Hydraulic Conductors

Types of Conductors

On the first page of the syllabus, there's a list of course outcomes that explain what you are learning in this course:

> By the end of this course, the student will be able to analyze, design, and build fluid power circuits, based on a knowledge and understanding of:
> - Basic properties of hydraulic and pneumatic fluids.
> - Basic fluid power components and symbols.
> - The four basic control types: manual, pilot, electrical, & air logic.

We started the course with properties of hydraulic and pneumatic fluids. We've talked about a variety of pumps, valves, and actuators. We've learned how to use fluid power symbols to create fluid power diagrams. We've used different control methods, although air logic will come later in the course. What we haven't talked about yet is the plumbing…the pipes, or conductors, that carry hydraulic fluid from point A to point B.

For hydraulic systems, we have four major types of conductors:

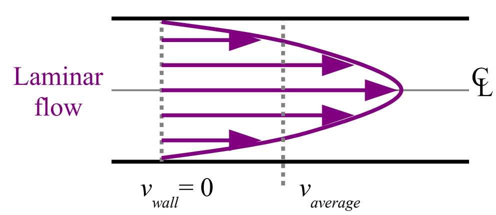
- **Steel pipe.**
- **Steel tubing.** Neater than steel pipe, but costs more money
- **Plastic tubing.** Unable to carry as much pressure as other conductors, but is light and cheap.
- **Flexible hose.** Used in applications where the conductor has to move, e.g. for connecting moving machinery.

Among the metals, you can use carbon steel, or stainless steel when corrosion is important. Copper pipe is a bad choice for hydraulic systems because it promotes oxidation of petroleum-based oils. Copper also is relatively soft, so it has a low pressure rating. It work-hardens, so it's a poor choice if vibration is present.

Galvanized pipe is a bad choice because zinc can flake off into the hydraulic fluid, clogging valves and actuators. If you've got water-glycol fluids such as automotive antifreeze, Zn, Mg, and Cd will corrode and contaminate the fluid.

Sizing a Conductor

Laminar Flow



In a fluid stream, if all the fluid molecules are moving in the same direction we have *laminar flow*. If the fluid stream forms eddies, we have *turbulent flow*. Turbulence causes a larger pressure loss in a hydraulic line than laminar flow. On the discharge side of a pump, we can keep the flow laminar if the average velocity is less than 20 ft./s.

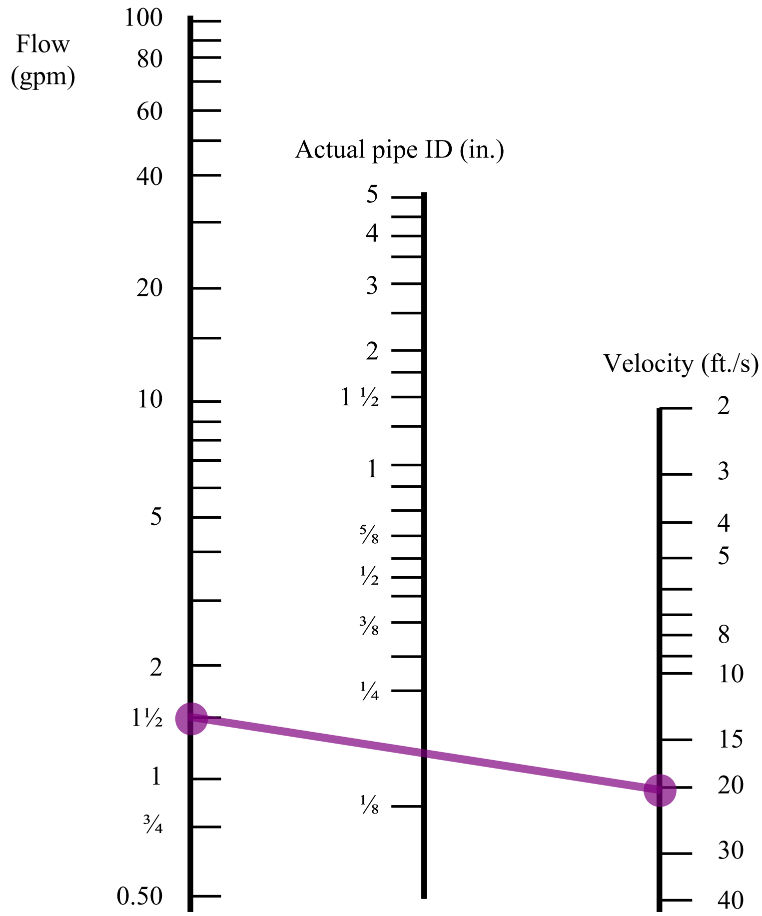
Another issue in liquid fluid flow is *cavitation*. If the pressure drops low enough, the liquid can turn to vapor, and we get bubbles. When the bubble is exposed to higher pressure it pops, and develops a shock wave with pressures in the tens of thousands of psi. The shock wave erodes solid materials. This is a problem in propellors on ships and submarines. Cavitation on pump parts causes leakage past sealing surfaces, and reduces the efficiency of the pump. We can also get cavitation on the walls of a suction line, between the tank and the pump. To prevent cavitation, we want to keep the average velocity less than 4 ft./s on suction lines.

Consider the hydraulic pump on the Vickers hydraulic stand, which delivers 1½ gpm. We can calculate the minimum pipe diameter required to maintain laminar flow. Flow rate divided by velocity equals the cross-sectional area of the pipe: $v=\frac{Q}{A}$.

Rewrite to solve for area $A=\frac{Q}{v}$. For a circular pipe, $A=\frac{\pi}{4}d^2$, so $\frac{\pi}{4}d^2=\frac{Q}{v}$, therefore

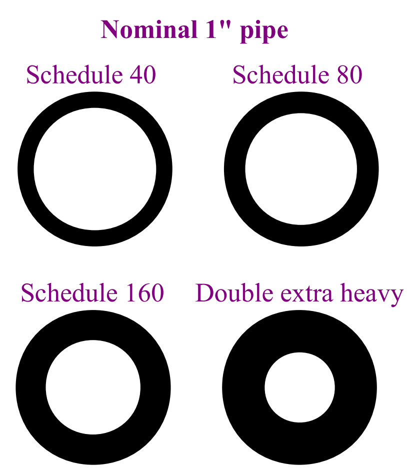
$$d=\sqrt{\frac{4Q}{\pi v}}=\sqrt{\frac{4}{\pi}\frac{1.5\,\text{gal.}}{\text{min.}}\frac{\text{min.}}{60\,\text{s}}\frac{\text{ft.}}{12\,\text{in.}}\frac{231\,\text{in.}^3}{\text{gal.}}}=0.175\,\text{in.}$$

You can save a lot of calculations by using a pipe-sizing nomograph. At 1 ½ gpm, and a velocity of 20 ft./s (purple circles), the actual pipe id required is somewhere between 1/8" and 1/4"…about 0.18". Since pipes are sold in stock sizes, pick the next size up.



Pipe Sizes

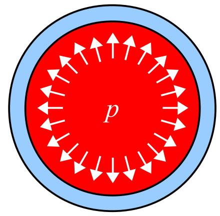
Many years ago, the nominal pipe size was equal to the actual pipe size. As higher pressures became more common, different wall thicknesses were developed. Fittings are based on the OD, so a thicker wall means a smaller ID. For example, if you have a 1" nominal steel pipe, the actual ID of the pipe may be 1.049 ", 0.9517 ", 0.815 ", or 0.599 ". A double extra heavy 1" pipe carries only 32% of the fluid that a 1" Schedule 40 steel pipe carries…it has 68% less cross-sectional area for the fluid to pass through.

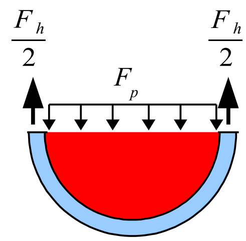


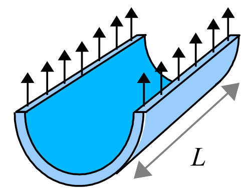
The 1" nominal diameter pipe cartoons are drawn to scale…this is what the cross-sections actually look like. The ratio of wall thickness to OD changes with pipe diameter…for example, the wall of a Schedule 40 1" nom. diameter pipe is 10% of the OD, but the wall of a Schedule 40 2" nom. diameter pipe is only 6.5% of the OD.

Why do we need all these different wall thicknesses? Recall Pascal's Law: pressure in a fluid acts equally in all directions. The pressure inside a pipe acts outward against the wall of the pipe.

Thin-Walled Pipe







Let's cut a cross section of thin-walled pipe along its length. We're also cutting the fluid in half. We'll call the force from the fluid pressure F_p, and we'll call the hoop force in the pipe F_h (it's called "hoop" because it acts in the direction of hoops on an old-fashioned wooden barrel). If we let L be the length of the pipe, then the force from the fluid is the pressure times the area it acts on, $F_p = p D_i L = F_h$.

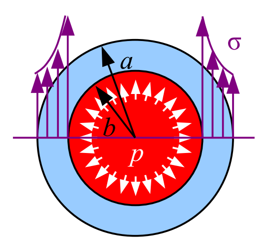
The fluid force and hoop force are equal. The hoop stress in the pipe wall is the hoop force divided by the wall thickness of the pipe times the length, times 2 walls: $\sigma_h = \frac{F_h}{2tL} = \frac{F_p}{2tL} = \frac{p D_i L}{2tL} = \frac{p D_i}{2t}$.

If you know the tensile strength σ_{UTS} of the pipe material, then you can calculate the burst pressure of the pipe, $BP = \frac{2 t \sigma_{UTS}}{D_i}$. This is the fluid pressure required to split the pipe. However, this value assumes that there are no scratches on the pipe, there's no corrosion, there are no pressure spikes, and the pipe material contains no defects. In reality, you have to include a *Factor of Safety*. Divide the burst pressure by the factor of safety to get the working pressure: $WP = \frac{BP}{FS}$

The textbook gives the factor of safety as:

- $FS = 10$ if severe pressure shocks are possible
- $FS = 8$ for $p = 0$-1000 psi
- $FS = 6$ for $p = 1000$-2500 psi
- $FS = 4$ for $p > 2500$ psi

Thick-Walled Pipe



The textbook defines thin-walled pipe as having a wall thickness less than 10% of the diameter; otherwise, we call it thick-walled pipe. When the wall is this thick, the stress distribution in the pipe wall is nonuniform; it's highest on the inside surface, and lower on the outside surface. If a crack develops, it will start on the inside and work its way out.

The stress at any given radius r is a function of the fluid pressure, the inside radius a, and the outside radius b. Stress $\sigma = \frac{p b^2 (a^2 + r^2)}{r^2 (a^2 - b^2)}$. The maximum stress occurs at the inside surface of the pipe, where $r = a$. Substituting, the maximum stress $\sigma_{max} = \frac{p(a^2 + b^2)}{(a^2 - b^2)}$. Rearrange the maximum stress equation to get an equation for burst pressure, $BP = \frac{\sigma_{UTS}(a^2 - b^2)}{(a^2 + b^2)}$.

The textbook has a rule-of-thumb equation: Equation 10-6. $BP = \frac{\sigma_{UTS} 2t}{D_i + 1.2t} = \frac{2(a-b)\sigma_{UTS}}{1.2a + 0.8b}$, which is close enough to the exact solution to be useful (within 1%). The rule of thumb equation is not as accurate as the exact equation, but it's easier to solve.

Conductor Sizing Procedure

Follow this 5-step procedure to size pipe or tubing in a hydraulic system:

- **Calculate minimum inside diameter based on flow rate.** On the suction side of the pump, keep the velocity below 4 ft./s to prevent cavitation; on the discharge side, use 20 ft./s to keep the flow laminar.
- **Select a standard size conductor.** Pick the next size up from your calculated minimum inside diameter, based on the tables for tubing and pipe in the texbook. If you're using pipe, start with Schedule 40.
- **Calculate the wall thickness.** Wall thickness is outside diameter minus inside diameter, all divided by 2.
- **Calculate the burst pressure and working pressure.** Use dimensions of the conductor, tensile strength of the material, and factor of safety. See the textbook for Factors of Safety appropriate for three different pressure ranges.
- **Determine if the selection is OK.** Compare the working pressure with the actual line pressure. If what you can survive is more than what you have, then you're OK. Otherwise, try different dimensions, a heavier pipe, or a different pipe material.

Design Considerations

A few other design considerations are important.

- **Keep pump inlet short & straight.** Short to minimize the pressure drop; straight for laminar flow and minimal pressure drop.
- **Seal inlet connections tightly.** Good sealing prevents air bubbles from forming.
- **Use large return lines.** These lines will reduce the backpressure in the system, and ensure laminar flow.
- **Seal return connections tightly.** Again, good sealing prevents air bubbles from forming.
- **Empty the return line below the fluid level in the tank.** Otherwise, you'll create air bubbles in the tank oil.

Rest of the Chapter

Read about fittings and plastic conductors in the textbook.

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