A study on the tracking system for vehicle crash simulator development

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Abstract- **Servo actuator systems can be used to simulate vehicle crashes. In order to replace the crash test conducted to evaluate the safety of a vehicle with a simulator, the simulator should be able to simulate an accurate crash situation. The method for simulating the collision situation in the actuator is to generate the same acceleration occurring during collision in the simulator. In this paper, a user PID control tracking algorithm is based on a nonlinear feedback control design and PID control circuit design for a closed circuit controller. Our servo actuator system tracking controller uses Feedforward and Feedback control as external loop controllers around the servo system to accurately track the measured acceleration and velocity at the desired acceleration and speed. Experimental results show that various types of acceleration target curves are being tracked relatively well. As a result of the pressure compensation, it can be seen that the target velocity waveform is almost the same, and the RMS error can be reduced by adjusting the control gain. Therefore, the servo actuator could be used as a vehicle crash test simulator to simulate crash behavior.**

Keywords – Actuator, Controller, Tracking, Simulator, RMS (Root Mean Square)

I. INTRODUCTION

A servo pneumatic cylinder is an actuator that converts compressed air energy into linear and reciprocating motion. It is commonly used as industrial actuators, such as automation facilities, general industrial machinery, robots, automotive assemblies, and shock vibration control systems. It is widely used because it is easy to install, can drive at high speeds and produce a sufficiently large force. Using these characteristics, attempts are being made to use pneumatic servo actuators for more detailed motor control, such as servo control pneumatic systems [1-3]. The servo actuator system used by the author is a kind of tracking control system [4-6]. The difficulty of controlling servo air due to nonlinearities is related to the complex friction distribution associated with the cylinder and the compressibility of air in the cylinder [7-8].

The average rate of use of servo actuators used in pneumatic systems is 1 to 5 m/sec. The actuator for the vehicle crash simulator shall be such that the maximum pressure is 300 bar and the maximum speed is 10 m/sec. The actuator currently used is a self-developed and manufactured servo cylinder, which is a combination of pneumatic and hydraulic actuators. The purpose of this study is to match the test data with the results of the target tracking control test by controlling the brake pressure of an actuator for a crash simulator. Crash testing can lead to an important step in ensuring new vehicle development design. However, the high-cost tests will limit the number of crash tests and the ability to obtain sufficient test data. As the final goal of this study, a crash test simulator using an acceleration tracking control algorithm is an essential tool to reduce vehicle development time and cost.

The actuator for the crash simulator used in this study was configured with a hydraulic brake device to sufficiently block the piston rod advancing momentarily by pneumatic pressure. The hydraulic brake system must be able to quickly and freely adjust the pressure according to the moving wave of the piston rod, and because it moves quickly with a high-pressure device, safety design and design with reproducibility have been given priority.

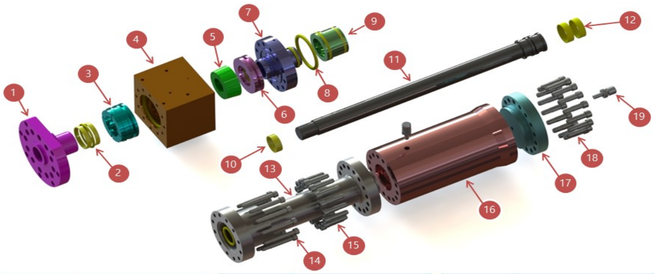
In servo actuators, the piston acceleration control adopts a meter-out control method that regulates the speed at the outlet side of the actuator, and when the piston collides with the cushion device, the cushion device absorbs the shock and discharges hydraulic pressure through the relief valve. It was designed as a hydraulic cushioning device that could be used semi-permanently.

II. SYSTEM STRUCTURE AND OPERATING PRINCIPLES

2.1 Devices and Configurations –

Figure 1 shows the disassembly of the servo actuator. The volume of the chamber of the actuator is defined by an actuator acting through an actuator rod. The device consists of a brake system to control the brake force during the test run and the actuator rod acting on the brake system. Due to the use of a small amount of hydraulic oil, small flow valves, especially servo valves, are used, and valves are mounted directly to the braking system regardless of the valve type. The braking system for hydraulic control of the braking force is connected to the hydraulic power unit(HPU), which consists of a pump and a hydraulic accumulator that first generates the required pressure. The hydraulic power unit is equipped with an acceleration sensor to measure the acceleration of the rod.

The test equipment is largely divided into three parts, the test mechanism where the test is performed by installing the test object, the endurance control panel that supplies and controls pneumatic and hydraulic power, and LabVIEW Software & Software that controls the test system and displays and acquires test data.



Part No.	Name	Part No.	Name	Part No.	Name
1	Front Cover	8	O-ring	15	M12–L45 Bolt
2	Piston Wearing	9	Cushion Piston	16	Air Chamber
3	Brake Release Piston	10	Rod Wearing	17	Rear Cover
4	Brake Block	11	Piston Rod	18	M12–L45 Bolt
5	Conical Brake	12	Piston Rod Wearing	19	Test Point
6	Braking Piston	13	Piston Body		
7	Sandwich Cover	14	M10-L75 Bolt		

Figure 1. An Exploded View of the Servo Actuator

The test mechanism consists of a high pressure pneumatic compressor that supplies high pressure air to the servo actuator, a low pressure pneumatic compressor that supplies low pressure air to the servo actuator, and a high pressure unit that supplies hydraulic power to the brake system for piston rod braking and acceleration control. It also consists of a pressure sensor to measure high pressure, low pressure, accelerometer to measure piston rod acceleration of servo actuator, temperature sensor to measure hydraulic pressure, proportional pressure control valve to precisely control pneumatic pressure, shock absorption pad and bracket.

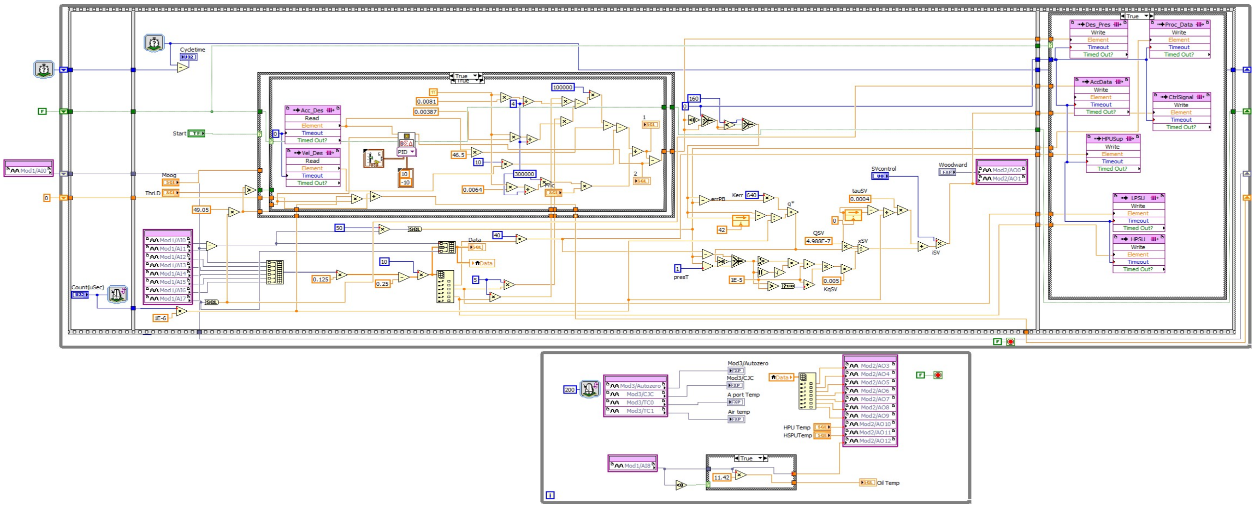


Figure 2. FPGA Target Configuraton

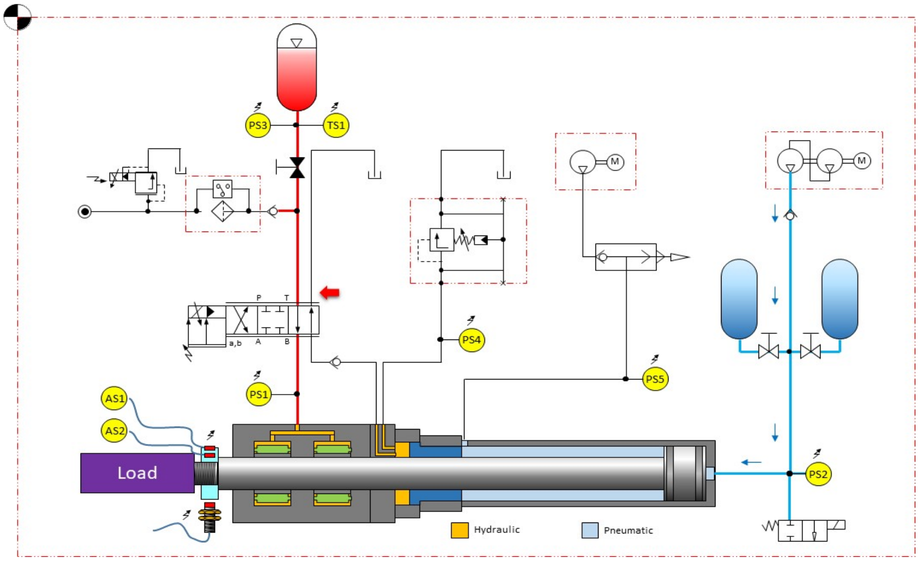


Figure 3. A Block diagram of the Servo Actuator

As shown in Figure 2, the FPGA is a device for controlling hydraulic servo valves and receiving acceleration data in a short period of time, while the DAQ model is responsible for all control devices, including servo valves, acceleration and pneumatic and hydraulic pressure. In the case of hydraulic servo valves, the FPGA and DAQ modules are separated to perform sensitive and mm seconds control commands.

2.2 Basic Operating Principles

Figure. 3 shows a block diagram of the servo actuator system. The desired air pressure can be generated in the compressed air container. The air is first supplied by a piston chamber separated from the hydraulic oil on one side of the piston and the air on the other side, which can be obtained using an industrial piston type accumulator. When the piston rod is fired and the test is finished, apply a hydraulic pressure to the chamber of the reservoir, causing the air to return to the air chamber. Hydraulic pressure is released by filling the cylinder chamber up to the hydraulic pump container. By operating the piston by hydraulic pressure and applying it to the oil chamber, all the air is filled with the piston to the air chamber and moved to the cylinder, thereby moving the air through the discharge pipe in the air chamber.

The remaining hydraulic oil in the storage container is returned to the pump container. At this time, when the air pressure is refilled, the air circulates in the feedback loop of the closed circuit. The remaining air pressure in the air chamber is restored after the end of the test. Upon completion of the test, it is fed back to the piston type accumulator. The air circulation is driven back by hydraulic oil and is preferentially utilized by an additional piston provided in the compressed air container. The hydraulic oil is discharged for air compression and the hydraulic oil is moved to the hydraulic pump, which is simply a air circulation returning to the air container.

2.3 Mathematical Model and Tracking Algorithm

A mechanical model is obtained by applying Newton's second law to the system.

$$(m_P + m_L)\ddot{y} + b\dot{y} = F_A - F_C - F_B$$

where m_L and m_P are load mass and piston mass, respectively. Compressed air propulsion force F_A, capillary resistance force F_c and braking force F_B of hydraulic brake are respectively expressed as follows:

$$F_A = P_P A_P$$
$$F_C = P_R(A_P - A_R)$$

$$F_B = \mu_s N = A_B P_B$$

where A_B, A_R, and A_P are effective area of piston brake, piston rod and piston, respectively.

In the Model Based Tracking Control algorithm, the brake pressure required for tracking the target acceleration to be tracked is calculated in real time by using the velocity profile integrated with the target acceleration. At this time, the target brake pressure generator calculated from the system mathematical model is used. Combining and rearranging the above equations, the target brake pressure generator is expressed mathematically as follows:

$$P_B = \frac{1}{\mu_s A_B}\left[\{A_p P_p - (A_p - A_R) P_R\} - \{(m_p + m_L)\ddot{y} + b\dot{y}\}\right]$$

where b and μ_s are the viscous friction coefficient and the brake pad friction coefficient, respectively.

To replace the crash test conducted to assess the safety of the vehicle with a simulator, the simulator must be able to simulate the exact situation. A method for simulating a crash situation is to generate the same acceleration that occurs during a crash in the simulator. Therefore, a control algorithm is needed to track the acceleration profile measured in a crash situation from the actuator of the simulator. To implement the developed acceleration tracking algorithm, a user graphical interface was developed using the LabVIEW program. The servo actuator system tracking controller includes a Model Based Tracking Control controller, which uses Feedforward and Feedback control as external loop controllers around the servo system to accurately track the measured acceleration and speed at the desired acceleration and speed. A block diagram of the Model Based Tracking Control algorithm is given in Fig. 4. In the "Model Based Tracking Control" algorithm, the brake pressure required for tracking is calculated in real time by using the velocity profile in which the target acceleration to be tracked is also integrated. At this time, the target brake pressure generator calculated from the mathematical model mentioned above is used.

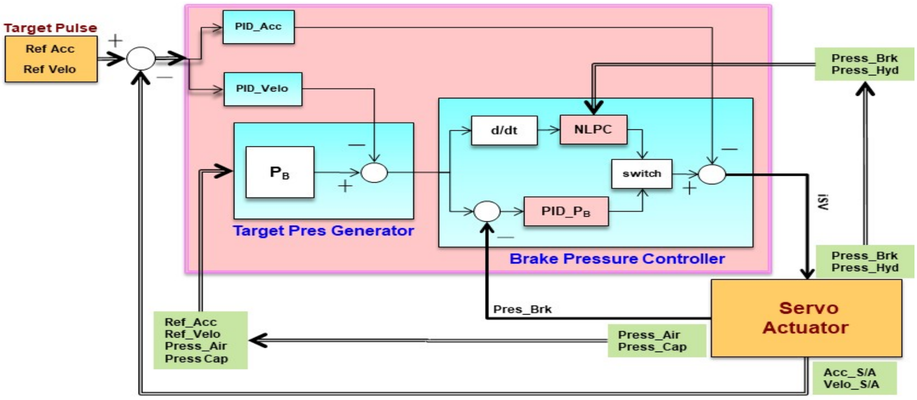


Figure 4. A Block Diagram of the Model Based Tracking Control algorithm

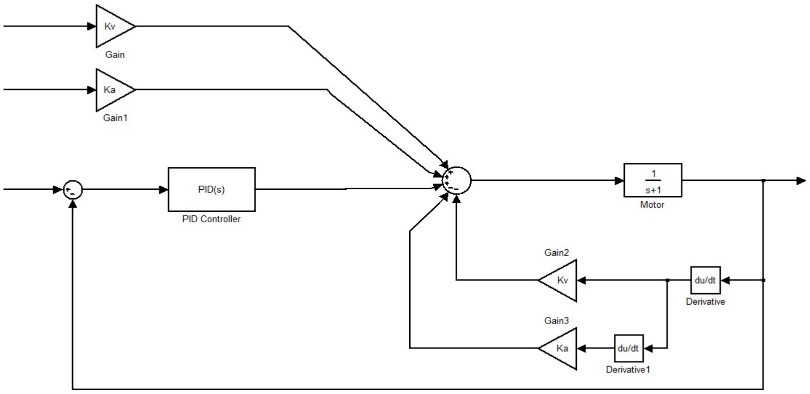


Figure 5. PID Algothm

Figure 5 is the PID algorithm. In order to reduce the target tracking error, a target acceleration compensator should be used, and the target acceleration compensator is the same as the "Feedforward Controller" concept and uses a PID controller. The expression of the control value u(t) is expressed by the following equation.

$$u(t) = K_P e + K_I \int e dt + K_D \frac{de}{dt}$$

where K_P, K_D and K_I mean proportional gain, derivative gain and integral gain, respectively.

In order to achieve the optimum performance of the PID, the control variable was properly set. From the above equation, in the closed loop state, we first remove K_D and K_I, and then increase K_P from a very small value, and then increase the value until the system response shows critical vibration. The remaining variables were set using the system characteristics that appear during critical vibration.

Proving tracking control performance is a measure of the precision of the RMS error. The target tracking acceleration and velocity error formula is given by the following equation, where X means velocity or acceleration.

$$\mathrm{RMS} = \sqrt{\frac{\sum_{i=1}^{n} \left(X_{target\_i} - X_{tracking\_i}\right)^2}{n}}$$

III. RESULTS AND ANALYSIS

Accurate modeling of vehicle crash propulsion must be prioritized in order to obtain results most similar to actual crash tests. In this technology development study, a simulator controller algorithm that inversely generates an acceleration signal generated in a vehicle collision situation is presented.

Labview can see that this approach, which is based on the design of the PID control circuit, which is well known as the nonlinear feedback control design and the closed loop controller, is well applied to the system with bandwidth. As a result of the simulation, the initial acceleration and vibration problem can be solved by adjusting the initial brake pressure. As an additional supplement, valve delay compensation and speed error compensation are required.

Figure 6 shows a picture of the servo actuator test equipment. To track and control the acceleration and pressure profiles using the manufactured crash test equipment, use the AMESim program to connect to LabVIEW to obtain experimental data. In the current system, if only used as a pressure controller, an open circuit can be used, and if an acceleration and speed control loop is used, a closed circuit can be used. In PID control, the loop was run at an execution speed of 2.2msec, and the control gain values were used.

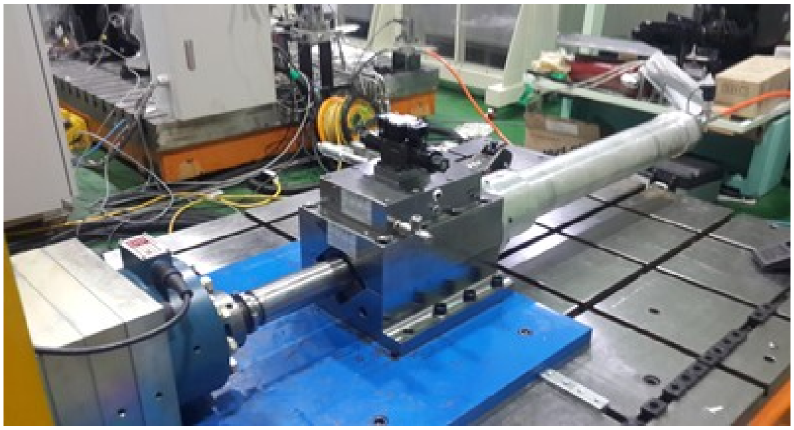
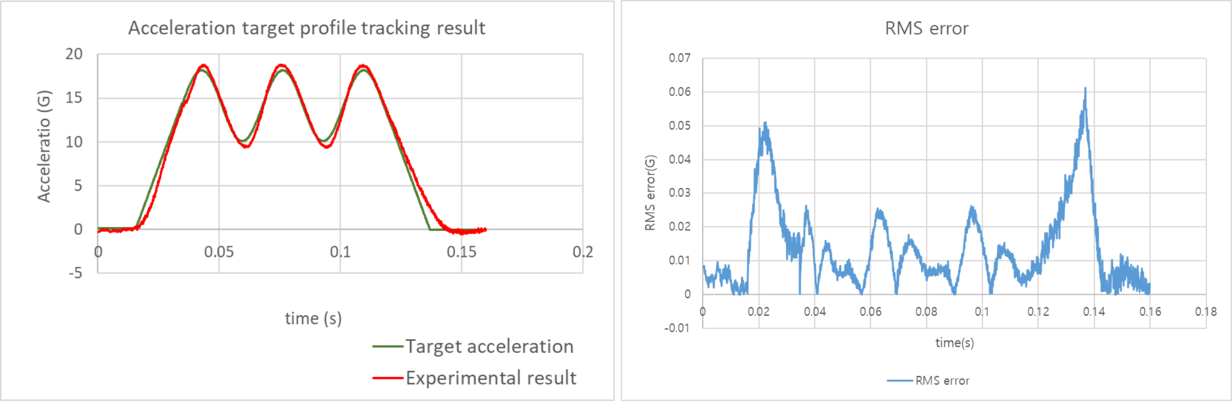


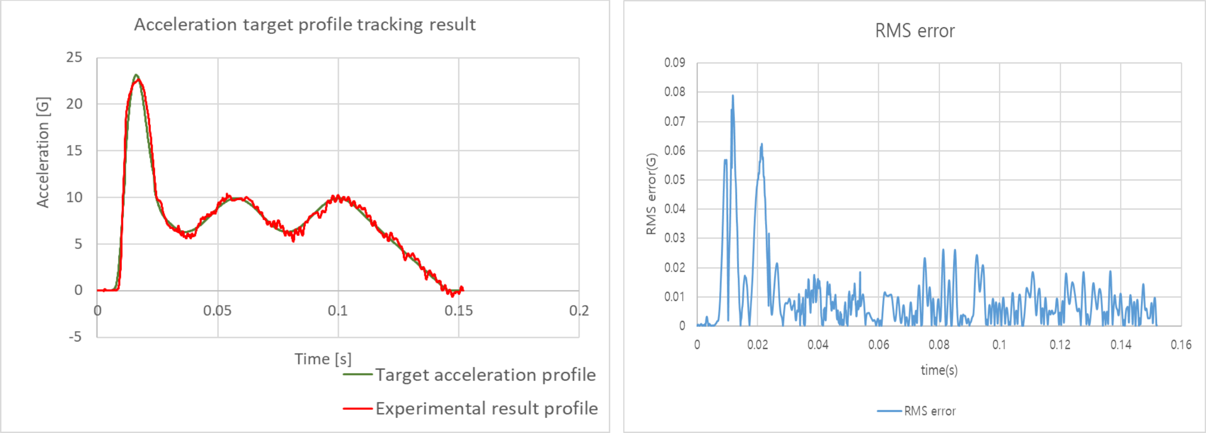
Figure 6. A Picture of the Servo Actuator Test Equipment

In the experiment, it is important to control the hydraulic brake pressure of the actuator because the actuator accelerates very quickly in a very short time. Figure 7, 8, and 9 show the actual measurement curves tracking the target acceleration profile and RMS error curve for various target curve shapes. It is necessary to try the control gain adjustment method in order to minimize the error of the tracking curves. The PID gains are 0.15, 0.0025, and 0.0001, respectively, to obtain the smallest RMS error by controlling the acceleration of the piston. From these figures, it is shown that various types of acceleration target curves are tracked relatively well.



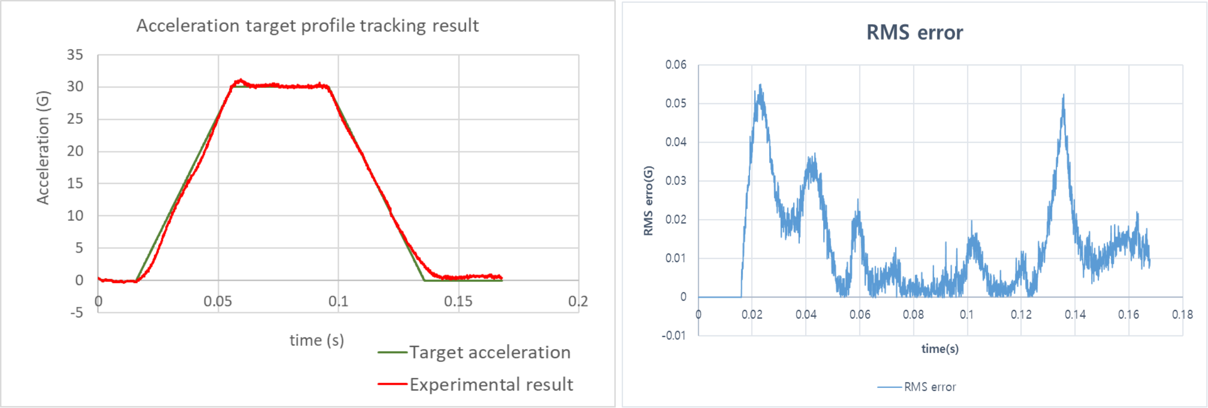
(a) (b)

Figure 7. (a) Tracking Target Acceleration Profile (b) RMS error at P=0.15, I=0.0025, D=0.0001



(a) (b)

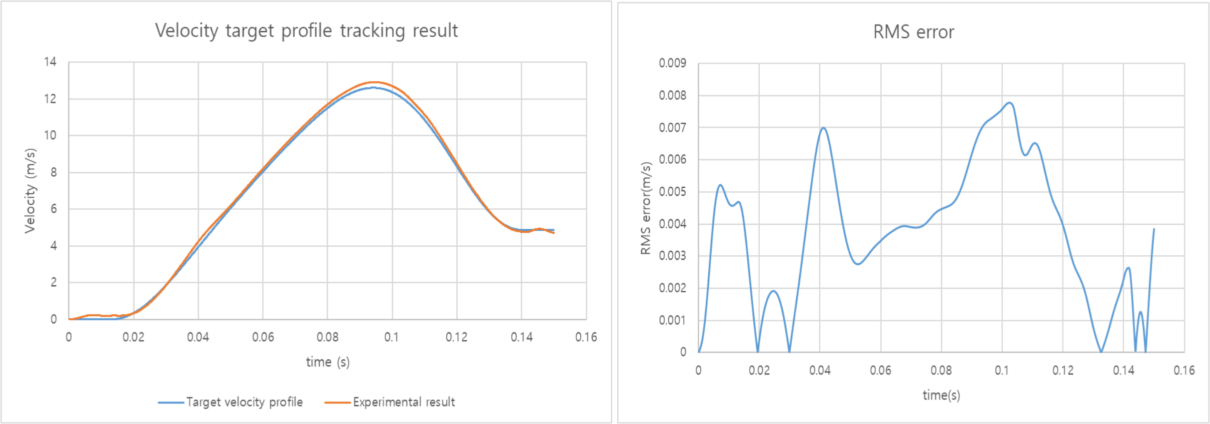
Figure 8. (a) Tracking Target Acceleration Profile (b) RMS error at P=0.15, I=0.0025, D=0.0001



(a) (b)

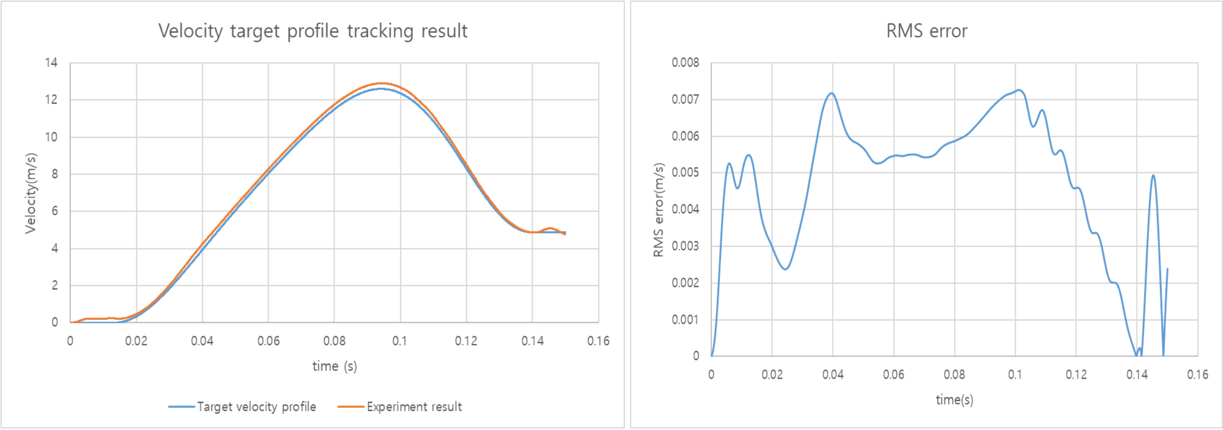
Figure 9. (a) Tracking Target Acceleration Profile (b) RMS error at P=0.15, I=0.0025, D=0.0001

Figure 10 and 11 show the actual measurement curve tracking the target velocity profile and RMS error curve. PID gain was measured by adjusting P=0.15, I=0.0025, D=0.0001, P=0.17, I=0.0009, and D=0.0, respectively, and the RMS error were 3.79×10^{-3}m/s and were 4.78×10^{-3}m/s. Thus it can be seen that the RMS error can be reduced by adjusting the PID gain.



(a) (b)

Figure 10. (a) Tracking Target Velocity Profile (b) RMS error at P=0.15, I=0.0025, D=0.0001



(a) (b)

Figure 11. (a) Tracking Target Velocity Profile (b) RMS error at P=0.15, I=0.0009, D=0.00

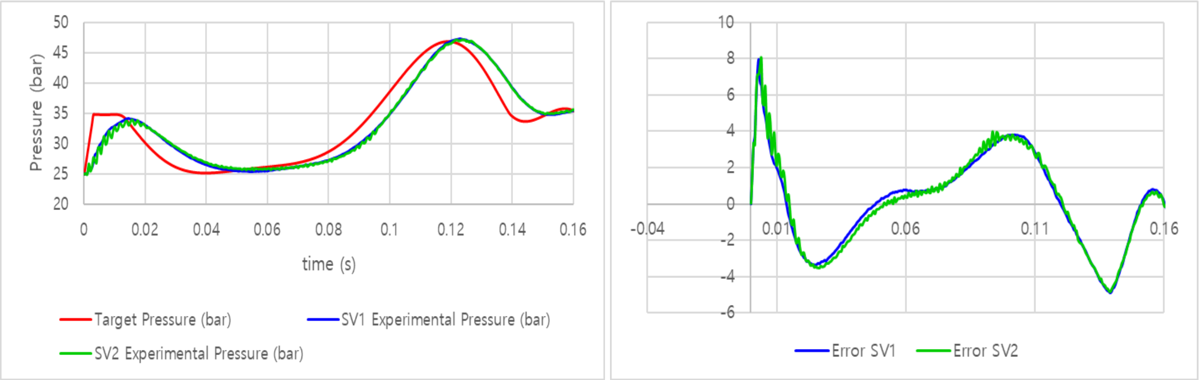
Figure 12 shows the target pressure profile tracking curve and RMS error curve using serve valve 1 and 2 without gain scheduling. On the other hand, Figure 13 shows a curve obtained using gain scheduling. As shown in the figure, the RMS error is reduced significantly when gain scheduling is used than when gain scheduling is not used.

Table 1 shows the RMS error when using two different servo valves depending on whether gain scheduling is used or not.

Table -1 RMS error of servo valve 1(SV1) and servo valve 2(SV2)

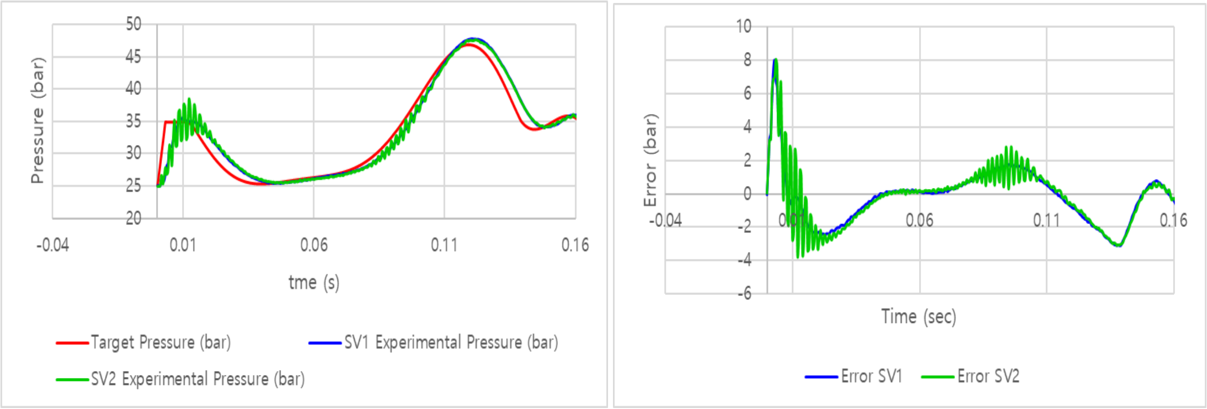
Item	Without gain scheduling	With gain scheduling
RMS Error SV1	**2.51 bar**	**1.64 bar**
RMS Error SV2	**2.62 bar**	**1.83 bar**

As shown in Table 1, the Moog D765 series servo valve(SV1) achieves better results than previous results achieved by the Moog G761 series servo valve(SV2) for pressure tracking. It means that RMS error is affected by the type of servo valve. Calibration of servo amplifier or pressure control algorithm should be checked in detail to increase performance of the servo valve. Then we expect better tracking results than we currently have.



(a) (b)

Figure 12. (a) Tracking Target Pressure Profile (b) RMS error at P=0.15, I=0.0025, D=0.0001 without gain scheduling



(a) (b)

Figure 13. (a) Tracking Target Pressure Profile (b) RMS error at P=0.15, I=0.0025, D=0.0001 with gain scheduling

IV.CONCLUSION

After conducting the test, some conclusions were drawn for the development of the crash test simulator.

1) The FPGA-based PID controller design is designed to enable test execution within approximately 0.3 sec. Thus, it was consistent with the assumption of system requirements.
2) The PID gain adjustment is related to the target tracking pressure, and the supply pressure of the servo valve also affects the PID gain selection.
3) The result of pressure compensation shows that target velocity graphs are almost same.
4) The RMS error is affected by the type of servo valve. Calibration of servo amplifier should be checked in detail to increase performance of the servo valve.
5) Servo actuators can be used as vehicle crash simulators to simulate crash motions.

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