Inexpensive Automatic Control System for Soils Testing

N. SIVAKUGAN, J. L. CHAMEAU, R. D. HOLTZ, AND A. B. HUANG

An inexpensive automatic control system for soils testing is described. The system comprises a microcomputer, an analog-digital conversion board, an output relay board, a parallel digital interface, and solenoid valves. Minimal programming is involved to set up the system, and the required software is ordinarily provided by the manufacturer at no cost. The system has been successfully used in K_o consolidation and strain-controlled loading of cubical clay specimens in a cuboidal shear device. The system may also be used to control other soil testing equipment.

The advent of microcomputers has had a tremendous impact on laboratory testing of soils. Using microcomputers and other electronic components, it is relatively easy to develop specialized interactive data acquisition and control systems for automation of laboratory tests. The rising costs of wages and the declining cost of microcomputers and other electronic components have resulted in rapid advances in such systems (*1–6*).

Microcomputers and automatic data acquisition systems have become essential to many laboratory experiments. They reduce operator time significantly because the entire bookkeeping (i.e., data recording process) is left to the microcomputer. When several readings are to be taken simultaneously or when high-speed recording is required, such data acquisition systems are almost a necessity. If any feedback or corrective action is required while processing the data, some form of servo-control is essential.

In this paper, an inexpensive but efficient servo-control system using solenoid valves is described. The system has been used successfully for cuboidal shear testing (*7,8*), and it could as well be used with other testing devices.

SOLENOID VALVES FOR SERVO-CONTROL

Solenoid valves are opened or closed by energizing or deenergizing (or vice versa) the magnetic coil inside the valve assembly. This moves a plunger in the middle of the magnetic coil. Solenoid valves can be either AC or DC operated, two way or three way, and normally open (*N/O*) or normally closed (*N/C*). For example, a two-way, normally open, AC-operated solenoid valve remains open when deenergized. A 115 V AC signal would energize the coil and close the valve.

N. Sivakugan, College of Engineering, Sultan Qaboos University, Muscat, Sultanate of Oman. J. L. Chameau, School of Civil Engineering, Purdue University, West Lafayette, Ind. 47907. R. D. Holtz, Dept. of Civil Engineering, University of Washington, Seattle, Wash. 98195. A. B. Huang, Dept. of Civil and Environmental Engineering, Clarkson University, Potsdam, N.Y. 13676.

The schematic diagram of a generic servo-control system is shown in Figure 1. This arrangement may be incorporated with little modification into any testing device such as an oedometer, triaxial equipment, or any other specialized testing apparatus. The solenoid valves can be opened or closed on command by the control system, which consists of a microcomputer, a relay output board, and a parallel input/output (I/O) interface board.

In the example in Figure 1, P_1, P_2, and P_3 are the pressures at the pressure source, the controlled device, and the exhaust, respectively. Initially, the *N/O* valve is energized, and the *N/C* valve is deenergized, that is, both valves are closed. The range of values that P_2 will take during the test is known, and P_1 and P_2 are set such that $P_1 > P_2 > P_3$ for the entire test. P_1 and P_3 remain constants and require no adjustment. A momentary deenergizing of the *N/O* valve or energizing of the *N/C* valve would accordingly increase or decrease P_2. After every adjustment of P_2, measurements and computations are made, followed by corrective action, if required. This process can be repeated until the desired value of P_2 is reached.

In the system developed at Purdue University, the solenoid valves (two-way, *N/O*, B90A303R; two-way, *N/C*, B90A360R; Spangler Valve Company) are operated by a 24-channel, double-pole–double-throw relay output accessory board (Model ERB-24, MetraByte Corporation). Each relay contains two *N/O* and *N/C* contacts for controlling up to 3 *A* loads at 120 V AC excitation. The ERB-24 is operated by a 24-bit, parallel digital I/O interface (Model PI012, MetraByte Corporation), which occupies an expansion slot of a microcomputer [IBM personal computer (PC)]. The PI012 is driven by programs written in BASIC. After processing the data (measurements of pressure, displacement, etc.) and making the appropriate decisions, the microprocessor sends instructions to the PI012 interface card, which are passed to the ERB-24 relay card down the line. Then, the relevant relays are activated to perform the desired adjustments.

An eight-channel A/D convertor (Model DASH-8, MetraByte Corporation) was used for data aquisition. For every measurement of pressure or displacement, 100 samples were taken, and the arithmetic average was computed and used. The frequency of measurement depends on the number of samples, number of channels, computations required in each cycle of measurement, efficiency of programming, and the programming language used.

Subroutines written in ASSEMBLY language that interact between the PC and computer boards were provided by the manufacturer at no extra charge. The actual data logging and servo-control programs, which communicate with the

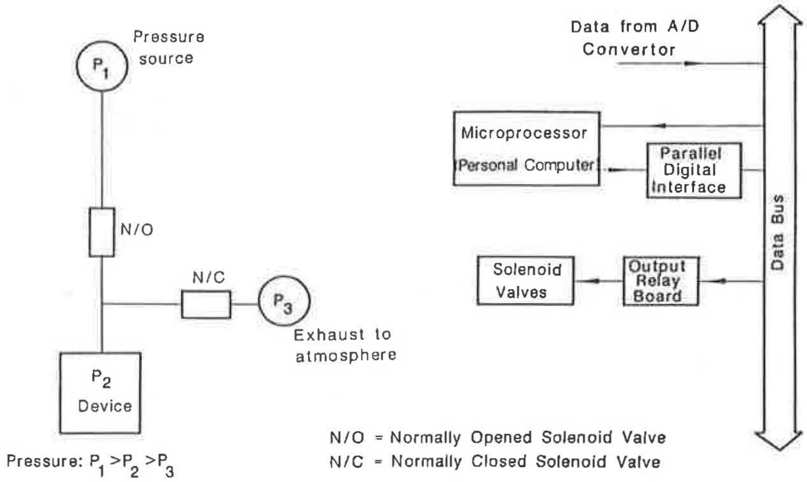

FIGURE 1 Schematic diagram of a generic servo-control system.

computer boards by calling the ASSEMBLY subroutines, can be written in BASIC or any other high-level compilers (e.g., FORTRAN or C). Sample basic programs that encompass a wide variety of applications were also given by the manufacturer. Thus, the actual programming is minimal because it normally involves modifying an existing program to fit a particular application. In addition, commercial data logging software (e.g., DADiSP, LABTECH NOTEBOOK, and ASYSTANT) is also compatible with the system described herein. All such software is menu-driven, which completely eliminates the need for programming. The programs are, however, copyrighted and usually cost more than $1,000.00.

COST

The two-way *N/O* and *N/C* solenoid valves were priced at $30.80 and $24.60, respectively. The relay output accessory board and the interface board were bought for $97.00 and $395.00, respectively. A complete IBM-compatible microcomputer system, which can also be used for other purposes, can be purchased for less than $1,000.00.

APPLICATIONS

Cuboidal Shear Device

The servo-control device described above, with an automatic data acquisition system, has been successfully employed with a cuboidal shear device built at Purdue. The system is very useful for performing K_o consolidation and strain-controlled loading of cuboidal specimens; predefined stress paths (e.g., a pressuremeter stress path) can also be imposed on a specimen. All can be accomplished without operator assistance during the test (*7,8*).

The schematic diagram of the servo-control system for the cuboidal shear device shown in Figure 2 is derived from the generic servo system of Figure 1. In the cuboidal shear device,

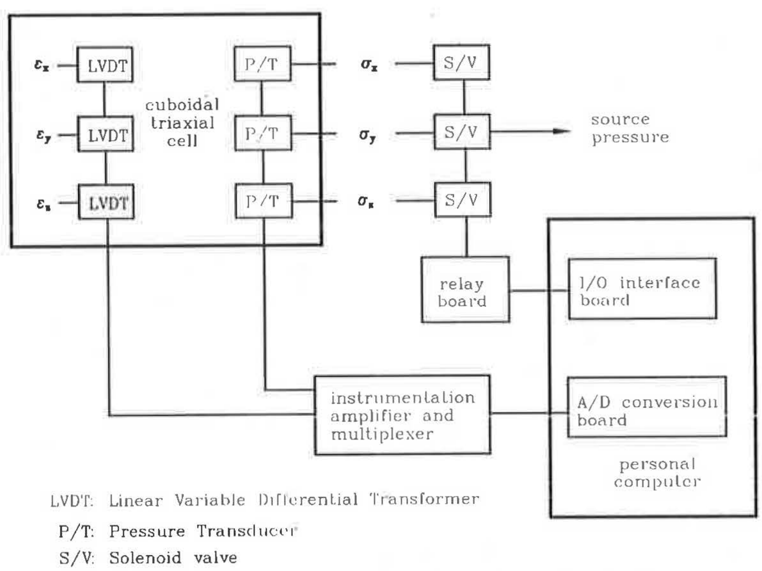

FIGURE 2 Schematic diagram of the servo-control system for the cuboidal shear device.

a 102 mm cubical specimen is compressed by air applied to 6 membranes, 1 on each face of the specimen. The pressure line in each of the three directions is connected to a pair of *N/O* and *N/C* valves (Figure 2). By energizing or deenergizing the appropriate valves, the three principal stresses (σ_x, σ_y, and σ_z) can be regulated to follow the desired stress path. K_o consolidation has been performed with the lateral strain controlled to within ± 0.025 percent. In maintaining essentially zero lateral strain, the two horizontal principal stresses were adjusted repeatedly by opening or closing the solenoid valves while the vertical principal stress was maintained constant. Each cycle of the servo-controlled K_o consolidation consists of the following operations:

- Measure 8 channels of displacements and 4 channels of pressures, each sampled 100 times;
- Display the readings on the monitor and record on the diskette;
- Open/close the solenoid valves; and
- Perform some computations.

Figure 3 shows the flow chart for servo-controlled consolidation. Even with all these operations, a cycle of measurement, calculation, and adjustment takes only 30 sec.

The strain-controlled loading has been performed within ± 5 percent of the specified strain rate. Strain rates were computed continuously with adjustments in pressure after each measurement. Experimental results obtained using this servo-control system are given elsewhere by Sivakugan et al. (*8*).

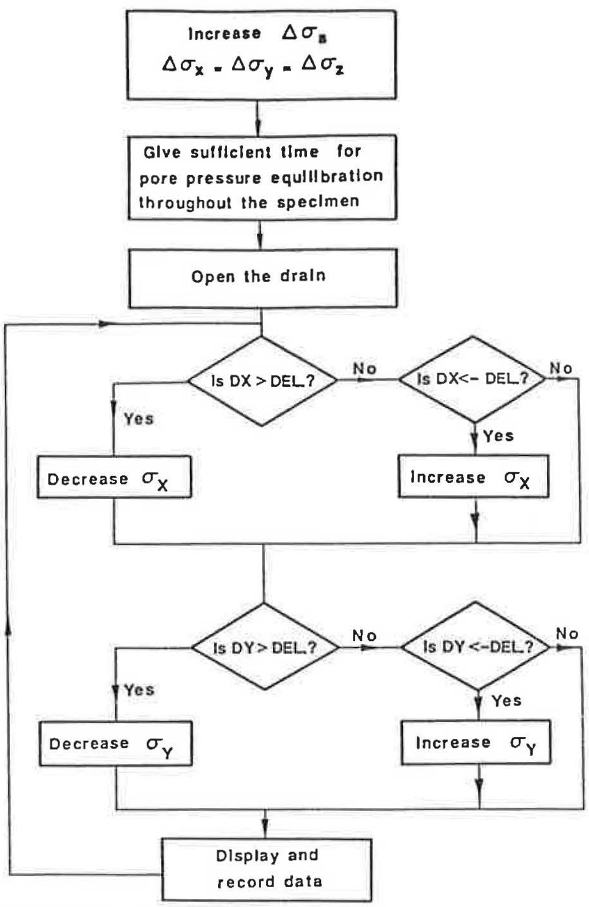

FIGURE 3 Flow chart for servo-controlled K_o consolidation.

Other Applications

Triaxial Testing

An ideal servo-controlled triaxial apparatus should allow for the following:

- Stress- and strain-controlled loading,
- Drained or undrained loading,
- Anisotropic consolidation and swelling,
- A pre-defined stress path, and
- Automatic data acquisition.

Coatsworth (*1*) described a computer-controlled triaxial device capable of data acquisition and control. The control was achieved by digital pressure/volume transducers interfaced to the microcomputer. Other possibilities for control include stepper motors, or screw jacks driven by a motor interfaced to a microcomputer. As an alternative, the servo system illustrated in Figure 1 may also be used to achieve all the objectives listed above. For example, K_o consolidation or swelling can be performed in the conventional triaxial cell by adjusting the axial load and the cell pressure.

Oedometer Testing

The use of a microcomputer for data acquisition and control in oedometer testing has been described by Armour and Drnevich (*2*), Sandbaekken et al. (*5*), and von Fay et al. (*6*). The servo system described above can with minor modifications be incorporated to the oedometer to perform conventional stress-controlled tests, constant rate of strain tests, and the like. In a constant rate of strain test, the mechanism would be similar to the strain-controlled loading performed in the cuboidal shear device. In the stress-controlled oedometer tests, the system can be programmed to add the subsequent stress increment at the appropriate time.

CONCLUSIONS

A simple and inexpensive servo-control system using solenoid valves was described. This system can be incorporated to control and at the same time acquire and record test data for most routine and research laboratory soils testing equipment. The efficiency of the system has been evaluated by a series of tests performed with a cuboidal shear device. In those tests, the servo-control system is used to monitor and adjust applied pressures and in turn ensure a desired set of conditions, for example, K_o consolidation, or strain-controlled loading.

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