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Design of a Microcontroller Operated PVC, uPVC and CPVC Pipe Internal Pressure Test Rig

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Abstract

PVC, uPVC and CPVC pipes are widely used in various construction projects because of their cost-effectiveness low maintenance and higher versatility. One of the key factors that has to be accounted for while choosing a pipe is the internal pressure that it can sustain without significant deformation. We propose to design a digital pipe pressure test rig which will be operated by a microcontroller and will incorporate a linear actuator in collaboration with a piezoelectric sensor to ensure higher accuracy of the test results. The design we propose is devoid of unnecessary complexity and can be operated with minimal training in both by the pipe manufacturing industry and by the construction engineers on site.

Keywords: PVC, uPVC, CPVC pipe, pressure test, microcontroller.

1. Introduction

Polyvinyl Chloride, commonly abbreviated PVC, is the world's third-most widely produced synthetic plastic polymer, after polyethylene and polypropylene [1]**.** Roughly half of the world's polyvinyl chloride resin manufactured annually is used for producing pipes for municipal and industrial applications [2]. In the water distribution market, it accounts for 66% of the market in the U.S., and in sanitary sewer pipe applications, it accounts for 75% [3]. Regular PVC is a common, strong but lightweight plastic used in construction. It is made softer and more flexible by the addition of plasticizers. PVC is used as a replacement for copper and aluminum pipes and is used in waste lines, irrigation systems and in pool circulation systems.

uPVC or unplasticized Polyvinyl Chloride is used for the majority of plastic pipes in the world, as it is incredibly resistant to chemical erosion and has smoother inner walls that help to encourage water flow. It also functions well in a wide range of temperatures and operating pressures. It is incredibly strong, stiff and cost-effective, and so is often used for sewage lines and exterior drainage pipes. This material has almost entirely replaced the use of cast iron for plumbing and drainage, being used for waste pipes, drainpipes and gutters [4].

Chlorinated polyvinyl chloride or CPVC is a thermoplastic produced by chlorination of PVC resin. CPVC pipes are commonly used in drinking water distribution systems.

When choosing a pipe for a particular application, whether it's PVC, uPVC or CPVC, it is necessary for safety concerns to select a pipe for which the operating pressure for that particular application stays significantly below the bursting pressure and also below the specified the maximum operating pressure. The manufacturer provides the internal pressure ratings for the pipe among other required specifications.

If the onsite engineer decides to test whether the pipe meets the internal pressure ratings for the required application or if it matches with the provided specifications from the manufacturer, they usually send a sample offsite to another facility for testing. But the internal pressure test rig design proposed in this paper can be utilized by both the manufacturers and the engineers to ensure that the pipe meets the specified or required internal pressure ratings. Moreover the simplicity of the design will allow it to be operated onsite and offsite with some very basic training.

2. Design of the internal pressure test rig

The basic components of the test rig are linear actuator, stainless steel cylinder, piston, microcontroller unit with piezoelectric sensor, lubricating oil and an adjustable clamp to hold the pipe. To make the design simple and cost effective, commonly available materials of standard sizes were used which minimized the necessity of designing each component according to the required parameters. The design also considers the fact that uPVC and CPVC pipes are capable of handling internal pressures lower than that of the PVC pipes [10] [11]. So a general design of internal pressure test rig for PVC pipes should also perform for uPVC and CPVC pipes. It is also noticeable from Fig. 2. that the all the internal pressure values gradually drop with the increase in nominal size. So designing a pressure test rig for the lowest standard nominal size ½ inch, will also work for all the sizes. The few parts that needs to be different for different pipe sizes are the adapter, the seal and the clamp.

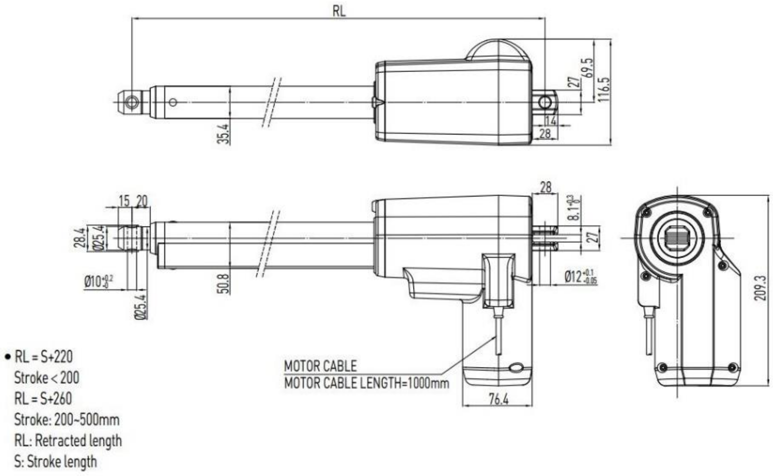

Fig. 1. Hiwin LAN3A series linear actuator [5]

The linear actuator is proposed to be Hiwin LAN3A-1 with a stroke of 200mm, 3mm/s speed under load and a maximum thrust of 12000 N shown in Fig. 1. The reason for choosing such a high load actuator is that the operating and the bursting pressures of PVC based pipes are quite high. Fig. 2. demonstrates the bursting and maximum operating pressure of both schedule 40 and schedule 80 PVC pipes.

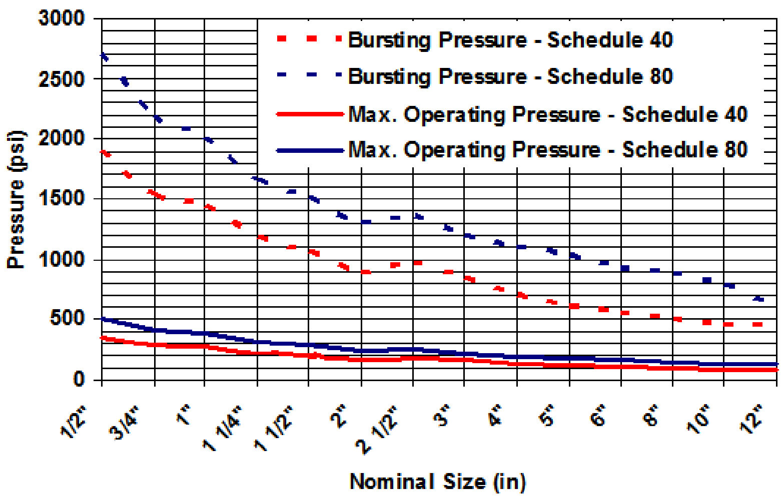

Fig. 2. PVC pipe pressure ratings [9]

The cylinder has to be able to withstand high pressure hence can be of stainless steel. It is proposed to choose an ASTM A312 stainless steel pipe of standard nominal size of 3/8 inch (schedule 80). The piston has to be able to move inside the cylinder freely. The reason for choosing this steel pipe as the cylinder is that it is capable of tolerating a much larger pressure than any plastic pipes and is easily available. The microcontroller unit with an attached keypad for data input, along with the piezoelectric sensor mounted on the inner side of the clamp, holding the pipe firmly, will control the whole operation. A metal pipe sweat union adapter (Fig. 3.) which is commonly available for various specifications, will be used to tightly join the steel pipe to the plastic pipe. Plastic lined Kalsi Seals will be used which can withstand up to 7500 psi [12], at the bottom of the pipe as a sealing component.

Table 1. Size and pressure parameters of the steel cylinder and the PVC pipe

Material name	Nominal size *(inches)*	Schedule number	Outside diameter *(inches)*	Wall thickness *(inches)*	Inside diameter *(inches)*	Bursting internal pressure *(psi)*	Ref
ASTM A312 stainless steel	3/8	80	0.678	0.126	0.423	27876	13
PVC	1/2	80	0.840	0.147	0.546	2720	10

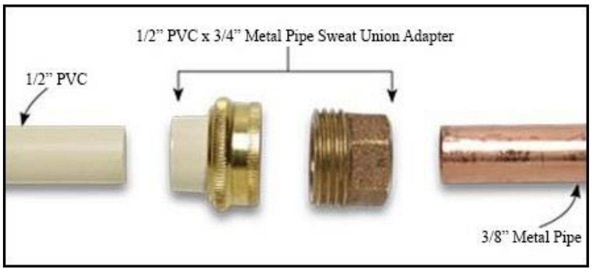

Fig. 3. Metal pipe sweat union adapter

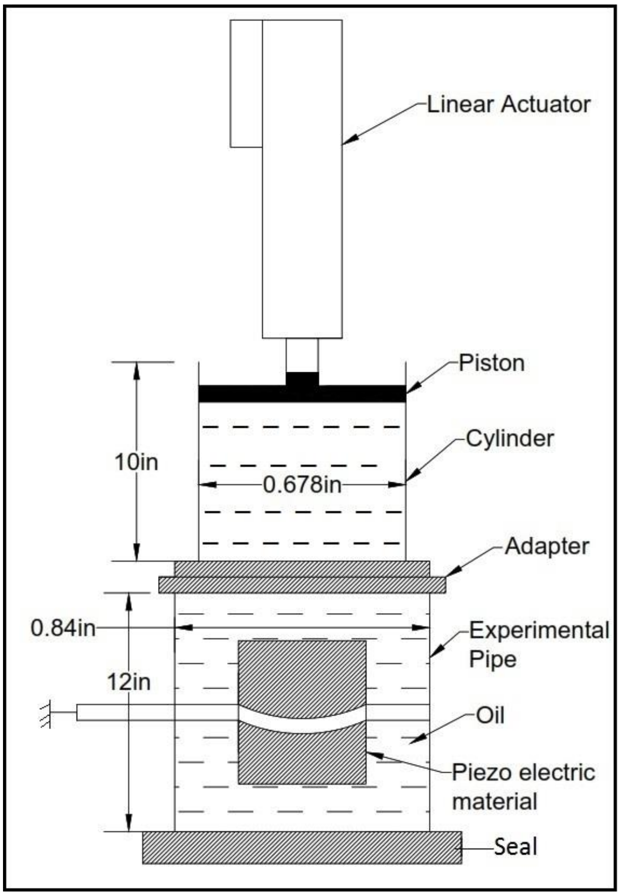

Fig. 4. Internal pressure test rig

3. Theory

The current drawn by the DC motor of the linear actuator is directly proportional to the mechanical load connected with the piston. By measuring the input current drawn by the actuator, the amount of force applied by the piston can be calculated from the datasheet supplied by the manufacturer of the actuator (Fig. 5). The pressure in the cylinder can be calculated from the basic equation,

$$P = \frac{F_1}{A_1} \tag{1}$$

According to Pascal's law, a change in pressure at any point in an enclosed fluid at rest is transmitted undiminished to all points in the fluid [7]. So this same pressure will be transmitted in the pipe but the force in the pipe will be much larger due to the difference in diameters, i.e. areas. This pressure can be used to calculate the circumferential stress or hoop stress which is mainly responsible for the strain on the wall of the pipe [8]. Considering the pipe as a thin wall cylinder, the hoop stress due to the internal pressure of fluid can be given by,

$$\sigma = \frac{Pd}{2t} \tag{2}$$

Where d is the internal diameter and t is the thickness of the pipe [8]. The piezoelectric sensor attached on the inner side of the clamp will detect expansion of the pipe and will turn off the actuator before reaching the bursting pressure.

4. Operational procedure

4.1 Closed system setup

After measuring the wall thickness and the inner diameter of the pipe, the respective values will inputted to the microcontroller by the connected keyboard. With the help of the clamp, adapter and the plastic seals, the sample pipe will be placed vertically and the steel cylinder on top of it. The whole system will be filled with lubricating oil and be checked for leaks. Then the piston will be placed inside the cylinder while keeping in contact with the retracted piston of the linear actuator and the whole setup will be like Fig. 4.

The test can be run in two separate methods. For the first method, we can switch on the linear actuator and it will generate a gradually increasing force till the pipe starts to expand under pressure at which point the piezoelectric sensor attached on the inner side of the clamp will detect this expansion and alert the microcontroller unit, which will turn off the actuator before the pipe bursts and save the pressure reading. For the second method, the linear actuator can be controlled by the microcontroller unit to input a fixed value of pressure under which the pipe can be tested. The piezoelectric sensor will act the same way and will be used as a safety feature to avoid testing the pipe over the bursting pressure.

4.2 Control mechanism

A control mechanism is devised to run the pressure test rig to its full potential (Fig. 6). Initially the 12-volt DC supply is stepped down to 5 volt using 7805 voltage regulator IC which is required for driving the electronic components used in the circuit (i.e. Microcontroller, ACS712 current sensor, piezoelectric sensor, LCD display etc.). When the static switch (i.e. MOSFET) is turned on current starts to flow from source to linear actuator through ACS712 current sensor, a voltage is generated at it's output terminal. ACS712 current sensor is based on the principle of Hall-effect, which was discovered by Dr. Edwin Hall in 1879 [6]. According to this principle, when a current carrying conductor is placed into a magnetic field, a voltage is generated across its edges perpendicular to the directions of both the current and the magnetic field.

The amplitude of the sensor output is directly proportional to the current flowing through it. This voltage is read using analog to digital conversion and from that the value of line current is measured. The manufacturing company provides the I-L characteristics (load vs. current, Fig. 5.), from which the line current can be used to calculate the force applied by the piston of linear actuator. The I-L characteristic and the hydrostatic gain will be uploaded in the microcontroller. From that data, microcontroller will automatically calculate the pressure applied to the pipe and show it in the LCD display.

To test the pipe under a specified pressure, the operator will need to type in the value using the keypad connected to the microcontroller. When the pressure reaches the preset level, the static switch (i.e. MOSFET / IGBT) will be automatically turned off.

For finding out the internal pressure under which it starts to strain, expansion of pipe due to increasing pressure will be continuously monitored by the microcontroller through a piezoelectric sensor. When the expansion of pipe reaches a certain level then the microcontroller will turn off the static switch and prevent the pipe from bursting.

For finding out the internal pressure at which the pipe explodes, the piezoelectric sensors need to be pulled out of the system. When the pipe will explode the line current will drop very fast as the pressure inside the pipe will fall. The microcontroller will store the reading of pressure before this rapid fall of line current.

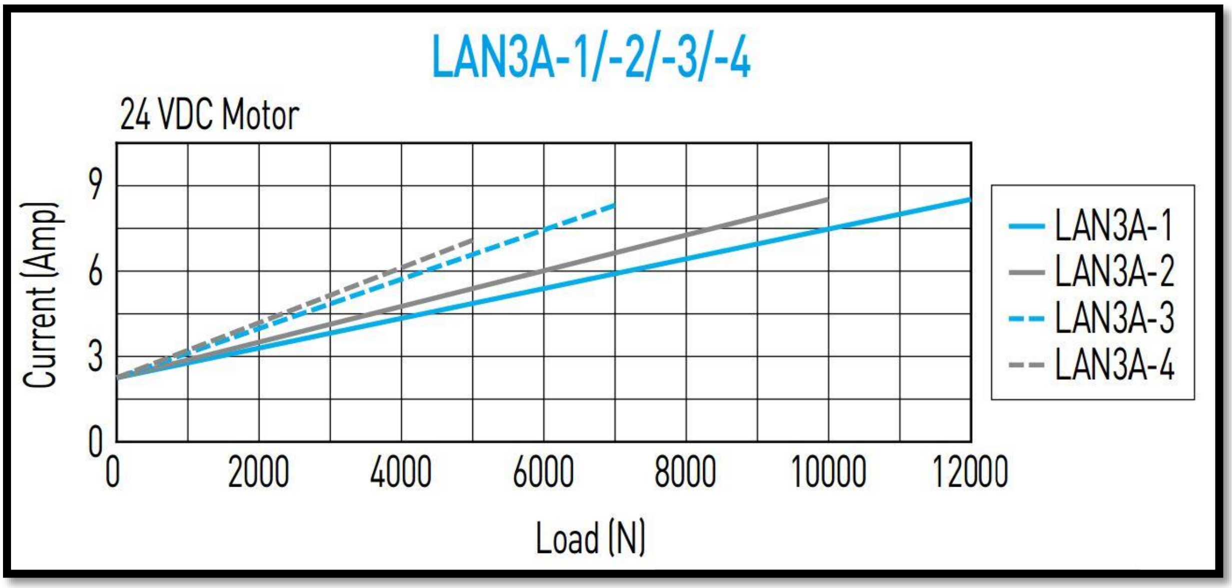

Fig. 5. I-L characteristics [5]

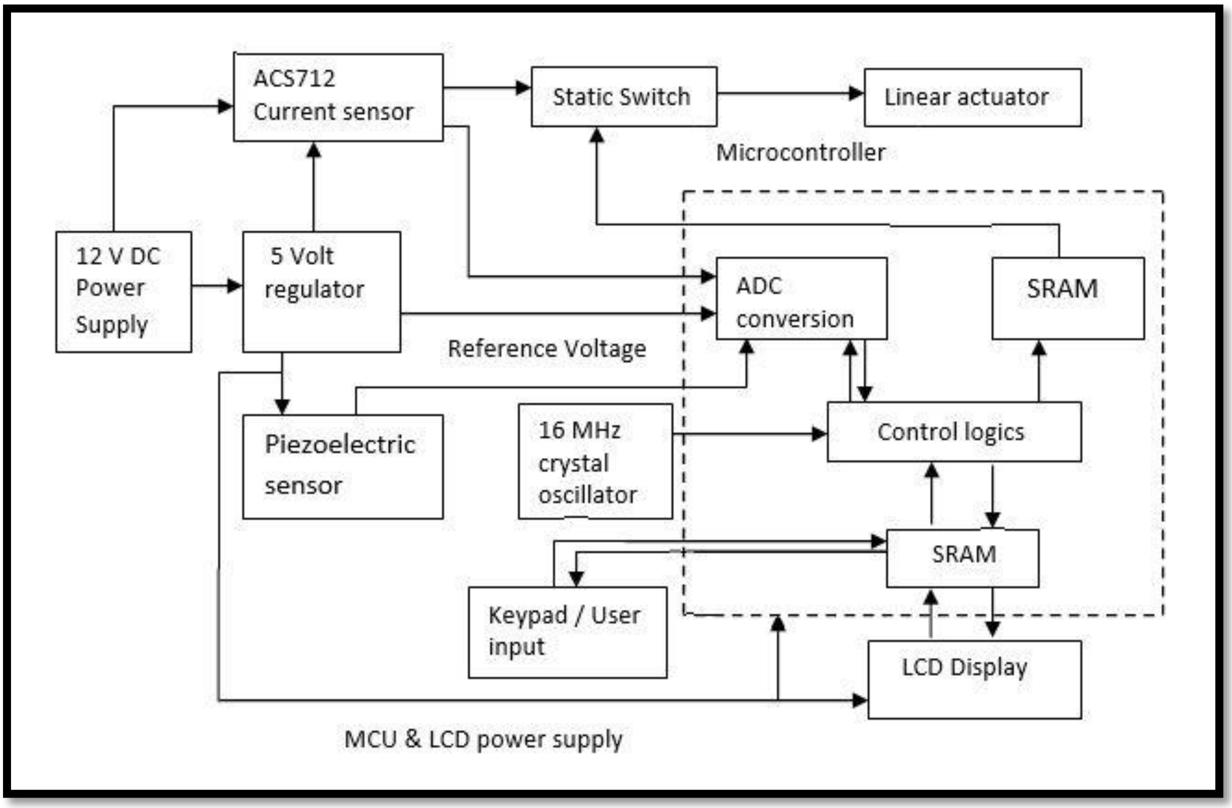

Fig. 6. Designed control mechanism

5. Conclusion

Using a pipe under its maximum operating pressure is a vital safety concern. The pipe manufacturer is focused to ensure that the pipe meets the specified internal pressure ratings whereas the onsite engineer is keen to verify the pressure ratings of a few samples before accepting and using the whole batch. And the proposed internal pressure test rig in this paper can help in both of those cases. The design and operational simplicity of the rig ensures that it can be used effectively onsite for virtually all nominal standard sizes which can save the cost of sending the samples to an offsite facility for testing both in terms of both time and money in the long run. The proposed test rig is theorized to be able to measure the internal pressures of a pipe with great accuracy in less amount of time due to digitizing most of the cumbersome processes. Further research and development is needed in terms of construction to make the test rig even more beneficial and cost effective.

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