Pneumatics for Newbies

Designing a Pneumatic Solution

DRAFT

FIRST Robotics Team 358, Hauppauge, NY

Introduction

Pneumatics is using air to push/pull things or suck them up. The pistons and tubing are light and powerful, lighter than equivalent motors, however, the compressor itself is heavy. Once the big decision to add the compressor is made, adding extra pistons is much easier than adding extra motors (and gearing).

The air compressor keeps the storage tanks filled and the storage tanks provide the reserve air to quickly fill the actuators or pistons. Storage tanks are at least twice the pressure of the actuators so one tank of storage air will fill twice the number of actuators, but the air compressor cannot replenish the used air very quickly. It adds roughly half a cubic foot of air per minute depending on the pressure already in the system that it's striving to shove more air into. Less air is moved near full pressure (.24cfm) and more at zero (.79cfm) pressure, so in an entire 2 minute match expect the air compressor to add ~.8 cubic feet of air. Plan on doing a test while watching the main high-pressure gauge to see how low it gets during what you expect to be normal operation.

This is an overview of layouts, assembly, wiring, programming, and troubleshooting common issues.

A must see is the FIRST Pneumatics Manual released at Kickoff each year, because it will cover new parts and devices and it shows photos of all the parts for easy identification. It will be available on the FIRST FRC documents webpage. Past versions are archived here: http://team358.org/files/pneumatic.

For a Pneumatics Step-by-Step putting together a working system see: http://team358.org/files/pneumatic/Pneumatics-StepByStep.pdf.

How it Works

Layout Options

Outside a few must-have critical items called-out by the rules for safety, teams have a lot of leeway in how the pneumatics can be laid out. The pneumatics system is divided into at least two circuits:

1. A high pressure (120psi) side for air compression and storage only
2. One or more low pressure sides (60psi or less) for operating stuff

High Pressure side (120psi)

Used for air compression and storage only.

~120psi maximum, the air compressor won't produce much beyond that anyway, but running it constantly can overheat it.

This side begins with the air compressor and includes any number of storage tanks, a manual exhaust valve, and a pressure gauge. The air compressor itself has an automatic emergency release valve that prevents the pressure from getting much above 120psi.

A pressure regulator is the last stop for the air on it's way to the low-pressure side where the actuators get used.

Must Haves:

- Manual exhaust valve

- Pressure gauge
- Regulator for the low side w/ pressure gauge
- Automatic emergency pressure release (on the compressor)

You don't actually have to have an air compressor. Storage tanks can be pre-charged from an off-board compressor before a game starts, but you'd better not have any leaks.

Low Pressure side (60psi or less)

Used for doing the work operating actuators/pistons/cylinders/vacuum pumps.
This side begins with a regulator output from the high pressure side that cuts the operating pressure down to 60psi or less. It doesn't have to be right at 60psi, but must not be greater. You'll sometimes want to use a lower pressure to, for instance, grab a ball with a little less crushing force. Also, in general using the lowest pressure you need to get the job done will preserve your stored air and means your compressor will have to work less to keep up.
Must Haves:

- Regulator from the high pressure side w/ pressure gauge

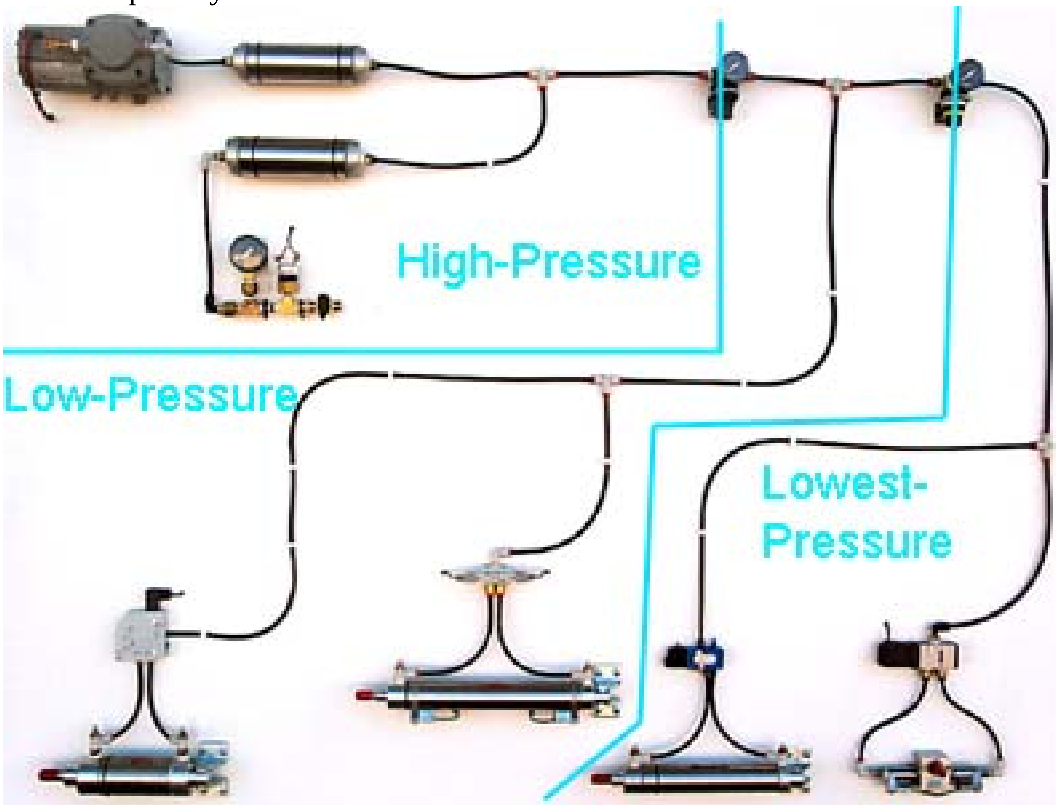
Even Lower Pressure side (50 to ~25psi)

Starts with another regulator taking input from the 60psi side and outputting an even lower maximum pressure. This is used to save on air and reduce the force pistons exert. Very low pressure sub-systems such as the Venturi vacuum needs a constant flow of pretty low pressure air, so typically it would be setup on it's own isolated circuit so as not to waste excess air.
Must Haves:

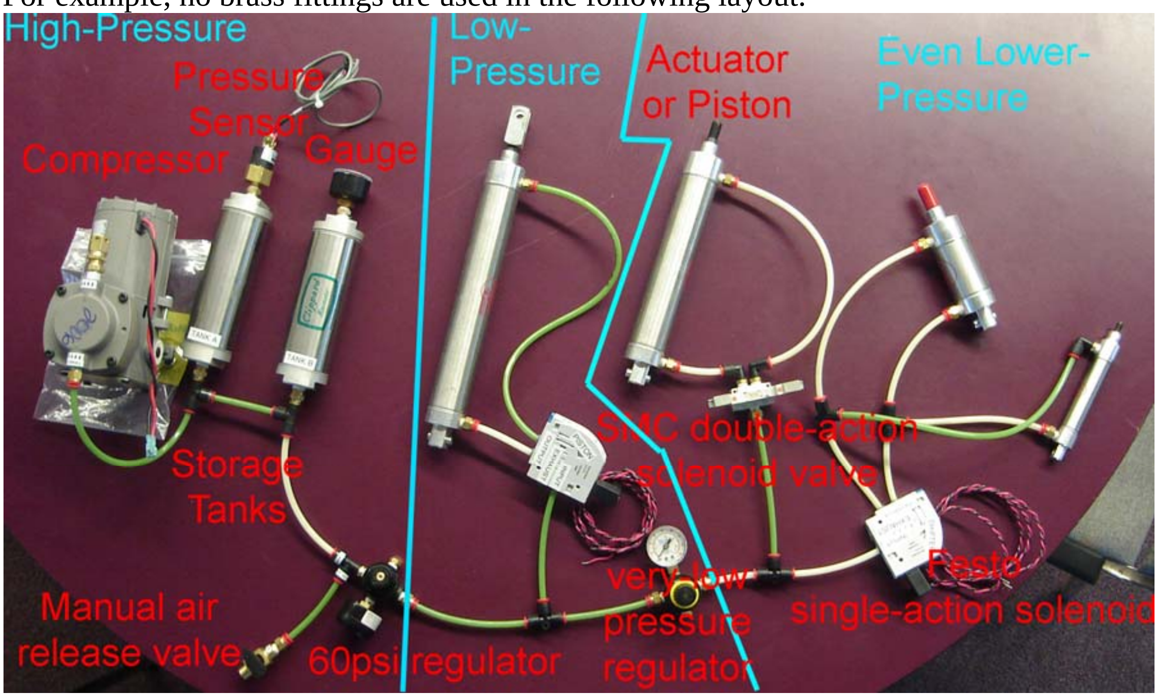
- Regulator from the low pressure side w/ pressure gauge

Layout Variations

- FIRST Example Layout



- Reduce the number of heavy brass fittings to save on overall robot weight by a little rearranging. For example, no brass fittings are used in the following layout.



- The fewer connections you have, the fewer places leaks can occur.

Choosing a Cylinder

First and foremost consider the total cylinders/vacuums you plan on using. There is only so much compressed air available during the short 2 minute matches we play. It gets used fast, but replenished slowly. You want to be sure you don't end up with a design that uses more air too fast than you've got.

Second, use the smallest cylinder with the shortest stroke that gets the job done. For example, a large 2" diameter cylinder with a 12" stroke requires ($3.14*1^2*12$" =) 38 cu. in. of air. At a working pressure of 60psi, that's the same amount of air found in one 18.85 cu-in storage tank (120psi/60psi * 18.85 = 38 cu. in.). You'll be able to use this cylinder once before the pressure drops low and you have to wait for the compressor to replenish it. Replace it with a ¾" x 12" cylinder and you'd need ($3.14*(.75/2)^2*12$" =) 5 cu. in. of air and one storage tank will supply enough air to open or close it eight times.
It's not quite as bad as it sounds. The compressor replenishes air at roughly an average of .4 cubic foot per minute or 11 cu. in./sec. supplying enough air to use the small cylinder twice a second and the large one once every 3 or 4 seconds. However, when you plan for multiple cylinders you can see that the air can get used up fast.

Another variation in your design is the working pressure. Using the above example, if instead of 60psi you design for 30psi, then the big 2"x12" cylinder can be used twice – open (once) and close (twice), and the small ¾" x 12" cylinder can be used 15 times.
The difference in using the 2" vs. ¾" is the force you'll get out of the cylinder. At 60 psi the 2" one will produce ($60psi * 3.14*(1)^2$=) 188 lbs, while the ¾" cylinder will give you ($60psi * 3.14*(.75/2)^2$=) 26 lbs. Of course, dropping the working pressure to 30 psi produces ($30psi * 3.14*(1)^2$=) 94 lbs and ($30psi * 3.14*(.75/2)^2$=) 13 lbs respectively. The difference between lifting a robot (once) and grabbing a light ball.

- Force – will vary with pressure drop as actuators use up air reserve.
- Length/diameter – using smaller cylinders has a side effect of reducing overall robot weight
- Pressure
- Speed/time – flow control valve can slow things down. You'll need to experiment with your real application to get a feel for the time required as it varies due to resistance and friction.
- Special options – magnetic reed switches have been an option for a few years. They give feedback for when the piston is at one end or another (usually), but the sensor can be positioned anywhere along the piston's travel. If it's in-between ends be careful that the piston doesn't flash by too fast to register. These sensors are wired as any other switch would be – signal/ground to a Digital Input on the RC. The software can just check the switch value each cycle and do what you want done.
- Halfway positions - The pneumatics system is designed for cylinders to go to one extreme or the other, not halfway. However, you can route the exhausts from a solenoid to another single-action solenoid and by controlling the exhaust in-between positions can be achieved. If the rules permit, then SMC has special valves you can order to do the job, e.g., 3 Position Closed Center (stiff when both coils are off) or a 3 Position, Exhaust Center (limp when both coils are off).

Cylinder Force Available

Force = Pressure x cylinder area

cylinder area = pi x (bore/2)^2

bore = the diameter of the cylinder

e.g., Force = 60psi x 3.14 x (3/4"/2)^2 = 26.49 lbs

When a piston is being pushed out air is forced against the full area of the piston's circular disk, but when it's being pulled closed pressure on the space occupied by the rod is lost (1/4" rod for the 3/4" bore cylinder). That's why pistons push with a little more force than they pull with. A smaller cylinder will add less weight to your robot and conserve air, so don't use a larger cylinder than you need to get the job done. The theoretical forces in the table will work out to be a little less in actual use, due to friction, and other conflicting demands on your pneumatic system, so over design a little.

	3/4" Bore	**3/4" Bore**	**1-1/2" Bore**	**1-1/2" Bore**	**2" Bore**	**2" Bore**	**90deg rotary**
Pressure (lbs/sq. in.)	*Force Extended (lbs)*	*Force Retracted (lbs)*	*Force Extended (lbs)*	*Force Retracted (lbs)*	*Force Extended (lbs)*	*Force Retracted (lbs)*	*Torque (in. lbs)*
20	9	8	35	32	63	57	3.32
25	11	10	44	40	79	71	4.15
30	13	12	53	48	94	85	4.98
35	15	14	62	57	110	99	5.81
40	18	16	71	65	126	113	6.64
45	20	18	79	73	141	128	7.47
50	22	20	88	81	157	142	8.3
55	24	22	97	89	173	156	9.13
60	26	24	106	97	188	170	9.96

Cylinder Air Volume Required

Volume = cylinder area x stroke
cylinder area = pi x (bore/2)^2
e.g., Volume = 3.14 x (3/4"/2)^2 x 12" = 5.3 cu. in.

Table entries are left blank where the cylinder is not allowed with that stroke, based on 2007 FIRST rules. This is, however, subject to yearly rule changes. Also, these are the volumes at full extension and retraction and in practice can be limited by outside mechanical stops, so, for instance, if a cylinder only extends halfway before being stopped by the maximum movement of an arm, then only half the volume listed in the table below will be necessary.

	3/4" Bore	**3/4" Bore**	**1-1/2" Bore**	**1-1/2" Bore**	**2" Bore**	**2" Bore**
Stroke (in)	*Volume in^2 Extended*	*Volume in^2 Retracted*	*Volume in^2 Extended*	*Volume in^2 Retracted*	*Volume in^2 Extended*	*Volume in^2 Retracted*
0.5	0.2	0.2	0.9	0.8	1.6	1.4
1.0	0.4	0.4	1.8	1.6	3.1	2.8
1.5	0.7	0.6	2.6	2.4	4.7	4.3
2.0	0.9	0.8	3.5	3.3	6.3	5.7
2.5	1.1	1.0	4.4	4.1	7.9	7.1
3.0	1.3	1.2	5.3	4.9	9.4	8.5
4.0	1.8	1.6	7.1	6.5	12.6	11.4
5.0	2.2	2.0	8.8	8.1	15.7	14.2
6.0	2.6	2.4	10.6	9.7	18.8	17.0
7.0			12.4	11.3	22.0	19.8
8.0	3.5	3.2	14.1	12.9	25.1	22.7
9.0			15.9	14.6	28.3	25.5
10.0	4.4	4.0	17.7	16.2	31.4	28.3
11.0			19.4	17.8		
12.0					37.7	34.0
24.0					75.4	68.0

References

1. Pneumatics Step-by-Step: http://team358.org/files/pneumatic/Pneumatics-StepByStep.pdf
2. Valuable information about the pneumatic components and ordering processes are included in each year's FIRST Pneumatics Manual. Check the FIRST website for the latest or see this one from 2007: http://team358.org/files/pneumatic/2007FRCPneumaticsManual.pdf
3. Each Year's FIRST Tips & Good Practices has a section on pneumatics as well. Check the FIRST website for the latest or see this one from 2007: http://team358.org/files/pneumatic/2007Guidelines_Tips_Good%20Practices_RevC.pdf
4. SMC solenoid value assembly: http://team358.org/files/pneumatic/SY3000valveAssembly.pdf
5. Festo solenoid valve assembly: http://team358.org/files/pneumatic/FestoFIRSTValveAssy.pdf