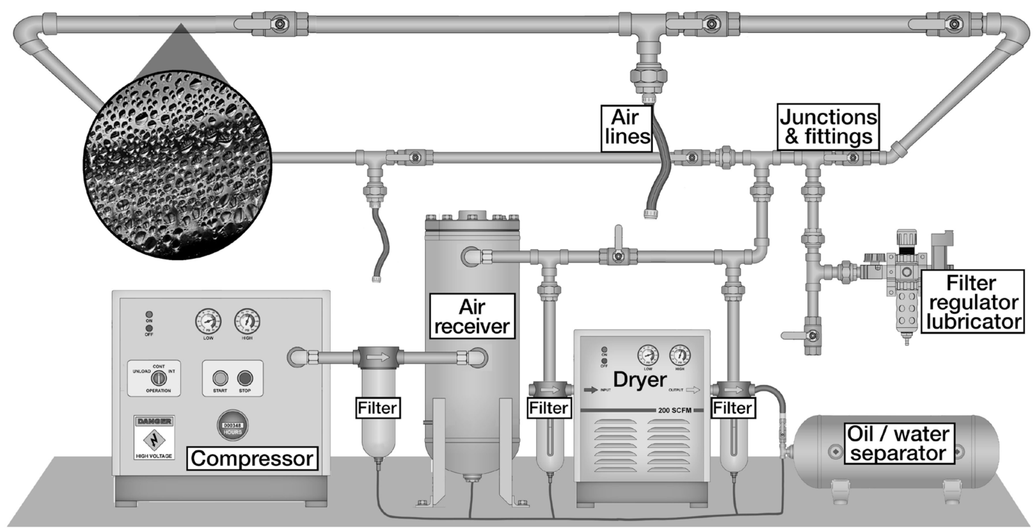
Electric actuator systems have relatively few components.

individual devices to ensure proper machine operation and process repeatability.

Many factories have preventative maintenance and replacement schedules for pneumatic cylinders to avoid unexpected downtime. The schedules must include time to test and tune systems on startup. Although periodic maintenance for pneumatic cylinders increases machine and process reliability, it also adds time, labor and costs for replacement parts, and someone must manage the maintenance schedule.

A final factor in cylinder reliability and service life is taking care of the air supply so that the compressed air is clean and free of moisture. Condensation in air lines can prematurely fail pneumatic components through corrosion and create an environmental risk through bacterial growth that might contaminate the manufacturing process.

Electric actuators can be sized for the application's life requirements. Their main torque and force transmission elements—the screw assembly (ball or roller screw) and bearings—have dynamic load ratings (DLRs) that estimate the actuator's service life. Designers can use the industry standard L10 life estimates to size and select components to help ensure equipment meets the life requirements. Some of these components may be greased for life. For those requiring maintenance, there are easy, in-the-field greasing methods to extend their service life in demanding applications.



Pneumatic/compressed air systems can be extensive and require lots of maintenance and servicing.

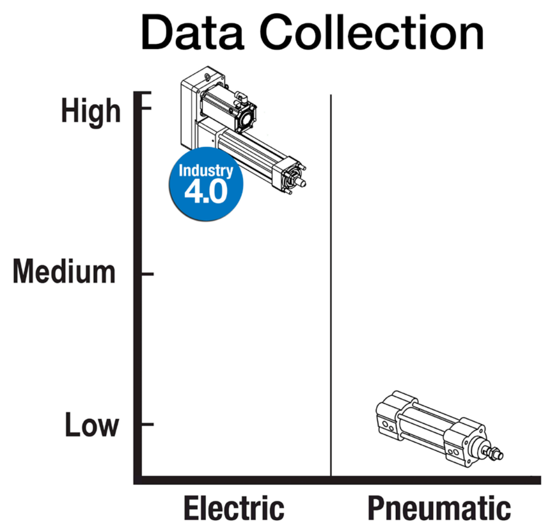
A secondary wear element on electric rod-style actuators is the rod seal. It keeps water, dust and other contaminants from getting inside the actuator and damaging torque transmission components. Unlike seals on pneumatic cylinders, those in electric actuators do not have the precise sealing requirements needed to contain high pressures. Even if the seal fails, electric actuators will still function. Rod seals on most electric actuators can be easily and inexpensively replaced.

Misuse is the primary reason electric actuators fail. The most common forms of misuse are exceeding the actuator's performance specifications for extended periods of time and damage during commissioning or installation due to inadequate attention to controls parameters.

Data Collection

Pneumatic cylinders can have proximity sensors with IO Link or an Ethernet valve bank to supply performance data. But without expensive linear transducers and other sensors to provide absolute-positioning feedback, the information reported back to the controls system is often inadequate to tightly monitor and control a process in real time.

Electric actuators commonly use servo drives that are available with off-the-shelf features that let operators monitor and send performance data to data acquisition systems. Current supplied to the motor can be easily used to track force and repeatability. The feedback device on the motor is used to accurately track position, velocity and acceleration/deceleration during the entire motion cycle at any point in time. With this data for every cycle, engineers can closely monitor actuator operation and then improve machine performance, reliability, and controls.



Electric actuators can use Ethernet connectivity for Industry 4.0 and Internet of Things (IoT) designs.

Efficiency and Electricity Costs

Pneumatic cylinders, the support components and the compressed air supplies typically operate at 10% to 20% efficiencies. Many factors affect this efficiency, including the number of components, leaks and air quality. As efficiency changes, so can accuracy and repeatability. Additionally, pneumatic systems must always be pressurized to guarantee specified motion and force. When the system is active, compressors must run even though many of the cylinders may not be working—an inefficient use of power.

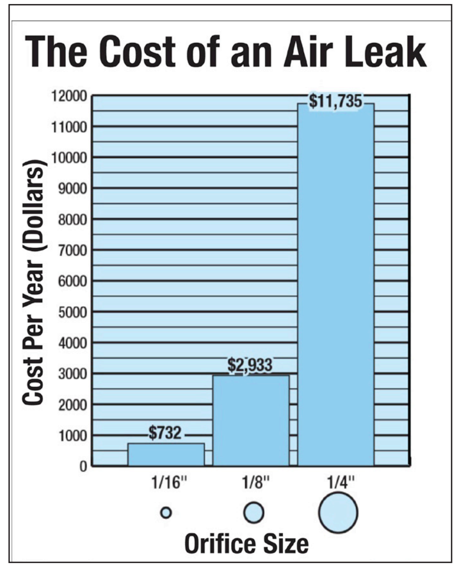
This inefficiency is exacerbated if there are leaks. The compressor continues working, providing air pressure and volume flow while air continuously leaks. Even several small leaks can mean a significant loss of air. The increased demand on the compressor adds to electricity costs. And in large plants with complex compressed air subsystems, it can often be difficult to locate and fix all the leaks in a system.

Electric actuators typically operate in the 75% to 80% efficiency range. Thanks to the mechanical construction and torque-transmission components, this efficiency remains consistent over time.

Electric actuators only demand current to the motor when force is needed. This means that when electric actuators are at rest, they require little to no current to hold position (unless force is required), which lowers electrical use and costs.

While pneumatic systems always need energy to maintain system readiness and responsiveness, electric actuators provide motion on demand and are highly efficient

Air leaks in a facility's compressed air subsystem can be costly. This chart shows the estimated annual costs of different-sized leaks in a compressed air network. They are calculated using the industrial electricity rate of $0.07 per kWh and assume consistent operation and an efficient compressor.

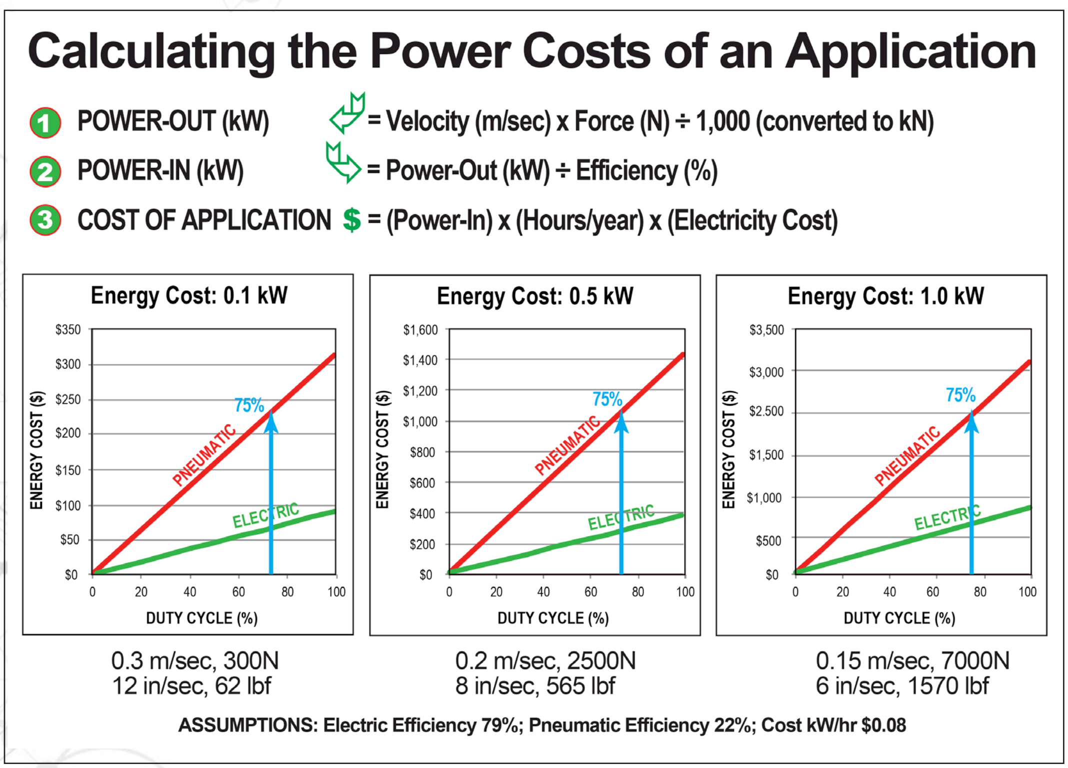


when operation is required. The use of holding brakes can further increase efficiency by holding large loads in place while power to the actuator is switched off.

With increased regulation requiring many manufacturing companies to limit or cap their use of electricity which, in turn, limits compressed air use, electric actuators are often put in place to lower electricity use and meet green and energy efficiency goals.

Shock and Side Loads

Pneumatic cylinders often use an integral air cushion that lets them withstand shock loads. Shock loads in line with the cylinder's rod are typically absorbed by the piston react-



Here is a graphic method of estimating the power used and estimated electric utility costs for an electric actuator. Blue arrows depict cylinder operation at 75% duty cycle.

ing against the compressed air in the cylinder.

Side loads due to misalignments or forces from a moment arm put stresses on both pneumatic cylinders and electric actuators. In pneumatic cylinders, they can cause premature wear or seal failure. This leads to poor velocity and force performance, an increase in leaks and premature cylinder failures. To protect against side loads, pneumatic cylinders should be aligned with the intended axis of motion.

Electric actuators, with their screw assemblies and bearings, lack any inherent protection against shocks and side loads so they can shorten the actuator's life. In some cases, it helps to oversize the actuator to better withstand anticipated shocks. Using a roller screw also adds protection against shock loads because it provides more contact points (rollers as the load transfer element from the nut to the screw) to resist the loads. Another layer of protection can be provided by adding shock absorbers, depending on the size of shock and load.

Electric rod style actuators also don't handle side loads well. They put lateral forces on the actuator's front rod seal as well as the screw and nut. Increased loading on the rod seal often puts more wear on it which lets contaminants into the actuator and causes premature screw and bearing failures. Additionally, side loading on the screw and nut can shorten their life.

	Electric Cylinder		Hydraulic Cylinder	Pneumatic Cylinder
Specification	Roller Screw	Ball Screw		
Motion Profile Control & Flexibility	Easy and most capable	Easy and most capable	Limited or complex servo-hydraulics	Limited or complex servo-pneumatics
Positional Accuracy & Repeatability	Best accuracy and repeatability	Best accuracy and repeatability	Limited with complex servo-hydraulics	Limited with complex servo-pneumatics
Max Force	Very high	High	Highest	Medium
Max Speed	High	High	Very High	Very High
Actuator Life / L10	Very high / calculated	Medium / calculated	Medium / NA	Medium / NA
Maintenance	Minimal	Minimal	High	High
System Efficiency	~75%	~80%	~40 to 55%	~10 to 25%
Energy Consumption	Low	Lowest	High	Very high
Shock Loads	High	Low	Very high	Very high
Operational Temperature Tolerance	Very tolerant & efficient	Very tolerant & efficient	Seal failure, sluggish operation	Seal failure, sluggish operation

This chart describes the relative performance of electric, hydraulic and pneumatic cylinders.

Summary

Pneumatic cylinders have a reputation as economical automation components. It is significantly less expensive to install them than an electric actuator/servo if there is already a source of compressed air. But pneumatic cylinders have some drawbacks compared to electric actuators. For example, they are generally limited to two-position motion profiles; they have more components; they have shorter and unpredictable lives; they need to be manually adjusted; and they consume more electricity.

Electric actuators let designers reliably control position, velocity, acceleration/deceleration and force. In addition to this flexibility, electric actuators can be correctly sized for the life of the application. Electric actuators can also use closed loop control which simplifies the task of collecting data and improving process control. They are virtually maintenance-free and highly efficient and don't need compressed air, which lowers costs. They also often have lower total cost of ownership versus alternative pneumatic cylinders despite their higher initial purchase price.

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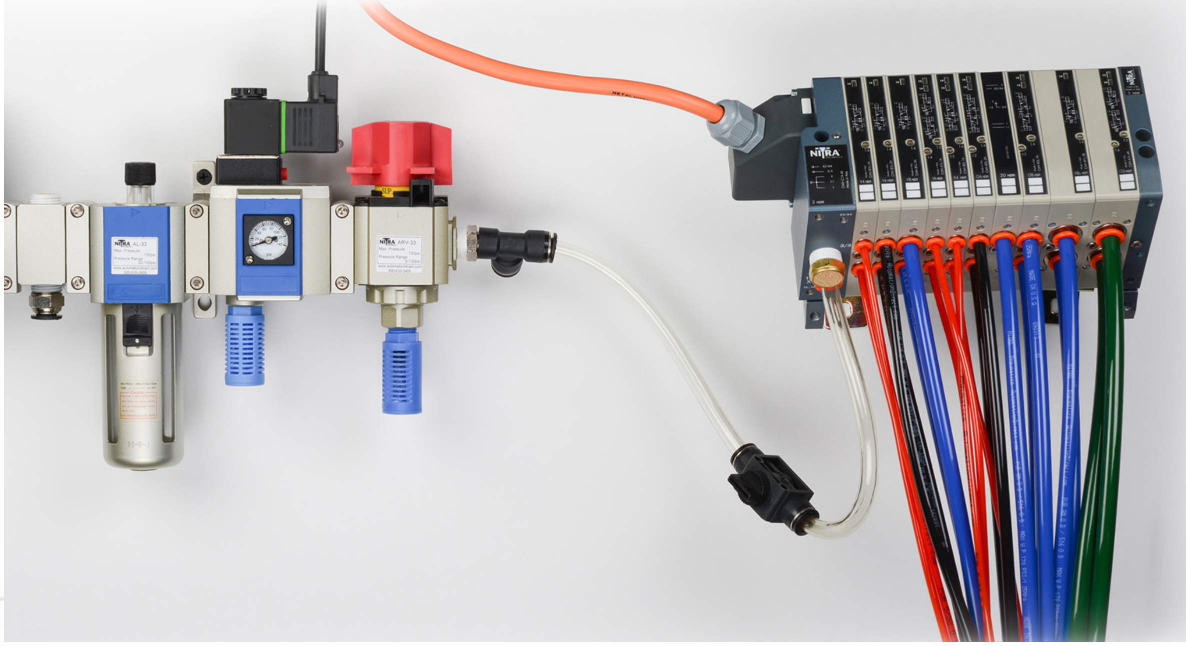

CHAPTER 3:

The Principles of Pneumatic Air Preparation

KEVIN KAKASCIK, Technical Marketing Engineer, AutomationDirect

Properly designed air preparation delivers clean and regulated compressed air to reliably power pneumatic equipment.

Air preparation is a fundamental, yet often underappreciated, aspect of pneumatics. “Air prep”, as it is often called, can seem unimportant or just adding needless upstream complexity. The reality is air prep ensures downstream devices get the correct air cleanliness, pressure, and lubrication.

Here are some tips on how engineers can design or specify air prep subsystems that make sure pneumatic equipment performs at its best for many years, cuts maintenance costs, and reduces downtime.

Pneumatic design basics

For any pneumatic components, port sizes must be matched to the inlet and outlet piping or tubing. Additionally, pneumatic devices can be rated for a normal operating pressure range, sometimes a proof pressure, possibly a burst pressure, and perhaps all three.

A device’s operating pressure is what is takes to operate properly. For example, a solenoid valve may have an operating pressure range of 20 to 100 psi. Too little or too much pressure means there is no guarantee the valve will operate correctly or at all.

Proof and burst pressure ratings are a little trickier. Proof pressure is the maximum air pressure a device can handle before it may fail and no longer work even if proper pressure is restored. Burst pressure is the maximum pressure the device will take before it may fail catastrophically, which can pose a danger to personnel and cause other equipment failures.

System Disconnect

Before addressing specific air prep concepts, it is prudent to consider methods of disconnecting the air prep equipment. The ability to remove hazardous energy from machinery that is not in use or when maintenance needs to be performed is crucial. OSHA and

ANSI consider compressed air a hazardous energy source, so provisions must be made to isolate downstream components from the source, bleed (or remove) downstream pressure, and lock the system in this state to protect against inadvertent re-energization.

Manual shut-off relief valves are the basic pneumatic disconnect component for isolating downstream equipment from the upstream and will also bleed or "relieve" downstream pressure. Most manual shut-off valves have much higher operating pressure ranges than other pneumatic devices.

A more advanced disconnect component is the isolation/lockout valve. These valves are analogous to an emergency stop device in an electrically controlled machine. Isolation/lockout valves are installed upstream of systems to be protected, and when activated, they disconnect incoming air pressure. They are similar to shut-off relief valves but have larger ports so they can release air from the downstream much faster. This quickly puts the downstream pneumatics into a safe state. Isolation/lockout valves can be locked in the "off" state.

An optional component which may be used with a manual shut-off valve is a soft-start valve. Soft-start valves are activated with an electrical signal and they gradually ramp up downstream pneumatic pressure. When the electrical signal is removed from the valve, it acts as a quick-dump valve, disconnecting upstream supply air and quickly removing pressurized air from the system.

Air pressure regulators can be dedicated devices or combined with other functions like this Nitra filter/regulator combination from AutomationDirect, shown here installed on a conveyor.

Air filtration

Even with proper pressure, contaminants in the airstream can wreak havoc on a pneumatic system over time. Millions of particles of dust, dirt, sand, oil, and water can be found in a cubic foot of compressed air, and sometimes even worse things such as metal particles. This makes proper filtration the unsung hero for preventing downtime due to contaminants.

Passive air filters come in two basic designs, centrifugal and coalescing. Centrifugal is more commonly seen and is good for removing most dirt and metal particles, as well as some water. They work by circulating the air and trapping contaminants in the filter as they pass around it.

Coalescing filters are typically used along with a centrifugal filter when more stringent filtration is needed. Coalescing filters excel at removing fine mists of moisture and oil. They filter them out by passing the air through the filter element to trap droplets of contaminants.

Both filters collect some moisture, even from the driest compressed air. Moisture or water collects in a bowl at the bottom of these filters, which needs to be drained periodically using one of three types of drains: manual, semi-automatic, and automatic. Manual drains require human intervention to operate; semi-automatic drains operate every time air pressure is dumped from the system; and automatic drains empty when the bowl is full.

Some compressed air supplies contain significant moisture, requiring more than passive filtration. These systems may need an active dryer, which usually needs electrical power. Active dryers for air prep may be one of three types: refrigerated, desiccant, or membrane. Each works on a different principle, but all three are large compared to other air-prep components. Active dryers add to the cost and complexity of air prep, but sometimes are an unavoidable necessity.

Getting the right pressure

Although air filtration is the first step in air prep, establishing proper downstream air pressure is usually considered air prep's most important aspect. Upstream pressure is usually

Total air preparation (TAP) units are a good choice for getting a filter, regulator, and varied shut-off feature in a compact and cost-effective unit.

generated and maintained at a higher level for distribution and must be stepped down to the proper operating pressure using an air pressure regulator.

Air pressure regulators have an input (high side) and an output (low side) and will not work if installed backward. Most regulators come with a built-in gauge so operators can see the exact value being supplied to the system at the downstream/low side of the regulator.

Just like downstream pneumatic components, regulators have operating, proof, and burst pressure ratings which must be compatible with high-side conditions and the low side requirements. Regulators can be specified within a standard range or as precision regulators. Precision regulators allow much finer tuning of output pressure, useful if downstream devices are sensitive to the operating pressure range.

To save space and overall cost, some designers opt for a filter/regulator combination or a total air preparation (TAP) unit. Filter/regulator units combine the two functions into one component, which saves space but may not have all of the features or specifications designers could get from two separate units. A TAP unit is even more comprehensive, combining a filter, regulator, and manual shut-off valve in one compact unit. Sometimes a soft-start valve is also available. When they meet the needs, TAP units minimize design work, save footprint space, and cut total installed costs.

Air lubrication

Most modern pneumatic components simply need clean dry air to work properly. However, some older devices or air tools still need proper lubrication be added to the compressed air. Moving parts and seals in some pneumatic devices need to be lubricated. For example, devices such as cylinders and valves require proper lubrication to prevent leaks, rust, premature wear, and seizing.

Pneumatic lubricators can be installed downstream of all other air prep devices. They inject a controlled fine mist of the proper oil type into the clean dry air. The amount it injects can be fine-tuned to precisely meet downstream needs. Because not all devices require lubrication, lubricators are most often installed just upstream of and close to the devices that need it.

The typical installation order from upstream to downstream, as depicted with these AutomationDirect Nitra devices, is filter, regulator, lubricator, and shut-off components.

Putting it all together

The normal installation order, from upstream to downstream, of pneumatic air preparation devices is:

- System isolation valve
- Filter
- Regulator
- Lubricator (if needed)
- Device shut-off valve

Users can select the exact right combination of devices needed for their application. Because filtration is typically upstream of regulation, the filter needs to be rated to handle the supply air pressure. TAP units are a useful way to get most of these functions, other than lubrication.

Air preparation is not complicated but is easy to neglect compared to the more active downstream aspects of pneumatics such as automatic valves and actuators. In all cases, ensuring proper air preparation is in place leads to years of safe and trouble-free pneumatic operation.

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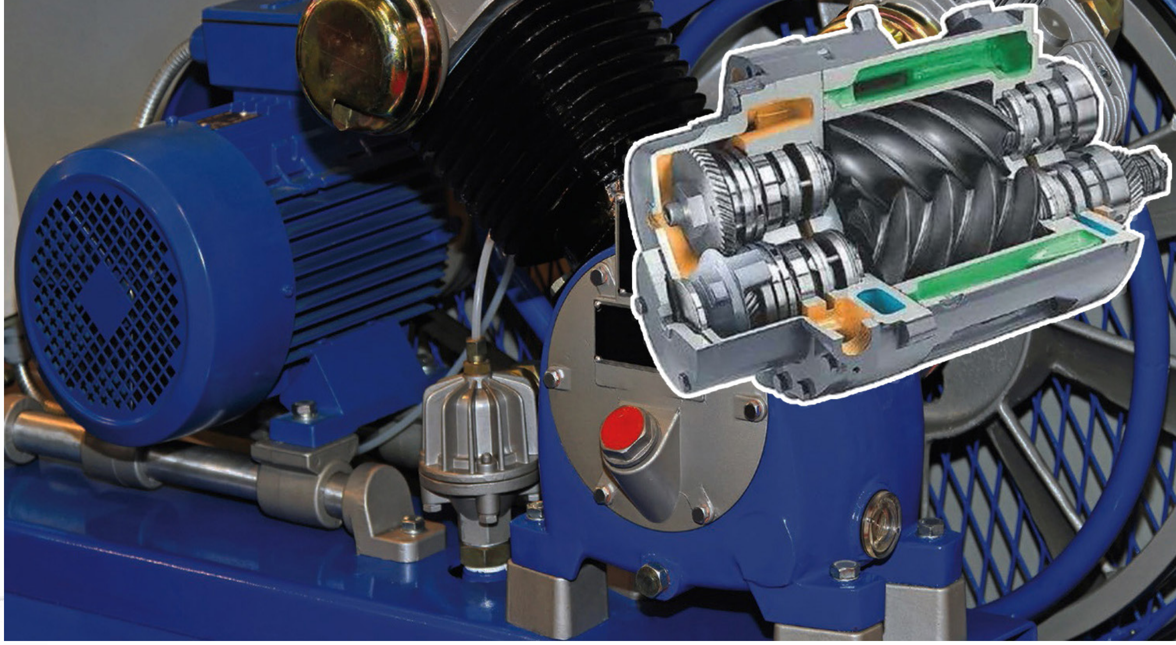

CHAPTER 4:

Pneumatic Basics: Air Compressors

JOHN CUMMINS, JEANNA VAN RENSESSLAR

Here's a look at the various types of air compressors and how they are lubricated.

Pneumatics, the technology that harnesses the power of compressed gases, touches everyone's life daily. 18% of all industrial energy is used to compress air and gases, according to the DoE. It is critical for making cement and flour, as well as blow-molding plastic bottles.

Pneumatics present several advantages: It is the least expensive transmission medium—air, or in some cases, separated or inert gases; it also has lower installation costs generally. But air pressure is typically below 250 psi, making it hard to detect and control leaks. It is also less efficient than hydraulics at transmitting fluid power.

Pneumatics powers a wide range of tools and equipment, in many instances replacing the electric power cord with an air hose. Since pneumatic power is intrinsically safe, a number of industries could not operate without it.

At the heart of all pneumatic systems is a compressor that turns the air or gas into kinetic fluid power.

Compressor Basics

Compressors turn gases into power. There are two main categories of air compressors:

Dynamic. These compressors raise air pressure by converting air velocity into pressure (centrifugal).

Positive displacement. These compressors trap a charge of air and physically shrink the space to increase pressure (sliding vane, rotary screw, reciprocating, rotary lobe).

There are also many types of compressors:

Centrifugal. Use low-pressure, high-volume air flow and no oil is added to the air (dynamic).

Sliding vane. Compact units act as compressors or when reversed as vacuum pumps (positive displacement).

Rotary screw. Most common (positive displacement).

Rotary lobed blowers. Low-pressure air flow used to move materials. No oils used in air (positive displacement).

Reciprocating. Reciprocating compressors compress air using pistons (positive displacement).

Different types of air compressors require lubricants with suitable ISO viscosities and additive packages. The lubricant usually depends on the compressor's load, environment, temperature, and speed parameters.

Centrifugal Compressors

Centrifugal compressors, also called radial compressors, increase air pressure by radially accelerating air flow and then pressing it against the compressor body. They are well-suited for continuous duty compressing large volumes of gas/air. They provide oil-free air and create higher airflows than similarly sized positive-displacement compressors. Centrifugal compressors can be a simple single stage for lower pressure or a more complex multi-stage design that supplies higher pressures.

Only the rotating shaft bearings and drive gears are lubricated, so the airflow is not exposed to oil. Lubricant viscosity varies between ISO 22 and 68, depending on shaft speed and bearing load. The oil must be compatible with the rotating shaft seals so no oil moves into the airflow area. The drive design of centrifugal compressors determines if anti-wear additives are needed or rust and oxidation additives for direct-driven journal bearings.

Sliding Vane Compressors

Sliding vane compressors have many advantages. They are light in weight, compact, operate quietly with minimal vibrations, have few parts and discharge the coolest possible air.

Sliding vane compressors are lubricated at the shaft bearings, vane slots, vane tips and chamber surfaces. The vane slots and tips, as well as the interior of the cylindrical compressor chamber, are oil-lubricated; thus, these compressors supply an air and oil mixture.

If the air needs to be oil-free, the supplied air must then go through a downstream air-oil separator. Separators use a filter to force the oil mist into larger droplets for easier separation and return to the compressor's oil supply.

Vane compressor oil viscosity is determined by operating temperature and speed. The need for anti-wear additives in the oil is typically determined by the load.

Oil is injected into the air stream to lubricate the seal between the vanes/rotor and cylinder (housing), the bearings, the vanes and cylinder surfaces.

Vane compressors are generally limited to applications well below 100 hp because of the bending stresses placed on the vanes. ISO 68 and 100 oils are the most common viscosity grades. Users should always reference the OEM manual for correct viscosity and recommendation for either anti-wear (AW) or rust and oxidation (R&O) oils.

Rotary Screw Compressors

Within the last 60 years, oil-injected screw compressors have become the most popular type of compressor in the world. It works by trapping a volume of air at the intake area between two counter-rotating screws and reducing its volume as the screws move it toward the discharge outlet. A film of lubricating and cooling oil on the screw's surfaces seals air in the confines of the screws to prevent leaks. Some tolerances are so tight that oil films are unnecessary.

Several lubrication concerns must be addressed to ensure screw compressors operate reliability:

- Oxidation-stable lubricants must be used to prevent varnish building up on the screw. The varnish reduces the clearance and greatly increases the operating temperature, leading to even more varnish production and eventual compressor failure.
- Intake air and oil must be clean to stop particulates from damaging the screw surfaces.
- Oil foaming reduces compressor efficiency as it cannot adequately seal the screw surfaces.
- The oil must have good demulsibility to prevent emulsions from interfering with oil removal in the air-oil separator. (Demulsibility is a measure of an oil's ability to release water.)

Rotary screw compressors are typically lubricated with ISO 46 or 68 anti-wear oils. Synthetic lubricants are gaining wide acceptance for controlling varnish deposits.

Rotary Lobe Compressors

These compressors consist of two symmetrical lobe rotors mounted on separate shafts in parallel, which rotate in opposite directions to each other at high speeds. Timing gears synchronize the lobes' rotation to maintain constant clearance between the two. The compressors are efficient at producing significant air flow.

Rotors can be up to eight feet long and three feet wide, or small enough to pick up and carry around in a lunchbox.

Non-contacting rotary lobe blowers belong to the group of dry-running positive-displacement compressors. This means there is no need for oil in the compression chamber. Only gearbox and bearings, which are separated from the pumping chamber, are oil-lubricated.

These compressors have low compression ratios with pressures up to 25 psi and high capacities up to 30,000 cfm.

Rotary lobe blowers/compressors tend to run hot (with exhaust air up to 350°F). Therefore, lubricant viscosity is usually an ISO 150 or 220 to handle the temperature thinning of the oil film in the gearbox. Synthetic oils are common to handle the high temperature and better resist oxidation.

At the gear end, timing gear teeth are lubricated by being partially submerged in non-extreme-pressure (EP) or anti-wear oil. The gear teeth also sling oil on the gear-end bearings. At the drive end (or belt side), bearings are typically grease-lubricated. Users should always check OEM specifications for correct fluid and/or grease specifications.

Reciprocating Compressors

Reciprocating compressors are based on the same principles as internal combustion engines (pistons, rings, cylinders and valves). The difference is the goal is gas compression instead of combustion at the top of the piston.

Reciprocating compressors are typically used for their high compression ratios (ratio of discharge to suction pressures) without high flow rates, and the process air/gas is relatively dry.

A reciprocating compressor uses the piston movement inside a cylinder to compress air. As the piston moves downward, the exhaust valve closes and a vacuum is created inside the cylinder, forcing the intake valve to open and suck air into the cylinder. As the piston rises, the intake valve closes, and compressed air leaves the cylinder through the exhaust valve.

Lubrication is typically handled by splash lubrication or a pressured central subsystem. Large piston compressors have direct-injected or drip-fed lubrication at the top of the piston-air valve area.

Small (up to 20 hp), air-cooled reciprocating compressors are usually lubricated with SAE 30 engine oil or ISO 68 to 100 R&O or anti-wear oils; 50 hp and greater reciprocating compressors typically have two separate lubricating subsystems: drip-feed a non-carbonizing ISO 100 or 150 synthetic ester or diester lubricant for the compressor head's reed valves, and SAE 30 or 40 engine oil or ISO 100 or 150 anti-wear in the crankcase.

For large, horizontal crosshead piston compressors, the choice of cylinder oils depends on the solvency of the gas and how much it prevents the lube from being washed off cylinder liners. Esters and diesters have replaced the compounded oils containing animal fats or vegetable oils—natural esters—that were first used years ago.

Compressor Lubricants

The most important property of a compressor lubricant is its viscosity. It must be matched to the compressor's load, environment, temperature, speed and its components. Considerations include:

Load. Input horsepower and delivered psi of the gas, single-stage versus multi-stage compression.

Environment. Type and reactivity of gas being compressed, cleanliness of gas for filtration, humidity.

Temperature. Ambient and operating temperature of compressor, and temperature of the compressed gas.

Speed. RPM of the rotating components.

Lubricant should have some of these qualities:

- A stable base oil that resists oxidation but reacts with other compressing gases to prevent deposits and extend or maintain oil life.
- Good demulsibility to handle humidity and prevent oil/water emulsions in the air-oil • Anti-corrosion protection to handle rust as well as any gas-induced corrosion.
- Non-foaming to provide a proper seal between rotating screws and vane and sliding pistons. Foaming also causes major problems in downstream air-oil separators.
- Balanced and compatible with additive package for compressor and the type of gas being compressed.

Users should follow these six simple rules during and after fluid changes to extend the compressor's life.

1. Analyze oil before changing it out.
2. If changing brand/type of fluid, get information on the current and new lubricants. Many compressor lubricants are not compatible with each other or with certain seal materials.
3. Flush system using approved blending agent and procedures.

4. Check sight glass daily for foaming tendencies.
5. Take and analyze sample a week after changing fluids.
6. Do a quarterly oil analysis/particulate count.

Compressor efficiency and operating life are directly affected by the lubricant used on it, it is only logical to conduct routine oil analysis, including particle count, of the compressor fluid to prevent failure.

Because of the high oxidative environment as well as moisture and high temperatures, an oil analysis program is recommended for any compressor critical for plant operations. Oil analysis programs allows changing fluids at the best time and assists in identifying equipment concerns before they become serious.

By their nature, air compressors take in airborne contaminants every second they operate. Contaminated lubricants hurt compressed air quality more than anything else. Just compressing atmospheric air to 125 psi creates an 800% increase in the concentration of contaminants.

The biggest problem on the maintenance side is air filtration. Users must keep the incoming air stream clean. Otherwise pneumatic tools wear out more quickly. Pulling air from hot, moist and dirty environments makes it more difficult to reduce operating expenses.

JOHN CUMMINS is vice president of product technology and an investing partner of Hydrotex. This article is based on material he delivered in a webinar presented by the Society of Tribologists and Lubrication Engineers, an international professional not-for-profit society based in Park Ridge, Ill. JEANNA VAN RENESSLAR is a freelance writer based in the Chicago area.

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CHAPTER 5:

Right-Sizing Rodless Pneumatic Actuators

Written and contributed by Tolomatic

Several factors should be taken into account to correctly size pneumatic rodless cylinders for an application.

Rodless pneumatic cylinders are a great alternative to conventional rod-style air cylinders and electromechanical actuators because they both support and guide a load. This eliminates the need for other load-bearing elements and reduces costs, size, and design time. The design of rodless cylinders benefits longer stroke, space-constrained applications.

But sizing a rodless cylinder involves more than merely calculating force and stroke. The following tips can help engineers spec the best actuator for a given application.

Sizing Basics

Know the air pressure. It might seem obvious that pneumatic actuators need the proper amount of air pressure to perform up to spec, but plant air pressure isn't always what it seems. So check the air pressure with a gauge to get an accurate reading and build in safe engineering practices.

For example, a plant may supply 100-psi (6.9 bar) air, but pressure can vary from site to site in the factory as much as 10% due to variable demand cycles. This means actual available air pressure might only be 90 psi (6.2 bar).

A 5-10% fluctuation in air pressure is quite common and can make a big difference in selecting the proper cylinder for an application. It is always best to factor in a 10% pressure loss factor from the gauge air pressure reading.

Determine working stroke and overall length. By design, a rodless actuator's stroke lies completely within the body, giving it a smaller working footprint than conventional cylinders. But part of the actuator stroke cannot be used due to interference of internal components and the room needed to reach the end-of-stroke. This is normally referred to as the actuator's "dead length." Manufacturers typically indicate this dimensional information for each actuator.

To properly specify the actuator's overall length (OAL), determine the required travel distance (working stroke), then add the given dead length at each end of the actuator. Keep in mind that auxiliary carriers and other actuator options can add to the actuator's dead length. For example, for a cylinder with two carriers, add the total dead length, working stroke, and distance between the centers of carriers to determine the cylinder's OAL. It is important to reference the manufacturer's dimensional information when ordering options to see if more dead length is needed.

Right-sizing the cylinder. When it comes to cylinder sizing, bigger is not necessarily better. Too large a cylinder means excessive costs and air consumption. On the other hand, too small a cylinder may save a few dollars but will not provide the best performance or operational safety factors.

Actuators that work best are sized based on load, force, and bending-moment capacities with a safety margin factor. To properly size a cylinder, take these application parameters into consideration:

- Magnitude of load.
- Orientation of load relative to the carrier.
- Orientation of the actuator.
- Final velocity of mass and carrier.
- Working stroke length.
- Cycle rate.

Once these factors are known, determine the cylinder's force (thrust) capacity based on available air pressure. The cylinder should perform within the specified capacity range. If the application requires performance at the maximum limit for that cylinder, consider a larger bore size or a different style cylinder with higher capabilities.

A rodless cylinder's carrier travels completely within the body, giving it a smaller footprint than conventional cylinders. The actuators also can support and guide loads, eliminating other load-bearing elements.

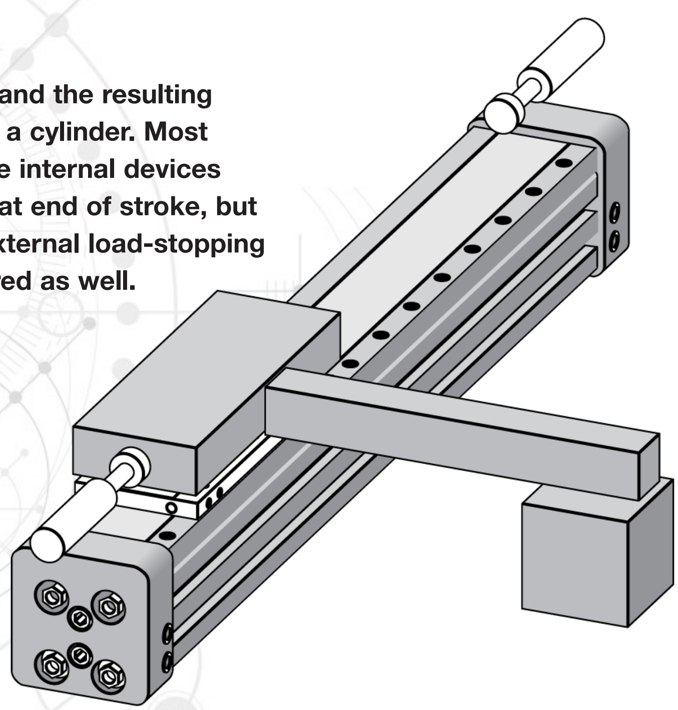
Loading Considerations

Moment loads. Often, engineers choose a cylinder based only on the force it produces. If the actuator must support an off-center load, it is important to know the bending-moment (torque) capacity of the cylinder's bearing and load carrying system to determine if it is capable of performing consistently under the load requirements. The position and size of the load on the carrier determine the bending moments applied to the cylinder. For off-center or side loads, find the distance from the load's center of mass to the center of the cylinder's carrier and calculate the resulting bending moment (force distance).

M_x moments (roll) are created by loads applied at a distance from the X axis and create a rotation around that axis. M_y (pitch) and M_z (yaw) are, similarly, moments about the *Y* and *Z* axes, respectively. The farther a load is from the center of the cylinder's carrier, the larger the resulting moment.

Published bending-moment capacities for rodless cylinders are usually maximums, but assume only one type of applied moment. Some applications have compound loading that combines two or more of the moments described above. Evaluate and calculate the combined effects to determine if the cylinder can handle the total moment force.

Dynamic moment loading. Even if a load is centered directly on the carrier, the cylinder will still be subject to bending moments during acceleration and deceleration. Failing to take this into account can lead to poor performance, reduced life, excessive wear, and cylinder failure. Thus, designers must also consider dynamic moment loading when determining force requirements because, unlike rod-style cylinders, many rodless cylinders support the load during acceleration and deceleration at each end of stroke. When the carrier reaches the end of stroke and stops, inertia keeps the load moving forward and creates a dynamic twisting moment (M_z) on the cylinder. The resulting dynamic moment can exceed the actuator's rated capacity and shorten life. Shock absorbers mounted on the cylinder are normally used to help compensate for dynamic loading's inertial effects.



Look at load position and the resulting moments when sizing a cylinder. Most rodless actuators have internal devices that cushion the load at end of stroke, but shock absorbers or external load-stopping devices may be required as well.

Shocks and Cushions

True velocity. Most rodless cylinders are equipped with internal devices to help cushion the load at the end of stroke. But it is important to know the final or impact velocity to determine the cylinder's cushioning capacity. This differs from average velocity.

For instance, stroking a 24-in. actuator in 1 sec yields an average velocity of 24 in./sec. A reasonable guideline for calculating the final (impact) velocity is that it's twice the average velocity, or 2 24 = 48 in./sec impact velocity in the example.

Deceleration forces. Given the impact velocity, engineers must then review load position and the resulting moments on the cylinder to determine if shock absorbers or external load-stopping devices are needed. Consider the following example. A cylinder carries a 10-lb. load offset 12 in. from the carrier, and travels at a final velocity of 80 in./sec when it hits shock absorbers at the ends of the cylinder stroke. The load must stop within the shock absorber stroke of 0.50 in. The Mz and equivalent force applied to the cylinder's load carrier need to be within the cylinder's rated capacity.

To determine this, first calculate the deceleration rate:
$a = v_f^2/(2s)$
$= (80 \text{ in./sec})^2/(2\ 0.50 \text{ in.})$
$= 6{,}400 \text{ in./sec}^2$
where:
a is the deceleration rate, in./sec^2,
s is shock stroke, in., and
v_f is final velocity, in./sec.

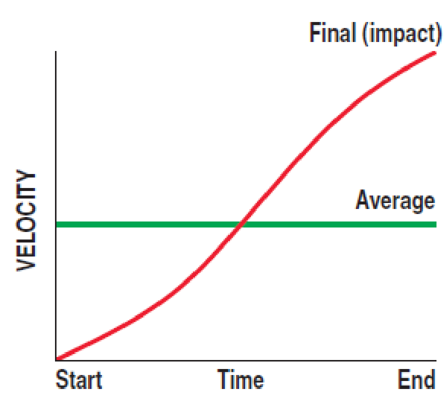
Then calculate deceleration force, F_d, from:
$F_d = (a\ P)/g$
$= (6{,}400 \text{ in./sec}^2\ 10 \text{ lb.})/(386.4 \text{ in./ sec}^2)$
$= 165.6$ lb.

where:
F_d is the deceleration force, lbf,
g is the gravitational constant, 386.4 in./sec^2, and
P is the load.

Finally, the moment load created during stopping is:
$Mz = F_d\ L = 165.6 \text{ lb. } 12 \text{ in.} = 1987.2 \text{ lb.-in.}$

where
M_z is moment about Z axis, and
L is distance of load from the cylinder's load carrying device.

Compare this value to the actuator's rated load capacity to ensure proper sizing. If the moments created during deceleration are more than the actuator's load capacity, you have two choices: Select a cylinder with a larger moment rating; or put shock absorbers at the load's center of gravity. The latter theoretically eliminates all



Designers must know the difference between average and final or impact velocity to determine the cylinder's cushioning capacities and correctly size rodless cylinders.

moments on the carrier during deceleration. If final velocity cannot be accurately determined, consider using limit switches with valve deceleration circuits, in addition to shock absorbers.

Additional Factors

Motion lag. It is important to understand how other forces and losses affect the total force needed to generate the desired motion. The total force is the sum of acceleration force, frictional forces, and the breakaway force. Here's a closer look at each:

- *Breakaway force*. It always takes a certain amount of force to move a rodless cylinder even with no load attached. This force is referred to as breakaway force. When reviewing performance data for a cylinder, be sure to account for breakaway force in the calculations. In pneumatic applications, it is best to have excess force available to ensure reasonable acceleration.
- *Acceleration force.* The force needed to accelerate a load is typically larger than the force needed to keep it in motion. When selecting an actuator, the cylinder's breakaway force and the load's frictional drag must be added to acceleration force requirements.
- *Friction forces.* Two materials sliding across each other generate frictional force in the opposite direction of the motion. The amount is defined by a numeric value called the coefficient of friction, μ, which varies by material and the type of friction (sliding or rolling). Engineering reference tables list coefficient values for a variety of materials.

For horizontal applications, the force required to overcome the friction is:

$F_f = \mu W$

where:

F_f is the frictional force, lbf, and

W = weight of the load, lb.

Mounting orientation. Vertically mounting the cylinder brings additional force, load, and air considerations. Vertical cylinders need to overcome the force of gravity before they can accelerate loads upward, which means they must produce more force than horizontal cylinders. In vertical applications, it is best to select cylinders with twice the force needed for adequate acceleration.

In addition, some types of pneumatic rodless actuators may leak air. If the actuator needs to hold a load vertically for any length of time, the air leak can affect how well that position is maintained. In certain circumstances, holding devices such as a brakes or external guidance systems may be required to safely control the load. Keep in mind that vertical applications with externally guided loads still see moment loads due to gravity. For example, a 50-lb. load with a bracket arm 12 in. from the actuator's load carrier would be subjected to a 600 lb.-in. moment load.

Environmental considerations. Failing to factor in environmental considerations can lead to catastrophic results. Extreme heat or cold, external abrasives, dirty or wet conditions, caustic fluids, and air quality are just a few of the conditions that affect cylinder life. Frictional wear (abrasive, pitting, adhesive, and corrosive) due to particulates or fluids hitting the cylinder can cause premature wear or failure and increase maintenance.

Most manufacturers specify cylinder performance based on normal operating conditions. If the cylinder must operate in adverse environments, it is best to discuss this with the manufacturer to determine if the cylinder can deliver the expected performance.

This article was written and contributed by Tolomatic.

Engineering Support to the Rescue

Designers need to consider many important points when sizing rodless cylinders. Determining the available air pressure, proper working stroke, and overall length are relatively simple. But determining the effects of moment loads, dynamic loading, inertia, and breakaway pressure can be more complex. Leading manufacturers offer sizing resources and engineering support to make it easier to specify the right cylinder.

For instance, Tolomatic provides an online pneumatic actuator application worksheet (*tolomatic.com/support/application-worksheets*) that can be submitted to the company's application engineers for assistance with determining the proper actuator for the job.

When sizing a cylinder, it is always best to discuss application requirements with the manufacturer. Determining the right pneumatic rodless actuator can be an in-depth process because there are many different styles to consider. But in many applications, the space saving features and load-bearing systems of rodless cylinders make them an ideal choice for linear motion.

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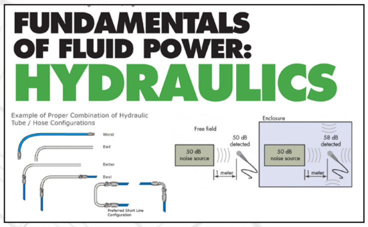
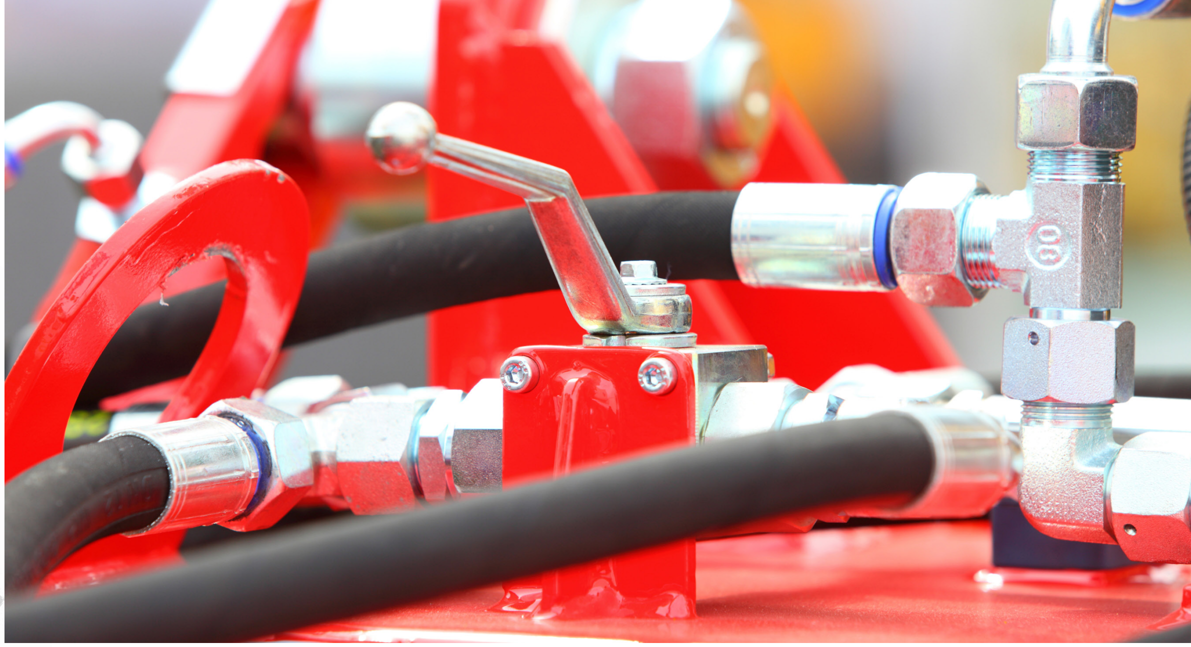




CHAPTER 6:

Understanding When to Use Hydraulics

SARA JENSEN, Technical Editor, *Power & Motion*

Use of hydraulics is best determined by considering the requirements of an application as well as several other factors.

Hydraulics is the segment of fluid power which typically uses pressurized oil to transmit power from one point to another, whereas pneumatic systems use gas.

Pascal's Law provides one of the basic laws of fluid power which essentially states that pressurized fluid in a contained body acts equally in all directions. The basic principle of this law and how it is applied in fluid power is outlined in the *Power & Motion* article "Chapter 1: Fundamentals of Fluid Power":

> Oil from a pump flows into a cylinder that is lifting a load. The resistance of the load causes pressure to build inside the cylinder until the load starts moving. While the load is in motion, pressure in the entire circuit stays nearly constant. The pressurized oil is trying to get out of the pump, pipe, and cylinder, but these mechanisms are strong enough to contain the fluid. When pressure against the piston area becomes high enough to overcome the load resistance, the oil forces the load to move upward. Understanding Pascal's Law makes it easy to see how all hydraulic and pneumatic circuits function.

While hydraulics and pneumatics each offer unique attributes, it is important to understand the requirements of an application to determine the best solution to use.

Why Choose Hydraulics?

In general, hydraulics is the preferred choice for higher force applications due to the higher power density they provide. Hydraulics typically come into play when needing to move something that weighs several hundred pounds or several tons said Jon Jensen (no relation to author), CFPPS, CFPECS & CFPAI, Industry Projects Manager – Energy at SMC

Corporation of America in an interview with *Power & Motion*.

He went on to explain that because the fluid does not compress in a hydraulic system, heavier objects can be moved with greater efficiency and control than with pneumatics. "It is usually a matter of loads and speeds [as well as] control that would dictate" which technology to use he said.

In addition, hydraulics is able to provide high power density in a small package. This gives hydraulics an advantage over pneumatics and other power transmission technologies in many applications.

Heavy-duty mobile machinery such as construction equipment is a key application in which hydraulic systems are utilized. Hydraulics are beneficial in heavy machinery because of the power density provided and the ability to transfer that power through hoses or other components to move parts of a machine such as the boom and bucket of an excavator.

Hydraulic systems can also be used in industrial equipment in manufacturing facilities, offshore equipment and are found in a range of other applications in which a large amount of power density or force is necessary.

Consider the Pros and Cons

Like any technology, hydraulics has its benefits and challenges which makes it vital to understand what they are and how they could impact system designs as well as end-use customers.

The cost and complexity of hydraulic systems is one of their potential cons said Jensen. There are more components to install and maintain over the life of a machine into which the system is integrated. This includes the system and the oil which flows through it.

Jensen noted each machine using a hydraulic system has its own motors and pumps to monitor and maintain whereas pneumatic systems can typically be run off a single, centralized compressor.

The ability of hydraulics to transfer power through long stretches of hoses, even when curved, benefits use in various applications. Image: Dreamstime/Voyagerix

However, many industry professionals consider hydraulics easier to maintain because there are fewer moving parts compared to other technologies. This equates to less wear and tear of components. And when a component does need repair or replacing, it is often relatively easy to do so, depending on the design of the system.

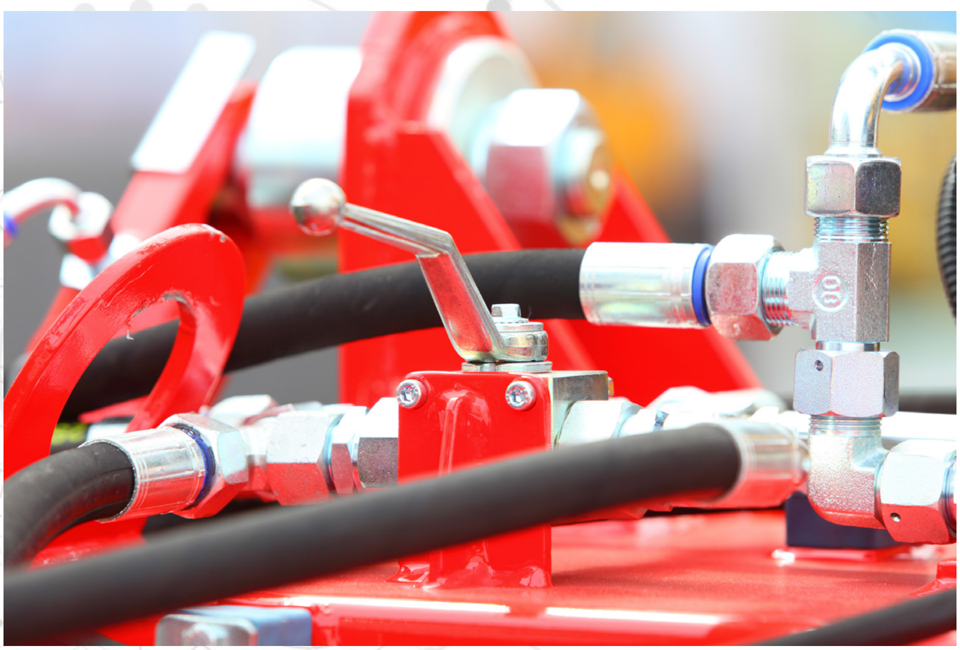
The use of oil is considered among the disadvantages associated with hydraulics due to the potential for leakage. It is generally a matter of when not if a hydraulic system will leak said Ryan Klemetson, Business Development Manager at Tolomatic, during a webinar hosted by the company discussing electromechanical components as an alternative to hydraulics.

Companies continue to look for methods to overcome this, such as new sealing solutions and use of other technologies when it makes sense like electric actuation. Development of oils which are safer for the environment or use in sensitive applications such as food production continue to progress as well.

Because of the potential for leakage from a hydraulic system, designers should be sure to take into consideration the environment in which the system will be utilized.

Efficiency is another challenge area for hydraulics. A substantial amount of power is typically lost during the energy conversion process, reducing a system's efficiency. Many manufacturers are working to improve efficiency, especially as it has become a more important aspect to OEMs and their customers.

The shift toward electrification is also necessitating efficiency improvements while simultaneously aiding the ability to achieve them through the incorporation of more electronics. Electrohydraulic solutions combining hydraulics and electronics are enabling more precision within systems and the ability to better manage pressure and flow so power is delivered when and where necessary.



Despite their high power density, hydraulics are challenged by power losses during energy conversion which can make them less efficient.
Image: Dreamstime/Voyagerix

Hydraulics are Here to Stay

General industry consensus is there will always be a need for hydraulics due to the power density they can provide. But like many other technologies, they will also continue to evolve to meet ever-changing customer and industry needs.

With the move toward electrification, there will be opportunities to rethink hydraulic component and system designs which will enable improvements in efficiency as well as the potential for a reduction in the number of parts required and system complexity.

Integration of sensors and software are bringing new opportunities as well. With sensors and software, more precision can be achieved through use of algorithms to provide more accurate performance as well as the ability to

Hydraulics are an appropriate choice for construction equipment due to their ability to provide the power necessary to move heavy loads in a controlled and efficient manner. Image: Dreamstime/Scruggelgreen

add new functionalities. All of this can help further improve efficiency and overall system performance.

Use of sensors and software also enables performance data to be collected which can aid with maintenance planning and future product developments. Better monitoring of components in a hydraulic system makes it easier to see when they may actually need maintenance instead of following a set schedule which can benefit an end user's time and costs by not making repairs until necessary.

While there are some applications in which hydraulics are being replaced by electromechanical solutions or pure electric systems, there will continue to be a need for hydraulic components and systems in many others. Understanding the application requirements and the attributes of hydraulics and other power transmission options will help to ensure the right solution is utilized.

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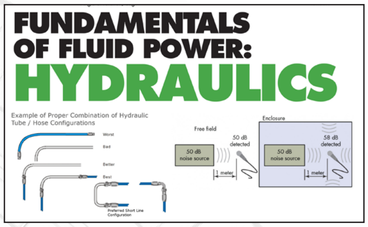

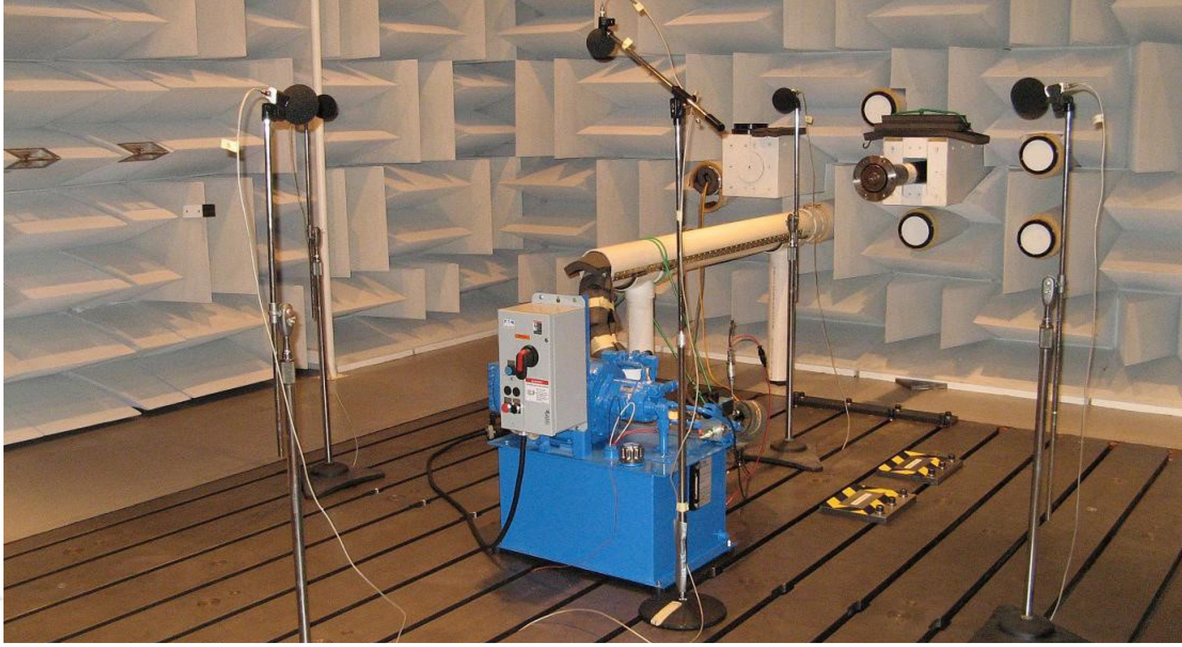

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CHAPTER 7:

How to Reduce Noise in Hydraulic Systems

MICHEL BEYER, *Chief Engineer, Noise, Vibration and Harshness at Danfoss Power Solutions*

Quieter systems not only have a perception of higher quality, but can also improve the health, safety, and productivity of machine operators.

The National Institutes of Health estimate that 15% of Americans between the ages of 20 and 69 have suffered hearing loss — mostly permanent — due to exposure to noise at work or in leisure activities. At the workplace, the combination of a quiet pump, well-engineered vibration and pulsation controls, and good, economical installation practices will result in a product with a distinct advantage in the marketplace.

Sound is formed by vibrations that create an audible mechanical wave of pressure through a medium, usually air or water. In hydraulics, noise can be grouped into three categories:

- airborne noise, which travels from the air to the ear;
- fluid-borne noise, which is transmitted through the hydraulic system; and
- structure-borne noise, which is created when one component of a system propagates vibration through another component.

The factors that influence noise generation are summarized in **Figure 1** (below). Unfortunately, people often reference only input excitation (force) and sound pressure or sound power. They tend to avoid the other factors that make up the physics of noise generation. Sometimes one part is dominant while others are not. Therefore, one must consider all of these factors when designing for low noise.

Furthermore, the process applies separately to airborne, fluid-, and structure-borne, noise. Each application is unique, so you can't assume that what works in one system or assembly will work in another.

A Closer Look at Noise Sources

Simply put, noise is any unwanted sound. More technically, it is the unwanted byproduct

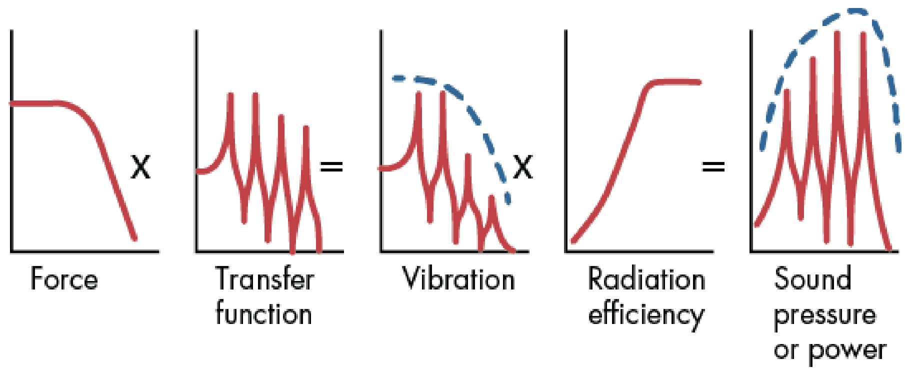


Figure 1: Factors that influence the generation of noise range from input excitation (far left) to sound pressure or sound power (far right).

of fluctuating forces in a component or system. As previously mentioned, noise can be transmitted in three ways: through the air, through the fluid, and/or through the system's physical structure.

Airborne

We generally think of noise as traveling only through the medium of the air, going directly from its source to some receiver — our ears. This is airborne noise. Airborne noise, however, must have a source within some component of the system or application. That component can be, but is not always, the pump.

All noise heard by the operator is technically airborne noise. From the perspective of the noise, vibration, and harshness (NVH) engineer, airborne noise refers to noise that came directly from the surface of the source.

Fluid-borne

Whether it's a piston, vane, or gear pump, these positive-displacement pumps all have

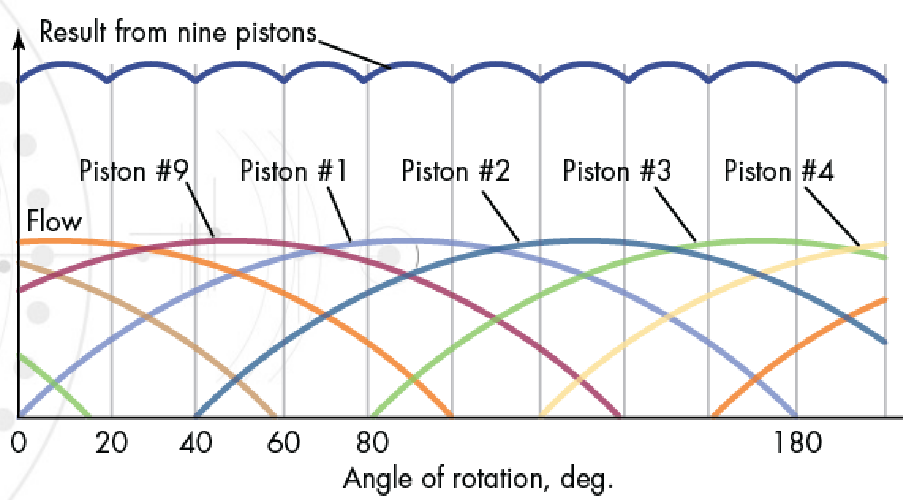
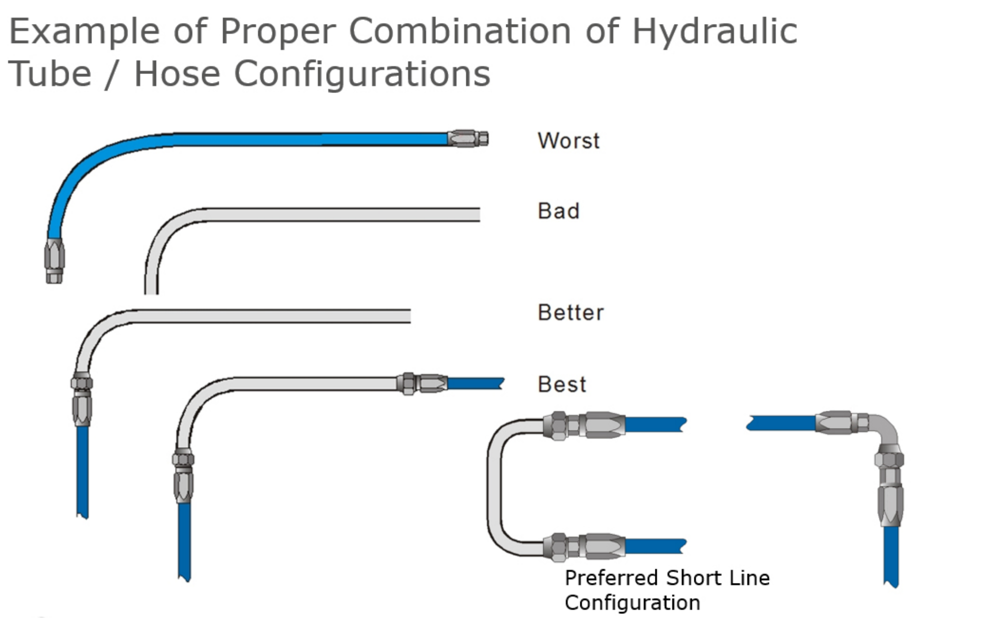


Figure 2: Characteristics of the noise generated by hydraulic pumps are determined by many factors, including their design and number of pumping chambers. This illustration shows individual and combined flow pulsations in a nine-piston pump.

some level of pressure ripple **(see Figure 2)**. As a result, uneven flow characteristics and pressure pulsations are created and transmitted through the fluid. This is known as fluid-borne excitation. The fluid-borne excitation generates vibration at the surface of the hose, which can be transferred into adjacent structures via the hose clamps/supports, or due to direct contact of the hose to the structure when under pressure.

The pressure pulsations of fluid-borne excitation, in turn, create corresponding force fluctuations. The vibrations in the hydraulic hoses are known as pressure ripple or fluid-borne excitation. These result in vibrations that create fluid-borne noise.

Proper hydraulic-line configuration can be used to maintain vibration isolation when pumps and electric motors are mounted on isolators. A proper combination of rigid tubing and flexible hose can provide a more stable configuration, reducing vibration and noise. The best combination is short lengths of rigid tubing connected at each end to flexible hose.



An example of hose vibration isolation.

Vibration isolation of hydraulic lines and hoses from the application structure (i.e., frame, supports, or panels) offers another opportunity to reduce noise in the design of the machine. Panels and shields can often act as speakers and amplify relatively low vibration levels into high noise sources.

Hydraulic hoses and tubing can be transmitters of fluid-borne vibration in these components, turning structural components into "speakers." It's important to address the position of hoses or tubes when designing quiet hydraulic equipment in order to achieve maximum noise reduction.

Pressure ripple can also be further reduced by incorporating a "hydraulic muffler", also known as resonators, attenuators, or suppressors into the hydraulic system. These components are optimized for each hydraulic system by their design and placement within the system.

Transmission loss is a measurement of the effectiveness of the component or the degree of optimization of its design. Insertion loss is the measure of the optimal placement of the resonator within the hydraulic system. Both transmission and insertion loss are important factors when trying to achieve a "low noise by design" hydraulic system. An optimized resonator system can reduce the magnitude of the pressure ripple by as much as 20dB or more.

Structure-borne

Structure-borne noise is the result of vibration transmitted only through the structure of the application. The vibration, as shown in **Figure 1**, is the combination of the force and the response of the component, and the radiation efficiency of the component. These structures then emit an audible sound, or airborne noise, which is what hydraulic equipment operators physically notice.

Structure-borne noise starts with vibration from an external source or component and is transferred directly into the electric motor, structure or frame of an application. Once the vibration enters the structure, it propagates through the structure at the speed of sound of the structure (most likely steel), which can excite other components and cause them to become radiators of noise, i.e. speakers.

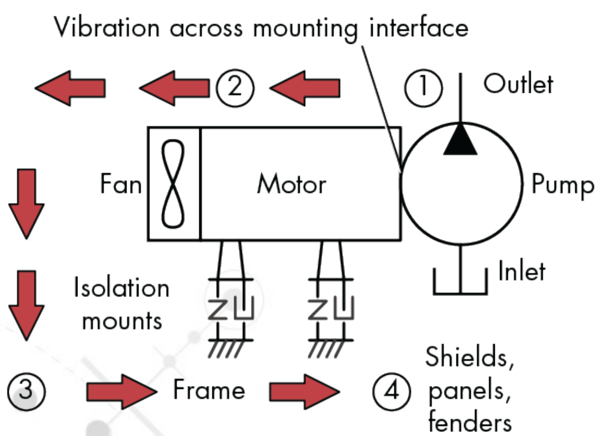


Figure 3: Structure-borne noise starts with vibration from an external source or component, and then transfers directly into the electric motor and structure of a machine.

Components on the machine, such as panels, shields, supports, and reservoirs, can radiate noise at pumping frequencies and multiples of pumping frequencies very effectively (**see Figure 3**). That's because these types of components have many resonant frequencies. Components such as these are known as high modal density components.

Vibration control can be used to minimize transmission of vibration from pumps and drives to machine structures and equipment. This can be achieved by isolating the pump and/or motor from rigid foundations by using subplates or other base isolators.

Large areas of thin metal in systems can also radiate noise effectively. This noise can be reduced by strategically placing engineered stiffening ribs or damping treatment to the metal surfaces.

Understanding Noise Parameters

Evaluating noise can become confusing, because multiple vibration paths can exist at the same time. One must understand the source ranking of the noise to properly evaluate the system transmission paths and effectiveness of each in any and all operating conditions.

A noise source is often surrounded by a box-like enclosure to provide a physical barrier between the noise sources, which can be caused by hydraulic power units, valves, hydraulic manifolds, motors, cylinders, hoses/tubing, and additional machine equipment. These barriers are designed to reduce the sound generated by hydraulic equipment at the operator or bystander locations.

Acoustic leakage around door seals, etc., can also greatly affect the ability of an enclosure to reduce the transmitted sound. In general, a 1% "hole" in an acoustic enclosure will permit 50% of the noise measured in it to leak out. When enclosed, amplitude of the noise within the enclosure actually increases as the noise reflects within the enclosure, rather than projecting out.

Noise amplitude within the enclosure depends on the distance from the dominant source that the noise is measured. As a general rule, the amplitude of a noise source when placed inside an enclosure can increase noise inside the enclosure by 5-8 decibels (dBA), or 78-151% greater than the source without an enclosure (**see Figure 4 below**).

Another important factor in terms of enclosures is absorption coefficient. All enclosures have some level of internal absorption but adding additional absorption material will help reduce noise. Larger enclosures will have a lower amplification factor than smaller enclosures. Gaps or holes in the enclosure will reduce the effectiveness of noise reduction outside of the enclosure. Even a tiny hole or gap in an enclosure can significantly reduce its effectiveness in curbing sound.

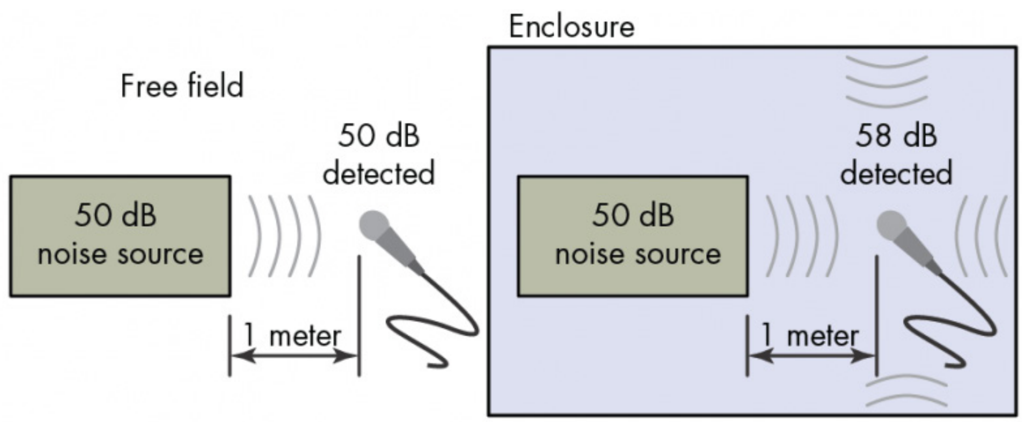


Figure 4: Enclosures are often used to isolate noise. However, placing a noise source in an enclosure can increase noise inside the enclosure by 5-8 dBA, which translates to a 78-151% increase over that without an enclosure.

Quieter Products and Systems by Design

A successful noise-control program requires a team effort by individuals in several areas of expertise. A quiet hydraulic pump does not guarantee a quiet system. Choosing a quiet pump should be only one part of a multifaceted program that calls upon the talents of the system designer, fabricator, installer, and maintenance technicians. A breakdown in any of these areas can unravel the entire noise control program.

System designers play a key role in achieving successful noise control. They must evaluate every noise-control technique available from the standpoints of effectiveness, cost and practicality. At the onset of developing a noise-control program, it's best to start at the source: the pump. Of course, the pump manufacturer is responsible for delivering a quiet pump. Subsequently, the most common strategy is to use a porting design to minimize the pressure pulsations at the pump's rated speed and pressure.

At the component level, designers may want to start off with variable-speed pumps. In variable-speed drive (VSD) systems, the pump speed varies to match the duty-cycle requirement. This will lower noise, because speeds are reduced when not needed by the system.

Although quieter individual components may contribute greatly to noise reduction, additional gains can be achieved by reviewing the overall system design for opportunities to reduce noise. Vibration control works to minimize transmission of vibration from pumps and electric motors to machine structures. This can be achieved by isolating the pump and/or electric motor from rigid supports via sub-plates or other base isolators.

System testing and evaluation can provide further insight into noise reduction. In properly designed testing areas, isolating components from background noise makes it possible to focus on noise sources, transmission paths and opportunities for reduction.

The potential for successfully reducing noise becomes greater when evaluating noise with a systematic approach rather than simply selecting individual components. An informed team, cognizant of the various components and roles in the overall system, can help identify noise sources and design for low noise.

Sound Quality in Hydraulic Systems

Hydraulics is not always the source of a noise problem, but hydraulics frequently get the blame. The reason has more to do with the quality of the sound produced than with its volume or pressure. Most readers are familiar with the annoying quality of a hydraulic whine. Measured objectively, that whine typically doesn't have a lot of sound power. However, it is unpleasant and tonal, and that makes the actual sound seem even louder.

There are a variety of sound quality measures that are used. For quantifying the "hydraulic whine" of a positive displacement pump, sound quality metrics such as loudness

A properly designed testing area isolates components from background noise to more easily focus on noise sources and transmission paths.

and tone-to-noise ratio are often used. To characterize flow noise, which can be generated within steering control units and valves, sound quality metrics such as sharpness and articulation index are often used. However, OEMs are not limited to using the metrics listed above and can instead use a single, but different, sound quality metric. More often, several weighted sound quality metrics are used to characterize the desired sound of their product.

Therefore, in addition to the objective issue of how much the hydraulic system contributes to overall sound levels, machine builders also have to address the subjective issue of how the quality of their application's sound affects overall customer perception of its quality. The rumbling of an engine is typically much louder than hydraulic whine, but the perception of engine noise is one of power and strength.

With hybrid- and full-electric applications becoming more abundant, the noise source contribution of a "typical" mobile application with an engine/exhaust/fan is changing. The downsizing or removal of the engine has reduced or removed noise sources that have "masked" the noise from the hydraulic system in the past. And the reduction or elimination in the amplitude of these other sources is placing a greater emphasis on hydraulic system noise reduction.

In future applications, the noise generated by the hydraulic system will be much more noticeable and form a more dominant noise source in the application.

This article was written and contributed by MIKE BEYER, Chief Engineer, Noise, Vibration and Harshness at Danfoss Power Solutions, in Eden Prairie, MN.

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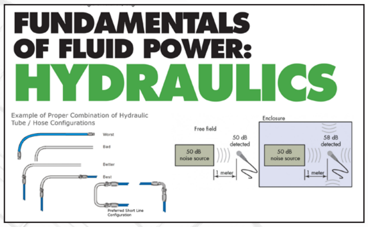

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CHAPTER 8:

A Checklist for Sizing Hydraulic Filters

DON KRAUSE, General Manager of Business Development, Ohio Fabricators Co.

There are a dozen questions designers and operators should consider before choosing a new or replacement filter for a hydraulic system.

To get the best performance out of a hydraulic system, it is essential that it have proper filtration. Choosing the right type of filter and sizing it properly could be the difference between a smooth running, long lasting hydraulic subsystem and one that performs poorly and is often down for maintenance.

But selecting the proper filter is not a simple task for designers or operators who must replace old or damaged filters. Even if a maintenance team is replacing a damaged filter with one just like it, the team should ensure it is the right filter for getting the job done efficiently and effectively.

To get the right filter, engineers and designers need to know and understand hydraulics and the application, including its performance requirements.

There are a dozen questions designers and operators should consider before that will help designers get to know the application and choose just the right filter.

What is the pump's flow rate? Knowing the pump's flow rate for the fluid will determine the filter media's surface area. The table below shows an approximate filter size (in square inch of filter media) and the acceptable flow rates.

FLOW RATE (GPM)	FILTER MEDIA (SQ. IN.)
3	33-38
5	55-65
10	110-118
20	150-165
30	250-270
50	300-330
75	355-405
100	455-500
150	640-690
200	965-1050
400	1740-1800

Table 1: All figures are approximation based on 149 microns at a standard operating temperature of 100°F. This allows for flexibility when using other levels of filtration and lets the table serve as a guideline.

What is the pipe size? Flow rate and pipe size go hand in hand. The filter must be properly sized to keep the pressure drop compatible with the fluid passing through it. A pump putting out 50 gpm, for example, will create less pressure drop when going through a 3-in. npt (American National Standard Taper Pipe Thread) pipe than through a 1-in. npt pipe. The pipe size will help focus filter selection. A general reference chart below relates pipe size to flow rate.

Typically flow velocities in hydraulic subsystems should be high enough to ensure the subsystems run smoothly and efficiently. In pump suction lines, flows should be travelling roughly 2-4 ft. per second (fps); in pressure lines, 10-25 fps is the range for fluid velocities; and for return lines, the figure is 5-10 fps.

FLOW RATE (GPM)	PIPE SIZE (NPT)
2	1/4" - 1/2"
3	3/8" - 3/4"
5	3/4" - 1 1/4"
10	3/4" - 1 1/4"
20	1" - 1 1/4"
30	1 1/2" - 2"
50	1 1/2" - 2"
75	2 1/2" - 3"
100	2 1/2" - 3"
200	3" - 4"
400	4" - 6"

Table 2: Common sense dictates that the higher the flow rate, the larger the pipe should be. Here are general approximations that relate flow rate to pipe size.

What is the working system pressure? The answer to this question will let designers choose a filter that will withstand that anticipated pressure. If the filter can't and it collapses, it will likely lose its integrity, break down, damage the entire hydraulic subsystem and lead to a possible breakdown. To make matters worse, when a filter collapses, fragments of epoxy or filter media are injected into the flow stream and can damage downstream equipment.

What is the fluid? Is it standard hydraulic fluid? Is it a petroleum-based product compatible with the equipment? These answers will let designers and operators know if the fluid is compatible with all system components as well as filters. If it is not, be prepared for serious system damage or destruction.

For example, if phosphate ester is the process fluid, polyester, nylon and stainless steel filter media are fine, but polypropylene is unacceptable. Standard hydraulic oils are compatible with filter media such as cellulose, polyester, polypropylene, stainless steel and most other types of media. The point is to ensure that the process fluid, filter media and seal material are all compatible. If there are any compatibility issues in any area, there will be leaks and major contamination problems.

What is the fluid's viscosity? Standard hydraulic fluid has a viscosity of 150-200 SUS (Saybolt Universal Seconds, the time [in seconds] for 60 ml of oil to flow through a standard orifice at a given temperature). Any fluid with a higher viscosity is thicker than standard hydraulic fluid. Fluids with higher viscosities create higher pressure drops as they flow through the system, especially during cold weather start-ups. Designers and operators should be aware that allowable initial pressure drops vary widely from component to component and so they should know system requirements for pressure and ensure they will be met.

What type of pump is being used? Is it a piston, gear, vane or other type of pump? This is important to know when installing a new or replacement suction strainer. Suction strainers keep contaminants out of the pump, the most important component in a hydraulic subsystem. Different types of pumps sometimes require more protection. The chart provides general guidelines for adequately protecting hydraulic pumps.

What mesh or micron should be used? To completely size a filter, knowing the filtration level is critical to efficiency. Suction lines should be no finer than 200 mesh (74 micron). Having filtration that is too fine on the suction side can cause pump cavitation. (See **chart 1** for guidelines on filter mesh.)

Piston Pump
Low pressure: 250-500 psi - use 100 mesh (149 micron)
High pressure: 1,000-2,000 psi - use 200 mesh (74 micron)
Gear Pump
Low pressure: 250-500 psi - use 30 mesh (595 micron)
High pressure: 1,000-3,000 psi - use 100 mesh (149 micron)
Vane Pump
Low pressure: 250-500 psi - use 60 mesh (238 micron)
High pressure: 1,000-5,000 psi - use 100 (149 micron)

Chart 1: This chart is a general guide to adequate protection for a pump

Typically, the pressure line has the finest filtration in the system because it is the most critical. So, the pressure line filter mesh could be in the sub-micron area, depending on the application. The return line should be anywhere from 5-74 microns, again depending on the application. This is an area that should be looked at closely because applications, requirements and operational scenarios vary so much.

The H7000 series suction strainer from Ohio Fabricators can filter petroleum-based fluids, fire-resistant fluids (phosphate esters and water glycols), lubricating oils, coolants, fuels and water. It handles flow rates of up to 50 gpm.

What type of filter is required? If it is a suction strainer, is it in-tank or in-line? Is it a replacement filter for an existing housing or does it also have a cartridge that must be replaced? Is the filter media wire cloth, cellulose or synthetic? If it's a synthetic material, has it been performing properly?

Will the system operate continuously, intermittently or infrequently? If a system operates continuously, possibly working three shifts per day, the filter chosen must be able to endure the rigors of that operational pace. If the filter will be used in a subsystem that operates only once in a while, a less costly filter may do the job. The worst possible occurrence is machine breakdown because the filter installed couldn't withstand the operation.

What is the system operating temperature? A hydraulic subsystem's standard operating temperature is usually around 100°F. If the temperature runs hotter than that, the system should be kept cool. Too hot a system destroys seals, causes leaks and breaks down the fluid. Either a cooler should be installed or high-temperature seals made of Buna, Teflon or Viton should be used.

Is the system mounted inside or outside? Moisture is the second most damaging contaminant in any hydraulic subsystem. With outdoor hydraulic subsystems, exposure to rain, snow and humidity gives water a good chance of getting inside them. To prevent this, adding hygroscopic breathers can keep water out. Even in some indoor systems, depending on the local weather, moisture can cause problems. It may be necessary to use stainless steel filters with housings to prevent corrosion. If unsure if the metal in the filter is stainless or plated steel, find out what the other components are made of as that may help determine which materials should be used.

What about the air that gets into the reservoir? The tank breather is an area of hydraulic subsystems which seems to be neglected and not serviced as often as it should. As reservoir fluid levels rise and fall, atmospheric air enters and is expelled. The air carries both particles and moisture which contaminate the fluid held in the reservoir. To keep out these contaminants, a hygroscopic breather may be warranted.

This pump motor was destroyed by contamination.

Sizing this component is just as critical as any other filter. Air intake is measured in standard cubic feet per minute (scfm or just cfm). A general rule of thumb for sizing a tank breather is to divide the pump rating by 7.5 to get the cfm. For example, if the system is running at 100 gpm, then divide that by 7.5 to get 13.3 cfm. Most small breathers are rated for up to 35 cfm and are available with 3-5 micron filtration. Remember, it is permissible to oversize the air filter.

The answers to these questions will help designers and operators choose the best filter for a specific hydraulic subsystem. To protect the entire subsystem, all lines—suction, pressure, return and tank breather—must be adequately and appropriately filtered to keep it running smoothly and efficiently.

This article was written and contributed by Don Krause, general manager of business development at [Ohio Fabricators Co](). in Coshocton, Ohio.

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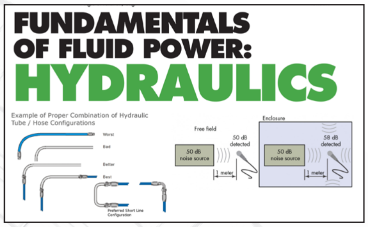

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CHAPTER 9:

Rotary Unions and Swivels

VINAY PATIL, Mechanical Design Engineer, United Equipment Accessories

Choosing effective rotary union and swivel fittings allow hoses to pivot, preventing stress and premature failure.

A rotary union is the fitting used to transfer the pressurized fluid from a fixed inlet to rotating outlet, without obstructing the flow of the fluid or air. This fitting is sometimes referred to as a swivel joint, rotating manifold, or rotary union.

Below, **Figure 1** shows a swivel fitting containing a single circuit to transmit fluid. These fittings pay for themselves many times over by reducing stress on a hose, thereby extending its life. This describes one end of the swivel spectrum.

At the other end are rotary unions that transmit fluid for multiple circuit lines through a single manifold that rotates continuously. In general, fluid enters one or more ports in the stationary portion of the manifold and exits through one or more ports on the other portion, which rotates with the machine. A rotary seal between the two halves contains the pressurized fluid, yet allows relative rotation between the halves. For simplicity of discussion, the term rotary union will be used here as an all-inclusive term to describe swivel fittings and rotating manifolds.

The rotary seal is probably the most critical part of the device, whether a swivel fitting or rotary manifold. This is because the seal between the rotating and station-

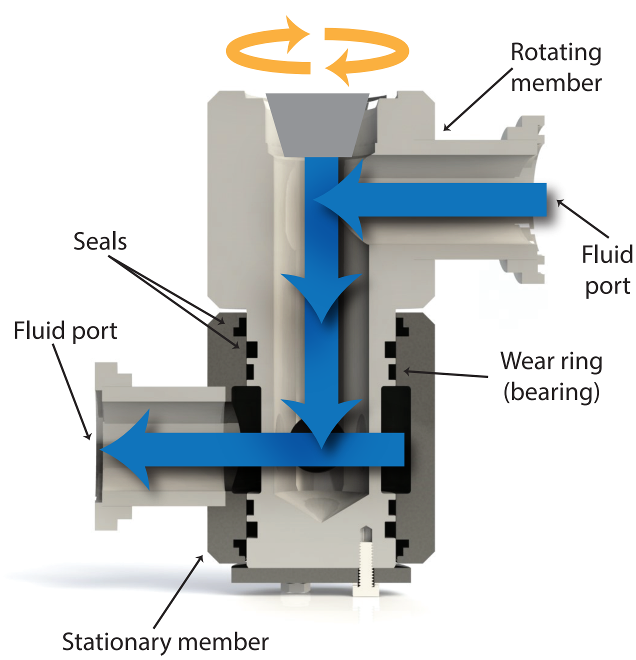

Figure 1: Cutaway view of single port swivel fitting.

ary halves must be tight enough to prevent leakage of pressurized fluid, while introducing as little torque drag as possible. Torque drag is a measure of the swivel joint's resistance to rotation.

These seals vary in complexity depending on the application. For simple swivel fittings undergoing less than 360 degrees of rotation, the seal may be little more than two machined surfaces loaded against each other. Rotating manifolds, however, may require ball bearings and spring-loaded seals with auxiliary loading by fluid pressure. If the seal is not pressure balanced (fluid pressure acting on opposite sides of the seal), torque drag may increase with fluid pressure.

As with any custom-engineered product, manufacturers can supply a swivel joint to meet virtually any specification. However, a variety of standard swivels is available to keep costs reasonable.

Configurations

Most swivel fittings are standard catalog items considered specialty fittings. However, depending on their complexity and manufacturer, rotating manifolds often are engineered items that must be special-ordered, especially if more than four independent flow paths are required. Standard configurations of swivel joints include straight through (where flow paths are coaxial) and right-angle (where outlet ports are perpendicular to inlet ports). A less common design is the offset configuration, which is essentially a straight-through design with a 90-degree elbow at each end.

Available space and fluid line routing generally determine which configuration should be used. Keep in mind that axial length and the overall diameter of a rotating manifold increases with the number of independent flow paths. In some applications, directional control valves can be mounted on the rotating end of the machine to allow routing only two common flow paths (pressure and return) through the rotating manifold. In this case, all valves connect to the common flow paths through a conventional manifold or line fittings.

In some instances, a valve is built into the rotating manifold to allow or block fluid flow as the rotating member advances through a revolution. Internal passageways open and close as the manifold turns, allowing fluid to flow only when the rotating member is in certain positions — a setup that operates much like a camshaft and cam follower. As with a cam, this arrangement is not as easy to reconfigure as using electrically actuated valves. However, it can be very practical for applications that have a repetitive, fixed operation — such as an indexing table.

Other considerations include through holes and integral valves. A hole through the center of the rotating manifold may be necessary to provide access for electrical lines, a shaft, or other machine elements that must be routed from the stationary member to the rotating one.

Mounting the rotary union in improper ways can cause vibration. The way a rotary union is secured to the equipment also plays an important role. Proper support for the rotary union based on its weight and center of gravity must be considered. The inappropriate location of a torque arm with respect to the mounting can transmit side load, which can increase the torque drag or damage or reduce the seal's life. The mounting flange and the torque arm can be welded or bolted to the rotary union depending upon the application. The rotary union can also be painted or provide some other means to prevent metal corrosion.

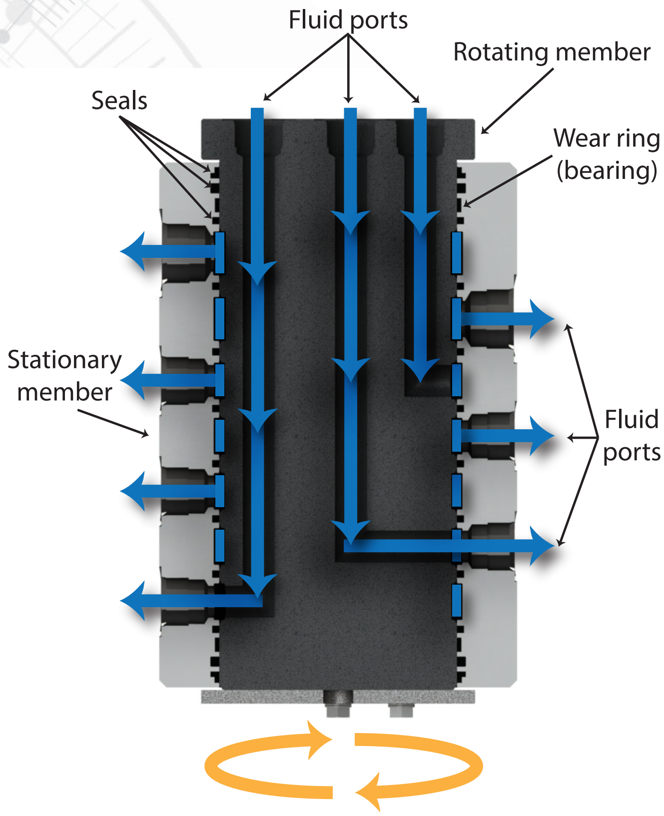

Figure 2: Cutaway view of the multi-port rotating manifold. Bearing construction allows the device to accommodate side loading.

Type of Motion

Just as swivel joints and rotating manifolds should exhibit minimal friction to allow free rotation, hoses and piping should transmit as little external load as possible to the swivel joint, unless the swivel joint is designed with adequate bearings to support external loads. Otherwise, seals can wear prematurely and leak. In extreme cases, the rotating joint itself may fracture.

Just the weight of components — hoses, tube assemblies, and fittings — may be substantial enough to transmit an external load to the swivel. For instance, the weight of a 10-ft. section of spiral-wound hose and the load exerted by the fluid under pressure can easily be underestimated or overlooked. However, it can transmit a substantial side load or bending moment on a swivel joint.

Size and Mounting

The swivel joint must have ports of the correct size and geometry to accommodate hose or tubing assemblies mating to it. Ensure that enough room is available on the equipment structure to accommodate the swivel joint. For swivel fittings, as with any fitting, the higher the flow rating, the larger the ID and external envelope of the fitting. For rotating unions, enough clearance must be provided between ports to allow threading and unthreading hose- and tube-end fittings to the manifold. Also keep in mind the physical size of the rotating union. The more fluid lines which are routed through the manifold, the larger will be its overall size.

A means must exist to either mount the swivel to the structure or to mount the connecting hose and/or tubing to the structure adjacent to the swivel joint. This practice helps prevent misalignment from long runs of unsupported hose or tubing. Misalignment can transmit side loads to the swivel, causing the detrimental effects outlined above. Side loading can also be introduced by forcing misaligned rigid tubing into position for mounting. The assembly may fit together, but life and performance of the swivel joint may suffer.

Rotary unions often are used in applications such as this excavator fitted with a log grapple. A rotary union mounted between the turret and track dive transmits hydraulic fluid between the rotating and non-rotating assemblies, respectively. The grapple also uses a swivel to allow continuous 360-degree rotation for hydraulic fluid and electrical power.

Selection Considerations

When selecting swivel joints, not adhering to manufacturers' specifications can result in leakage, premature failure of the joint, premature failure of the hose, or all of these conditions. Exceeding manufacturers' published pressure ratings can cause fluid leakage by pushing fluid past the joint's rotary seals.

Rotary unions often are used in applications such as this excavator fitted with a log grapple. A rotary union mounted between the turret and track dive transmits hydraulic fluid between the rotating and non-rotating assemblies, respectively. The grapple also uses a swivel to allow continuous 360-degree rotation for hydraulic fluid and electrical power.

Excessive pressure can also increase friction, leading to premature wear and higher torque drag. The seal material also plays an important role in controlling friction, as harder material can increase the friction but is more stable at higher pressures and temperatures. However, seals made from a softer material may reduce friction, but they are not stable at high pressures.

Also ensure that the swivel joint is compatible with the application environment — the chemical composition of the fluid being used, operating temperature, and the external environment. Swivel joints are readily available in ductile iron, steel, aluminum, brass, and other materials to match the chemistry and temperature of the fluid with that of the seals and surroundings. Perhaps more importantly, a variety of seal materials are available to accommodate any hydraulic fluid along with a wide range of temperatures.

If possible, mount the swivel joint where it will have minimal exposure to abrasive or corrosive particles. In some applications, an elastomeric boot, bellows, or cover may be necessary to help isolate the seal area of the swivel joint from an extremely dirty environment.

This article was written and contributed by Vinay Patil, a mechanical design engineer at United Equipment Accessories.

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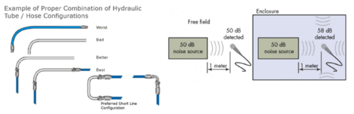

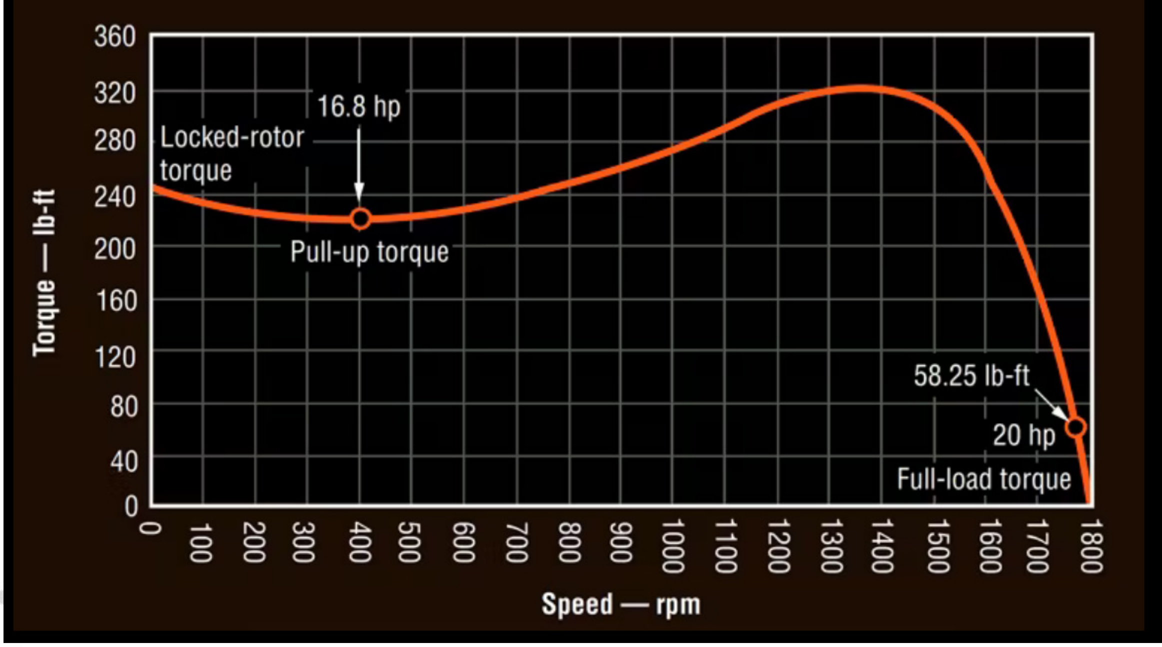

CHAPTER 10:

Hydraulic Power Units

POWER & MOTION STAFF

A hydraulic power unit driven by an electric motor must be sized differently from one driven by an internal combustion engine—due to differences in their torque-speed curves.

When specifying components for a hydraulic power unit (HPU), the prime mover is sized based on torque, speed, and power requirements of the hydraulic pump. This is fairly straightforward for electric motors because they generally have a starting torque that far exceeds running torque. Often, though, designers specify motors sized larger than necessary. This results in wasted energy because the motor operates at less-than-maximum efficiency.

Diesel and gasoline engines are another matter. They have a much flatter torque-speed curve, so they deliver roughly the same torque at high speed as they do at low speed. This means an internal combustion engine may develop high enough torque to drive a loaded pump, but not enough to accelerate it to operating speed. Consequently, with all other factors being equal, a power unit requiring an electric motor of a given power rating usually requires a gasoline or diesel engine with a power rating more than double that of the electric motor.

Selecting the Optimum Motor Size

The cost of electricity to operate an electric motor over its entire lifespan generally is many times that of the cost of the motor itself. Therefore, sizing the motor correctly for a hydraulic power unit can save a sizable amount of money over the life of the machine. If system pressure and flow are constant, motor sizing simply involves the standard equation:

$hp = (Q \times P) \div (1{,}714 \times E_M)$, where: hp is horsepower, Q is flow in gpm, P is pressure in psi, and E_M is the pump's mechanical efficiency.

However, if the application requires different pressures during different parts of the operating cycle, you often can calculate root mean square (rms) power and select a smaller, less-expensive motor. Along with the calculation of rms power (**Fig. 1**), the maximum torque required at the highest pressure level of the application also must be found. Actually, the two calculations are quite simple.

For example, such an application might use a 6-gpm, 3,450-rpm gear pump to power a

Root mean square horsepower:

$$hprms = \{\Sigma[(hp_1)^2(t_1) + (hp_2)^2(t_2) + \ldots (hp_n)^2(t_n)] / \Sigma(t_1 + t_2 + \ldots t_n + t_{off}/F)\}^{1/2}$$

where: t is the time interval in sec, and F is a constant — 3 for open drip-proof motors; 2 for totally enclosed fan-cooled motors.

Figure 1: Calculation for root mean square power.

cylinder linkage that operates for an 85-sec cycle (**Fig. 2**). The system requires 3,000 psi for the first 10 sec, 2,200 psi for the next 30 sec, 1,500 psi for the next 10 sec, and 2,400 psi for the next 10 sec. The pump then coasts at 500 psi for 20 sec, followed by 15 sec with the motor off.

It's tempting to use the standard formula, plug in the highest-pressure segment of the cycle, and then calculate:

hp = (6 × 3000) ÷ (1,714 × 0.9) = 11.7 hp for 10 sec.

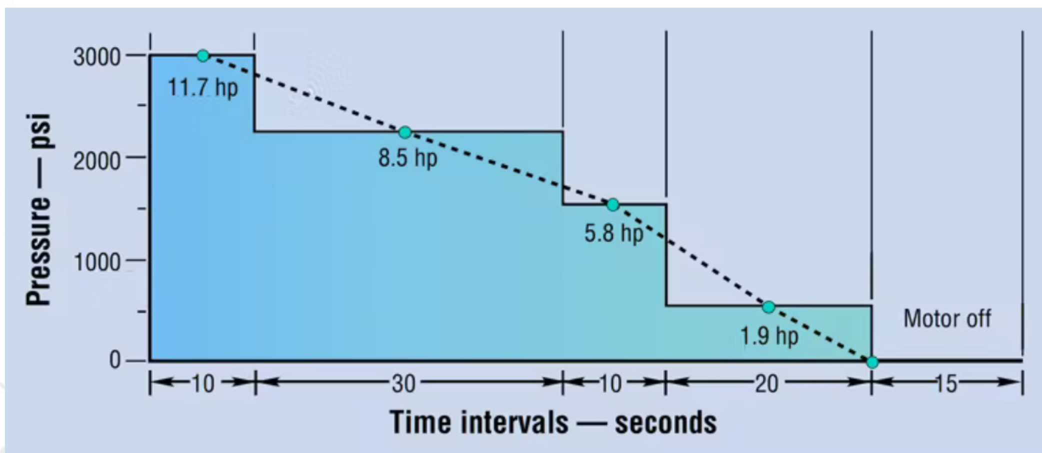

Figure 2: Multiple-pressure duty cycle for 6-gpm gear pump from example with calculated horsepower values.

To provide this power, some designers would choose a 10-hp motor; others would be ultra-conservative and use a 15-hp motor; a few might take a chance with 7-1/2 hp. These motors in open drip-proof C-face models with feet would carry a relative price of about $900, $1,200, and $600, respectively, so you could save hundreds of dollars per power unit by choosing the 7-1/2 hp motor—if it will do the job.

To determine this, first calculate the power required for each pressure segment of the cycle:

hp_1 = (6 × 2200) ÷ (1,714 × 0.9) = 8.5 hp for 30 sec.

hp_2 = (6 × 1500) ÷ (1,714 × 0.9) = 5.8 hp for 10 sec.

hp_3 = (6 × 500) ÷ (1,714 × 0.9) = 1.9 hp for 30 sec.

The rms horsepower is calculated by taking the square root of the sum of these power values squared, multiplied by the time interval at that power, and divided by the sum of the times plus the term (toff ÷ F), as indicated in Fig. 1.

Substituting the example values into the boxed equation and solving reveals that hp_{rms} = 7.2. Thus, a 7-1/2 hp motor can be used from the standpoint of power alone. However, the second item, maximum torque, still must be checked before reaching a final decision. The maximum torque required to drive this particular pump will be found at the highest pressure—because the gear pump's output flow is constant. Use this equation:

$T = DP \div (12 \times 6.28 \times E_M)$, where T is torque in lb.-ft., and D is displacement in in.^{3}

For this example, $D = (6 \times 231) \div (3{,}450) = 0.402$ in.^{3}

Then $T = (0.402 \times 3{,}000) \div (12 \times 6.28 \times 0.9) = 17.8$ lb.-ft.

Because electric motors running at 3,450 rpm generate 1.5 lb.-ft./hp, the 17.8 lb.-ft. of torque requires 11.9 hp (17.8 ÷ 1.5) at 3,000 psi. This matches closely enough for the example application. (At other standard motor speeds: 1,725 rpm generates 3 lb.-ft. per hp; 1,150 rpm, 4.5 lb.-ft. per hp; 850 rpm, 6 lb.-ft. per hp.)

Now the second criteria can be checked against what the suggested motor can deliver in torque. What is the pull-up torque of the 7-1/2 hp motor selected? Because the torque is least as the motor accelerates from 0 to 3,450 rpm, it must be above 11.9 lb.-ft. with an acceptable safety margin. Note that a motor running 10% low on voltage will produce only 81% of rated pull-up torque: in other words, $(208 \div 230)^2 = 0.81$. Reviewing motor manufacturers' performance curves will show several available 7-1/2 hp models with higher pull-up torque. Any of these motors could be a good choice for this application.

Both motor criteria now have been verified. The RMS power is equal to or less than the rated motor's power. The motor's pull-up torque is greater than the maximum required.

Gas and Diesel Engine Power

Correctly sizing an electric motor for a hydraulic power unit is a straightforward procedure. And if load pressure and flow remain fairly constant, determining the power requirement is relatively simple by using the familiar equation:

$hp = (q \times p) \div (1{,}714 \times E_M)$ where: q is flow, gpm (and accounts for the pump's volumetric efficiency), p is system pressure at full load, psi, and E_M is the pump's mechanical efficiency

For example, assume an application requires a flow of 13.7 gpm at a maximum pressure of 2,000 psi, and with a pump efficiency of 0.80. From the equation above: hp = (13.7 × 2,000) ÷ (1,714 × 0.80) = 20 hp.

It may seem that a gas or diesel engine as the prime mover would have the same power rating as an electric motor. However, the general rule of thumb is to specify an internal combustion engine with a power rating 2-1/2 times that of an equivalent electric motor (**Fig. 2**). This is due primarily to the fact that internal combustion engines have different torque-speed relationships than electric motors do. Examining the different torque characteristics will provide the understanding to make a choice based on solid reasoning, rather than putting faith in a rule-of-thumb.

Pump Torque Requirements

Power, of course, is the combination of torque and rotational speed. A pump's torque requirement is the main factor that determines whether a motor or engine is suitable for an application. Speed is less critical, because if a pump runs slowly, it will still pump fluid. However, if the prime mover does not develop enough torque to drive the pump, the pump will not produce any output flow.

To determine the torque required by a hydraulic pump, use the following equation:

$T = (p \times D) \div (6.28 \times 12 \times E_M)$ where: T is torque, lb.-ft., and D is displacement, in.^{3}/revolution

Pump displacement is provided in a manufacturer's literature. Continuing with the example introduced above, if the pump has a displacement of 1.75 in.^{3}/rev., required torque is calculated as follows:

$T = (2{,}000 \times 1.75) \div (75.36 \times 0.80)$ $T = 58$ lb.-ft.

Torque can also be calculated using the familiar horsepower equation:

$hp = (T \times n) \div 5{,}250$ where: n is shaft speed, rpm. Substituting values from the example: $20 = (T \times 1{,}800) \div 5{,}250$ $T = 58$ lb.-ft.

Electric Motor Torque Signature

To understand the differences in power characteristics between an electric motor and internal combustion engine, we'll first examine characteristics of a standard 3-phase electric motor. **Figure 3** shows the torque-speed relationship of a 20 hp, 1,800 rpm, NEMA Design B motor. Upon receiving power, the motor develops an initial, *locked-rotor torque*, and the rotor turns. As the rotor accelerates, torque decreases slightly, then begins to increase as the rotor accelerates beyond about 400 rpm. This dip in the torque curve generally is referred to as the *pull-up torque*. Torque eventually reaches a maximum value at around 1,500 rpm, which is the motor's *break-down torque*. As rotor speed increases beyond this point, torque applied to the rotor decreases sharply. This is known as the *running torque*, which becomes the *full-load torque* when the motor is running at its rated full-load speed—usually 1,725 or 1,750 rpm.

The torque-speed curve for a 3,600-rpm motor would look almost identical to that of the 1,800-rpm motor. The difference would be that speed values would be doubled, and torque values would be halved.

Common practice is to ensure that torque required from the motor will always be less than breakdown torque. Applying torque equal to or greater than breakdown torque will cause the motor's speed to drop suddenly and severely, which will tend to stall the motor and most likely burn it out. If the motor is already running, it is possible to *momentarily* load a motor to near its breakdown torque. But for simplicity of discussion, assume

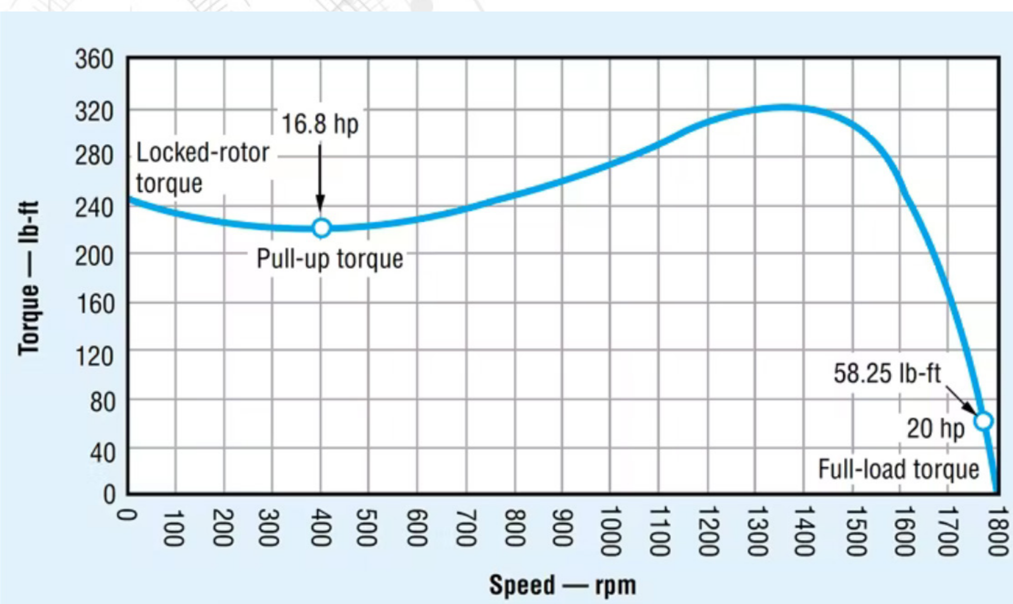

Figure 3: The torque-speed curve of an AC electric motor reveals that much higher torque can be generated at low speed than is needed to drive a hydraulic pump at full-load speed.

the electric motor is selected based on full-load torque.

Note that **Fig. 3** shows a temporary large torque excess that can provide additional muscle to drive the hydraulic pump through momentary load increases. These types of electric motors also can be run indefinitely at their rated hp plus an additional percentage based on their service factor — generally 1.15 to 1.25 (at altitudes to 3,300 ft.).

Catalog ratings for electric motors list their usable power at a rated speed. If the load increases, motor speed will decrease, and torque will increase to a value higher than full-load torque (but less than breakdown torque). So when operating the pump at 1,800 rpm, the electric motor has more than enough torque in reserve to drive the pump.

Torque Signature of Engines

A gasoline engine has a dramatically different torque-speed curve (**Fig. 4**) than an electric motor does. This means a gasoline engine exhibits a much less variable torque output throughout its speed range. Depending on their design, diesel engines with the same power ratings may generate slightly higher or lower torque at lower speeds than gasoline engines do, but diesels exhibit a similar torque curve throughout their operating speed range.

Calculations above determined that 58 lb.-ft. of torque is required to drive the pump at any speed. Referring to **Fig. 4**, the 20-hp gasoline engine develops a maximum torque of only 31 lb.-ft. — clearly not enough to drive the pump. This is because its 20-hp rating is based on performance at 3,600 rpm. Maximum torque occurs at speeds near 3,000

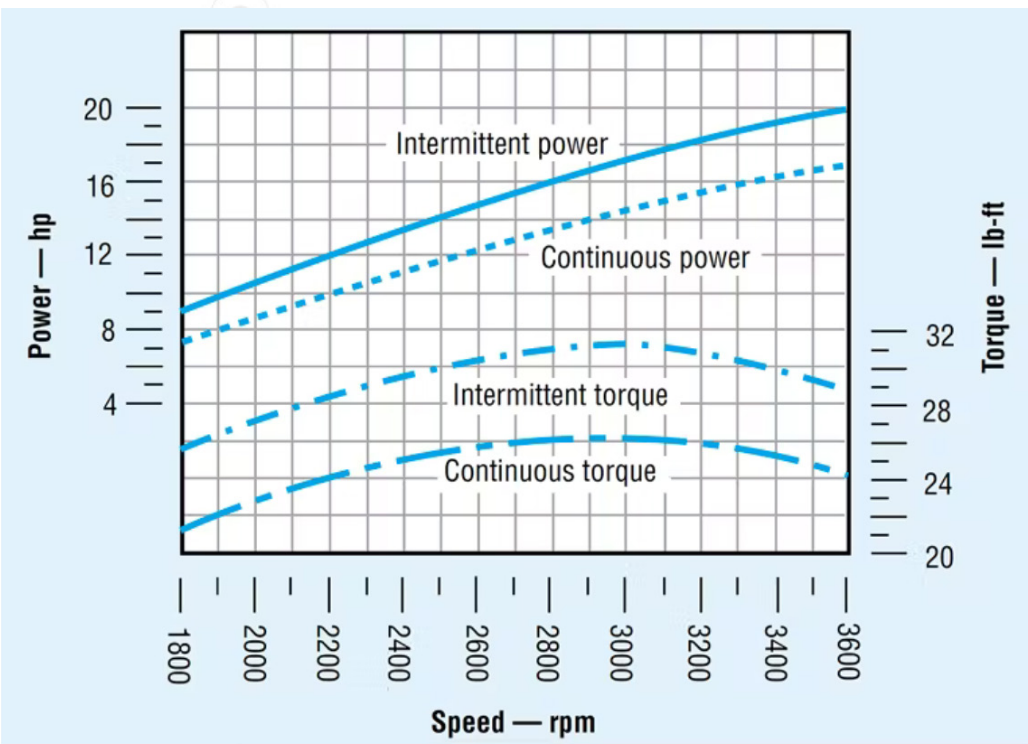

Figure 4: The torque-speed curve for an internal combustion engine is much more linear than that for an electric motor. This illustrates that to provide the torque to drive a hydraulic pump at low speeds, gas and diesel engines must have a higher power capacity than an electric motor for driving the same pump.

rpm but is still well below the 58 lb.-ft. required by the pump. Even if the engine produced enough torque at this speed, power would still be inadequate due to the lower speed.

This is where the 2-1/2 sizing rule comes from. A hydraulic power unit requiring a 20-hp electric motor to drive the pump at 1,800 rpm would require a gas or diesel engine rated at about 50 hp. Moreover, these values are based on an engine operating at its maximum torque and power ratings. However, manufacturers recommend that gasoline and diesel engines only operate continuously at about 85% of their maximum rated values to prevent seriously shortening of their service lives. So referring again to **Fig. 4**, a 20-hp gasoline engine would develop just over 26 lb.-ft. of maximum torque, and only 24 lb.-ft. at 3,600 rpm.

It is also interesting to compare this performance with fuel consumption. The fuel consumption chart (**Fig. 5**) shows that a 20-hp gasoline engine achieves greatest fuel efficiency at about 2,400 rpm, where it consumes just over 8.2 lb./hr (0.41 lb./hp × 20 hp). At 3,600 rpm, the engine would be considerably less fuel efficient.

Actions to Take

By now it should be clear that specifying a gasoline or diesel engine to drive an HPU follows a different procedure than that for specifying an electric motor. If you are accustomed to specifying electric motors for HPUs, you may be tempted to size a pump to be driven at 1,800 rpm, then specify an oversized motor that can develop enough torque to drive the pump at this speed. This technique will produce a reliable power unit, but one that is relatively heavy, bulky, inefficient, and noisy.

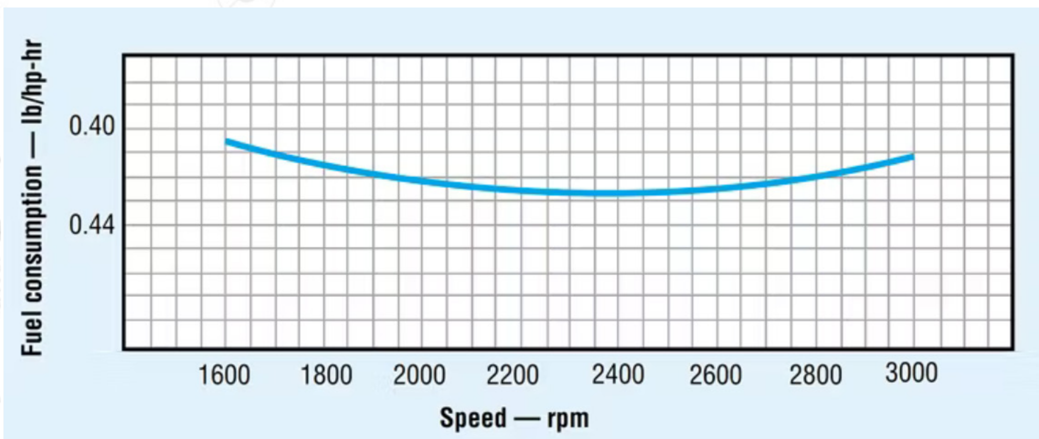

Figure 5: Depending on its design, a gas or diesel engine's optimum fuel efficiency often occurs at a speed other than where it produces maximum torque.

Instead of following this procedure, any of several options should be considered. One would be to drive the pump at a speed higher than 1,800 rpm. Pump literature for mobile equipment should list ratings at a variety of speeds. If it doesn't, consult the pump manufacturer. Driving the pump at a higher speed decreases its required displacement, thereby reducing its size, weight, and torque requirement. So operating the power unit at higher speed more closely matches engine performance to the application by increasing torque produced by the engine and reducing the torque required by the pump.

More specifically, operating the pump in our example at 2,800 rpm would increase engine torque to more than 30 lb.-ft. and reduce torque required by the pump to perhaps 38 lb.-ft. Although the engine torque still would fall short of that required, it obviously comes much closer to matching pump torque than when operating at 1,800 rpm.

Designers may be tempted to run a gas or diesel engine at or near the speed at which it exhibits optimum fuel efficiency. However, an operating speed where the engine produces maximum torque generally takes priority. This is because if the engine doesn't generate enough torque at its optimum fuel efficiency speed, a larger engine would be required. But a larger engine consumes more fuel, which would defeat the purpose of trying to conserve fuel by operating at a specific speed.

In addition, pumps generally have a speed range at which they are most efficient. So even if an engine operates a few hundred rpm above or below its optimum fuel efficiency speed, torque produced and pump dynamics generally have a more pronounced effect on overall efficiency of the power unit. Therefore, the speed at which the gas or diesel engine operates should take all of these considerations into account.

As far as pump performance, many designs exhibit higher mechanical and volumetric efficiencies when operated at speeds greater than 1,800 rpm. On the other hand, operating a pump at a speed higher than what it was designed for would reduce its service life. Therefore, it is important to choose a pump speed that offers the best combination of pump and engine performance.

Perhaps an even better alternative would be to provide a gearbox or other type of speed reducer between the engine and pump. Although this would add components to the power unit, it would increase torque and reduce speed while allowing both the engine and the pump to operate at their optimum speeds. The additional cost of the speed reducer may be offset by the lower cost of a smaller, lighter, and less expensive engine.

Other Considerations

Because gas and diesel engines do not exhibit the torque reserve of electric motors — especially when accelerating from rest — it is especially important that the pump be unloaded whenever the HPU is started. This can be done hydraulically, or mechanically through a centrifugal clutch or other type of drive element.

Finally, as with HPUs driven by electric motors, pump size — and, therefore, size of the prime mover — often can be reduced by incorporating accumulators into the hydraulic system. If the hydraulic system operates in cycles where full flow is needed only for brief periods, an accumulator can store hydraulic power during periods of low flow demand and release this energy when full flow is needed.

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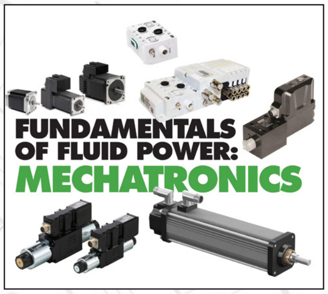

Image: Tolstykh

CHAPTER 11:

The Role of Fluid Power in Mechatronics

SARA JENSEN, Technical Editor, *Power & Motion*

Hydraulic and pneumatic components can play an integral part in systems which combine mechanical and electronic principles.

Mechatronics is a term originally coined in the 1970s to denote the integration of mechanics and electronics. It has since evolved into a branch of engineering which takes an interdisciplinary approach to integrating mechanical, electrical and electronics as well as telecommunications, computer science and more.

The general industry consensus is that mechatronics is synonymous with automation, robotics and electromechanical solutions. Those working in this field bring together principles of mechanical and electrical systems as well as computing and other technologies to create advanced systems which are smarter and simpler to use.

Although the development of advanced manufacturing systems is often associated with mechatronics, it can also be applied in a range of other applications.

How Does Fluid Power Factor In?

When it comes to mechatronics, fluid power is typically considered a part of mechanical engineering. As hydraulic and pneumatic components remain powerful methods for transmitting energy, they are often used as an actuator within a larger mechatronics system.

While electric alternatives are used in some applications, there are many which will better benefit from the power density, speed and flexibility offered by fluid power components. Therefore, it is important to understand the requirements of an application as well as the differences between fluid power and other potential power transmission options, such as electromechanical actuators.

A common use case for fluid power components in mechatronic-related applications is robotics. Both hydraulic and pneumatic components can be utilized; hydraulic control offers the high forces and loads required for moving large components in automated systems as an example.

Pneumatics are commonly utilized for the end effectors of robots. This is due to pneumatic components being cost effective and easy to use as well as lightweight and powerful enough for the tasks for which robots are being used.

Beyond gripping, holding or moving objects, pneumatics in robots can also be used for driving, welding or boring tools attached to the end of a robot arm. All of these tasks require fast, reliable and repeatable movements which pneumatics can provide.

Festo has developed several pneumatic and electric components which can provide precise part movement for batteries and other sensitive electronics.

Image: Festo

Electrohydraulic and Electropneumatic Systems

Mechatronics can also come in the form of combining fluid power components with electronic technologies. Electrohydraulic and electropneumatic systems are becoming increasingly more common examples of this through the integration of sensors, software and other components.

Neal Gigliotti, Manager, Applications Engineering, Industrial Hydraulics at Bosch Rexroth said in an interview with *Power & Motion* that mechatronics have been an integral part of electrohydraulic systems for many years.

"A common example is controlling the position of a hydraulic cylinder," he said. "A combination of electronic closed loop motion controller, position feedback sensor, and proportional hydraulic control valve with hydraulic drive are used to maintain control of the cylinder position, insuring smooth and accurate motion control."

Bringing fluid power technologies together with electronics, software and other technologies can provide a range of benefits. It is a trend that will only continue to grow as automation of various types increases as well as electrification and digitization, all of which will require the combining of technologies to ensure performance, productivity and efficiency.

Electromechanical vs. Fluid Power

Electromechanical devices, also often referred to as electric actuators, have become a more common alternative to fluid power due in part to the level of accuracy and force they can provide. These actuators convert rotational force from an electric rotary motor into linear movement using either a belt or a screw.

Compared to hydraulic and pneumatic alternatives, electromechanical actuators offer reduced size, maintenance and energy use which can benefit various applications, particularly factory automation. The use cases for electromechanical devices are growing as technology continues to advance.

Determining which type of device to use – electromechanical or fluid power – for actuation in a mechatronic or other system will depend on the requirements of a given application.

Richard Vaughn, Automation Engineering Manager at Bosch Rexroth, said in a webinar with *Power & Motion* that it is not necessarily one outweighs the other in many applications

Advanced manufacturing is a key use case for mechatronics, including systems which utilize fluid power components. Image: Bosch Rexroth

but it is important to understand the advantages when choosing between the technologies. He also noted there are times where they could even be used in parallel.

A key benefit offered by electromechanical devices is their lower energy consumption. The energy provided by the devices servo drive can be stored and reused in many cases which can help reduce energy consumption and provide higher mechanical efficiency. The lack of oil or air leaks with these devices is beneficial as well from a maintenance and sustainability standpoint.

Being a servo-driven technology, electromechanical devices offer quieter operation. Vaughn also noted precise following of complex motion profiles are possible with electromechanical components, enabling implementation of much more complex applications than what is possible with pneumatic or hydraulic solutions. This enables quick changes to be made as necessary.

When looking at the advantages offered by fluid power components, higher forces and power density are the key advantage, particularly with hydraulics. These components tend to have longer life spans and are better suited to handle shock loads and vibrations, making them beneficial for applications in harsh environments.

Vaughn said when looking at initial material costs, electromechanical solutions will typically be higher. But if the advantages outweigh those initial costs to achieve lower operating expenses in the long term, then it may be worthwhile to choose the electromechanical option.

Although fluid power alternatives exist, there will always be a place for hydraulic and pneumatic solutions. Understanding application requirements and end use customer needs will remain an important factor for determining when and how to apply fluid power solutions, whether they be in a mechatronic or other type of system.

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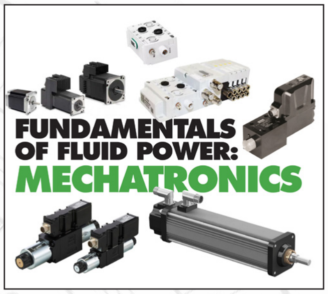
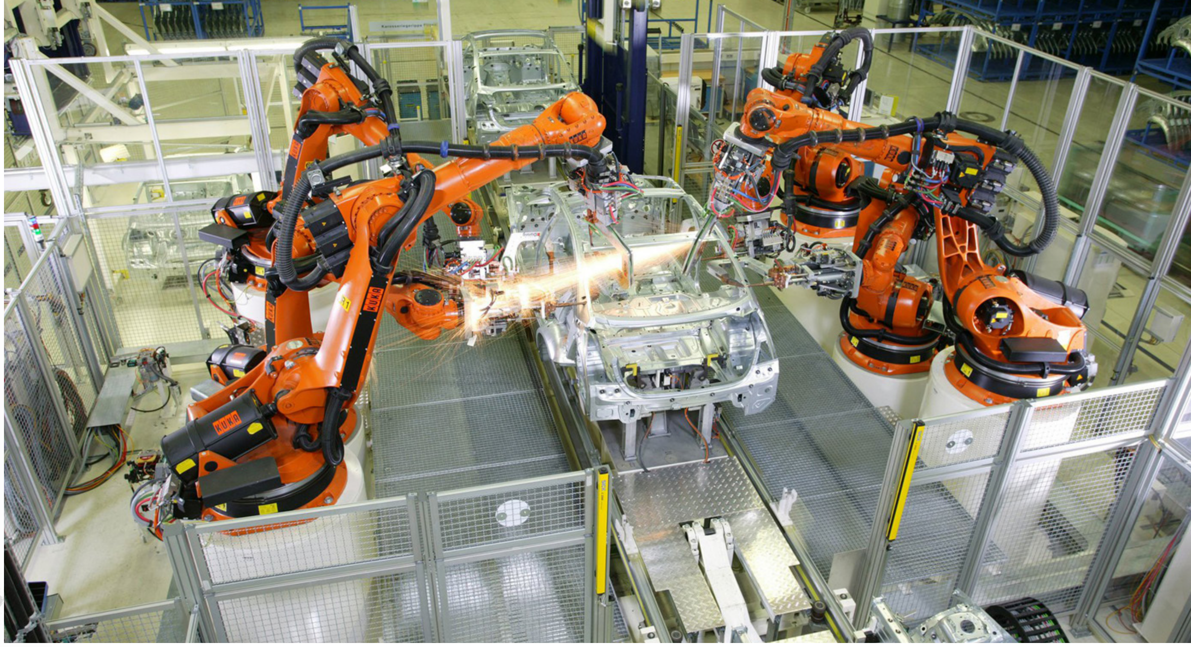




CHAPTER 12:

The Basics and Benefits of Electromechanical Actuators

STAFF, *Power & Motion*

Electromechanical actuators offer the strength of hydraulic actuators with more precise movement and motion control.

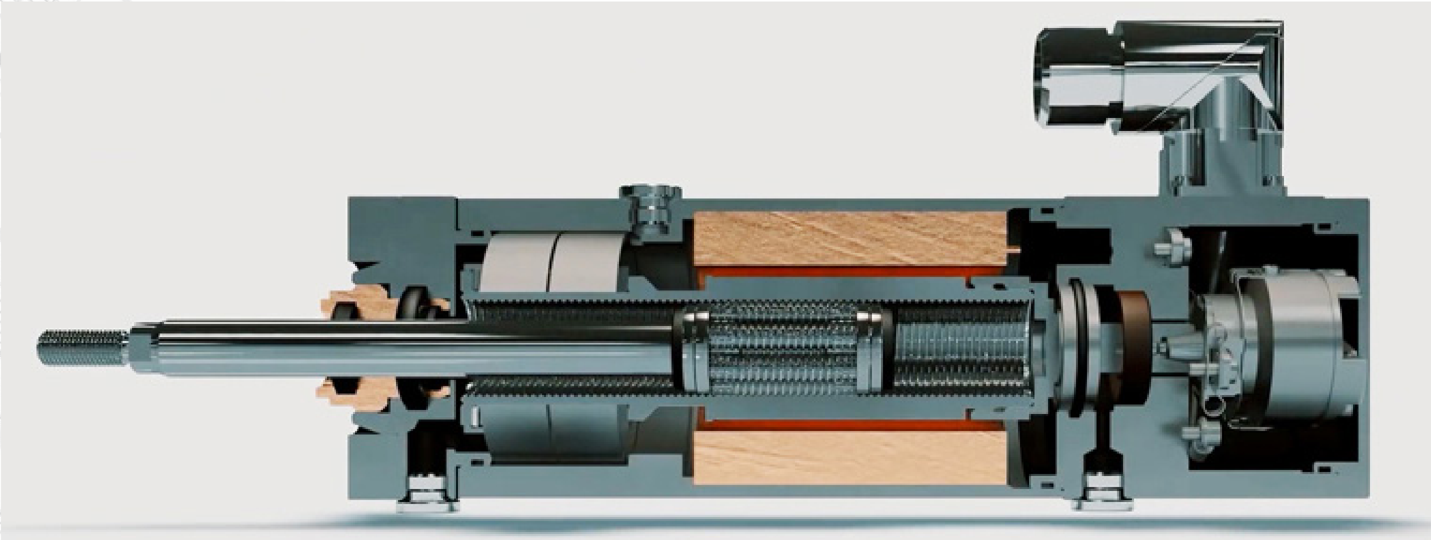
Electromechanical actuators are mechanical actuators where the control knob or handle has been replaced by an electric motor. The rotary motion of the motor is converted into linear displacement. The principle operation in most electromechanical actuators is based on the inclined plane concept. The threads of the lead screw are used as a ramp that converts the small rotational force by magnifying it over a long distance. This enables a large load to be moved over a small distance.

The simplified design of the motor motion is mechanically converted into linear displacement. Variations on electromechanical actuators have been devised to achieve higher mechanical efficiency, speed operation, and increase load capacity. Designs will differ from manufacturer to manufacturer, but in most designs the lead screw and the nut are incorporated into the motion.

The common design of the traveling screw actuator is where the lead screw passes through the motor. The lead screw is fixed and non-rotating, making the only moving part the lead nut. It is rotated by the motor, and the lead screw can extend outbound or retract inwards. The motor moves up and down while the lead screw remains fixed. The motor is the only remaining rotating part.

There are different designs that have multiple starts with alternating threads on the same shaft. They start on the lead screw and provide a higher adjustment capability between the starts and the nut thread area of contact, influencing the extension speed and load capacity of the threads. The lead screw determines the direction of the motion of the nut, and linear displacement is attained by connecting the linkages to the nut.

In most cases, the screw is connected to a motor or manual control knob. Other designs use a ball screw and ball nut, or have the screw connected to the motor directly via gears. The gears help to transmit the low power motion at a high revolution per minute (RPM) through the gears to magnify its torque. This is done so it can handle the weight exerted



The Inmoco DA99 from Diakont is an example of linear roller screw actuator. The actuator is used in nuclear power plants worldwide, and delivers increased load capacity with greater reliability and a longer operational lifetime.

on the screw, preventing the motor from engaging the heavy load directly.

This concept compromises linear actuator speed for attaining favorable actuator thrust, preventing the nut from moving with the screw head, and the non-rotating part is forced to interlock with the actuator. It is common for a worm gear to be used, as it allows for a smaller built-in dimension while allowing for greater travel length.

There are different types of travel within the actuator. As mentioned earlier, a traveling-nut linear actuator has a motor that stays attached to one end of the lead screw. It is either parallel or perpendicular to the actuator, perhaps indirectly through a gearbox. The motor rotates the lead screw and the lead nut is retained so it does not rotate. In this setup, the nut travels up and down the lead screw.

A traveling-screw linear actuator configuration is different as it has a lead screw that passes entirely through the motor. The motor essentially crawls up and down the lead screw that is prohibited from rotating. The only rotating parts the inside the motor, with the moving parts not being visible from the exterior.

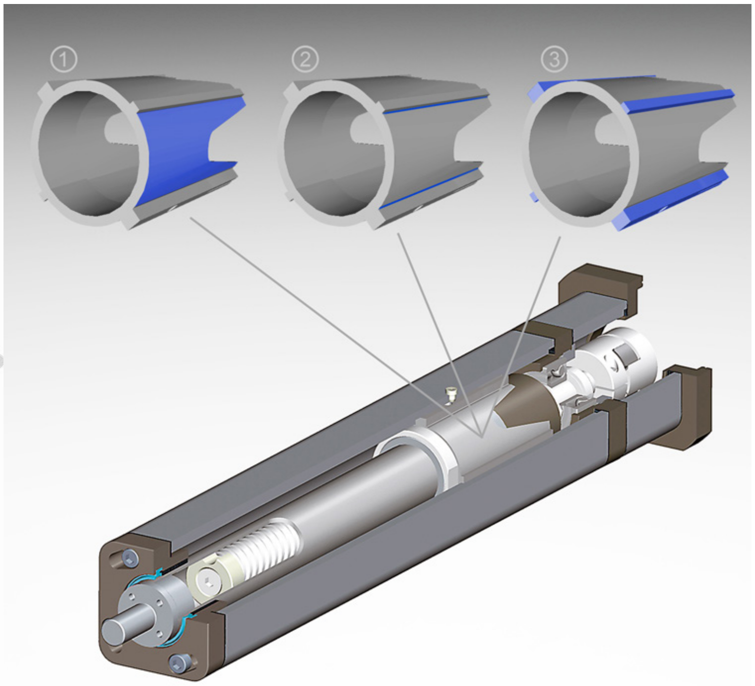
Several types of motors can be used for an electromechanical actuator: DC brush, DC brushless, stepper, or even induction motors. The motor used is based on the application requirements and the loads the actuator is expected to move. An actuator using an AC induction motor for example, will be used to operate a large valve in a refinery process. This is because accuracy and high resolution are not the priority—rather, high force and speed are.

With actuators used in a lab setting (such as for robotic instrumentation, laser equipment, or X-Y tables), finer resolution and high accuracy are required. In this case a fractional horsepower stepper motor with a fine pitch lead screw will be used.

Benefits of Electromechanical Actuators

According to Niklas Sjöström, product line manager, Systems Group, at Thomson Industries Inc., the desire for electromechanical actuators has increased in recent years. A few of the goals that have influenced the industry are:

- Improving machine performance with electromechanical actuators capable of higher precision.
- Reducing the size of equipment with electromechanical actuators that require only



The image shows a cross section of an electromechanical actuator. Inside the actuator, side loads are handled by maximizing the surface area. By increasing the surface area, lateral loads are supported and help reduce play in thrust situations.

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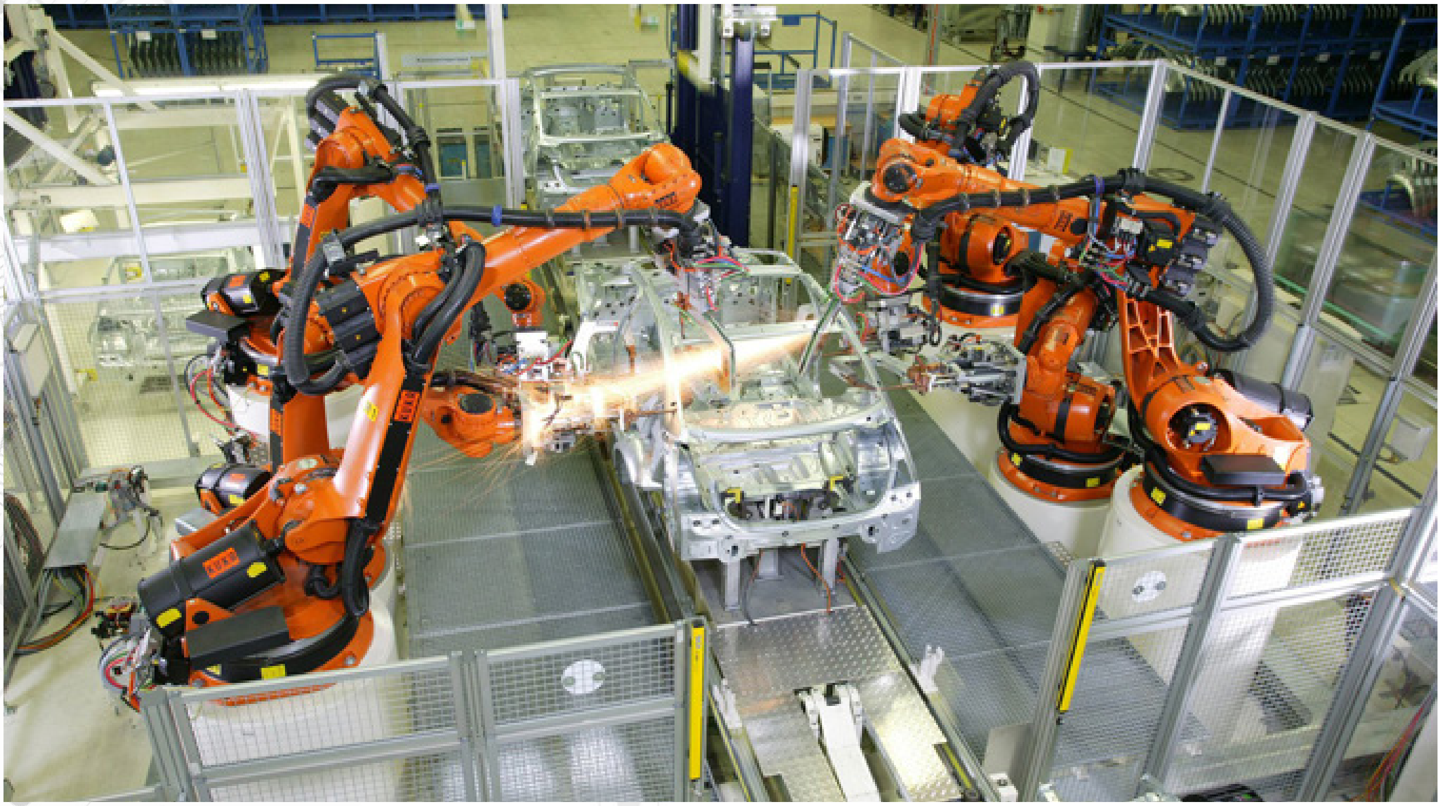
about a quarter of the space to deliver the same thrust as pneumatic actuators.
- Utilizing energy more efficiently, because electromechanical actuators do not need air compressors running 24/7 maintaining pressure.
- Reducing maintenance and total cost of ownership, because electromechanical actuators use fewer components, do not require compressors, and do not suffer air leaks.

It is common to compare electromechanical actuators against hydraulic or pneumatic actuators. Typically, pneumatic actuators have been used for light loads and only for travel between two positions. Each end of the travel is controlled by mechanical limits or hard stops. At these conditions, since control is not required at either end position, pneumatic actuators travel at a high speed and are inexpensive. It is possible to achieve more accurate control using pneumatics if proportional regulators and valves are implemented.

However, the consequence is a more expensive and complex system. Maintenance costs for the system increase as well. Also, maintaining control of the actuators while at the same time keeping the air compressed has its limitations. To apply the constant pressure, the compressor must be running continuously. Pneumatic actuators have problems providing slow and controlled speeds.

Hydraulic actuators are typically used for high-force applications, producing forces 25 times greater than that of an equal size pneumatic cylinder. Using fluid power, a constant pressure can be held without having to apply additional amounts of energy. Hydraulic actuators, just like pneumatic actuators, have motion profiles which are difficult and costly to control. With hydraulic actuators, oil leakage and disposal are persistent problems. Both pneumatic and hydraulic systems have issues due to impurities in their pressure and return lines.

The major benefit of electromechanical actuators is that engineers have complete con-



The Kuka robots are performing a welding operation with robotic weld guns. They are using electromechanical actuation to perform the various welds need on the car chassis.

trol over the motion profile. They are equipped with encoders that can be used to accurately control velocity and position. Some of them provide the ability to control and monitor torque and, as a result, the amount of applied force. Electromechanical actuation systems can be reconfigured and programmed without having to be shut down, which means the force and motion profile can be modified with software while the device is running.

Electromechanical actuators offer significant cost savings because they only consume power when they are performing work. To maintain a position, the system stays in place while idle. The average efficiency of a ball and roller screw actuator is around 90%. Their high efficiencies, low maintenance, and increased uptime also help to reduce operating costs. They are also environmentally friendly since they do not require hydraulic fluid. This makes them ideal in hazardous areas.

For engineers, electromechanical actuators can simplify the design process since they are easier to specify and design. There are only three steps required to determine the necessary size of an actuator: determining the duty cycles, calculating the load requirements, and specifying the stroke and retract length.

Electromechanical Actuators in the Field

Different industries are starting to find areas in their process where an electromechanical actuator can be used. Industries like packaging, food, energy, process control, construction, and the automotive industry have started to turn towards electromechanical actuation systems.

An example from Motion Control Online, part of the Association for Advancing Automation (A3), analyzed how the automotive industry has started to use robotic weld guns powered by electromechanical systems. Before, the weld gun operations were operated via air or fluid power systems but suffered from inefficiencies and were difficult to control. Using electromechanical systems have offered a greater range of control and efficiency.

The primary application for robotic weld guns is in spot welding of stamped sheet metal parts to form the car chassis. These operations require high accuracy and consistency due to the high number of welds used in the car chassis. This work is repetitive in nature, which is the reason it is an automated process. The weld gun sits at the end of the robot arm and is required to reach specific positions of the parts of the car chassis.

Now, the robots that control the movement have been driven by electric servo motors, but the weld gun actuators have typically used servo-pneumatic actuators driven by pneumatic cylinders. This offered manufactures the benefit of a simple design and low acquisition cost. The tradeoff, though, is a system that is at times hard to control and inefficient.

The most common electromechanical actuator found in heavy industries, such as automotive manufacturing, is the rotary servo motor coupled with a rotary-to-linear mechanical transmission. It can be found in either a ball screw or roller screw configuration. Roller screws are the preferred option, since they offer 5-15 times the lifespan when compared to a ball screw. Three main advantages of a roller screw over a ball screw are:

1. More contact points, which means the friction force can be evenly spread out against a bigger surface. The overall friction is less and the life of the actuator is increased.
2. Rollers are synchronized when connected to the nut with the screw, allowing for higher rotational and linear speeds.
3. Rollers circulate in a synchronized motion around the roller screw, which results in less vibration and noise.

The Exlar GSX-Series roller screw actuator combines both the mechanics of the screw and a servo motor in one unit. The traditional roller screw design is converted into an inverted design. The roller screw nut runs in a ground hollow shaft that is used as the rotor of the servo motor with shaped neodymium iron boron magnets bonded on.

There are different types of configurations of the roller screw actuator. The motor can either be external or ones where the motor and roller screw are integrated into one unit. In the second configuration, coupling the motor directly with an actuator eliminates the backlash resulting in higher dynamic response and better performance.

Using an electromechanical roller screw actuator in place of pneumatic actuators for robotic weld guns offers significant benefits. First, the life expectation of the actuator increases. Roller actuators offer higher load capacities; hence they deliver advantages in working life. The relative travel life for a roller screw for a 2,000 lbf/8900N load application will have an expected service life that is 15 times greater.

Second, the actuators can maintain a tight force repeatability. For example, a roller actuator can hold a force repeatability of 50 Newtons within its nominal welding force. Lastly, the energy savings when using electromechanical actuators are high. According to a 2011 study at the University of Kassel in Germany, it is possible to have 90% of savings when compared to fluid power. A hydraulic actuator operating under the same load and duty cycle conditions would require 4.4 times more energy and a pneumatic cylinder 10 times more energy than the electromechanical actuator.

With these benefits, it's easy to see how electromechanical actuation offers many industrial areas an alternative for their actuation systems.

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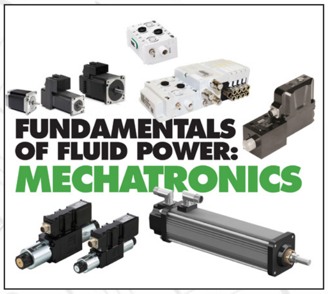

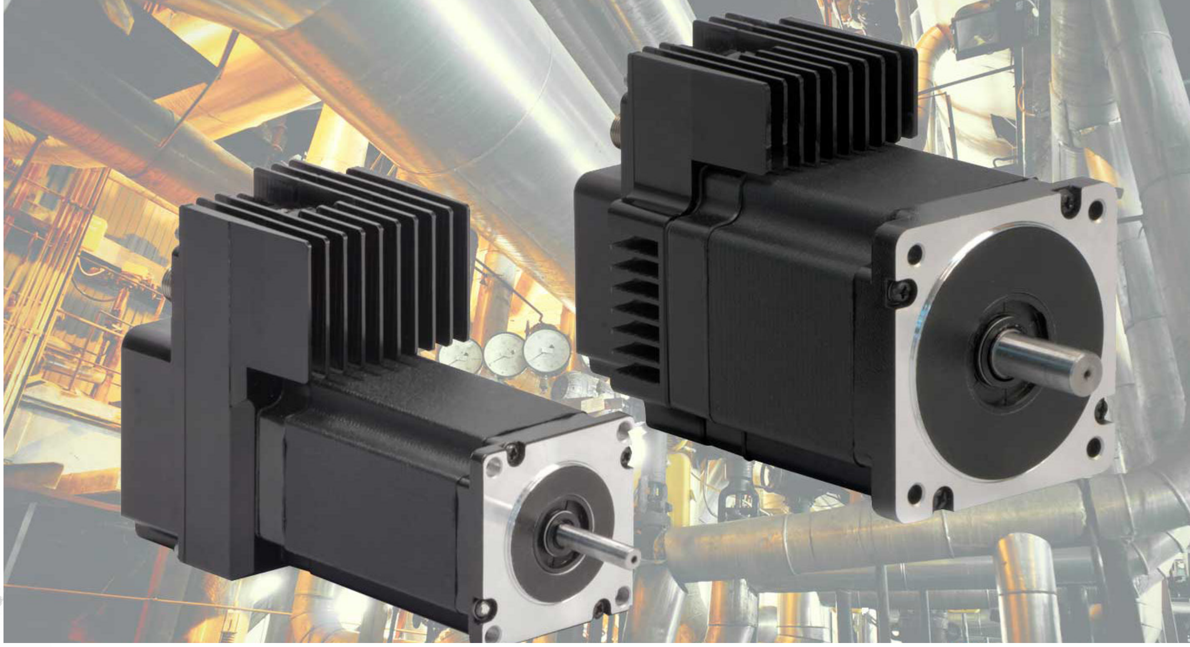

CHAPTER 13:

Getting the Right Stepper or Servo Motor for Electric Actuators

ED HESS, Senior Automation Engineer, Flow Products Inc.

As usual, the needs of the application play a major role in determining which is the best type of motor to use.

As the shift to automation continues to gain momentum in the industrial sector, servo motors and stepper motors with electric actuators become ever more important. When selecting a motor for an application, it is the functions that are important, not necessarily the construction.

Throughout this article we'll evaluate the characteristics of servo and stepper motors as they relate to linear motion. (Brushless DC motors will be considered servo motors for this article.)

Torque vs. Speed

Servos have a constant torque over their total usable range of speeds. So, if a servo motor has 1.2 Nm of torque at 10 rpm, then it also has 1.2 Nm of torque at 3,000 rpm.

Steppers on the other hand, have their maximum torque at low or zero speed and it falls off quickly at the much lower speed of a servo. If a stepper has 3.4 Nm of torque at 1 rpm, it is not unusual to see a drop to 0.2 Nm at 1,200 rpm.

Engineers should look at each motor's torque curves to select the proper size motor for an application.

Servos go faster than steppers no matter what the torque is. In some applications, this lets a gearbox be used with a servo to increase the torque for the application. The gearbox multiplies the torque by its ratio and the motor rpm will go up by the same ratio. Engineers should be careful not to exceed the motor's maximum rpm.

For example, a motor with a torque of 2.3 Nm at 500 rpm when used with a 3:1 gearbox will have a 6.9 Nm output, but the motor's rpm will climb to 1,500 rpm to drive the gearbox. Steppers' higher torque and lower speed curve generally mean they will not use a gearbox.

Pictured are two servo motors and a stepper motor.

Feedback

Steppers are generally open loop. Position is determined by the number of steps or pulses given to the motor for it to rotate. The total number of steps equals the motor shaft's amount of rotation or rotations. If a pulse is missed or the motor cannot move after the pulse because it lacks the power to rotate the shaft, then a position error is introduced but the motor/drive does not know it.

This can be a problem in some applications and is taken care of by re-zeroing the system back to home. Also, an external sensor or encoder (rotary device mounted to the motor that outputs shaft position) can be used.

Servos, on the other hand, are inherently closed loop and use an encoder. Using an encoder lets them constantly monitor their position, current and speed versus what the motor has been told to do. If position falls behind, the controller can increase parameters to catch up. As such, the motor is always under control. If it cannot catch up, the controller knows it and will generate an error alert to make the problem known.

Load Holding

Actuators often need to hold position at zero speed. How this is done by servos and steppers differs and often not considered by designers.

A stepper, as noted above, has maximum power at zero speed. It will hold this position with full torque until another pulse is received telling it to move. It is open loop with no feedback. As long as the holding torque is enough, generally sized for 50% more than needed, this can be ideal for holding a load at a standstill.

If the stepper is not sized correctly and the load changes, the motor can stall, and pulses are missed. There is no feedback for this, so there ends up being an error in positional accuracy. However, steppers are the most economical solution, and in low-speed applications they deliver more torque than a servo.

A servo does not use the same procedure. Instead, it monitors the encoder to stay at a zero-speed position. Usually, a programmed plus and minus window is used to define In Position. This means the motor is told to move back to a position when the controller sees a difference that puts it outside the In Position window. This movement must be planned for in critical applications by using motor resolution that is more than the application needs, so that position hunting or dither is not seen by the actuator rod or carriage.

Servos can usually generate up to three times their constant torque for a short period. This gives them reserve power needed to compensate for load changes without being greatly oversized. The servo monitors the encoder position and can increase speed or current to get back in position when it sees a difference.

Accuracy and Repeatability

Both motors are generally accurate and repeatable enough for most industrial linear motion applications, mainly because of a gear reduction. This can be the ball screw's pitch or a gearbox giving the advantage of more position counts on a measured linear position. Remember, these actuator applications typically use belt or screw drives. A 1,024-count encoder used with a 5-mm pitch ball screw has a control resolution of 0.005 mm per count (5 mm/1,024 = 0.005 mm/ct.). For general industrial applications, this is normally very good and can easily be increased if needed.

These resolutions need to be calculated for each application, but any required positional resolution can be done for most industrial applications.

Motor Selection

Some general guidelines for choosing between steppers and servos include:

- If low cost is needed, a stepper is a good choice.
- If loads are unpredictable and create extra torque requirements, a servo is a good choice.
- If complete reliability even with power loss is needed, a servo should be chosen.
- If it's a low speed or low torque application, a stepper should be used.

Engineers may need to go through the specific characteristics of the motors and look at the pros and cons of each for applications they are working on.

However, if there is no clear choice on motor type because features of both steppers and servos are needed, perhaps a stepper with servo control is a good option.

There is also a new type of motor being used: the hybrid stepper. The ServoStep motor offers the benefits of steppers and servos by having some characteristics of both. They provide a closed loop on the stepper motor to get some of the advantages of the servo control.

Stepper and servo motors offer a wide array of features that can benefit specific applications. The key is understanding what the application requires and selecting a motor that best meets application requirements and complies with engineering specifications. While this article offers the basic information needed to choose the motor type for an electric actuator application, there are also other elements needed to complete the system. These include a drive/controller, smart controller, serial or discrete control, and proper sizing for the application.

Automation engineers are a good resource when designing complete systems and they can offer more details specific to an application.

This article was written and contributed by ED HESS, a senior automation engineer at Flow Products Inc.

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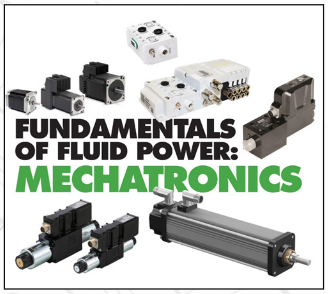
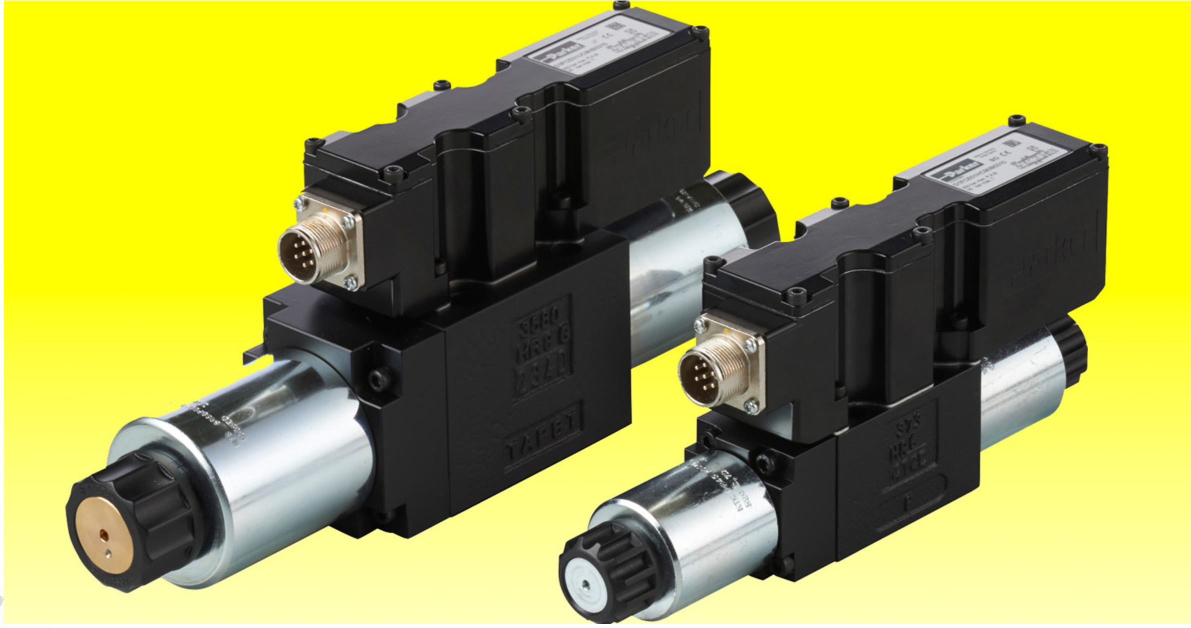




All images courtesy of Parker Hannifin

CHAPTER 14:

Getting the Most out of Electrohydraulic Valves

TOM GIMBEN, MATHEW DAVIS, MITCH EICHLER
Parker Hannifin Hydraulic Valve Division

There are various types of electrohydraulic valves which can be applied in many different ways, with common variations including proportional and on/off versions.

The basics of electrohydraulic valves are simple: They are electrically operated valves that control how hydraulic fluid is sent to actuators. However, to use them efficiently and effectively, designers must consider several factors.

This article will explore seven key design considerations for applying electrohydraulic valves.

On/Off vs. Proportional Valves

On/off valves are basically on/off switches for hydraulic systems. They are typically installed in applications where precise position or speed control is not required. Proportional valves adjust flow rates for hydraulic systems. These valves are typically used in applications where more control and adjustments are needed beyond a standard directional control valve.

A few applications that call for variable flow rate control where proportional valves perform well include wind turbine pitch control, wood processing, machine tools, and metal forming. If specific timing or positioning is required, proportional is the way to go.

Onboard vs. Offboard Electronics

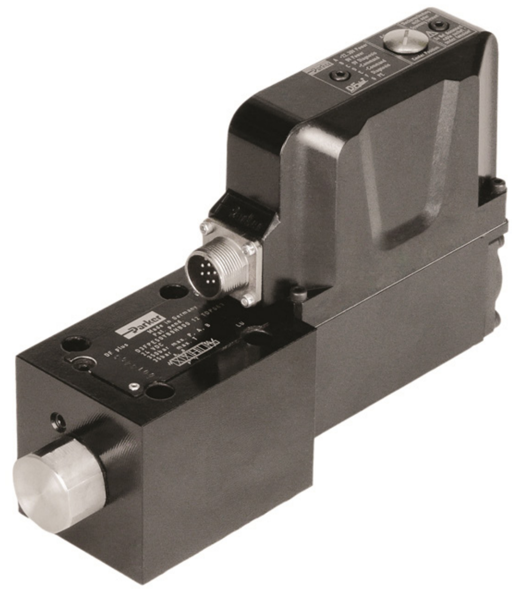
Determining whether a valve with onboard or offboard electronics is the best choice requires an in-depth evaluation of the application. Generally, onboard electronics put control at the valve, thus simplifying the wiring at the controller. Offboard electronics are often used in areas with high vibration levels and temperatures that can degrade the electronics' performance.

Driving an offboard electronics valve requires an electronic module, such as a series PWD00A-400, which can be configured to customer-specified parameters such as desired solenoid drive current or ramp rates. Onboard electronics valves can be commanded directly with a standard command including 4-20 mA or ±10V DC and allow for the same level of customization.

Open vs. Closed-Loop Control

There are two control options for hydraulic systems: open-loop and closed-loop. In general terms, an open-loop system cannot compensate for any disturbances that alter the controller's driving signal.

Closed-loop systems do not have this shortcoming. Disturbances in the closed-loop setups are compensated for by measuring the output response and comparing it to the input (feedback). If there is an observed difference (known as an error signal), the error is fed back to the controller to adjust the output to the desired value. FB series valves, used for acceleration and metering applications, do not internally close the loop around the spool. FC and FP series valves do close the loop internally around the spool but can be used in either open-loop or closed-loop systems. Error in the system is measured by a transducer, such as a position or speed sensor on an actuator, a pressure transducer, or a flow meter for even greater accuracy. Electrohydraulic servo valves operating in closed-loop control systems use low power and mechanical feedback to provide precise control.



The Series D3FP direct-operated control valve from Parker Hannifin combines high dynamics with high flow. It is used for precise accuracy in positioning the hydraulic axis and controlling pressure and velocity.

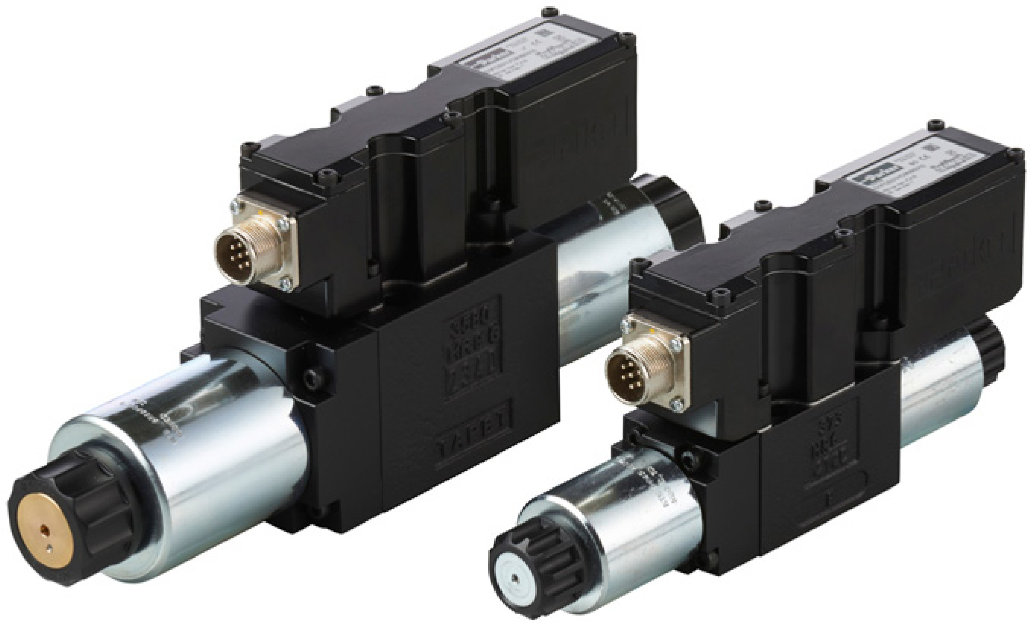
Parameters that must be considered when specifying open- and closed-loop control systems include:

- Hysteresis: The difference in measured output between increasing and decreasing
- Step response: The time required from initial command to when the valve stabilizes at the desired output.
- Frequency response: The maximum speed a valve can operate at accuracy.
- Internal leakage: Bypass flow inherent to spool valves due to mechanical clearances.
- Flow capacity: The amount of fluid that can pass through the valve.

Sizing Spools

Proportional valve spools are typically rated for a nominal flow at a differential pressure of 10 bar and servo valve spools are typically rated for a nominal flow at a differential pressure of 70 bar.

Equal metering spools provide symmetrical flow to each work port. This can be useful when driving a motor or a double-rod cylinder with equal effective areas. Equal metering spools results in reduced speed during retracting of a single-rod cylinder due to the differential area between the rod and piston.



Closed loop control continually considers the current output and alters it to meet the programmed condition. Servo valves use low power and mechanical feedback to provide precise control.

Ratio spools provide asymmetrical flow between work ports. The most commonly used have a 2:1 ratio. When used to drive a 2:1 ratio cylinder, for example, equal speed will be reached between extension and retraction of the cylinder due to matching imbalanced areas.

Engineers should size proportional valves as small as possible to control the load. To maintain control, back pressure must be exerted against the load at all times. A general rule of thumb is to select a spool that will use 90-95% of the maximum flow rating. Selecting a spool with too much flow capacity can make the system unstable.

Sealing Compounds

When selecting the compound for elastomeric seals in directional control valves, consult the seal manufacturer's resources for fluid and compound compatibility information. Industrial applications using mineral oil will typically have a nitrile seal, which is also recommended when controlling water-glycol.

Applications involving high temperatures or less-commonly-used fluids may use one of many grades of fluorocarbon seals. When in doubt, consult the factory for assistance in selecting a seal compound.

Regenerative Circuits and Hybrid Functions

Regenerative circuits route fluid evacuated from the rod end of a cylinder back to the piston end instead of to the tank. This speeds up actuator extension. Regenerative circuits can let system designers use smaller pumps to meet design requirements when rapid movement is needed in only one direction. Some regenerative directional control valves combine on/off and proportional control to let designers include regenerative functions without adding more valves to the circuit.

Hybrid regenerative valves let designers trigger regenerative control through an electrical signal different from the command signal. When using regenerative control, force is sacrificed for speed. The hybrid function (Z flow code) lets designers select between standard hydraulic function to build force and regenerative function to accelerate the load quickly.

Mounting Patterns

Mounting configurations for electrohydraulic valves are guided by NFPA/ISO standards. D03, D05, D07, D08, and D10 series designations indicate compliance with the standards. Pilot-operated valves are more stable across a wide range of flows and let systems operate with greater flow capacity. Often, the hydraulic pilot pressure used to control the main-stage spool provides greater force than that of a solenoid on a directional drive valve, resulting in more predictable performance for users.

There are many resources available to design engineers when specifying components for systems, including reference sheets, calculators, and configuration tools. However, there is no substitute for experience and application knowledge. Take advantage of the “been there” and “seen that” experience of your supplier’s applications engineers. Not only do they understand how components their company offers perform, they have the benefit of having helped others in the same situation correct design mistakes and they have problem-solved for some of the most unique applications.

This article was written and contributed by MITCH EICHLER, an applications engineer, and TOM GIMBEN and MATHEW DAVIS, product sales managers, at the Parker Hannifin Hydraulic Valve Division.

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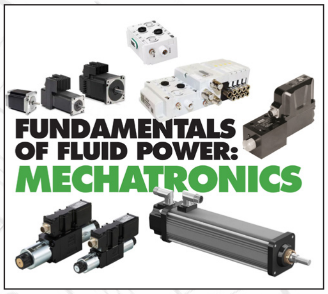

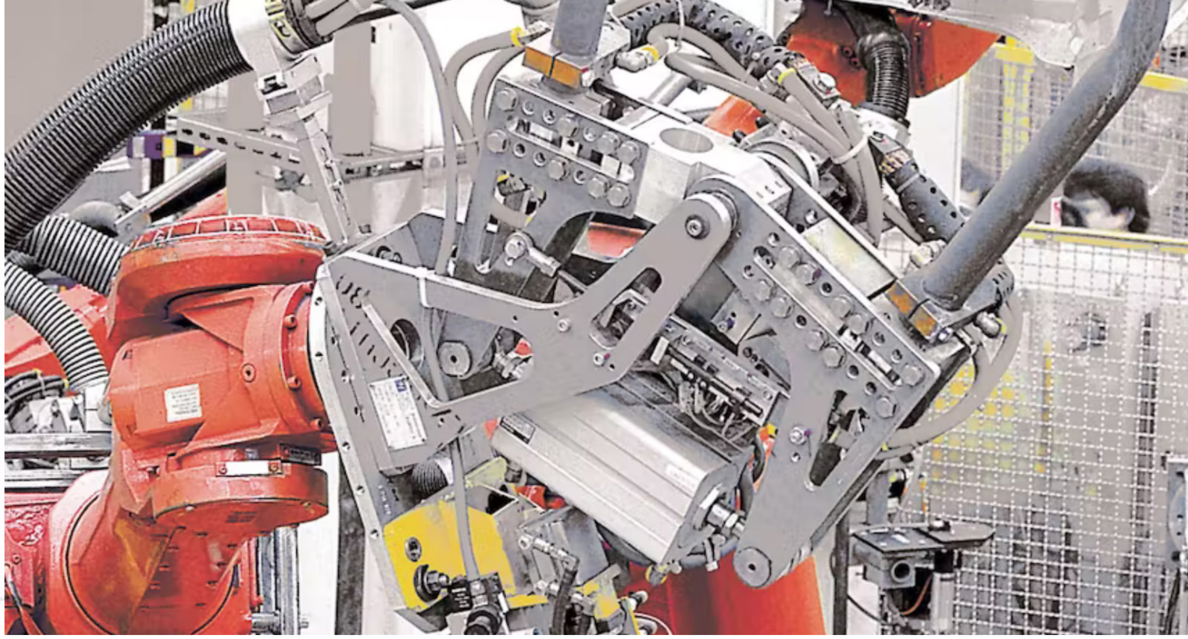

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CHAPTER 15:

Advanced Electropneumatic Positioning Achieves Dynamic Force Control

JON REVLETT, Electro-Pneumatic Systems and Controls, Aventics Corp.

Today's electropneumatic postioning systems break from convention by offering efficient and reliable position and force control.

Linear devices that lift, move, and place a load require tight closed-loop positioning accuracy, which either pneumatic and electromechanical technologies can provide. However, between the two technologies, variables affect manufacturing costs, safety, and productivity in different ways. Moreover, recent developments in applying multiple closed-loop control to electropneumatic positioning systems (EPS) bring a new level of precision and safety by using dynamic force control to maintain load position, overcoming traditional E/P, and electromechanical system limitations.

How Electromechanical and Pneumatic Systems Differ

Electromechanical positioning systems. With any positioning system, accuracy is critical, including along any point of the motion path, but also at the actuator endpoint. An electromechanical system (EMS) performs positioning tasks by using electric servo motors and servo controllers with toothed belt axes, spindle axes, or electromechancial cylinders to move loads.

An advantage of an EMS is that it can accommodate high-speed production systems that require high accuracy for positioning control.

But there are disadvantages:

- Thermal: Electromechanical positioning systems can heat up and undergo temperature-related changes. Significant downtime is needed for cooling to avoid excessive wear and tear. In fact, many low-cost EMS platforms are only capable of 50% duty cycles, spending as much time off as they spend working.

- Electrical: If power is lost, an EMS can reset but work is lost prior to the power outage.
- Financial: Cost can be an issue. Over the long term, the need to replace failure-prone electromechanical components can lead to higher maintenance and production costs. When an electromechanical system has issues, it typically requires an expensive new electric drive.

Traditional electropneumatic systems. To move an actuator to the required location, an EPS uses electrically actuated valves to control air flow, pressure, or both. Typical components of an EPS include a pneumatic cylinder, valves, electropneumatic pressure regulators, and related sensors. The pneumatic cylinders typically include both conventional and rodless versions. Many systems use basic flow-control valves and open-loop operation for positioning, which require large amounts of air flow. Other systems use direct-acting proportional pressure control combined with typical analog signals and single feedback circuits to enhance positioning accuracy and system efficiency.

Compared to an EMS, a traditional EPS has the advantage of providing greater productivity, better reliability, and more maintenance options for repair. They are often more energy efficient; unlike EMS (that use servo motors), EPS consume no electricity when holding a position. Overall, an EPS can provide lower cost of ownership than an EMS.

There are more advantages:

- Reliability: Maintenance issues occur far less frequently, as an EPS does not overheat. Components stay cool and can work around the clock in a 100% duty cycle. They can withstand harsh conditions such as temperature extremes, dusty conditions, and wet and dirty environments.
- Electrical: If power is lost, an EPS can use standard pneumatic valves to block air flow, which automatically freezes the position of the cylinder piston. It is also much easier to restart operation when power is restored.
- Financial: When pneumatic cylinders break or wear out, they can be repaired or replaced at a low cost and typically are easy to install. These advantages, combined with the inherent low-maintenance nature of pneumatic devices, significantly lower the cost of ownership compared to EMS. In fact, the cabling alone on an electromechanical device can cost more than an entire pneumatic system.

There is one disadvantage: An EPS cannot be perfectly sealed, so an incremental or intermittent loss of air or pressure is unavoidable. Minor leaks can cause the pneumatic cylinder to move slightly (drift). Low air flow can cause the cylinder to begin undergoing stiction, or chatter, which degrades system accuracy and performance. However, electropneumatic systems using direct-acting proportional pressure control can reduce the effects of stiction.

Advanced Electropneumatic Positioning with Dynamic Force Control

The ability to accurately control position is critical in any type of positioning system. Many applications typically require a specification for zero deviation from setpoint once the load reaches the desired position.

With an EPS, a conventional solution is to include a rod lock on the end of a piston rod when force control is required. When the load reaches the desired horizontal or vertical movement, the mechanical rod lock engages to apply a braking force against the rod.

However, in certain dynamic applications where the position changes frequently, the rod lock could disengage or cause damage to the equipment during an abrupt change in position. If the rod lock disengages, this could cause the load to drop or lunge forward and create a safety issue.

Overcoming Perceived Limitations

One of the shortcomings of traditional electropneumatic systems is the inability to control both position and force. For example, maintaining welding tip force in automotive body welding applications at an accurate position is very difficult to achieve. However, by using a closed-loop feedback system, advanced electropneumatic positioning systems can apply the additional pressure required at a given position to maintain the force needed to achieve an accurate weld.

The solution is to combine EPS regulators with advanced electropneumatic closed loop systems. This technology uses dynamic direct-acting proportional control valves combined with precision feedback for positioning. This combination enables higher performance and repeatability, all the while securing a position without the use of a mechanical rod lock and ensuring the load does not drop, move, or lunge forward.

High-dynamic EPS valves allow for high positioning accuracy and precision through the process of pressure regulation. They can achieve a resolution accuracy of within 0.12 psi during positioning. Dynamic force control is achieved by using multiple closed-loop control systems with the EPS regulators, rather than utilizing basic flow control valves and open-loop control. Some electropneumatic positioning systems offer one basic closed loop, which allows for precise positioning without providing force control.

Additional closed loops enhance monitoring and stability control, employing the process of feedback from pressure regulators on either side of the piston. Multiple closed loops also provide dynamic force control once the load and cylinder has reached the desired position.

Unlike a traditional EPS, advanced electropneumatic positioning systems with multiple closed-loop control can switch from dynamic positioning to force control via a quick parameter setting. This design augments the ability of precise pressure regulation to eliminate the effects of dithering. With a properly selected actuator and optimized tuning of the controller, it is possible to attain ±1 mm (or 1% of stroke) positioning accuracy.

Applications for Advanced Electropneumatic Positioning Systems

Systems using multiple closed-loop control systems are designed to provide an economical solution for a broad range of automation and industrial applications.

Application examples include automotive body welding (mentioned above), electropneumatic material handling systems (such as pick and place), hopper/damper/gate control, and other systems requiring precision indexing. Basically, suitable applications are anywhere force control is needed in addition to accurate positioning.

Traditional electropneumatic positioning systems have provided acceptable positioning for several years. An advanced electropneumatic system using multiple closed loops now allows dynamic force control and can compete with servo motor technology. Users will find that many applications do not require “ultra-precise” servo motors and can benefit from a more cost-effective electropneumatic solution with other inherent advantages. Due to safety and structural factors, system designers should consult with the manufacturer to account for the load, bore size, and stroke length needed for a particular application.

Aventics, for example, has a multiple closed-control loop positioning system available as a module that is compatible with current AV valve systems. The modularized design easily integrates into valve manifold assemblies to turn valves on and off using different communication protocols.

An advanced electronic pneumatic positioning system (AES) integrated with PID technology eliminates dithering associated with flow-based pneumatic positioners. And adding multiple closed-loop control enables dynamic force control for reliability and safety in securing load position.

This article was written and contributed by JON REVLETT, product specialist, Electro-Pneumatic Systems and Controls, at Aventics Corp., Lexington, KY.

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