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AN IMPROVEMENT OF ON-LINE COMPUTER TEST CONTROL METHOD

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SUMMARY

A on-line computer test control method has been examined, accepted, and improved by many researchers in the past decade. This paper describes two improvements oriented for 1) the rapid simulation speed, and for 2) the accuracy of displacement control. The concept of the continuous loading algorithm is applied to carry out a rapid simulation, and one-fifth of real time speed has been successfully attained. Numerically controlled servomotor system was used as a loading apparatus to obtain high preciseness in the displacement control. The control error was suppressed within 20 microns by a suitable control method.

INTRODUCTION

An epoch-making techniques to simulate inelastic structural responses during an earthquake was initiated more than a decade ago. The equation of motion is integrated by computer in a step-by-step reference of the actual restoring force measured from the loading test, which is also carried out by computer-controlled actuators in parallel with the integration, as shown in Fig. 1. This computer on-line test control method is a cross-over between analysis and experiment, and it has been widely utilized in many countries as well as in Japan (Refs. 1 and 2), examined, accepted, and improved by many researchers in the past decade. The main objective of this paper is to describe two kinds of system recently developed to satisfy further requirements from recent research aspects.

First requirement is high speed response simulation to study velocity sensitive behavior of structural members and frames. In most of past on-line systems, quasi-static loading tests were carried out to measure restoring force of specimens, and the velocity dependent portions of actual restoring force were usually ignored. Some attempts were made to use a dynamic loading test instead of a quasi-static one (Refs. 3 and 4). This paper describes the attempt which was made under the same configuration with the original quasi-static system by an algorithm to control the displacement of the specimen continuously.

Another requirement is to attain the accurate displacement control of actuator strokes. The positioning error of actuator causes incorrect values of restoring forces, and especially in the case of stiff specimen, such as a braced frame and shear wall system, this gives a fatal influence to the accuracy of the simulation. Hydraulic actuators with electro-servo control widely used in the on-line tests have constitutional weaknesses: the insufficient rigidity and pulsation of the oil pressure. An attempt was made to alternate the hydraulic actuator by a new type of loading apparatus, a positioning system driven by a NC (Numerical Control) servomotor, which has been widely used in the field of industrial machining (Ref. 5).

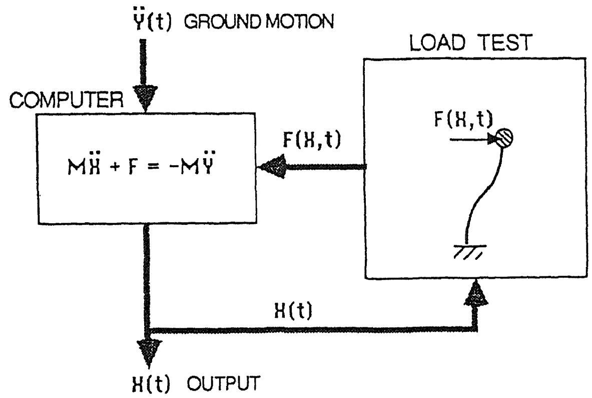


Fig. 1 Basic Concept of Computer On-line Testing

CONTINUOUS LOADING FOR RAPID ON-LINE TESTING

In the original form of the on-line test, actuator motion is stopped when the test specimen arrives at the target displacement so that the reactional force can be measured. Instead of stopping the actuator, the actuator in the test algorithm used herein moves continuously, and the reactional force is measured immediately after the specimen passes the target displacement. Recognizing this reactional force as the restoring force at the target displacement, the equation of motion is integrated in one time split by the explicit formula (the central difference approximation of response acceleration). After the next target displacement is determined by this integration, the direction and the rate of command signal is changed, as shown in Fig.2. During the one time split, especially at the moment of the reactional force reading, the velocity of actuator is kept constant in order to remove the inertial effects of the load cell and the actual mass associated with the test setup.

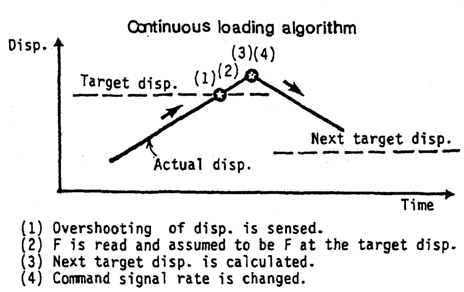


Fig. 2 Continuous Loading Algorithm

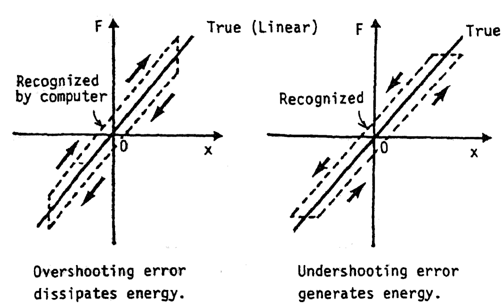
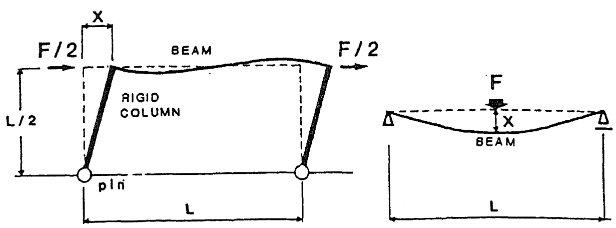


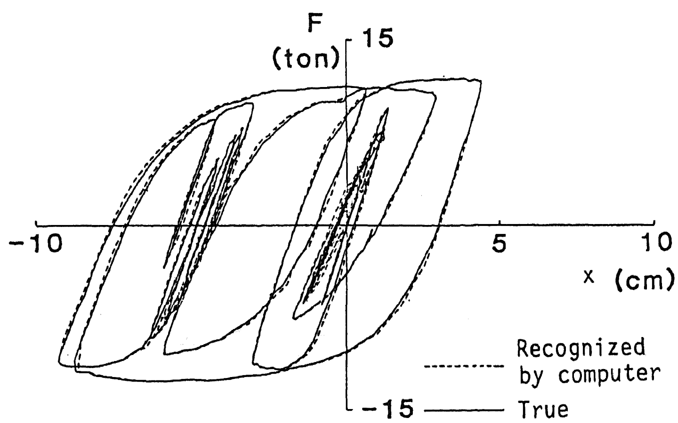
Fig. 3 Systematic Error Effects

Strictly speaking, the restoring force reflected to the response analysis in this test algorithm is not a true one, because the displacement of the specimen is already overshoot beyond the target displacement at the moment of reactional force reading. Fig. 3 illustrates the influence of the overshoot and undershoot errors on completely linear structures. As for the overshooting errors, incorrect energy dissipation would be recognized by computer, while incorrect energy would be generated for the undershoot errors. The overshoot errors in the above algorithm, however, are believed to have a small effect on the response since the processing speed of the computer is high, resulting in only slight overshoot.



(a) Analyzed model (b) Test specimen

Fig. 4 Verification Test for Fast On-line System



SDF response of steel H-shaped beam
Duration of earthquake: 10 sec
Simulation time : 54 sec

Fig. 5 Typical Test Results

Fig. 5 shows an example of inelastic response simulation by this test algorithm. Simply supported H-shaped steel beam was tested dynamically as shown in Fig.4. The natural period in elastic range was set to 0.3 second, and El Centro NS component of 10 second duration was used for excitation. Total simulation time by the above algorithm is 54 second, that is, about one fifth of real time speed was attained in the on-line test. The dashed curve in Fig.5 is the hysteresis curve recognized by computer, that is, the dashed curve satisfies the equation of motion at each time step, while the solid curve is the actual hysteresis curve of specimen under the overshoot control. It was found that the two hysteresis curves have no fatal difference to predict such inelastic response. If an elastic response is simulated, however, a careful attention should be paid to the the additional hysteretic damping due to the overshoot error and also to the velocity dependent error of the load cell itself.

ACCURATE POSITIONING BY NC SERVO-MOTOR DRIVE

The another system recently developed comprises a numerically controlled electric motor, a transmission device with a ball screw which converts the rotational power of the motor into translational movements. This NC servomotor drive was originally developed for accurate positioning of a table of machine tool. High accuracy of positioning, say, within 2 microns, is usually required for such machine tool, and its high resolution capacity will be also useful for precise displacement control in a structural test. Various combinations of load capacity, stroke speed, and resolution capacity can be obtained by adjusting the pitch of ball screw and the rotation resolver. Even if the power of electric motor is restricted, high load capacity will be obtained with slow stroke speed by use of ball screw with dense pitch. In the positioning system herein, 10 cm/sec maximum stroke speed, 3 ton load capacity, and 1 micron resolution capacity were chosen under 2.8 KW power of the motor.

Fig.6 outlines the framework of newly developed system. Numerical Control of the servomotor herein is categorized as CNC (Computerized Numerical Control) or softwired NC, which were developed in 1970's. In this type of NC, a small micro-computer (positioning processor) is installed in each controller, this processor controls positioning of the movable table including backlash compensation of ball screw. While the host computer in the previous system transmits analog command signal to analog actuator controller, the host computer herein communicates with the positioning processor through serial communication interface.

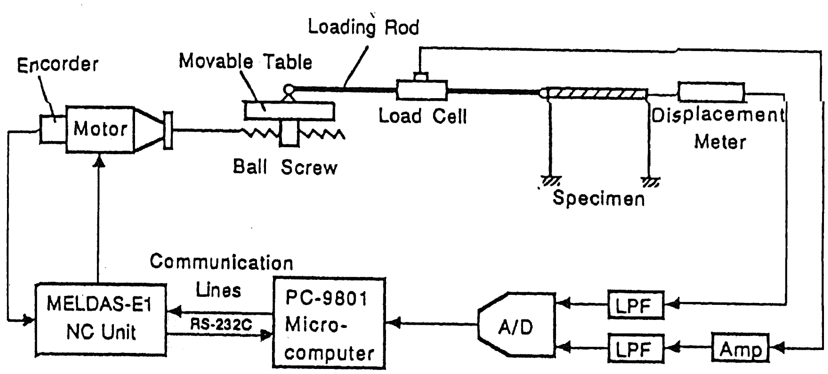


Fig. 6 Framework of Testing System Driven by NC Servomotor

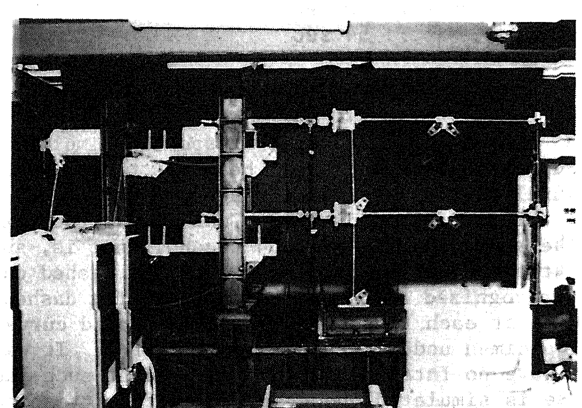


Photo 1 Testing System for 2-story Frame

There are two manners to control the displacement of specimen as shown in Fig.7. This is associated with the tightness and the preciseness of the test setup. If the target point of specimen to be controlled is tightly connected to the movable table, the displacement controlled by the positioning processor is regarded as the target displacement of the specimen. In such case a open-loop displacement control method can be applied, where the host computer only informs the target displacement to the positioning processor. In another case, if the target point is loosely connected to the table or there are some interventions between the table and the specimen, such as a loading rod and clevises, a closed loop control method is suitable, where the host computer measures the target displacement by transducer attached to the specimen directly as a feedback signal and informs movements for compensation to the positioning processor.

A portal frame composed of steel plates was tested in elastic range by the above two control method, where a loading rod with mechanical pinned joints existed between the specimen and the table. The natural period of the frame was set to 0.5 second and El Centro NS excitation was used. Positioning errors in the two control method are compared in Fig.8. 100 micron error due to the looseness of the test setup was observed in the open-loop control case, and the error was reduced within 20 microns in the closed-loop control. Generally speaking, a closed loop displacement control with a reliable target transducer is a feasible choice for these types of on-line test system, because the tightness of test setup will be different for each cases.

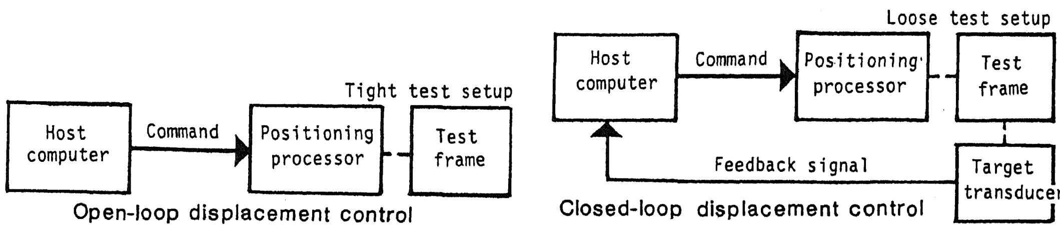


Fig. 7 Two Manners in Displacement Control

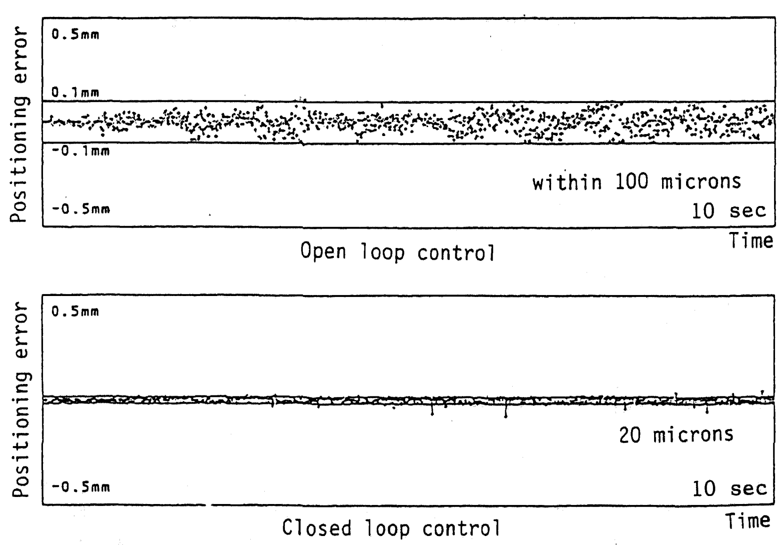


Fig. 8 Control Errors in Loose Test Setup

CONCLUDING REMARKS

Two improvements have been achieved about computer on-line pseudo-dynamic testing as follows:

1. Fast(rapid) on-line test algorithm was summarized and some problems to be recognized in implementing this algorithm were discussed. This test algorithm aims to provide as rapid simulation speed as possible in the present pseudo-dynamic testing concepts. One-fifth of real response speed has been successfully attained for a single-degree-of-freedom earthquake response in the present system. This is rapid enough to investigate rate sensitive structural properties.

2. An on-line test system was developed by use of NC servomotor drive instead of electro-hydraulic actuators. This system aimed to provide a precise positioning in control of response displacement. If a good direct driving test setup would be made, this loading apparatus could make a precise positioning within 2 micron control error. In case of a loose test setup with 100 micron error due to the looseness at connections or deformation of loading rod, it is recommended to use a closed-loop displacement control instead of an open-loop control. After using the closed-loop control, the control error was reduced within 20 microns. This new type of loading apparatus needs no oil supply system, and it is free from many disadvantages due to insufficient rigidity and pulsation of hydraulic oil. Additionally, it can be used anywhere electrical power is available. For example, an on-site simulation of earthquake response of machineries equipped inside a building will be possible by this system.

The above two improvements were achieved in independent configuration of testing systems. There exists a conflicting idea in the two improvements, because the rapidity in the former system was achieved, in a sense, on the sacrifice of the precise positioning. It depends entirely on the research objective which system would be suitable.

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