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NOTES

BRIEF contributions in any field of instrumentation or technique within the scope of the journal should be submitted for this section. Contributions should in general not exceed 500 words.

Microprocessor-based pressure controller

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A device for automatic control of pressure in an ion-atom scattering experiment has been constructed. The system was modeled to achieve the minimum time for transition from one pressure to another. The pressure controller "learns" the system response and iterates the parameters used in "profiling" the valve voltage to reduce the transition time. The device has been used with two different scattering chambers and has worked well with both.

PACS numbers: 07.30.Kf, 06.70.Td, 35.80. + s

A microprocessor-based pressure controller was built to facilitate removal of human involvement in controlling the pressure in an otherwise automatic, computer-controlled ion-atom scattering experiment[1] and to reduce the natural transition time required to go from one pressure to another.[2]

Before the pressure controller was constructed, the gas flow of the scattering chamber system was modeled. The model consisted of a gas reservoir at a constant pressure P_1 connected by a variable opening to the scattering chamber at pressure P. The scattering chamber was connected to the vacuum of pressure P_0 by a fixed opening. The "normalized" gas flow into the chamber was assumed to be $f(t)(P_1-P)$ while the flow out was $k(P-P_0)$ so that the differential equation governing the model is

$$dP/dt = f(t)(P_1 - P) - k(P - P_0).$$

The general solution to this equation is[3]

$$P(t) = e^{-\int [k + f(t)]dt} \times \left\{ \int [P_1 f(t) + kP_0] e^{\int [k + f(t)]dt} dt + C \right\}.$$

Adding and subtracting kP_1, rearranging and performing one perfect integration gives

$$P(t) = P_1 + e^{-\int [k + f(t)]dt} \times \left[k(P_0 - P_1) \int e^{\int [k + f(t)]dt} dt + C \right].$$

If we take

$$f(t) = \sum_{i=1}^{n} a_i \, \theta(t - t_i),$$

$P(0) = P_0$, and the integration from 0 to t, the constant C evaluates to $(P_0 - P_1)$ so that

$$P(t) = P_1 + (P_0 - P_1) e^{-\int_0^t [k + f(t)]dt} \times \left(1 + k \int_0^t e^{+\int_0^t [k + f(\tau)]d\tau} dt \right).$$

This function is numerically evaluated by replacing the last integral with a simple summation that approximates it. With a suitable choice of a_i, t_i, and k, $P(t)$ gives a sharp rise to the final pressure and remains there. For this result $f(t)$ is a large pulse of the proper height and duration followed by a step of lower value necessary to maintain the final pressure [Fig. 2(a)].

During preliminary testing of the pressure controller, a similar valve "profile" of a pulse followed by a step was used. A sharp rise plus an overshoot (that took the system response time to dissipate) resulted. Relaxation of the Veeco valve[4] caused the overshoot which the model did not predict. The Veeco valve literature[4] admits that the exact response of the piezoelectric crystal is influenced by many factors other than the voltage. These include temperature, time, mechanical loading, and hysteresis.[4] This required that the pressure controller be complex enough to compensate for these effects.

The necessary complexity as well as the ability for computer interface led to the selection of a microcomputer for control of the pressure. The microcomputer can accurately change its action for various changes in the system response. It also allows data to be input for customizing the pressure controller for various systems and permits a sophisticated regulation algorithm to be implemented in software.

The pressure controller (Fig. 1) consists of a 4-kbyte controlling program written in FORTH and assembler running on an AIM–65[5] microprocessor system with other associated hardware and software. The other software is an AIM-65 FORTH[6] altered for run-time use. Rockwell International now has RM 65 Run-Time FORTH[7] that will serve in this application. The hardware consists of interfaces developed in this laboratory for this device. They are: (i) A manual or computer interface for inputing the desired pressure in the form of $3\frac{1}{2}$ BCD digits, range, interrupt, and communication control lines; (ii) An analog-to-digital, digital-to-analog converter interface; (iii) A 16-bit digitial-to-analog converter connected with a high-voltage operational amplifier for con-

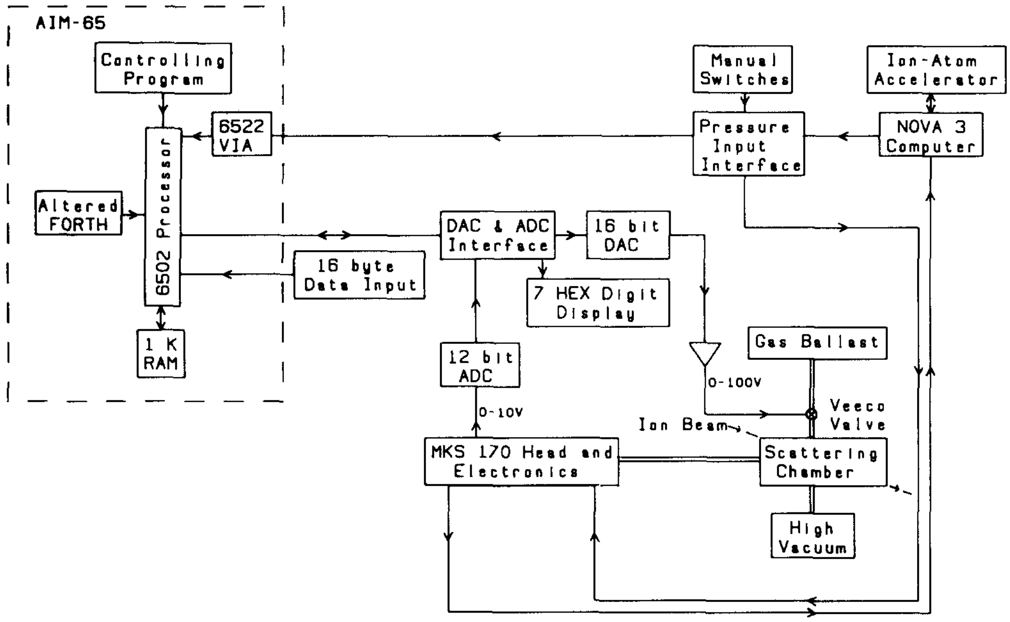

FIG. 1. A block diagram of the pressure controller showing its relation to the other components of the ion-atom scattering experiment.

trolling a PV-10 Veeco piezoelectric valve[4]; (iv) A 12-bit analog-to-digital converter for digitizing the analog signal of a MKS 170 pressure measurement system[8]; and (v) A 16-byte, switch programmable input device.

The device waits until interrupted with a request for a new pressure. (This can be initiated by a computer or manually.) It then profiles the voltage on the valve to make the transition time between the "old" pressure and the new pressure as short as possible. After the profiling is done, the pressure controller then goes into a regulate mode. The "regulator" uses the current pressure deviation and the average rate of pressure change over the previous 1 s to calculate the correction in the valve voltage. Repeatedly, after a suitable lapse of time, the regulator adjusts the valve voltage again.

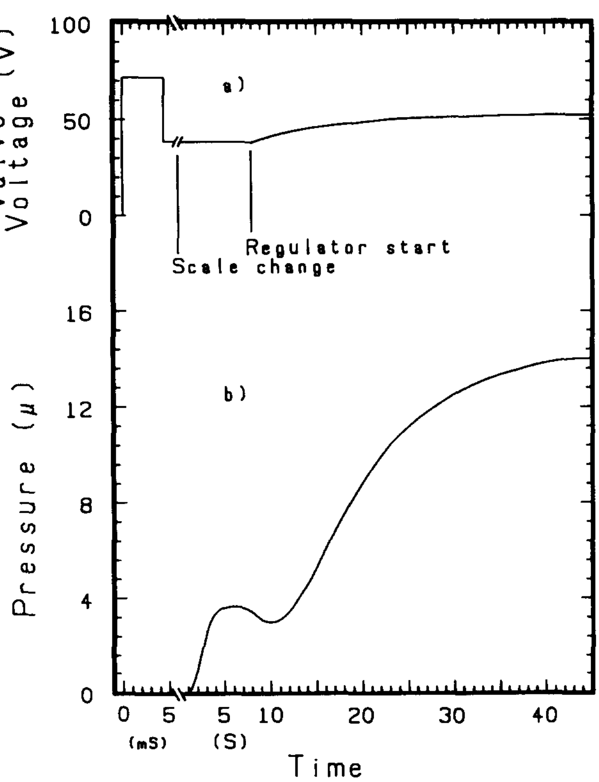

FIG. 2. (a) Valve voltage for the first attempt to make the transition from 0 to 14 μ. Its profile before "Regulator start" is the modeled profile. Some of the parameters input via the 16-byte input device determine the form of this profile. The regulation starts at $t = 8$ s. (b) Pressure response of the first attempt. It takes 37 s to reach $14.0 \pm 0.5\,\mu$.

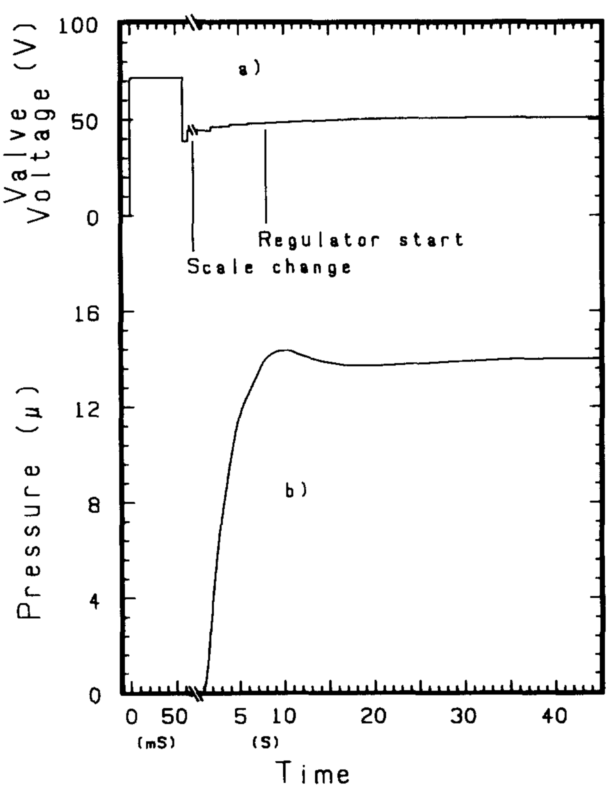

FIG. 3. (a) The valve voltage vs time for a fifth transit from 0 to 14 μ is shown. The voltage is the result of the pressure controller learning the system response from four previous attempts. The regulation starts at $t = 8$ s. (b) Pressure response of the system due to the voltage profile in (a). The pressure of $14.0 \pm 0.5\,\mu$ is achieved in 7 s.

When this process is interrupted by a request for a new pressure, several parameters are updated from the results obtained at the regulated pressure so that the pressure controller "learns" how to modify its actions to optimize the system's operation.

The profile modeled earlier and shown in Fig. 2(a) is used as the first profile. Its pulse length and step height are not optimized for any particular pressure but serve as a base for learning. Subsequent profiles replace the step with a stepwise approximation to $B\text{-}Ae^{-\alpha t}$ to compensate for relaxation in the valve. The pulse length and parameters B and A are learned for each pressure. The pulse height, base line, number of steps, step duration, "velocity," and "spring" constants of the regulator, and other parameters are user controlled through the 16-byte input device. These parameters are used to customize the controller for different scattering chambers. Figure 3 shows the fourth subsequent profile and the pressure response to it. The pressure changed from 0 to $14.0 \pm 0.5\,\mu$ in less than 7 s after that pressure was requested. This compares with the time of 37 s for the pressure to reach the desired value in response to the initial profile and regulation, as shown in Fig. 2. The pressure controller rapidly converges to an acceptable profile. The system has worked well with two different scattering chambers and typically responds better if the beginning pressure is different from zero since valve relaxation has already occurred.

The pressure controller was relatively simple to build and has many advantages. A pressure can be either manually or computer requested. The modeling gave a form for the profile that is quickly optimized for each pressure. The controller works well with different scattering chambers and reduces the time required by the experimental apparatus to take data.

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[5]AIM-65 Microcomputer User's Guide, Rockwell International Document No. 29650N36, 1979.
[6]FORTH User's Manual, Rockwell International Document No. 29650N72, 1981.
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[8]Baratron Pressure Meter Type 170, MKS Instruments, Inc., 22 Third Avenue, Burlington, MA 01803.

Hollow-cathode magnetron ion source

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A new type of ion source with axial extraction, based on hollow-cathode magnetron discharge, has been developed. Constant hydrogen ion currents in excess of 1 mA with an exit source aperture of 1 mm in diameter and accelerating voltages up to 3 kV, have been extracted axially from the cylindrical hollow cathode. Similar results have been obtained with helium, argon, and nitrogen plasmas.

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The theory of the vacuum magnetron diode was given by Hull.[1] The fundamental characteristic of this diode is that the anode current cutoff takes place at a critical value of the magnetic field. Then, under the influence of the crossed electric and magnetic fields, electrons rotate around the cathode. In the gas magnetron diode such an increase of electron path length increases the probability for electron–atom collisions. Consequently, the rate of excitation and ionization of the gas increases rapidly. That is why the gas magnetron is used as an ion source.[2–5] In the last few years, a type of magnetron discharge has been used for neutral beam sources[6] related to the problems of thermonuclear fusion.

In this paper a new type of ion source, based on a hollow-cathode magnetron discharge is presented. This ion source has all the good characteristics of a conventional magnetron ion source, but in addition, it provides a very effective axial ion extraction from a cylindrical hollow cathode.

In order to obtain an ion current from an ion source, it is of equal importance to provide a plasma with as high degree