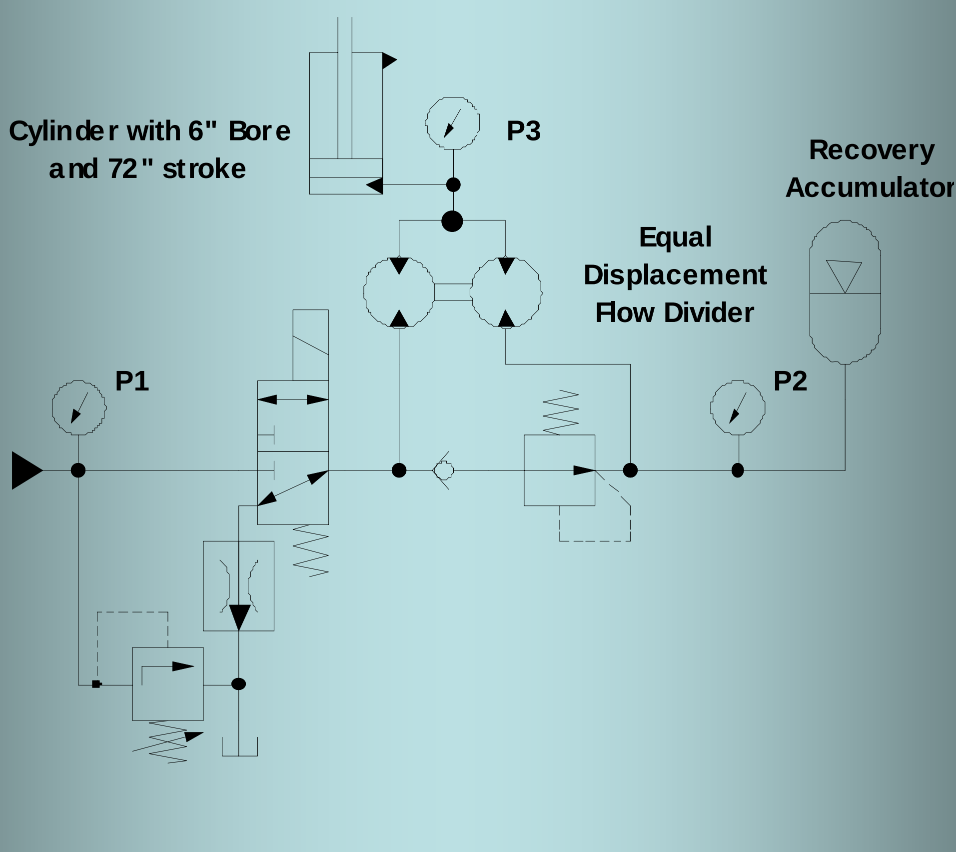
Watts It All About

A series of articles on the use and misuse of energy in Fluid Power Systems



by: Dan Helgerson

Ok, I admit it. I made a mistake.

It has been my focus to design energy efficient Fluid Power Systems. To me, every lost BTU or SCFM is a failure. I joke when seeing large heat-exchangers that it is like seeing work done by a carpenter who uses 12 inch trim. The heat-exchangers cover up a problem, addressing the symptom but not the cause. In many instances this is true but I was still ignorant of another major factor in providing the most efficient Fluid Power systems.

If you are a Certified Fluid Power Professional (and if not, why not?) you certainly see a problem with a hydraulic system using a fixed displacement pump and a relief valve for speed control or a pneumatic system using unregulated pressure and only meter-out flow control. However, we, the professionals, have others somewhat at our mercy. We understand the "black box" of Fluid Power. They only want to move their stuff from point A to point B and have chosen Fluid Power as the means to do the energy transfer.

We sometimes tend to provide systems based on habit and convention as well as what may be in inventory. How often do we stop and look at the actual energy requirements and then design backward from that point? How often do we consider the fact that, even though we do not have to pay the energy bill for our customer, the cost to operate a Fluid Power system will have a direct effect on the way Fluid Power is viewed and will impact the future of our industry?

What is the most efficient Fluid Power System? It is one where the flow and pressure exactly match the energy transfer requirements of the system. More flow and/or pressure than is necessary will have to be unloaded in some manner as wasted energy.

Ok, Ok! I know all this stuff already. What's all this about "I made a mistake"? What did I overlook?

All systems have a prime mover; most commonly an electric motor and this is what I have neglected. I have typically recommended systems that have; A) a larger than necessary motor, and B) that spend a lot of time in an idle mode. I did not pay attention to the fact that; A) electric motors are designed to operate most efficiently within 10% of the name plate power and; B) electric motors idle using about 30% of their full load amperage. Under utilized, a motor has a poor power factor that will affect the whole facility.

The use of variable frequency drives to help match electric motors to the load or a soft-start to allow the motor to be turned off during prolonged idle can make a dramatic difference in the energy used by a Fluid Power system.

I used to think of variable frequency drives as competition to Fluid Power systems. I now realize that VFD's and Soft-Starts should be a part of our repertoire in providing the best of Fluid Power.

Focus on Energy

This is what we know: An electro-mechanical system can operate at about 96% overall efficiency. A typical hydraulic system will operate at about 78% overall efficiency. Down at the bottom of the list we find that a typical pneumatic system is about 6% efficient. So, this begs the question; with the price of energy constantly increasing and with the pressure to "go green", why would anyone in his right mind choose to use Fluid Power as a means to do work?

I was recently on a guided tour of a major plastics injection molding facility accompanied by a group of about 20 mechanical engineers. The tour led us to an experimental molding machine that was entirely electro-mechanical. There was not so much as a cooling air jet blowing on the equipment. The tour guide proudly announced that the company was looking at this machine in the hope of getting away from Fluid Power because everyone knows, and I quote, "Hydraulics is messy and expensive." I was a guest and quietly and painfully bit my tongue while everyone else nodded in unquestioning agreement.

Now, I know that this is anecdotal. But a large number of anecdotes can show a pattern and enough anecdotes may even be considered data. The fact is that a substantial group of design engineers currently planning the equipment of tomorrow do not question the idea that it is wise to avoid Fluid Power if at all possible.

Those of us who are passionate about Fluid Power know that there are a number of very good reasons to consider Fluid Power as a means to do work. There is the concentration of force, the removal of heat, the flexibility, and the ability to produce both linear and rotary motion from a common power source. We can take very heavy objects and repeatedly position them within .0005". We can create vacuum that will allow us to pick up delicate and oddly shaped material and safely move it. These are all appropriate things to discuss when presenting the case for Fluid Power and many of us have been successful in doing so. However, in this article, we are going to **focus on energy** because if Fluid Power cannot be shown to be an efficient alternative to other forms of power transfer, then we may as well start packing up our formulas and find some other line of work.

The frustrating fact is that Fluid Power does not ***have*** to be so inefficient.

For years Fluid Power Professionals have been complaining about having to give away engineering in order to be competitive and sell products. The irony is that the complaint spotlights the fact that we are the ones that have designed the very inefficient systems that are now haunting the Fluid Power Industry. The users of Fluid Power have come to us, the Professionals, asking us to provide a solution to their power transfer needs. Many of them would not know a kilowatt from a horse radish or a BTU from a lemon drop. But we do! In order for us to design their systems, we have to calculate the forces, speeds, pressures and flows that are required to get the job done.

I had the opportunity to supply a system where an upward acting press had a 32,000 pound platen that had to be lifted at a rate of 5 inches per second and then move 1 inch per second applying a force of 150 tons. I suggested a system using a 40 hp electric motor. The machine designer was skeptical and told me he did not think it would work. His company had built similar machines before and had always been supplied with 60 hp electric motors to drive the hydraulic pumps.

I asked him to do the math with me. The greatest amount of power was consumed in the lifting of the platen. The pressing force required relatively little power because of the slow speed. Knowing that HP = 550 lb/ft/sec, I asked him to tell me how much power would be needed to lift the platen at the rated speed. He got out his calculator and did (32,000 / 550) * (5/12) = 24.24 or about 25 hp. My 40 hp unit was a concession to the inefficiency of the system and to the availability of the type of electric motor I planned to use.

When the finished machine arrived at its new home in a manufacturing facility, the plant engineer was skeptical because we had placed a relatively small heat exchanger on the system. He was convinced the power unit would overheat. He had several other machines with 60 hp electric motors and they all had large heat exchangers.

The point is this; the users of Fluid Power have placed themselves at our mercy. Otherwise competent engineers, lay aside what they know about physics when it comes to Fluid Power. They want us to handle the “black box” and trust us to provide the best system. In the illustration, neither the machine designer nor the plant engineer had done the math to see what the actual requirements where to move the load. They had left it up to us, the Fluid Power Professionals, to tell them what they needed. We failed them. Oh, we gave them systems that worked and met the stated requirements, but not systems that represent the best that could be done. The result was that, for years, the machine designer had been supplying inefficient systems and the manufacturer had been paying the energy bill for that inefficiency. They had accepted the wasted energy as simply the cost of doing business, an inherent characteristic of Fluid Power.

By the way, the system works great and has been in service for about 15 years. My one regret is that it was after the fact that I realized I could have supplied a 12 hp electric motor to do the job. I plan to discuss that in another article.

We are Fluid Power Professionals. That means we are professionals at transferring energy. We need to think of ourselves as Energy Professionals specializing in Fluid Power. We need to involve the users of Fluid Power in the decision making process and let them know the cost of inefficiency and offer them the most efficient system available. We need to begin thinking about the entire energy transfer system; from the combustion engine or electric motor to the work being performed. We need to view every kW wasted, every scfm tossed away, and every BTU removed as an opportunity for improvement.

To do less would be a disservice to our profession and to those who depend on our expertise.

In future articles I plan to discuss some of the ways we can do a better job of making our Fluid Power systems more efficient. We will take a hard look at the way electric motors work and how we can best use them. We will talk about air compressors and receivers. We will determine the best way to adjust the speed of air cylinders and motors. We will look at different circuits to show the comparative operating costs when using pumps with a fixed displacement, variable displacement, load sensing, or electronic swash plate positioning. Using and setting up accumulators will also be analyzed. I am looking forward to the discussions and I appreciate any feedback from other Fluid Power professionals as well as from ~~our victims~~ the users of Fluid Power equipment.

Flow Controls: If in Doubt…

Ok, let me see a show of hands. How many of you have designed or installed Fluid Power Systems that used flow controls? Keep them up so I can count… It looks like about 99%.

Let me ask another question. How many of you thought about the fact that using a flow control wasted energy? Be honest now. I can't see everybody but I'd say it's about 15%.

You might want to stop reading right now because, after you read this article, you will never again be able to specify or install a flow control without feeling that twinge reminding you that you are wasting energy.

Now, I am not suggesting that we eliminate flow control altogether. One of the beauties of Fluid power is the fact that we can regulate the speed of linear and rotary functions from a single power source. This requires some type of flow modulation. What concerns me is that we may consider the energy consumed by the control as just part of the cost of using Fluid Power and not take into consideration the impact our choices may have on the cost of operation and on our industry.

There is no such thing as an energy efficient flow control. A system that requires flow control will ***always*** be generating more flow and pressure than is needed and the excess is wasted energy. The best we can do is to limit the waste. A pump pushes a volume of fluid at a pressure determined by the resistive load. By definition then, we charge the fluid with energy. If we require something less than the full flow at system pressure, the excess energy will be lost.

Pneumatics and hydraulics have significant differences in the way energy is lost when using flow control. The pneumatic loss is more subtle and often more expensive than that with hydraulics. You are not likely to burn your hand on a pneumatic needle valve but some of us have seen the paint burnt off a flow control in a hydraulic system. With hydraulics the wasted energy can have a dramatic and immediate impact while pneumatic inefficiency tends to lurk in the background.

The difference is in the way the energy is put into the fluid. Hydraulics is sort of a "pay-as-you-go" system. There is usually no energy charge in the fluid until we begin to use it. With pneumatics we charge the fluid with energy and then store it in a receiver for future use. When we waste hydraulic energy it immediately turns to heat and we have to deal with it. When we squander our stash of stored air molecules, it can often go unnoticed.

I was invited into a manufacturing facility where they make threaded brass parts. They have a number of pneumatic presses that are used to secure a ferrule into a fitting. The press operators used to place the ferrule into the fitting and then quickly move their fingers out of the way while they activated the press. As a safety measure the company had decided to use a horizontally mounted air cylinder to slide the ferrules into place and so prevent the operators from endangering their appendages. The ferrules weigh about 2 ounces. Someone (I am hoping it was not a Fluid Power Professional) had selected cylinders with a 2" bore to push the ferrules into position. There were directional valves and meter-out flow controls. The system worked quite well and everyone was happy.

I noticed that each machine had a pressure regulator with a gauge. The pressure was set at 100 psi. Now, Blaise Pascal informed us that **F = PA**. The area of a 2" bore cylinder is 3.14 square inches, so… let's see; 100 psi times 3.14 square inches equals… 314 pounds of force! Did I mention the ferrules weigh 2 ounces? I think it was Isaac Newton that informed us that **F = ma**. If we have a whole lot of **F** and not much **m**, we get a very large **a**. Unregulated, the cylinder force would have accelerated the ferrules to 194 miles per hour by the time it reached the end of the six inch stroke. To prevent the operator at the next work station from constantly having to remove the imbedded brass ferrules, the meter-out flow controls where used to slow the system down. It worked great!

However, the air system supplied about 313 pounds more force than was required. In energy terms, our Fluid Power customer used up 313 times more of his stored air molecules than was necessary to get the job done.

While working for a new hydraulic distributor who dealt with mobile and marine customers, we sold a fixed displacement pump that produced twice the flow that was required for a street sweeping machine. When the problem was discovered, one of our countermen gave the customer a 50/50 restrictive flow divider to fix the problem. He told the customer that half of the fluid would now be diverted to the reservoir and his system should work correctly. The first report we got was that things were great and the customer was pleased at the easy fix. But soon after, we got the call that the system was overheating.

What the counterman did not understand is that a positive displacement pump is a relatively unintelligent device. All it knows is that it is being driven by a prime mover to push out fluid against a resistance. It has no idea how much fluid is needed or how big the resistance is. It will push until something gives way or until it reaches the limits of the prime mover. If we add any type of restrictive flow control to the fluid stream, the pump will still have to push all the fluid against the resistive load; it will energize all the fluid. The energized fluid that does not perform useful work will release its energy in the form of heat at the location where the pressure is reduced. In the case of the street sweeper, about 11 gallons/minute at 1500 psi were being released into the already undersized reservoir adding 425 BTU/minute.

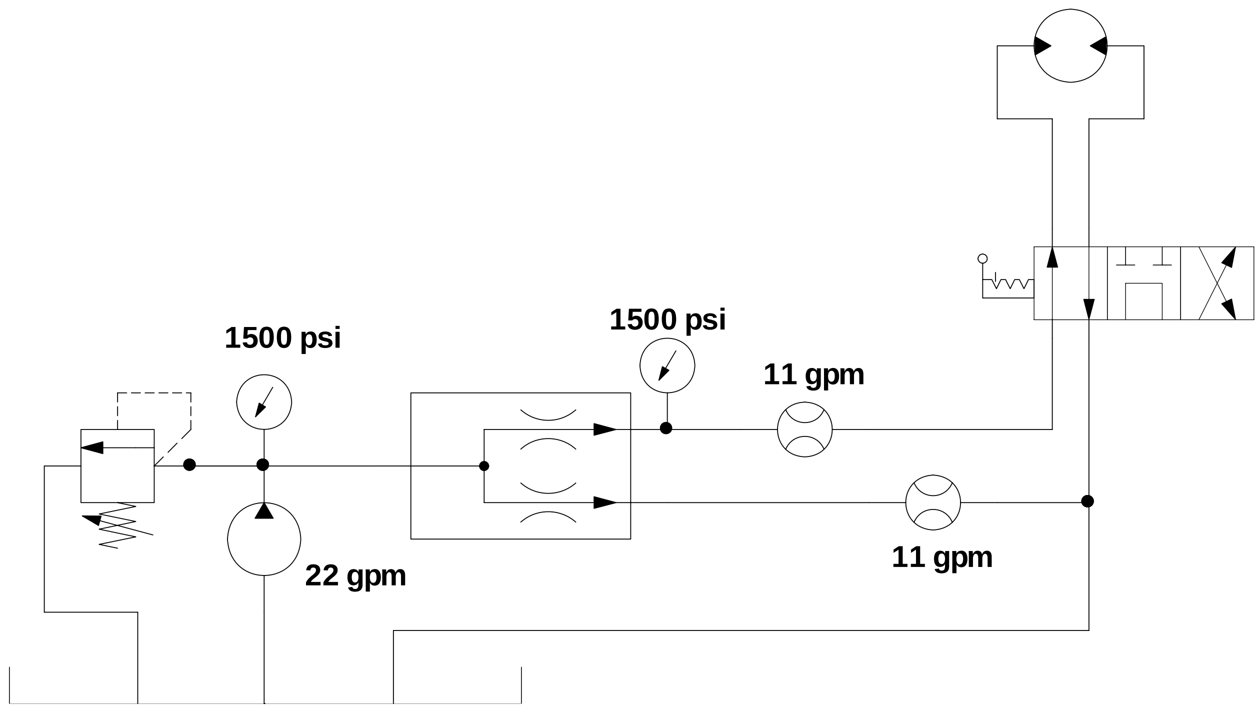
Going back to the overpowered ferrule transfer system, how do you set up the speed control for a pneumatic system that will minimize the energy loss?

Here is the ideal way to set the flow control for a pneumatic device: First, choose a cylinder that can develop an appropriate force for the work to be accomplished given the available system pressure. Install a pressure regulator upstream from the directional valve if the load is the same extending and retracting or on each of the working ports if there is a substantial difference in load extending and retracting. Then add meter-out flow controls to the working ports. Open up the flow controls all the way. Set the pressure regulator(s) at the lowest available pressure. Apply the load to the cylinder and energize the directional control. The cylinder should not move. Now increase the pressure until the load begins to move. Continue to increase the pressure until the cylinder is traveling a little faster than desired. Now adjust the meter-out flow control to tune in the desired speed. You now have a system that will not squander the inventory of stored air molecules.

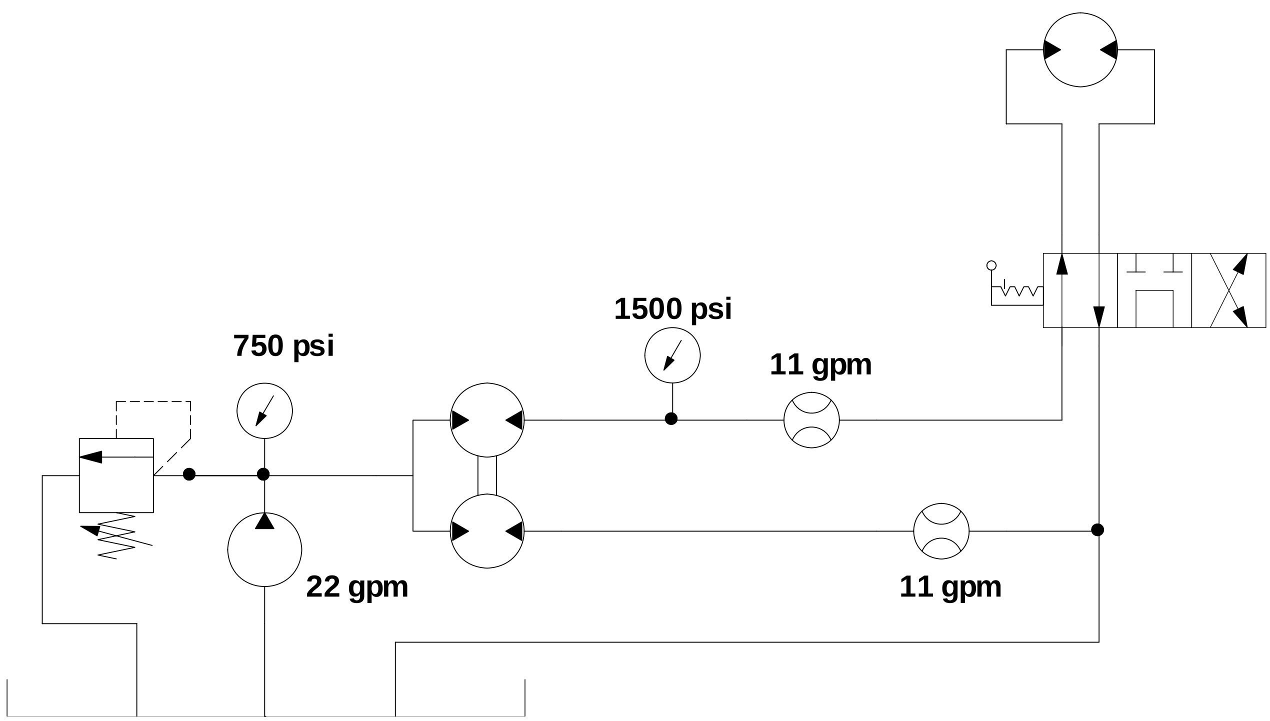
Ok, how do we deal with the street sweeper? Well, we should try and apply the correct pump. But sometimes that is not practical. There is a way to divert the extra fluid to the reservoir without wasting very much energy. By using a displacement flow divider (usually a gear flow divider) we can do some amazing things. If we had directed the flow from the 22 gallon pump on the street sweeper through a 50/50 displacement flow divider, something very different would have happened. Half the flow would have been directed to the work and half would have been directed to the reservoir as before. But this time the extra fluid would be used to boost the pressure in the working fluid. The result would be a resistive pressure of only 750 psi applied to the total flow. All the fluid would be doing useful work and so the only wasted energy would be that used to rotate the displacement flow divider.

We will continue the discussion on flow control and the special functions of displacement flow dividers next time. As always, I look forward to your thoughts and comments.

Flow Controls Illustrated



Restrictive Flow Divider



Displacement Flow Divider

Flow Control

If in doubt, think about…Energy

I see some of you forgot to bring your calculators with you. We'll wait right here and chat a bit while you go fetch your equipment…

I stated in my first article, "Focus on Energy", that I could have lifted a load that required 25 hp using only 12 hp and that I would discuss it in a future article. Well, the future is now. We will need some background information that we will discuss while we are waiting for the others to come back.

When covering the material for taking the CFPS exams, I remind people about some of the laws of physics, namely the relationship between effort, work, and power. If I lean up against my file cabinet, I will be putting in some effort but I will not be doing any work. "Work" is defined as "effort over distance", so, unless I actually *move* the file cabinet, all my effort will technically have done no work. If I am able to tilt the cabinet up and then realize I forgot to bring the hand truck and set it back down again, I will have done some work but then the work would be undone because the cabinet is in exactly the same spot as before I started. The net result is zero work with a lot of effort.

An illustration of this is what I am told about the DeLorean "Back to the Future" ride that used to be at a famous amusement park. The customers got into the car and closed the doors. A marvelous hydraulic system tossed them up and down, back and forth, this way and that while they watched a movie screen that depicted the virtual ride. When the ride was over, the doors opened and everybody got out… right where they started. It took 1000 hp to operate the ride but no useful work was done. Every motion was undone. So, where did the energy go? It all went into Btu's through a huge heat exchanger. The ride was 100% inefficient. Despite all the movement, everyone landed right back where they had started. No work was accomplished. The thrill ride dumped about 42,000 Btu's per minute into the atmosphere.

The point is this; when we lift a load we give it potential energy. When we set it back down again, we dissipate that energy, usually in the form of heat.

Now, if everyone is back with their calculators, we can begin.

In the earlier article we had an upward acting press with a 32,000 pound platen that had to be lifted at a rate of 5" per second. We did the math and found that (32,000 / 550) * (5/12) = 24.24 or about 25 hp. (This will give you a chance to synchronize your calculators). Reflecting on the DeLorean illustration, it should occur to us that when the press operators turn off the machine and go home for the evening, the 32,000 platen is right where it was when they started up in the morning. A lot of energy had been put in but it had all been undone.

Once the platen is lifted, we could just let it drop and we would have a dramatic illustration of the fact that the potential energy has become kinetic when the platen hit the bottom and suddenly dissipated all its energy into the floor of the building. To avoid this show, I had added a pressure compensated flow control to limit the speed of descent.

We know that when hydraulic fluid goes from high pressure to a lower pressure without doing work the energy is converted into heat. So, here are the questions. Given a 6" bore cylinder controlling a 32,000 pound load and lowering it at 5" per second, what would the pressure be upstream from the flow control? What would be the flow rate across the flow control? What would be the hp loss across the flow control? What would be the total Btu load added to the fluid if the load dropped 72”?

No, I’m not going to give you the answer. You have to figure it out for yourself. This is interactive journalism.

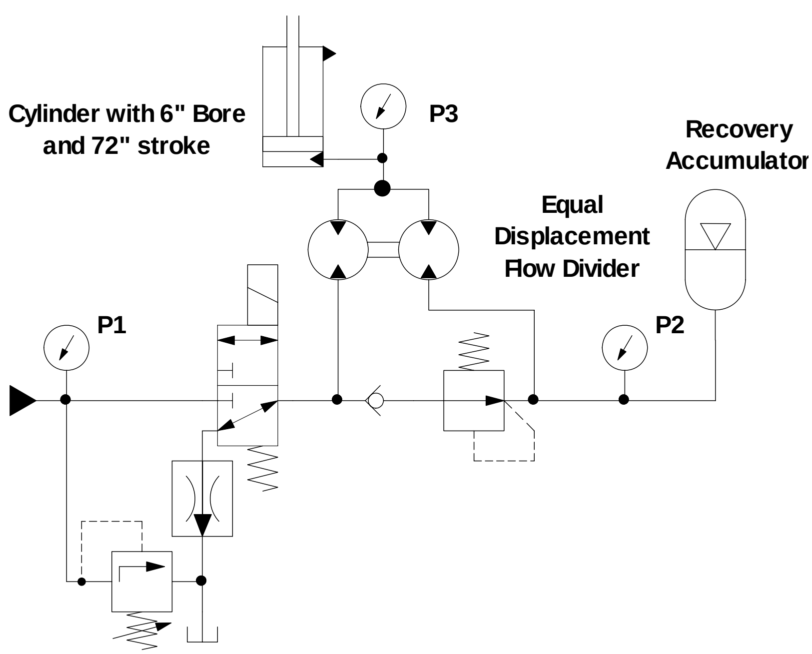
Well, alright, if you’re going to whine, you can find the answers at the end of the article.

In any case, compare the hp loss to the hp required to lift the load. Do you see some similarities? The math tells us that all the energy we put in was taken out again in the form of Btu’s; hence the need for a substantial heat exchanger. In the actual system, I was using a double acting cylinder and so I was pushing the cylinder down adding to the pressure drop across the flow control. I was actually wasting more energy as I lowered the platen than I had put into the system as I raised it.

What if we could find a way to save and store some of the energy as we lowered the platen? Well, with the right flow control system, we can.

Remember, we are not necessarily talking about the least expensive system to design or purchase. We are talking about a more efficient system to operate using a smaller pump, a smaller electric motor and a reduced heat load, the combination of which may indeed mean a competitively priced system.

To do our magic, (actually, there is no magic, just math) we will need to return to the lowly and often unappreciated equal displacement flow divider. Only in this case it will have triple duty; once a flow combiner, then a pressure intensifier, and then a flow amplifier. We will also need an accumulator, a pressure reducing valve, and a pump producing half the flow as before.



The displacement flow divider is placed in the line going to the blind end of the cylinder with the combined flow going to the cylinder. The two ports opposite the combined flow port are separated by a non relieving pressure reducing valve set at a pressure that is a little higher than what is required to lift the load.. Upstream from the reducing valve the port is connected to the directional control valve. Downstream from the reducing valve the port is connected to the accumulator. The accumulator has a gas volume of 15 gallons and is pre-charged to 760 psi.

We will go step by step as we activate the system referencing the drawing above. Keep your calculator handy and your brain clear.

The first time we energize the directional control valve, fluid is sent to both sides of the flow divider and also to the accumulator. The pressure reducing valve is a normally open valve and so it does not come into play at this point. The easiest flow path is into the accumulator and so the accumulator begins to fill until it reaches the pressure necessary for the fluid to rotate the flow divider and begin to lift the load. The cylinder extends at ½ the desired speed.

When the cylinder reaches the top of its stroke, the pressure rises to the setting of the reducing valve which then closes and the system rises to the relief valve setting.

What happens next is where it gets exciting. Are you ready? We de-energize the directional valve and the cylinder begins to retract. Flow is directed to the inlet of the flow divider where it is split evenly through the divider. The reducing valve remains closed because of the pressure in the accumulator and so half the return flow is diverted into the accumulator. The remaining flow passes through the directional valve to the pressure compensated flow control. As the cylinder descends, the pressure in the accumulator rises.

As the accumulator pressure rises, what happens to the pressure of the fluid passing through the pressure compensated flow control? Anybody want to answer? Yes, I see that hand. Right! The pressure continually drops as the accumulator pressure rises. The flow divider is responding as a pressure intensifier.

As the cylinder reaches the bottom of its stroke, the accumulator pressure approaches twice the load pressure and the return line pressure approaches zero.

Now we are ready to go into production. We energize the directional valve and something amazing happens. The pressure at the power source (P1) is near zero. The accumulator pressure (P2) is at twice the load pressure (P3). The flow from the pump enters one side of the flow divider while the other side is driven by the stored energy in the accumulator. Surprise! The cylinder extends at twice the rate that would be expected from the pump flow. Our lowly flow divider has become a flow amplifier. The pressure in the accumulator continually drops and the pressure at the source continually rises until the cylinder reaches the end of its stroke.

This process will repeat from now on. We will lift the load at the desired speed and, using the stored energy in the accumulator, and we will do it with half the pump flow. In this illustration we will actually store about **70%** of the potential energy of the platen. The maximum pump pressure will still be what it was but only as the cylinder reaches the end of its stroke.

Flow control is a necessary part of our arsenal of Fluid Power components. We need to use them wisely with the best interest of the user in mind, including the cost of operation. If you must use a flow control and are not sure exactly what approach to take, remember,

"If in doubt, think about… Energy".

What would the pressure be upstream from the flow control?	1132 psi
What would be the flow rate across the flow control?	37 gpm
What would be the hp loss across the flow control?	24.4 hp
What would be the total Btu load added to the fluid if the load dropped 72"?	248 Btu's

Power Factor

For the purpose of this article, I would like you to divide yourselves into two groups; the "Energy Suppliers" and the "Energy Consumers". While you are deciding which group you want to be in, I will give some introductory comments. Oh, and you should still have your calculators handy from the last article.

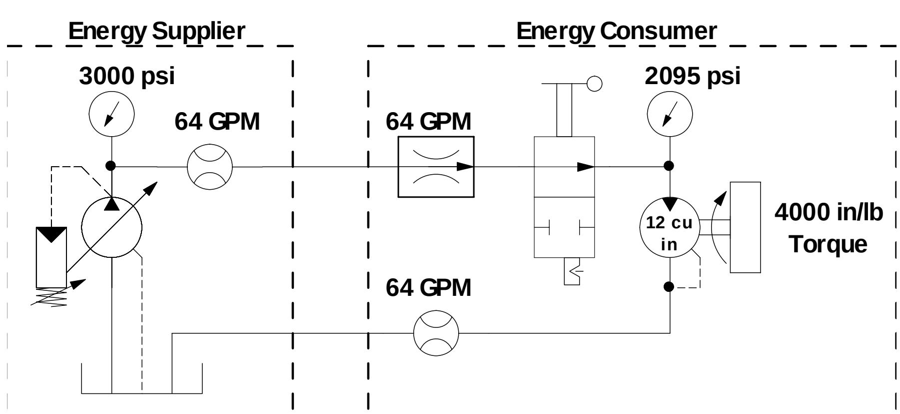
A country preacher was once asked how it was that he had been so successful in teaching his congregation. He responded by saying, "First I tell them what I'm going to tell them. Then I tell them. Then I tell them what I told them."

I plan to accomplish two things as a result of this article. **First**, I plan to raise the level of understanding of "Power Factor" for those of us who do not have a good handle on it. I will do this by giving an illustration rooted in Fluid Power concepts. This will lead to the **second** result. The illustration will highlight an area of Fluid Power Design where we often do a poor job. The overall result will be an increased awareness in both of these subjects that will help us provide more energy efficient Fluid Power Systems.

There, I told you what I'm going to tell you.

Are we ready? All those who chose "Energy Suppliers" raise your hands. Ok, now all who are "Energy Consumers" raise your hands. I see we are a little heavy on the "Consumer" side but that will be alright for our discussion. It will be the job of you "Suppliers" to provide whatever the "Consumers" want. You "Consumers" can ask for anything you want but you will have to pay for all the energy consumed.

So what is this Power Factor thing? Well, the best way to describe it for us Fluid Power people is to think of a circuit provided by the "Energy Supplier" using a pressure compensated variable displacement pump. The "Energy Consumer" is driving a fixed displacement motor at a constant speed. The speed of the motor is controlled by a pressure compensated flow control set at the correct flow to match the displacement and speed required by the motor. (See the circuit below).



To illustrate the point, we have assigned some values to the circuit. The load on the motor will be 4000 in/lb and the speed will be 1200 rpm. The pump compensator is set at 3000 psi. A quick calculation tells us that we will need a motor with a displacement of 8.4 cu in to meet the torque requirements. The flow from the pump will be 44 gpm and will require about 57 kW.

But we decide to be very conservative and place a motor with a displacement of 12 cubic inches in the circuit. Let's take a look at what happens.

The larger motor will require about 64 gpm to run at 1200 rpm so we will set our flow control accordingly. The motor will have a ΔP of 2095 psi which translates into 57 kW.

So what's the problem?

For you "Energy Consumers" it appears that you are using exactly the same energy as with the smaller motor. But we need to examine this from the point of view of an "Energy Supplier". Take a look at what you Suppliers have to provide. Remember, you are using a pressure compensated pump set at 3000 psi. You "Energy Suppliers" will have to produce the 64 GPM but you will produce it at the compensated pressure of 3000 psi resulting in a power requirement of 84 kW.

This is exactly the kind of thing that happens when we Fluid Power Professionals apply an oversized electric motor for our equipment. As mentioned in earlier articles, when we apply an electric motor that is oversized, we wind up using more energy than is necessary. We tend to ignore this because we are not usually the ones responsible for paying the energy bill. The wasted energy does not show up in meters that we use because we focus on the kW at the motor and not on what the power company has to do to provide those kW.

The difference between the energy required from the power company and the energy actually used by the motor is determined by Power Factor. This is described as the relationship between the power used by the motor and the power supplied by the power company and is given as a percentage. The ideal would be a power factor of 100% but is typically accepted as reasonable when the Power Factor is about 80%. This means that the power company would have to generate 20% more power than was actually being used. In our Fluid Power illustration, you "Suppliers" had to generate about 31% more energy than was actually used by the "Consumers".

There is not an exact correlation between the flow and pressure of our Fluid Power System and what the power companies experience. Electric motors are driven by an alternating system that at one moment induces a magnetic field and the next moment has the magnetic field collapse. There are iron losses and copper losses and a host of other issues that are beyond the scope of this discussion. They describe their power production in terms of KVA (Kilo-Volt-Amps) while we tend to only think of the kW on our end. The point is this; just like you "Suppliers" had a production requirement that was greater than what the "Consumers" actually needed, power companies have a greater burden than is seen simply from the kW meter.

Now the folks at the power companies are generally really nice people but they have to answer to stockholders or government agencies and so need to show a positive bottom line. They cannot afford to supply the extra power for nothing. What they do is keep a record of the kW used by the equipment and then tack on a Power Factor charge that covers the additional energy consumed in the process. We do not usually see this and so we do not usually consider it when we specify or apply an electric motor. The companies that use the motors that we have specified see the add-on but often do not associate the charge directly to our equipment. It gets buried in the cost of running the facility and we are not held responsible.

As Fluid Power Professionals, we need to become aware of the impact our choices make on the energy cost of Fluid Power.

Now, I've told you.

There are two things that we can take from this discussion. **First**, using an oversized electric motor in our circuits has a direct impact on the utility bill for the Fluid Power user. **Second**, using a pressure compensated pump without due consideration for the pressure requirements of the actuators, is also an energy waster. As Fluid Power Professionals, we need to be aware of these opportunities to improve our image and the efficiencies of the Fluid Power Systems we apply.

There, now I've told you what I told you.

<u>Power Factor</u>

… an opportunity

I know, I know, you're tired of having to think about energy and you can't find your calculator. We've covered a lot of bad news about our Fluid Power Systems and you're feeling discouraged. Well, I have some good news! What we just learned about Power Factor can provide an excellent and relatively untapped opportunity to apply Fluid Power.

You see, we are not the only ones who specify oversized electric motors in our applications. As a matter of fact, nearly all manufacturers do the same thing. If 10 kW will do the job, they will put on a 20 kW motor just to be on the safe side. The result is that almost every industrial facility is loaded with electric motors that are oversized for the job they are performing. There are exhaust fans, water pumps, conveyors, and blowers, all with oversized motors. Each motor requires an electrical cabinet to hold the starter, circuit breakers, maybe a start/stop button, and an "E Stop". Often the cost of the starter and controls approaches or exceeds the cost of the motor itself. The Power Factor that is accumulated by this array of motors pushes up the cost of electricity to these industries. **We can help!**

Now, some of you are going to get a little nervous about what I am going to say next but before you get too upset, listen carefully and then do the math. Remember, this is just a suggestion, a potential opportunity that we ought to have at least explored.

The basic premise is this; one properly sized electric motor supplying power to a number of smaller systems has a lower installed cost and lower operating cost than the combination of all the small motors that would be required to drive those same systems. It follows then that using a properly designed central hydraulic power unit supplying a variety of hydraulic motors can replace a bunch of smaller electric motors and with a reduced installed and operating cost.

Now, in order to make this work, we, the Fluid Power Professionals, will have to really do our homework. Reject the "rules of thumb". Forget the "fudge factor". Shun the shortcut. This is not going to fall into our laps. We are going to have to work for it, but in the end it will be in the best interest of those who have put their trust in our abilities. It will help reduce costs, make better use of energy, and help establish the image of Fluid Power Professionals as Energy Professionals.

So, where do we begin? First of all, think about the things you already know about Fluid Power. We can take a single power source and transfer the energy to perform linear and/or rotary motion. We can build in soft starts and torque limiting, not to mention reversibility. We can operate in hostile environments and can be used under water. We are equally happy with high speed and low speed applications without the use of gear reductions.

Second, find the right application. It can be really difficult to make changes to an existing system. Management is usually reluctant to try something new on a system that is already working. Try to find a new application or an old system that is ready for an upgrade.

I worked at a plastic blow molding facility for a while. There were 16 molding machines and each had its own grinder that was used to reclaim the material that was trimmed during the process. Two additional grinders where used to shred other discarded plastic material. There was a blower system on each machine that conveyed the trimmings to a specific grinder so as not to mix the materials. The grinders were belt driven to reduce the knife speed to 600 rpm and each was powered by a 7.5 kW electric motor. This gave them enough muscle to chew up large quantities if plastic if necessary but most of the time only a few small pieces of trim were conveyed to the grinder. The grinders spent about 1% of the time under heavy load, 20% under no load, and 79% under low load conditions.

I also had an opportunity to do a study at a water treatment plant. It had six 7.5 kW motors connected to gear reducers driving centrifugal water pumps. There were also two 38 kW motors connected to gearboxes driving circulating pumps. The system operated 24/7.

Both of these facilities provide an excellent opportunity to demonstrate the advantage that Fluid Power Professionals can bring to the table. It was shown that both companies could save about $30,000 a year in energy costs if they switched to central hydraulic power systems.

So, how would you, as a Fluid Power Professional, approach these challenges?

Well, I'm not going to do the math for you even if you whine about it. I will, however, discuss some steps you could take, depending on your relationship with the facilities.

Let's say you are a Fluid Power Professional who is the facilities manager of one of these companies. You've been reading these articles and are convinced that it would be in the best interest of the company to make the Fluid Power choice. Where would you begin?

The hardest step is overcoming the inertia of "We've never done it that way before." At both facilities it would be best if you can get in at the planning stage for a new installation.

At the molding plant you can tell the grinding machine manufacturer that you want a quote on the equipment with hydraulic motors driving the knives directly and with no belt drives for speed reduction. You want a central hydraulic power unit that can handle the average load of the combined motors. You want directional valves that will allow you to reverse the motors (something the original grinders cannot do) because sometimes material gets stuck in the knives and without the reversing capability, you will have to disassemble the grinder to clean it out.

At the water treatment plant, you would let the contractor know that you want an alternative approach using a central hydraulic system driving the water pumps without gear reduction. You will probably have to get the contractor to give you the model number of the water pump so you can call the manufacturer and find out what the actual input torque requirement is. The literature on the water pump will probably only tell you the suggested input horse power. What you need to know is the actual running torque without going through a reducer. This may take a little pushing because the manufacturer is not used to being asked that kind of question. You may wind up talking to some lonely engineer in a back room somewhere who keeps that sort of information either in her head or in a box under the desk. (Oops! Did I say that out loud?) As I said, this is not going to fall into your lap. You will have to work for it, but it is worth the effort.

If you happen to be a Fluid Power Professional involved in application engineering, then you can approach the OEMs and let them know that you can help them in marketing their equipment by introducing central Fluid Power as an alternative.

If you are attempting to make changes in an existing system, there are some basic things you will need to do whether you are the facilities manager or the sales person. Find the actual torque and rpm rating for the driven components. From this, calculate the theoretical kW to operate the machine. Then contact the local power company and have them place meters on the machines to give you the data on the actual power usage and get a report on the Power Factor. With this information you will be able to calculate the current cost, the potential savings and environmental benefits of the new system.

In all cases you will need to be able to accurately and convincingly defend the benefits of Fluid Power including efficiency, reliability, and flexibility.

Some utility companies are offering incentives making systems more efficient. Contact you local utility and find out what is available. This information, along with your Fluid Power Professionalism will help you see the Power Factor as an Opportunity.

Accumulators

Energy Savers / Energy Wasters

It looks like the next few articles will be about some specific components and how they can be best utilized in a circuit for maximum energy savings. Previous articles have laid the foundation for understanding the need for efficient systems both in terms of Fluid Power and electricity. We will build on that knowledge as we move forward.

I started out my career in Fluid Power in the Mobile and Marine markets. We had a limited product line and an even more limited knowledge of Fluid Power. In some of my earliest training, when the question of accumulators came up, I was told that it would be best to stay away from them. They were really complicated and would only be confusing. I was led to believe that accumulators were only used in special industrial applications. I did not need to be bothered with them. Seven years later, I found myself working for a company that was the US distributor for a major line of accumulators. It seemed the cure for every problem was to throw an accumulator into the circuit.

Somewhere between never and always is the right time and place to use an accumulator. Now, accumulators have a number of uses such as pulsation dampening, surge suppression, emergency energy storage, and cushioning but we are only going to be looking at the applications for energy savings. We will give some guidelines to help you choose, not only whether or not to use an accumulator, but also how to properly make the application for maximum energy efficiency.

As a general statement, whenever there is a substantial dwell time, i.e. when the regular source of fluid power is not being used, it is a good idea to consider the use of an accumulator in the system. Remember, from the point of view of the Power Company, the electric motor driving the system is most efficient when it is running near its name plate power rating. If there is a dwell time when our hydraulic pump is unloaded or in low flow compensation, we tend to be pretty content because we are not generating much heat and our hydraulic system is not working very hard. However, the electric motor driving the unloaded pump becomes very inefficient. Typically, the motor can not drop below 1/3 of its rated amperage load and at that point its power factor becomes very low. The ideal situation is to find the average system flow and then use a pump that will provide only that much flow.

For example, let's say we have a system that requires 20 gpm at 1714 psi for 5 minutes and then rests for 5 minutes. To supply the system without an accumulator we would have to provide a 20 gpm pump driven by a 20 hp electric motor and with some type of unloading circuit. However, during the resting time, our electric motor would be drawing about 7 hp with a low power factor that would send a ripple back through the entire facility.

By taking the average flow requirement of 10 gpm we have an opportunity to dramatically reduce the size of the electric motor. We could use a 10 gpm pump with a 10 hp motor and an accumulator. Half the time we would be supplying 10 gpm more than was needed and would store the excess in the accumulator. The other half of the time we would be providing 10 gpm less than was needed but we would borrow from what was stored in the accumulator. The electric motor would run continually at its rated power and everybody is happy!

Ok, I see a couple of you in the back row waving frantically. What's the matter? You say it won't work? Why not? You want me to do the math? But the rest of these guys are sick of doing math. They want some easy fixes. Ok, Ok! I'll do the math. Let's see…

Oh, oh! We have a problem. If I need 10 gpm from my accumulator for 5 minutes, that means I need to have 50 gallons stored in the accumulator. When I use my handy-dandy accumulator sizing formula, and assume a pre-charge of 50% of minimum pressure (rule of thumb), it turns out we will need at least 170 gallons of accumulator gas volume with a maximum pressure of 5000 psi. We will have to use a 30 hp electric motor to drive the pump and we will have about a 3300 psi pressure drop adding heat to our system. The electric motor will sometimes be operating at only 30% of its rated hp. This system will not provide any significant benefit to the facility. In fact it will actually use more energy than if we hadn't messed with it. The system will be more complicated and harder to maintain. It looks like it was a good thing we did the math.

Let's change the scenario. We still have a requirement of 20 gpm at 1714 psi, but now we will be on for 30 seconds and off for 30 seconds. We will still have the same average pump flow of 10 gpm but we will only need 5 gallons stored in the accumulator. This makes a dramatic change in the accumulator gas volume bringing it down to only 20 gallons. But we are still driving our pump at 5000 psi and so will still require a 30 hp motor to operate the system. We still have a 3300 psi pressure drop adding to the heat load. We will have done no favors to anyone.

Take a look at our "rule of thumb" pre-charge of ½ the minimum system pressure. Where did that come from, anyway? This is an example of a "rule of thumb" with a built in "fudge factor". Bladder type accumulators have a check valve that closes to prevent the bladder from extruding into the plumbing if the gas pressure is higher than the system pressure. If the gas pressure is set right at minimum system pressure, the check valve may have a tendency to pound away on the valve seat and cause excessive wear resulting in a premature failure. To prevent this, the pre-charge pressure needs to be below the minimum system pressure so that the fluid pressure is always holding the check valve off its seat. A pre-charge of anything below system pressure would be adequate to accomplish this but, as a safety measure and as a way to avoid doing a lot of math, using ½ the minimum pressure will always insure the longevity of the valve seat. Oh, and as a side benefit, it requires a substantially larger accumulator.

So let's pretend we really like doing our math homework and say we are quite confident that our minimum pressure is really 1714 psi. If we pre-charge the accumulator to about 96% of minimum pressure (about 1650 psi) and change the maximum pressure to 2000 psi, take a look at what happens. We will now need 50 gallons of gas volume and our power requirement will become about 12 hp. We will have less than a 300 psi pressure drop so there will be a very manageable heat load with which to deal. If this system runs 24/7, the resultant savings will be about 55,000 kWh/yr with a cost benefit of about $6,000/yr.

When deciding to use an accumulator as an energy saving device, remember to take into consideration, not only the average flow and system pressure, but also the relative dwell time, the pre-charge gas pressure and the maximum accumulator pressure. Remember also that the larger the accumulator, the lower the maximum pressure will be and the greater the energy savings. Reject the rule of thumb, forget the fudge factor, and shun the shortcut. It is tempting to be content with simply providing a smaller pump, but if it requires running at a much higher pressure, we may not be providing any substantial savings. The goal is not the smallest flow or the smallest accumulator, but the optimum system for low energy consumption.

The previous discussion has all been related to using accumulators with a fixed gas volume. There is another way. For maximum energy efficiency, the best accumulator is one that is weighted instead of charged with a gas. In our example we needed 5 gallons of stored fluid at 1714 psi. If we took a 4” bore cylinder with a 92” stroke mounted vertically and placed a weight of 22,000 pounds on it, we could store our fluid in the cylinder at 1750 psi. We could then drive our 10 gpm pump with the 10 hp motor. The resultant savings would be about 64,000 kWh/yr with a cost benefit of about $7,000/yr. This may be unconventional but we need to allow ourselves to think creatively if we are serious about being Fluid Power Professionals.

Outside the Box

I've got an idea. Tell me what you think. You have an application where you need to store 20 liters of hydraulic fluid to be used at 120 bar. You know that using a conventional accumulator will do it but it is not the most efficient way. The minimum pressure in the accumulator will have to be higher than the working pressure to get any flow and the pressure will increase as the accumulator fills. That means that extra hp will be needed to push the fluid into the accumulator and the extra power will be lost as heat when the fluid is used. You know that a weighted accumulator would be more efficient because all the fluid could be stored at the working pressure but the application would be awkward. The facility uses compressed air at 6.6 bar.

You can take a regular hydraulic cylinder with an 80 mm bore and a 4000 mm stroke and use it to hold the 20 liters of fluid. Then connect the rod of an air cylinder with a 350 mm bore and a 4000 mm stroke to the rod of the hydraulic cylinder. The rod end of both cylinders will be vented to atmosphere. The blind end of the air cylinder will be connected to the unregulated air supply while the blind end of the hydraulic cylinder will be connected to the high pressure fluid source. Because of the relative areas of the cylinder pistons, the hydraulic fluid will have to be at about 130 bar to move the air cylinder. However, as hydraulic fluid enters the blind end of the storage cylinder, the exhausting air from the pneumatic cylinder is pushed back into the air supply and remains at 6.6 bar. This means that all the fluid can be stored at 130 bar. No compressed air will be consumed and the energy will be stored as though you were using a weighted accumulator.

Unconventional? Yes.
Practical? You decide.
Energy efficient? Absolutely!

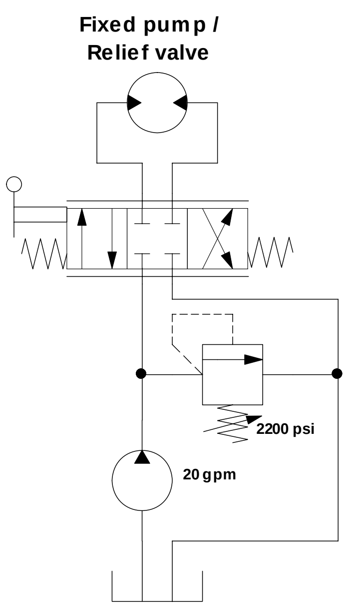
Efficient Hydraulic Systems

I think I may have a surprise for you.

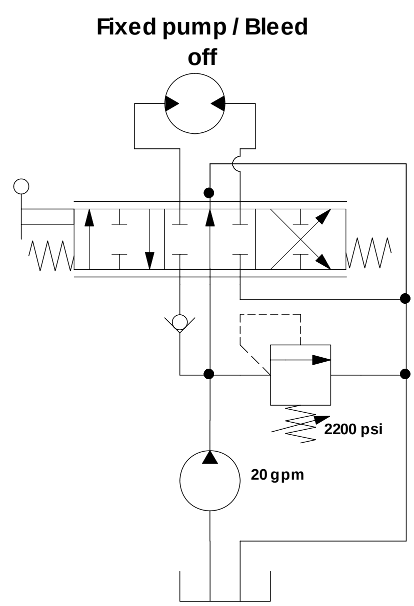
We will look at a system and try three different hydraulic systems and see which is best from an energy perspective. The requirements are these: a hydraulic pump needs to supply either 17 or 20 gpm at either 1750 or 2100 psi to do some work. 20% of the time the system operates at maximum flow and maximum pressure. 20% of the time it is at maximum flow and minimum pressure. Another 20 % of the time it sees minimum flow at maximum pressure. 5% of the time it is at minimum flow and minimum pressure. That leaves 35% of the time during which the system is idle (dwells).

We will first use a fixed displacement pump, a relief valve, and a metering directional control valve that has a center condition with all ports blocked. We will then try a fixed displacement pump, a relief valve, and a metering directional control valve with a center condition where all pump flow goes to tank (a bleed off circuit). Finally, we will try a pressure compensated pump and a metering directional control valve with a center condition having all ports blocked. (See circuits below).

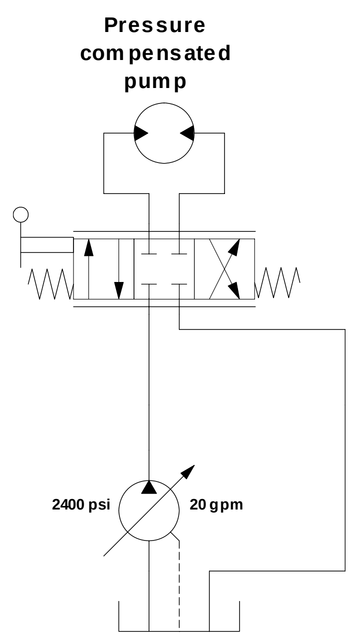
Option 1



Option 2



Option 3



Let's see a show of hands. How many of you think the first application will be the most efficient? I see three hands. Ok, how many think the second option will be most efficient? I see twelve hands. How many think the third option will be the best? Wow! Number three is the big favorite.

Now, let's do the math. For those of you who are not yet Fluid Power Professionals, we will be using the formula HP = (GPM x psi) / 1714.

In the first instance, we will have a pump that produces 20 gpm with the relief valve set at 2200 psi. This pressure is for 2100 psi to do the work, 100 psi tank line pressure, and 100 psi buffer.

In the second instance, we will use the same 20 gpm pump and relief set at 2200 psi.

In the third system we will use a pressure compensated pump set at 2400 psi. This pressure is higher than the relief settings on the fixed displacement pumps because this pump begins to compensate at about 90% of the compensator setting so we need the higher pressure to be certain we have enough flow to do the job.

System Information			Fixed Displacement Closed Center	Fixed Displacement Bleed Off Center	Pressure Compensated
Max Flow to Motor	20	GPM	20	20	20.25
Min Flow to Motor	17	GPM	20	20	17.25
Max Pressure (ΔP)	2100	PSI	2200	2100	2400
Min Pressure	1750	PSI	2200	1750	2400
Circulating Pressure	100	PSI	100	100	2400
Dwell Flow	20	GPM	20	20	0.25
Relief Pressure	2200	PSI	2200	2200	
Compensator Pressure	2400	PSI			2400
Max Flow/Max Pressure	20	%	20%	20%	20%
Max Flow/Min Pressure	20	%	20%	20%	20%
Min Flow/Max Pressure	20	%	20%	20%	20%
Min Flow/Min Pressure	5	%	5%	5%	5%
Dwell Time	35	%	35%	35%	35%
Max HP	**25.67**	**HP**	**26.84**	**25.67**	**28.35**
Max Flow Low PSI HP	21.59	HP	26.84	21.59	28.35
Min Flow High PSI HP	21.82	HP	26.84	25.67	24.15
Min Flow/Low PSI HP	18.35	HP	26.84	21.59	24.15
Dwell HP	1	HP	26.84	1.17	0.35
Average HP	**15.14**		**26.84**	**16.07**	**17.50**

The chart above is taken from a working spreadsheet. You can find it on line at: http://www.cfpsos.com/Most%20Efficient%20Hydraulic%20System.xls.

Only three of you will be surprised to see that the fixed pump with a closed center valve is not the most efficient. Twelve of you either knew or played a hunch. The rest of us are probably a little surprised that the bleed-off circuit beat out the pressure compensated pump by about .5 HP.

We will take a look at what is happening. It is important to understand the “why” as well as the “what” when we are specifying components.

The pressure compensated pump and the fixed closed center system have something in common. They are always at maximum pressure at the pump. The difference is the flow. The fixed pump produces 20 gpm continually. Any flow that is not needed for the job is sent across the relief valve at full pressure. So this system always operates at maximum hp no matter what.

The pressure compensated pump always operates at its set pressure but it will vary the flow based on demand. But when the required pressure is less than the compensator setting, there is a pressure drop across the metering directional control valve. The excess energy goes into heat. In addition, there is a constant case drain flow of about .25 gpm which is also generated at compensator pressure. So, even when in dwell mode, the system remains at compensated pressure.

The bleed-off system and the fixed closed center system also share a characteristic. They both produce all the flow all the time. The big difference, listen up now, the big difference is that the fixed closed center system is always at **relief pressure**. The bleed-off system is always at **load pressure**. Any excess flow from the bleed-off circuit is diverted to tank at load pressure, not at relief pressure. In a dwell mode, all flow is directed to tank at a low pressure.

I am not saying that the bleed-off system is always the best. I am trying to point out that we need to do our homework and look at all the options when offering the best in Fluid Power.

Forget the fudge factor, reject the rule of thumb, shun the shortcut, do the math.

Reducing Pressure; A Way to Save or Waste Energy?

If you are a pneumatics person, you will be thinking of a pressure regulator; the hydraulic people among us will be thinking of pressure reducing valves. In concept the two controls are similar but the way they effect the energy requirements is quite different. In hydraulics, the pressure reducing valve is an energy waster; in pneumatics it can be an energy saver.

In both systems, the valve is normally open (passing). This is important to remember. I have seen examples of applications where this has not been considered in both hydraulic and pneumatic systems with some surprising results, not related to energy.

On the hydraulic side, I recently had to deal with an application where a cylinder had to move a wheeled carriage horizontally. The load on the carriage varied from about 6,000 pounds to 34,000 pounds. The problem was that the carriage system would abruptly stop at the end of its travel. The shock would send a shutter through the mechanical components producing a nightmare of mechanical problems needing repair. Someone had decided to add a pressure reducing valve to the circuit to reduce the shock load. The idea was that, by reducing the pressure on the cylinder, it would not have such an impact when it stopped. The system pressure was set at 190 bar (2800 psi) but it only required 50 bar (750 psi) to accelerate the load. The pressure reducing valve was set at 50 bar and the system was operated. BANG! The carriage slammed at the end of its travel as before. The reduced pressure was reset to 40 bar. The carriage took longer to come up to speed but when it came to the end… BANG! So what was going on?

I can see that some of you are grinning because you have gone through this same thing yourselves, but don't get cocky. We all had to learn this at some point. I made a similar mistake in a clamp circuit, but we can talk about that later.

Here is the problem; remember the pressure reducing valve is a what? That's right, a **normally open (passing)** valve. The reducing valve was in the pressure line to the directional valve. When the valve was shifted, reduced pressure was directed to the cylinder and affected the rate of acceleration. However, once the carriage reached its top speed, it required less than then the reduced setting to maintain the speed and so the pressure reducing valve did what? It opened up… all the way. When the carriage came to the end of its travel, it hit at full speed and there was a sudden spike in pressure as system pressure was felt in the line. Immediately *after* the carriage stopped, the pressure reducing valve modulated to reduce the pressure but the damage was already done. It was like putting on the brakes right after you hit the wall.

On the pneumatic side, I was called in to troubleshoot a system where some test tube grippers were failing to release the tubes. The components were all safely protected in a Plexiglas enclosure. The problem only occurred after someone opened a particular door in the enclosure that had an "E" Stop function. If any other door was opened or if the system was shut down normally, everything operated properly. But, if someone opened that one door while the grippers where holding the tubes and then closed the door and restarted the system, some of the grippers would not release. The valve manufacturer was pointing fingers at the gripper people and the gripper people were pointing back at the valve folks and the owner of the machine was loosing production and just wanted it to be fixed.

The plant air system operated at 7 bar (100 psig). The grippers were designed to work at 4 bar (60 psig). There was a pressure regulator in the supply line set at 4 bar. The FRL had a built in safety unloading valve tied into the "E" Stop circuit that cut off the air supply and vented the system. The directional control valves for the grippers where all solenoid operated and remained in the last commanded position. The grippers were double acting; power to close; power to open.

Once again we ask, "What is going on here?" At the time, it was a real head scratcher but in retrospect it is pretty clear. The key is that a pressure regulator is a **normally open (passing)** valve. During normal shutdown, the pressure to the system remained available at 4 bar so, even if someone opened another door that stopped the motions, the grippers never saw more than their allotted 4 bar. However, when someone activated the "E" stop in the middle of an operation, the system pressure was vented and the pressure regulator, you guessed it, the pressure regulator opened up. Upon closing the door and de-activating the "E" Stop, 7 bar of pressure zipped through the open regulator and sent a shock wave traveling at the speed of sound through the directional valves and into the grippers causing them to jam even tighter against the test tubes. A few milliseconds later the pressure regulator sensed the change and modulated to reduce the pressure to 4 bar. When the grippers were directed to release the test tubes, some were jammed so tight that it required more than 4 bar to open them and so they were unable to release the tubes.

For the hydraulic system, the answer was to replace the bang-bang valve with a proportional valve that allowed us to softly start and stop the carriage. On the pneumatic side, the answer was to supply a regulator that is specifically designed to gradually increase the pressure in a system.

Now, as I was going to say before all this discussion about the function of these regulators, there is an energy aspect to both hydraulics and pneumatics; one negative and one positive. Hydraulically, a pressure reducing valve can give the illusion of conserving energy because, at the actuator, we have less pressure and would appear to be using less energy. In reality, we are using more energy on two counts. First, remember that whenever there is a pressure drop in a hydraulic system, there has to be flow. Without flow, we have a static situation and pressure would be equal everywhere in the system. Whenever we have flow and a drop in pressure that does not produce useful work, the energy is lost in the form of heat. If we have a system that provides 10 GPM at 1714 psi and add a pressure reducing valve to make only 857 psi available to the actuator, 5 hp will be lost in Btu's that will have to be removed from the system. Second, even if the load is static as in a clamp system, there is a constant flow through the drain line going from system pressure to tank. The pressure reducing valve is one of the hot spots for energy loss.

Pneumatically, the pressure regulator is an energy saver. We pointed out in an earlier article "Flow Controls: If in Doubt…" that we store our pneumatic energy in the form of pressurized air molecules stuffed in a receiver. We conserve on energy when we only use as many air molecules as necessary to do the job. The more molecules we stuff into a cylinder, the higher the pressure will be and the greater the available force. If we allow a cylinder to go to the end of its stroke and then continue to add more molecules, the pressure will build with no useful purpose and we will squander our reserve of energy. By properly setting the pressure regulator we limit the number of molecules allowed into the actuator to what is required to produce the needed pressure.

Now, some of you are thinking, "Just stick a flow control valve in the line and that will reduce the amount of air that is used, right?" Wrong! The flow control limits how fast the molecules get stuffed into the actuator. It is the regulator that determines how many air molecules are actually used.

Hydraulically, I am not suggesting that we stop using pressure reducing valves. I am simply pointing out that we need to understand exactly how they work and use them correctly knowing that they are always a source of energy loss.

Pneumatically, I am suggesting that we start using more pressure regulators. They are a neglected item in our arsenal of energy saving devices.

Systems Integrators
An Energy Challenge

I have to admit that I am a little bit skeptical. Now, don't get me wrong. I am not saying that system integrators don't know anything about saving energy. In fact, I am convinced that they may be, and certainly ought to be, the most qualified to inject energy saving concepts into the design and implementation of Fluid Power Systems. My skepticism comes from having spent more than 30 years in sales and application engineering in Fluid Power, using both hydraulics and pneumatics. During that time I do not recall a single supervisor encouraging me to try and provide the most energy efficient solution to a problem. Our customers had come to depend on us for Fluid Power solutions because they generally lacked the expertise to design systems themselves. We usually wanted to supply the best solution but the criteria that defined "best" did not often include the energy requirements of the system.

Some of us have a tendency to over-design systems that we offer as "robust" or "bullet proof". The systems work well and last a long time but often with an unnecessary consumption of energy or overly complicated electronic controls. If a 50 hp motor would do the job, then we provide a 75 hp motor. If a proportional control would work, then we would choose a servo valve. We love systems that required a lot of system integration because we get to show off the neat stuff in our arsenal.

Some of us would rather make a quick sale or find a quick solution then spend time laboring over the energy requirements of a system because the customer's energy bill does seem to directly affect our salary. Some businesses are often more interested in a quick, robust, and short range solution than in long term energy savings. The urgent often takes precedent over the important.

Our management has recently implemented a serious program for continuous improvement. Included in that program is the use of energy. Any suggested changes in the hydraulic, pneumatic, or lubrication systems need to include the impact on energy and the environment as well as on productivity and efficiency.

I count myself among those who could be classified as Fluid Power nerds. I know that there is a point at which "good enough" is good enough and it can drive a sales manager or plant manager nuts while we labor on to squeeze the last Btu or SCF out of a system. At the end of the day there has to be a profit made or a solution found or we will not be able to open the doors tomorrow. What I am trying to get across is that we need to think of energy as an integral part of our system integration.

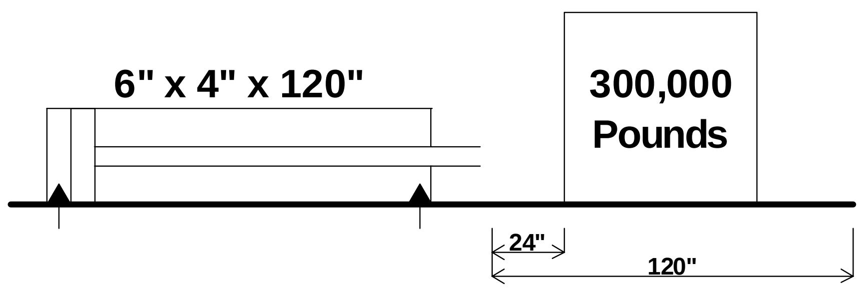
So, here is the challenge. I am going to describe two fictitious Fluid Power systems; one pneumatic and one hydraulic, to see who can come up with the most energy efficient approach. I am not interested in the lowest price. It is the lowest energy use that is the criteria. The entry that has the best energy usage in each category gets the prize. The energy standard for hydraulics will be in terms of kWh. The pneumatics system will be rated in Standard Cubic Feet. You will submit your proposals and I will submit mine. If no one exceeds the efficiency of my systems, then no prize will be awarded. A panel of judges from the Board of Directors of the International Fluid Power Society will judge the entries and their decisions will be final. The winners will have their names and organizations published in a future article. I will describe in detail my thought process and the math behind the energy requirements of my proposed circuits in the next addition of the Journal. We will then publish the winning circuits for all to see.

I admit that I have an advantage in that I am initiating the contest and have had a chance to think about it for some time but I am not going to use some devious devices or mathematical wizardry to come up with my energy usage. I will only use concepts that have been addressed in my earlier articles.

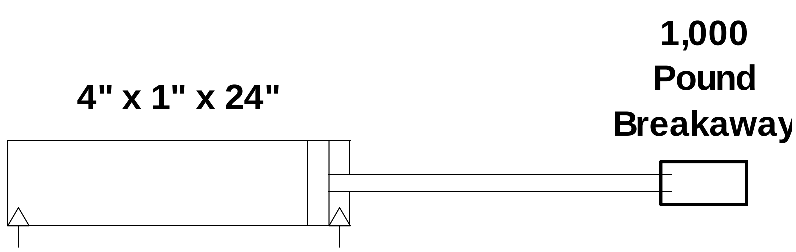
Two $50 gift certificates for the IFPS Store will be awarded; one for the most energy efficient hydraulic and one for the most energy efficient pneumatic system that can be shown to use less energy than my systems. All entries must be submitted to Kristine Coblitz, the Editor of the Fluid Power Journal, by March 15, 2009 to be eligible for consideration. She can be reached at kcoblitz@fluidpowerjournal.com or a Fax can be sent to **866-723-5220**. The entries must include a copy of the suggested circuit along with an explanation of the math used to determine the energy consumption of the system.

Are you ready? Here we go!

Hydraulic: A 6” bore cylinder with a 4” rod and a 120” stoke is mounted horizontally. It is used to slide a cargo container across a platform and onto a conveyor. The loaded container weighs 300,000 lbs with a friction factor of .25. The container is positioned 24” from the retracted position of the cylinder. The cylinder rod has to extend the 24” in 2 seconds before it comes in contact with the container. Once in contact with the container, it has to traverse the remaining 96” in 8 seconds. The cylinder then must retract fully in 10 seconds. The cylinder now waits for 2 minutes while another container is positioned for being moved and then repeats the sequence. The system operates 12 hours a day, 6 days a week. Assume 85% overall efficiency. Assume 100 psi tank line pressure. Keep in mind that the container is not moving when the cylinder rod makes first contact and will have to be accelerated to a speed that will allow it to cover the distance in the allotted time.



Pneumatic: A 4” bore cylinder with a 1” rod and a 24” stroke is used to extract a spacer that is wedged between two components. Breaking the spacer loose for the first 1” of travel requires 1000 pounds of force but sliding the wedge out of the way only requires overcoming the inertia and the friction factor of .15 for the 85 pound wedge and must be accomplished in 1 second. The system rests for 30 seconds and then the cylinder fully extends in 1 second with only the inertia and friction resistance to the end of the stroke. The components are then positioned against the spacer again requiring the 1000 pounds of force to retract. After 10 seconds, the system repeats. This operation runs 24/7.



Take the challenge. Make energy consumption a part of your system integration planning. We can show that Fluid Power Professionals are indeed Energy Professionals.

System Integrators Energy Challenge

Follow Up

There are some prerequisites for reading this article. You need to read last month's article entitled "System Integrators, an Energy Challenge", you need to have your calculator handy, and you probably ought to have your "Lightening Reference Handbook" at your finger tips (available at www.ifps.org for only $18.50) because this article is going to examine the thought process used when trying to provide the most energy efficient Fluid Power system.

A quick recap: Two fictitious Fluid Power applications were described; one hydraulic and one pneumatic. The challenge is to see who can come up with the most energy efficient system to do the work. The hydraulic system will be rated by the kW used and the pneumatic system by the standard cubic feet of air consumed. A prize of a $50 gift certificate is to be awarded to each winner, unless of course, I am the winner. This article will cover what I believe should be considered for the two systems. I will not give away my answer but I will tell you what I think the targets should be.

With the hydraulic system the first thing we need to do is determine the power requirements for the system. This is a challenge because of the changing power requirements throughout the cycle. As you recall (or maybe just read) a cylinder rod has to extend horizontally for two seconds with almost no load at a rate of 12"/second. The rod then comes in contact with a heavy object that it has to move 96" in 8 seconds. It then has to retract under no load for the full 120" and cover the distance in 10 seconds. The system now rests for a full 2 minutes waiting to start again. We were given the fact that the cylinder has a 6" bore, a 4" rod, and a 120" stroke. We are to assume a return line pressure of 100 psi and an overall efficiency of 85%. The weight of the object to move is 300,000 pounds but it is slid sideways, not lifted, and there is a given coefficient of friction of .25.

Now, at first look, it seems pretty straight forward; the speed is always 12"/second so we only have to calculate the flow rate for that speed and then add the pressure required. But there is a wrinkle here. The heavy object is not moving when the rod comes in contact with it so it will have to be accelerated at a rate that will allow it to cover the distance in 8 seconds. It seems reasonable that there will be a hesitation of about 1 second as the rod contacts the object, builds pressure, and satisfies the capacitance of the plumbing. This means I have to cover the 96" in just 7 seconds.

Now pull out your "Lightning Reference Handbook" and turn to page 101 where the formulas are listed. Take a pencil and write these acceleration formulas in the margin. **F = ma**, **$d = .5at^2$**, and **V = at** where **F** equals force in pounds, **m** equals mass, **a** equals imperial acceleration, **d** equals distance traveled in feet, **t** equals time in seconds, and **V** equals velocity in feet/second. You'll be glad you have these the next time you take an IFPS Certification exam.

We first have to solve for **a**. We know the distance the object has to move and we know how much time it will take to move it. It travels 96"or 8' in 7 seconds. So warm up your calculator and what do you get? $8 = .5a7^2$. So, 16 = 49a. 16/49 = a. **a = .3265**.

Who remembers how to find the mass of the object? Ok, you with the pocket protector full of pens, how do we do it? That's right! We divide the weight by the acceleration of gravity which in imperial speak is 32.2. So 300,000 / 32.2 = 9317ish so **m = 9317**.

Force and velocity will now fall into place. F = ma. So F = 9317 x .3265 giving us **F = 3042** pounds of force. V = at. So V = .3265 x 7 giving us **V = 2.29** feet/second maximum speed.

I like to use **$Q = 2.45\ Vd^2$** to find the flow rate where **Q** equals flow in GPM, **V** equals velocity in feet/second, and **d** equals the inside diameter through which the fluid moves. When we apply this to our 6" bore cylinder we find we need a pretty high flow rate by the time the rod reaches the end of its stroke. Q = 2.45 x 2.29 x 36 so **Q = 202 GPM**.

We have the maximum flow rate but who can tell me how to find what pressure we need to move the load? Come on. You know the answer. Just shout it out! Right! **P = F/A** where **P** equals pressure, **F** equals force, and **A** equals the area acted on by the pressure. We know the area (6^2 x .7854) so **$A = 28.27\ in^2$** but what is the resistive force? Careful now! We have the 300,000 pound object with a coefficient of friction of .25 providing a resistive load of 75,000 pounds. But that's not all. We also have an acceleration force of 3,042 pounds and a pressure off 100 psi in the return line acting on the annuls area of the piston… Quick; who has that figured already? 1571 pounds? Everybody agree? There is a total resistive load of 75,000 + 3,042 + 1571 pounds for a total of **79,613 pounds**. P = 79,613 / 28.27 so **P = 2816 psi**.

We know that HP = GPM x psi / 1714. This means that, as the cylinder approaches the end of its stroke, we have to provide 202 x 2816 / 1714 or **332 HP** in order to do the work. Throw in the 85% efficiency and we are looking at **391 HP (292 kW)**.

A 400 HP motor with a 205 GPM pump would do the job but remember, the contest is to find the most energy efficient system. That means we need to use the smallest electric motor/pump combination that will do the job and then push it to its nameplate power as long as it is running. We need to take a look, not at the maximum power consumption, but at the average power consumption.

To find the average power consumption, let's take a second by second snapshot at what is going on in the system. I know, I know. It sounds like a lot of work but we are the professionals, right? It really will not be that bad. The total cycle time is 140 seconds but the working portion is only 20 seconds. So we need 20 snapshots of the energy usage; 2 seconds no load extending, 8 seconds full load extending, and 10 seconds no load retracting. When we calculate the flow at pressure at each second we can find he kW usage at each second. We then add them all up and divide by the total cycle time to get our average power usage.

I see some of you are getting glassy eyed already so I will give you the answer. The average power consumption for this system is 7.51 kW (10.07 HP). Given the 85% overall efficiency, we have a target of 8.84 kW (11.85 HP). The winning system will be the one that comes closest to this number.

Ok, let's take a 10 minute break and then we will come back and take a look at the pneumatic challenge….

The pneumatic system poses a somewhat different set of challenges. We discussed in an earlier article that hydraulics and pneumatics differ in the way they use energy. Hydraulics is a "pay as you go" system where we put in the energy and then immediately either use it by doing useful work or release it by turning it into heat. Pneumatics is more of a "store it now and use it later" system where we add energy to a volume of air, store it in a receiver, and then use it later as needed. The amount of air we use is described in terms of Standard Cubic Feet (SCF). In order to determine the amount of SCF to be consumed we need to find two things; the maximum pressure required, and the volume to be filled.

This is what we know. A 4" bore cylinder having a 1" rod and with a 24" stroke is mounted horizontally and is fully extended. It is attached to an 85 pound spacer that is wedged between to parts. It will take 1000 pounds of force to break the spacer free and then the cylinder retracts in 1 second dragging the weight of the spacer with a coefficient of friction of .15. After a 30 second dwell time, the cylinder extends in 1 second against the inertia of the spacer and the .15 coefficient of friction. The parts are then placed against the spacer and 10 seconds after the extension the process repeats.

We will again use the formula **P = F/A**. The **F** will be the given 1000 pounds plus the acceleration force required of the 85 pound spacer plus the frictional resistance. To be on the safe side, let's add in a 15 psi resistive load as the air is exhausted from the cylinder. We find the **F** to be 1000 + 10.56 + 12.75 + 188.55 or 1211.86 pounds. Remember that, in this case the **A** is the area of the rod end of the cylinder which is 11.78 in^2. So P = 1211.86 / 11.78 or **102.87 psig**. We now have the maximum pressure.

We next have to calculate the volume. This is easy. We already know the annulus area and the stroke so the volume is 11.78 x 24 or 282.72 in^3. We will add in the volume to fill when we extend which is 12.57 x 24 or 301.68 for a total volume of **584.40 in^3**.

The conventional way of calculating the required SCF would be to take the maximum pressure in terms of psia and divide it by the atmospheric pressure and multiply that result times the total volumes of the cylinder. We would use (102.87 + 14.7) / 14.7 giving us about 8. So 8 x 584.40 in^3 = **4675.2 in^3**. Now we want SCF not in^3. So we divide 4675.2 in^3 by 1728 in^3 and get 2.71 SCF for each complete cycle of the system. We would use meter-out flow controls to control the cylinder speed.

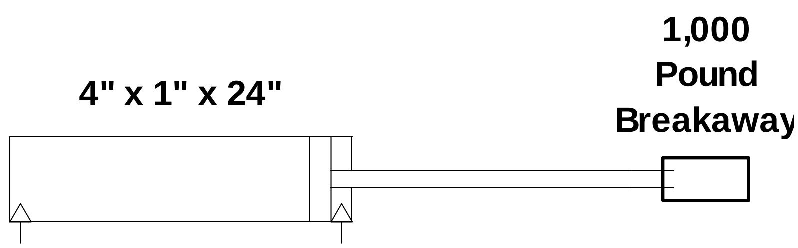
The fact is we never need both the maximum pressure and the full volume at the same time. Once we break the spacer free, we only have 211.86 pounds of resistive force requiring only 18 psig. When we are extending we have the same relatively small resistive load. Your job is to find a way to use the least SCF and still get the work done. I am suggesting a target of .4 SCF per cycle. Give it your best shot.

System Integrators Challenge

The Pneumatic Solution

You may not believe this, but I did not have the solution to the challenges when I wrote the article. I simply chose two scenarios where I knew there would be a variety of pressure and flow requirements that are usually the areas where we tend to loose sight of the energy consumption. As of this printing, I do not know what solutions are being offered but I am now going to let you know what I think is the best energy solution for the pneumatic portion of the challenge. So get out your calculator and bear with me as we walk through the process.

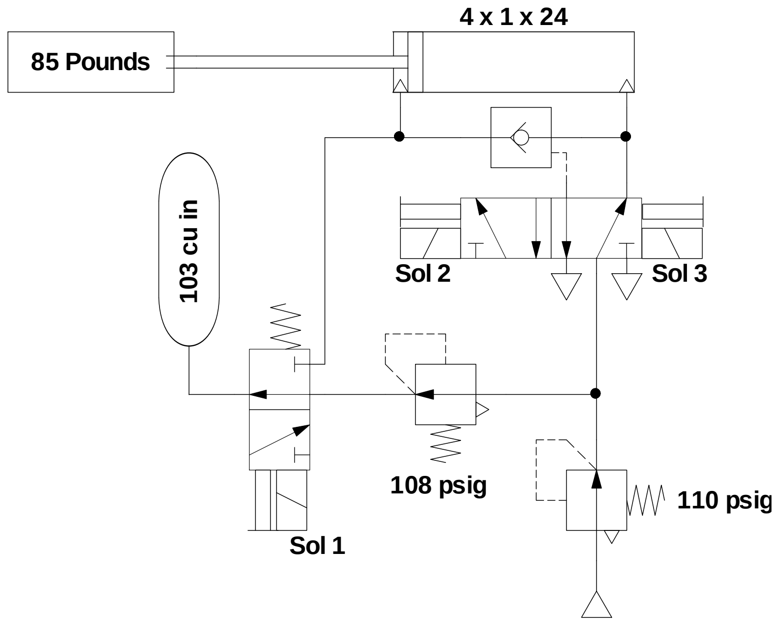
A quick recap for those of you who may be new to the Journal; A 4” bore cylinder with a 1” rod and a 24” stroke is used to extract a spacer that is wedged between two components. Breaking the spacer loose for the first 1” of travel requires 1000 pounds of force but sliding the wedge out of the way only requires overcoming the inertia and the friction factor of .15 for the 85 pound wedge and must be accomplished in 1 second. The system rests for 30 seconds and then the cylinder fully extends in 1 second with only the inertia and friction resistance to the end of the stroke. The components are then positioned against the spacer again requiring the 1000 pounds of force to retract. After 10 seconds, the system repeats. This operation runs 24/7.



The challenge is to see who can come up with the most energy efficient way to accomplish the task. The criterion is the amount of air used in terms of Standard Cubic Feet (SCF).

We calculated the volumes on both sides of the piston in the last article. The rod side volume is **282.72 in^3** and the blind side volume is **301.68 in^3**. We calculated the breakaway force in retraction as **1211.86 pounds**. We did not calculate the required extending force. This force will be the inertia load plus the friction load plus the resistive load from the exhausting air at 5 psig. I see this as **10.56 pounds** + **12.75 pounds** + **62.83 pounds** respectively for a total of **86.14 pounds**. This will make the pressure required to extend the cylinder **6.54 psig** if we use the area of the piston as our force source.

I am going to do two unconventional things in this circuit. First, I am going to use a small accumulator to supply the breakaway force and the volume necessary to fully retract the cylinder. Second, I am going to use a regenerative circuit for the extension of the cylinder. Take a look at the circuit below and then we can do the math.



Energizing solenoid 3 causes the cylinder to extend in a regenerative mode. Energizing solenoids 1 & 2 causes the cylinder to retract.

In order to retract the cylinder, we have to have 1211.86 pounds of force for the first inch of travel. This will require 103 psig. After that, we only need 211.86 pounds of force to complete the stroke requiring 18 psig. If we supply the 103 psig for the whole stroke, after 1 inch of travel the force will produce too much acceleration and the cylinder will bounce as the rapid acceleration overcomes the ability of the exhaust flow to leave the blind end. We could add a meter-in flow control, but that would not reduce the air consumption. Does anyone remember why? Yes, you are right! Once the rod is fully retracted the pressure will equalize to 103 psi and we will have used the same amount of air that would be required to move the full load the entire stroke. When the cylinder is fully retracted, we should have only 18 psig at the rod end of the cylinder. Any higher pressure will require more air molecules than are necessary.

This is where the accumulator comes in. The volume is determined by doing the math (I know, I know, you don't want to have to think that hard) to have enough pressure after 1 inch of stroke to complete the breakaway and then have only 18 psig left at the end of the stroke.

I see a hand there in the back. You want to know how to determine the accumulator volume? The rest of you stop smirking. It is a good question. First we will find the ratio of the final pressure and the initial pressure. The initial pressure is actually **108 psig** because we will be consuming some air during that first inch of travel. The ratio then between the initial and final pressures is **3.75:1**. The volume of the rod end of the cylinder plus the volume of the accumulator will equal 3.75 times the accumulator volume. The accumulator volume is **103 in^3**. If you have a question about this, we can talk after class or you can send me an email and I will show you my spreadsheet.

Charging the 103 in^3 accumulator with 108 psig air, we will provide enough force to breakaway the cylinder and then will provide a constantly decreasing rate of acceleration as the cylinder rod retracts. When the cylinder is fully retracted, there will be only 18 psig in the rod end. If we add a flow control the result will be the same. **The SCF used will be .36**.

To extend the cylinder, we will use a regenerative circuit. This is not often done in a pneumatic circuit but it can be a handy tool. To do this, we connect the rod end of the cylinder to the blind end. The effective area is determined by the rod diameter. So we are working on an area of **.7854 in^2**. To move the **86.14 pound load** we will need 110 psig. The volume taken up by the rod is .7854 x 24 or 18.85 in^3. At 110 psig, this translates into about 160 in^3 or **.09 SCF**.

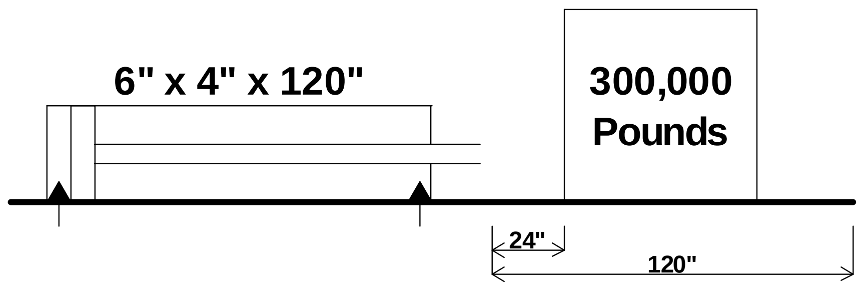
The total S CF per cycle is .45 S CF. The average flow rate will be .66 SCFM. This is 346,896 SCF/Year. If the facility is paying $.10 kWh, it would be at a cost of $115.63 per year. If we had used the maximum pressure of 110 psig, we would have increased the SCF/Year to 2,175,038 at a cost of $725.01 per year. We just saved the facility $609.38 per year.

Energy Challenge
The Hydraulic Solution

And the winner is…

You had your chance. But now you will have to endure listening to me explain how I would achieve the most efficient hydraulic system. I gave my solution to the pneumatic challenge in the previous article.

A quick recap for those who may be new to the Journal; A 300,000 pound load has to be moved 8 feet horizontally in 10 seconds by a 6" x 4" x 120" cylinder. The load is positioned 2 feet away from the retracted cylinder. The cylinder rod must extend 24" in one second before it contacts the load and then slide the load sideways covering the remaining 96" in 8 seconds. The cylinder then immediately retracts fully in ten seconds. We were given a coefficient of friction of .25, a tank line pressure of 100 psig, and an assumed system efficiency of 85%. There is a dwell time of 2 minutes before the system repeats. The system operates 12 hours per day and for 6 days per week.



In a subsequent article I gave you some calculations including the frictional load, the acceleration load, the maximum flow rate, and the maximum pressure. We looked at this information and showed that it would take 292 kW, 202 GPM at 2,816 psi to do the job.

But then I had you look at the average power consumption over the 140 seconds of cycle time. We took one second snapshots of the power usage and I gave you the average power consumption of 8.84 kW. All you had to do was come up with a circuit that would approach that number. And remember, the goal is to find the most energy efficient system, not the simplest or the cheapest.

Now, get out your calculator and let's do some math!

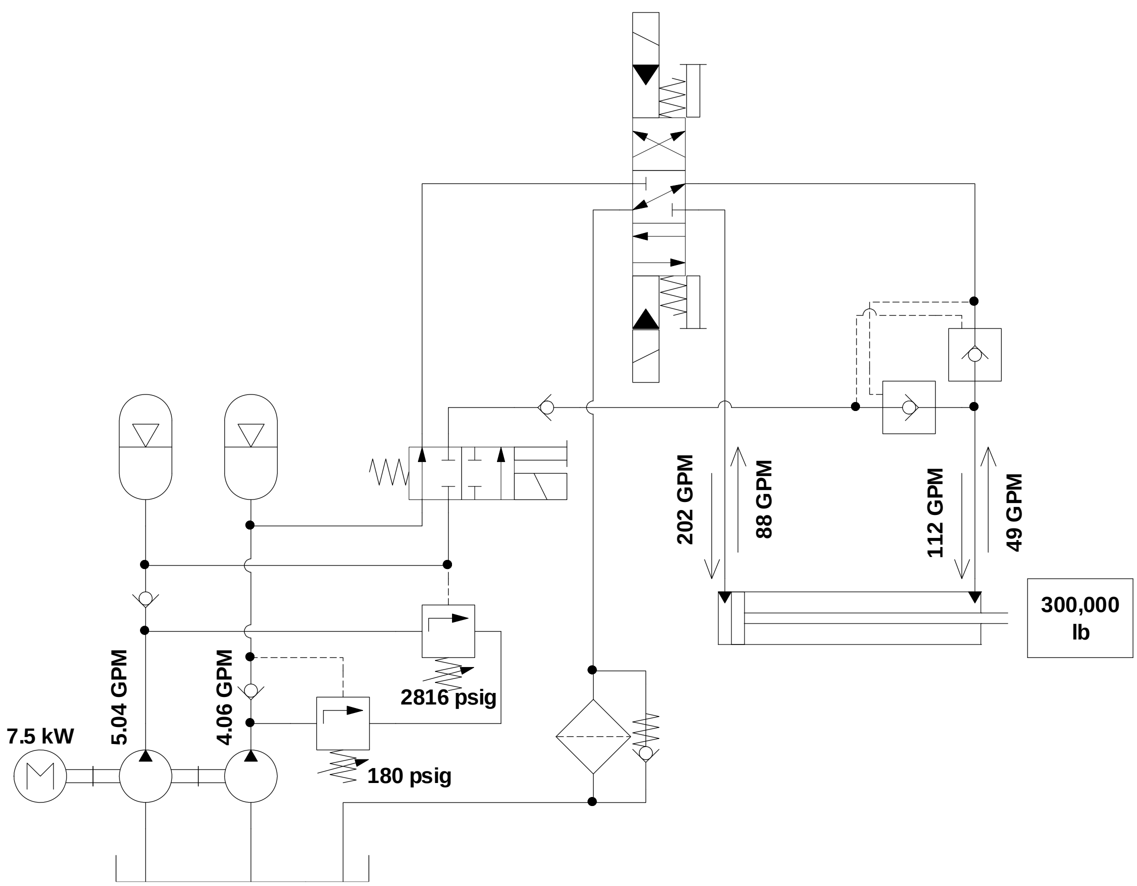
I hope that most of you have immediately concluded that, because of the relatively long dwell time, this system cries out for some type of accumulator. By finding the average flow over the entire cycle time, we might be able to have a constant power draw storing the energy in an accumulator during the dwell time. So, who wants to tell how to find the average flow rate? I want someone who has not participated before. How about one of you mobile guys? Ok, you with the John Deere cap, what do we do? Right! We take the total cylinder volume, both extending and retracting, and divide it by the cycle time. And what did you find? A total volume of 22.85 gallons divided by a cycle time of 140 seconds (2.33 minutes) gives an average flow rate of 9.81 GPM. So, if we take our average flow and charge a very large or a properly weighted accumulator at 2,816 psi, we will need ((9.81 x 2,816) / 1714)/ .85 or 18.96 hp which is 14.14 kW. This is certainly a lot better than the 292 kW but I think we can do better.

I am going to suggest three things that will dramatically reduce the kW requirements of the system. First of all, I will use a regenerative system for the first two seconds as the cylinder rod moves toward the load. This reduces the average pump flow from 9.81 GPM down to 9.10 GPM. It also makes the extending no-load pressure very close to the retracting pressure. I calculate this knowing a tank pressure of 100 psi will cause a resistive load requiring 125 psi in regeneration and 180 psi in retraction. This makes it practical to think of this as a two pressure system; one for no-load and one for full load. If we try to store all the fluid in a single accumulator, more than half of the volume will be at a pressure that is higher than what is needed. This extra pressure will have to be reduced as pressure drop across a flow control and will waste energy.

So, the second thing I will do is make it a two accumulator system; one for low pressure and one for high pressure. Now, if I choose to use a single pump to supply both pressures, I will waste energy because the pump will spend about half the time at low pressure which will not keep the motor running near its capacity. (See the article on Power Factor)

This brings us to the third feature. I will use a double pump, one side with a flow of 4.06 GPM feeding the low pressure accumulator at 180 psi, and the other side at 5.04 GPM feeding the high pressure accumulator at 2,816 psi.

The kW requirements for this system will be ((4.06 x 180 / 1714) x .7457) + ((5.04 x 2816 / 1714) x .7457) for a total of 6.49 kW. When we divide this by the given efficiency of 85% we get 7.64 kW.



This is how it works: Start the 7.5 kW motor and the pumps will charge their respective accumulators to the setting of the unloading valves. Once the pressures are reached, the directional valve is shifted to extend the cylinder at low pressure. The pilot operated check valves in the circuit cause the cylinder to extend in a regenerative mode. After 24 inches of travel, the directional valve is de-energized and the selector valve is shifted directing high pressure fluid to the cylinder. Fluid is returned through the directional valve. When the cylinder reaches the end of the stroke, the selector valve is de-energized and the directional valve is shifted to direct low pressure fluid to the rod end of the cylinder causing it to retract. Once retracted, the directional valve is de-energized and the pumps proceed to replenish the accumulators.

The winner is… well, the winner is all of us who have begun to think more about the way we use energy in our Fluid Power Systems.

A Failed Experiment

Now, don't get discouraged. When we push the envelope trying to change the paradigm of thinking in the transfer of energy in Fluid Power Systems, we will sometimes have to go against conventional wisdom and will certainly have to do things for which there is no precedent. Whether we succeed or fail, we will be in the spotlight. When we succeed, folks will take notes to see how they can implement changes in their own spheres of influence. We establish precedent on which others can build and improve. When we fail, folks will take mental notes about how to not get into the same kind of trouble and we may erect barriers to those who follow. Probably the one barrier that is worse then the "we've never done that before" resistance is the "we tried that once but it didn't work" objection.

I find myself having just created the "we tried that once but it didn't work" objection.

Now, I'm a little sensitive here. I admit it. I have written about ways to save and recapture energy, not just to tweak your brains, but to actually make a difference in the way we apply Fluid Power. I want you to know that I am also on the front lines trying to apply these ideas to benefit our industry and the community in which I work. I would like to have only success stories to report, both for my own ego and for your encouragement but that is an unrealistic expectation.

I am reminded of a quote from Thomas Edison; "I have not failed. I've just found 10,000 ways that won't work." I am certain that there were times during the 10,000 that he felt the sting of having failed but he pressed on and we are grateful.

So, in my case, what is the "it" that didn't work?

Well, the "it" that failed was not actually the circuit or the concept. It was the choice of the components and a failure to get all the information. Let me explain.

I put together a modification to a hydraulic system intended to save energy where, twice an hour, we lift and lower a heavy load and also use a very large volume of fluid at a relatively low pressure. These functions are very important and so it is necessary to have enough energy stored to accomplish these movements if we were to have a power disruption. The original designers had wisely put in a large bank of accumulators to do this and it had worked well for a number of years. I had reason to review the system and became convinced that we could make better use of the energy being used. I was still "the new guy" but a couple of small successes had given me some credibility and I was allowed the opportunity to make some changes in the system. Besides, there was a substantial amount of funding available from the Power Company for energy saving projects. If I was successful, the project would be almost completely funded and we would be saving energy for years to come.

There were three things that I chose to do to reduce our energy consumption, two of which made use of common gear flow dividers. The third was to make better use of the electric motors being operated. We were using five electric motors and each was oversized for the pump it was driving. By increasing the pump volume to match the power available and by implementing the flow dividers, we should be able to run the entire system with just one motor/pump combination.

The first use of the gear flow divider/combiners is discussed in an earlier article entitled "Flow Control; If in doubt, think about…Energy", where I describe in some detail the process of using a simple gear flow divider/combiner to recover energy when lowering a heavy load. I won't repeat it all here but basically it entails pushing a portion of the returning fluid into an accumulator to be used the next time the load is lifted. The process recovers about 75% of the energy used to lift the load. This is one of the systems I put into place.

The second use of the gear flow divider/combiner is not described anywhere else that I know of. It exists out here in the Land of No Precedent. I refer to it as a flow augmenter. In brief, it simply entails using the combining function with one side of the device being used as a motor and the other side as a pump. Combining the flow out of the motor side and the flow out of the pump side provides an increased flow at a decreased pressure. With an equal displacement gear set, you get twice the flow at half the pressure. If you will, it is nothing more than a hydraulic turbo charger. I saw this as a perfect way to make better use of the stored energy in the accumulators. We were storing the energy at 2000 psi but only requiring 600 psi for the work. That meant a 1400 psi pressure drop that was a waste of energy. By augmenting the accumulator flow the system required less accumulator volume and reduced the pressure drop by 1000 psi.

It all sounded really, really good. I promoted it. The Power Company loved it. The folks at the mill were a little bewildered but accepted it. The primary supplier embraced it. What could go wrong?

Details!

A gear flow divider is not a zero leak device. The two sections are connected internally by a shaft that passes through a sleeve. There is no seal and so there is a flow path, although very small, from one side to another. In addition, there is a necessary clearance between the gear teeth and the housing that prevents the gear device from holding pressure. Generally this is not a significant issue but in this case it was a real problem. We needed to store fluid in the accumulators for an emergency but the internal leakage of the device provided a constant bleed down of the stored energy because the side used as a pump led directly to the reservoir. No problem! We just added a check valve in the suction line to prevent the bleed off. It worked perfectly; for two days. That is when I heard over the two-way radio that the hydraulic room was awash in hydraulic fluid and the reservoir (1800 gallons) was empty. No one had communicated to the manufacturer of the custom made check valve that the down stream pressure was to be 2000 psi. They made a valve rated at 500 psi.

The only things that were damaged were an O ring and my credibility. The cost and lead time for a proper check valve were unacceptable. The system was working perfectly well before I decided to improve it.

The energy recovery system was a different story. This is where communication was an issue. The system naturally depended on the weight of the load to drive the fluid into storage. Something that everybody knew and so nobody needed to mention was that the cylinder is not attached to the load but fits into a pocket for lifting. When lowering, the cylinder continues to retract under no load after the weight is resting on its base. The recovery system would not allow the cylinder to retract once the weight was removed. I quickly became part of the everybody that knew. This was relatively easy to fix but it added another layer of complication to a process that was already being questioned. I placed a sequence valve in the system that would shift the recovery device out of the circuit when there was no load. It worked great; for about 1 second. The load is cantilevered out so that as it lowers it has a bit of a bounce. The bounce caused a change in pressure that the sequence valve interpreted as the weight being removed and so it shifted only to sense the load again and shift back causing another bounce causing... well, you get the picture. The slamming and banging made it sound like the entire plumbing system was about to fall apart. It was scary!

I started to say, "I can fix this…" but one look at the foreman told me it wasn't going to happen. Enough was enough. The perceived perplexity of the system was not deemed to be worth the energy savings when it is only used twice an hour.

The good news? The concepts were proved to be correct. I learned some valuable lessons. We are operating using fewer electric motors and there is some energy savings to be enjoyed. I may never get the chance to try it again because of the "we tried that once but it didn't work" syndrome but you might be able to build on my experience.

Think about it.

Something Is Missing

Using Alternative Energy

There is something missing in my repertoire of Fluid Power components. Can you help me?

A couple of months ago, in the Off Highway addition of the Fluid Power Journal, Brian Hageman had an article on a new hydraulic pump. How many of you read it? Keep your hands up. Oh, you intended to read it but never got around to it. I see. Ok, you can put your hands down now. We are going to discuss some of the implications of what was presented in the article, so, those of you who read it can stay with me. The rest of you need to go back and read the article. When you have finished you can come back here and catch up.

Brian opens the door to the discussion of using Fluid Power as an efficient and environmentally friendly way to capture and transfer energy. Now, in his article, he is promoting a device where heat energy derived from waste, solar, geothermal, and even internal combustion is converted directly into hydraulic energy, but the fact is that alternative energy from heat, wind, or ocean waves would be more efficiently captured if the energy where converted directly and used as fluid power. The problem as I see it is two fold; there is the assumption that alternative energy needs to be converted to electricity in order to be used and, we do not promote an economical way of directly using stored energy.

I am not saying that all electrical systems could be replaced with Fluid Power. We would be hard pressed to provide lighting, toasters, computers, and microwave ovens driven by Fluid Power, but for many industries, the major energy requirements are for rotary and linear motion. This is where we should really shine. **The fact is that we could replace almost every electric motor in a facility with a hydraulic motor and operate more efficiently.** If the hydraulic energy where produced by an alternative energy device, then this is doubly true.

How many of you believe that? No, really… give me a show of hands. How many of you actually believe that? I see some enthusiastic hand waving, some tentative half-mast waves, a bunch of blank stares, and a group of petulant grumps who are thinking, "That will never happen". This is important. If we are not convinced, we will never be able to encourage others to move outside their comfort zone and try something new; but being convinced is not enough. We have to be right and we have to have the knowledge and the components to follow through.

There is no question that we have the ability to capture and store energy using Fluid Power. Where we are weak is in the area of using the energy efficiently. Pneumatic folks have an advantage here because they are used to storing energy at a higher than required pressure and then using a regulator for a controlled release. But hydraulic aficionados typically store the energy at high pressure and then use flow controls or pressure reducing valves for the controlled release. This can be a huge waste of energy that is directly proportional to the ratio of the pressure stored and the pressure required where the work is being done. (See the article on "Reducing Pressure; a Way to Save or Waste Energy").

If we are to successfully replace electric motors with hydraulic motors, we need to understand how an electric motor uses energy and then mirror that process and even improve on it. Let's take a look at a typical AC motor application with a varying load and, without getting too technical, talk about what goes on electrically.

The speed of the electric motor is established by the windings and the frequency. The torque available is a factor of the voltage and the current through the motor. It is important to remember that there is never a time when there is no load on a rotating motor. Energy is required for the developing and collapsing magnetic fields as well as for overcoming the resistance to motion from the rotating components. You may have heard the expression "no load amps" which is a bit of an oxymoron. It describes the power consumption of an electric motor when there is no external resistance on the shaft. The "no load" power consumption is typically one third of the fully loaded condition.

On start up, there is a large inrush of current as the windings develop the magnetic fields and the motor mass accelerates to its rated speed. A few milliseconds later when the motor is at rated speed, the current settles down to what is needed to maintain that speed against the resistive load. As the load varies, the voltage is constant and the speed stays the same. It is the current that changes to match the load. There is no metering for a standard electric motor. The speed and voltage are continuous. Only the current changes to match the load.

So the question is; how can we mirror that process and can we do it even better?

We will begin by using a variable displacement hydraulic motor. For the sake of the illustration, let's assume a power source that will be capable of sufficient flow and with a fixed pressure that will provide enough torque to meet the speed and load requirements with the motor at maximum displacement. To control the displacement of the motor, we will provide a tachometer that senses the rpm of the motor shaft. The displacement is spring biased to maximum. We now have a system that can mirror the characteristics of a standard electric motor.

As in the electric motor, there is never an actual "no load" condition. Pressure and flow are always required to rotate the motor. With a variable displacement motor, the minimum displacement can be near zero and so the available torque would also be near zero no mater what the available pressure may be. (Torque = pressure x displacement / 2π). For any given motor speed, available pressure, and external resistive load, there will be a discreet displacement to match that speed.

On start up, there is an inrush of flow (current) at a fixed pressure (voltage) as the motor mass at full displacement accelerates to its rated speed. A few milliseconds later, the tachometer commands the displacement to diminish until it reaches the discreet location for the speed and resistive load. As the load varies, the displacement and flow (current) will change to match the new requirement but all the while remaining at the same speed. All this is without the accompanying pressure drop across a flow control or pressure reducing valve.

So, we ***can*** match the functionality of the electric motor; but can we do better? Absolutely!

This is what we can do: We can provide a soft start with no additional controls. We can provide variable speed without having to add an expensive variable frequency drive. We can provide rapid reversing. We can do many starts and stops per hour without special equipment. We can provide high speed / low torque or low speed / high torque without the expense of gear boxes. We can fit our motors into more compact spaces because of a higher power density. We can place our motors under water and/or in locations where there would be the danger of explosion if there where a spark.

In our illustration we used a fixed pressure but in reality we could use a variable pressure and achieve the same results. This throws open the door to efficiently using accumulators to store alternative energy converted to Fluid Power.

So, what's missing? Controlling displacement is relatively easy using electronics but I think if we are going to be successful in replacing electric motors, we will need to have a simpler and less expensive way of doing it. I am not aware of any hydraulic motors in production where there is a non-electronic sensor to control displacement based on rpm. If you know of such a device, please contact me and let me know.

I Know, It Hertz

I am pretty sure I am going to get some flack from what I am going to say in this article but, before you conclude that I don't know what I am talking about, hear me out. It is not my intent to turn people against using one of the most excellent components for accurate control of Fluid Power Systems. In this, as in all the other articles, I want to stimulate your thinking. We all need to be sure that we represent the best in Fluid Power professionalism. This includes looking at the energy consumption of the systems we use.

One of the favorite valve categories in Fluid Power is the servo. Since its inception, the servo valve has allowed remarkable control of speed and position in processes controlled with Fluid Power.

I recently had an opportunity to take part, along with a number of Certified Fluid Power Accredited Instructors, in a review of the new Certified Fluid Power Electronic Specialist study guide. As we went through the material, we were reminded that the standard flow rating for a servo valve is determined using a 1000 psi pressure drop through the valve; 500 psi P to A or B, and 500 psi A or B to T. I was half expecting and certainly hoping that there would be a collective gasp of incredulity as this was presented but then we were all experienced professionals and had come to except this as normal. The 1000 psi pressure drop is accepted as the characteristic necessary for control.

I think that a lot of us do not automatically think of pressure drop in terms of energy consumption. Oh, I know we immediately recognize that there will be some more kilowatts pumped into the system and that will mean more Btu's to remove. We use our rules of thumb and various charts to select the heat exchanger and the fine filtration. It is simply accepted as the cost of control.

Let's think about that for a moment with energy in mind. In a system where I need 2000 psi at an actuator controlled by a servo valve, I would need to have 3000 psi available. That means that right from the get-go I am sacrificing 33% of the energy needed for the system. So the question is this; why do we need the high pressure drop?

In the study guide, the servo valves are defined as either "flapper-nozzle" or "jet-pipe" in their control mechanism. High pressure fluid is used to shift the valve spool and also to develop a high velocity flow through the jet-pipe or nozzle. The result is that the servo is a very dynamic valve. Like a racehorse waiting at the gate, the spool is excited, just waiting for the command to go. Because of the pressure and consequent high velocity, the spool can move very fast and will respond quickly to subtle changes in the system. This speed is very important in developing the control expected of the servo valve.

However, we do not always need the speed. There are times when accuracy and repeatability are the issues and speed is not the biggest factor. There is a class of servo valve that is not often discussed but that could provide an excellent alternative to the customary high delta P valves. These valves are driven by a stepper motor. This is a rotary motor with digital positioning. They require no pressure drop to change the spool position. Because they are digital, some operate at zero hysteresis. I have seen an application where there was remarkable positioning control of a cylinder using this type of servo with only a 75 psi pressure drop through the valve. The downside is that the response time is relatively slow but we need to ask what response time is really necessary for our application.

The response times that are listed for valves are based on their ability to jump from one extreme to another in a certain time frame. The distance is typically 90% of the full potential movement of the spool and it is rated by how many times it can do it within a span of one second. Some of the flapper-nozzle and jet-pipe servo valves have spools that can travel almost all the way from one side to the other 250 times in one second and are said to have a response time of 250 hertz. The stepper-motor driven valves have a much slower response time; about 75 hertz. At 250 hertz, the spool in a typical servo valve can leap from one extreme to the other in 4 milliseconds. The stepper-motor driven valve takes 13.3 milliseconds to cover the same distance. To give you an idea of how fast that is, the lights in the room where you are reading this article are probably flickering on and off at 60 hertz but you perceive it as a continuous light source. These spools can bounce around inside the valve bodies up to four times faster than the light bulb flickers. That is pretty impressive and makes for a good sales presentation.

However, for many of our applications the major activity of the valve is within a very narrow band of spool motion. When we are holding a cylinder at some location and want to keep it within one kazilienth of an inch, the spool usually has to travel a very short distance, modulating to hold the cylinder position. Moving within this narrow band may dramatically reduce the necessary speed of the spool and the fact that a valve may provide zero hysteresis may be more valuable to the control system.

I just thought of something while I was writing and I need to take a ten minute break to do some calculations. If some of you want to stick around and help out, that would be great. The rest of you can take a break but be back in ten minutes…

For those of you who are staying, I need to figure out the acceleration required to achieve a 250 hertz and a 75 hertz spool movement before I go too far out on a limb. I am going to assume a total spool travel of one inch. I am then going to assume a travel distance of .0625 inches for the valve modulation. The result will show the performance differences between the valves in the critical modulating position. I appreciate your help. The results will be the basis for the next statements when everybody returns.

Ok, we are ready to resume. This is what we found out; a system capable of 250 hertz and with a spool travel of one inch would have to see an acceleration of about 500 g's. That is the reason for the high pressure drop. The pressure provides the necessary force to develop that rate of acceleration. A 75 hertz valve with the same travel needs less than 50 g's of acceleration. Now, let's take a look at the critical time for both valves to jump .0625 inches responding to a command signal. The faster valve will cover the distance in 6.2×10^{-7} seconds. The slower valve will cover the distance in 6.8×10^{-6} seconds. It is true that the 250 hertz valve is 11 times faster but the actual time difference is .0062 milliseconds. This would be considered a tie in a photo finish.

The point, as always, is this: Choose the components that will do the job without consuming more than the necessary amount of energy. Don't be awe-struck by a hertz rating. Figure out what is actually needed. Forget the fudge factor, shun the shortcut, and reject the rule of thumb. Do the math. Choose the best.

Use It or Lose It

We are planning on making a system more efficient here at the steel mill. Two overdesigned hydraulic power units are each operating continuously 24/7. Each one would be capable of performing both jobs on its own and we are thinking of consolidating the two into one system. There are some obvious environmental and energy benefits to doing this but it requires moving us out of our comfort zone and rethinking the way we do things. In order to make the change, we will have to alter the sequence of events in our process. This required a detailed time study, partly to be certain that it can be done, and partly to assure those responsible for production that the new procedure will not interfere with productivity. In doing the time study, we found that, even consolidating the power units gives us a dwell time of more than 50%. In other words, for every hour the power unit is running, the motor/pump is in a stand-by mode for over one half hour. Technically, we could use a power unit with half the capacity and run it at full load continually, storing the energy during the dwell times.

The situation seems to cry out for an accumulator and I'm watching some of you reach for your pens so you can jot down my email address to offer us your services. I appreciate that but it is not that easy. We are trying to save energy and reduce complexity. The various functions use pressures ranging from 40 bar to 125 bar and there is a requirement that our pump pressure not exceed 140 bar.

If this were a pneumatic system, it would be no big deal. We would automatically think of sizing the compressor for the average flow and then put on a receiver to store the energy during the dwell times. Because of the way we store and release compressed air, we would use only the air molecules necessary for the job. Even if we store the energy at substantially higher pressures then required for the loads, the proper use of pressure regulators would mitigate the energy loss.

But this is a hydraulic system. If we store the energy in a common gas accumulator with a maximum pressure of 140 bar and a minimum pressure of 125 bar, we would need a gas volume 15 times greater than the available fluid volume. When the load requirement is only 40 bar, the 100 bar differential would be lost in heat. If we were to use weighted accumulators, we would reduce the accumulator volume but we would still have to deal with the varying pressure requirements and the 100 bar pressure differential lost as heat during the low pressure portions of the cycle.

This brings us to the title of the article. The most efficient Fluid Power System is the one where the flow and pressure exactly match the load requirements. When we store hydraulic fluid in an accumulator, whether gas, spring, or weighted, almost by definition, we will waste some energy as we release it, restricting either the flow or the pressure or both. When we use a pressure compensated or load sensing pump, our pressure setting or our differential pressure setting will be higher than the load requirement and we will waste energy. Our flow will match the speed but our pressure will be higher than the load requires. To be efficient, we need to use *all* the stored or induced energy for useful work. What we do not use for useful work we will lose in Btu's. Use it or lose it.

A couple of articles ago we discussed the fact that we have an advantage when it comes to alternative energy systems because we have the ability to store energy in ways that no mechanical system can match. Our weakness is in the wasteful way we typically release that energy.

We put energy into a fluid when we push it against a resistance. That resistance could be a load we are trying to move, a restriction such as a flow control valve, or, if we are storing the fluid for future use, the resistive load of an accumulator. When we take a volume of fluid out of storage, it has a potential energy based on the pressure under which it was stored. When we use that volume of fluid to do some work, we direct the potential energy to the load. Because of the relative incompressibility of liquid, the only variable in the energy equation is the pressure. If the load requires more pressure than is available, no work is done. If the load requires less pressure than is available, work is done and the remaining energy is lost in heat.

What we should try to do is use all the energy in the fluid to do useful work regardless of the flow and pressure requirements of the load. If we can take all the energy in a stream of fluid and do useful work regardless of the initial pressure, we will be able to make some very energy efficient systems.

I am suggesting, for want of a better term, a variable hydraulic transformer that matches the available pressure and flow to the required pressure and flow. It is simply a variable displacement hydraulic motor coupled to a fixed displacement hydraulic pump as in the circuits below.

Some of you are going to want to stop reading right now because it is going to get technical but give it a shot and at least try to get the concept. Get out your calculators and check my math to see if it all makes sense. Forget the fudge factor, reject the rule of thumb, and shun the shortcut. Do the math.

This is how it would work; we will have the variable displacement of the motor controlled electronically. A flow transmitter would be placed in the pressure line from the pump and its setting is what would determine the displacement of the motor. No matter what the load pressure was, the motor would be commanded to drive the pump at an rpm that would produce the required flow. The motor must develop enough torque to drive the pump and so the motor output torque will be the same as the pump input torque. Torque is a factor of the pressure and the displacement. If we call the available pressure from the accumulator P_1, the motor displacement D_1, the load pressure P_2, and the pump displacement D_2, then P_1 x $D_1 = P_2$ x D_2. For any given flow and pressure requirement from the pump there will be a discreet displacement required from the motor based on the available pressure.

Let's walk through an example. We have a pump with a displacement of 8^3 inches and we are asking it for a flow of 18 GPM at a resistive pressure of 1400 psi. The energy source for the system is an accumulator loaded to 2000 psi. We know that torque equals the pressure times the displacement divided by 2π (T = P x D_{isp} / 6.2832) and that the flow equals the displacement times the RPM divided by the number of cubic inches in a gallon (Flow = RPM x D_{isp} / 231). Doing the math; 18 = RPM x 8 / 231 and solving for RPM, our pump will have to rotate at about 520 RPM and will need an input torque of… anybody what to jump in here?? Ok, you with the IFPS shirt (available at the IFPS Store), what have you got? That's right! 1400 X 8 / 6.2832 = 1,783 in/lb of torque.

So, what will be the motor torque? Right, again! The motor torque has to be the same as the pump torque so it will be… 1,783 in/lb. What will be the displacement of the motor? Remember the formula. 1,783 = 2000 x D / 6.2832 and solving for D we find the motor displacement to be 5.6^3 in. Some of you may also have noticed that the ratio of the displacements of the pump and motor is the same as the ratio of the load and available pressures.

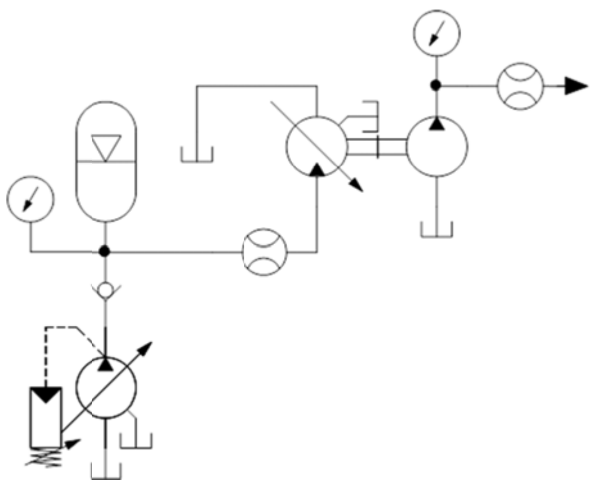
However, the controlling flow transmitter is not looking at the pressure; only the flow. If the flow begins to exceed the command setting, the control will cause the motor displacement to decrease to where the motor is just able to maintain the necessary torque to maintain speed. If the flow drops below the command setting, the control will cause the motor displacement to increase, maintaining speed. As the accumulator drains down or as the load increases, the flow transmitter will direct the motor displacement to increase to maintain speed. The motor displacement will always try to match the available pressure to the torque requirement of the system. It will also become the flow control matching the motor RPM to the pump flow. All the available stored energy will be used for work and the only losses will be from the relative efficiencies of the components.

In the table and circuit below you will see three different pressure scenarios. The first is what is described above. The next two show what happens when the input or output pressures change. Notice that the pump and motor HP is the same for each scenario.

Use it or lose it? Let's use it.

Hydraulic Transformer										
Input Variables					Results					Energy Transformed		
Fixed Pump Disp in3	Load Flow gpm	Load Pressure psi	Accumulator or PC Pressure psi		Pump and Motor rpm	Pump and Motor Torque in/lb	Variable Motor Disp in3	Motor Flow gpm		Pump HP		Motor HP
8	18	1400	2000		520	1783	5.60	13		15		15
8	18	600	2000		520	764	2.40	5		6		6
8	18	1400	800		520	1783	14.00	32		15		15

Hydraulic Transformer Circuit



You Made the Mess;

Now You Clean It Up!

Now, don't laugh, but I once designed a hydraulic system for automatically cleaning horse stalls using the energy from the movement of the waiting horse. I won't get into the details but I was going to market it with the slogan, "You made the mess, now you clean it up!"

When I think about the way we usually do off-line filtering and cooling, I was reminded of this. Our systems generate the particles and the heat that needs to be removed. So, why do we ask electric motors to drive our off-line filtering and temperature control systems? We already have a hydraulic power unit that probably has a slightly oversized electric motor and maybe even some significant dwell time. Why add to the inefficiency with another oversized electric motor? And, by the way, why not replace that electric fan motor on the heat exchanger with a hydraulic motor?

Let's talk about it. Take an application where we have a 500 gallon reservoir and a system using a pressure compensated pump set at 2000 psi. We have a high pressure in line filter and a return line filter but there is a fair amount of dwell time and we want to have a kidney loop to "scrub" the hydraulic fluid. We want to exchange the reservoir volume 4 times an hour through an off-line filtration system. We do the math and find that we will need a pump that will flow about 30 GPM to accomplish this. Our filter has a 25 pound by-pass spring and so we know the resistive load on the pump will be less than 30 psi if we use the correct line size.

Now we have a decision to make. We do the math and we see that 30 GPM at 30 psi is going to be fractional HP. A 30 GPM pump coupled to a fractional HP motor is going to look a little silly, so we discard our calculator and apply a 5 HP, 1800 RPM electric motor to drive the 4.3 in^3 pump. We tell ourselves that we need the extra torque to start the pump and an oversized motor will run forever without any problem. The important thing is to clean and cool the fluid. No one is going to notice the little bit of energy consumed by the motor. It is simply the cost of properly conditioned fluid.

We have talked before about the fact that an oversized electric motor will waste energy. (See the article on "Power Factor"). This system, running 24/7, will have an operating cost of about $1,100 per year, assuming a $.10 / kWh cost of electricity. The waste will not show up in the heat load for the hydraulics but it will add operating cost to the owner of the hydraulic power unit both in kW used and in the power factor charge from the power company. The installed cost will also have to include a bell-housing, couplings, mounting pad, and an electrical panel with controls.

This brings us back to my first question. Why don't we use a hydraulic motor to drive the pump? Think of some of the advantages. The motor and pump can be combined into one unit similar to a displacement flow divider/combiner. One section of the device would be the motor having a common internal shaft with the pump. The motor would have a displacement that would require almost all of the 2000 psi to develop the necessary torque to drive the pump. In this case a .1 in^3 motor would drive a 6.4 in^3 pump at 1200 RPM and the combined flows would pass through the filtration system. The motor flow at 2000 psi would be about .5 GPM; little more than case drain flow. There is no bell-housing, no coupling, and no electrical panel. The additional load on the hydraulic power unit would be about .44 kW at a cost of $400 per year; a savings of $700 per year over the electric motor. A ¼" tube from the pressure line with a simple flow limiter would be all the control necessary. When the main pump is running, the off-line filtration system is also working. (See Figure 1)

We have an application here at the steel mill where we want to add some off-line filtration to our bulk storage. There would be a problem with the device described above because the flow through the hydraulic motor portion would be continually added to the bulk storage tank. The cure for this is simple. In this case, we would add a seal on the connecting shaft of the motor/pump and a return line from the motor back to the main reservoir. The seal is necessary because there is a normal internal leakage in the motor/pump and some fluid would continually be added to the bulk storage even if the motor had its own return line. The seal also provides the added advantage of allowing the use of different fluids for the motor and the pump. A power unit with one type of fluid could be used to drive the off-line filtration of another power unit or bulk storage having a different type of fluid. (See Figure 2)

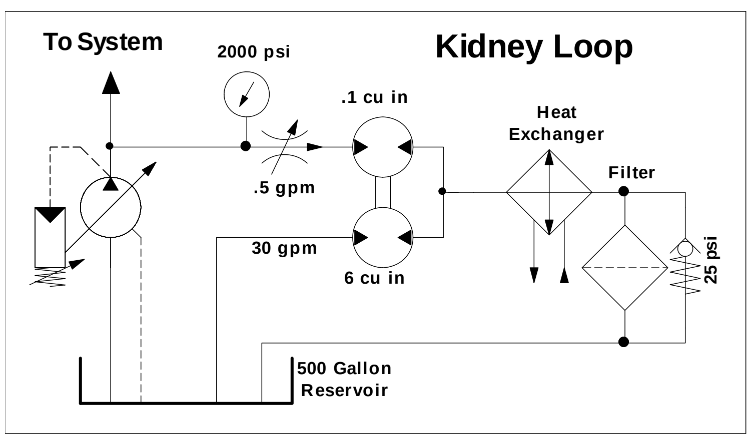


Figure 1

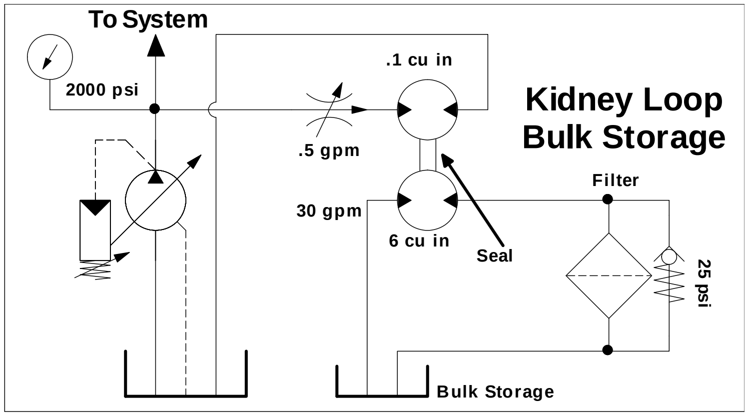


Figure 2

The next time we decide to add an off-line fluid conditioning system, we should consider doing it with Fluid Power. We made the mess, and we can clean it up.

So, You Say You Want to Make a Difference

One of the most rewarding things that ever happened to me in the field of Fluid Power was when a High School student spoke to me after a two hour Pneumatic training session for FIRST Robotics mentors. She told me that she had learned more about physics in those two hours than she had learned in all her classes in High School.

Now, I am not saying that I am a particularly good teacher. I know of many that are much better than I am. What was exciting was that this girl had come to see the interaction between Fluid Power and one of the other physical sciences. This is something that has fascinated me for some time; how we, as Fluid Power Professionals, have to be conversant, if not competent, in almost every field of science.

Every year, here at the steel mill, we have some apprentices come in from local colleges to help out with some of the work. In the group there are usually a few who are studying some field of engineering. I tend to seek them out and try to spend some time talking to them about the advantages of Fluid Power. All of them have been environmentally conscious and, as the Energy Project Manager as well as the resident Fluid Power Specialist, I have had the opportunity to draw them into discussions about the impact of Fluid Power on energy transfer. I often elicit their help in solving some engineering problem and use the opportunity to talk about the various fields of science required to properly apply Fluid Power. Without exception they have been surprised at all that is involved when applying a Fluid Power System.

Those of you who have been following my articles know that I have a particular interest in energy and we will talk about that a little bit later, but I also want to point out some of the other fields of science that are a requirement for the Fluid Power Professional.

Thermal Transfer: We have to ale to understand the nature of energy in the way it is released as heat when not used for mechanical work. This in turn involves knowing about specific heat and the ability of various materials to capture, retain, transfer, and release heat energy.

Physics: We deal with the acceleration and deceleration of loads. We calculate the velocity of fluid through valves and connectors. We recognize the frictional effect that produces pressure losses in dynamic systems. We partner with Blaise Pascal when using his formula of F = PA.

Geometry: Pythagoras is an old friend. We could not work without him. His $A^2 + B^2 = C^2$ is fundamental to our ability to determine angular forces, whether from a cylinder or within the workings of a piston pump or motor.

Gas Laws: Boyle and Bernoulli; we build on the work of these men every time we size an accumulator, specify an air receiver, establish a vacuum, or calculate the pressure drop through an orifice.

Chemistry: Some of us have learned the hard way that you should not mix different types of hydraulic or lubricating fluid. The chemical reactions can create acids that can eat the chrome off valve spools. The wrong fluid can interact with seals and either cause them to disintegrate, stiffen, or expand.

Material Science: Following that last thought, we need to be aware of different materials that can be used for the different types of fluids. Do we use Nitrile, Teflon, Viton…? Our actuators and valves are made of steel, stainless steel, aluminum, bronze, and/or plastic and we need to be aware of which is best for an application.

Electricity: The most common prime mover for Fluid Power is the electric motor. There are issues of power factor that we have discussed at length in earlier articles. We may be confronted with AC or DC, single phase or 3 phase, 50 hertz or 60 hertz. We deal with power from fractional Wattage to hundreds or even thousands of horsepower.

Electronics: Have you taken a look at the latest certification from the International Fluid Power Society? It is the Electronic Specialist certification. Many thousands of dollars were put into developing this certification because the need was obvious.

Tribology: For those of you who may not be familiar with this term, it is the study of interacting moving surfaces. A Fluid Power Professional has to know about dealing with the tight tolerances of parts that must be separated by a thin film of lubricant, sometimes very cold and sometimes very hot.

Alternative Energy: This is a very exciting new field where Fluid Power can have a tremendous future. Those who are harvesting energy from solar, wind, ocean waves, geothermal, or process generated heat are all finding that hydraulics is the preferred method for capturing, storing, and releasing that energy. Check out the article in the January/February 2011 issue of the Fluid Power Journal entitled “Use It or Lose It” for an idea of one of the opportunities before us.

Ecology: Saving and harvesting energy certainly have environmental implications. It is just plain good stewardship to wisely use the resources we have. It is also important to “stop the leaks”. Every year it is estimated that as much oil is leaked out from improperly designed hydraulic systems as was dumped during the Exxon Valdez oil spill. This not only *should* be stopped; it *can* be stopped when properly trained Fluid Power Professionals use the correct connectors and conductors as well as the right sealing material.

Economics: Much of what has been mentioned above has a direct economic impact. Here at the steel mill, my predecessor helped save many thousands of dollars by stopping leaks, properly filtering our fluids, and helping to choose components that were properly suited for the work to be done. Many thousands more have been saved by making the existing systems more efficient. Often times the right question is not, "What will it cost to do this?" but, "What will it continue to cost if we don't do it?"

Math: My Dad once asked me what I did as a Fluid Power Professional. He had done a fair amount of carpentry in his life and so I gave him this illustration. I said, "What if someone came to you and asked you to build him a table? You would get an idea of what he needed, maybe from some good drawings or more likely from a pencil sketch on a piece of scratch paper. You would then take the information and go out to your workshop where you have your tools. You have various saws, chisels, sanders, and such, as well as some home-made tools that you had developed to make your work more efficient. You would set to work and would produce the table doing what the customer was not able to do on his own." I said, "That is exactly what we do. Someone comes to us and asks for a Fluid Power solution to a problem. We are given an idea of what the need is and then we go off to the workshop where we have the tools to do the job. Only our tools are mathematical formulas that we use to meet the need." As Fluid Power Professionals we apply the mathematics of the sciences listed above to properly implement Fluid Power solutions.

So, you say you want to make a difference? You want to protect the environment and save energy? You want to reduce operating costs? You want to do something challenging that requires many disciplines? **You can begin and end with Fluid Power.**

Quads and the EEHPC

When I first heard the word quadrillion, I thought it was a fictitious number like gazillion or bazillion, but it turns out to be a real number: 10^{15} or, if you will, a million times a billion. Now, I don't know about you, but I have a hard time getting my mind around a number that big. I did some calculations that I thought might help: there are 31,536,000 seconds in a year, so a quadrillion seconds would be the number of seconds in nearly 31,709,792 years which is about 3,171 times longer than the Earth, or even time, has been in existence. This is still nearly impossible to grasp so I decided to resign myself to the fact that it is just a really big number.

Another term with which I am more familiar is "Btu," which stands for *British thermal unit*. It represents the amount of energy required to raise the temperature of one pound of water one degree Fahrenheit. When talking about very large amounts of energy, the insiders like to combine the two terms and just call them "Quads," meaning quadrillions of British thermal units. So, what's the point? Well, a recent study explored the use of fluid power in the agricultural, mobile, industrial, and aerospace industries. It found that fluid power is one of the leading consumers of energy in North America, using somewhere in the area of 3.1 quadrillion Btu's (Quads) per year. The same study suggested that fluid power is, on average, only 21% efficient. This is like good news and bad news. The good news is that we are recognized as a leader in the transfer of power and are likely to remain so for the foreseeable future. The bad news is that our systems are inefficient, and we are vulnerable to losing market share to other means of power transfer.

I have some more mind-boggling numbers for you to consider: it is estimated that 45 million gallons of water flow over Niagara Falls every minute. The amount of power consumed by fluid power systems in one year is enough to take all the icy water flowing over the falls for 33 days and bring it to the boiling point, an increase of 180° F. The *wasted* energy is enough to raise the temperature of that same amount of water 142° F. Given a cost of $.10/kWh, each year about $88 billion is spent powering fluid systems. Of that, about $70 billion is wasted due to inefficiency. Someone responded to this information and suggested that the fluid power industry could make a 5% improvement by simply using "best practices." If this is true, then we could save about $3.5 billion in energy costs just by doing what we already know how to do and know we should do.

It was this information that caused the National Fluid Power Association (NFPA), the Fluid Power Distributors Association (FPDA), and the International Fluid Power Society (IFPS) to join forces and sponsor the first ***E***_nergy_ ***E***_fficient_ ***H***_ydraulic and_ ***P***_neumatic_ ***C***_onference (EEHPC)_ in November of 2011. People from all aspects of the Fluid Power Industry gathered to take a hard look at the way we use energy as well as ways in which we can improve. I had the privilege of participating in the conference and experienced the enthusiasm of those who attended. We heard discussions on new, efficient fluids; hybrid hydraulic drive systems; tiny hydraulic systems used as prosthetics; ways to improve the efficiency of compressed air systems; and methods to better store and release fluid energy with minimal waste. The conference revealed that there is much more that needs to be done and that there is a lot of interest from all corners of the industry to get it done. As a result, plans immediately began for a second conference to be held in Chicago, November 27-29, 2012 and it looks like this will be an annual event, at least until we reach an acceptable level of efficiency.

Back in the October, 2008 issue of the Fluid Power Journal, I wrote an article entitled, “Focus on Energy” where I made this observation:

> This is what we know: An electro-mechanical system can operate at about 96% overall efficiency. A typical hydraulic system will operate at about 78% overall efficiency. Down at the bottom of the list we find that a typical pneumatic system is about 6% efficient. So, this begs the question; with the price of energy constantly increasing and with the pressure to ‘go green’, why would anyone in his right mind choose to use Fluid Power as a means to do work?
>
> Those of us who are passionate about Fluid Power know that there are a number of very good reasons to consider Fluid Power as a means to do work. There is the concentration of force, the removal of heat, the flexibility, and the ability to produce both linear and rotary motion from a common power source. We can take very heavy objects and repeatedly position them within .0005". We can create vacuum that will allow us to pick up delicate and oddly shaped material and safely move it. These are all appropriate things to discuss when presenting the case for Fluid Power and many of us have been successful in doing so.

I then drew this conclusion,

> … if Fluid Power cannot be shown to be an efficient alternative to other forms of power transfer, then we may as well start packing up our formulas and find some other line of work.
>
> The frustrating fact is that Fluid Power does not ***have*** to be so inefficient.
>
> We are Fluid Power Professionals. That means we are professionals at transferring energy. We need to think of ourselves as Energy Professionals specializing in Fluid Power… We need to begin thinking about the entire energy transfer system; from the combustion engine or electric motor to the work being performed. We need to view every kW wasted, every scfm tossed away, and every Btu removed as an opportunity for improvement. To do less would be a disservice to our profession and to those who depend on our expertise.

Many of the problems involving the efficient use of Fluid Power are of our own making. Because we could do things that no other means of power transfer could do, we thought we were invincible. Energy was relatively inexpensive so, who cared if the air system consumed a lot of extra kW to operate? If our hydraulic power unit needed 7.5 kW to run, we would put on a 10, 15, or even 20 kW motor, just in case. We explained away high system pressure drop as just the cost of doing work or the cost of control. Many distributors stopped providing training for their sales force and became replacement parts suppliers instead of initiators of positive change. Even

International Fluid Power Society certifications became a sales tool rather than a badge of achievement and professionalism. Manufacturers still offer pipe thread on their cylinders and pumps knowing full well that it is not good for the industry, the consumer, or the environment.

The study cited in the fourth paragraph is both a great challenge and a great opportunity for the Fluid Power Industry. With competitive means of transferring energy nipping at our heels, environmental concerns weighing heavily on the minds of everyone and huge economic issues at stake, we cannot afford to remain idle or complacent. Fluid Power can and must continue to be a major player in the transfer of energy that is so necessary for our economic health. We can continually improve our efficiency, sometimes by doing what we already know how to do, and sometimes by creating new products and new approaches to energy transfer.

Welcome to the future of Fluid Power!

I hope to see you at the EEHPC

Watts It All About

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