Variable Positioning of Pneumatic Cylinders

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FRC 687
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The Problem:

A few days before the robot was due to ship, the motor that actuated the main part of the arm went up in smoke. This was a problem, since there were no suppliers that could provide a new motor in time for the San Diego regional competition. Without a motor, our robot would only be able to deploy a minibot, which wasn't good enough, to us. Thus, we explored other options for actuating the arm. One of the proposed solutions was a pneumatic actuator. This came close to rejection, since the team had never tried a variable-position setup with a pneumatic cylinder. However, we decided to try it out, since there was a possibility that it could turn out to work better than a motor.

Design Process:

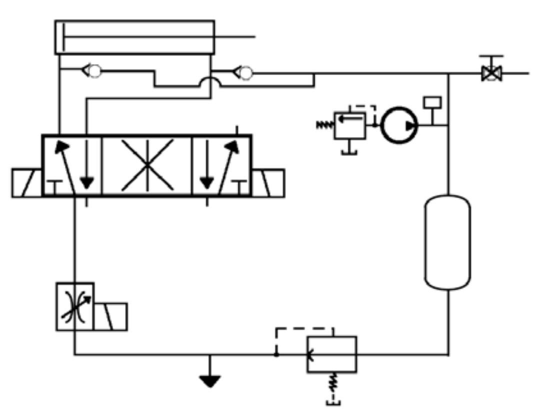
After proposing the variable-position setup, I checked with several manufacturers of pneumatic components for an appropriate valve. We needed a five-port, four-way, three-position solenoid valve that was center blocking in the off position. This means that when electricity is applied to either solenoid, the valve will function like a normal 5/4 valve for double-acting cylinders, but when power is removed, the spool will move to the center position, blocking air from entering into or exhausting from the cylinder. The valve had to have 12-volt solenoids, as well as a Cv (coefficient of flow) of less than .32. Unfortunately, very few manufacturers actually listed this information on their website, including SMC, a company from which we have ordered valves in the past. Norgren turned out to be the company of choice. The V50P611AA2 valve was perfect for our application, with dual 12-volt solenoids, a Cv of .27, and 1/8" NPT ports (all requirements specified in the game manual).

Due to the time it took for the order from Norgren to arrive, we decided to prototype a slightly more complex system involving two regular 5/4 valves. This system emulated the function of a center-blocking three-position valve, but was not legal under <R74> in the Game Manual. Our prototype system was successful in stopping a pneumatic cylinder partially through its stroke, while still retaining all of its force. Unfortunately, as we would soon learn, making the final system legal would involve far more effort than we had initially anticipated.

> **<R74>**
> Each commanded motion of a pneumatic cylinder or rotary actuator must be accomplished via the flow of compressed air through only one approved pneumatic valve. Plumbing the outputs from multiple valves together into the same input on a pneumatic cylinder is prohibited.

In the beginning, we were under the impression that making this system work would be as simple as connecting the valve, as if it were any other 5/4 valve for a double-acting cylinder. This was not so, due to <R73>. Since the Norgren valve is center blocking, it traps pressure in the lines to the cylinder. This is advantageous to us, since the cylinder will retain all of its force when we turn the solenoid valve off. However, the same feature that makes the system work also makes it illegal, without a few modifications. As shown in the schematic, I added two check valves, one from each cylinder supply line, to allow air out when the vent plug valve is

> **<R73>**
> The pressure vent plug valve must be connected to the pneumatic circuit such that, when manually operated, it will vent to the atmosphere to relieve all stored pressure. The valve must be placed on the ROBOT so that it is visible and easily accessible. If the compressor is not used on the ROBOT, then an additional vent valve must be obtained and connected to the high-pressure portion of the pneumatic circuit off board the ROBOT with the compressor (see Rule <R69>).



opened. These are lines are tied together after the check valves, so that air is not allowed to flow freely between the two ports of the cylinder, which would make the entire system useless. Normally, the check valves do not affect the pneumatic circuit's operation in any way, since the pressure differential is such that it seals off the check valves. If the pressure on the "high" side of the circuit were to drop below the "working" pressure trapped in the cylinder, as is the case when the vent plug valve is opened, the check valves allow air to flow freely out the vent valve. This would legalize the system, if check valves were legal. Unfortunately, in this year's game, they are not.

After thinking about this problem for a few hours, I thought of a simple solution – flow-control valves. Many pneumatic flow-control include a check valve so that, in one direction, flow is regulated, but in the other, it is unimpeded. If the knob on this type of valve is turned down all the way, the valve is closed in one direction, but open in the other. This acts as a check valve, while remaining legal for this year's game. McMaster P/N 62005K313 was a perfect candidate for this application, primarily because it was the least expensive option for ¼" OD tubing.

Eventually, once all the parts arrived, we were able to assemble a prototype arm out of 2x4 lumber. Initial tests were good – we were able to stop the cylinder anywhere in its stroke easily and quickly, with minimal oscillations. A bit of fine-tuning yielded an arm that was both precise and quick in its movements. However, once weight was added to the end of the arm to simulate the load of the gripper, forearm, and associated motor, a single 1.5" bore cylinder simply could not handle the load, even at 60 psi. There was a simple solution to this – a larger cylinder! I harvested a 2" bore cylinder from a previous year's robot. At 60 psi, the cylinder exerted 188 lbs of force, compared to the first cylinder's 105 lbs. 188 lbs of force was able to move the arm fairly authoritatively, even under load. Although we considered this system a working prototype, there were still a few kinks that needed to be worked out.

The major problem with the prototype was that even though we could vent any stored pressure, the check valves would prevent the flow of air **into** the cylinder when the vent plug valve was open. Due to this, the cylinder would not move because there was still atmospheric pressure in the system, which would not come out – a totally legal system, with one major drawback. Once the system was powered down and all air released, the arm would not move. Fortunately, this was a quick fix. We installed two mushroom-head pushbutton valves – one per cylinder supply line – to allow outside air into the cylinder, in the case that we had to move it without a pressurized system. McMaster P/N 6790T45 worked nicely for this application. Once these valves were installed, and the system was tuned, the prototype arm worked very well. By the time we had completed the prototype, we were getting ready for the San Diego regional competition, so we packed the system as a "Plan C" – it was to be used in the case of a catastrophic failure, in which "Plan B" – the new gearbox – did not work at all. We did not end up using Plan C in either of the two regional competitions that we attended.

Conclusion:

Once the minor difficulties we encountered were overcome, the prototype system worked very well, considering it was a mere prototype. Given more time, we could have created a more robust system that was more compact. As it was, the 2" cylinder, solenoid, flow-control valves, fittings, tubing, pushbutton valves, and hardware weighed two pounds less than the motor/gearbox setup we ended up using at both regional competitions. There are certainly improvements that could be made to the system, but overall, it worked remarkably well. It is definitely a viable solution to the problems posed by <R73> and <R74>, in regards to variable positioning of a pneumatic cylinder.

Schematic: