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RTMD Servo Hydraulic System Acceptance Test

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by

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ABSTRACT

The results and findings in this report construct an acceptance criterion for the Real-Time Multi-Directional (RTMD) servo hydraulic systems which consist of two parts: Part I the servo actuator system and Part II the accumulator system.

The servo actuator system uses servo controller with traditional PID control and user-socket-implemented advanced control law to track and regulate the target displacement and force. Therefore its acceptance criterion is made to evaluate its static accuracy and dynamic bandwidth, as well as the power capacity. The tests are conducted subsequently and the conclusion is provide for this equipment.

The accumulator system uses gas bottles and hydraulic accumulators to store the hydraulic energy and release it when needed. Since it is an auxiliary hydraulic power supply equipment, its acceptance criterion is based on the power supply capacity, the dynamic interaction between accumulator pistons and servo valves, and pressure fluctuation. The test procedure is then elaborated and test result are provided with a conclusion summarizing the system features.

PART I

SERVO ACTUATOR SYSTEM ACCEPTANCE TEST

SERVOTEST ACCEPTANCE TEST PLAN

ACTUATOR AND CONTROLLER ACCEPTANCE TESTS

Table 1. Summary of Tests

Acceptance Test	Description of Test	Location of Test	380 kip [1695KN] Actuator	515 kip [2300KN] Actuator
Test 1	Displacement accuracy	Lehigh	0.2% accuracy	0.2% accuracy
Test 2	Displacement bandwidth	Lehigh	-3db@10Hz, ±0.15/0.3/0.45in	-3db@10Hz, ±0.15/0.3/0.45in
Test 3	High velocity accuracy	Lehigh	2% error @± 45 in/s [1.14 m/s]	2% error @ ±33 in/s [0.84 m/s]
Test 4	Maximum power output	Lehigh	2440 kip in/s [277kw]	2440 kip in/s [277kw]
Test 5	Pseudo dynamic functioning & User control algorithm implementation	Lehigh	Test 1, Test 2 Test 5.1, Test 5.2	Test 1, Test 2 Test 5.1, Test 5.2
Test 5.1	Force accuracy	Lehigh	0.2% accuracy	0.2% accuracy
Test 5.2	Force bandwidth	Lehigh	-3db@10Hz, ±224kip[±1000KN]	-3db@10Hz, ±298kip[±1333KN]

• For test 4 & 5 Lehigh will provide test rig.

Test 1: displacement control accuracy test

Purpose: Test displacement control accuracy, repeatability, and drift.

Procedure: Closed-loop, PID control, without load. Define actuator full travel range dmax as ±10%, ±20%, ±100% of the actuator maximum stroke (±500mm). The test cycle (Figure 1) shall be performed for 3 servo valve combinations (1, 1+2, 1+2+3), and for all 5 free-standing actuators (Figure 4).

Expectation: During the 10 seconds of holding, the maximum position error e_d should be $|e_d| < 0.2\%$ of actuator maximum stroke.

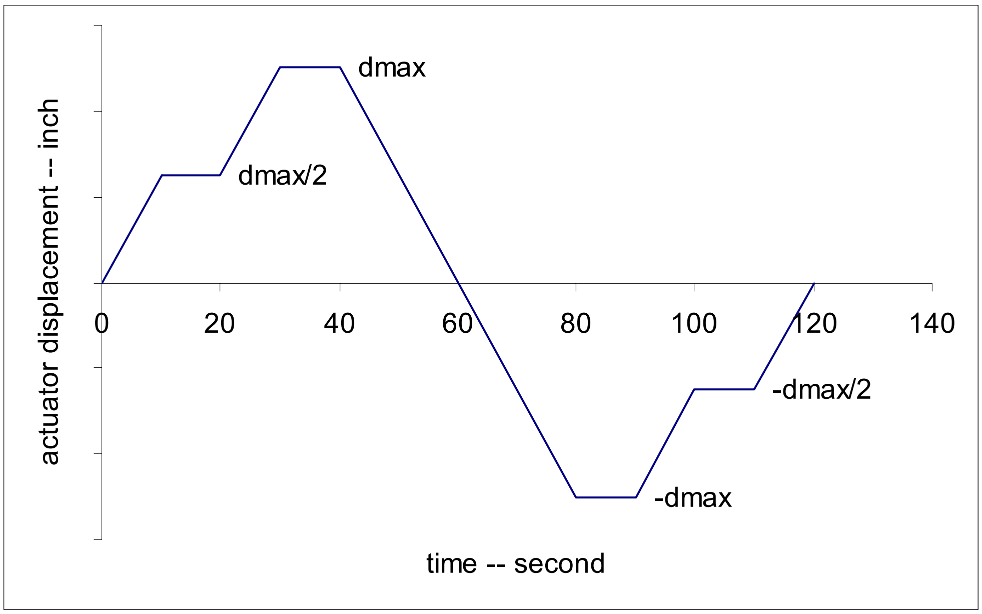


Figure 1. One test cycle for displacement control

Test 2: displacement control bandwidth test

Purpose: Test displacement control bandwidth.

Procedure: Closed-loop, PID displacement control, free standing actuator without load. Issue 5 seconds of a 10Hz sinusoid signal with magnitude of +/-0.15, 0.3 or 0.45 inches (according to valve combination) to achieve no less than -3db amplitude for displacement control. Test all five channels with 3 servo valve combinations (1, 1+2, 1+2+3). This should follow Test 1 with same setup (Figure 4).

Expectation: -3db@10Hz, ±0.15 in for 1 servovalve, ±0.3 in for 2 servovalves, ±0.45in for 3 servovalves.

Test 3: high velocity test

Purpose: Test high velocity capacity and system integrity.

Procedure: Closed-loop, PID position control with highest gain, without load. Displacement command follows the curve in Figure 2 (Table 2), which has a maximum velocity of ±45in/s [±1.14m/s], for the 380 kip [1695KN] actuator and in Figure 3 (Table 3), which has a maximum velocity of ±33in/s [±0.84m/s] for the 515kip [2300KN] actuator. This test will be performed for all 5 free-standing actuators (Figure 4).

Expectation:

(1) The maximum steady velocity error e_v should be $|e_v| < 2\%$ of 45in/s [1.14m/s] for a 380 kip [1695KN] actuator;

(2) The maximum steady velocity error e_v should be $|e_v| < 2\%$ of 33in/s [0.84m/s] for a 515kip [2300KN] actuator.

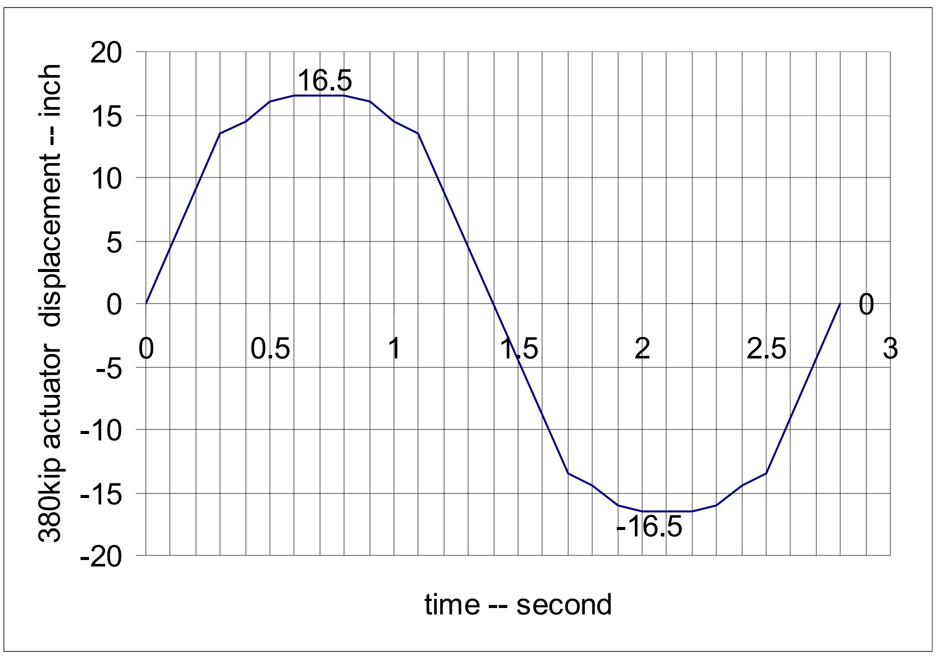


Figure 2. Displacement command for high velocity test of a 380 kip [1695KN] actuator

Table 2. 380kip actuator displacement vs. time relationship shown in Figure 2

Time (sec.)	0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.8
Disp. (inch)	0	13.5	14.5	16	16.5	16.5	16.5	16	14.5	13.5	-13.5	-14.5	-16	-16.5	-16.5	-16.5	-16	-14.5	-13.5	0

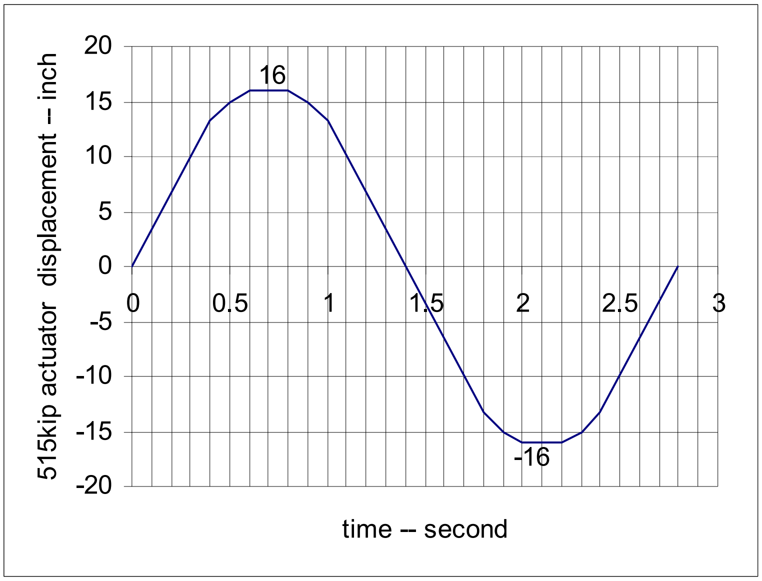


Figure 3. Displacement command for high velocity test for a 515kip [2300KN] actuator

Table 3. 515kip actuator displacement vs. time relationship shown in Figure 3

Time (sec.)	0	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.8
Disp. (inch)	0	13.2	15	16	16	16	15	13.2	-13.2	-15	-16	-16	-16	-15	-13.2	0

Figure 4. Free-standing servo actuator for Test 1, 2, and 3

Test 4: maximum power test

Purpose: Test maximum power output.

Procedure: Closed-loop, PID displacement control for the main actuator (Figure 5, left actuator), and PID force control for the load actuator (Figure 5, right actuator). The main actuator 380 kip [1695KN] (or 515 kip [2300KN]) holds a constant velocity of ±10.6 in/s [±0.27m/s] (or ±7.8 in/s [±0.2m/s]) while it pushes and drags the load actuator which simulates a load of ±224 kip [±1000KN] (or ±298 kip [±1333KN]). Detail velocity and force data are given in Figure 9 and Table 4 as well as Figure 10 and Table 5. In this way, the system power consumption reaches 2440 kip in/s [277kw]. Repeat the test cycle 3 times for all actuators.

Note: the main actuator and the load actuator are same type, and can be redefined during the test.

Expectation: Power output reaches 2440 kip in/s [277kw]. The velocity output at a servo actuator is force dependent: $V = V_{\max}\sqrt{1 - F/F_{\max}}$, as shown in Figure 11. When load reaches 2/3 of the load capacity, maximum power appears.

Figure 5. Test power with displacement actuator and load actuator

Test 5: SCRAMNet test

Purpose: Test pseudo dynamic functionality with the SCRAMNet interface between Servotest Systems Controller Computer and the Simulation Computer and User control algorithm implementation.

To make the test more efficient, the algorithm implemented in Sockets will be such that it can be used both in Displacement and Load control.

Lehigh to provide algorithm at the NEES simulation computer.

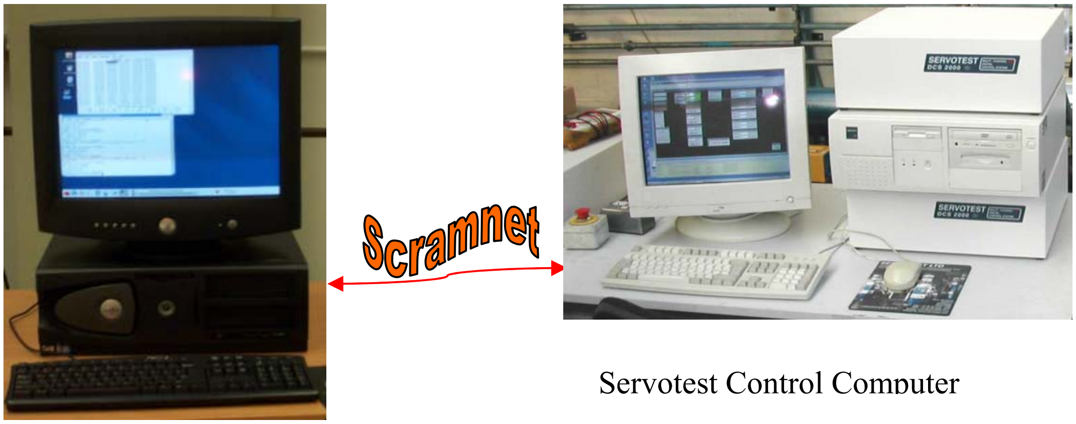
Procedure: Closed-loop, PID displacement and force control. For displacement control, the actuators are free-standing (Figure 4) while for force control the actuators are constrained at both ends (Figure 7). The issued command is dependent on the Simulation Computer, which receives force, velocity and displacement signals from the Controller Computer. The communication between these two computers (Figure 6) is through SCRAMNET to specify the command signal to the Controller Computer for each control step. The clock speed in the control shall be 1 ms. In addition to this, a user control algorithm will be implemented using the Servotest Systems Control Computer via Sockets. All channels are to be used concurrently. The test details are similar to those of Test 1 and Test 5.1, except all channels in Test 5 are tested only at a full range defined as 100% of the full actuator capacity. Test 2 and Test 5.2 shall also be performed.

Expectation:

Position error $|e_d| < 0.2\%$ of actuator maximum stroke;

Force error $|e_f| < 0.2\%$ of actuator maximum force.

-3db@10Hz, ±0.15 in for 1 servovalve, ±0.3 in for 2 servovalves, ±0.45in for 3 servovalves;
-3db@10Hz for 224 kip [1000KN amplitude], 298kip [1333KN amplitude].



Servotest Control Computer

NEES Simulation Computer

Figure 6. SCRAMNet test at Test 5 (with servo-hydraulics on)

<u>Test 5.1: force control accuracy test</u>

Purpose: Test force control accuracy, and drift.

Procedure: Closed-loop, PID control, actuator constrained at both end (Figure 7). Define actuator full load range fmax as ±5%, ±20%, ±100% of the actuator maximum load capacity 380 kip [1695KN] or 515kip [2300KN]. The test cycle (Figure 8) shall be performed for 3 servo valve combinations (1, 1+2, 1+2+3), and for 2 actuators (one of each type).

Expectation: During the 10 seconds of holding, the maximum force control error e_f should be $|e_f| <$ 0.2% of actuator maximum force.

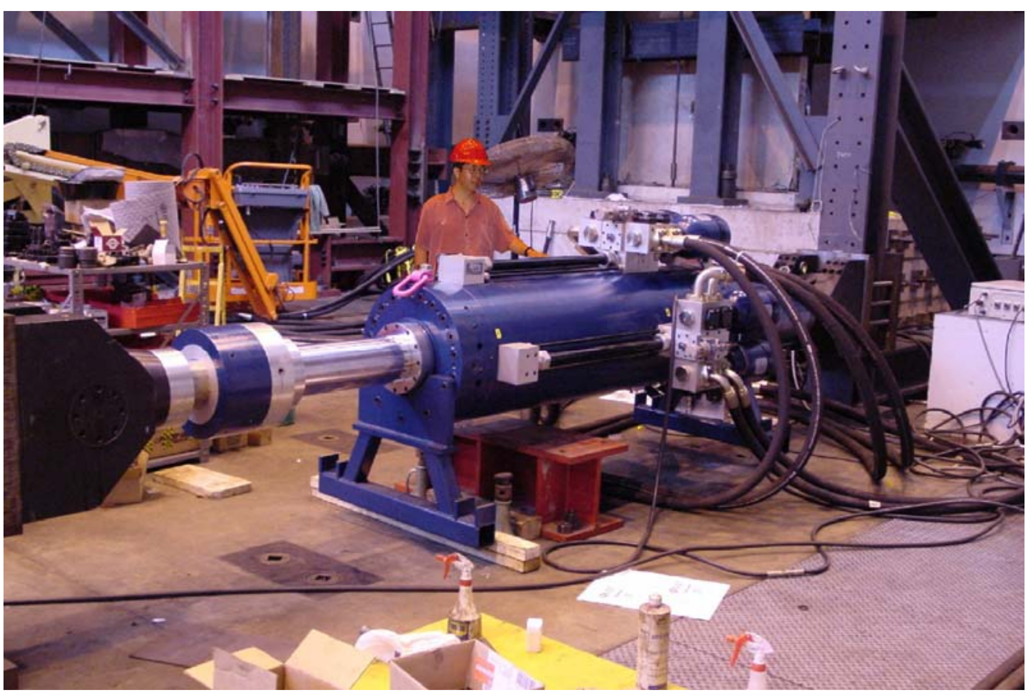


Figure 7. Force control setup for Test 5.1 and Test 5.2

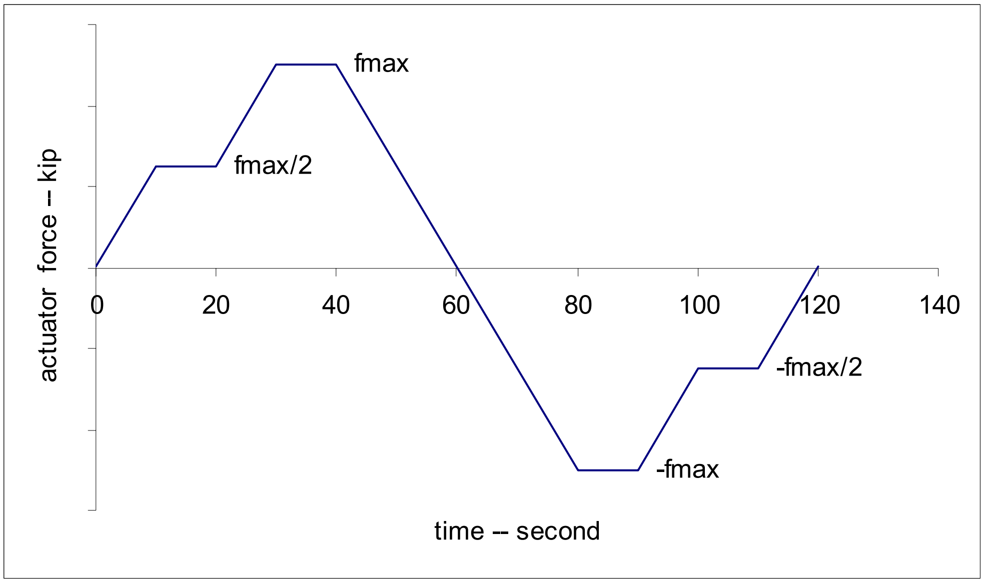


Figure 8. One test cycle for force control

Test 5.2: force control bandwidth test

Purpose: Test force control bandwidth.

Procedure: Closed-loop, PID force control, actuator acting against reaction frame as shown in Figure 7. Issue 5 seconds of a 10Hz sinusoid signal with amplitude of 224kip [1000KN] for the 380kip [1695KN] actuator and 298kip [1333KN] for the 515kip [2300KN] actuator to achieve no less than -3db amplitude for force control. Test two channels (one of each actuator type) with all 3 servo valve combinations(1, 1+2, 1+2+3). This test follows Test 5.1.

Expectation: -3db@10Hz for 224 kip [1000KN amplitude], 298kip [1333KN amplitude].

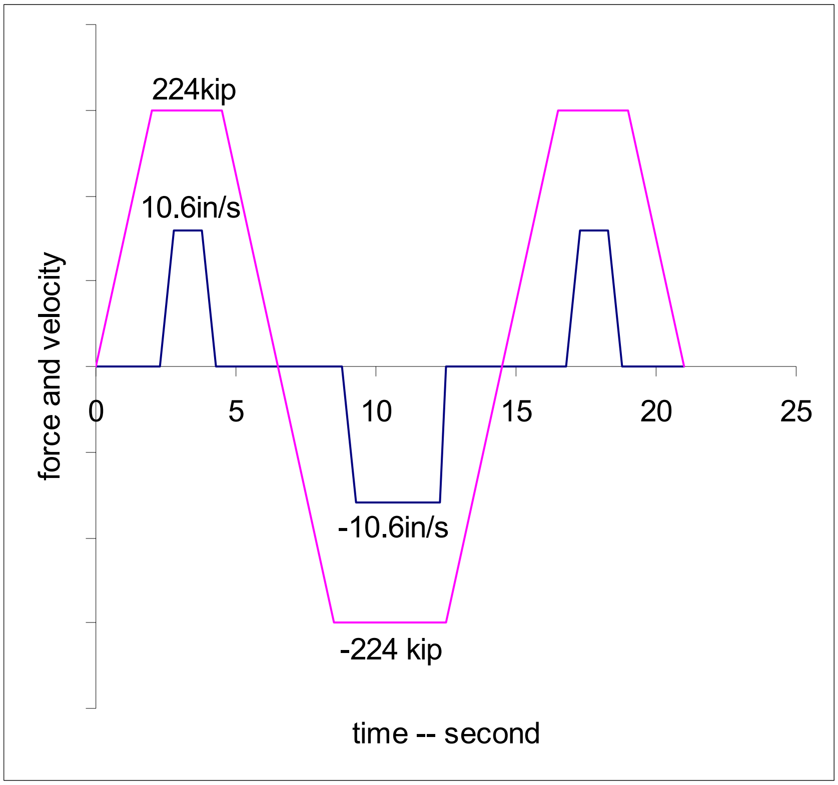


Figure 9. Force and velocity command for power test of 380 kip [1695KN] actuator

Table 4. Velocity vs. time and force vs. time relationships shown in Figure 9

Time (sec.)	0	2.25	2.75	3.75	4.25	6.5	8.75	9.25	11.75	12.25	14.5	16.75	17.25	18.25	18.75	21
Velo. (in/s)	0	0	10.6	10.6	0	0	0	-10.6	-10.6	0	0	0	10.6	10.6	0	0
Force (kip)	0	224	224	224	224	0	-224	-224	-224	-224	0	224	224	224	224	0

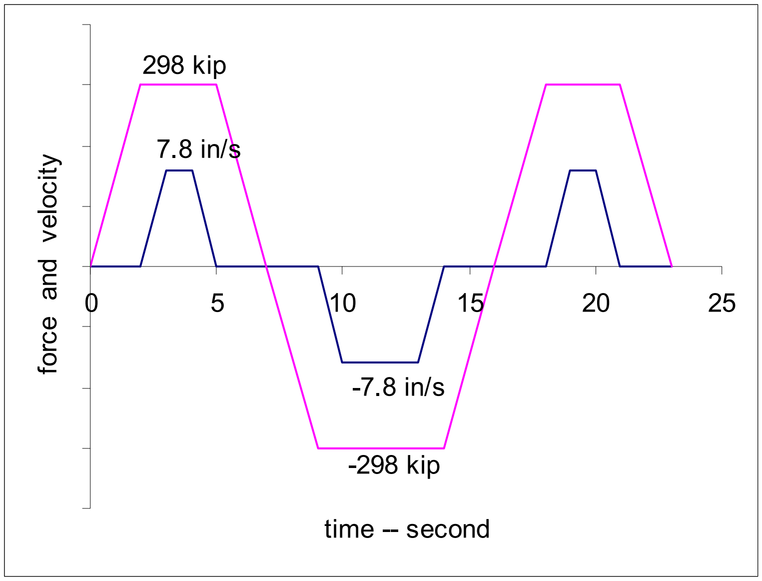


Figure 10. Force and velocity command for power test of 515 kip [2300KN] actuator.

Table 5. Velocity vs. time and force vs. time relationships shown in Figure 10

Time (sec.)	0	2	3	4	5	7	9	10	13	14	16	18	19	20	21	23
Velo. (in/s)	0	0	7.8	7.8	0	0	0	-7.8	-7.8	0	0	0	7.8	7.8	0	0
Force (kip)	0	298	298	298	298	0	-298	-298	-298	-298	0	298	298	298	298	0

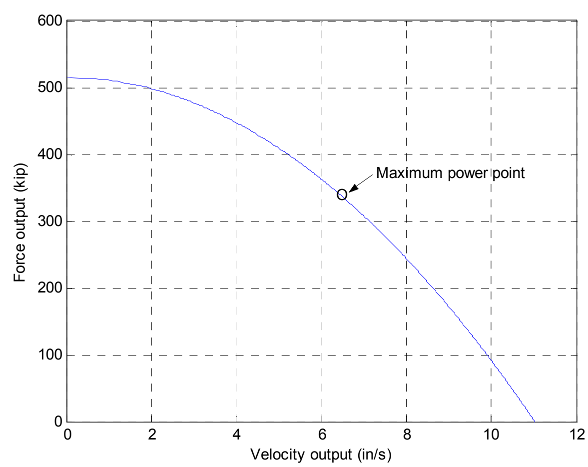


Figure 11. Force and velocity output for the 515kip actuator with single servo valve

SERVOTEST ACCEPTANCE TEST RESULT

Actuator 1

1.1 0.2% displacement accuracy test (travel range: ±500mm)

1.1.1 10% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±50mm displacement control on Actuator 1 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/26/2004

Servo Control Parameter
Configuration--1 valve A PID control at actuator 1
PID control-- Kp=40; Ki=10; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; (B: 0.00; K: 0.0)
Servo valve offset – A: 0.0; (B: 0.0; K: 0.469)
Servo valve spool zero – A: 0.0; (B: 0.0; K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 1.1.1.1.

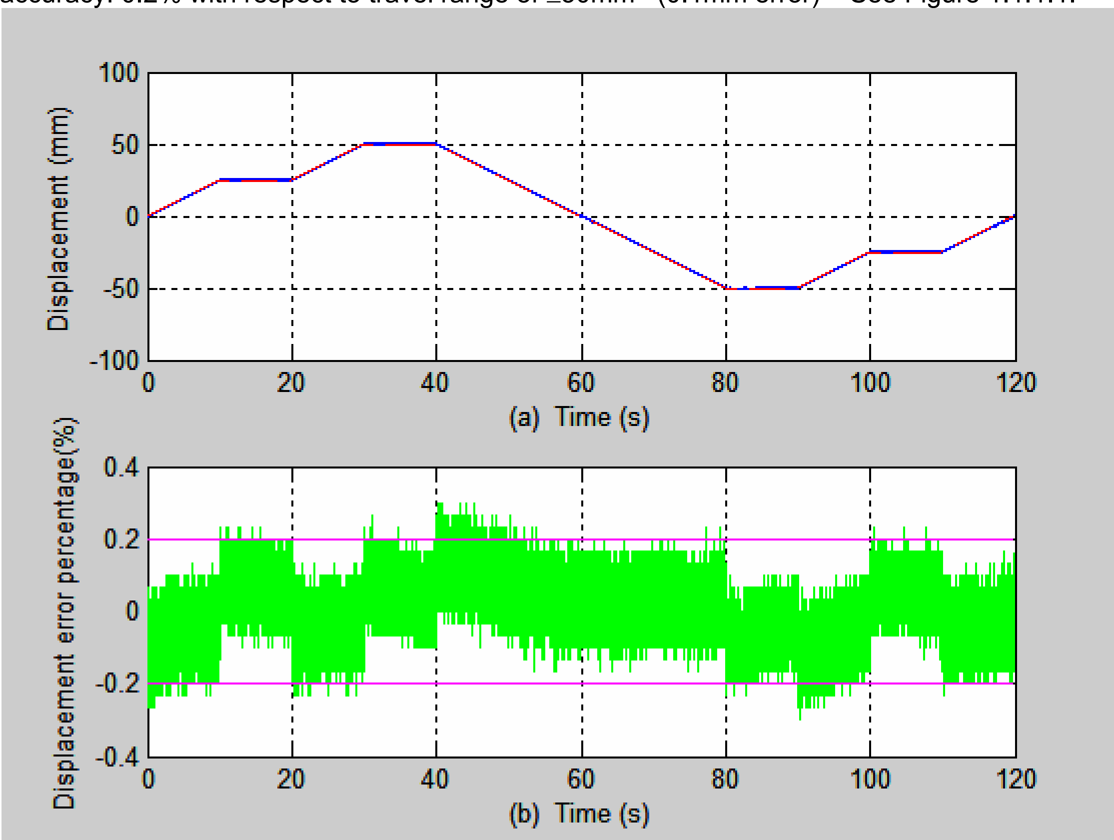


Figure 1.1.1.1. 10% stroke accuracy test at Actuator 1 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 1 (2 valves)

Servotest Systems Ltd: Paul Murdoch

Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/26/2004

Servo Control Parameter
Configuration--2 valve AB PID control at actuator 1
PID control-- Kp=20; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (K: 0.0)
Servo valve offset – A: 0.0; B: 0.0; (K: 0.469)
Servo valve spool zero – A: 0.0; B: 0.0; (K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 1.1.1.2.

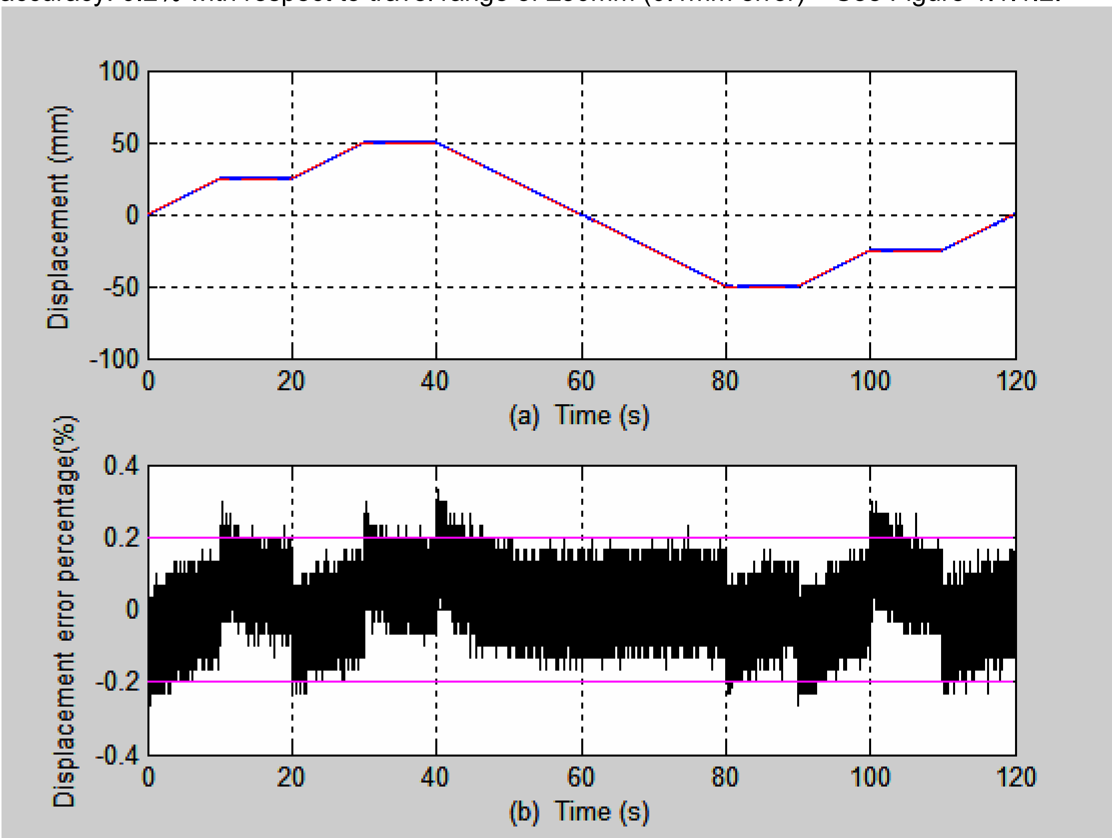


Figure 1.1.1.2. 10% stroke accuracy test at Actuator 1 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 1 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/26/2004

Servo Control Parameter
Configuration--3 valve ABK PID control at actuator 1
PID control-- Kp=15; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; K: 0.88

Servo valve offset – A: 0.0; B: 0.0; K: 0.469
Servo valve spool zero – A: 0.0; B: 0.0; K: 0.00
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 1.1.1.3.

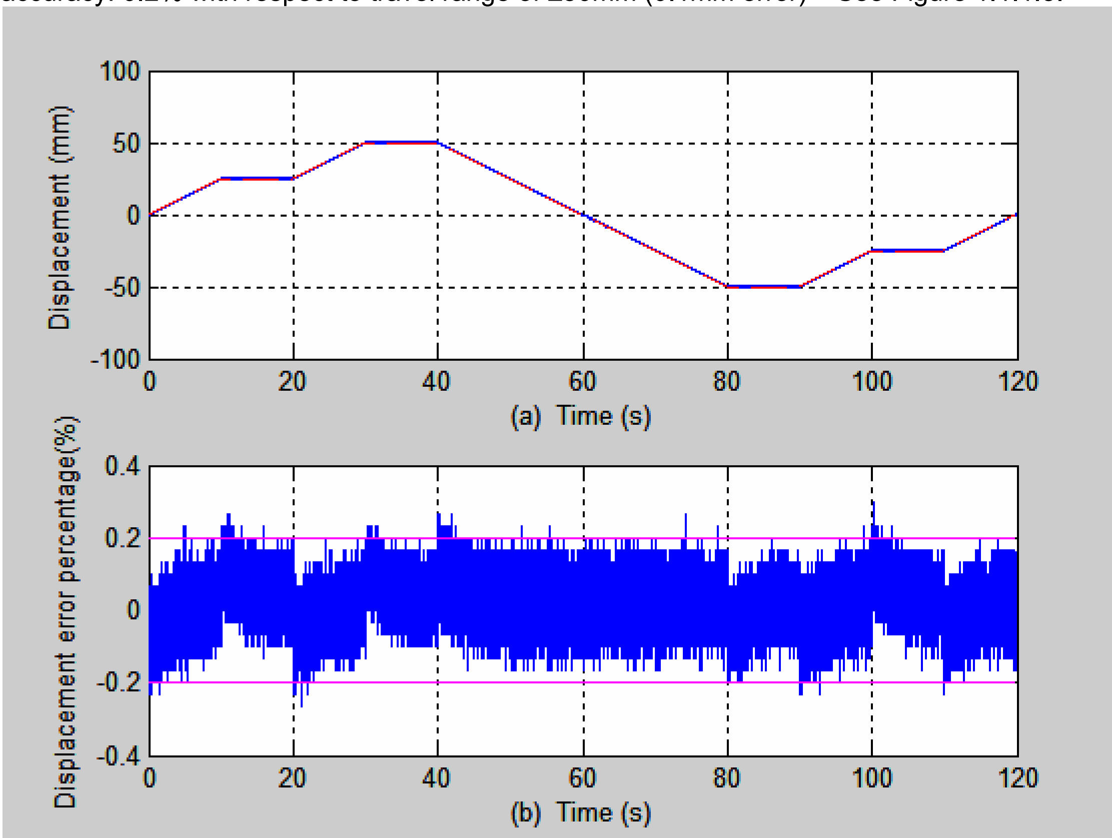


Figure 1.1.1.3.   10% stroke accuracy test at Actuator 1 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

1.1.2 20% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±100mm displacement control on Actuator 1 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/25/2004

Servo Control Parameter
Configuration--1 valve A PID control at actuator 1
PID control-- Kp=40; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; (B: 0.0; K: 0.0)
Servo valve offset – A: 0.0; (B: 0.0; K: 0.469)
Servo valve spool zero – A: 0.0; (B: 0.0; K: 0.00)

Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±100mm (0.2mm error) – See Figure 1.1.2.1.

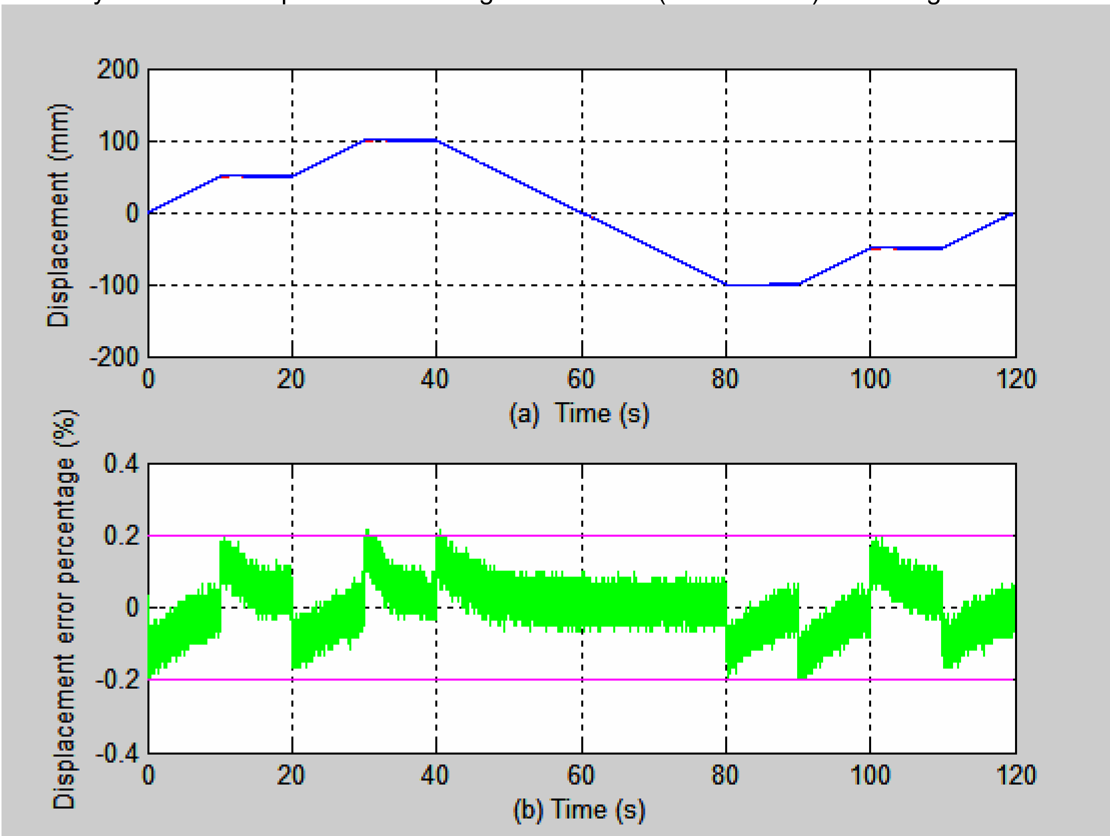


Figure 1.1.2.1. 20% stroke accuracy test at Actuator 1 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 1 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/26/2004

Servo Control Parameter
Configuration--2 valve AB PID control at actuator 1
PID control-- Kp=20; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (K: 0.0)
Servo valve offset – A: 0.0; (B: 0.0; K: 0.469)
Servo valve spool zero – A: 0.0; B: 0.0; (K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±100mm (0.2mm error) – See Figure 1.1.2.2.

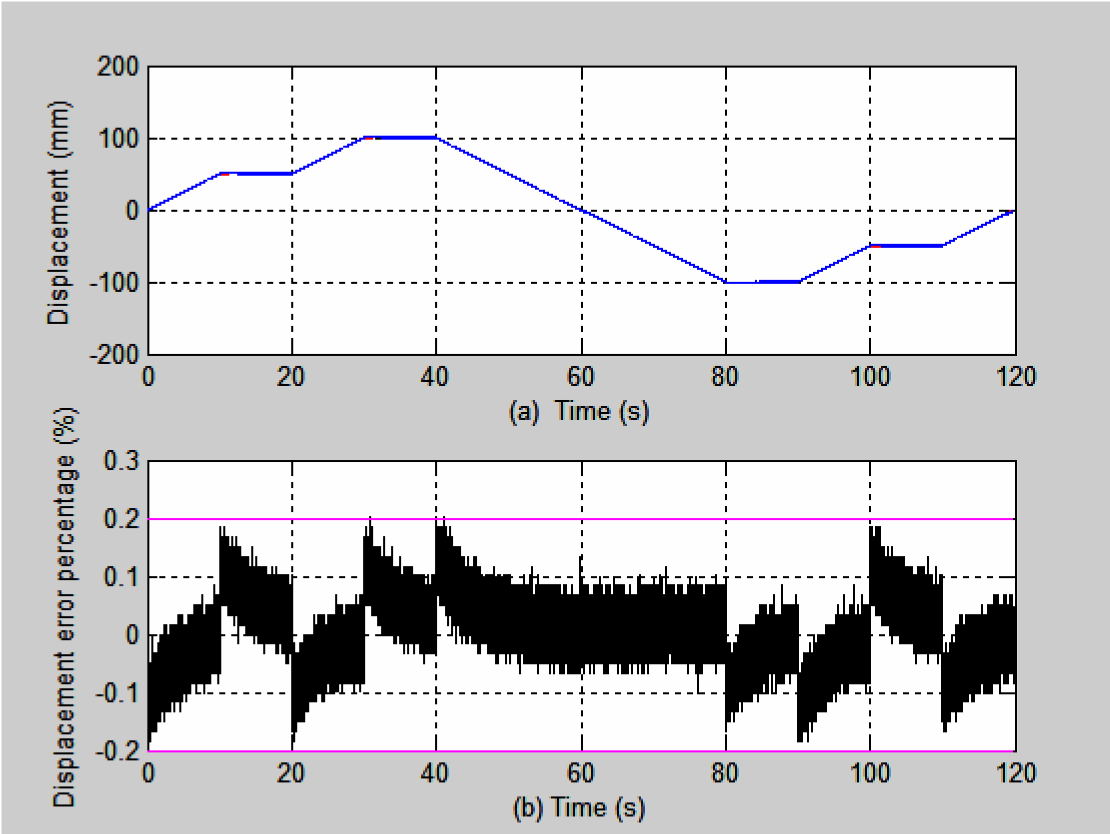


Figure 1.1.2.2. 20% stroke accuracy test at Actuator 1 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 1 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/26/2004

Servo Control Parameter
Configuration--3 valve ABK PID control at actuator 1
PID control-- Kp=15; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; K: 0.88
Servo valve offset – A:0.0; B: 0.0; K: 0.469
Servo valve spool zero – A: 0.0; B: 0.0; K: 0.00
Hydraulic supply pressure: 3000psi

Test result
Static accuracy:0.18% with respect to travel range of ±100mm (0.18mm error)–See Figure 1.1.2.3.

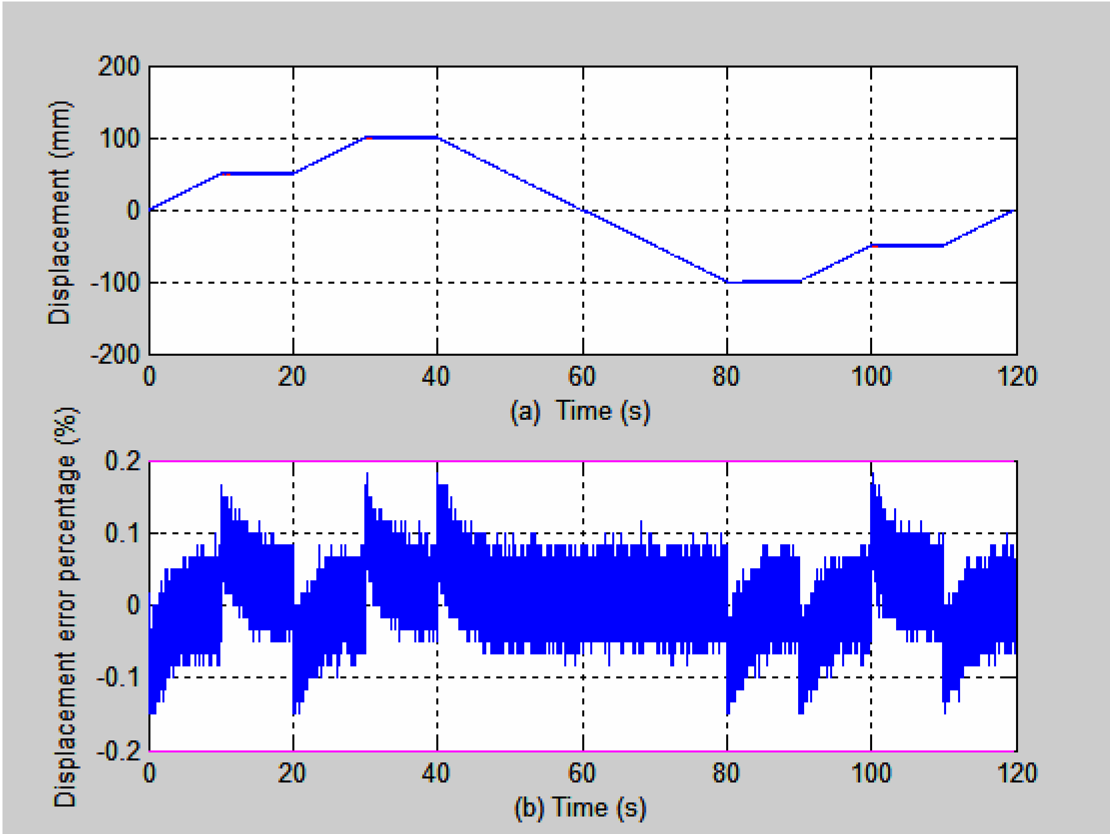


Figure 1.1.2.3. 20% stroke accuracy test at Actuator 1 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

1.1.3 100% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±500mm displacement control on Actuator 1 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/25/2004

Servo Control Parameter
Configuration--1 valve A PID control at actuator 1
PID control-- Kp=40; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; (B: 0.00; K: 0.0)
Servo valve offset – A: 0.0; (B: 0.0; K: 0.469)
Servo valve spool zero – A: 0.0; (B: 0.0; K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.18% with respect to travel range of ±500mm (0.9mm error)– See Figure 1.1.3.1.

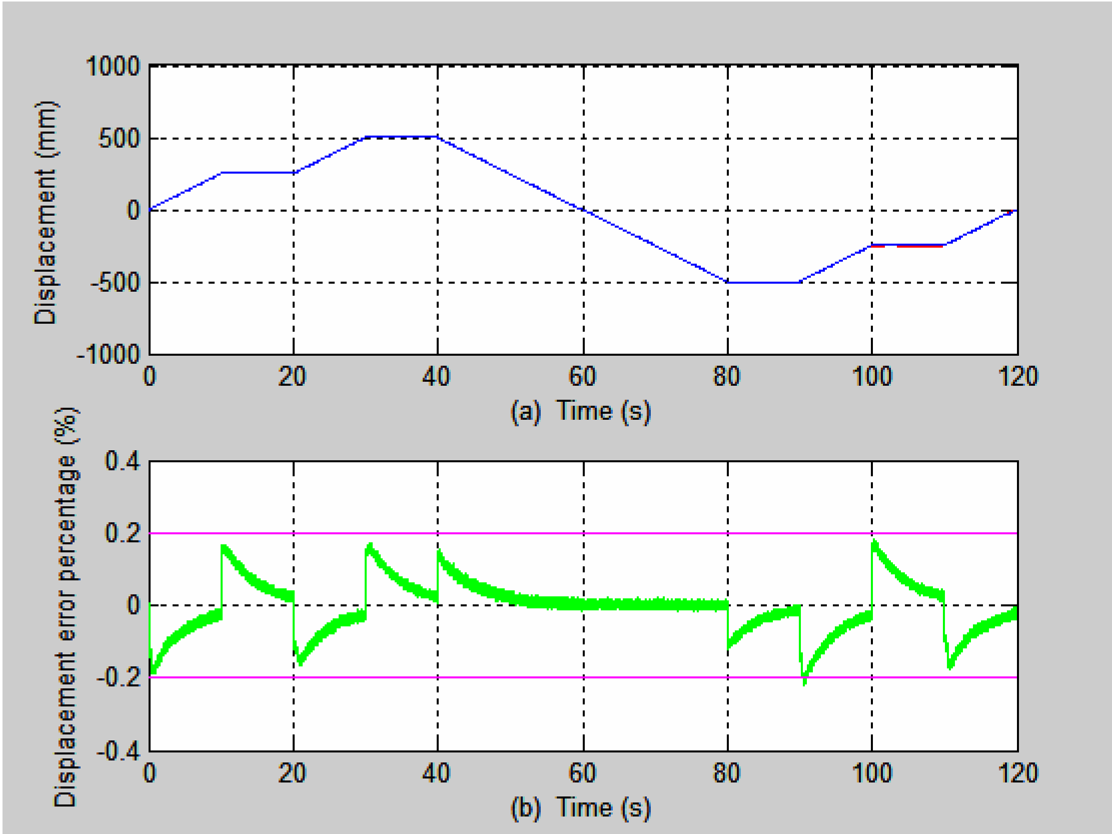


Figure 1.1.3.1. 100% stroke accuracy test at Actuator 1 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 1 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/26/2004

Servo Control Parameter
Configuration--2 valve AB PID control at actuator 1
PID control-- Kp=20; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (K: 0.0)
Servo valve offset – A: 0.0; B: 0.0; (K: 0.469)
Servo valve spool zero – A: 0.0; B: 0.0; (K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy:0.13% with respect to travel range of ±500mm (0.65mm error)–See Figure 1.1.3.2.

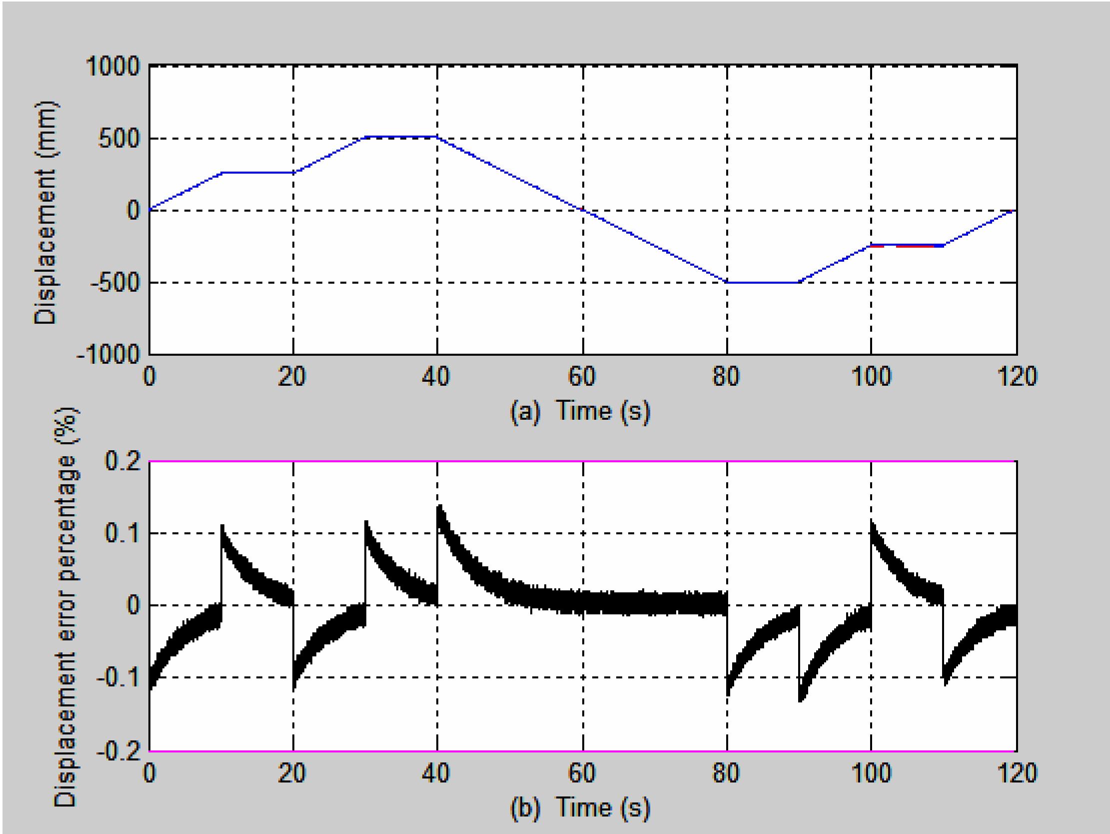


Figure 1.1.3.2. 100% stroke accuracy test at Actuator 1 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 1 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/26/2004

Servo Control Parameter
Configuration--3 valve ABK PID control at actuator 1
PID control-- Kp=15; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; K: 0.88
Servo valve offset – A:0.0; B: 0.0; K: 0.469
Servo valve spool zero – A: 0.0; B: 0.0; K: 0.00
Hydraulic supply pressure: 3000psi

Test result
Static accuracy:0.12% with respect to travel range of ± 500mm (0.6mm error)– See Figure 1.1.3.3.

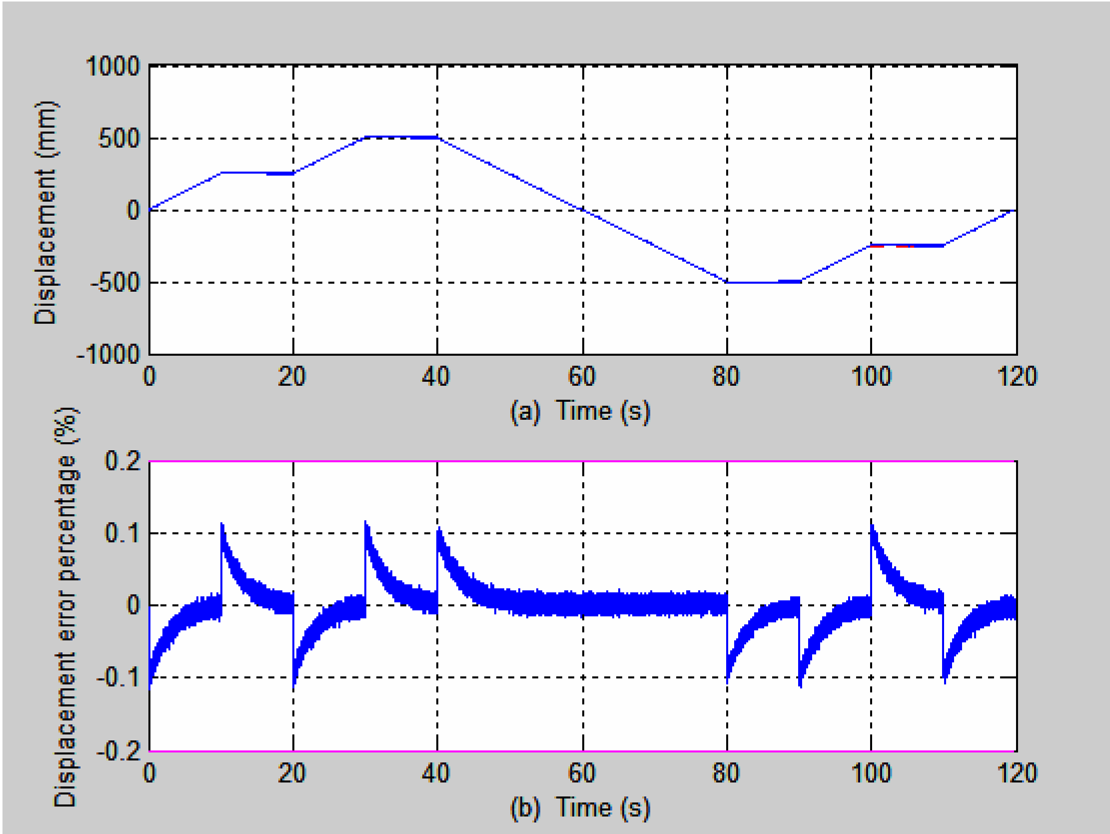


Figure 1.1.3.3. 100% stroke accuracy test at Actuator 1 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

1.1.4 SCRAMNet 100% travel range displacement accuracy test (3 valves)

- Test task: SCRAMNet ±500mm displacement control on Actuator 1 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/27/2004

Servo Control Parameter
Configuration – 3 valve ABK PID control at actuator 1
PID control – Kp=15; Ki=3; Kd =0
Servo valve loop gain – Kv=30
Servo valve input scale – A: 0.87; B: 1.00; K: 0.88
Servo valve offset – A:0.0; B: 0.0; K: 0.469
Servo valve spool zero – A: 0.0; B: 0.0; K: 0.00
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.1% with respect to travel range of ± 500mm (0.5mm error) – See Figure 1.1.4.1.

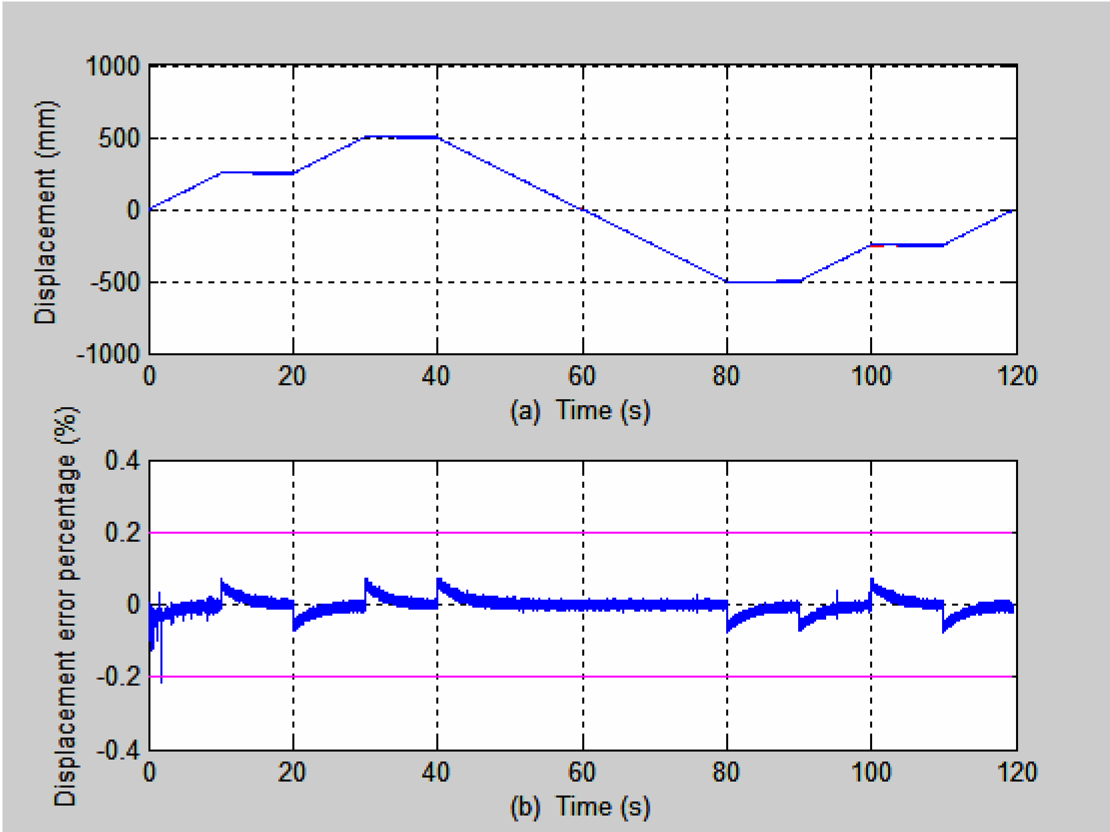


Figure 1.1.4.1. SCRAMNet 100% stroke accuracy test at Actuator 1 (Test 5 -Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Blue: error percentage; Magenta: error boundary ±0.2%

1.2 10Hz displacement bandwidth test

1.2.1 ±3.81mm@10Hz sinusoid with 1valve operation

- Test task: Sinusoid displacement control on Actuator 1 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/25/2004

Servo Control Parameter
Configuration --1 valve A PID control at actuator 1
PID control -- Kp=60 Ki=5 Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; (B: 0.0; K: 0.0)
Servo valve offset – A: 0.0; (B: 0.0; K: 0.469)
Servo valve spool zero – A: 0.0; (B: 0.0; K: 0.00)
Hydraulic supply pressure – 3000psi
Hydraulic supply flow rate – 310gpm

Test result
Dynamic bandwidth: 10Hz@0.15inch (19% attenuation, less than 3 db) – See Figure 1.2.1.1.

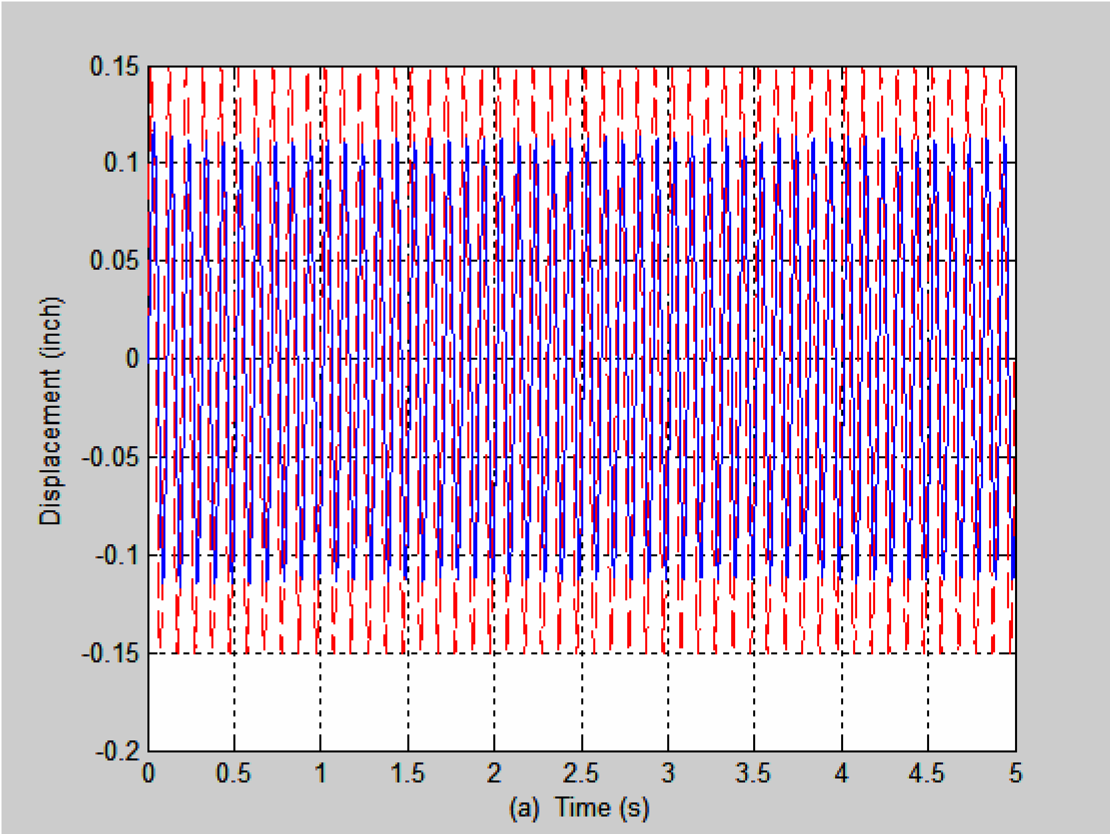


Figure 1.2.1.1. Dynamic bandwidth test at Actuator 1 (Test 2: 1 vale)
Red: command (0.15inch@10Hz); Blue: response (0.11inch@10Hz)

1.2.2 ±7.62mm@10Hz sinusoid with 2 valve operation

- Test task: Sinusoid displacement control on Actuator 1 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/26/2004

Servo Control Parameter
Configuration --2 valve AB PID control at actuator 1
PID control -- Kp=35; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (K: 0.0)
Servo valve offset – A: 0.0; B: 0.0; (K: 0.469)
Servo valve spool zero – A: 0.0; B: 0.0; (K: 0.00)

Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 620gpm

Test result
Dynamic bandwidth: 10Hz@0.30inch (15% attenuation, less than 3 db) – See Figure 1.2.2.1.

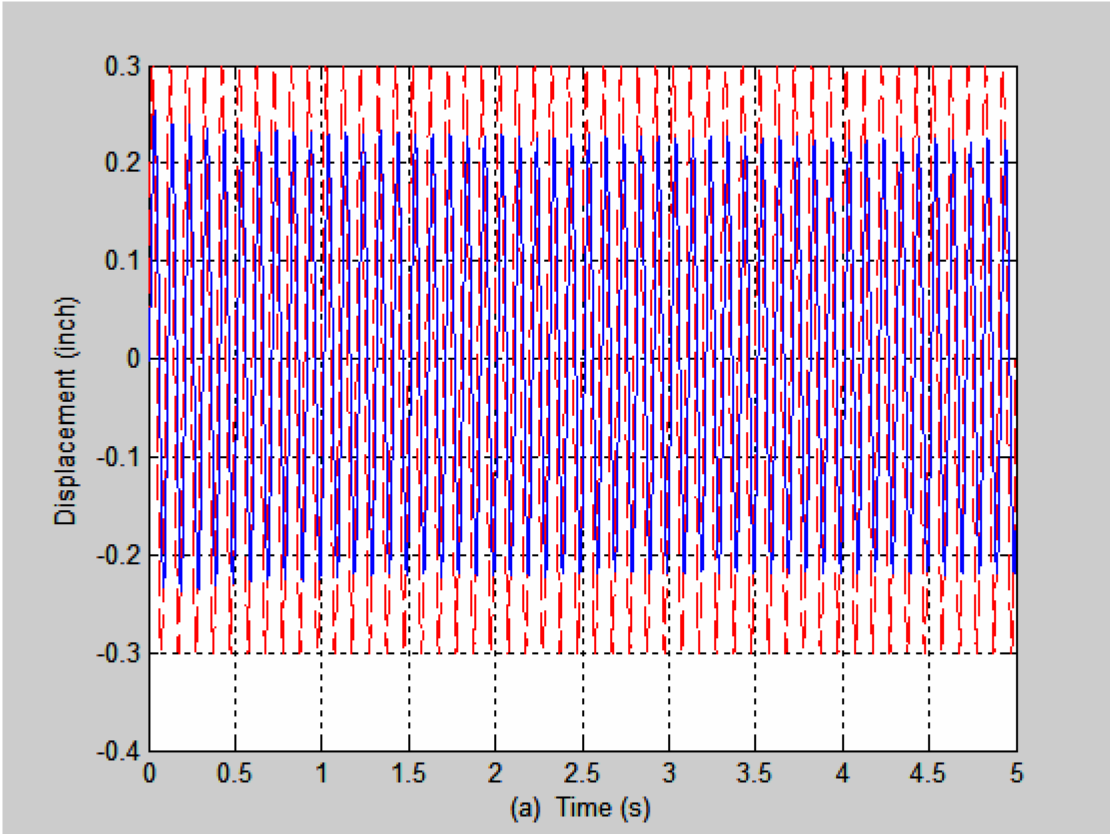


Figure 1.2.2.1. Dynamic bandwidth test at Actuator 1 (Test 2: 2 vales)
Red: command (0.30inch@10Hz); Blue: response (0.22inch@10Hz)

1.2.3 ±11.43mm@10Hz sinusoid with 3 valve operation

- Test task: Sinusoid displacement control on Actuator 1 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/27/2004

Servo Control Parameter
Configuration – 3 valve ABK PID control at actuator 1
PID control – Kp=23; Ki=3; Kd =0
Servo valve loop gain – Kv=30
Servo valve input scale – A: 0.87; B: 1.00; K: 0.88
Servo valve offset (%) – A: 0.0; B: 0.0; K: 0.469
Servo valve spool zero (%) – A: 0.0; B: 0.0; K: 0.00
Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 930gpm

Test result
Dynamic bandwidth: 10Hz@0.45inch (16% attenuation, less than 3 db) – See Figure 1.2.3.1.

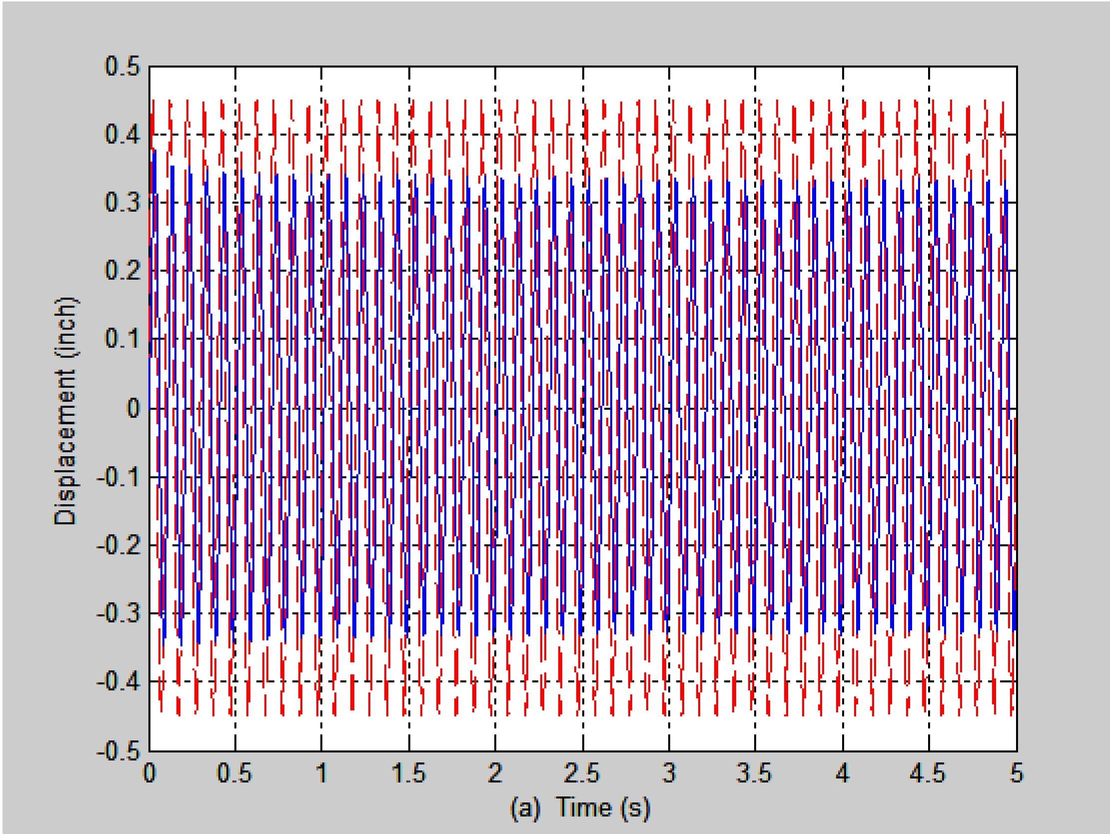


Figure 1.2.3.1. Dynamic bandwidth test at Actuator 1 (Test 2: 3 valves)
Red: command (0.45inch@10Hz); Blue: response (0.32inch@10Hz)

1.2.4 SCRAMNet ±11.43mm@10Hz sinusoid with 3 valve operation

- Test task: SCRAMNet Sinusoid displacement control on Actuator 1 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 5/27/2004

Servo Control Parameter
Configuration –3 valve ABK PID control at actuator 1
PID control – Kp=23; Ki=3; Kd =0
Servo valve loop gain – Kv=30
Servo valve input scale – A: 0.87; B: 1.00; K: 0.88
Servo valve offset (%) – A: 0.0; B: 0.0; K: 0.469
Servo valve spool zero (%) – A: 0.0; B: 0.0; K: 0.00
Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 930gpm

Test result
Dynamic bandwidth: 10Hz@0.45inch (21% attenuation, less than 3 db) – See Figure 1.2.4.1.

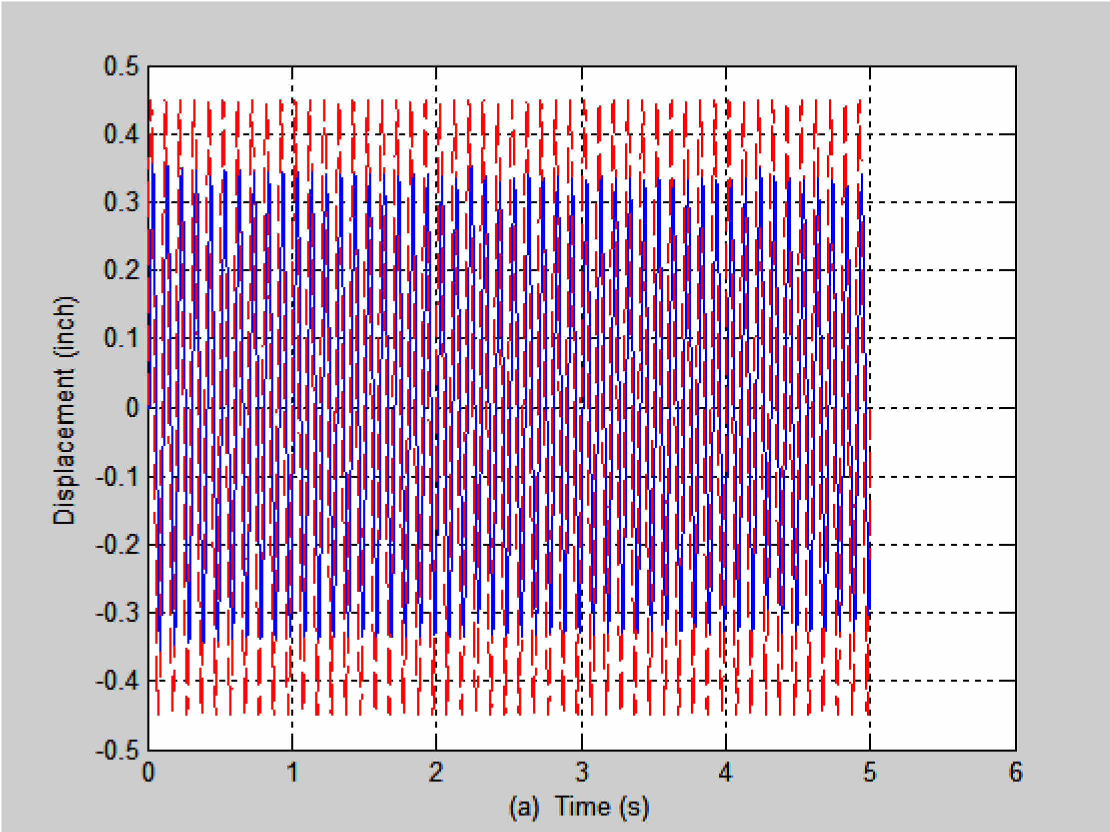


Figure 1.2.4.1. SCRAMNet dynamic bandwidth test at Actuator 1 (Test 5 - Test 2: 3 valves)
Red: command (0.45inch@10Hz); Blue: response (0.32inch@10Hz)

1.3 1.14m/s high velocity test

- Test task: High velocity test on Actuator 1 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/19/2004

Servo Control Parameter
Configuration--3 valve ABG PID control at actuator 1
PID control – Kp=45; Ki=2; Kd =0; f=39.8Hz
Servo valve loop gain – Kv=30
Servo valve input scale – A: 0.87; B: 1.00; G: 1.0
Servo valve offset (%) – A: 00.938; B: 0.0; G: -1.25
Servo valve spool zero (%) – A: 1.953; B: 3.516; G: -1.016
Hydraulic supply pressure: 3400psi
Hydraulic supply flow rate: 1500gpm

Test result: Speed reaches 1.14 m/s – See Figures 1.3.1.

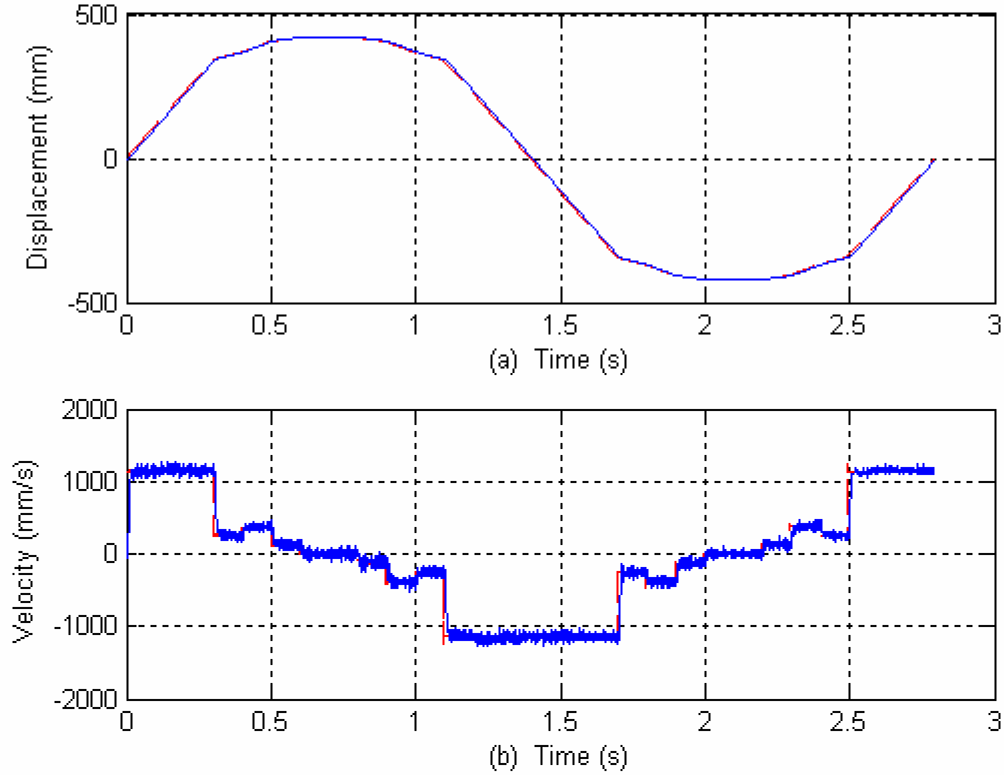


Figure 1.3.1. High velocity test at Actuator 1 (Test 3)
(a) Displacement (mm) – Red: command; Blue: response
(b) Velocity (mm/s) -- Red: command; Blue: response

1.4 277KW power test with single valve operation (0.27m/s@1000KN)

- Test task: Power test on Actuator 1 (1 valve, against Load Actuator 2)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/11/2004

Servo Control Parameter
Configuration:
1 valve A displacement PID control at Actuator 1
1 valve C load PID control at Actuator 2
Actuator 1 displacement PID control-- Kp=45; Ki=2; Kd =0.1; f=39
Actuator 2 load PID control-- Kp=2; Ki=3; Kd =-1; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; C:0.87; (COM)
Servo valve offset (%) – A: -2.031; C: 1.406 (COM)
Servo valve spool zero (%) – A: -0.703; C: 0.703
Servo valve offset (%) – A: -2.031; C: 0.625 (TEN)
Servo valve spool zero (%) – A: -0.703; C: -0.391(TEN)
Hydraulic supply pressure: 3377psi

Test result
Power capacity: power output at Actuator 1 reaches 277KW. – See Figure 1.4.1.

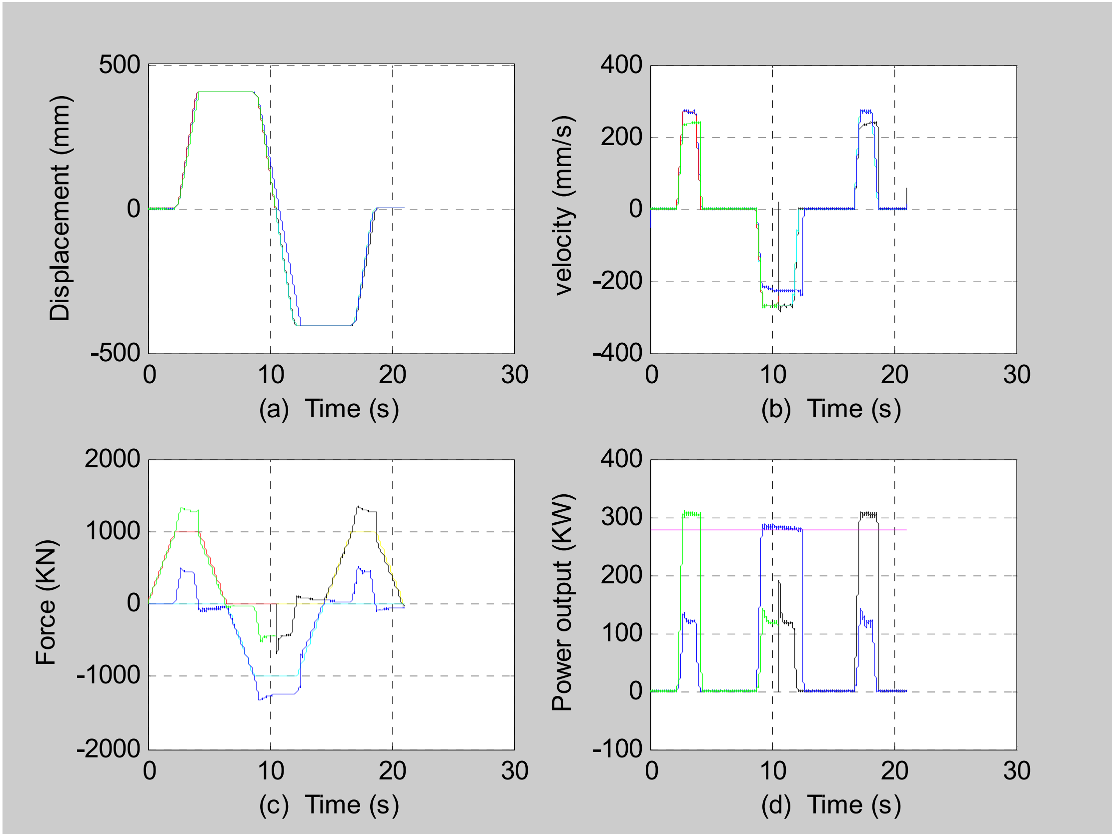


Figure 1.4.1. Power test at Actuator 1 (Test 4: 1 valve; Actuator 2 simulates load)
(Actuator 1 –displacement and Actuator 2—load)
(a) Displacement (mm) (b) Velocity (mm/s)
(c)Force (KN) (d) Power (KW)
– Red: command (1st test); Green: response (1^{st} test)
– Cyan: command (2^{nd} test); Blue: response (2^{nd} test)
– Yellow: command (3^{rd} test); Black: response (3^{rd} test)
Magenta: power target value (277KW)

1.5 0.2% force accuracy test (load range: ±1695KN)

1.5.1 5% load range force accuracy test (1, 2, 3 valves)

- Test task: ±84.75KN force control on Actuator 1 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter
Configuration--1 valve A PID control at actuator 1
PID control-- Kp=6; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; (B: 0.0; G: 0.0)
Servo valve offset (%) – A: -0.391; (B: 0.234; G: -1.484)
Servo valve spool zero (%) – A: 5.0; (B: 1.016; G: -2.891)
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±84.75KN(0.17KN error) –See Figure 1.5.1.1.

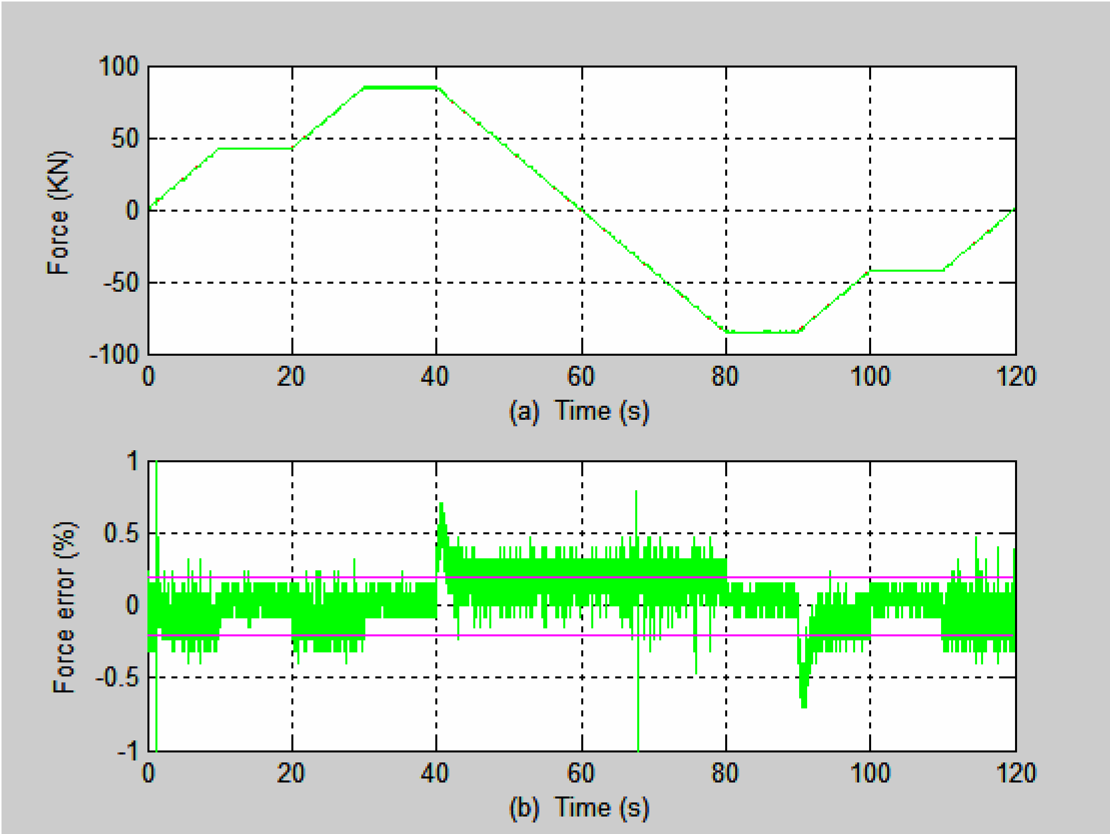


Figure 1.5.1.1. 5% maximum force accuracy test at Actuator 1 (Test 5.1: 1 valve)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±84.75KN; – Green: error percentage;
-- Magenta: error acceptance boundary ±0.2%

- Test task: ±84.75KN force control on Actuator 1 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter
Configuration--2 valve AB PID control at actuator 1
PID control-- Kp=3; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (G: 0.0)
Servo valve offset (%) – A: -0.391; B: 0.234; (G: -1.484)
Servo valve spool zero (%) – A: 5.0; B: 1.016; (G: -2.891)
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±84.75KN (0.17KN error)–See Figure 1.5.1.2.

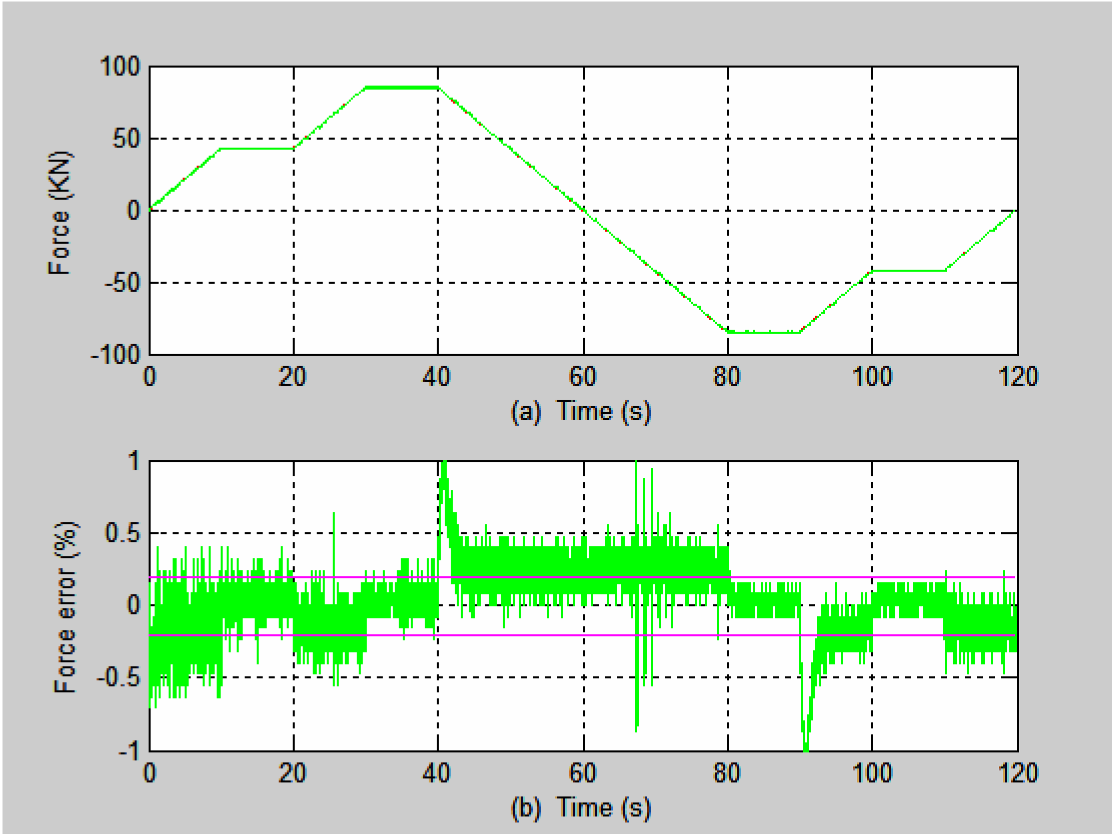


Figure 1.5.1.2. 5% maximum force accuracy test at Actuator 1 (Test 5.1: 2 valves)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±84.75KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

- Test task: ±84.75KN force control on Actuator 1 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

<u>Servo Control Parameter</u>
Configuration--3 valve ABG PID control at actuator 1
PID control-- Kp=1.5; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; G: 1.0
Servo valve offset (%) – A: -0.391; B: 0.234; G: -1.484
Servo valve spool zero (%) – A: 5.0; B: 1.016; G: -2.891
Hydraulic supply pressure: 3300psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ± 84.75KN(0.17KN error)–See Figure 1.5.1.3.

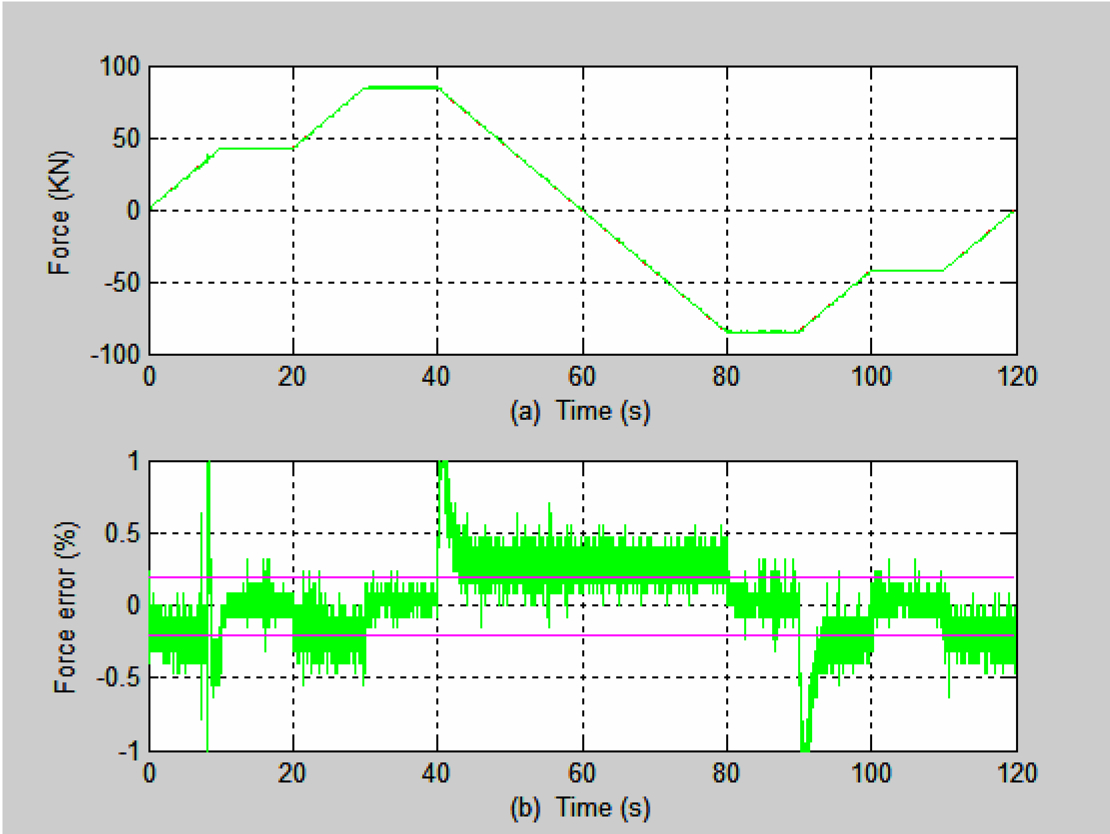


Figure 1.5.1.3. 5% maximum force accuracy test at Actuator 1 (Test 5.1: 3 valves)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±84.75KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

1.5.2 20% load range force accuracy test (1, 2, 3 valves)

- Test task: ±339KN force control on Actuator 1 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

<u>Servo Control Parameter</u>
Configuration--1 valve A PID control at actuator 1
PID control-- Kp=6; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; (B: 0.0; G: 0.0)
Servo valve offset (%) – A: -0.391; (B: 0.234; G: -1.484)
Servo valve spool zero (%) – A: 5.0; (B: 1.016; G: -2.891)
Hydraulic supply pressure: 3300psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ±339KN (0.68KN error) –See Figure 1.5.2.1.

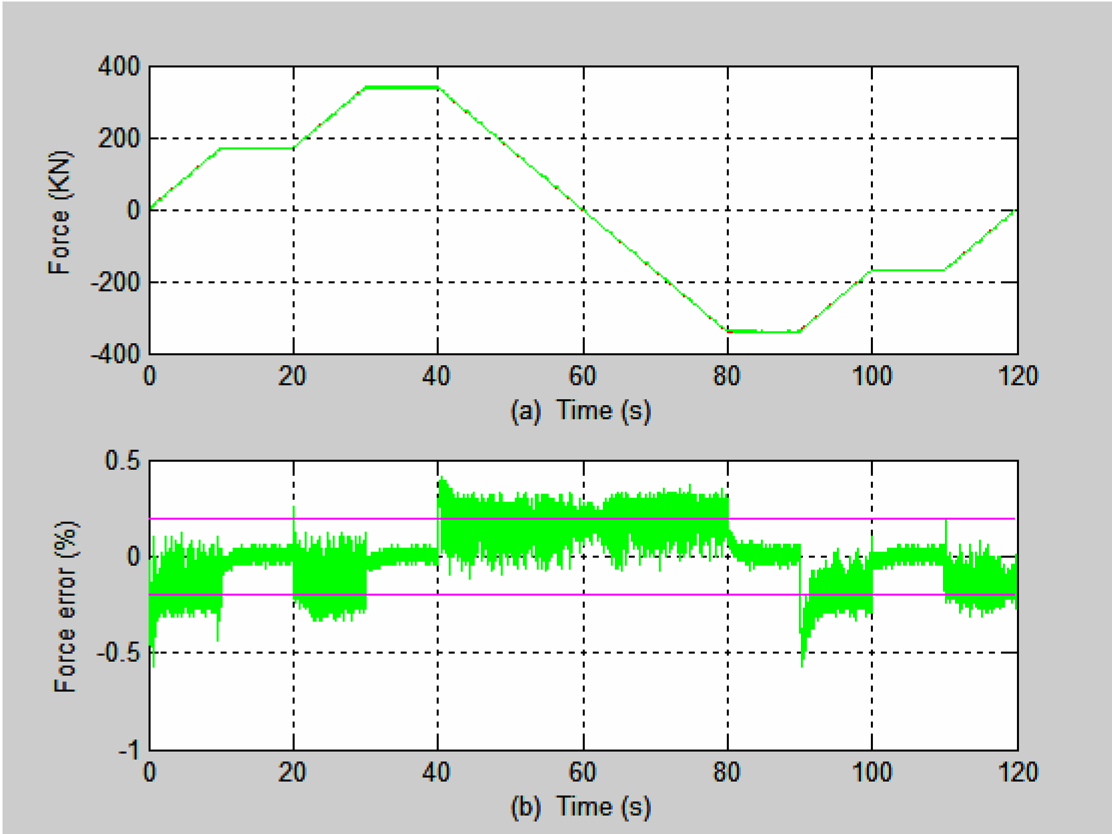


Figure 1.5.2.1. 20% maximum force accuracy test at Actuator 1 (Test 5.1: 1 valve)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±339KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

- Test task: ±339KN force control on Actuator 1 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

<u>Servo Control Parameter</u>
Configuration--2 valve AB PID control at actuator 1
PID control-- Kp=3; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (G: 0.0)
Servo valve offset (%) – A: -0.391; B: 0.234; (G: -1.484)
Servo valve spool zero (%) – A: 5.0; B: 1.016; (G: -2.891)
Hydraulic supply pressure: 3300psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ±339KN (0.68KN error) –See Figure 1.5.2.2.

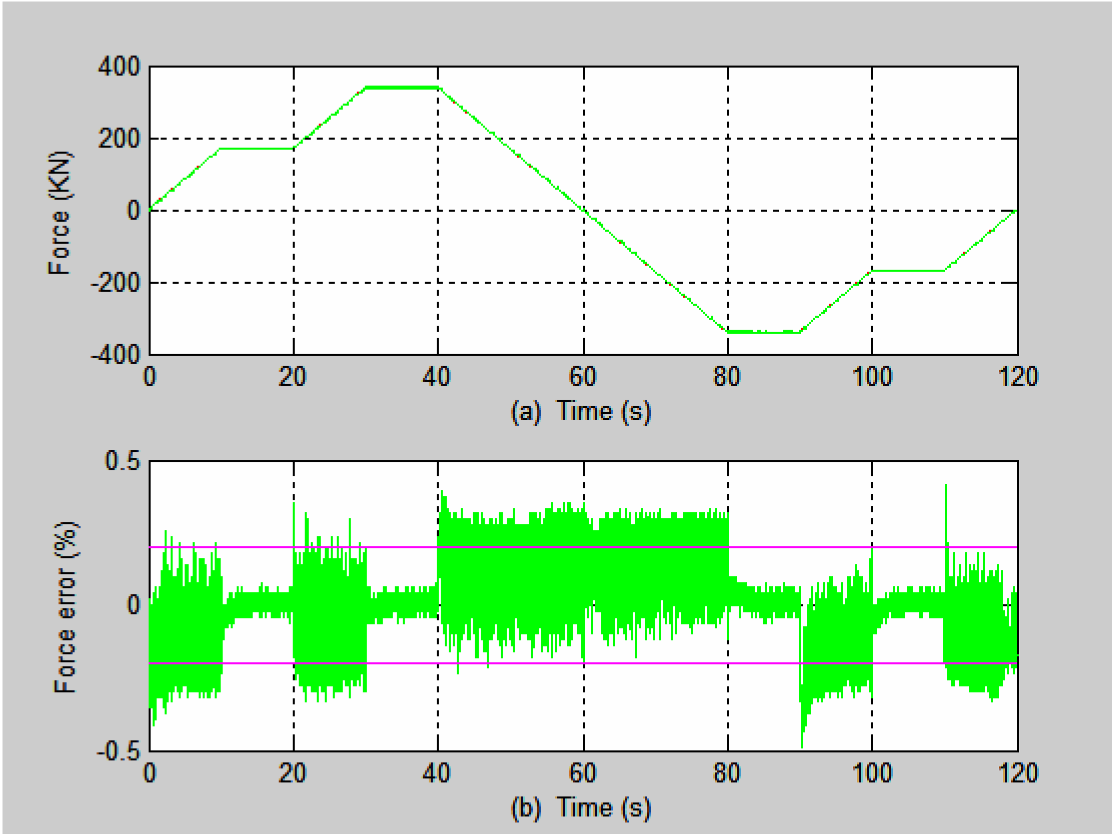


Figure 1.5.2.2. 20% maximum force accuracy test at Actuator 1 (Test 5.1: 2 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±339KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

- Test task: ±339KN force control on Actuator 1 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter
Configuration--3 valve ABG PID control at actuator 1
PID control-- Kp=2.2; Ki=3; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; G: 1.0
Servo valve offset (%) – A: -0.391; B: 0.234; G: -1.484
Servo valve spool zero (%) – A: 5.0; B: 1.016; G: -2.891
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ± 339KN (0.68KN error) –See Figure 1.5.2.3.

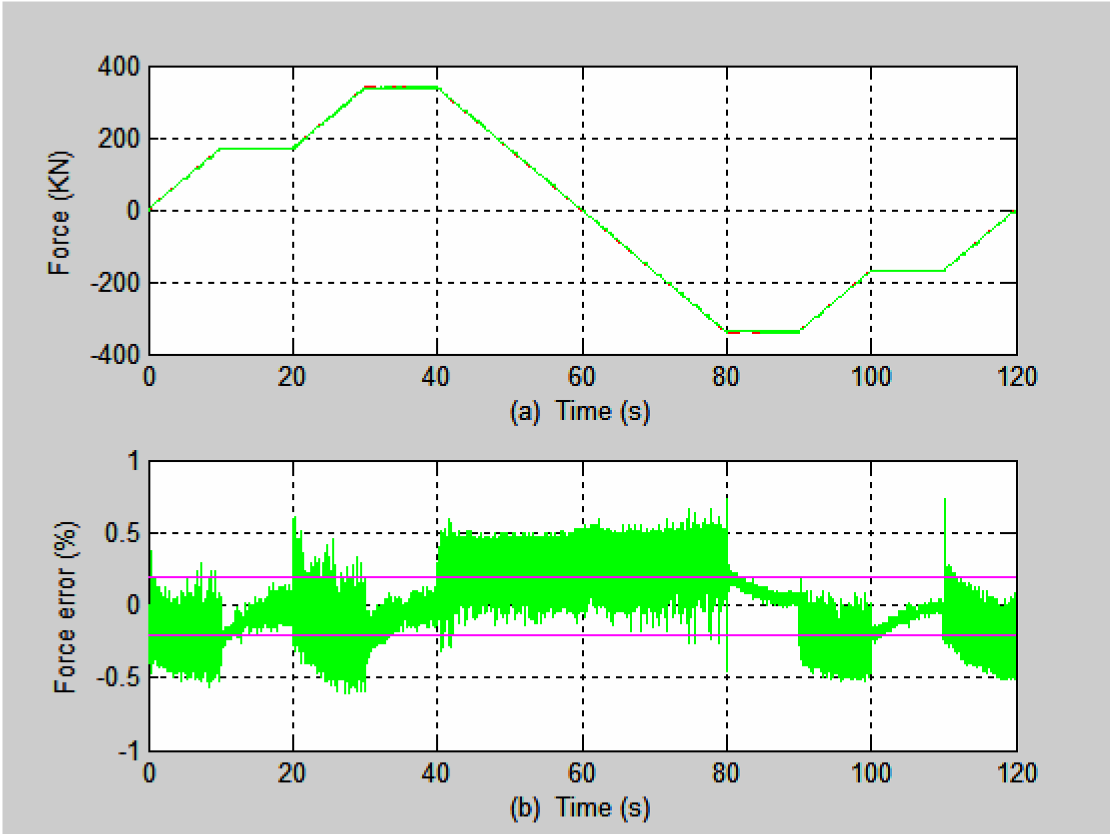


Figure 1.5.2.3. 20% maximum force accuracy test at Actuator 1 (Test 5.1: 3 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±339KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

1.5.3 100% load range force accuracy test (1, 2, 3 valves)

- Test task: ±1695KN force control on Actuator 1 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

<u>Servo Control Parameter</u>
Configuration--1 valve A PID control at actuator 1

<u>Tension:</u>
PID control-- Kp=9; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; (B: 0.0; G: 0.0)
Servo valve offset (%) – A: -0.391; (B: 2.266; G2.578)
Servo valve spool zero (%) – A: 5.0; (B: -0.547; G: -4.922)

<u>Compression:</u>
PID control-- Kp=6; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (G: 0.0)

Servo valve offset (%) – A: -0.391; B: -1.797; (G: -6.562)
Servo valve spool zero (%) – A: 5.0; B: 2.031; (G: 0.156)

Hydraulic supply pressure: 3200psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ± 1695KN (3.3KN error) –See Figure 1.5.3.1.

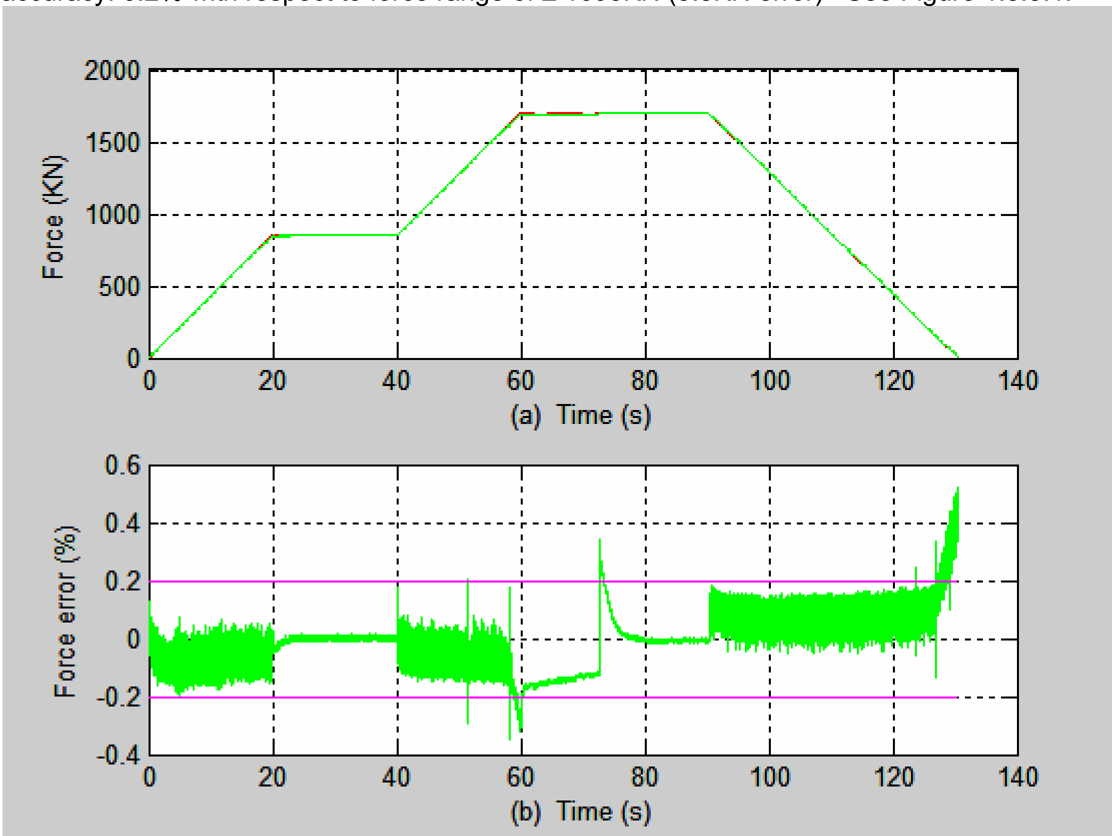


Figure 1.5.3.1a.   100% maximum force accuracy test at Actuator 1 (Test 5.1: 1 valve) - Tension
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN ; Green: error percentage;
– Magenta: error acceptance boundary ±0.2%

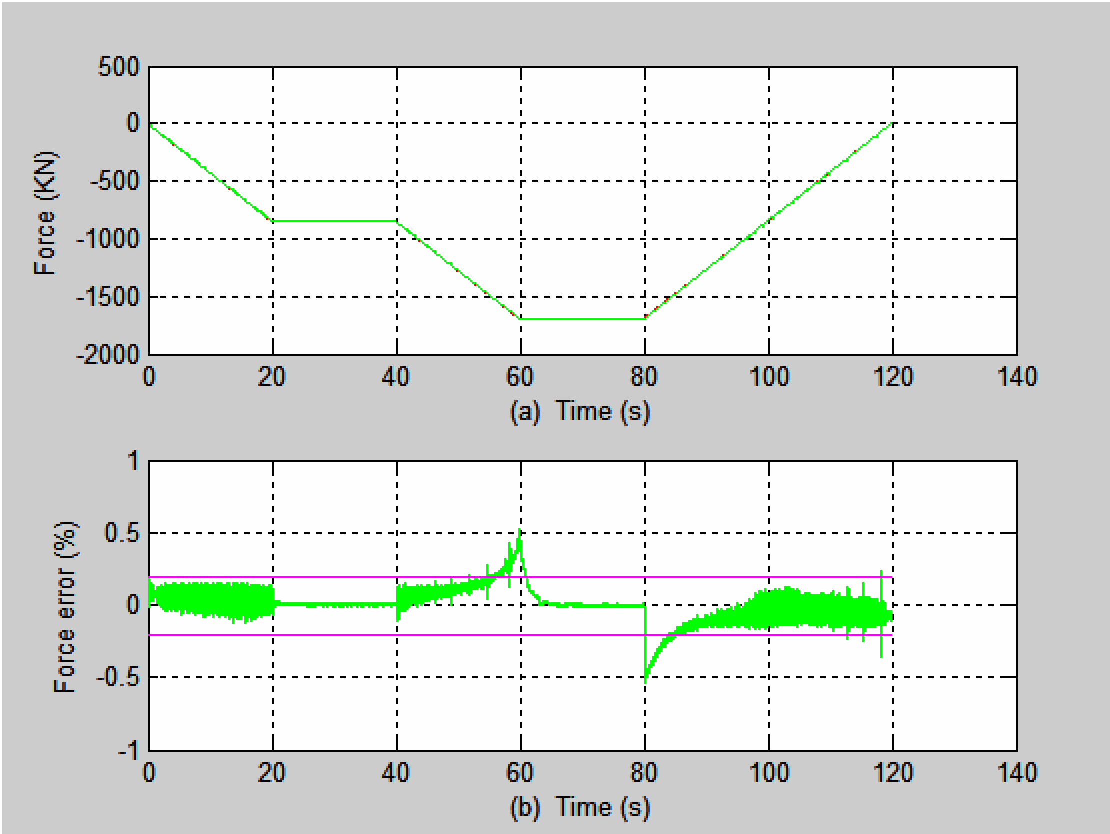


Figure 1.5.3.1b. 100% maximum force accuracy test at Actuator 1 (Test 5.1: 1 valve) - Compression
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
--Magenta: error acceptance boundary ±0.2%

- Test task: ±1695KN force control on Actuator 1 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter
Configuration--2 valve AB PID control at actuator 1

Tension:
PID control-- Kp=6.0; Ki=1.0; Kd =-1; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (G: 0.0)
Servo valve offset (%) – A: -0.391; B: 2.266; (G: 2.578)
Servo valve spool zero (%) – A: 5.0; B: -0.547; (G: -4.922)

Compression:
PID control-- Kp=3; Ki=1; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (G: 1.0)
Servo valve offset (%) – A: -0.391; B: -1.797; (G: -6.562)
Servo valve spool zero (%) – A: 5.0; B: 2.031; (G: 0.156)
Hydraulic supply pressure: 3200psi

Test result
Static accuracy: 0.2% with respect to force range of ± 1695KN (3.3KN error) –See Figure 1.5.3.2.

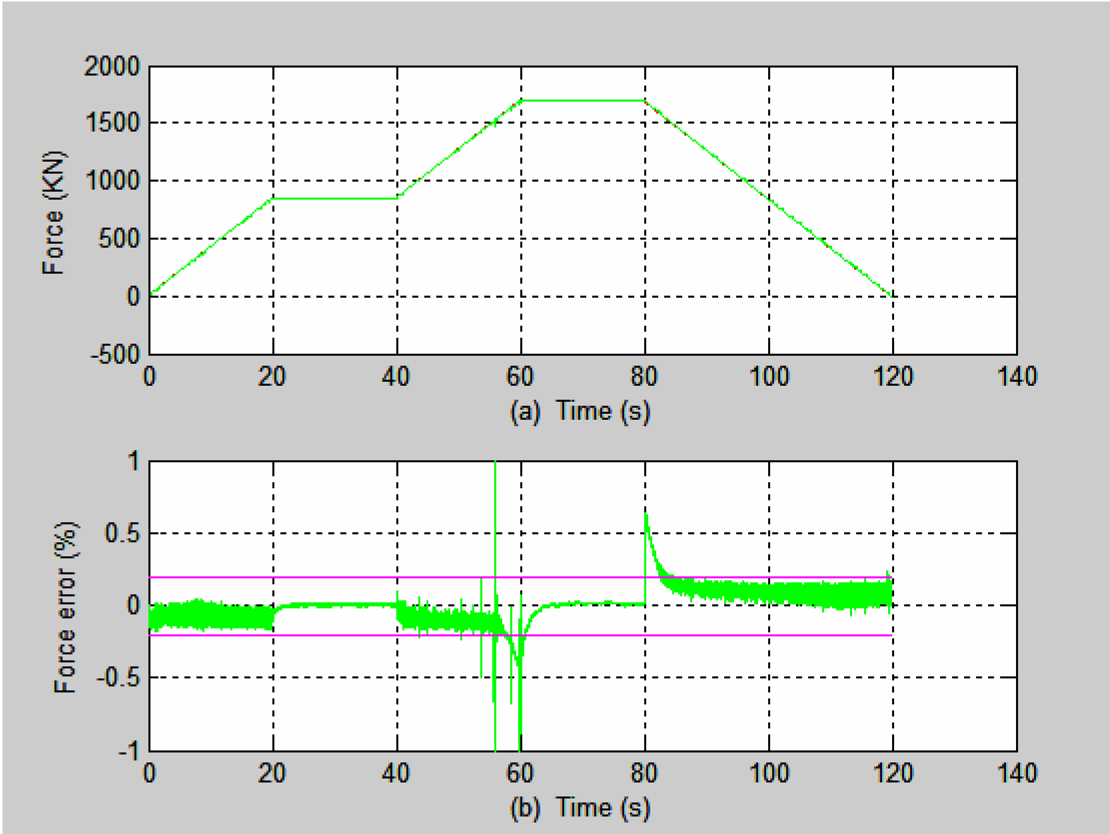


Figure 1.5.3.2a. 100% maximum force accuracy test at Actuator 1 (Test 5.1: 2 valves) - Tension
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

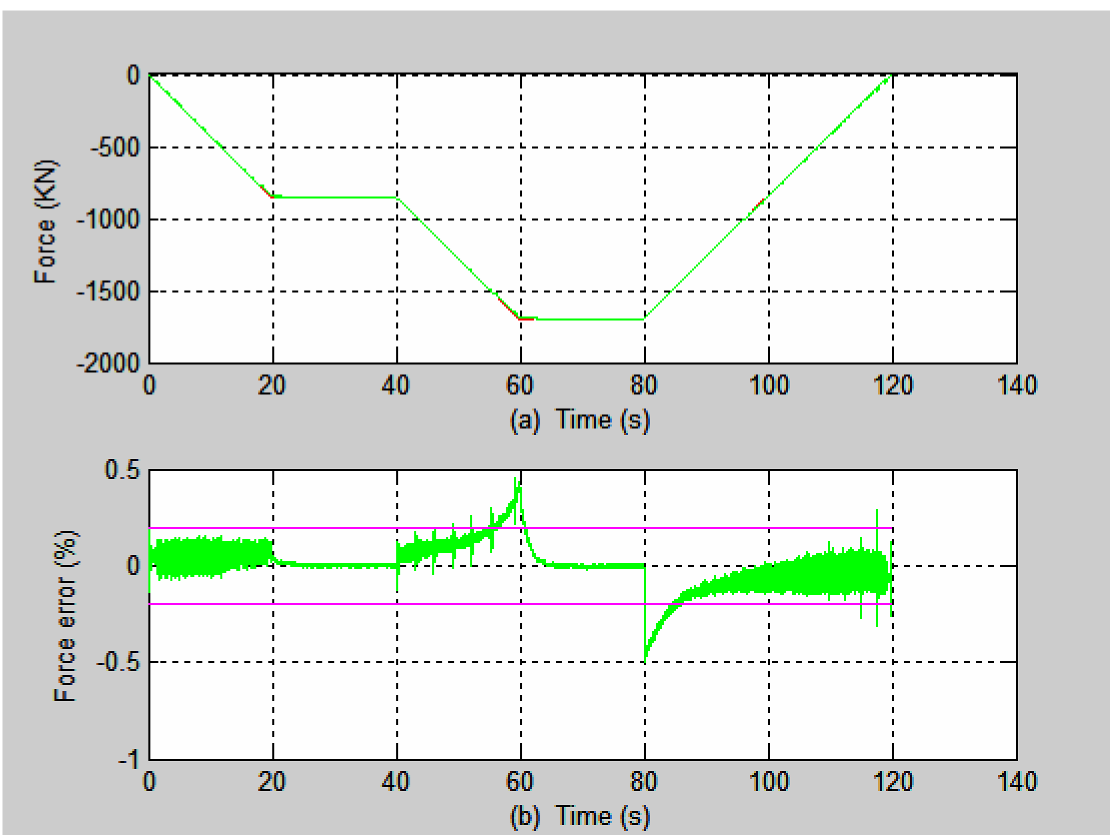


Figure 1.5.3.2b. 100% maximum force accuracy test at Actuator 1 (Test 5.1: 2 valves) - Compression
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

- Test task: ±1695KN force control on Actuator 1 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter
Configuration--3 valve ABG PID control at actuator 1
PID control-- Kp=1.8; Ki=1.7; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; G: 1.0
Servo valve offset (%) – A: -0.391; B: 0.234; G: -1.484
Servo valve spool zero (%) – A: 5.0; B: 1.016; G: -2.891
Hydraulic supply pressure: 3200psi

Test result
Static accuracy: 0.2% with respect to force range of ±1695KN (3.3KN error) –See Figure 1.5.3.3.

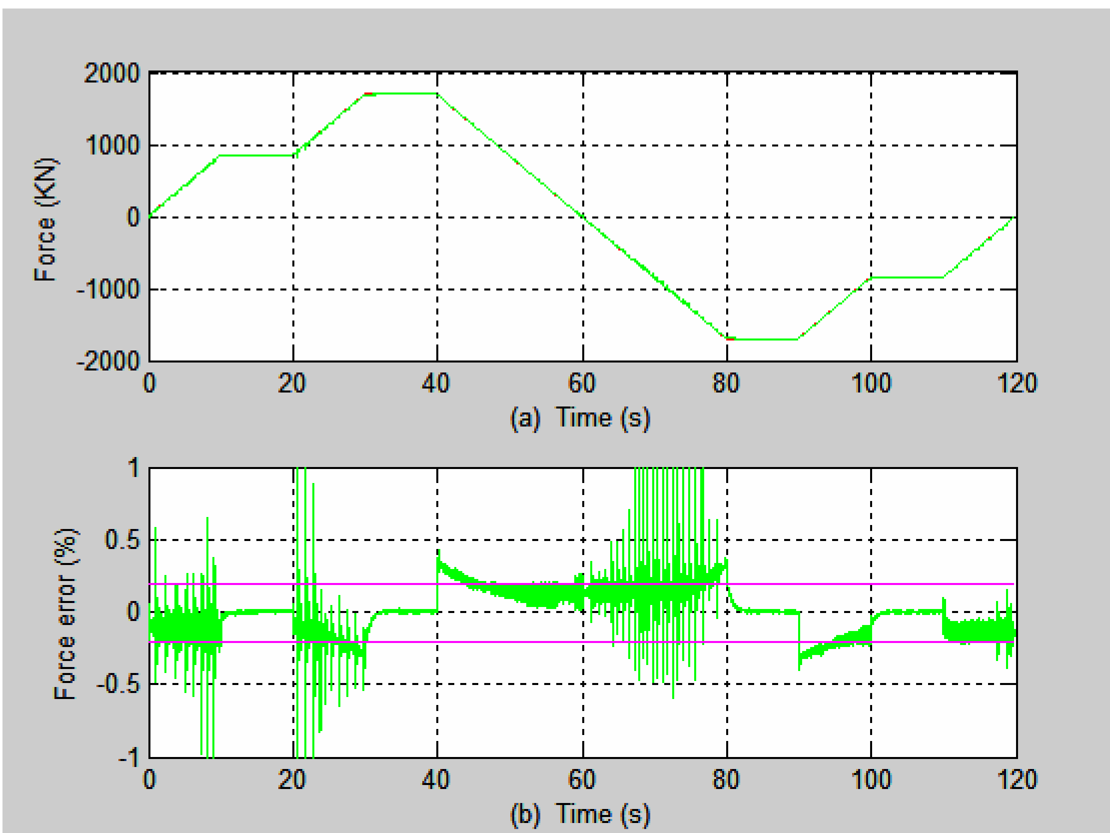


Figure 1.5.3.3. 100% maximum force accuracy test at Actuator 1 (Test 5.1: 3 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

1.5.4 SCRAMNet 100% load range force accuracy test (3 valves)

- Test task: SCRAMNet ±1695KN force control on Actuator 1 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter
Configuration--3 valve ABG PID control at actuator 1
PID control-- Kp=1.7; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; G: 1.0
Servo valve offset (%) – A: -0.391; B: 0.234; G: -1.484
Servo valve spool zero (%) – A: 5.0; B: 1.016; G: -2.891
Hydraulic supply pressure: 3200psi

Test result
Static accuracy: 0.2% with respect to force range of ±1695KN (3.3KN error) –See Figure 1.5.4.1.

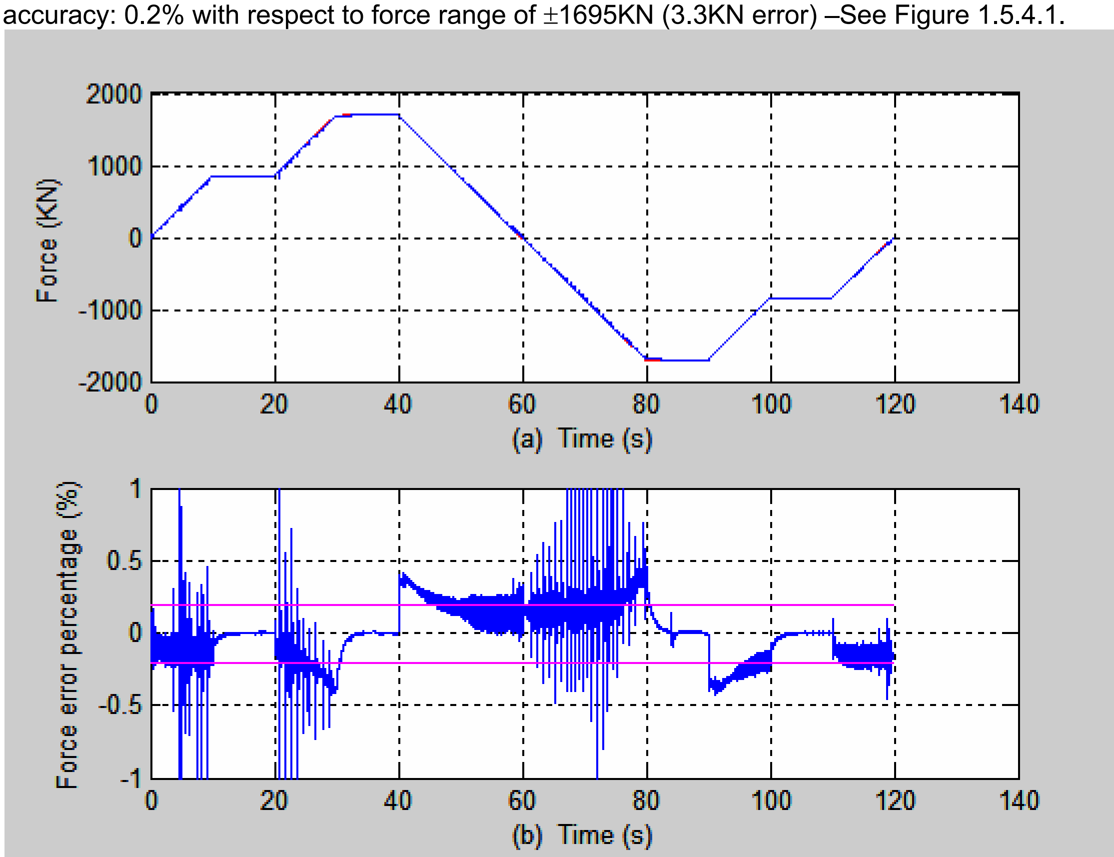


Figure 1.5.4.1. SCRAMNet 100% maximum force accuracy test at Actuator 1
(Test 5 repeats Test 5.1: 3 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±1695KN; Blue: error percentage
–Magenta: error acceptance boundary ±0.2%

1.6 10Hz force bandwidth test

1.6.1 ±1000KN@10Hz sinusoid with 1 valve operation

- Test task: Sinusoid force control on Actuator 1 (1valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter
Configuration--1 valve A PID control at actuator 1
PID control-- Kp=6.0; Ki=1.0; Kd =-1.0; f = 35 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; (B: 0.0; G: 0.0)
Servo valve offset (%) – A: -0.391; (B: 0.234; G: -1.484)
Servo valve spool zero (%) – A: 5.0; (B: 1.016; G: -2.891)
Hydraulic supply pressure: 3300psi

Test result
Dynamic bandwidth: 10Hz@1000KN (10% attenuation, less than 3 db) –See Figure 1.6.1.1.

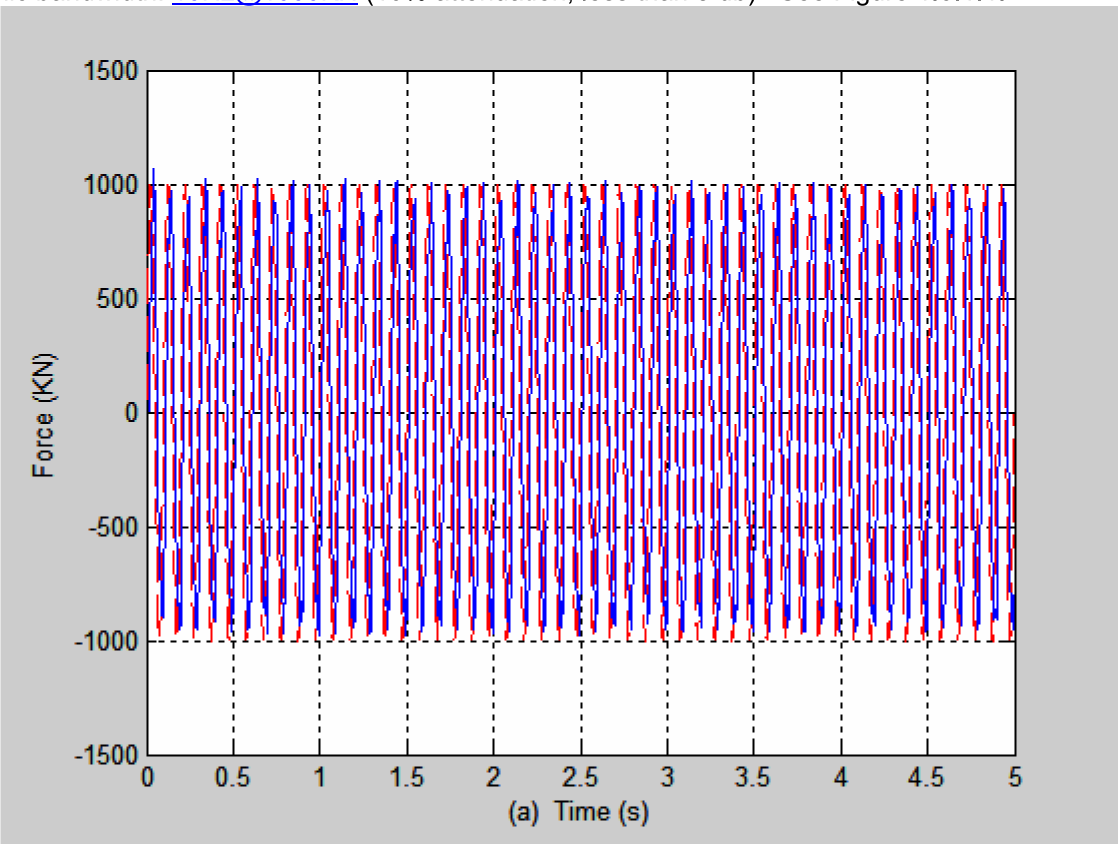


Figure 1.6.1.1. Force control dynamic bandwidth test at Actuator 1 (Test 5.2: 1 valve)
Red: command (1000KN@10Hz); Blue: response (900KN@10Hz)

1.6.2 ±1000KN@10Hz sinusoid with 2 valve operation

- Test task: Sinusoid force control on Actuator 1 (2valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang

Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter
Configuration--2 valve AB PID control at actuator 1
PID control-- Kp=3.0; Ki=1.0; Kd =-1.0; f = 35 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; (G: 0.0)
Servo valve offset (%) – A: -0.391; B: 0.234; (G: -1.484)
Servo valve spool zero (%) – A: 5.0; B: 1.016; (G: -2.891)
Hydraulic supply pressure: 3300psi

Test result
Dynamic bandwidth: 10Hz@1000KN (20% attenuation, less than 3 db) –See Figure 1.6.2.1.

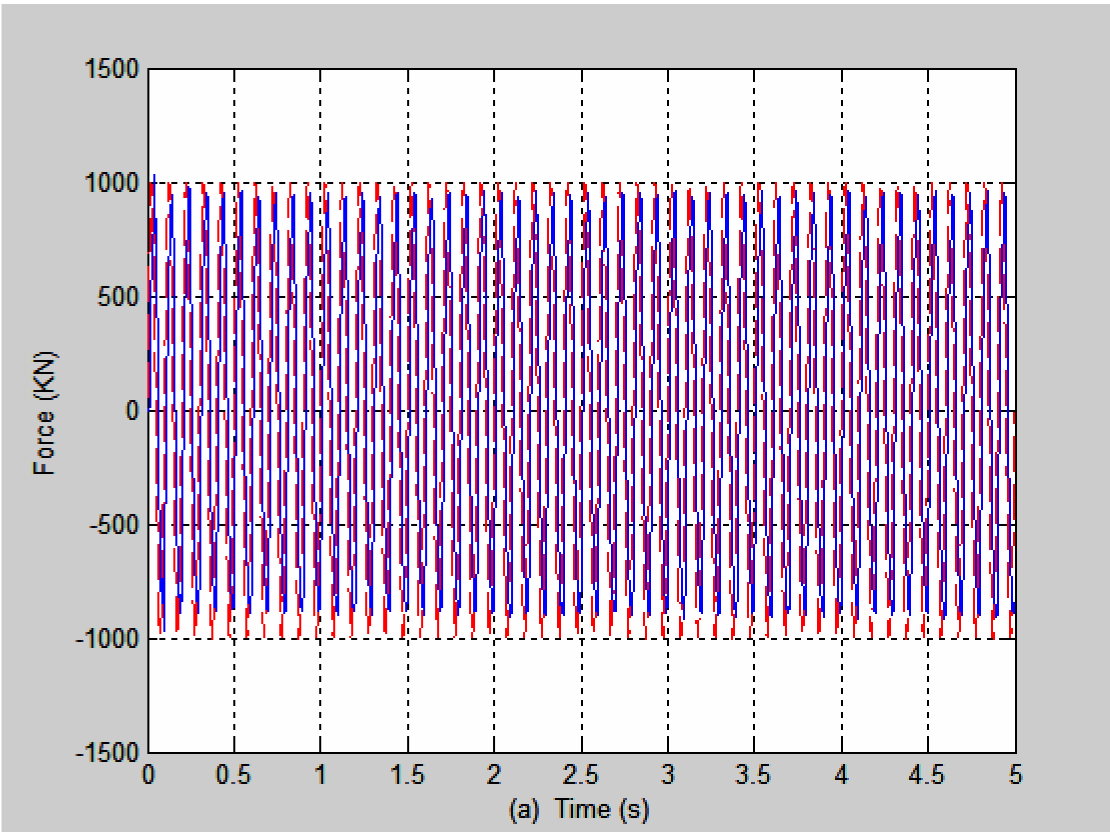


Figure 1.6.2.1. Force control dynamic bandwidth test at Actuator 1 (Test 5.2: 2 valves)
Red: command (1000KN@10Hz); Blue: response (800KN@10Hz)

1.6.3 ±1000KN@10Hz sinusoid with 3 valve operation

- Test task: Sinusoid force control on Actuator 1 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter
Configuration--3 valve ABG PID control at actuator 1
PID control-- Kp=1.7; Ki=1.0; Kd =-1.0; f = 35 Hz

Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; G: 1.0
Servo valve offset (%) – A: -0.391; B: 0.234; G: -1.484
Servo valve spool zero (%) – A: 5.0; B: 1.016; G: -2.891
Hydraulic supply pressure: 3300psi

Test result
Dynamic bandwidth: 10Hz@1000KN (20% attenuation, less than 3 db) –See Figure 1.6.3.1.

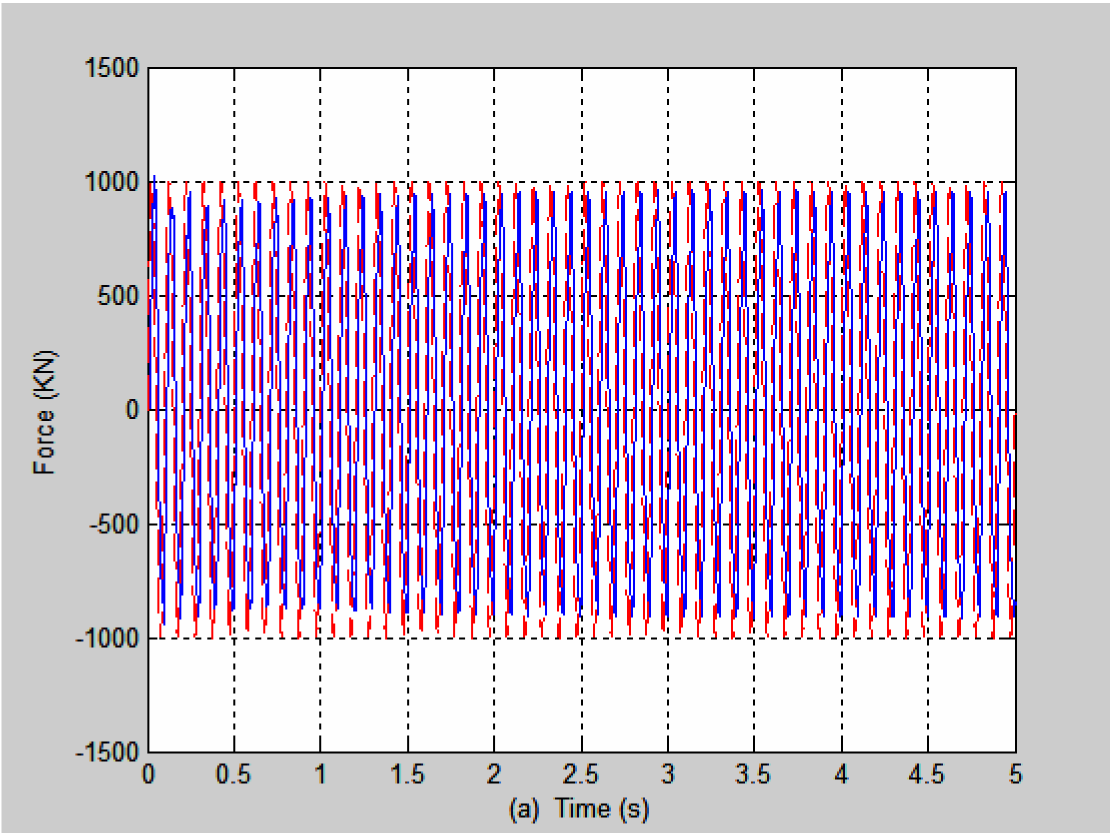


Figure 1.6.3.1. Force control dynamic bandwidth test at Actuator 1 (Test 5.2: 3 valves)
Red: command (1000KN@10Hz); Blue: response (800KN@10Hz)

1.6.4 SCRAMNet ±1000KN@10Hz sinusoid with 3 valve operation

- Test task: SCRAMNet sinusoid force control on Actuator 1 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/22/2004

Servo Control Parameter:
Configuration--3 valve ABG PID control at actuator 1
PID control-- Kp=1.7; Ki=1.0; Kd =-1.0; f = 35 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; B: 1.00; G: 1.0
Servo valve offset (%) – A: -0.391; B: 0.234; G: -1.484
Servo valve spool zero (%) – A: 5.0; B: 1.016; G: -2.891
Hydraulic supply pressure: 3300psi

Result:
Bandwidth reaches 10Hz@1000KN (10% attenuation, less than 3 db) – See Figure 1.6.4.1.

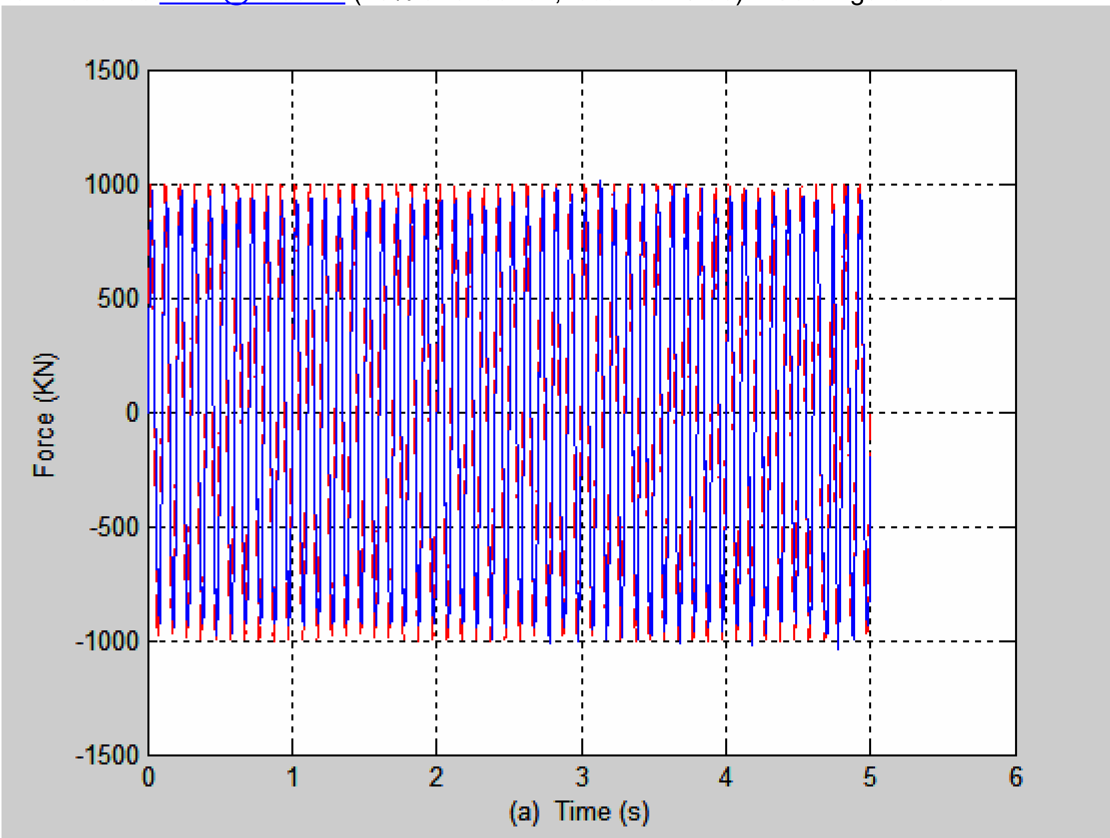


Figure 1.6.4.1. SCRAMNet force control dynamic bandwidth test at Actuator 1
(Test 5 repeats Test 5.2: 3 valves)
Red: command (1000KN@10Hz); Blue: response (900KN@10Hz)

Actuator 2

2.1 0.2% displacement accuracy test (travel range: ±500mm)

2.1.1 10% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±50mm displacement control on Actuator 2 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

Servo Control Parameter
Configuration--1 valve C PID control at actuator 2
PID control-- Kp=40; Ki=10; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; (D: 0.0; K: 0.0)
Servo valve offset – C: 0.0; (D: -0.859; K: 0.469)
Servo valve spool zero – C: 0.0; (D: 0.0; K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 2.1.1.1.

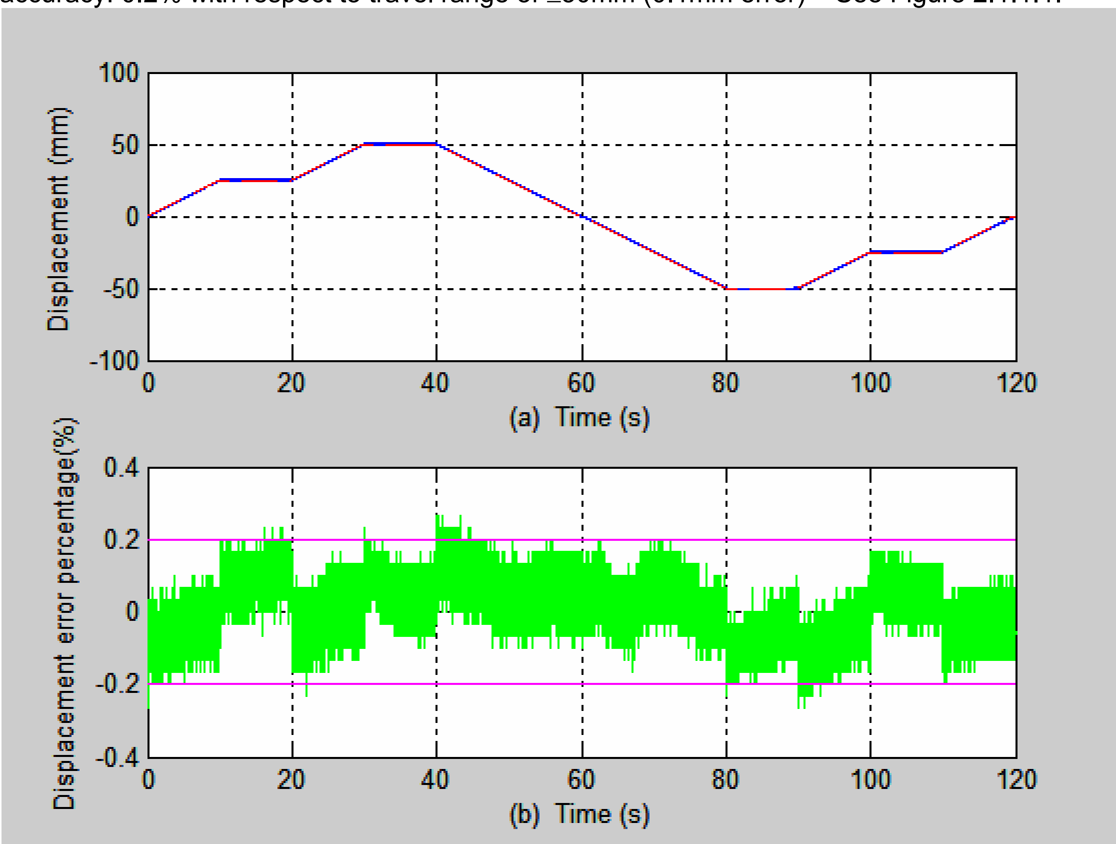


Figure 2.1.1.1. 10% stroke accuracy test at Actuator 2 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 2 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

Servo Control Parameter

Configuration--2 valve CD PID control at actuator 2
PID control-- Kp=20; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; (K: 0.0)
Servo valve offset – C: 0.0; D: -0.859; (K: 0.469)
Servo valve spool zero – C: 0.0; D: 0.0; (K: 0.00)
Hydraulic supply pressure: 3000psi

Test result

Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 2.1.1.2.

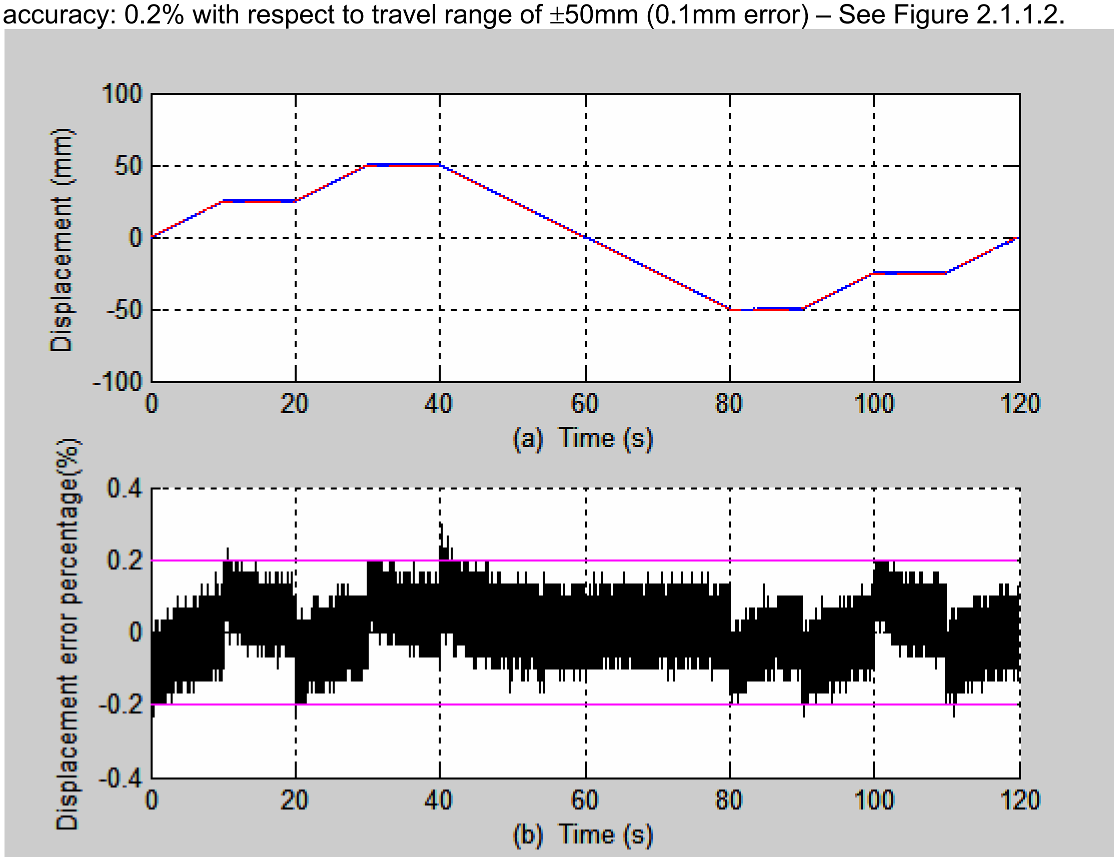


Figure 2.1.1.2. 10% stroke accuracy test at Actuator 2 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 2 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

Servo Control Parameter

Configuration--3 valve CDK PID control at actuator 2
PID control-- Kp=15; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; K: 0.88
Servo valve offset – C: 0.0; D: -0.859; K: 0.469
Servo valve spool zero – C: 0.0; D: 0.0; K: 0.00
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 2.1.1.3.

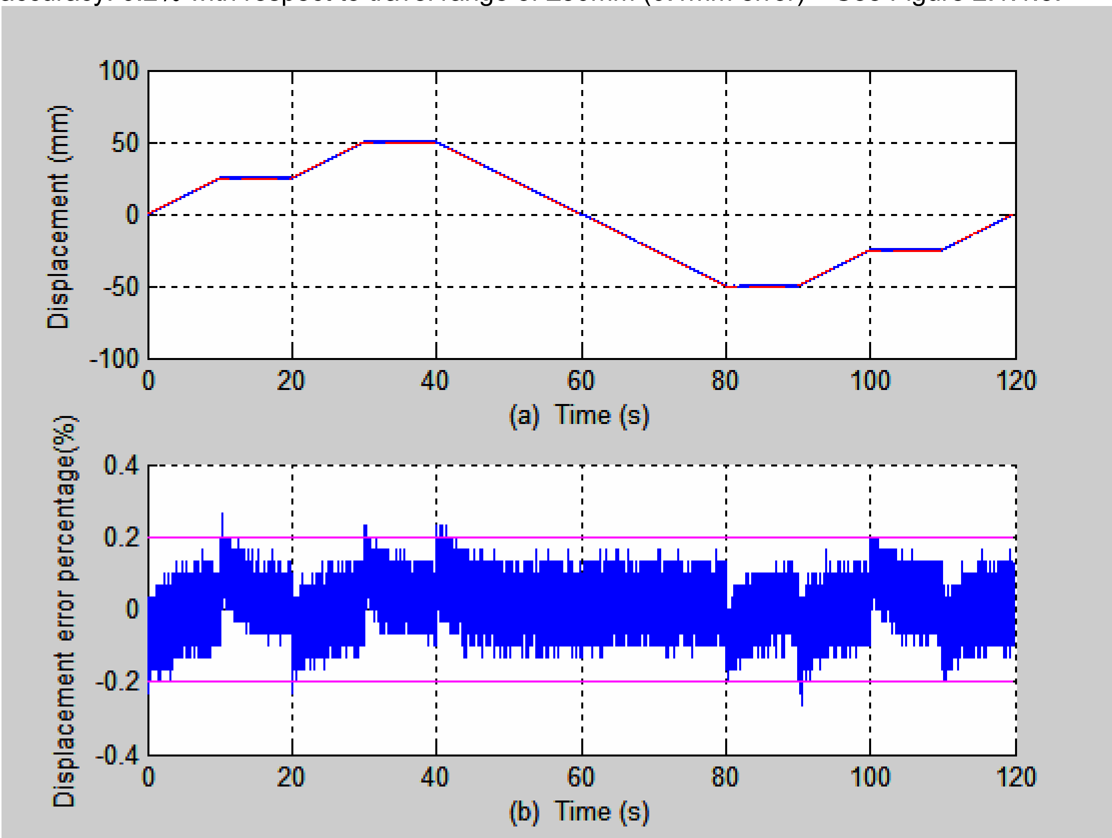


Figure 2.1.1.3. 10% stroke accuracy test at Actuator 2 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

2.1.2 20% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±100mm displacement control on Actuator 2 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

Servo Control Parameter
Configuration--1 valve C PID control at actuator 2
PID control-- Kp=40; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; (D: 0.0; K: 0.0)
Servo valve offset – C: 0.0; (D: -0.859; K: 0.469)
Servo valve spool zero – C: 0.0; (D: 0.0; K: 0.00)

Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.2% with respect to travel range of ±100mm (0.2mm error) – See Figure 2.1.2.1.

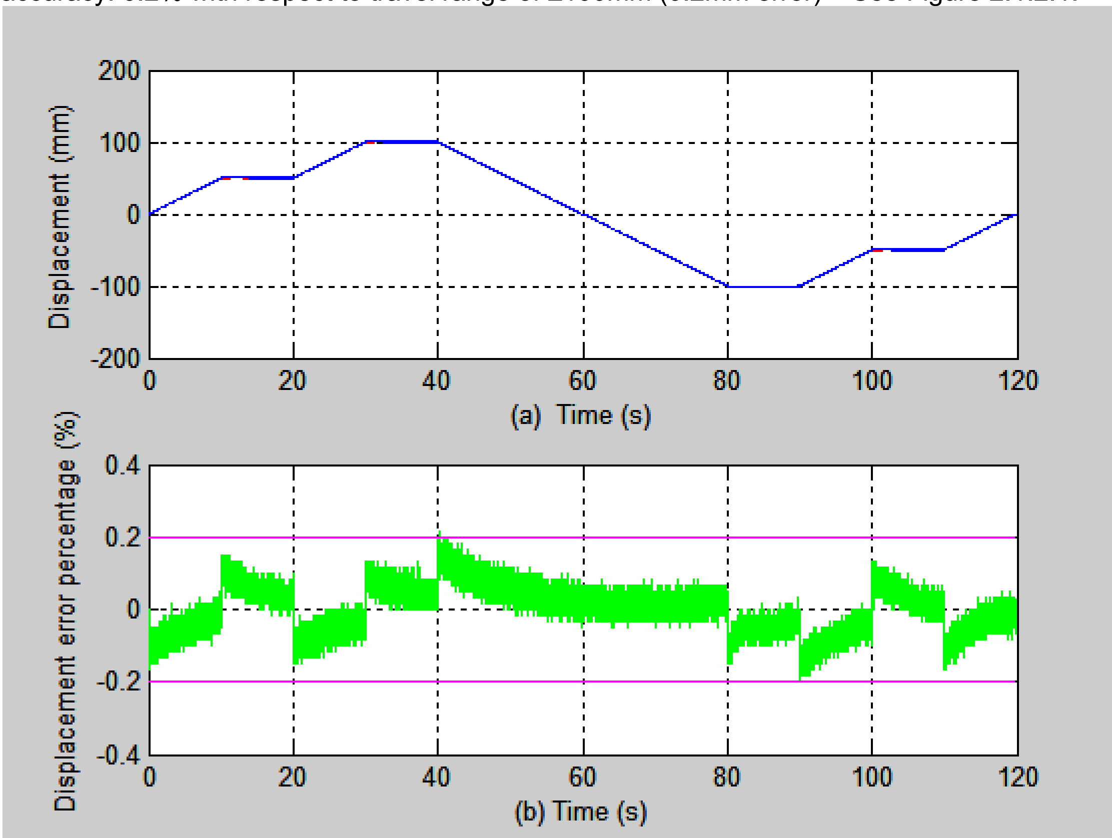


Figure 2.1.2.1.   20% stroke accuracy test at Actuator 2 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 2 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

<u>Servo Control Parameter</u>
Configuration--2 valve CD PID control at actuator 2
PID control-- Kp=20; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; (K: 0.0)
Servo valve offset – C: 0.0; D: -0.859; (K: 0.469)
Servo valve spool zero – C: 0.0; D: 0.0; (K: 0.00)
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.2% with respect to travel range of ±100mm (0.2mm error) – See Figure 2.1.2.2.

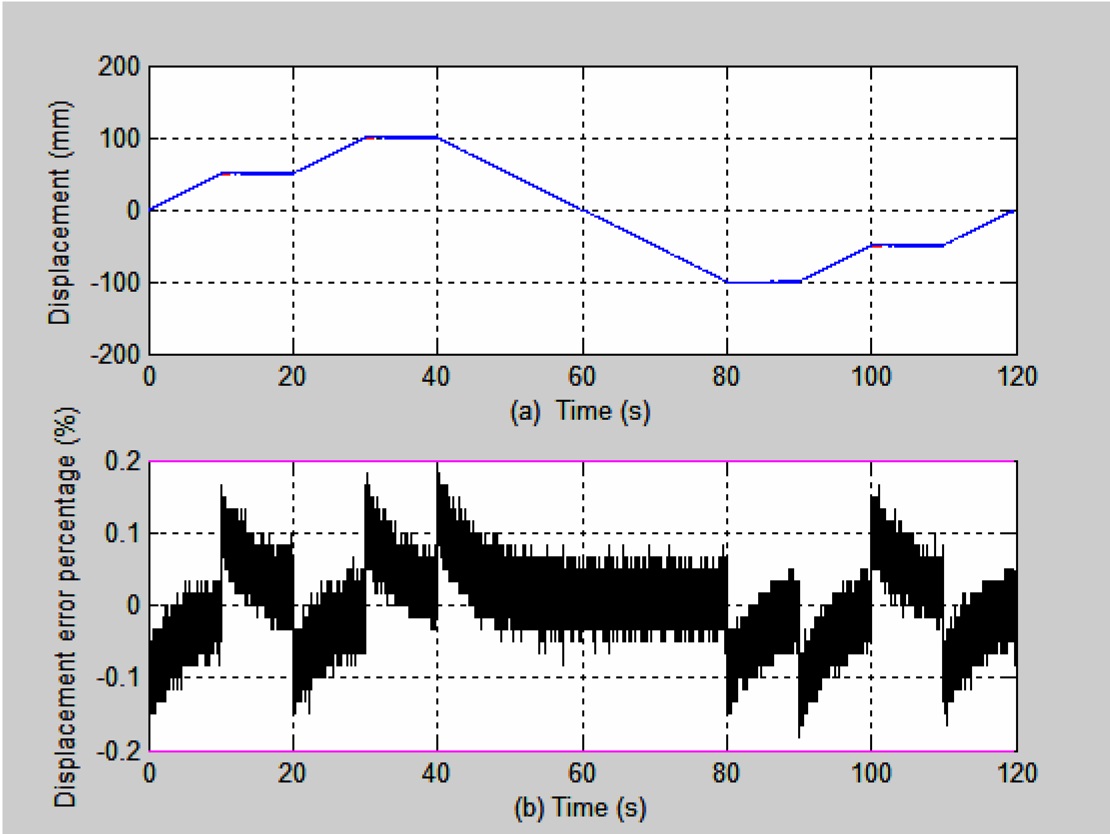


Figure 2.1.2.2. 20% stroke accuracy test at Actuator 2 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 2 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

Servo Control Parameter
Configuration--3 valve CDK PID control at actuator 2
PID control-- Kp=15; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; K: 0.88
Servo valve offset – C: 0.0; D: -0.859; K: 0.469
Servo valve spool zero – C: 0.0; D: 0.0; K: 0.00
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.18% with respect to travel range of ±100mm(0.18mm error)–See Figure 2.1.2.3.

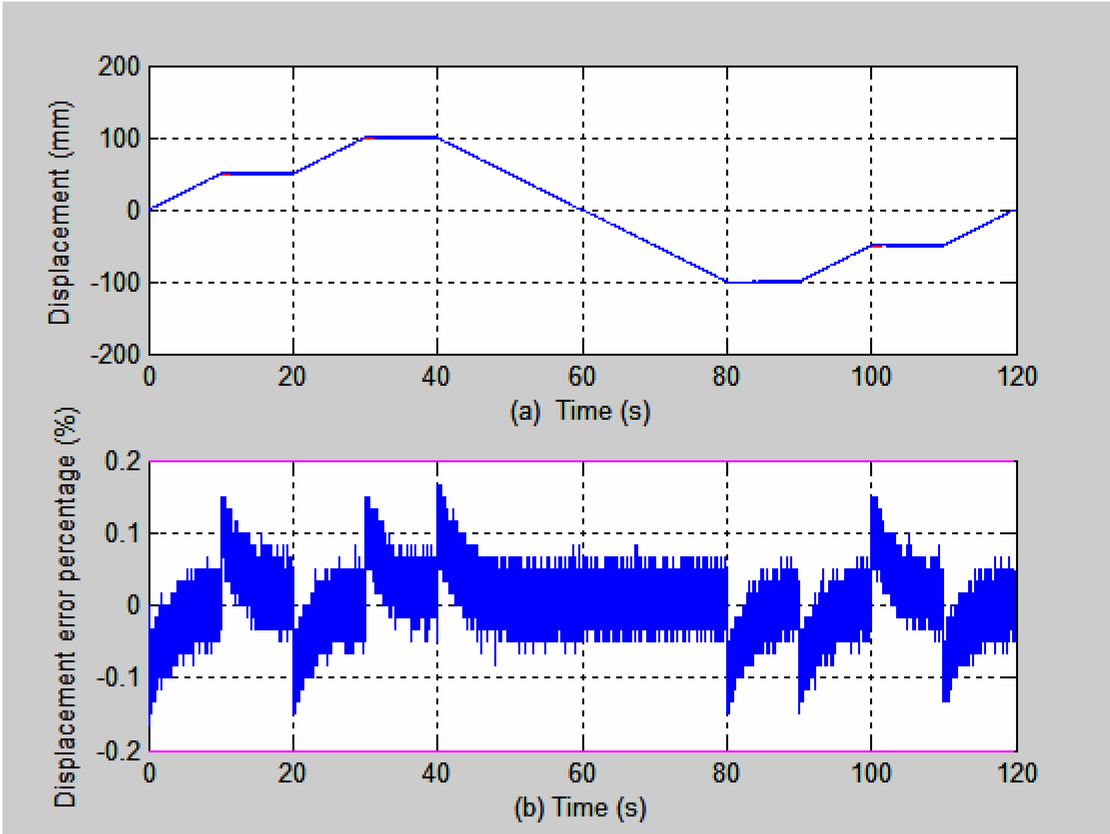


Figure 2.1.2.3. 20% stroke accuracy test at Actuator 2 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

2.1.3 100% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±500mm displacement control on Actuator 2 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

Servo Control Parameter
Configuration--1 valve C PID control at actuator 2
PID control-- Kp=40; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; (D: 0.0; K: 0.0)
Servo valve offset – C: 0.0; (D: -0.859; K: 0.469)
Servo valve spool zero – C: 0.0; (D: 0.0; K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.18% with respect to travel range of ±500mm (0.9mm error)–See Figure 2.1.3.1.

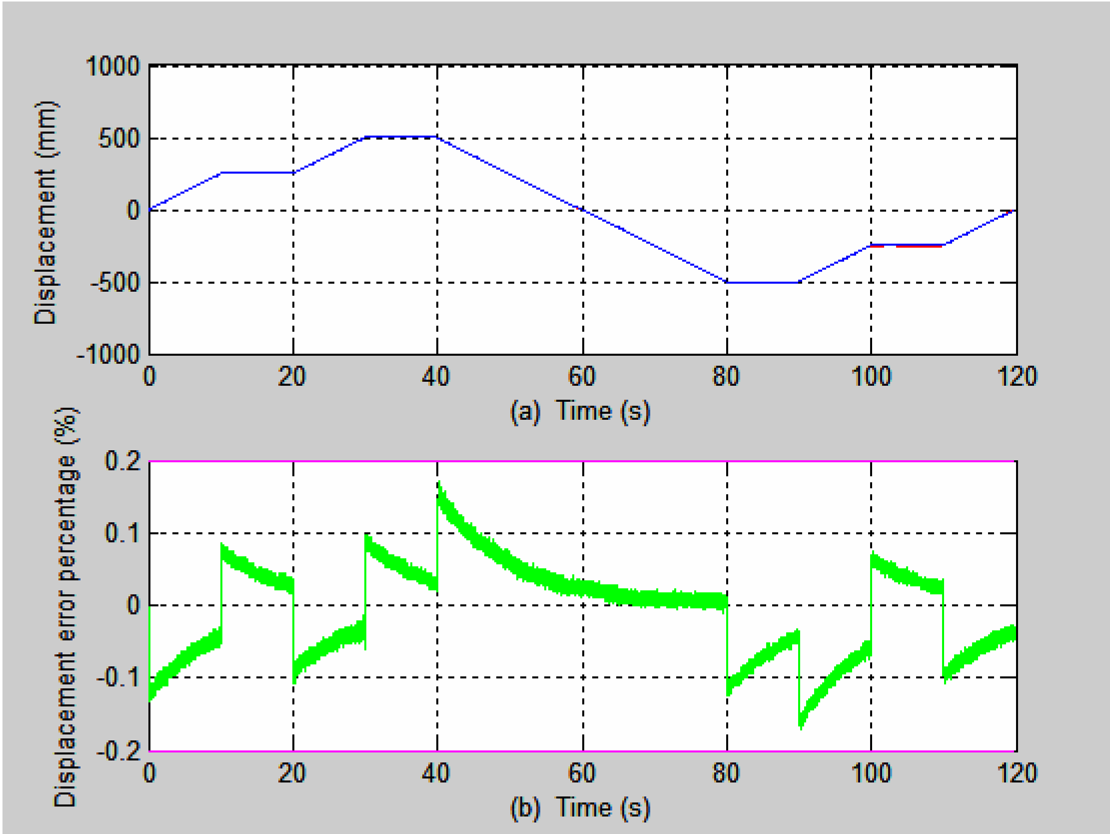


Figure 2.1.3.1. 100% stroke accuracy test at Actuator 2 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 2 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

Servo Control Parameter
Configuration--2 valve CD PID control at actuator 2
PID control-- Kp=20; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; (K: 0.0)
Servo valve offset – C: 0.0; D: -0.859; (K: 0.469)
Servo valve spool zero – C: 0.0; D: 0.0; (K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.13% with respect to travel range of ±500mm(0.65mm error)–See Figure 2.1.3.2.

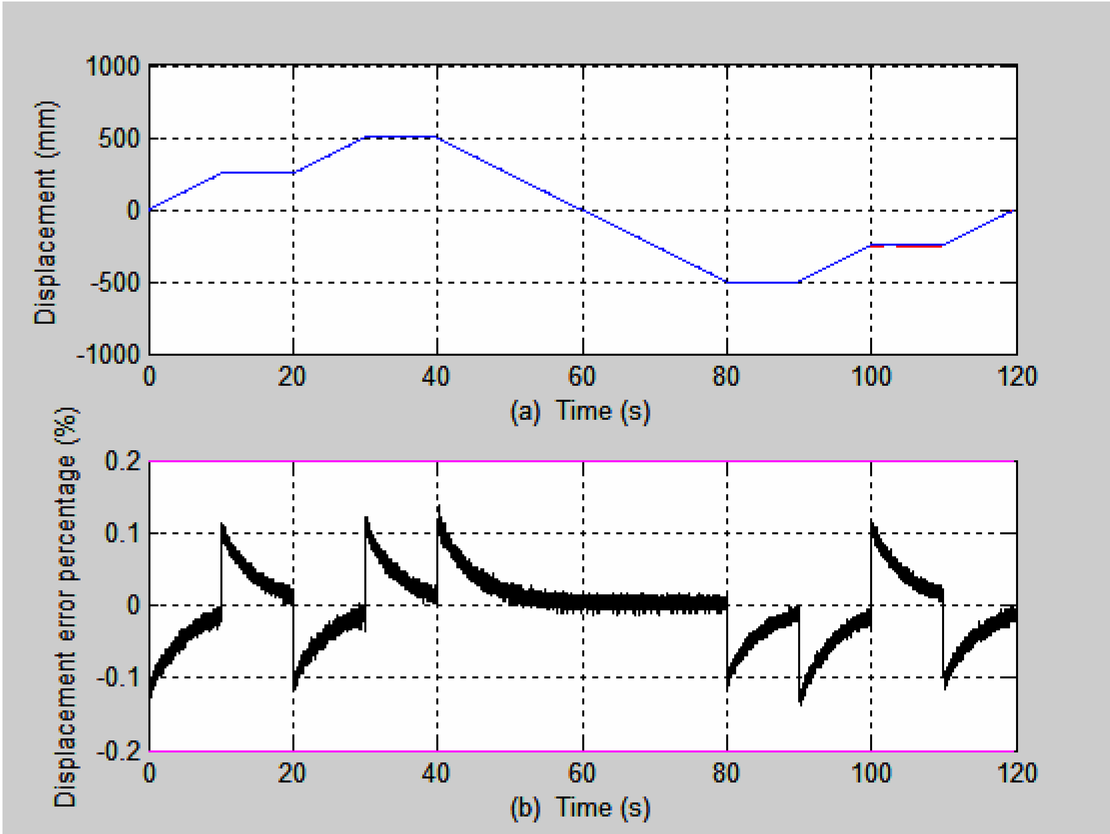


Figure 2.1.3.2. 100% stroke accuracy test at Actuator 2 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 2 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

<u>Servo Control Parameter</u>
Configuration--3 valve CDK PID control at actuator 2
PID control-- Kp=15; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; K: 0.88
Servo valve offset – C: 0.0; D: -0.859; K: 0.469
Servo valve spool zero – C: 0.0; D: 0.0; K: 0.00
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.12% with respect to travel range of ±500mm(0.6mm error)–See Figure 2.1.3.3.

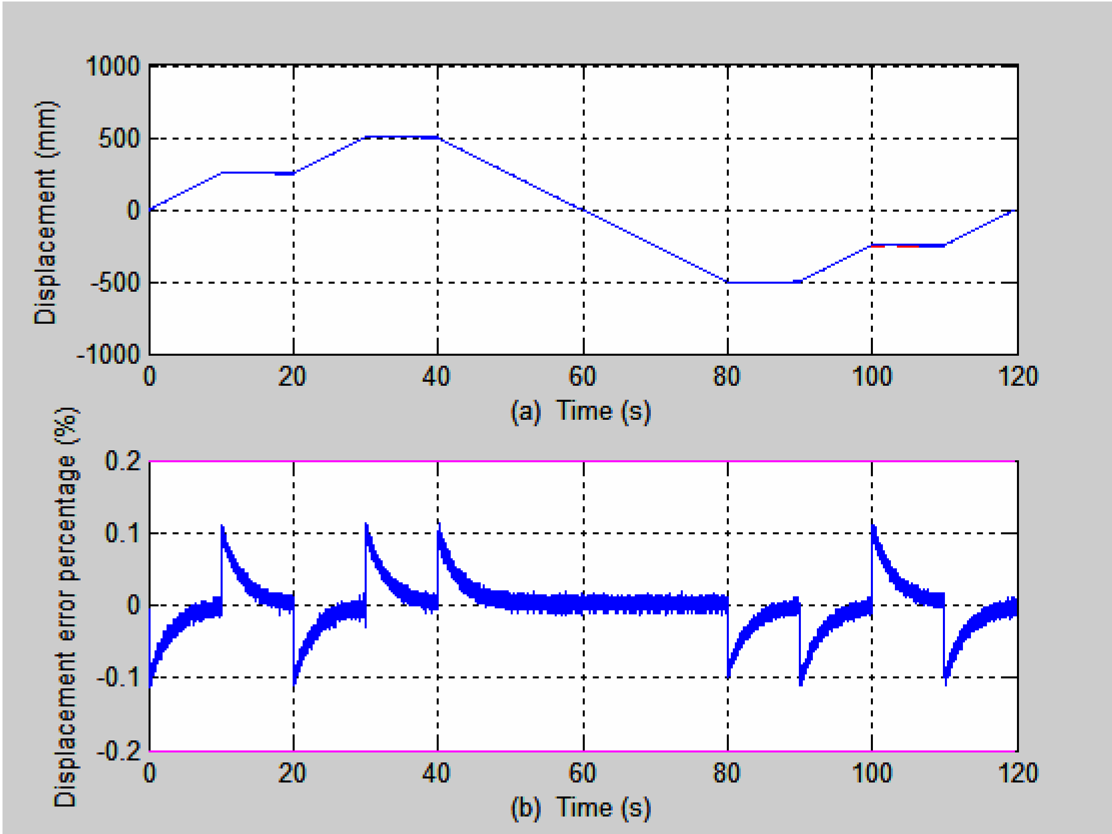


Figure 2.1.3.3. 100% stroke accuracy test at Actuator 2 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

2.2 10Hz displacement bandwidth test
(±3.81mm, ±7.62mm, ±11.43mm sinusoid for 1, 2, 3 valves respectively)

- Test task: Sinusoid displacement control on Actuator 2 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

Servo Control Parameter
Configuration --1 valve C PID control at actuator 2
PID control -- Kp=60; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; (D: 0.0; K: 0.0)
Servo valve offset – C: 0.0; (D: -0.859; K: 0.469)
Servo valve spool zero – C: 0.0; (D: 0.0; K: 0.00)

Hydraulic supply pressure – 3000psi
Hydraulic supply flow rate – 310gpm

Test result
Dynamic bandwidth: 10Hz@0.15inch (19% attenuation, less than 3 db) – See Figure 2.2.1.

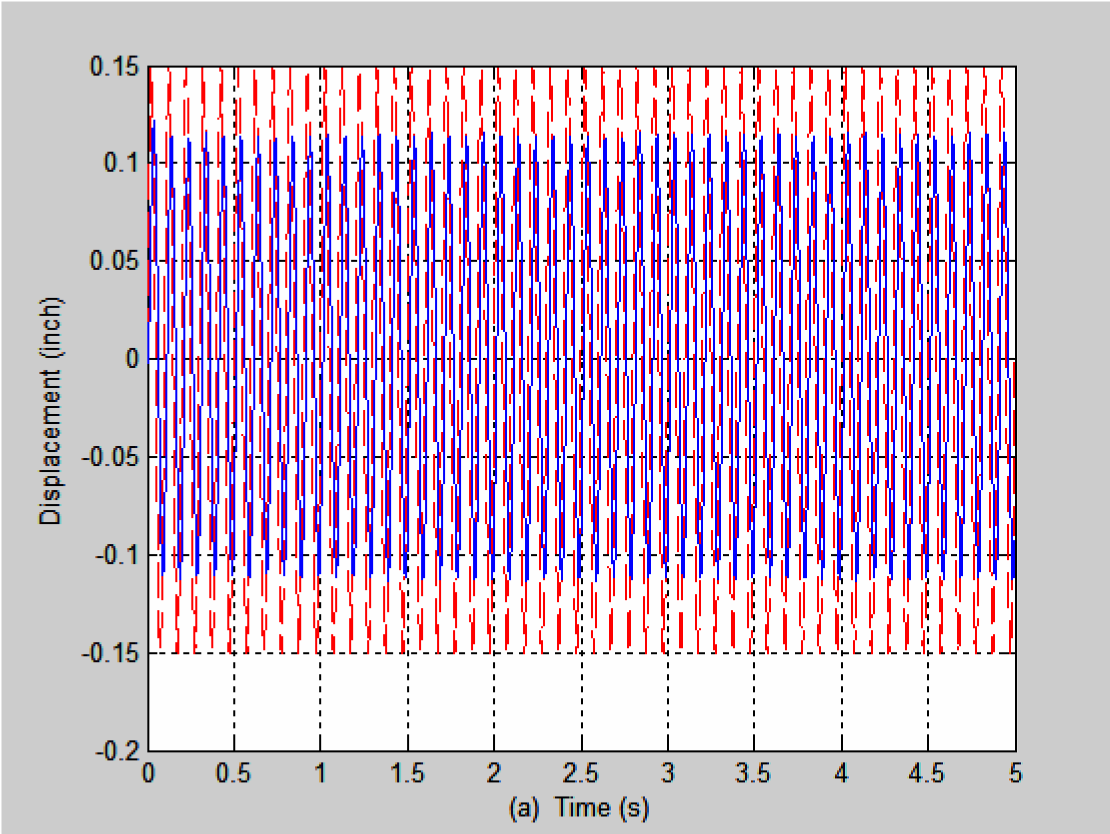


Figure 2.2.1. Dynamic bandwidth test at Actuator 2 (Test 2: 1 vale)
Red: command (0.15inch@10Hz); Blue: response (0.11inch@10Hz)

- Test task: Sinusoid displacement control on Actuator 2 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

<u>Servo Control Parameter</u>
Configuration --2 valve CD PID control at actuator 2
PID control -- Kp=35; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; (K: 0.0)
Servo valve offset – C: 0.0; D: -0.859; (K: 0.469)
Servo valve spool zero – C: 0.0; D: 0.0; (K: 0.00)
Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 620gpm

<u>Test result</u>
Dynamic bandwidth: 10Hz@0.30inch (15% attenuation, less than 3 db) – See Figure 2.2.2.

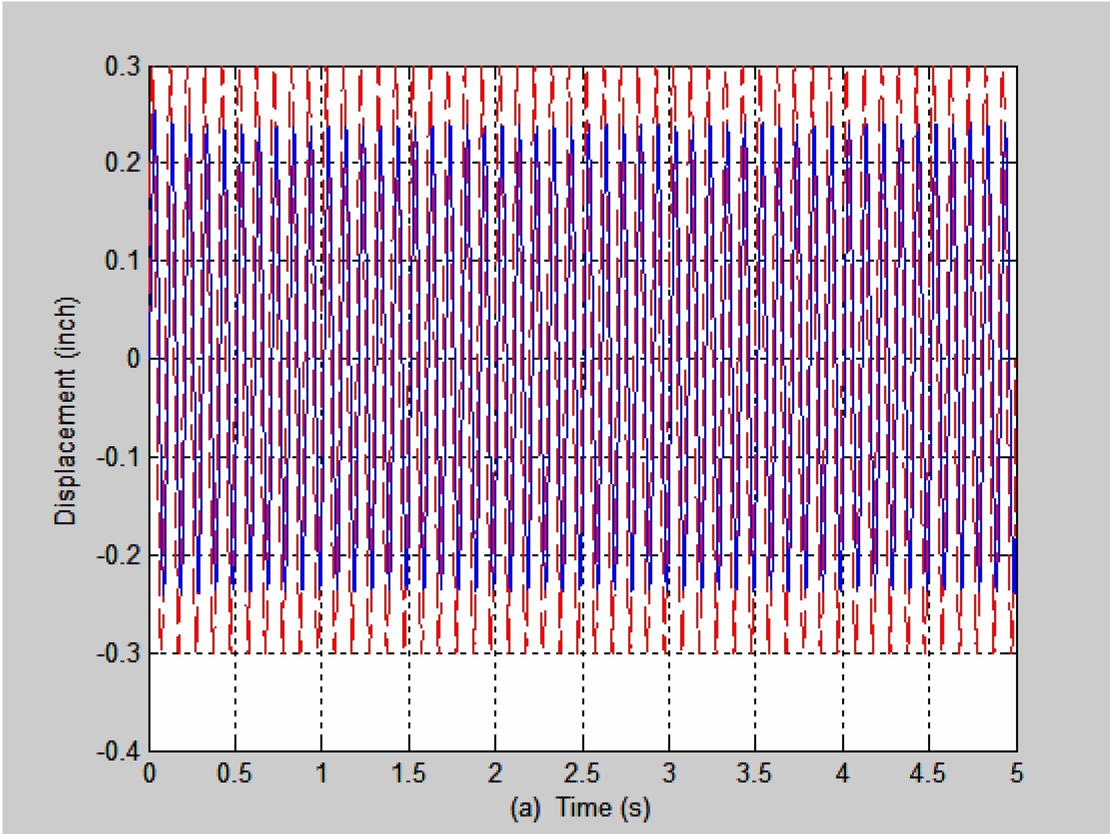


Figure 2.2.2. Dynamic bandwidth test at Actuator 2 (Test 2: 2 vales)
Red: command (0.30inch@10Hz); Blue: response (0.22inch@10Hz)

- Test task: Sinusoid displacement control on Actuator 2 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/2/2004

Servo Control Parameter
Configuration --3 valve CDK PID control at actuator 2
PID control -- Kp=23; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; K: 0.88
Servo valve offset (%) – C: 0.0; D: -0.859; K: 0.469
Servo valve spool zero (%) – C: 0.0; D: 0.0; K: 0.00
Hydraulic supply pressure – 3000psi
Hydraulic supply flow rate – 930gpm

Test result
Dynamic bandwidth: 10Hz@0.45inch (16% attenuation, less than 3 db) – See Figure 2.2.3.

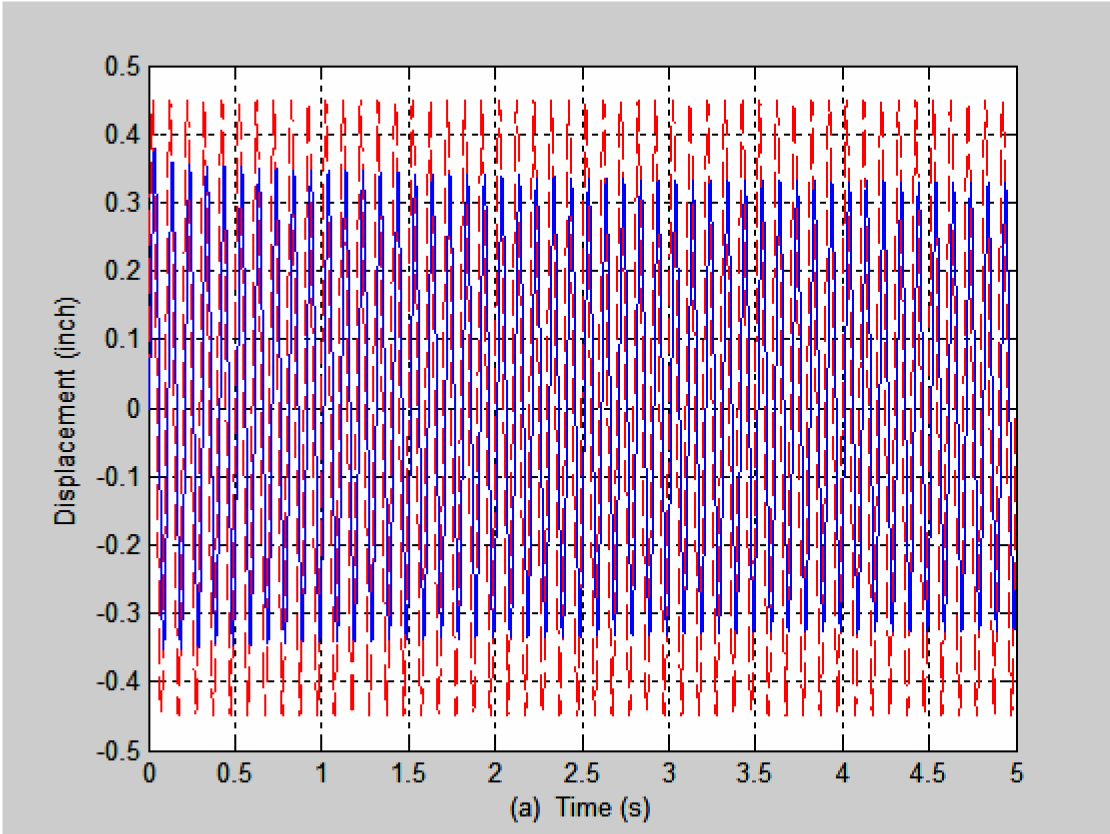


Figure 2.2.3. Dynamic bandwidth test at Actuator 2 (Test 2: 3 valves)
Red: command (0.45inch@10Hz); Blue: response (0.32inch@10Hz)

2.3 1.14m/s high velocity test

- Test task: High velocity test on Actuator 2 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/16/2004

Servo Control Parameter
Configuration--3 valve CDG PID control at actuator 2
PID control-- Kp=45; Ki=5; Kd =0; f=39.8Hz
Servo valve loop gain – Kv=30
Servo valve input scale – C: 0.87; D: 0.95; G: 1.0
Servo valve offset (%) – C: 0.0; D: -0.859; G: -2.266
Servo valve spool zero (%) – C: 0.0; D: 0.0; G: 1.106
Hydraulic supply pressure: 3200psi
Hydraulic supply flow rate: 1500gpm

Test result
Speed reaches 1.14 m/s – See Figures 2.3.1.

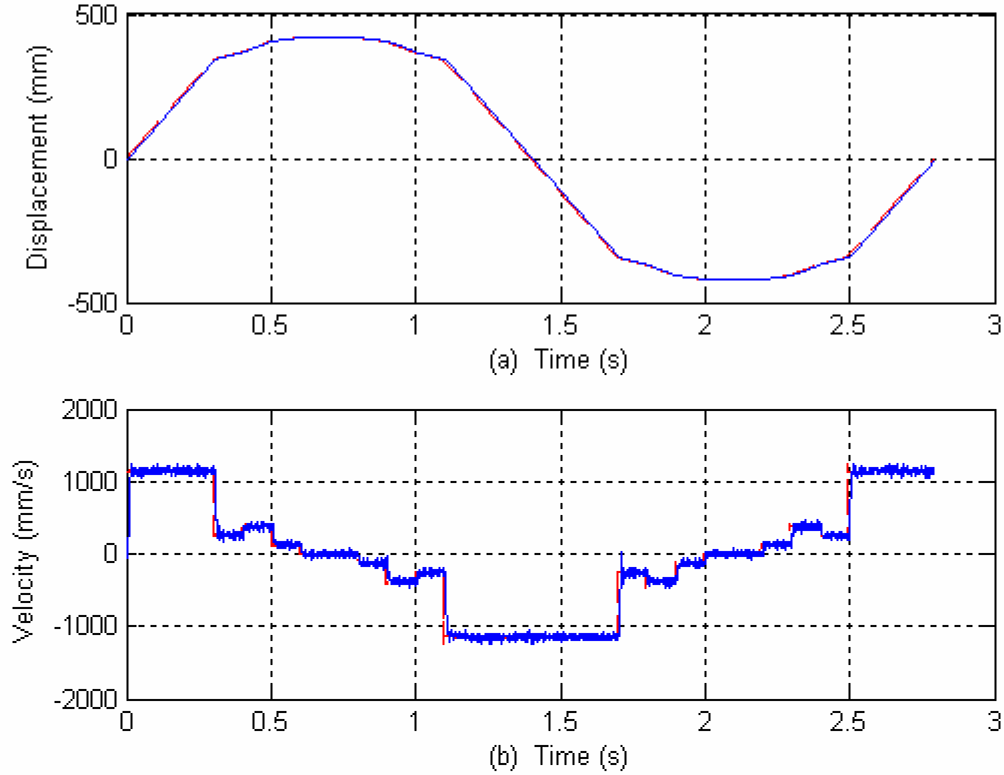


Figure 2.3.1. High velocity test at Actuator 2 (Test 3)
(a) Displacement (mm) – Red: command; Blue: response
(b) Velocity (mm/s) -- Red: command; Blue: response

2.4 277KW power test with single valve operation (0.27m/s@1000KN)

- Test task: Power test on Actuator 2 (1 valve, against Load Actuator 1)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/11/2004

Servo Control Parameter
Configuration:
1 valve C displacement PID control at Actuator 2
1 valve A load PID control at Actuator 1
Actuator 2 displacement PID control-- Kp=70; Ki=2; Kd =0.1; f=39 (COM, 2nd test)
Actuator 1 load PID control-- Kp=2; Ki=3; Kd =-1; f=10Hz (COM, 2nd test)
Actuator 2 displacement PID control-- Kp=50; Ki=2; Kd =0.1; f=39 (TEN, 3rd test)
Actuator 1 load PID control-- Kp=1.8; Ki=3; Kd =-1; f=10Hz (TEN,3rd test)
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; C:0.87;
Servo valve offset (%) – A: -2.031; C: 1.406
Servo valve spool zero (%) – A: -0.703; C: 0.703
Hydraulic supply pressure: 3377psi

Test result

Power capacity: power output at Actuator 2 reaches 277KW. – See Figure 2.4.1.

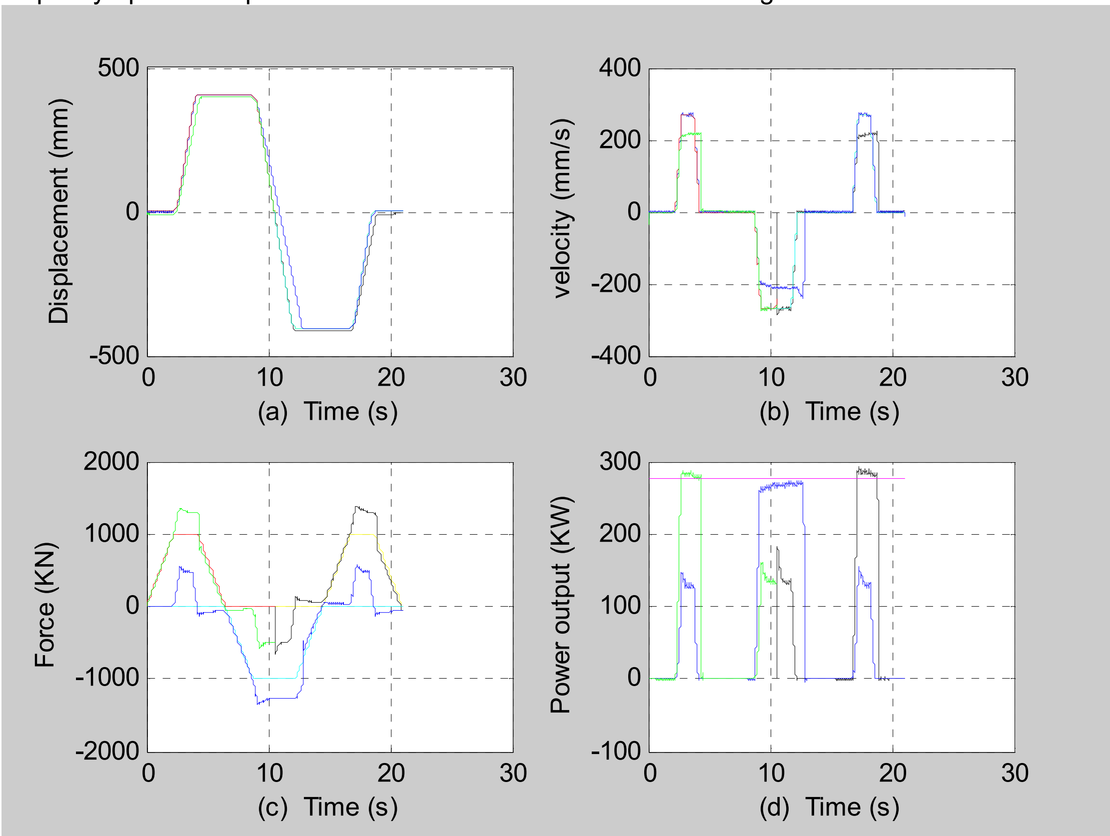


Figure 2.4.1.   Power test at Actuator 2 (Test 4: 1 valve; Actuator 1 simulates load)
(Actuator 2 –displacement and Actuator 1—load)
(a) Displacement (mm)   (b) Velocity (mm/s)
(c)Force (KN)   (d) Power (KW)
– Red: command (1st test); Green: response (1st test)
– Cyan: command (2nd test); Blue: response (2nd test)
– Yellow: command (3rd test); Black: response (3rd test)
Magenta: power target value (277KW)

2.5 0.2% force accuracy test (load range: ±1695KN)

2.5.1 5% load range force accuracy test (1, 2, 3 valves)

- Test task: ±84.75KN force control on Actuator 2 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

<u>Servo Control Parameter</u>
Configuration--1 valve C PID control at actuator 2
PID control-- Kp=2.8; Ki=0.8; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; (D: 0.0; K: 0.0)
Servo valve offset (%)– C: 1.875; (D: 0.391; K: -0.859)
Servo valve spool zero (%) – C: 0.937; (D: -0.781; K: 0.703)
Hydraulic supply pressure: 3300psi

<u>Test result</u>

Static accuracy: 0.2% with respect to force range of ±84.75KN (0.17KN error)–See Figure 2.5.1.1.

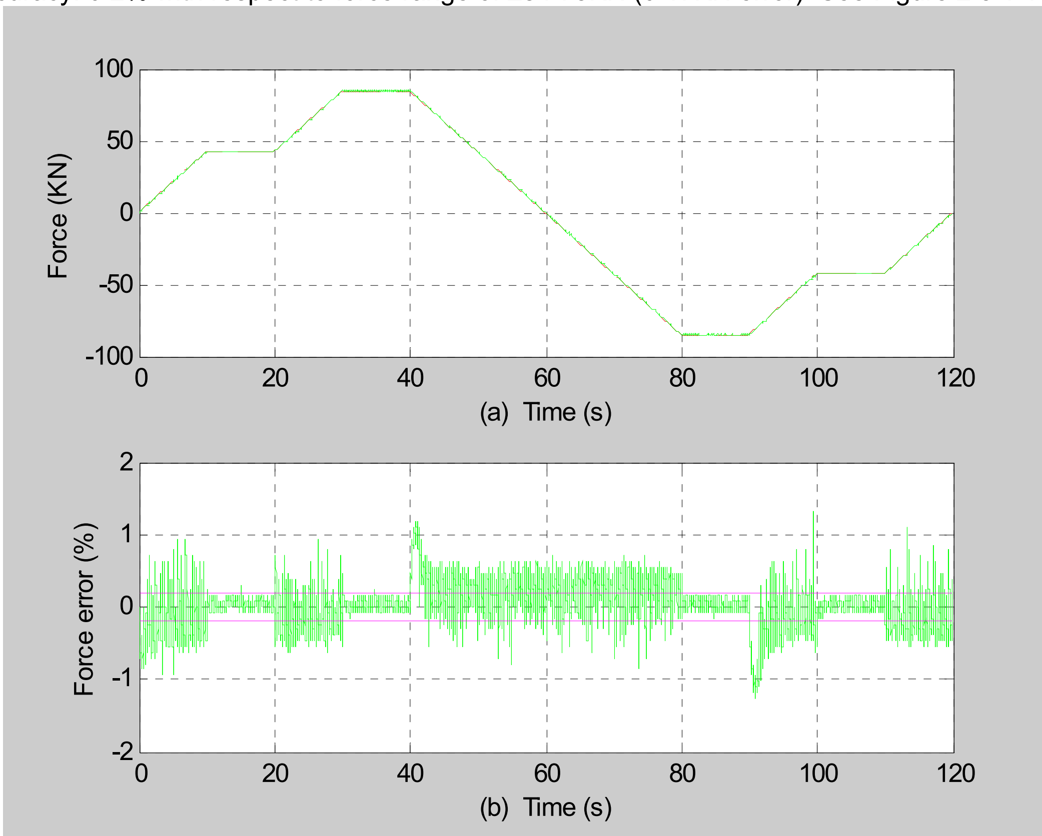


Figure 2.5.1.1. 5% maximum force accuracy test at Actuator 2 (Test 5.1: 1 valve)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±84.75KN; – Green: error percentage;
-- Magenta: error acceptance boundary ±0.2%

- Test task: ±84.75KN force control on Actuator 2 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

Servo Control Parameter
Configuration--2 valves CD PID control at actuator 2
PID control-- Kp=2.5; Ki=0.8; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; (K: 0.88)
Servo valve offset (%)– C: 1.875; D: 0.391; (K: -0.859)
Servo valve spool zero (%) – C: 0.937; D: -0.781; (K: 0.703)
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±84.75KN(0.17KN error) –See Figure 2.5.1.2.

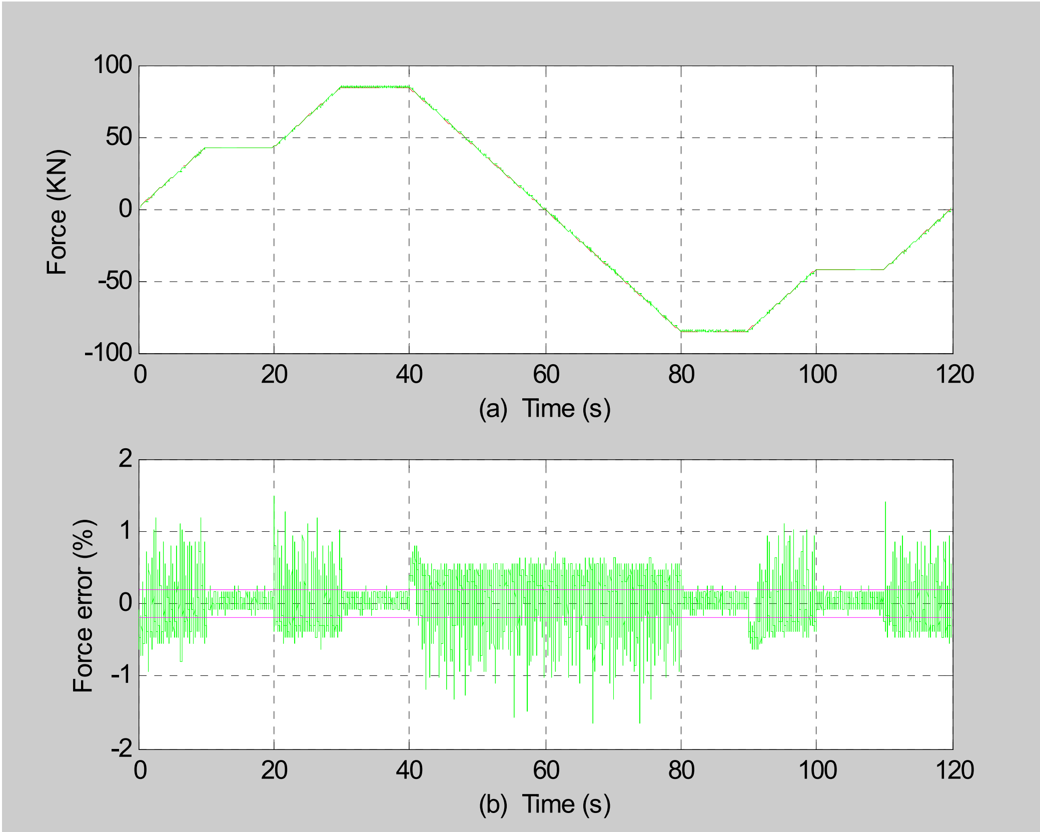


Figure 2.5.1.2. 5% maximum force accuracy test at Actuator 2 (Test 5.1: 2 valves)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±84.75KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

- Test task: ±84.75KN force control on Actuator 2 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

Servo Control Parameter
Configuration--3 valves CDK PID control at actuator 2
PID control-- Kp=2.0; Ki=0.8; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; K: 0.88
Servo valve offset (%)– C: 1.875; D: 0.391; K: -0.859
Servo valve spool zero (%) – C: 0.937; D: -0.781; K: 0.703
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±84.75KN (0.17KN error)–See Figure 2.5.1.3.

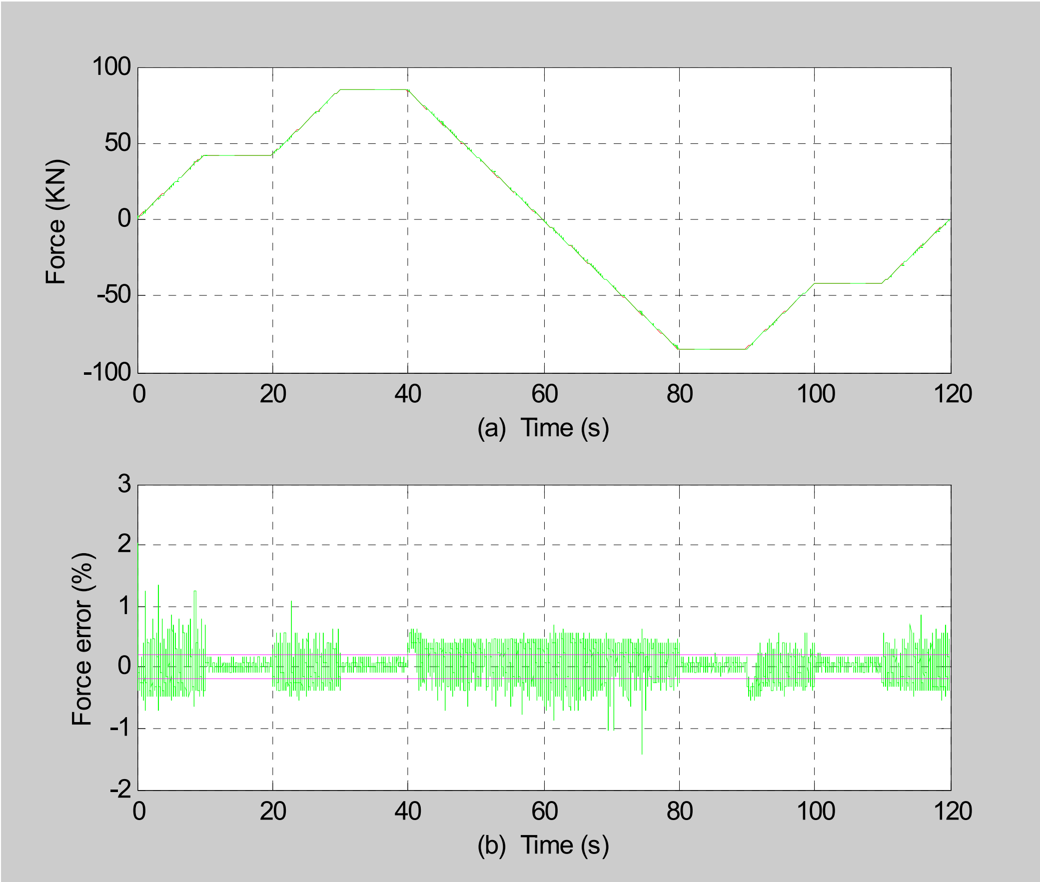


Figure 2.5.1.3. 5% maximum force accuracy test at Actuator 2 (Test 5.1: 3 valves)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±84.75KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

2.5.2 20% load range force accuracy test (1, 2, 3 valves)

- Test task: ±339KN force control on Actuator 2 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

<u>Servo Control Parameter</u>
Configuration--1 valve C PID control at actuator 2
PID control-- Kp=3.5; Ki=0.8; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; (D: 0.0; K: 0.0)
Servo valve offset (%)– C: 1.875; (D: 0.391; K: -0.859)
Servo valve spool zero (%) – C: 0.937; (D: -0.781; K: 0.703)
Hydraulic supply pressure: 3300psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ±339KN (0.68KN error) –See Figure 2.5.2.1.

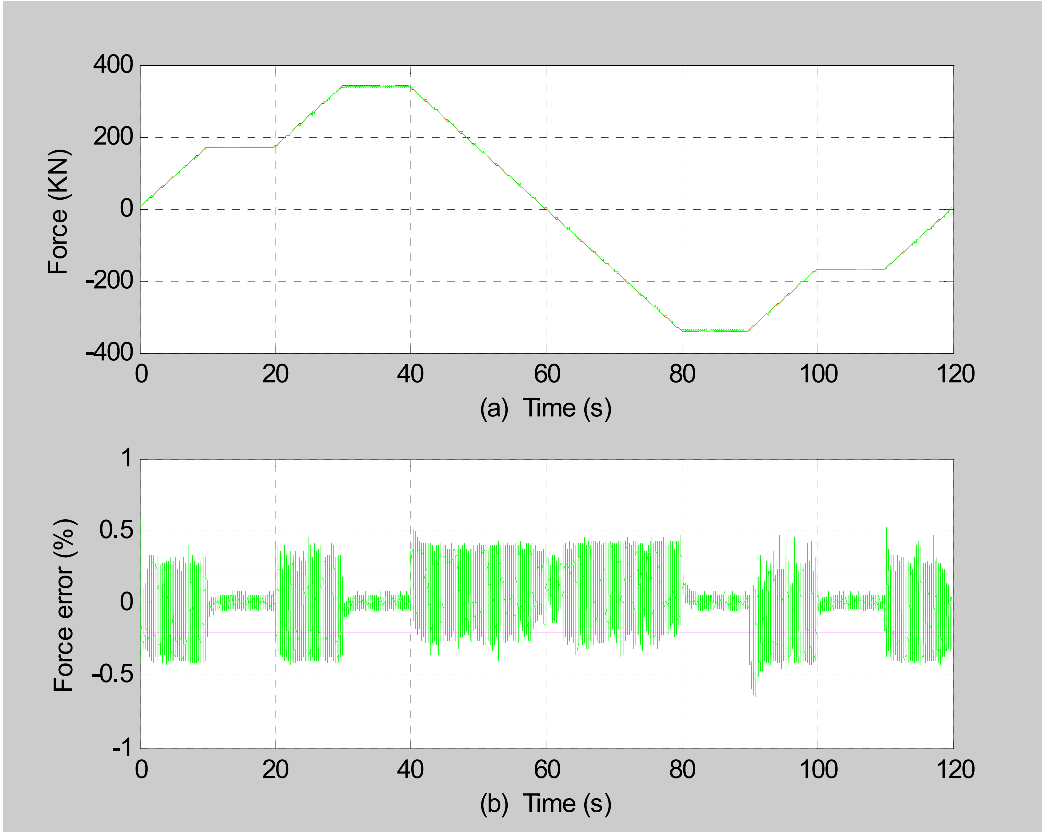


Figure 2.5.2.1. 20% maximum force accuracy test at Actuator 2 (Test 5.1: 1 valve)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±339KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

- Test task: ±339KN force control on Actuator 2 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

Servo Control Parameter
Configuration--2 valve CD PID control at actuator 2
PID control-- Kp=2.5; Ki=0.8; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; (K: 0.0)
Servo valve offset (%)– C: 1.875; D: 0.391; (K: -0.859)
Servo valve spool zero (%) – C: 0.937; D: -0.781; (K: 0.703)
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±339KN (0.68KN error) –See Figure 2.5.2.2.

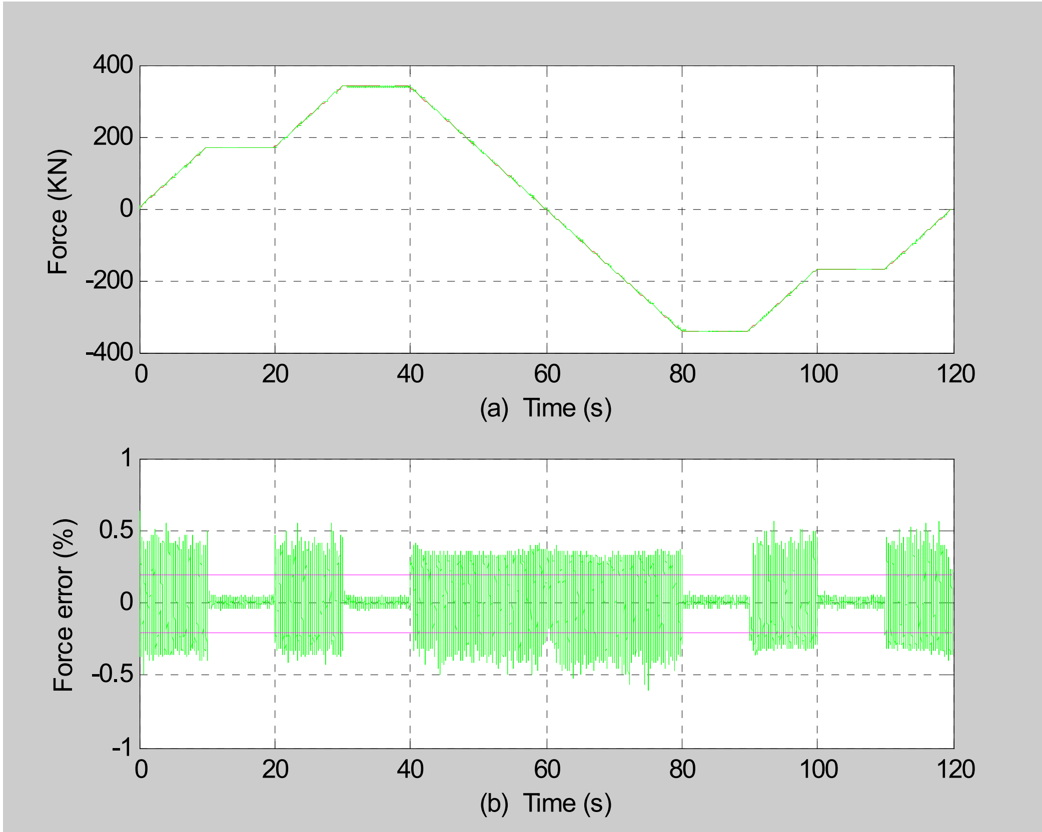


Figure 2.5.2.2. 20% maximum force accuracy test at Actuator 2 (Test 5.1: 2 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±339KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

- Test task: ±339KN force control on Actuator 2 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

<u>Servo Control Parameter</u>
Configuration--3 valve CDK PID control at actuator 2
PID control-- Kp=2.0; Ki=0.8; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; K: 0.88
Servo valve offset (%)– C: 1.875; D: 0.391; K: -0.859
Servo valve spool zero (%) – C: 0.937; D: -0.781; K: 0.703
Hydraulic supply pressure: 3300psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ±339KN (0.68KN error) –See Figure 2.5.2.3.

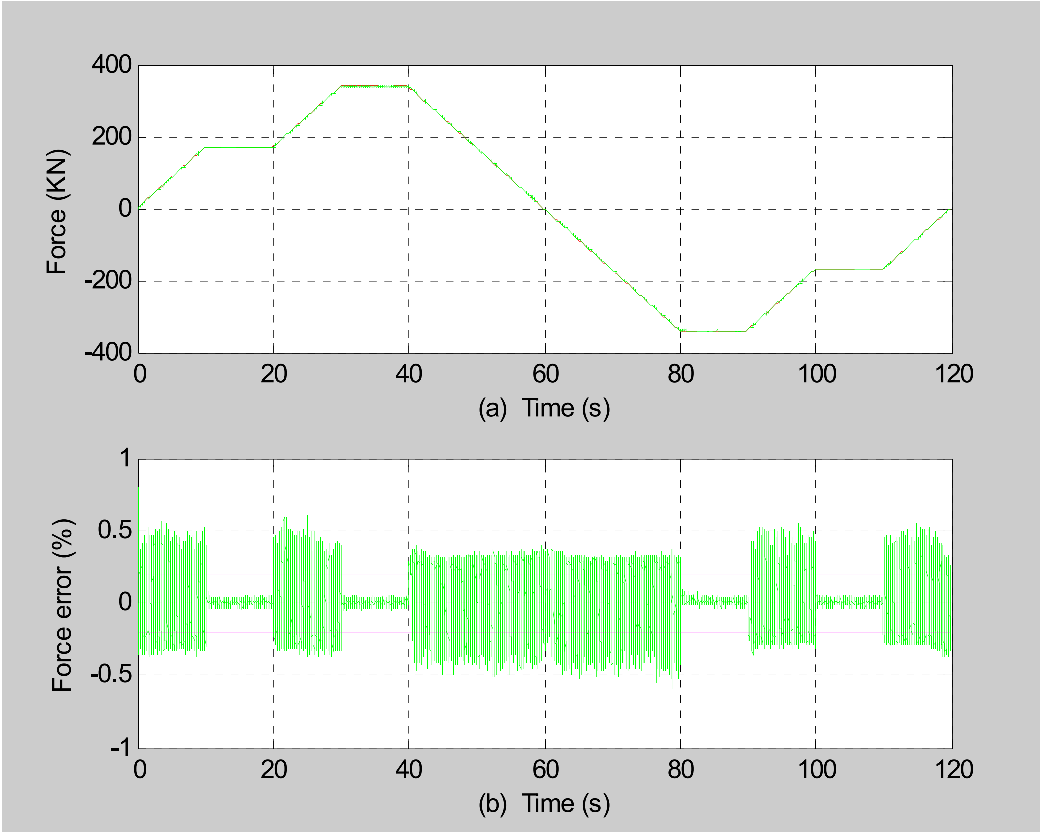


Figure 2.5.2.3. 20% maximum force accuracy test at Actuator 2 (Test 5.1: 3 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±339KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

2.5.3 100% load range force accuracy test (1, 2, 3 valves)

- Test task: ±1695KN force control on Actuator 2 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/13/2004

<u>Servo Control Parameter</u>
Configuration--1 valve C PID control at actuator 2

<u>Tension:</u>
PID control-- Kp=2.5; Ki=1.4; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; (D: 0.0; K: 0.0)
Servo valve offset (%) – C: 0.859; (D: 0.391; K: -0.859)
Servo valve spool zero (%) – C: 0.937; (D: -0.547; K: 0.703)

<u>Compression:</u>
PID control-- Kp=2.5; Ki=1.4; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30

Servo valve input scale – C: 0.87; (D: 0.95; K: 0.88)
Servo valve offset (%) – C: 0.859; (D: 0.391; K: -0.859)
Servo valve spool zero (%) – C: 0.937; (D: -3.828; K: -1.484)
Hydraulic supply pressure: 3333psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ± 1695KN (3.3KN error) –See Figure 2.5.3.1.

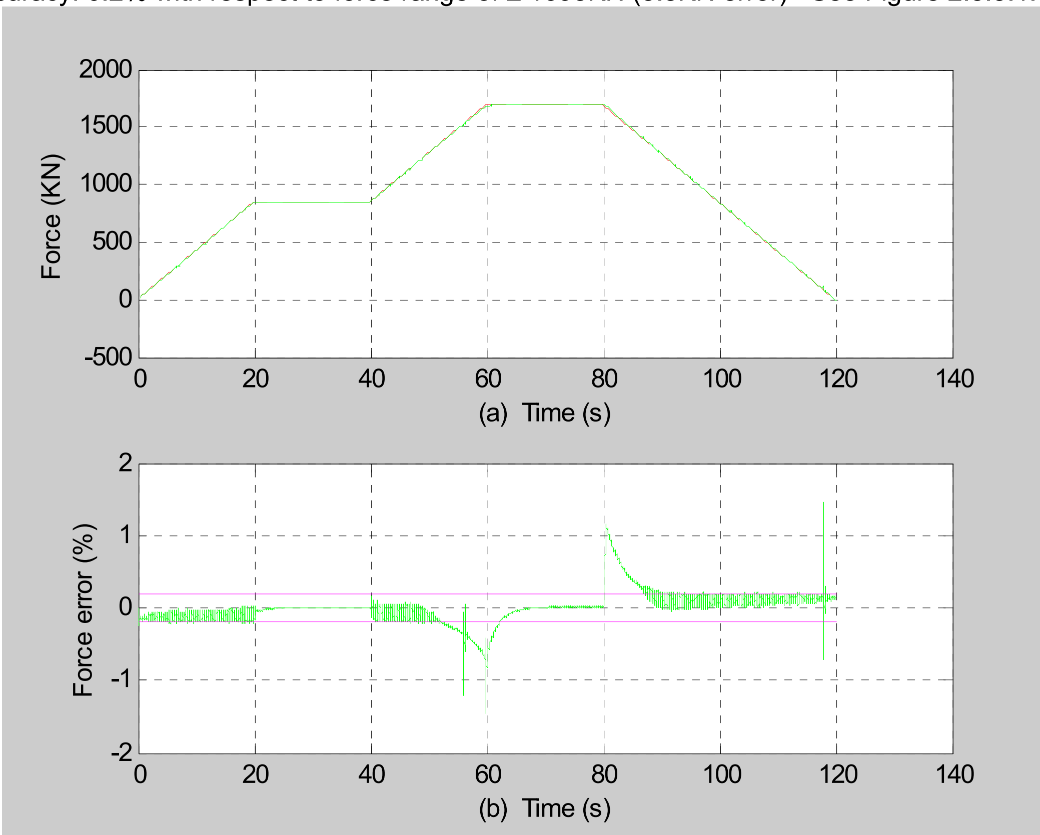


Figure 2.5.3.1a. 100% maximum force accuracy test at Actuator 2 (Test 5.1: 1 valve) - Tension
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN ; Green: error percentage;
– Magenta: error acceptance boundary ±0.2%

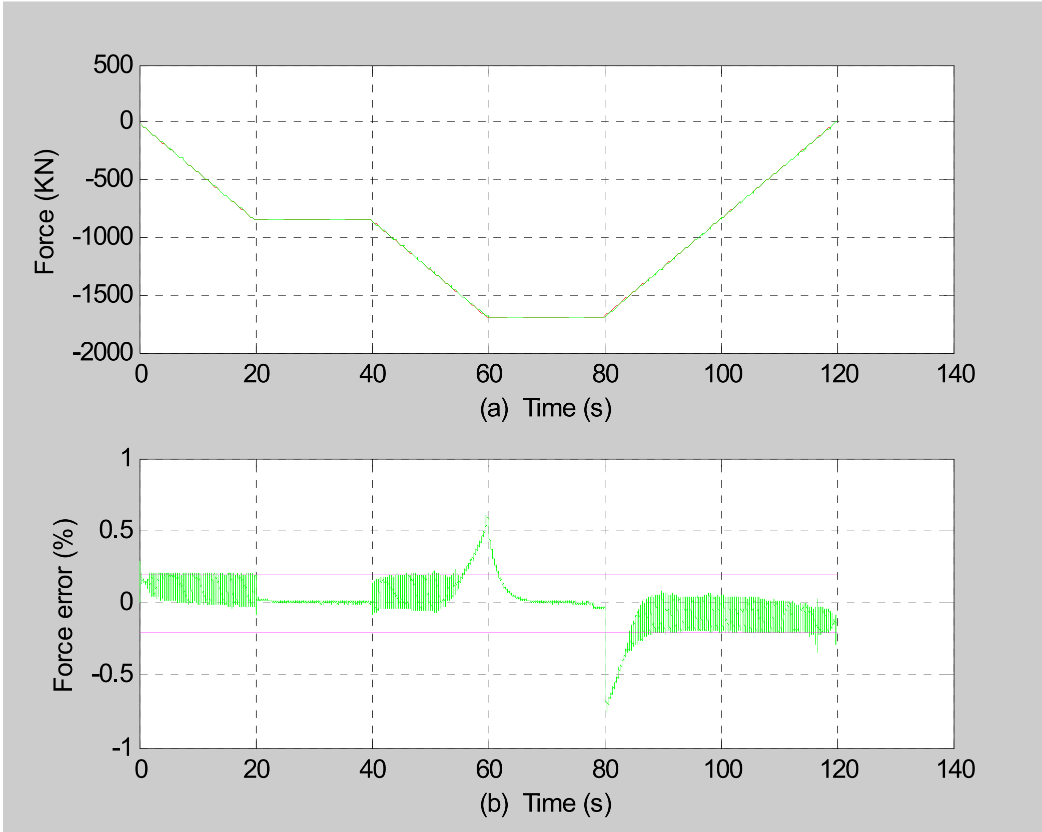


Figure 2.5.3.1b. 100% maximum force accuracy test at Actuator 2 (Test 5.1: 1 valve) - Compression
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
--Magenta: error acceptance boundary ±0.2%

- Test task: ±1695KN force control on Actuator 2 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/13/2004

<u>Servo Control Parameter</u>
Configuration--2 valve CD PID control at actuator 2
PID control-- Kp=1.8; Ki=1.8; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; (K: 0.0)
Servo valve offset (%)– C: 1.875; D: 0.391; (K: -0.859)
Servo valve spool zero (%) – C: 0.937; D: -0.781; (K: -0.469)
Hydraulic supply pressure: 3333psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ±1695KN (3.3KN error) –See Figure 2.5.3.2.

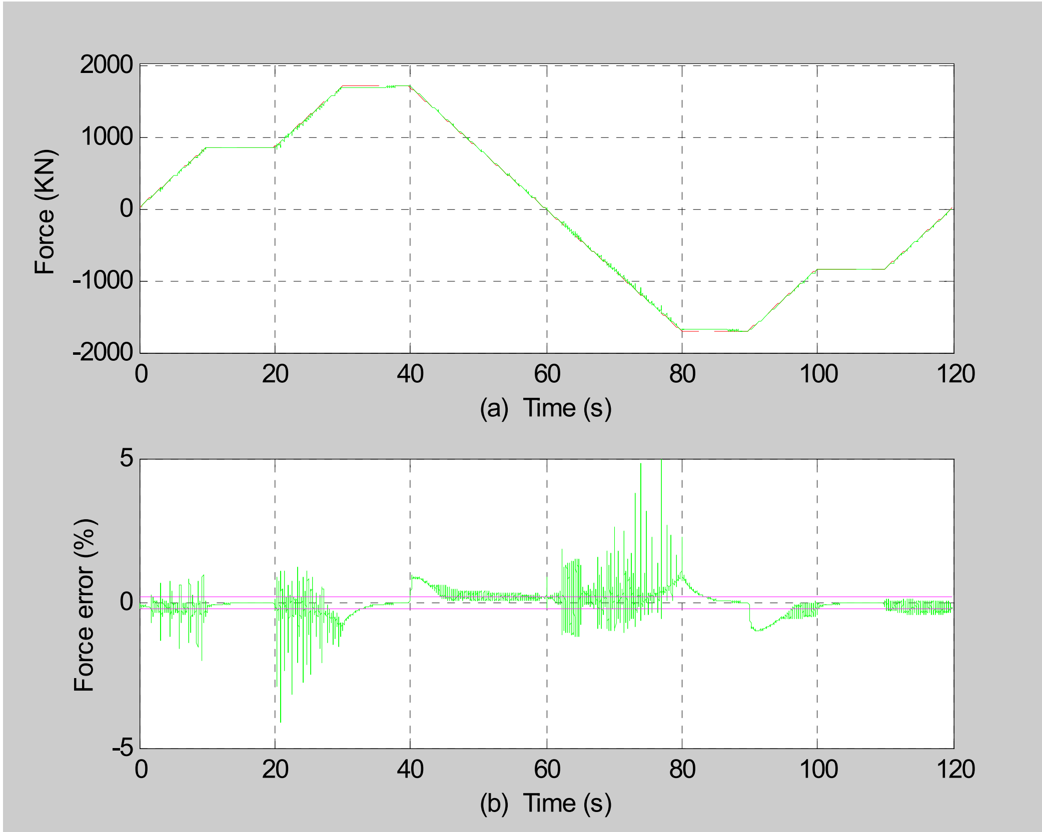


Figure 2.5.3.2. 100% maximum force accuracy test at Actuator 2 (Test 5.1: 2 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

- Test task: ±1695KN force control on Actuator 2 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/13/2004

Servo Control Parameter
Configuration--3 valve CDK PID control at actuator 2
PID control-- Kp=1.8; Ki=1.8; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; K: 0.88
Servo valve offset (%)– C: 1.875; D: 0.391; K: -0.859
Servo valve spool zero (%) – C: 0.937; D: -0.781; K: 0.703
Hydraulic supply pressure: 3333psi

Test result
Static accuracy: 0.2% with respect to force range of ±1695KN (3.3KN error) –See Figure 2.5.3.3.

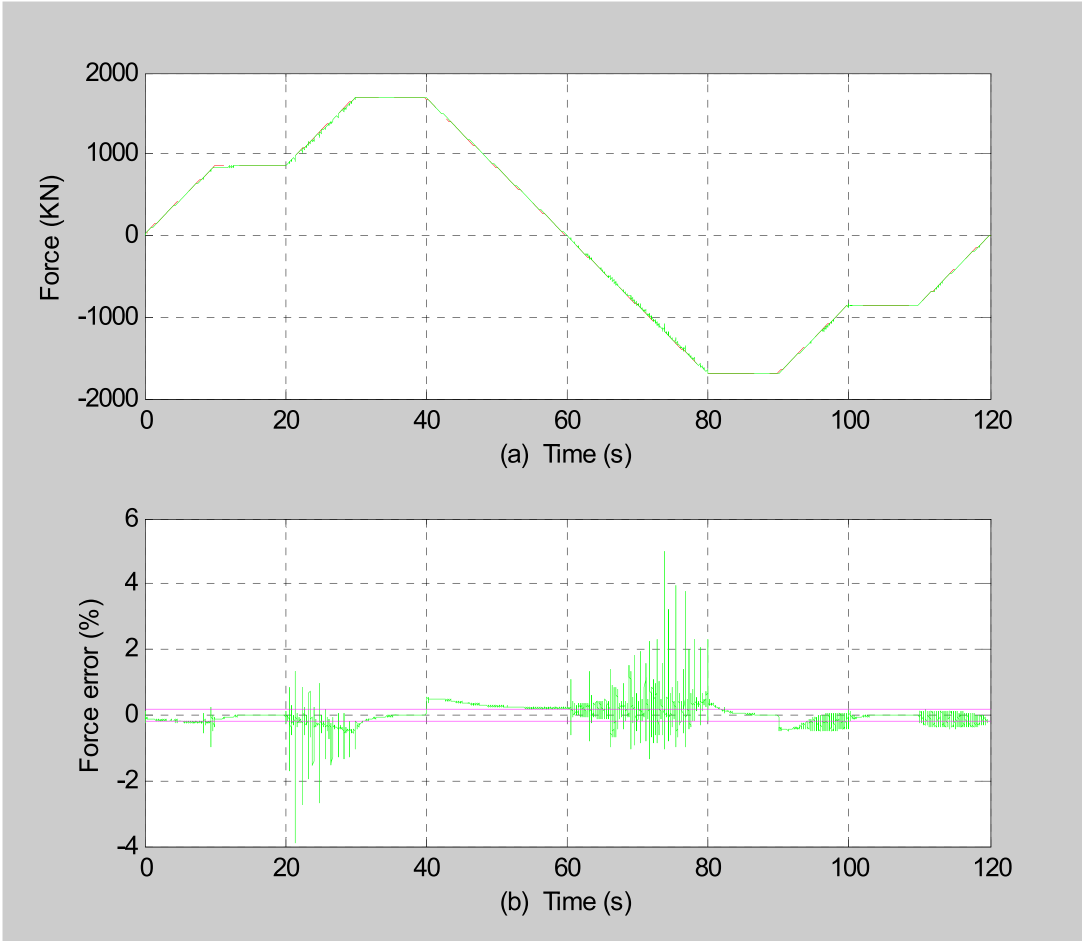


Figure 2.5.3.3. 100% maximum force accuracy test at Actuator 2 (Test 5.1: 3 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

2.6 10Hz force bandwidth test (±1000KN sinusoid for 1, 2, 3 valves)

- Test task: Sinusoid force control on Actuator 2 (1valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

<u>Servo Control Parameter</u>
Configuration--1 valve C PID control at actuator 2
PID control-- Kp=4.0; Ki=3.0; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; (D: 0.0; K: 0.0)
Servo valve offset (%) – C: 0.0; (D: -0.859; K: 0.469)
Servo valve spool zero (%) – C: 0.0; (D: 0.0; K: 0.00)
Hydraulic supply pressure: 3300psi

Test result
Dynamic bandwidth: 10Hz@1000KN (-10% attenuation, less than 3 db) –See Figure 2.6.1.

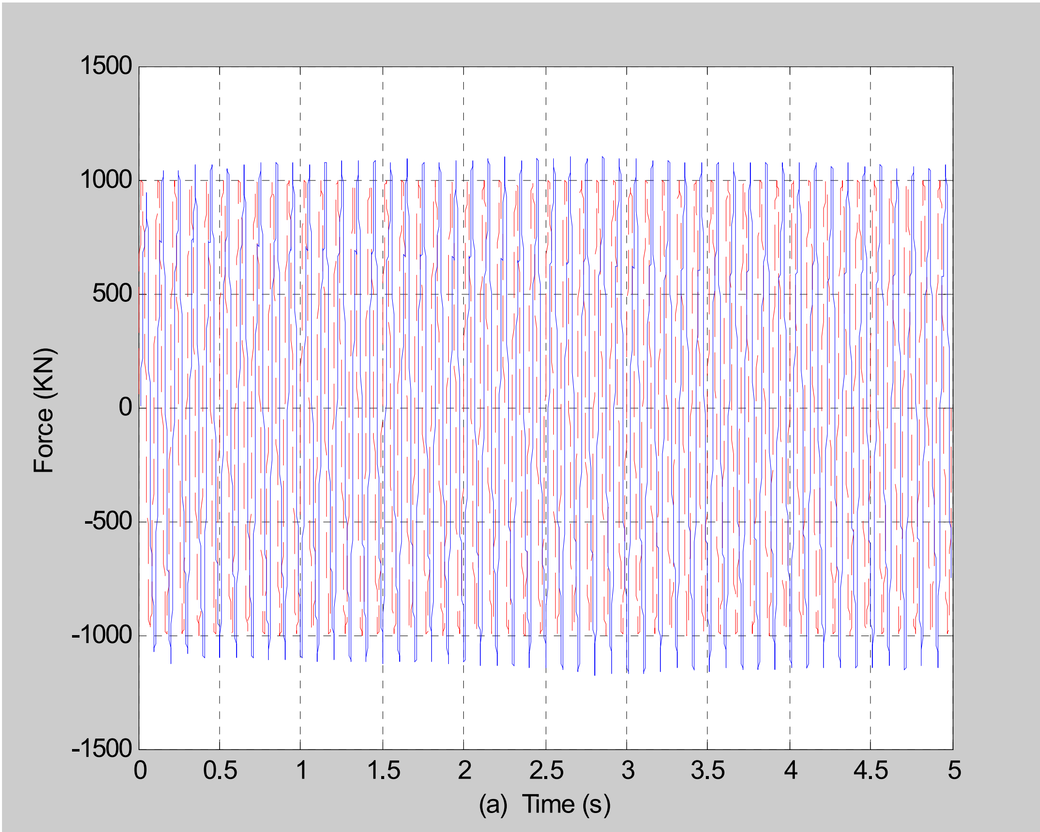


Figure 2.6.1. Force control dynamic bandwidth test at Actuator 2 (Test 5.2: 1 valve)
Red: command (1000KN@10Hz); Blue: response (1100KN@10Hz)

- Test task: Sinusoid force control on Actuator 2 (2valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

Servo Control Parameter
Configuration--2 valve CD PID control at actuator 2
PID control-- Kp=2.5; Ki=3.0; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; (K: 0.0)
Servo valve offset (%) – C: 0.0; D: -0.859; (K: 0.469)
Servo valve spool zero (%) – C: 0.0; D: 0.0; (K: 0.00)
Hydraulic supply pressure: 3300psi

Test result
Dynamic bandwidth: 10Hz@1000KN (-15% attenuation, less than 3 db) –See Figure 2.6.2.

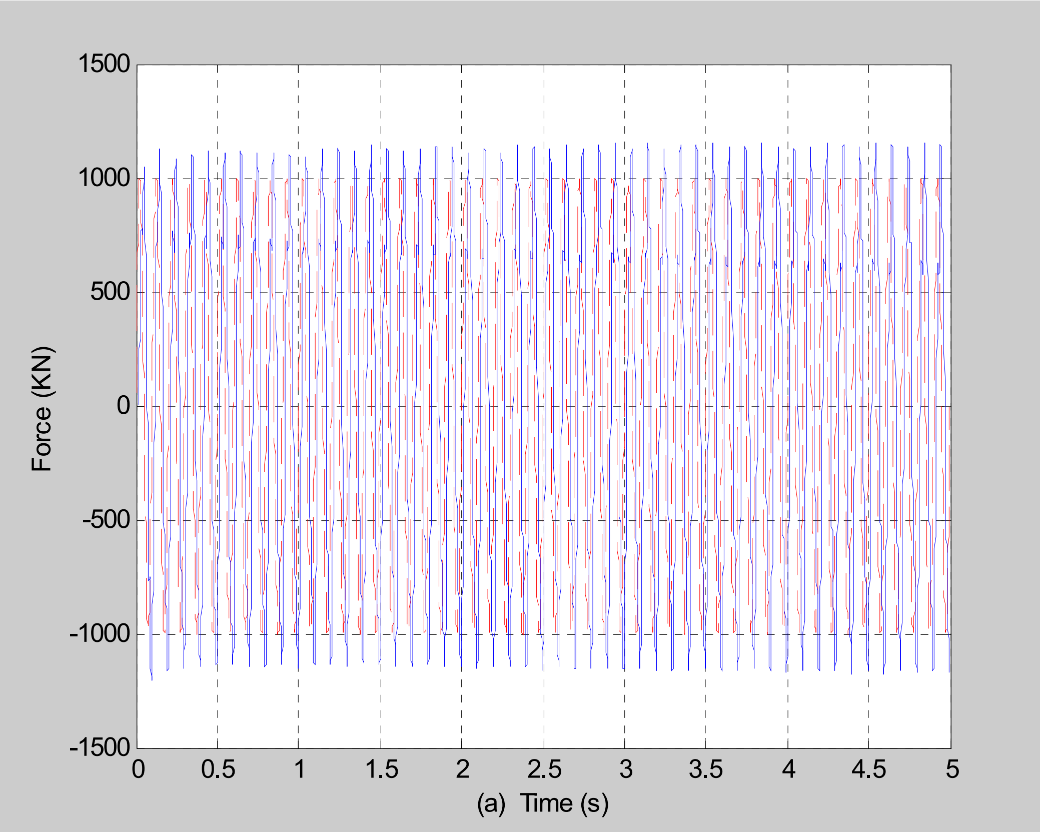


Figure 2.6.2. Force control dynamic bandwidth test at Actuator 2 (Test 5.2: 2 valves)
Red: command (1000KN@10Hz); Blue: response (1200KN@10Hz)

- Test task: Sinusoid force control on Actuator 2 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

Servo Control Parameter
Configuration--3 valve CDK PID control at actuator 2
PID control-- Kp=1.5; Ki=3.0; Kd =-1.0; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – C: 0.87; D: 0.95; K: 0.88
Servo valve offset (%)– C: 1.406; D: -1.016; K: 0.0
Servo valve spool zero (%) – C: -1.641; D: 0.625; K: 2.969
Hydraulic supply pressure: 3300psi

Test result
Dynamic bandwidth: 10Hz@1000KN (-15% attenuation, less than 3 db) –See Figure 2.6.3.

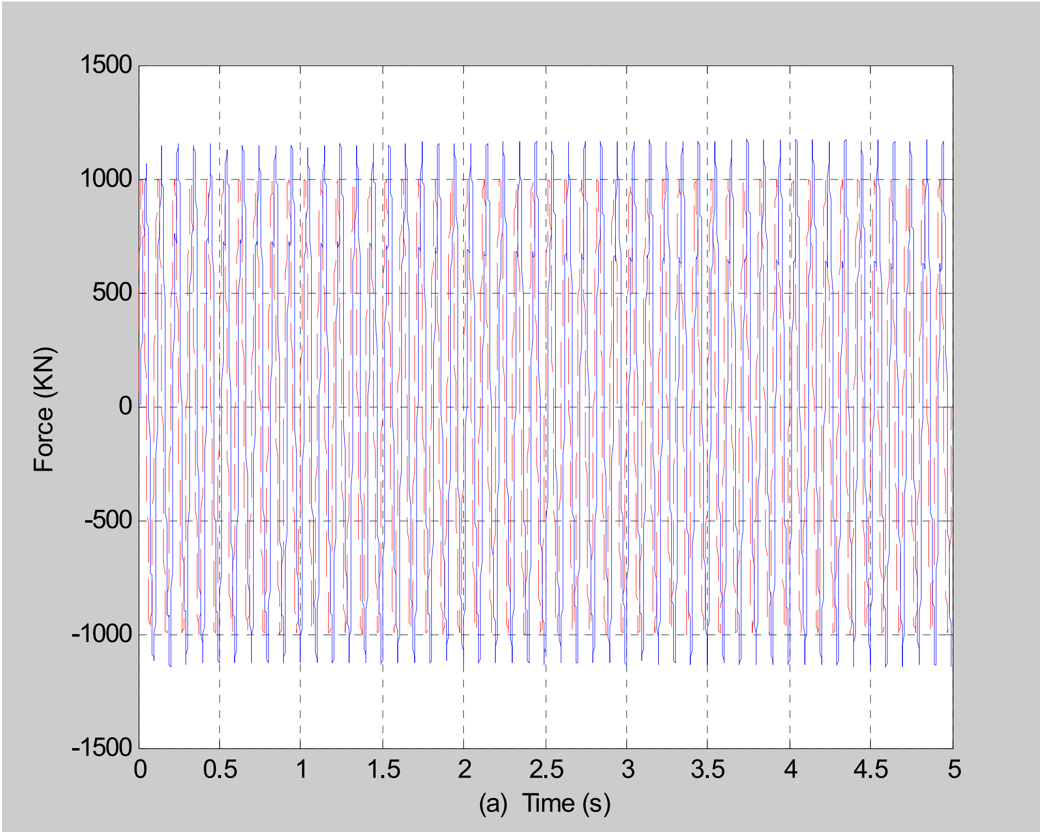


Figure 2.6.3. Force control dynamic bandwidth test at Actuator 2 (Test 5.2: 3 valves)
Red: command (1000KN@10Hz); Blue: response (1200KN@10Hz)

3 ACTUATOR 3

3.1 0.2% displacement accuracy test (travel range: ±500mm)

3.1.1 10% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±50mm displacement control on Actuator 3 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

Servo Control Parameter
Configuration--1 valve E PID control at actuator 3
PID control-- Kp=40; Ki=10; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; (F: 0.0; K: 0.0)
Servo valve offset – E: 1.484; (F: 1.250; K: 0.469)
Servo valve spool zero – E: 2.50; (F: 1.641; K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 3.1.1.1.

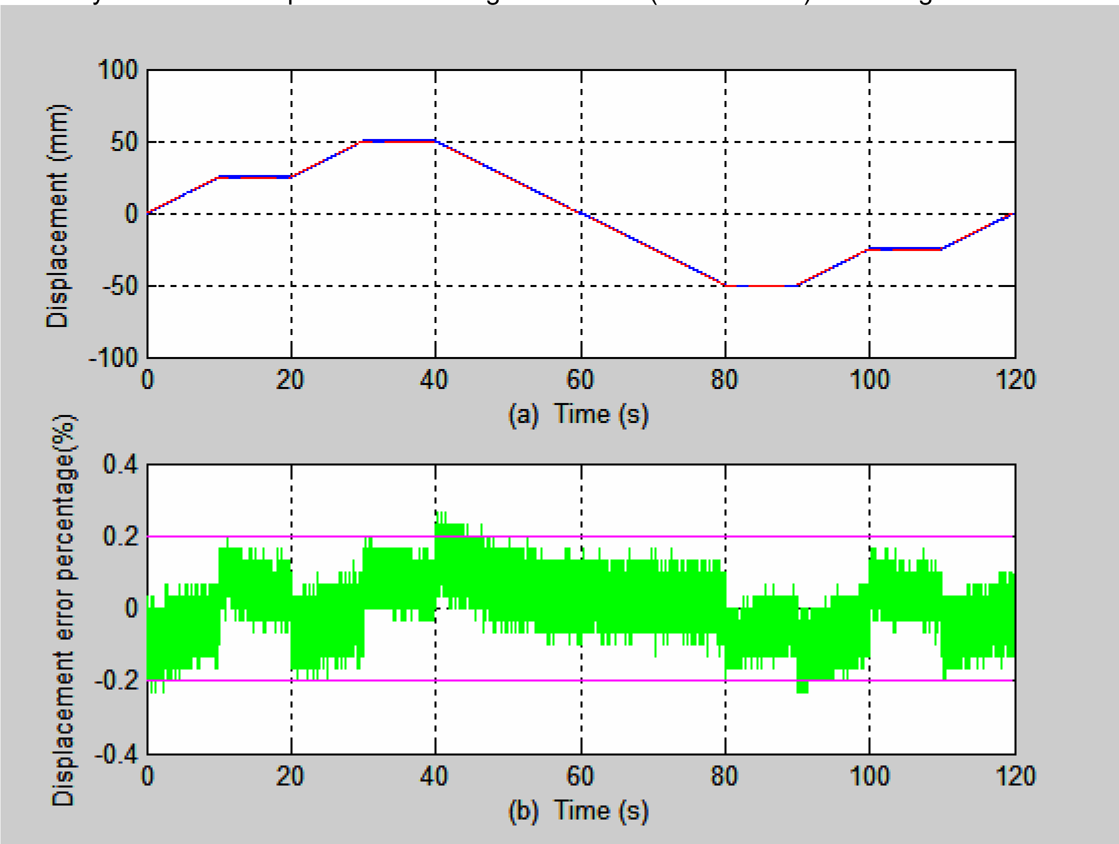


Figure 3.1.1.1. 10% stroke accuracy test at Actuator 3 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 3 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

Servo Control Parameter

Configuration--2 valve EF PID control at actuator 3
PID control-- Kp=20; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.0; (K: 0.0)
Servo valve offset – E: 1.484; F: 1.250; (K: 0.469)
Servo valve spool zero – E: 2.50; F: 1.641; (K: 0.00)
Hydraulic supply pressure: 3000psi

Test result

Static accuracy: 0.2% with respect to travel range of ±50mm   (0.1mm error) – See Figure 3.1.1.2.

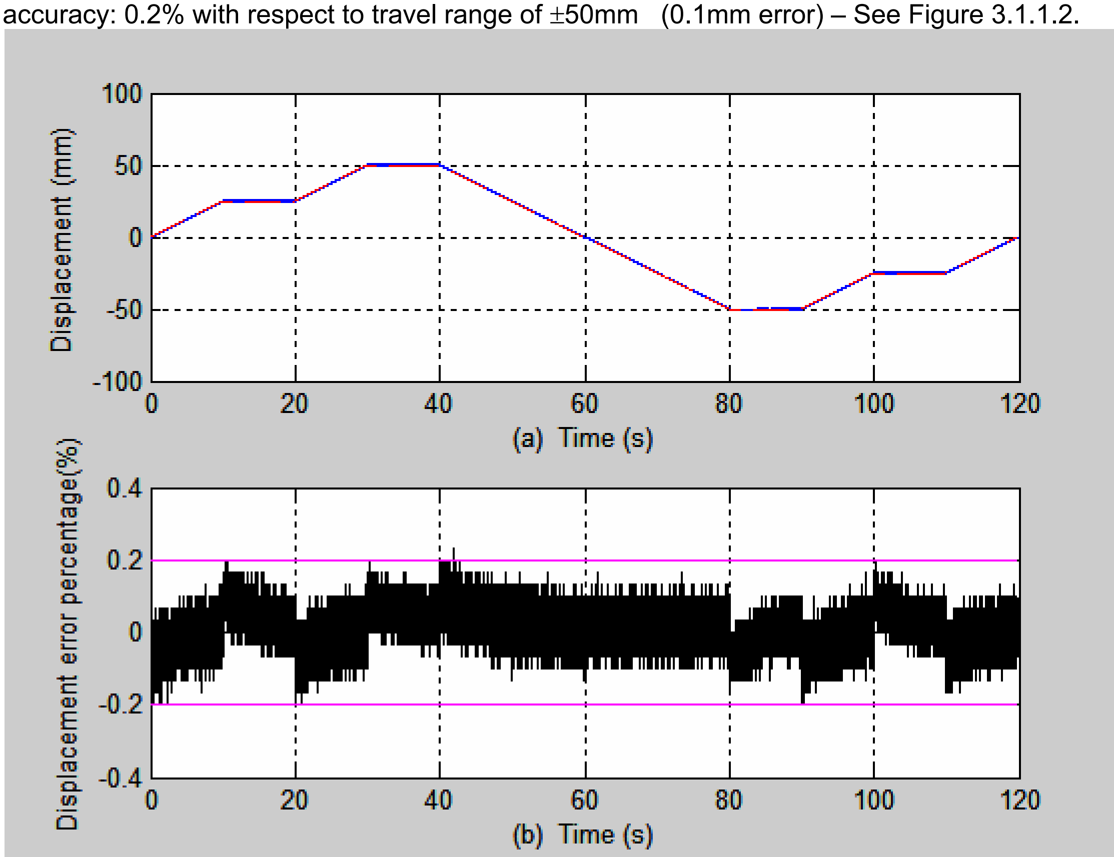


Figure 3.1.1.2.   10% stroke accuracy test at Actuator 3 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 3 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

Servo Control Parameter

Configuration–3 valve EFK PID control at actuator 3
PID control– Kp=15; Ki=3; Kd =0
Servo valve loop gain – Kv=30
Servo valve input scale – E: 0.98; F: 1.0; K: 0.88
Servo valve offset – E: 1.484; F: 1.250; K: 0.469
Servo valve spool zero – E: 2.50; F: 1.641; K: 0.00
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 3.1.1.3.

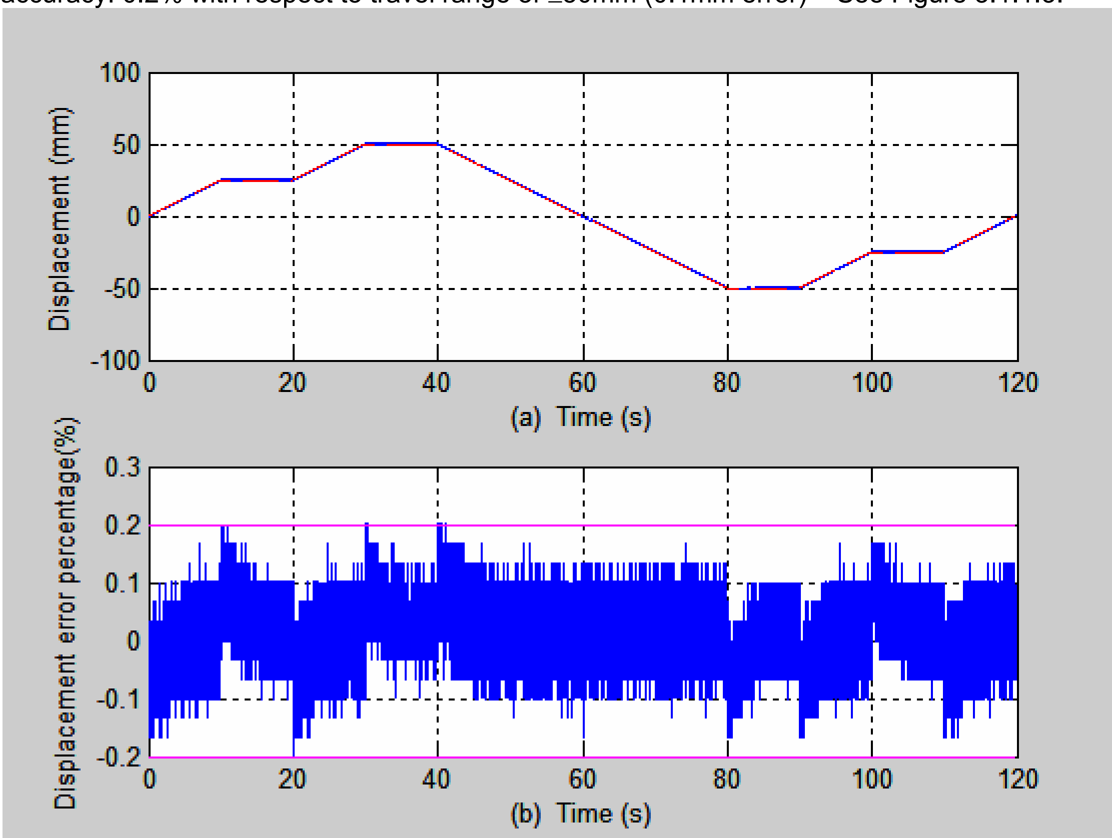


Figure 3.1.1.3.   10% stroke accuracy test at Actuator 3 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

3.1.2 20% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±100mm displacement control on Actuator 3 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

Servo Control Parameter
Configuration--1 valve E PID control at actuator 3
PID control-- Kp=40; Ki=5; Kd =0
Servo valve loop gain -- Kv=30

Servo valve input scale – E: 0.98; (F: 0.0; K: 0.0)
Servo valve offset – E: 1.484; (F: 1.250; K: 0.469)
Servo valve spool zero – E: 2.50; (F: 1.641; K: 0.00)
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.2% with respect to travel range of ±100mm (0.2mm error) – See Figure 3.1.2.1.

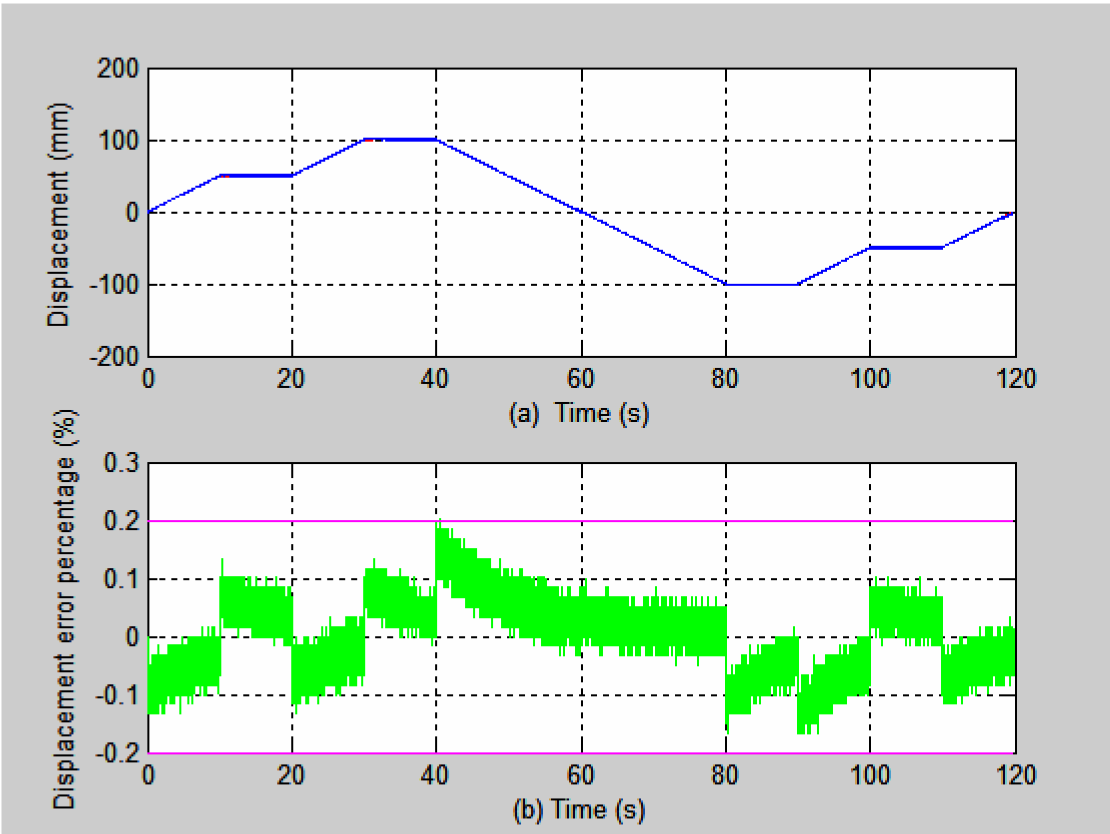


Figure 3.1.2.1.   20% stroke accuracy test at Actuator 3 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 3 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

<u>Servo Control Parameter</u>
Configuration--2 valve EF PID control at actuator 3
PID control-- Kp=20; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.0; (K: 0.0)
Servo valve offset – E: 1.484; F: 1.250; (K: 0.469)
Servo valve spool zero – E: 2.50; F: 1.641; (K: 0.00)
Hydraulic supply pressure: 3000psi

<u>Test result</u>

Static accuracy: 0.2% with respect to travel range of ±100mm (0.2mm error) – See Figure 3.1.2.2.

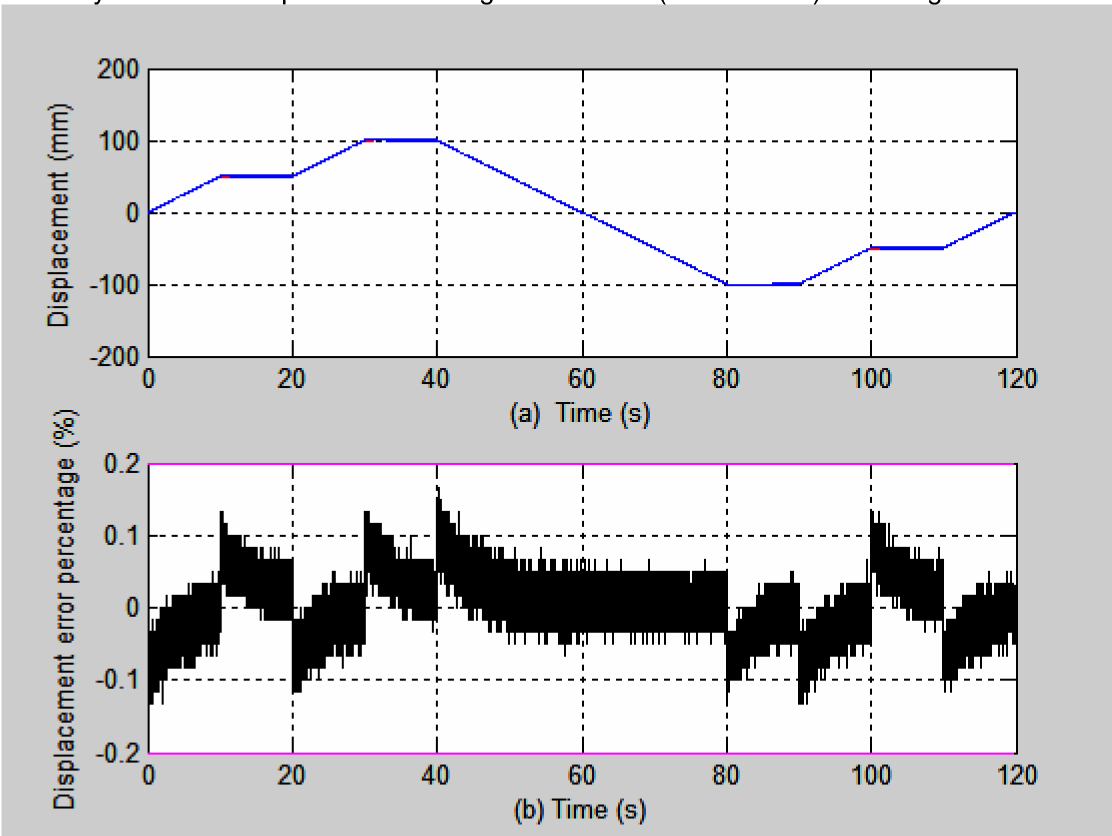


Figure 3.1.2.2. 20% stroke accuracy test at Actuator 3 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 3 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

Servo Control Parameter
Configuration--3 valve EFK PID control at actuator 3
PID control-- Kp=15; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.0; K: 0.88
Servo valve offset – E: 1.484; F: 1.250; K: 0.469
Servo valve spool zero – E: 2.50; F: 1.641; K: 0.00
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.18% with respect to travel range of ±100mm(0.18mm error)–See Figure 3.1.2.3.

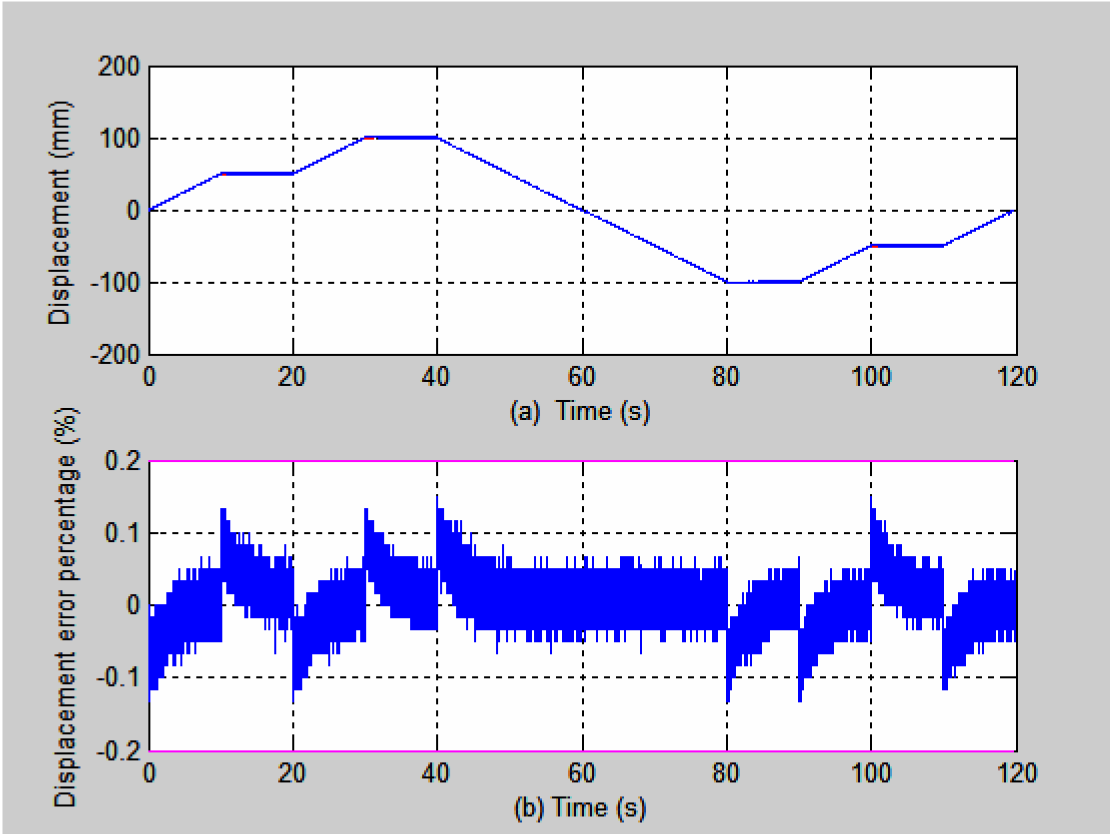


Figure 3.1.2.3. 20% stroke accuracy test at Actuator 3 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

3.1.3 100% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±500mm displacement control on Actuator 3 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

Servo Control Parameter
Configuration--1 valve E PID control at actuator 3
PID control-- Kp=40; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; (F: 0.0; K: 0.0)
Servo valve offset – E: 1.484; (F: 1.250; K: 0.469)
Servo valve spool zero – E: 2.50; (F: 1.641; K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.18% with respect to travel range of ±500mm (0.9mm error)– See Figure 3.1.3.1.

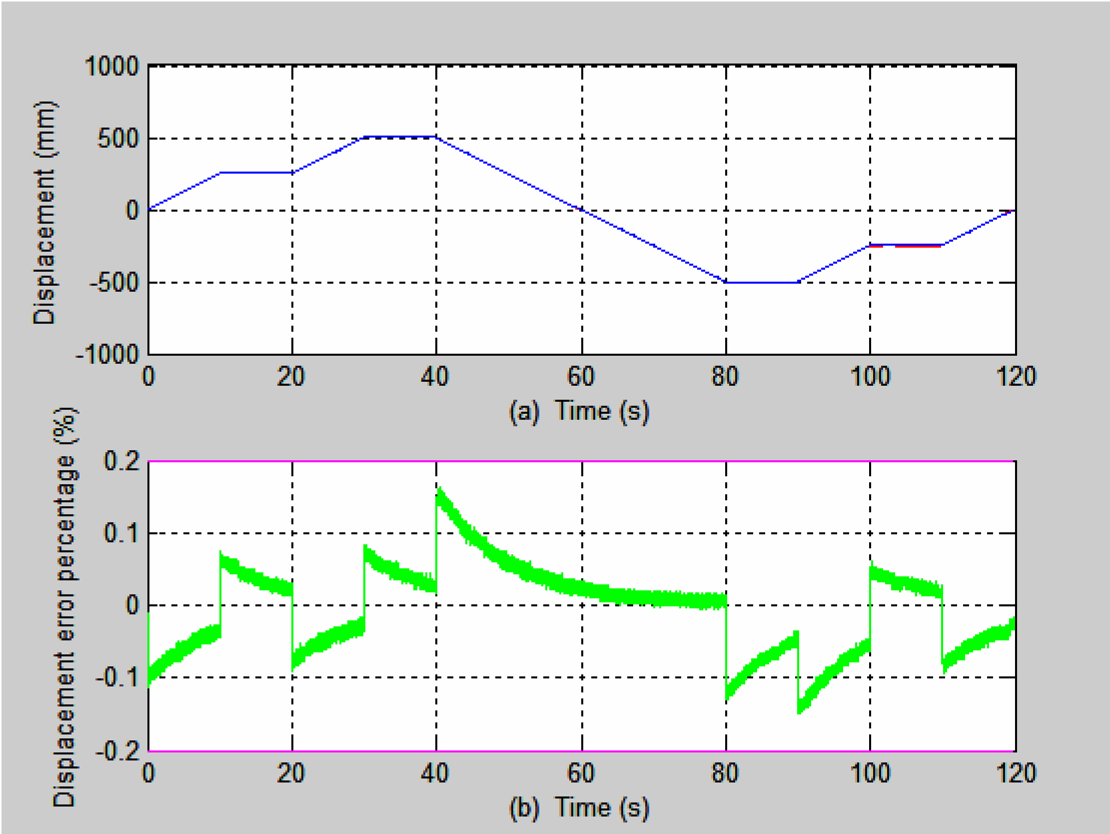


Figure 3.1.3.1. 100% stroke accuracy test at Actuator 3 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 3 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

<u>Servo Control Parameter</u>
Configuration--2 valve EF PID control at actuator 3
PID control-- Kp=20; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.0; (K: 0.0)
Servo valve offset – E: 1.484; F: 1.250; (K: 0.469)
Servo valve spool zero – E: 2.50; F: 1.641; (K: 0.00)
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.13% with respect to travel range of ±500mm (0.65mm error)–See Figure3.1.3.2.

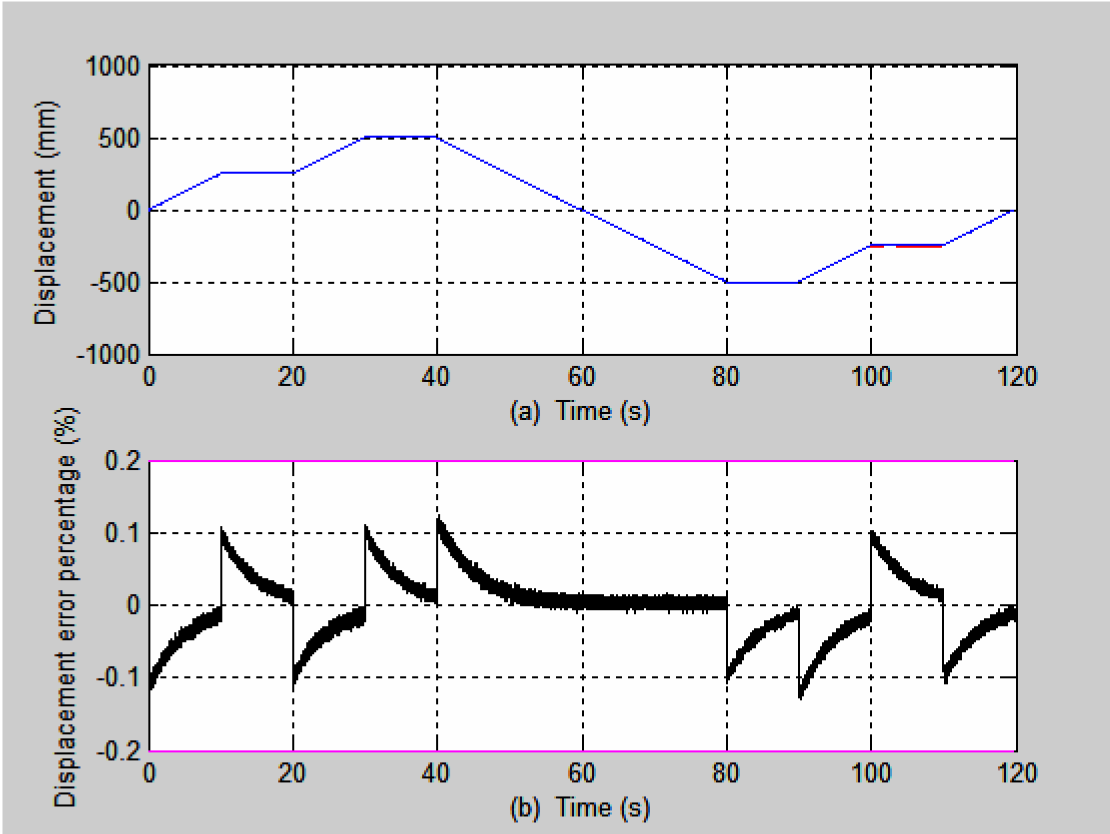


Figure 3.1.3.2. 100% stroke accuracy test at Actuator 3 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 3 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

<u>Servo Control Parameter</u>
Configuration--3 valve EFK PID control at actuator 3
PID control-- Kp=15; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.0; K: 0.88
Servo valve offset – E: 1.484; F: 1.250; K: 0.469
Servo valve spool zero – E: 2.50; F: 1.641; K: 0.00
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.12% with respect to travel range of ± 500mm (0.6mm error)–See Figure 3.1.3.3.

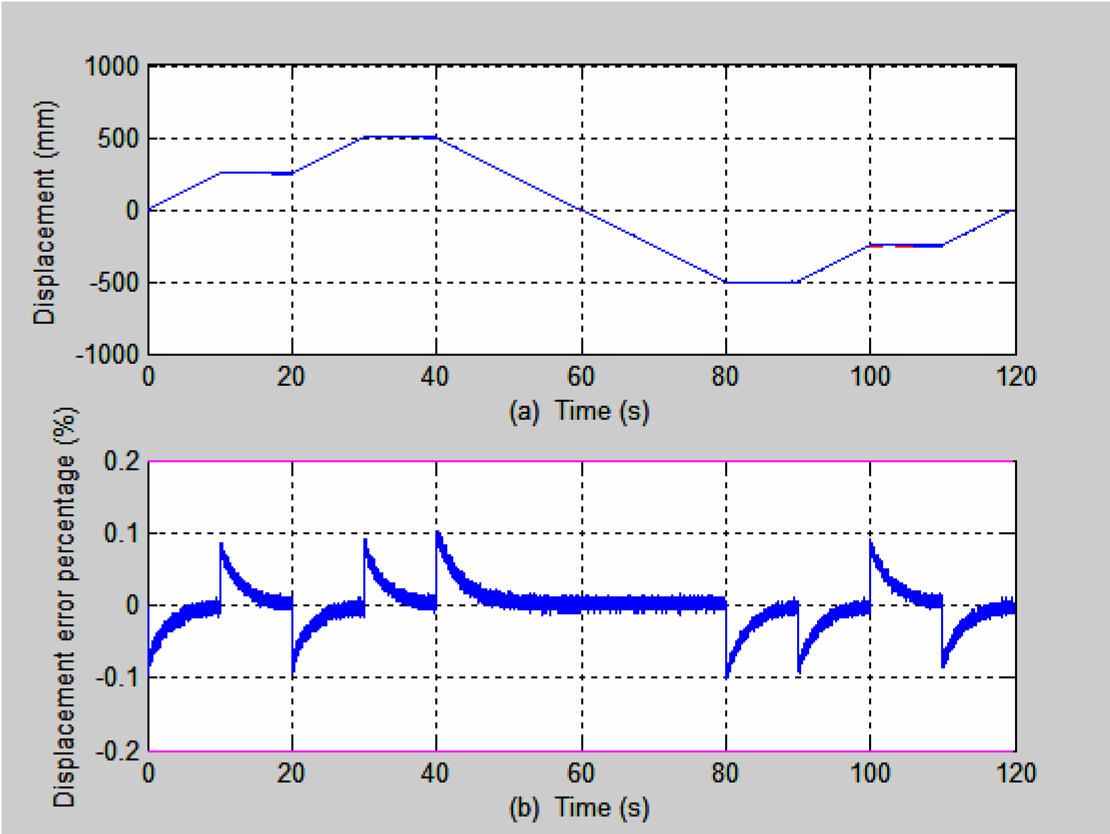


Figure 3.1.3.3. 100% stroke accuracy test at Actuator 3 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

3.2 10Hz displacement bandwidth test
(±3.81mm, ±7.62mm, ±11.43mm sinusoid for 1, 2, 3 valves respectively)

- Test task: Sinusoid displacement control on Actuator 3 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

Servo Control Parameter
Configuration --1 valve E PID control at actuator 3
PID control -- Kp=60; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; (F: 0.0; K: 0.0)
Servo valve offset (%) – E: 1.484; (F: 1.250; K: 0.469)
Servo valve spool zero (%) – E: 2.50; (F: 1.641; K: 0.00)
Hydraulic supply pressure – 3000psi
Hydraulic supply flow rate – 310gpm

Test result

Dynamic bandwidth: 10Hz@0.15inch (19% attenuation, less than 3 db) – See Figure 3.2.1.

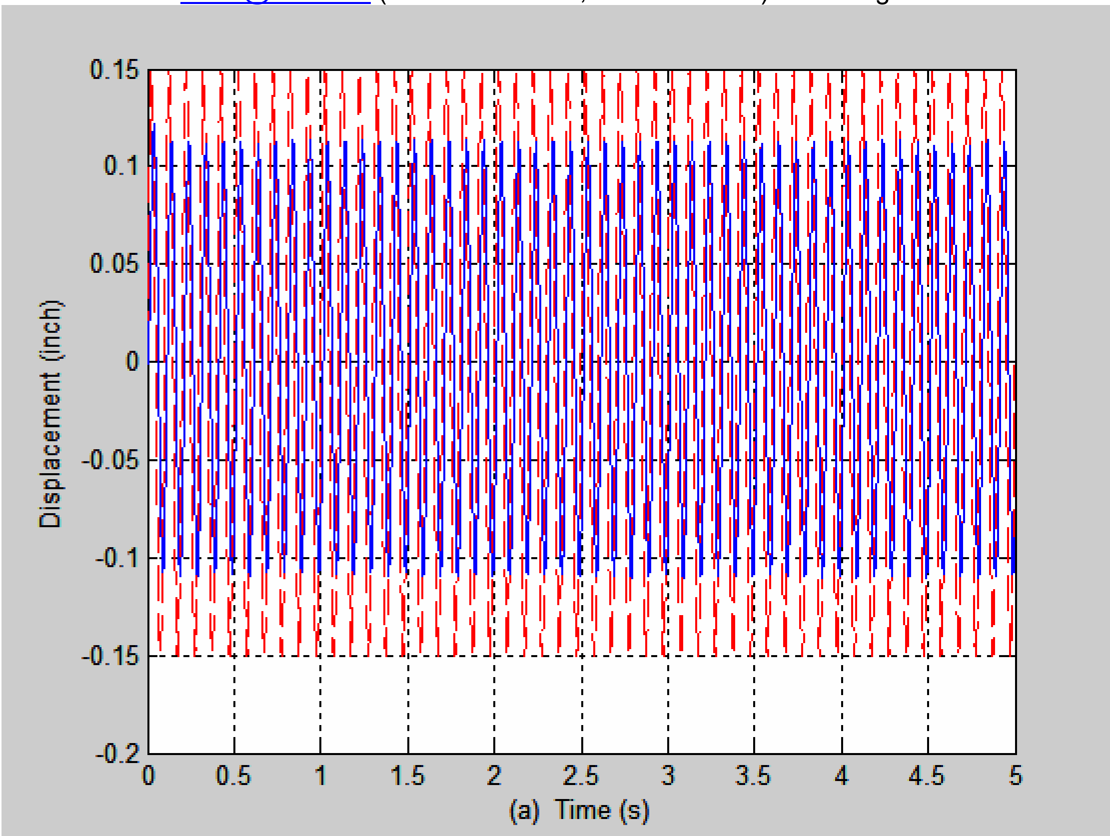


Figure 3.2.1. Dynamic bandwidth test at Actuator 3 (Test 2: 1 vale)
Red: command (0.15inch@10Hz); Blue: response (0.11inch@10Hz)

- Test task: Sinusoid displacement control on Actuator 3 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

Servo Control Parameter
Configuration --2 valve EF PID control at actuator 3
PID control -- Kp=35; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.0; (K: 0.0)
Servo valve offset (%) – E: 1.484; F: 1.250; (K: 0.469)
Servo valve spool zero (%) – E: 2.50; F: 1.641; (K: 0.00)
Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 620gpm

Test result
Dynamic bandwidth: 10Hz@0.30inch (15% attenuation, less than 3 db) – See Figure 3.2.2.

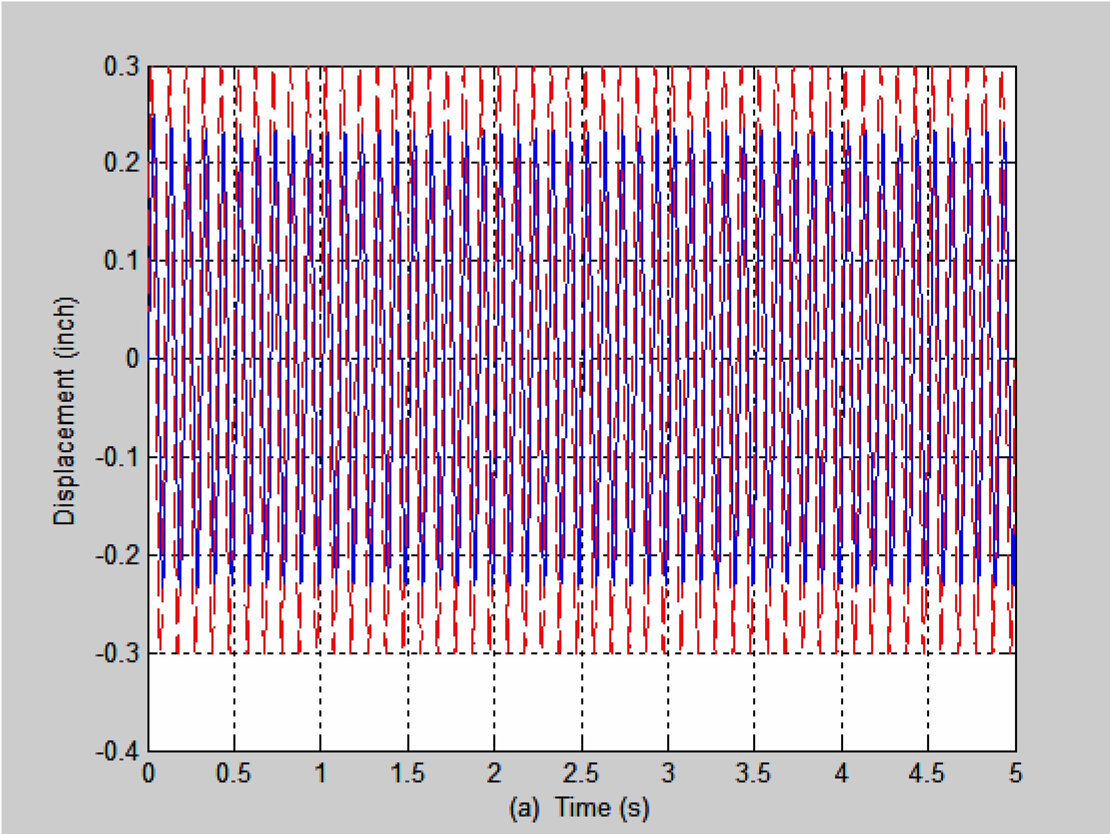


Figure 3.2.2. Dynamic bandwidth test at Actuator 3 (Test 2: 2 vales)
Red: command (0.30inch@10Hz); Blue: response (0.22inch@10Hz)

- Test task: Sinusoid displacement control on Actuator 3 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/3/2004

Servo Control Parameter
Configuration --3 valve EFK PID control at actuator 3
PID control -- Kp=23; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.0; K: 0.88
Servo valve offset (%) – E: 1.484; F: 1.250; K: 0.469
Servo valve spool zero (%) – E: 2.50; F: 1.641; K: 0.00
Hydraulic supply pressure – 3000psi
Hydraulic supply flow rate – 930gpm

Test result
Dynamic bandwidth: 10Hz@0.45inch (16% attenuation, less than 3 db) – See Figure 3.2.3.

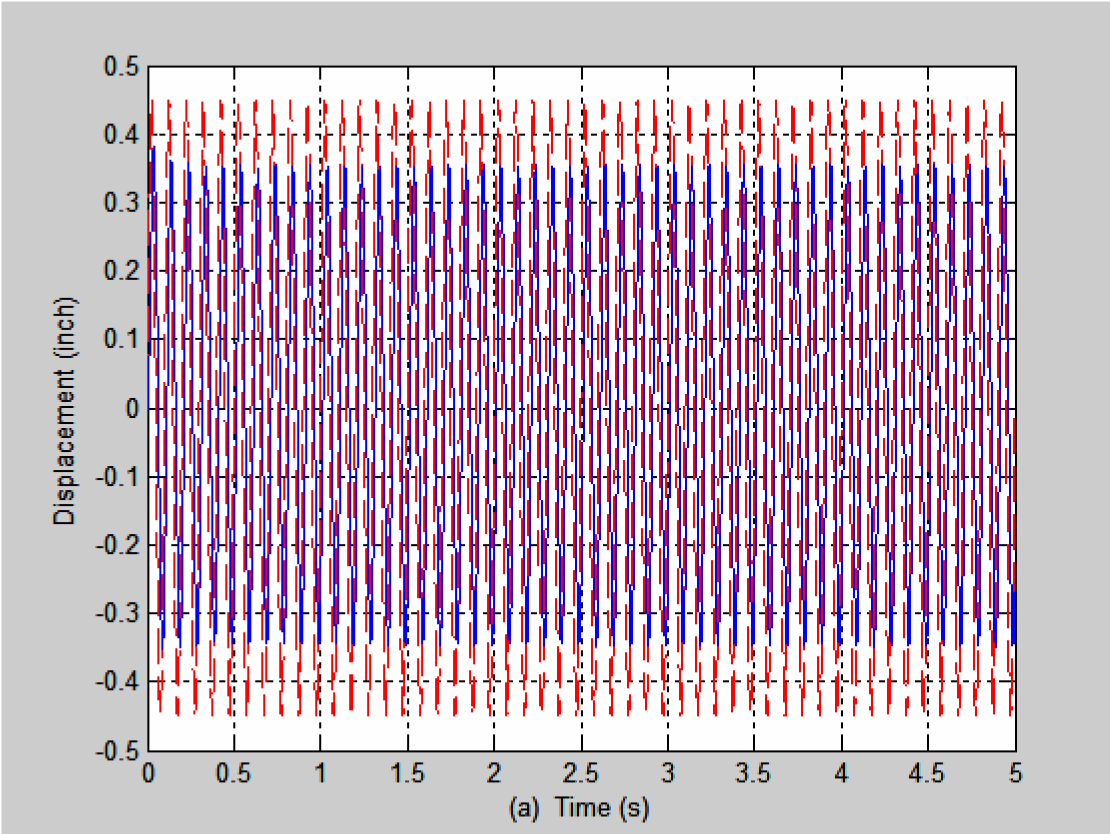


Figure 3.2.3. Dynamic bandwidth test at Actuator 3 (Test 2: 3 valves)
Red: command (0.45inch@10Hz); Blue: response (0.32inch@10Hz)

3.3 1.14m/s high velocity test

- Test task: High velocity test on Actuator 3 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/15/2004

Servo Control Parameter
Configuration–3 valve EFG PID control at actuator 3
PID control– Kp=40; Ki=5; Kd =0; f=39.8Hz
Servo valve loop gain – Kv=30
Servo valve input scale – E: 0.98; F: 1.0; G: 1.0
Servo valve offset (%) – E: -0.234; F: -0.156; G: -2.266
Servo valve spool zero (%) – E: 4.141; F: 5.078; G: 1.016
Hydraulic supply pressure: 3200psi
Hydraulic supply flow rate: 1500gpm

Test result
Speed reaches 1.14 m/s – See Figures 3.3.1.

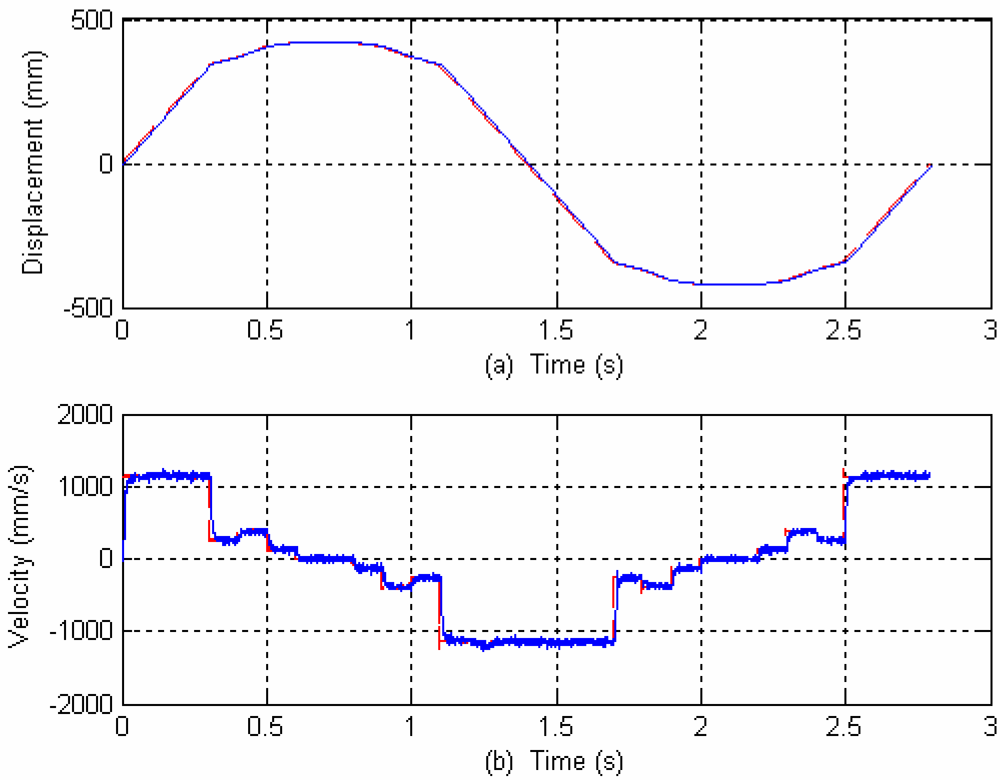


Figure 3.3.1. High velocity test at Actuator 3 (Test 3)
(a) Displacement (mm) – Red: command; Blue: response
(b) Velocity (mm/s) -- Red: command; Blue: response

3.4 277KW power test with single valve operation (0.27m/s@1000KN)

- Test task: Power test on Actuator 3 (1 valve, against Load Actuator 1)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 8/12/2004

Servo Control Parameter
Configuration:
1 valve E displacement PID control at Actuator 3
1 valve A load PID control at Actuator 1
Actuator 3 displacement PID control-- Kp=50; Ki=2; Kd =0; f=39
Actuator 1 load PID control-- Kp=1.8; Ki=3; Kd =-1; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – A: 0.87; E:0.98;
Servo valve offset (%) – A: -2.031; E: 1.406
Servo valve spool zero (%) – A: -0.703; E: 2.187
Hydraulic supply pressure: 3377psi

Test result
Power capacity: power output at Actuator 3 reaches 277KW. – See Figure 3.4.1.

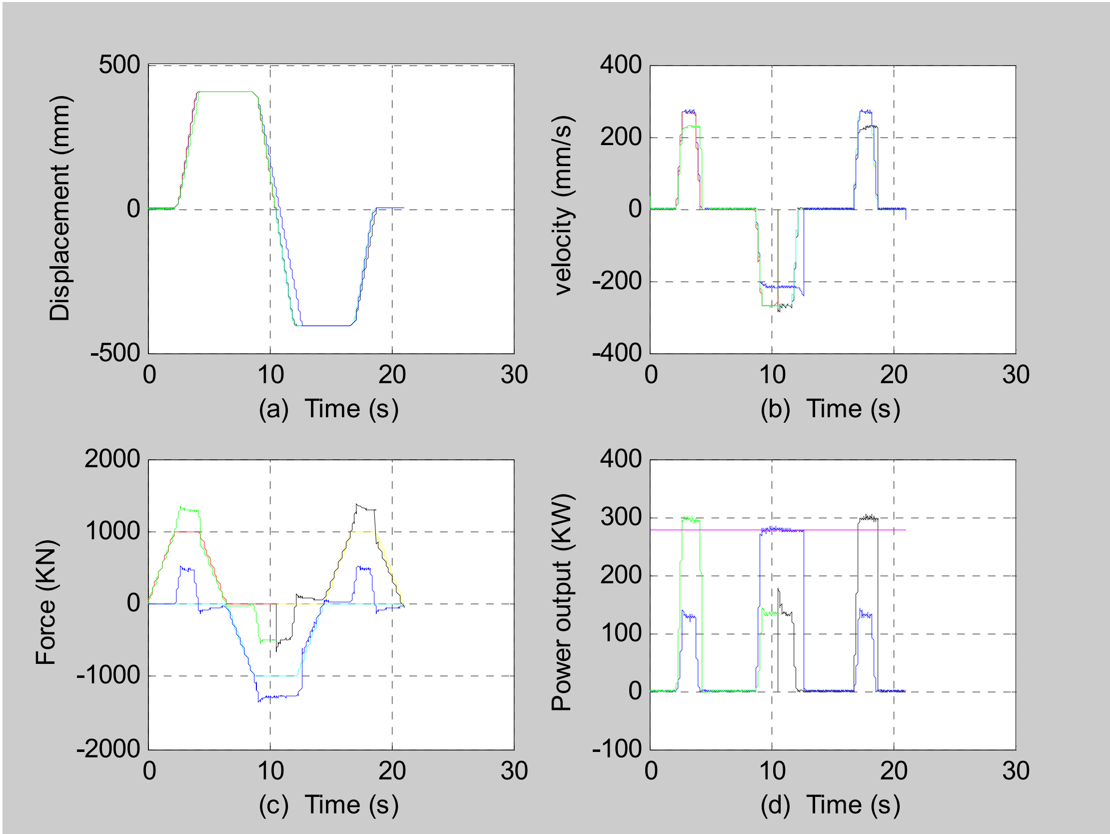


Figure 3.4.1. Power test at Actuator 3 (Test 4: 1 valve; Actuator 1 simulates load)
(Actuator 3 –displacement and Actuator 1—load)
(a) Displacement (mm) (b) Velocity (mm/s)
(c)Force (KN) (d) Power (KW)
– Red: command (1st test); Green: response (1st test)
– Cyan: command (2nd test); Blue: response (2nd test)
– Yellow: command (3rd test); Black: response (3rd test)
Magenta: power target value (277KW)

3.5 0.2% force accuracy test (load range: ±1695KN)

3.5.1 5% load range force accuracy test (1, 2, 3 valves)

- Test task: ±84.75KN force control on Actuator 3 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

<u>Servo Control Parameter</u>
Configuration--1 valve E PID control at actuator 3
PID control-- Kp=2.8; Ki=0.4; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; (F: 0.0; K: 0.0)
Servo valve offset (%) – E: 1.797; (F: 0.391; K:1.016)
Servo valve spool zero (%) – E: 2.031; (F: 4.062; K:0.00)
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±84.75KN (0.17KN error)–See Figure 3.5.1.1.

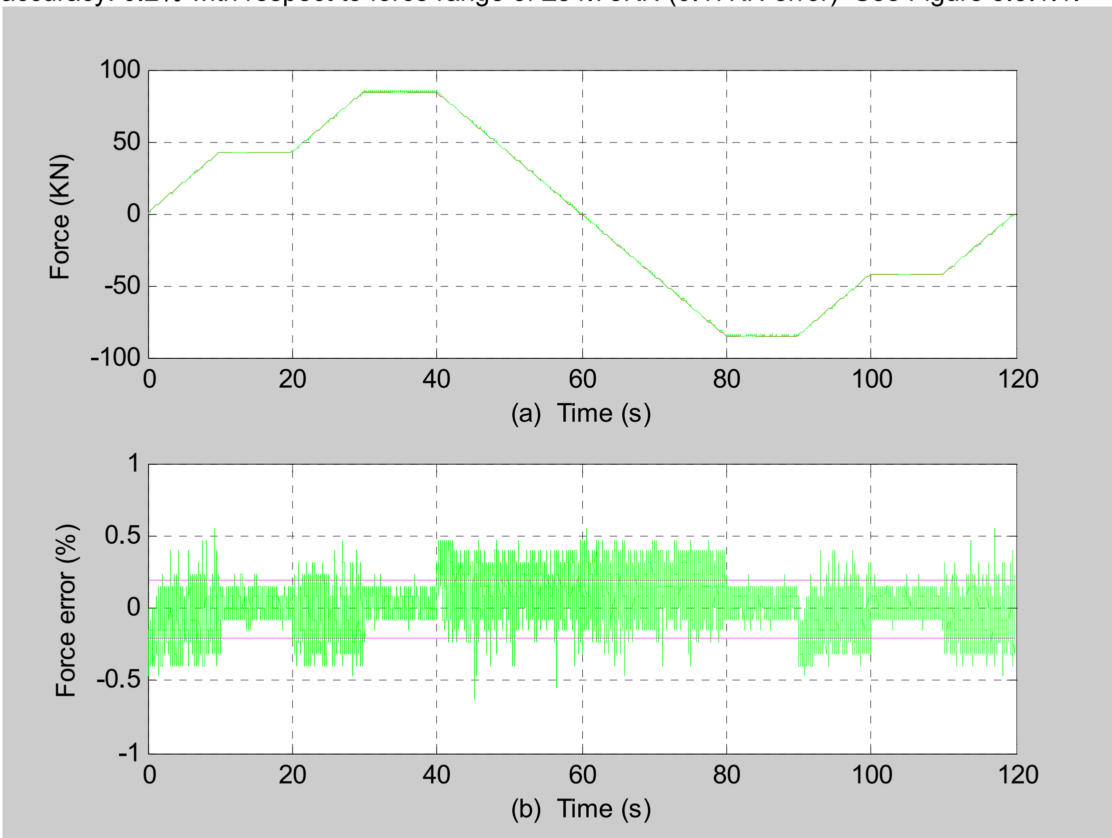


Figure 3.5.1.1. 5% maximum force accuracy test at Actuator 3 (Test 5.1: 1 valve)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±84.75KN; – Green: error percentage;
-- Magenta: error acceptance boundary ±0.2%

- Test task: ±84.75KN force control on Actuator 3 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

Servo Control Parameter
Configuration--2 valves EF PID control at actuator 3
PID control-- Kp=2.5; Ki=0.8; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.00; (K: 0.0)
Servo valve offset (%) – E: 1.797; F: 0.391; (K:1.016)
Servo valve spool zero (%) – E: 2.031; F: 4.062; (K:0.00)
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±84.75KN (0.17KN error)–See Figure 3.5.1.2.

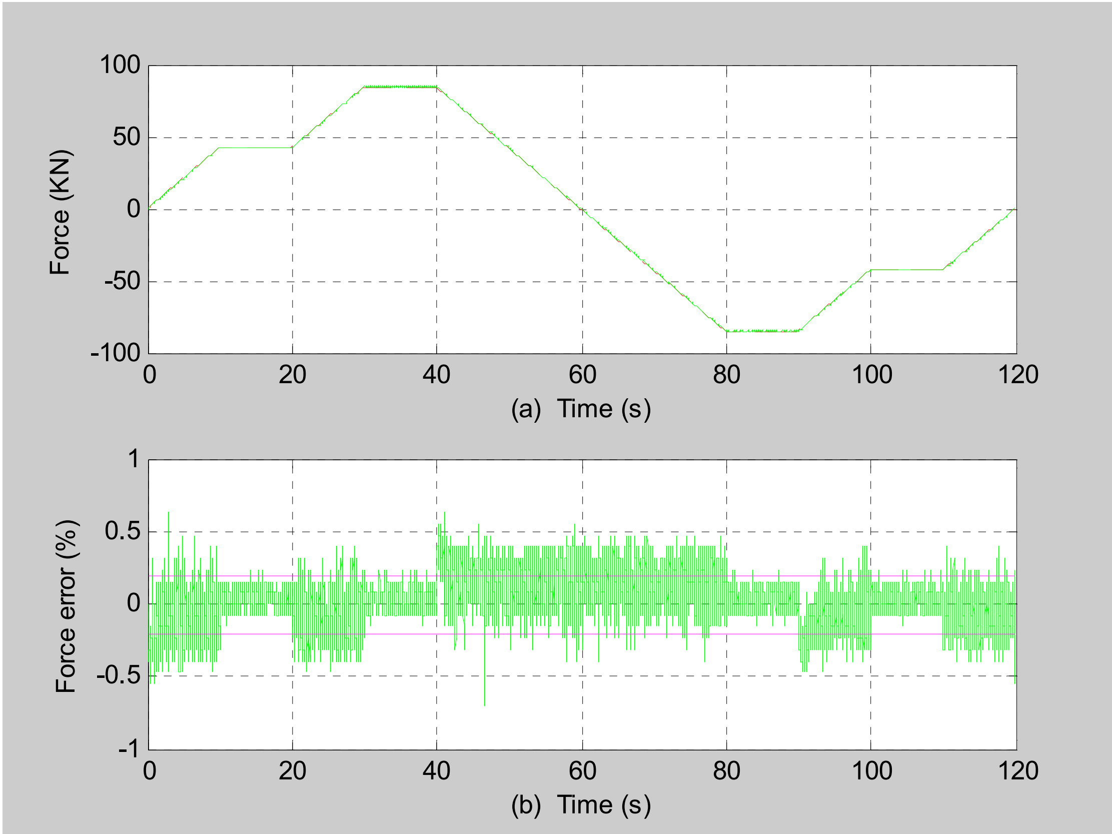


Figure 3.5.1.2. 5% maximum force accuracy test at Actuator 3 (Test 5.1: 2 valves)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±84.75KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

- Test task: ±84.75KN force control on Actuator 3 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

Servo Control Parameter
Configuration--3 valves EFK PID control at actuator 3
PID control-- Kp=2.0; Ki=0.8; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.00; K: 0.88
Servo valve offset (%) – E: 1.797; F: 0.391; K: 1.016
Servo valve spool zero (%) – E: 2.031; F: 4.062; K: 0.00
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±84.75KN (0.17KN error)–See Figure 3.5.1.3.

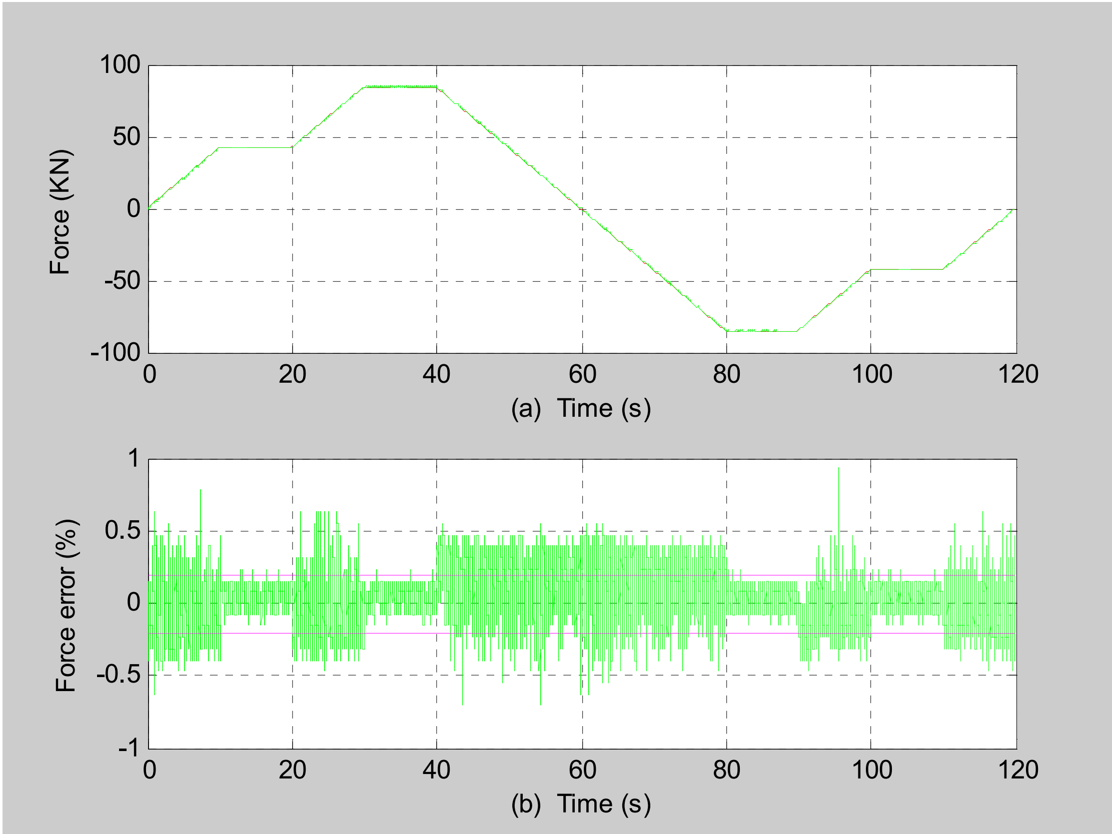


Figure 3.5.1.3. 5% maximum force accuracy test at Actuator 3 (Test 5.1: 3 valves)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±84.75KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

3.5.2 20% load range force accuracy test (1, 2, 3 valves)

- Test task: ±339KN force control on Actuator 3 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

Servo Control Parameter
Configuration--1 valve E PID control at actuator 3
PID control-- Kp=3.4; Ki=0.8; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; (F: 0.0; K: 0.0)
Servo valve offset (%) – E: 1.797; (F: 0.391; K:1.016)
Servo valve spool zero (%) – E: 2.031; (F: 4.062; K:0.00)
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±339KN (0.68KN error) –See Figure 3.5.2.1.

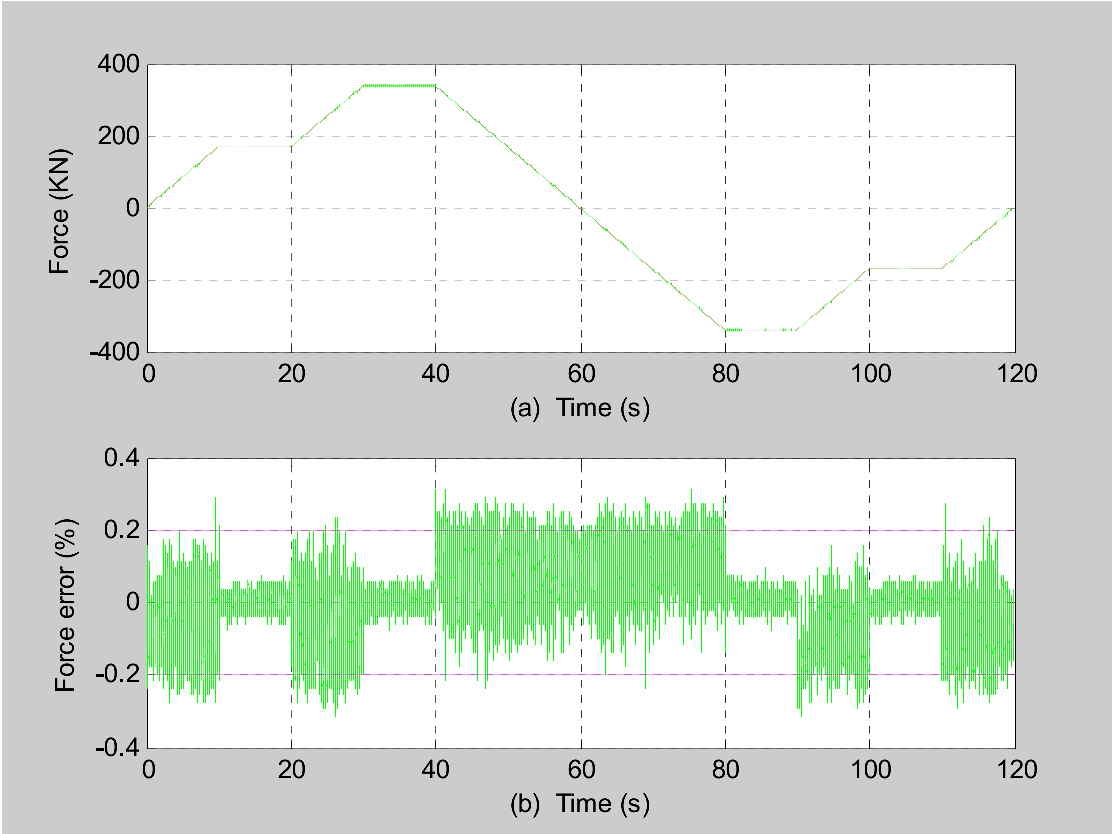


Figure 3.5.2.1. 20% maximum force accuracy test at Actuator 3 (Test 5.1: 1 valve)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±339KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

- Test task: ±339KN force control on Actuator 3 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

<u>Servo Control Parameter</u>
Configuration--2 valve EF PID control at actuator 3
PID control-- Kp=2.5; Ki=0.8; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.00; (K: 0.0)
Servo valve offset (%) – E: 1.797; F: 0.391; (K: 1.016)
Servo valve spool zero (%) – E: 2.031; F: 4.062; (K: 0.00)
Hydraulic supply pressure: 3300psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ±339KN (0.68KN error) –See Figure 3.5.2.2.

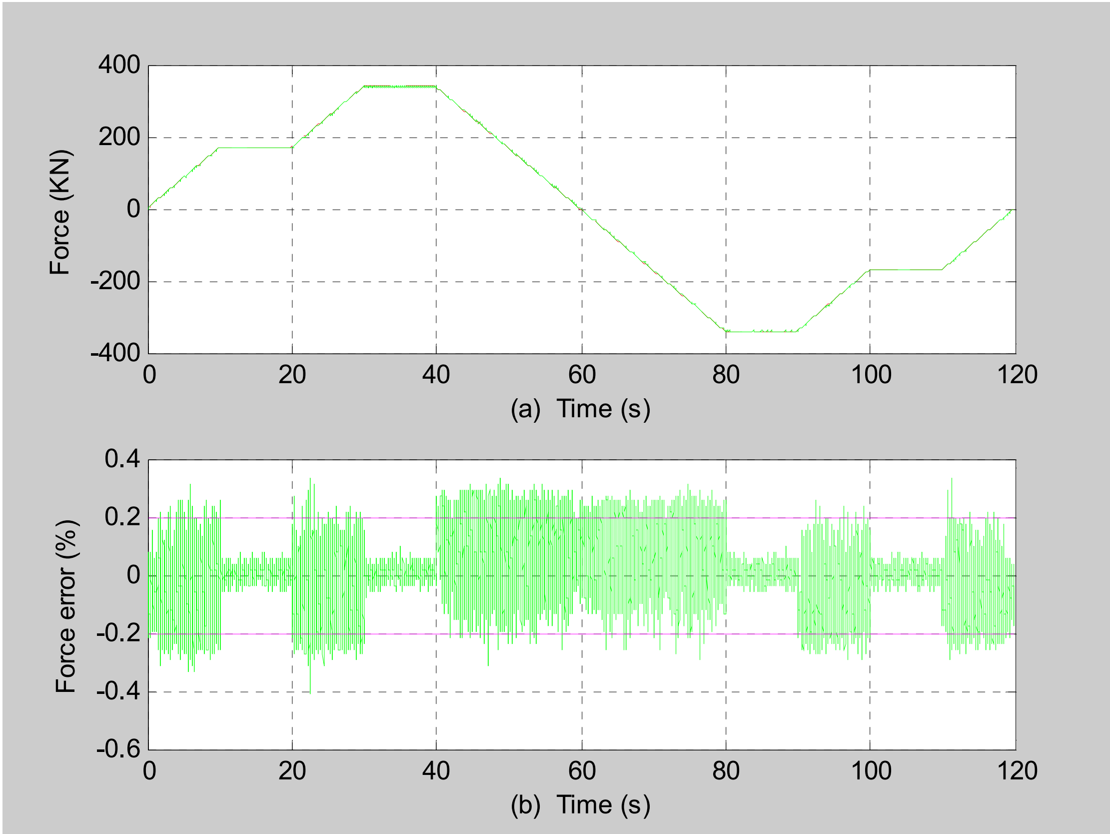


Figure 3.5.2.2. 20% maximum force accuracy test at Actuator 3 (Test 5.1: 2 valves)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±339KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

- Test task: ±339KN force control on Actuator 3 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

Servo Control Parameter
Configuration--3 valve EFK PID control at actuator 3
PID control-- Kp=2.0; Ki=0.8; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.00; K: 0.88
Servo valve offset (%) – E: 1.797; F: 0.391; K: 1.016
Servo valve spool zero (%) – E: 2.031; F: 4.062; K: 0.00
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ±339KN (0.68KN error)–See Figure 3.5.2.3.

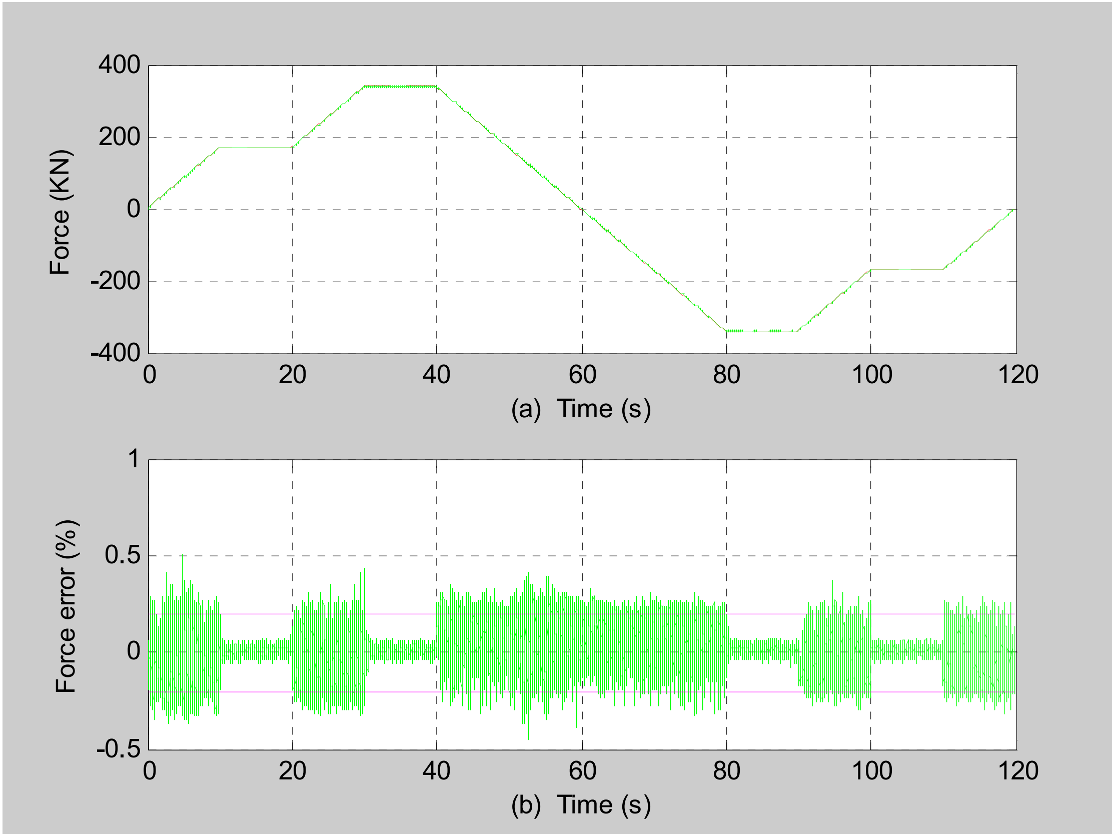


Figure 3.5.2.3. 20% maximum force accuracy test at Actuator 3 (Test 5.1: 3 valves)
(Butterworth filter cut off at 50Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±339KN; Green: error percentage
–Magenta: error acceptance boundary ±0.2%

3.5.3 100% load range force accuracy test (1, 2, 3 valves)

- Test task: ±1695KN force control on Actuator 3 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

Servo Control Parameter
Configuration--1 valve E PID control at actuator 3

Tension:
PID control-- Kp=4; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; (F: 0.0; K: 0.0)
Servo valve offset (%) – E: 1.797; (F: 2.422; K: 1.016)
Servo valve spool zero (%) – E: 2.031; (F: 4.062; K: 0.0)

Compression:
PID control-- Kp=4; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; (F: 1.00; K: 0.88)
Servo valve offset (%) – E: 1.797; (F: 0.391; K: 1.016)
Servo valve spool zero (%) – E: 2.032; (F: 4.062; K: 0.0)

Hydraulic supply pressure: 3200psi

Test result
Static accuracy: 0.2% with respect to force range of ±1695KN (3.3KN error) –See Figure 3.5.3.1.

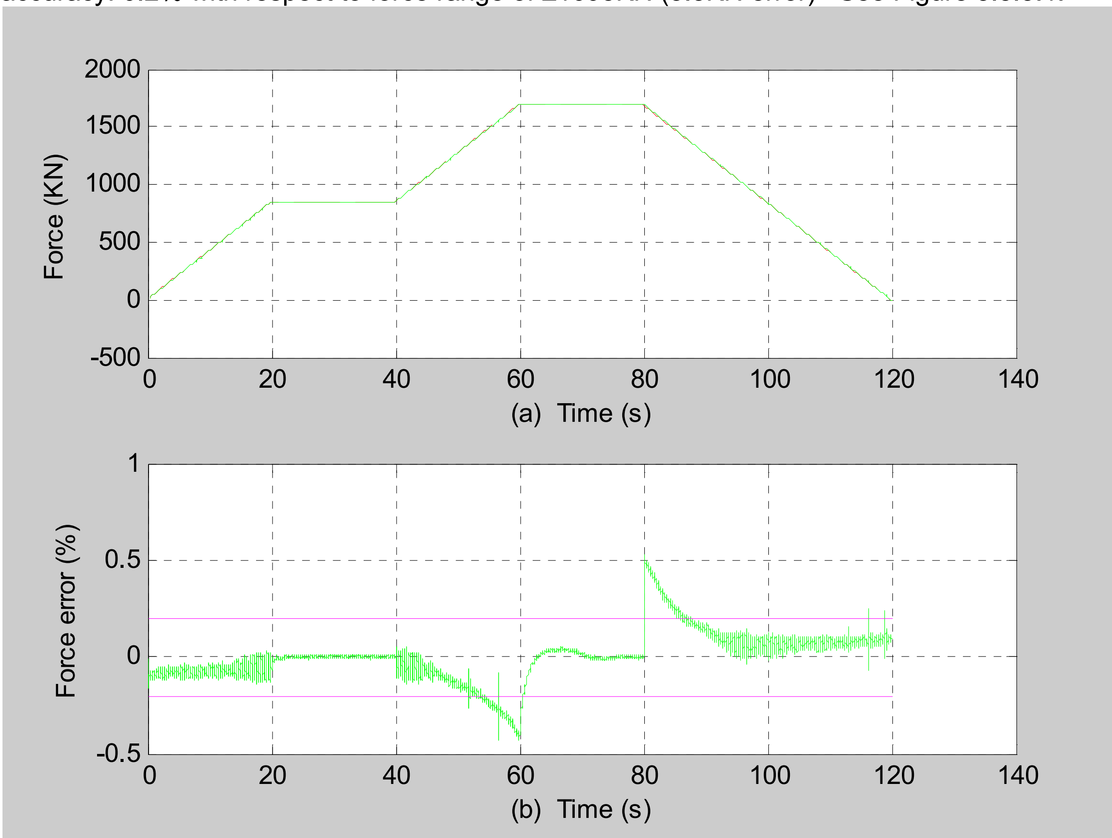


Figure 3.5.3.1a.   100% maximum force accuracy test at Actuator 3 (Test 5.1: 1 valve) - Tension
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN ; Green: error percentage;
– Magenta: error acceptance boundary ±0.2%

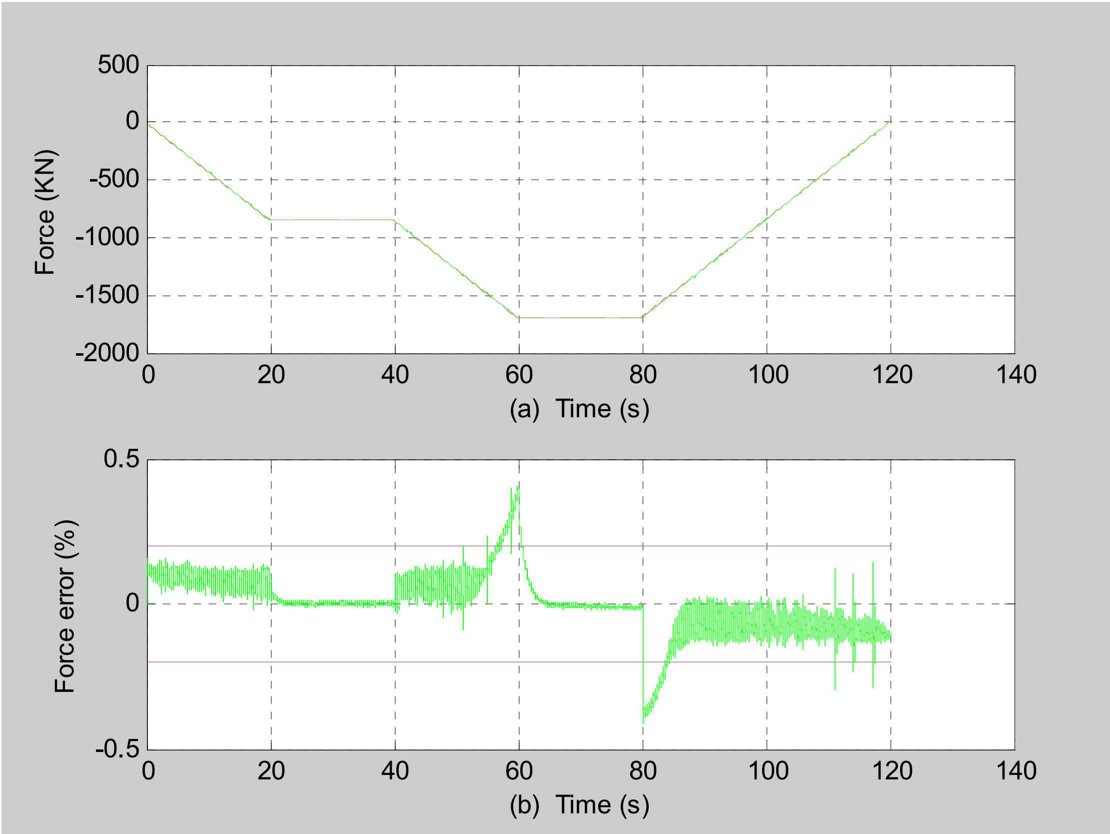


Figure 3.5.3.1b. 100% maximum force accuracy test at Actuator 3 (Test 5.1: 1 valve) - Compression
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
--Magenta: error acceptance boundary ±0.2%

- Test task: ±1695KN force control on Actuator 3 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

Servo Control Parameter
Configuration--2 valve EF PID control at actuator 3
PID control-- Kp=2.5; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.00; (K: 0.0)
Servo valve offset (%) – E: 1.797; F: 0.391; (K: 1.016)
Servo valve spool zero (%) – E: 2.031; F: 4.062; (K: 0.00)
Hydraulic supply pressure: 3300psi

Test result
Static accuracy: 0.2% with respect to force range of ± 1695KN (3.3KN error) –See Figure 3.5.3.2.

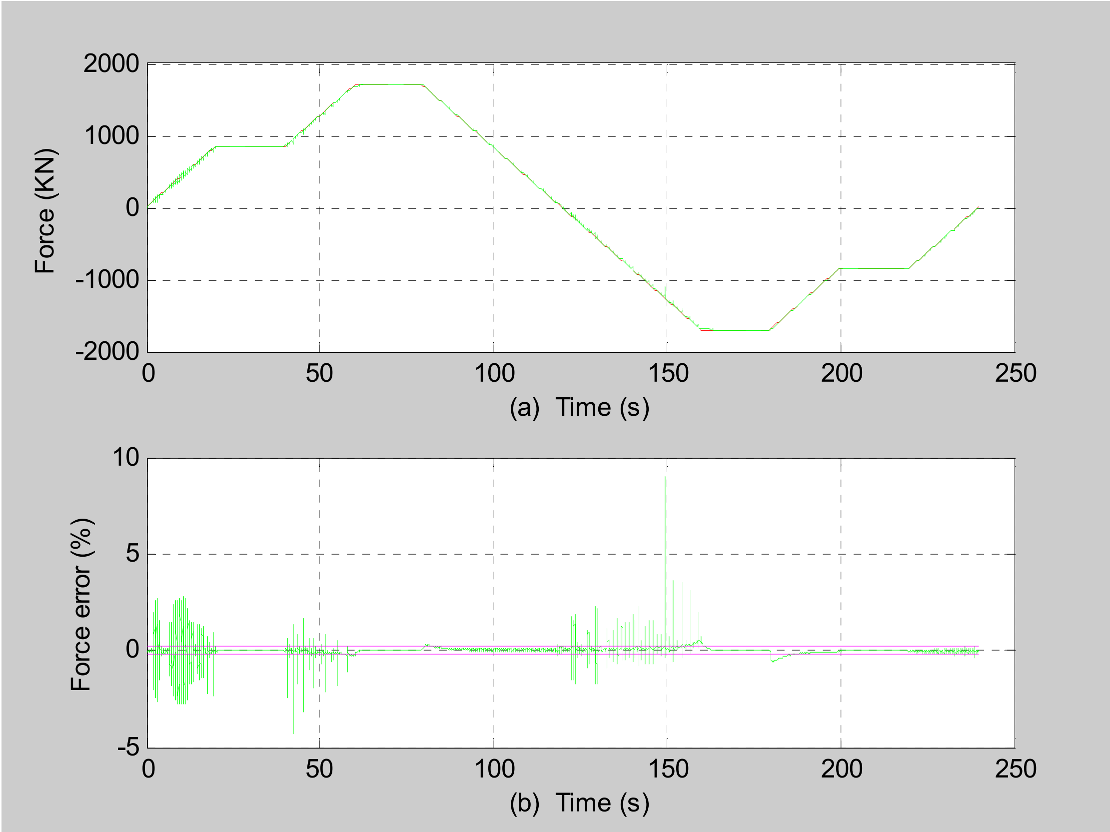


Figure 3.5.3.2. 100% maximum force accuracy test at Actuator 3 (Test 5.1: 2 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

- Test task: ±1695KN force control on Actuator 3 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

<u>Servo Control Parameter</u>
Configuration--3 valve EFK PID control at actuator 3
PID control-- Kp=2.0; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.00; K: 0.88
Servo valve offset (%) – E: 1.797; F: 0.391; K: 1.016
Servo valve spool zero (%) – E: 2.031; F: 4.062; K: 0.00
Hydraulic supply pressure: 3300psi

<u>Test result</u>
Static accuracy: 0.2% with respect to force range of ±1695KN (3.3KN error) –See Figure 3.5.3.3.

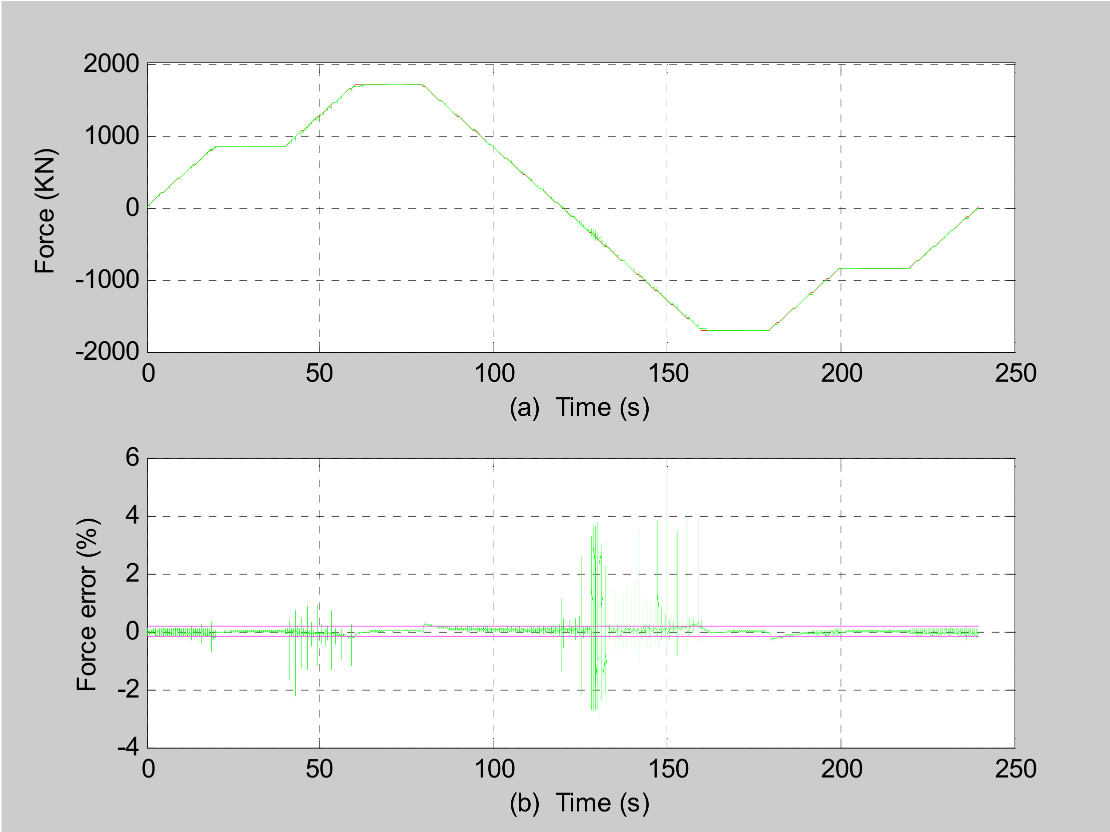


Figure 3.5.3.3. 100% maximum force accuracy test at Actuator 3 (Test 5.1: 3 valves)
(Butterworth filter cut off at 100Hz)
(a) Force (KN) – Red: command; Green: response
(b) Force error with respect to force range of ±1695KN; Green: error percentage;
–Magenta: error acceptance boundary ±0.2%

3.6 10Hz force bandwidth test (±1000KN sinusoid for 1, 2, 3 valves)

- Test task: Sinusoid force control on Actuator 3 (1valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

Servo Control Parameter
Configuration--1 valve E PID control at actuator 3
PID control-- Kp=3.4; Ki=0.8; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; (F: 0.0; K: 0.0)
Servo valve offset (%) – E:1.797; (F: 0.391; K:1.016)
Servo valve spool zero (%) – E: 2.031; (F: 4.062; K:0.00)
Hydraulic supply pressure: 3300psi

Test result
Dynamic bandwidth: 10Hz@1000KN (1% attenuation, less than 3 db) –See Figure 3.6.1.

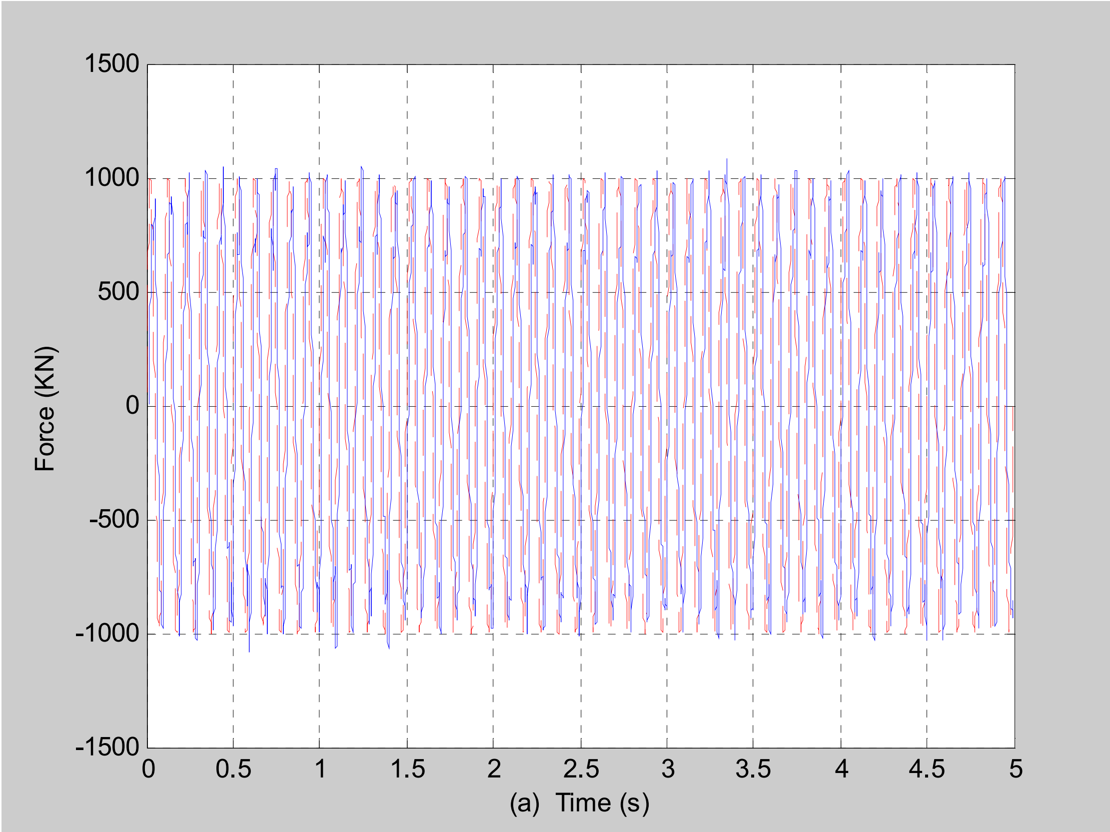


Figure 3.6.1. Force control dynamic bandwidth test at Actuator 3 (Test 5.2: 1 valve)
Red: command (1000KN@10Hz); Blue: response (990KN@10Hz)

- Test task: Sinusoid force control on Actuator 3 (2valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

Servo Control Parameter
Configuration--2 valve EF PID control at actuator 3
PID control-- Kp=2.5; Ki=0.8; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.00; (K: 0.0)
Servo valve offset (%) – E: 1.797; F: 0.391; (K: 1.016)
Servo valve spool zero (%) – E: 2.031; F: 4.062; (K: 0.00)
Hydraulic supply pressure: 3300psi

Test result
Dynamic bandwidth: 10Hz@1000KN (15% attenuation, less than 3 db) –See Figure 3.6.2.

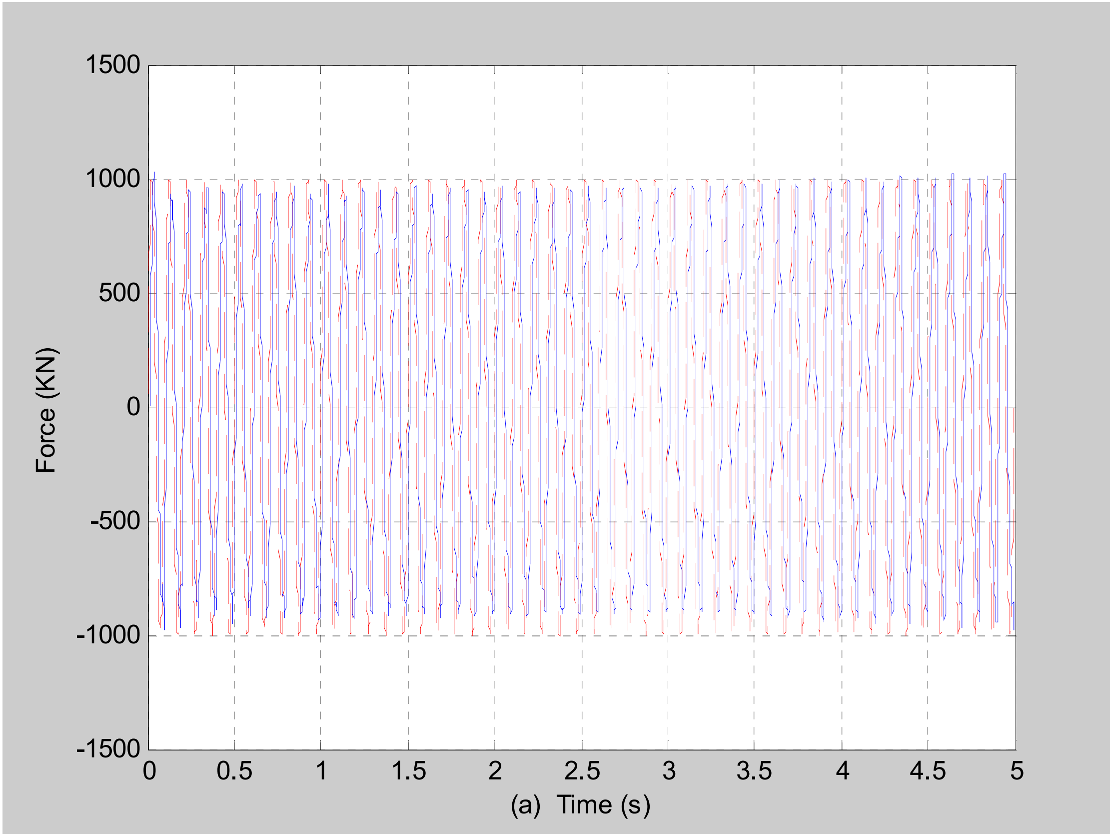


Figure 3.6.2. Force control dynamic bandwidth test at Actuator 3 (Test 5.2: 2 valves)
Red: command (1000KN@10Hz); Blue: response (850KN@10Hz)

- Test task: Sinusoid force control on Actuator 3 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: James Ricles
Test site: Lehigh ATLSS Center
Date: 8/9/2004

Servo Control Parameter
Configuration--3 valve EFK PID control at actuator 3
PID control-- Kp=2.0; Ki=0.8; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – E: 0.98; F: 1.00; K: 0.88
Servo valve offset (%) – E: 1.797; F: 0.391; K: 1.016
Servo valve spool zero (%) – E: 2.031; F: 4.062; K: 0.00

Test result
Dynamic bandwidth: 10Hz@1000KN (15% attenuation, less than 3 db) –See Figure 3.6.3.

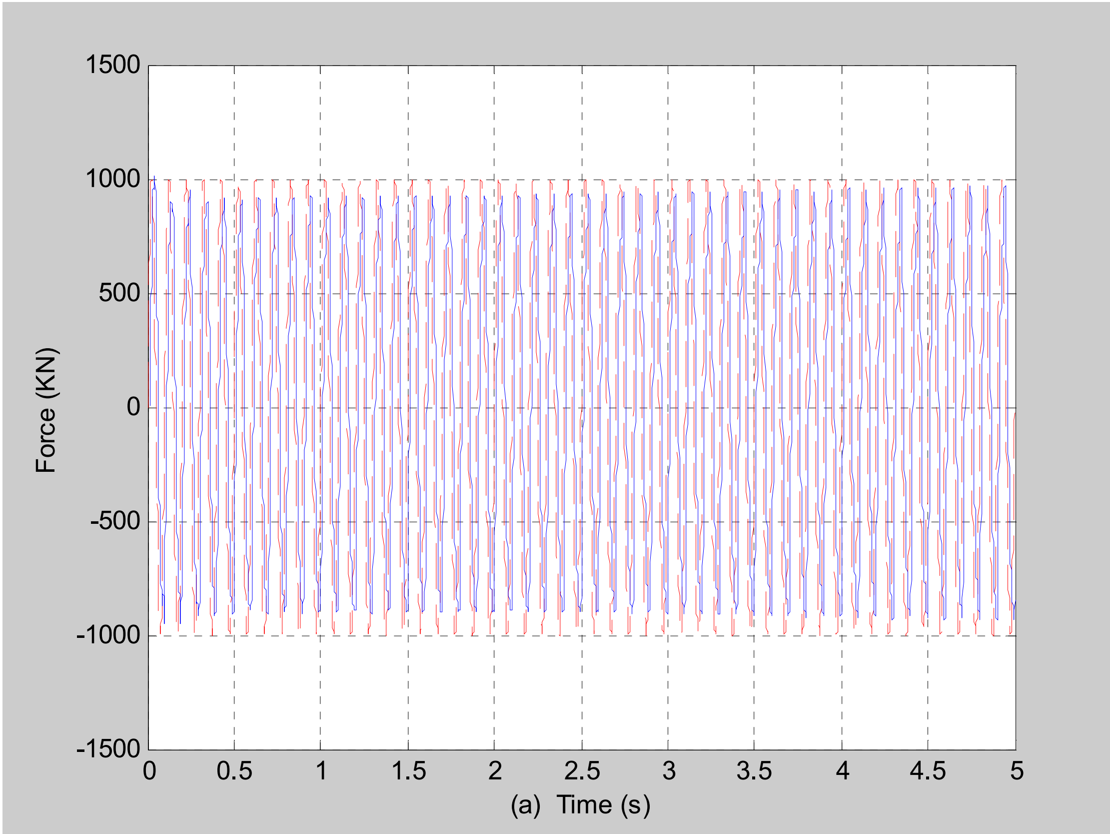


Figure 3.6.3. Force control dynamic bandwidth test at Actuator 3 (Test 5.2: 3 valves)
Red: command (1000KN@10Hz); Blue: response (850KN@10Hz)

4 ACTUATOR 4

4.1 0.2% displacement accuracy test (travel range: ±500mm)

4.1.1 10% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±50mm displacement control on Actuator 4 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/15/2004

Servo Control Parameter
Configuration--1 valve G PID control at actuator 4
PID control-- Kp=60; Ki=10; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; (H: 0.0; K: 0.0)
Servo valve offset – G: 1.094; (H: 1.953; K: 2.5)
Servo valve spool zero – G: 3.096; (H: 2.187; K: 2.187)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 4.1.1.1.

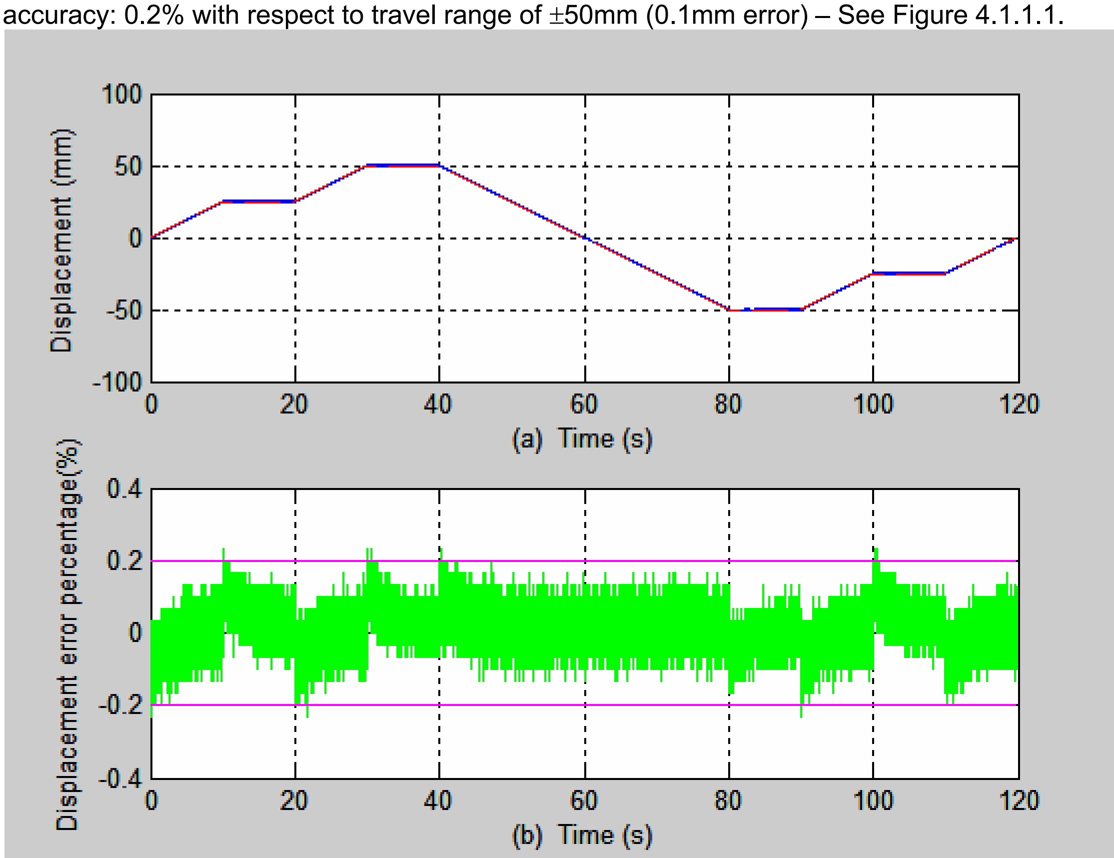


Figure 4.1.1.1. 10% stroke accuracy test at Actuator 4 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 4 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/15/2004

Servo Control Parameter:
Configuration--2 valve GH PID control at actuator 4
PID control-- Kp=27; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; (H: 1.00; K: 0.0)
Servo valve offset – G: 1.094; (H: 1.953; K: 2.5)
Servo valve spool zero – G: 1.106; (H: 2.187; K: 2.187)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 4.1.1.2.

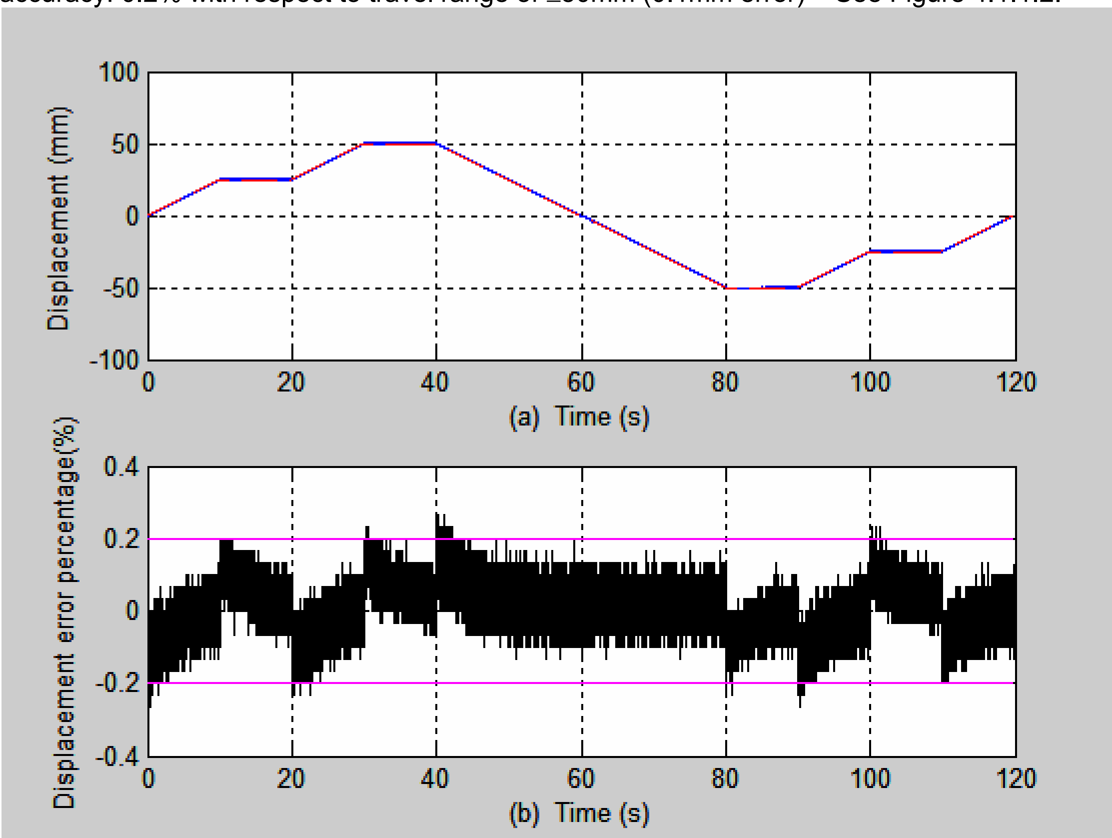


Figure 4.1.1.2. 10% stroke accuracy test at Actuator 4 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 4 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/15/2004

Servo Control Parameter

Configuration--3 valve GHK PID control at actuator 4
PID control-- Kp=20; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset – G: 1.094; H: 1.953; K: 2.5
Servo valve spool zero – G: 1.106; H: 2.187; K: 2.187
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 4.1.1.3.

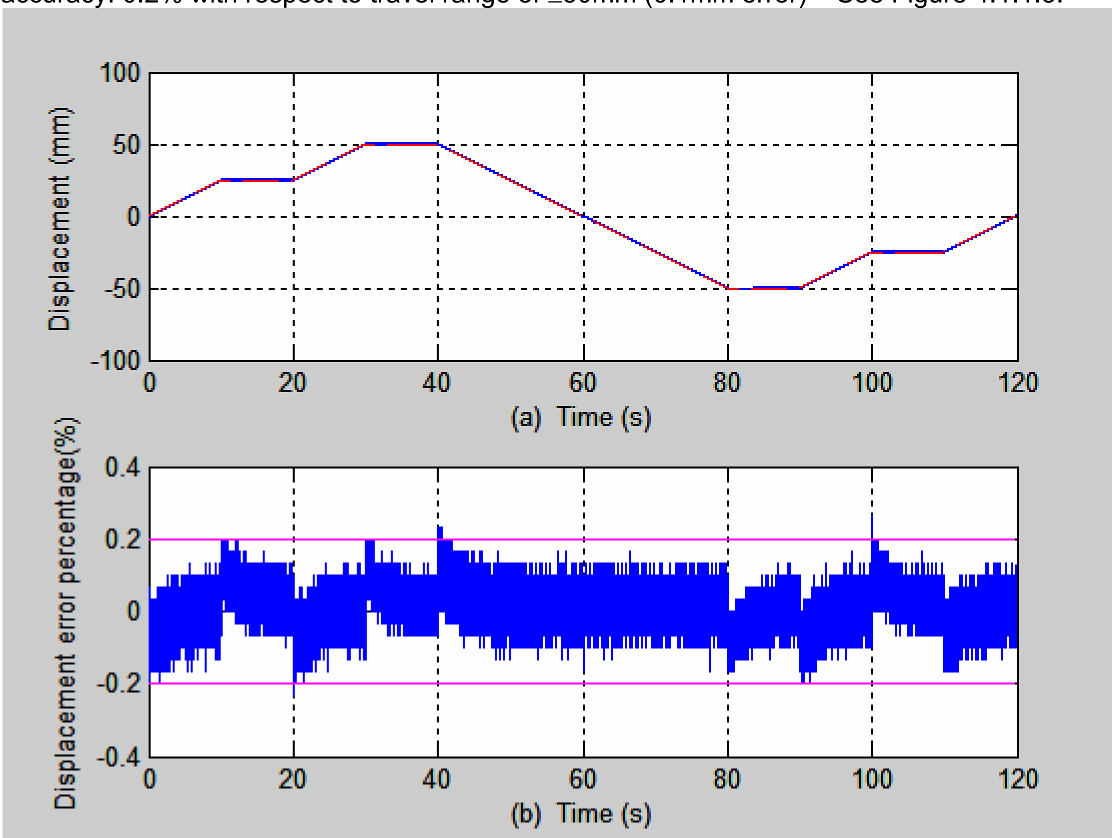


Figure 4.1.1.3.   10% stroke accuracy test at Actuator 4 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

4.1.2   20% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±100mm displacement control on Actuator 4 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/15/2004

Servo Control Parameter
Configuration--1 valve G PID control at actuator 4
PID control-- Kp=60; Ki=10; Kd =0
Servo valve loop gain -- Kv=30

Servo valve input scale – G: 1.0; (H: 0.0; K: 0.0)
Servo valve offset – G: 1.094; (H: 1.953; K: 2.5)
Servo valve spool zero – G: 3.096; (H: 2.187; K: 2.187)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±100mm (0.2mm error) –See Figure 4.1.2.1.

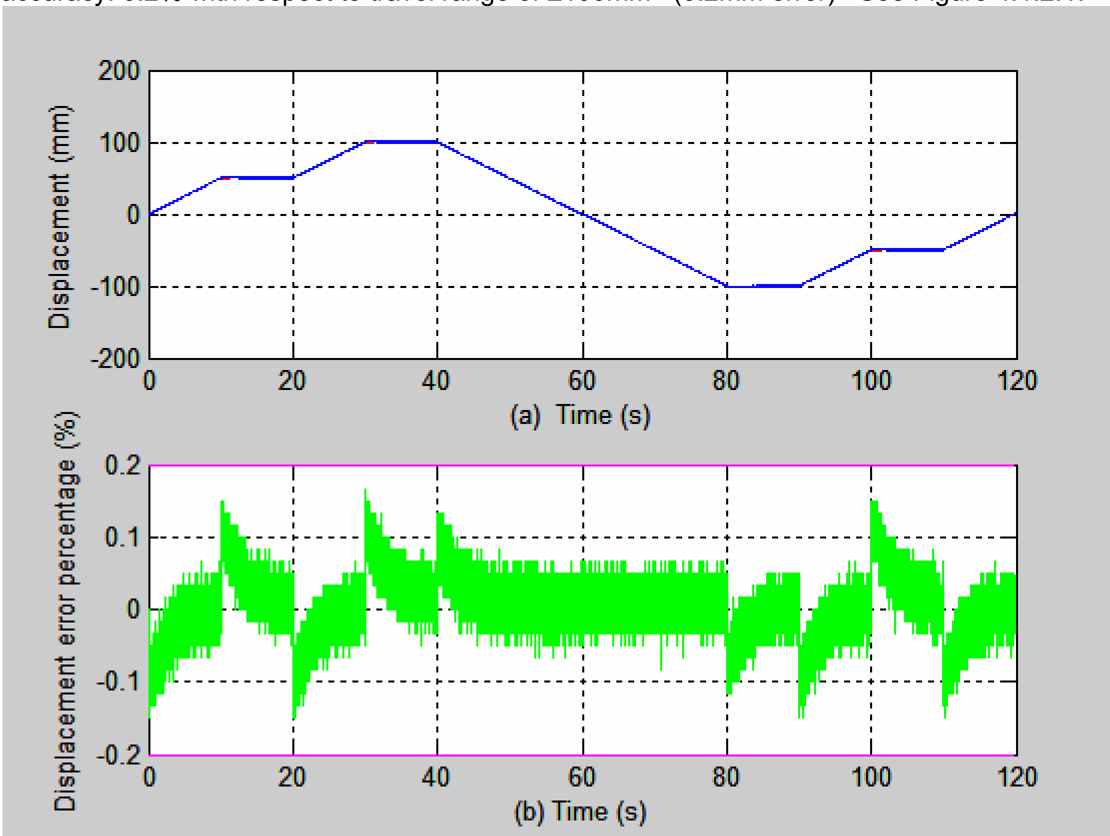


Figure 4.1.2.1. 20% stroke accuracy test at Actuator 4 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 4 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/14/2004

Servo Control Parameter
Configuration--2 valve GH PID control at actuator 4
PID control-- Kp=27; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; (K: 0.0)
Servo valve offset – G: 1.094; H: 1.953; (K: 2.5)
Servo valve spool zero – G: 1.016; H: 2.187; (K: 2.187)
Hydraulic supply pressure: 3000psi

Test result

Static accuracy: 0.2% with respect to travel range of ±100mm (0.2mm error) –See Figure 4.1.2.2.

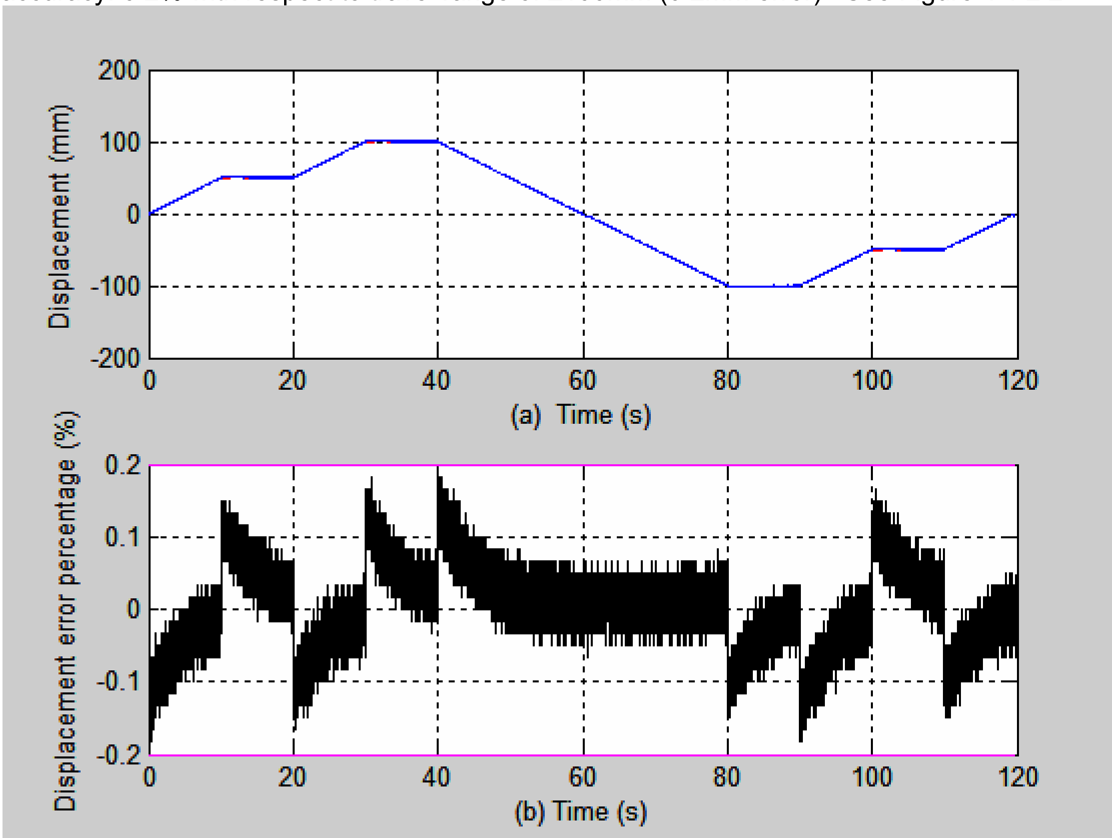


Figure 4.1.2.2. 20% stroke accuracy test at Actuator 4 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 4 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/14/2004

<u>Servo Control Parameter</u>
Configuration--3 valve GHK PID control at actuator 4
PID control-- Kp=20; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset – G: 1.094; H: 1.953; K: 2.5
Servo valve spool zero – G: 1.106; H: 2.187; K: 2.187
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy:0.18% with respect to travel range of ±100mm (0.18mm error)–See Figure 4.1.2.3.

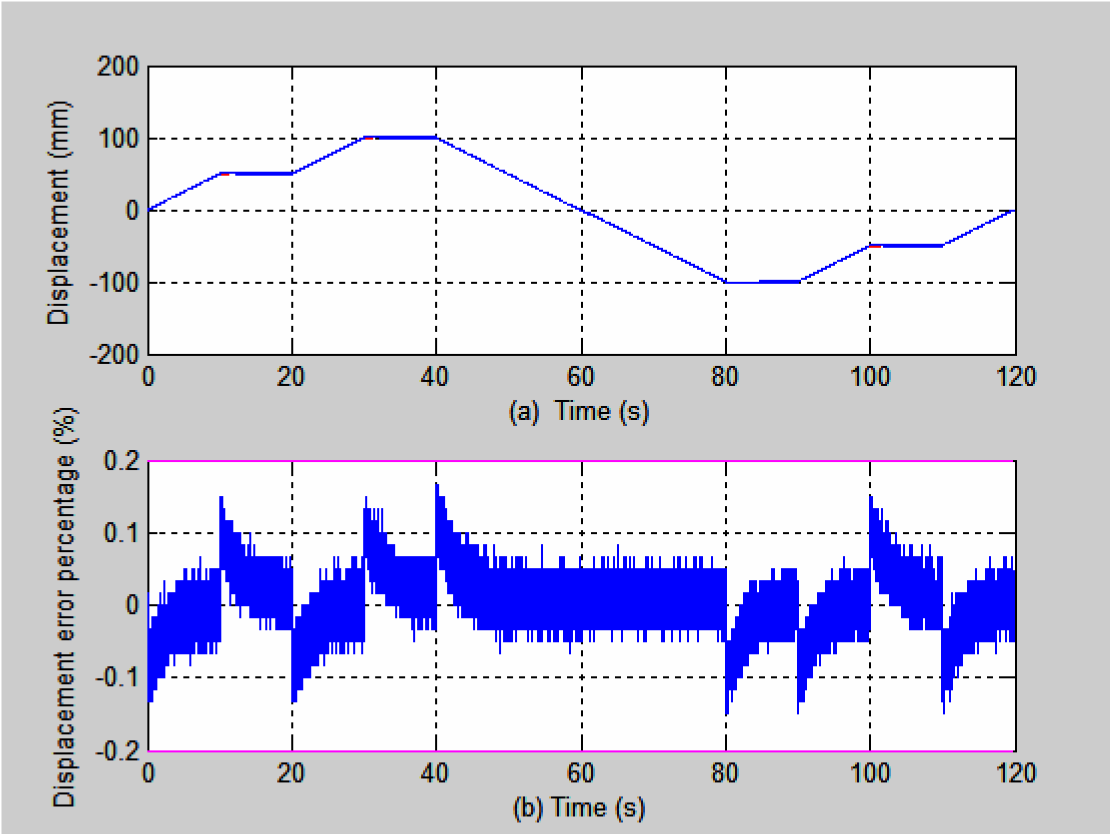


Figure 4.1.2.3. 20% stroke accuracy test at Actuator 4 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

4.1.3 100% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±500mm displacement control on Actuator 4 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/15/2004

Servo Control Parameter
Configuration--1 valve G PID control at actuator 4
PID control– Kp=60; Ki=10; Kd =0
Servo valve loop gain – Kv=30
Servo valve input scale – G: 1.0; (H: 0.0; K: 0.0)
Servo valve offset – G: 1.094; (H: 1.953; K: 2.5)
Servo valve spool zero – G: 3.096; (H: 2.187; K: 2.187)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.18% with respect to travel range of ±500mm (0.9mm error)– See Figure 4.1.3.1.

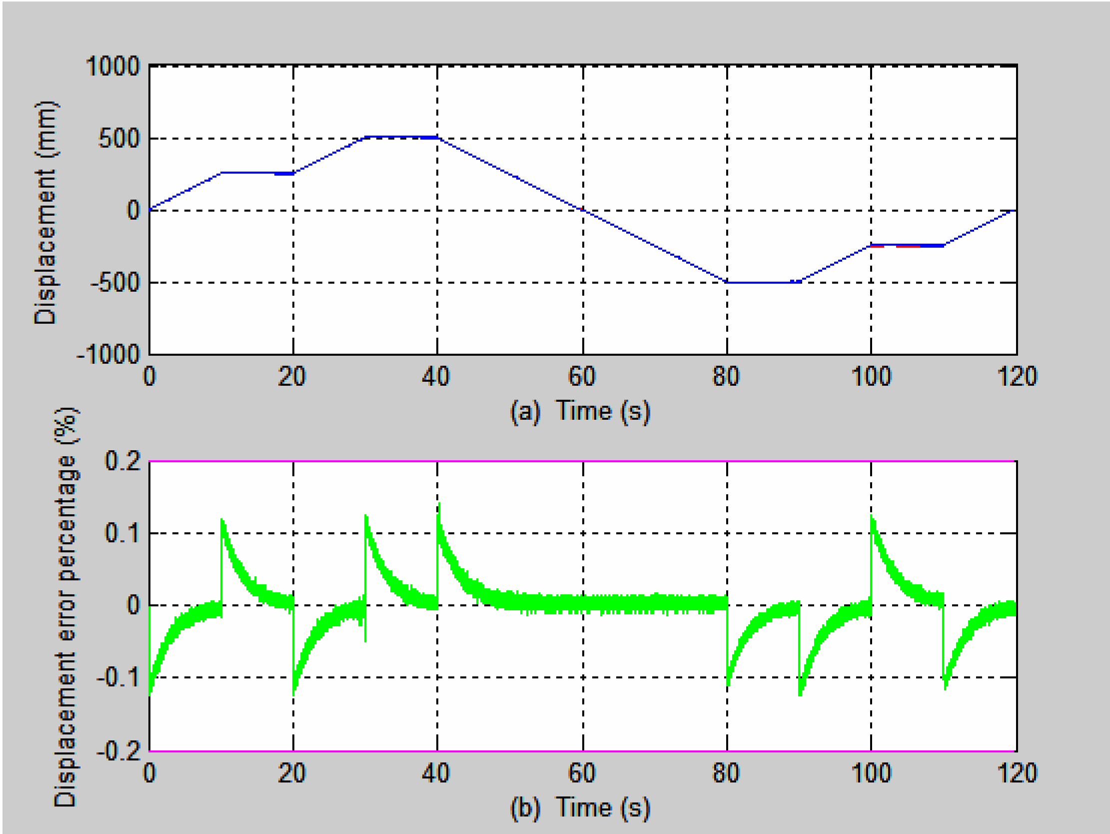


Figure 4.1.3.1. 100% stroke accuracy test at Actuator 4 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 4 (2 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/14/2004

Servo Control Parameter
Configuration--2 valve GH PID control at actuator 4
PID control-- Kp=27; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; (K: 0.0)
Servo valve offset – G: 1.094; H: 1.953; (K: 2.5)
Servo valve spool zero – G: 1.106; H: 2.187; (K: 2.187)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.13% with respect to travel range of ±500mm(0.65mm error)–See Figure 4.1.3.2.

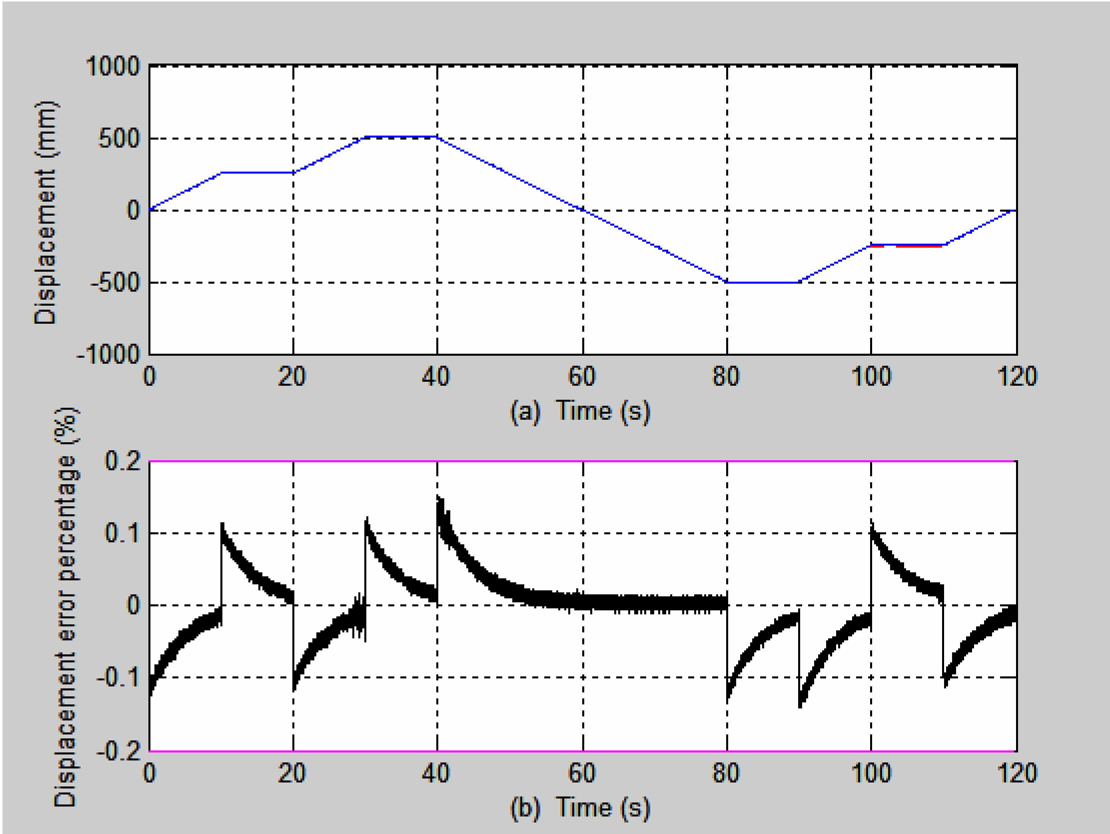


Figure 4.1.3.2. 100% stroke accuracy test at Actuator 4 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 4 (3 valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/14/2004

Servo Control Parameter
Configuration--3 valve GHK PID control at actuator 4
PID control-- Kp=20; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset – G: 1.094; H: 1.953; K: 2.5
Servo valve spool zero – G: 1.106; H: 2.187; K: 2.187
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.12% with respect to travel range of ± 500mm (0.6mm error)–See Figure 4.1.3.3.

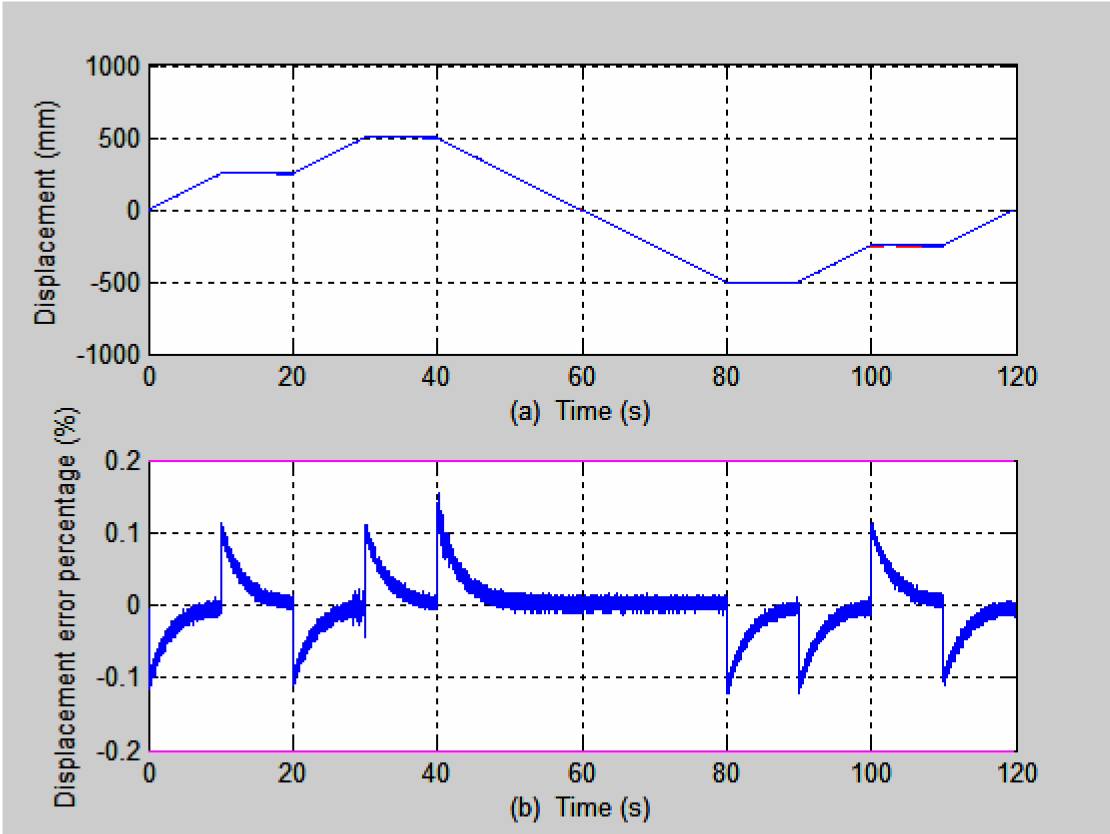


Figure 4.1.3.3. 100% stroke accuracy test at Actuator 4 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

4.1. 4 SCRAMNet 100% travel range displacement accuracy test (3 valves)

- Test task: SCRAMNet ±500mm displacement control on Actuator 4 (3valves)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/14/2004

Servo Control Parameter
Configuration –3 valve GHK PID control at actuator 4
PID control – Kp=20; Ki=3; Kd =0
Servo valve loop gain – Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset – G: 1.094; H: 1.953; K: 2.5
Servo valve spool zero – G: 1.106; H: 2.187; K: 2.187
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.14% with respect to travel range of ± 500mm (0.7mm error)–See Figure 4.1.4.1.

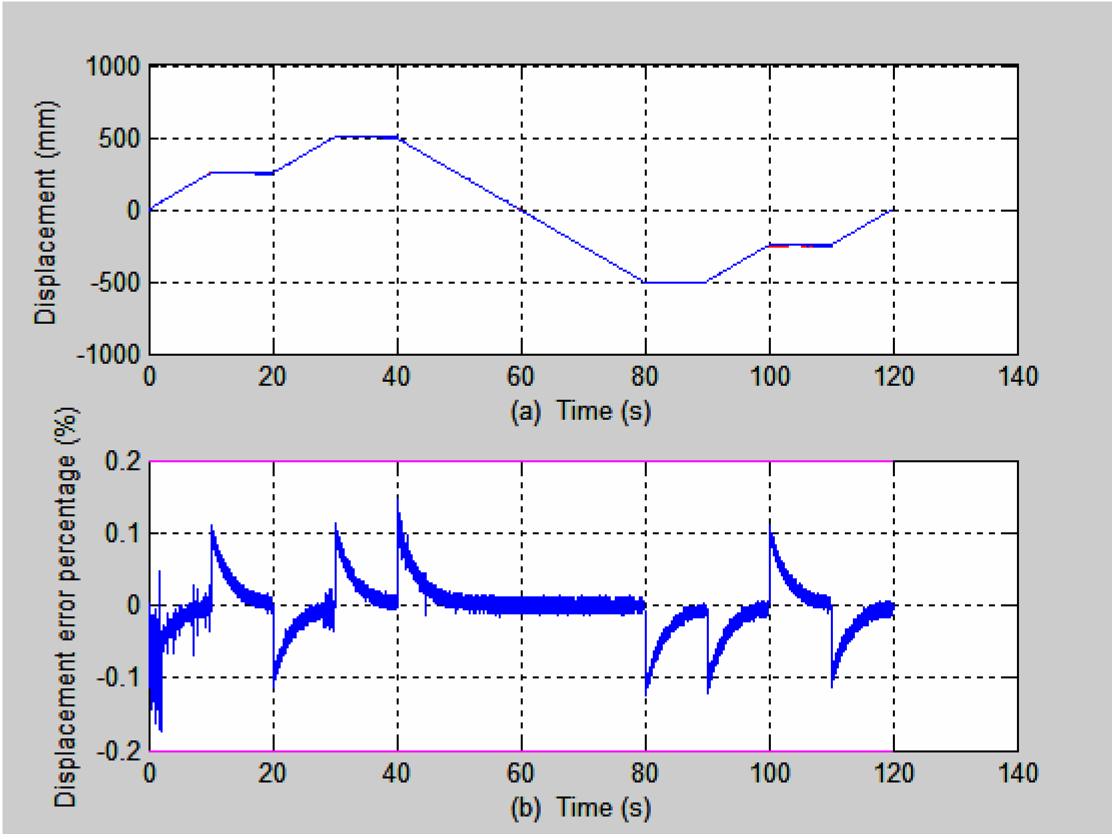


Figure 4.1.4.1. SCRAMNet 100% stroke accuracy test at Actuator 4 (Test 5 -Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Blue: error percentage; Magenta: error boundary ±0.2%

4.2 10Hz displacement bandwidth test

4.2.1 ±3.81mm@10Hz sinusoid with 1valve operation

- Test task: Sinusoid displacement control on Actuator 4 (1 valve)

Servotest Systems Ltd: Troy Diller
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/15/2004

Servo Control Parameter
Configuration --1 valve G PID control at actuator 4
PID control -- Kp=90; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; (H: 0.0; K: 0.0)
Servo valve offset – G: 1.094; (H: 1.953; K: 2.5)
Servo valve spool zero – G: 3.096; (H: 2.187; K: 2.187)
Hydraulic supply pressure – 3000psi
Hydraulic supply flow rate – 420gpm

Test result
Dynamic bandwidth: 10Hz@0.15inch (30% attenuation, 3 db) – See Figure 4.2.1.1.

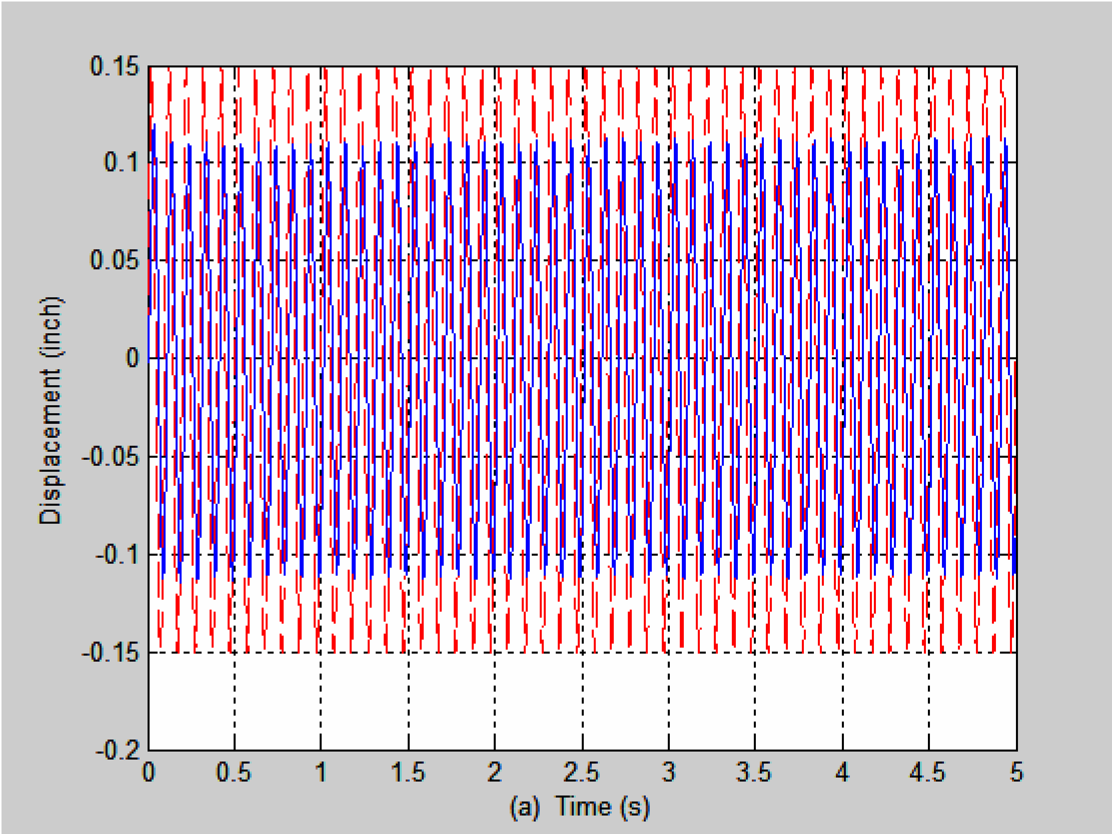


Figure 4.2.1.1. Dynamic bandwidth test at Actuator 4 (Test 2: 1 vale)
Red: command (0.15inch@10Hz); Blue: response (0.11inch@10Hz)

4.2.2 ±7.62mm@10Hz sinusoid with 2 valve operation

- Test task: Sinusoid displacement control on Actuator 4 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/28/2004

Servo Control Parameter
Configuration --2 valve GH PID control at actuator 4
PID control -- Kp=70; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; (K: 0.0)
Servo valve offset – G: 1.094; H: 1.953; (K: 2.5)
Servo valve spool zero – G: 1.106; H: 2.187; (K: 2.187)
Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 840gpm

Test result
Dynamic bandwidth: 10Hz@0.30inch (15% attenuation, less than 3 db) – See Figure 4.2.2.1.

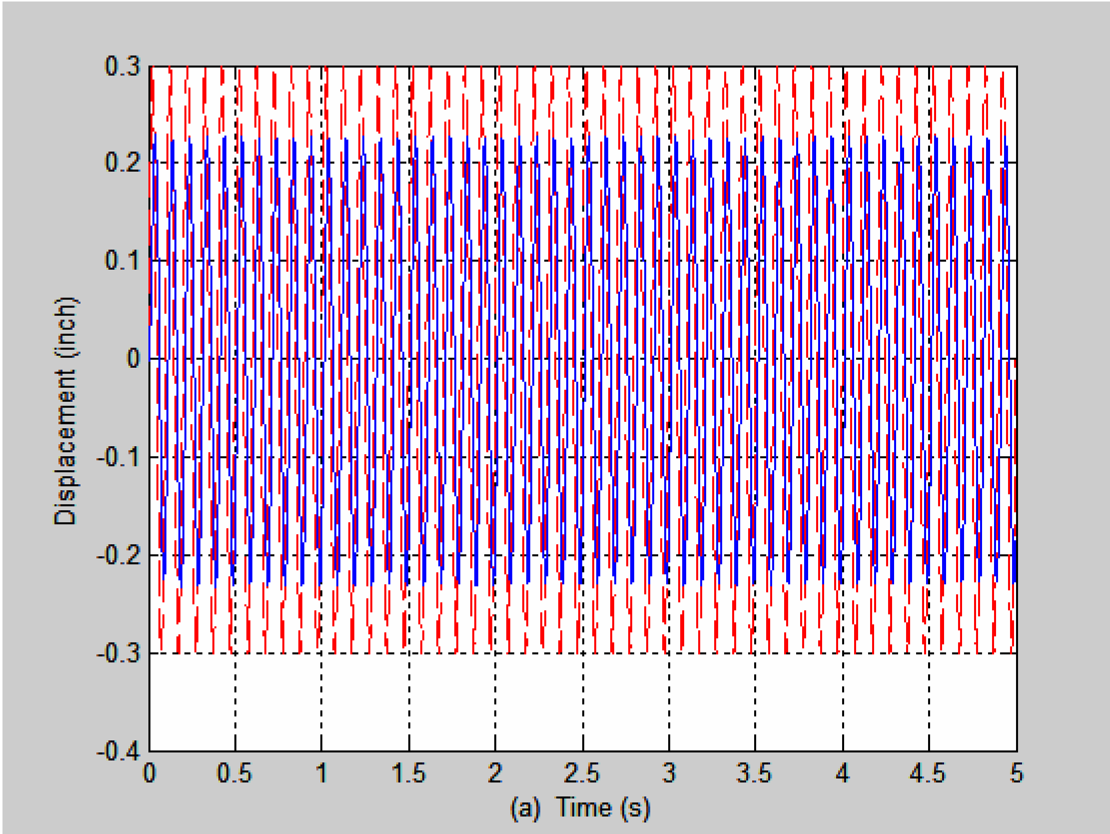


Figure 4.2.2.1. Dynamic bandwidth test at Actuator 4 (Test 2: 2 vales)
Red: command (0.30inch@10Hz); Blue: response (0.22inch@10Hz)

4.2.3 ±11.43mm@10Hz sinusoid with 3 valve operation

- Test task: Sinusoid displacement control on Actuator 4 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/28/2004

Servo Control Parameter
Configuration --3 valve GHK PID control at actuator 4
PID control -- Kp=40; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset (%) – G: 1.094; H: 1.953; K: 2.5
Servo valve spool zero (%) – G: 1.106; H: 2.187; K: 2.187
Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 1260gpm

Test result
Dynamic bandwidth: 10Hz@0.45inch (16% attenuation, less than 3 db) – See Figure 4.2.3.1.

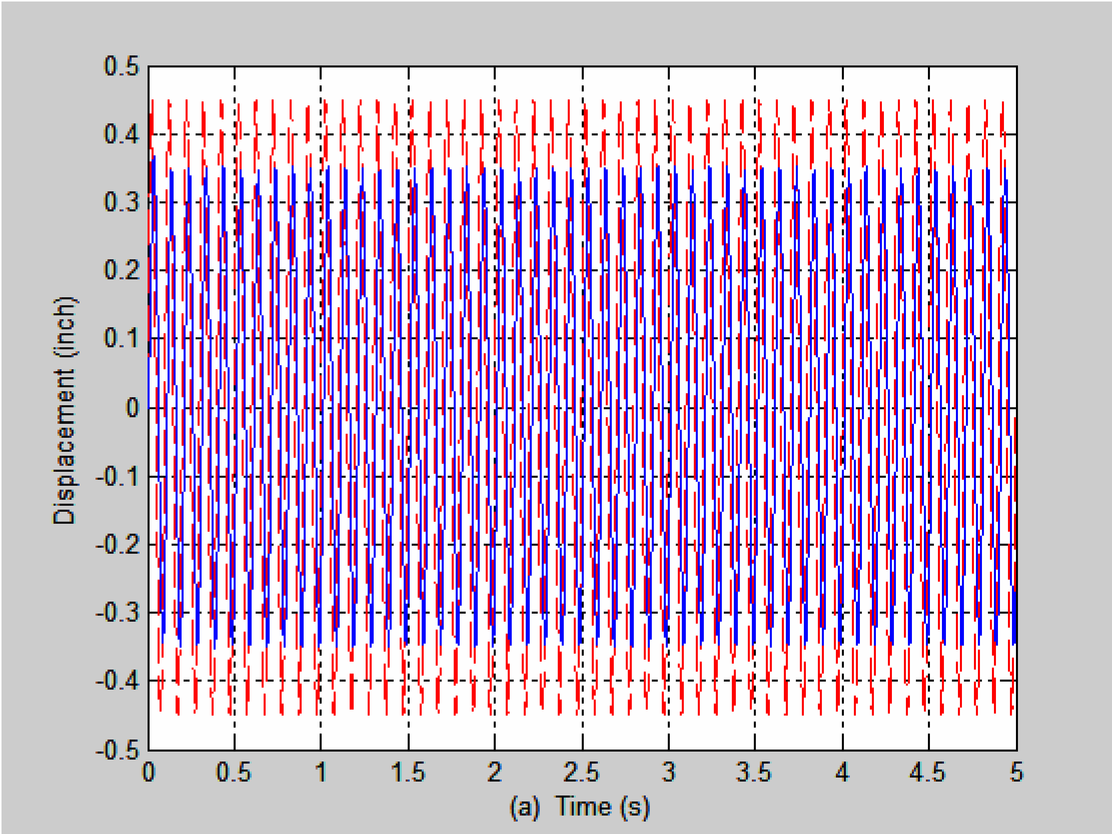


Figure 4.2.3.1. Dynamic bandwidth test at Actuator 4 (Test 2: 3 valves)
Red: command (0.45inch@10Hz); Blue: response (0.32inch@10Hz)

4.2.4 SCRAMNet ±11.43mm@10Hz sinusoid with 3 valve operation

- Test task: SCRAMNet Sinusoid displacement control on Actuator 4 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/28/2004

Servo Control Parameter
Configuration –3 valve GHK PID control at actuator 4
PID control – Kp=40; Ki=3; Kd =0
Servo valve loop gain – Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset (%) – G: 1.094; H: 1.953; K: 2.5
Servo valve spool zero (%) – G: 1.106; H: 2.187; K: 2.187
Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 1260gpm

Test result
Dynamic bandwidth: 10Hz@0.45inch (21% attenuation, less than 3 db) – See Figure 4.2.4.1.

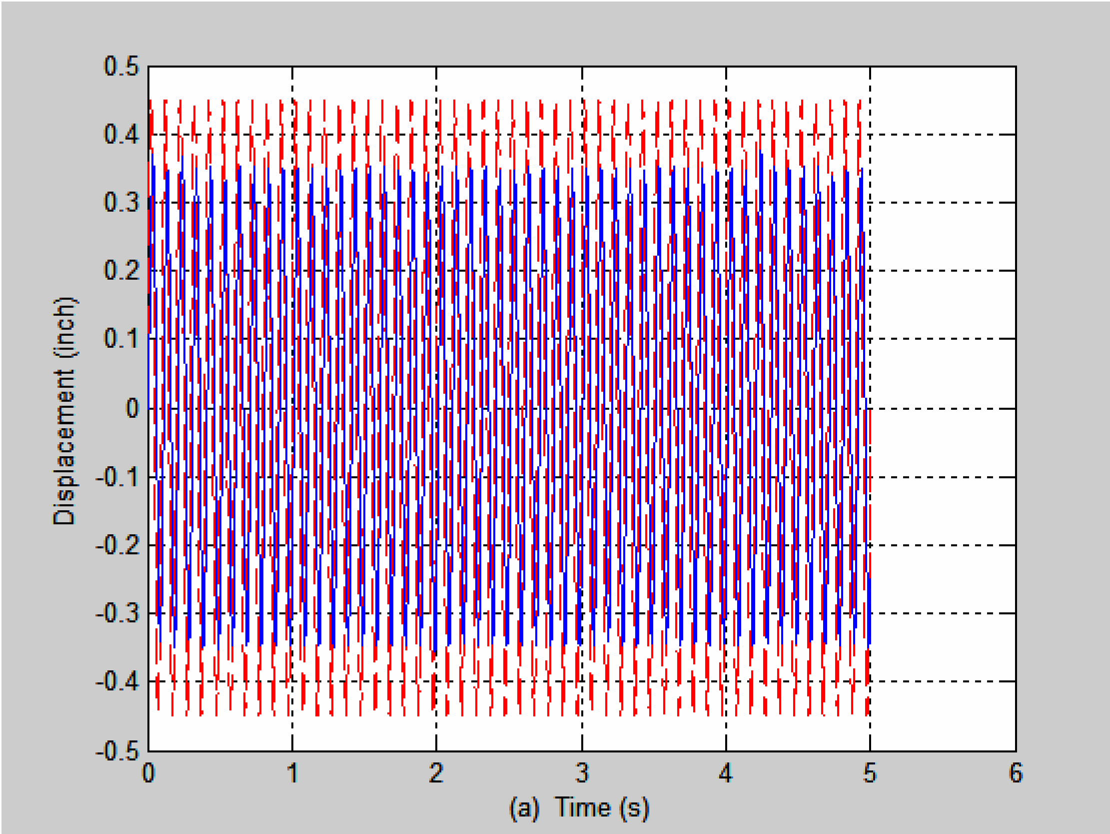


Figure 4.2.4.1. SCRAMNet dynamic bandwidth test at Actuator 4 (Test 5 - Test 2: 3 valves)
Red: command (0.45inch@10Hz); Blue: response (0.32inch@10Hz)

4.3 0.84m/s high velocity test

- Test task: High velocity test on Actuator 4 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/28/2004

<u>Servo Control Parameter</u>
Configuration--3 valve GHK PID control at actuator 4
PID control– Kp=40; Ki=3; Kd =0
Servo valve loop gain – Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset (%) – G: 1.094; H: 1.953; K: 2.5
Servo valve spool zero (%) – G: 1.106; H: 2.187; K: 2.187
Hydraulic supply pressure: 3200psi
Hydraulic supply flow rate: 1500gpm (with accumulator banks)

<u>Test result</u>
Speed reaches 0.84 m/s momentarily (RG accumulator is used for oil supply-1500gpm) – See Figure 4.3.1.

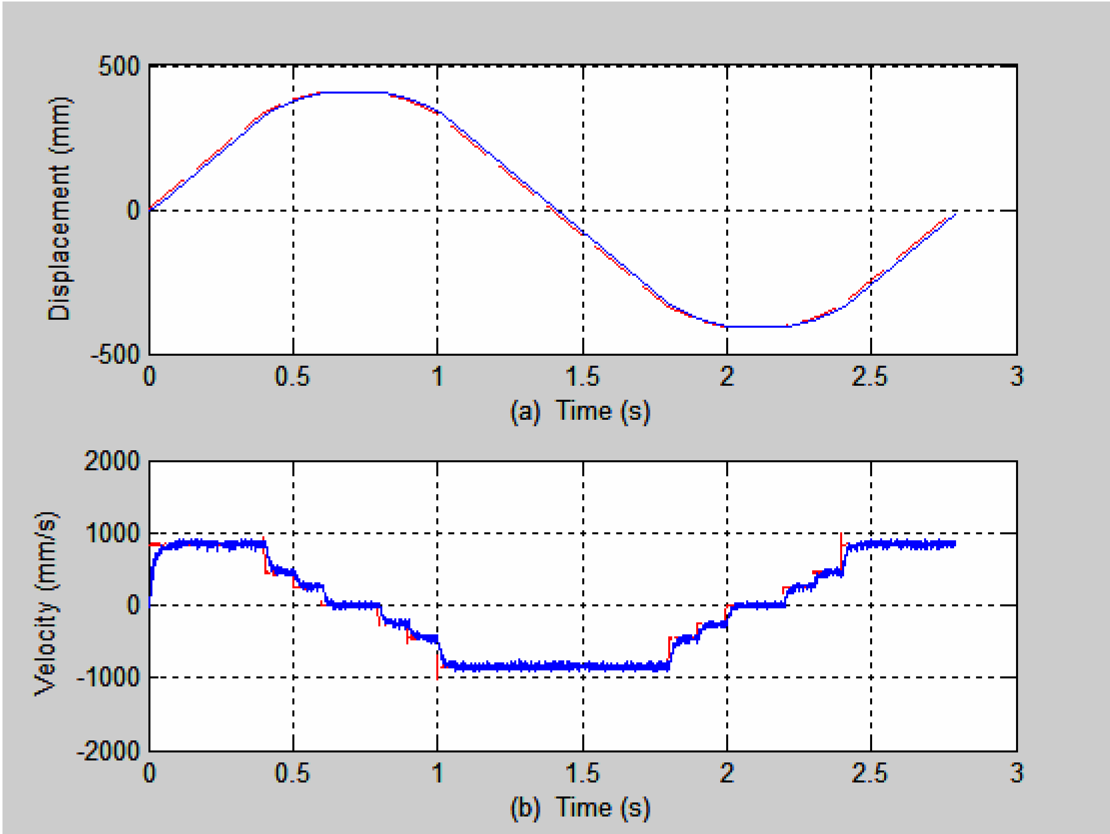


Figure 4.3.1. High velocity test at Actuator 4 (Test 3)
(a) Displacement (mm) – Red: command; Blue: response
(b) Velocity (mm/s) -- Red: command; Blue: response

4.4 277KW power test with single valve operation (0.20m/s@1333KN)

- Test task: Power test on Actuator 4 (1 valve, against Load Actuator 5)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/14/2004

Servo Control Parameter
Configuration:
1 valve H displacement PID control at Actuator 4
1 valve J load PID control at Actuator 5
Actuator 4 displacement PID control-- Kp=45; Ki=3; Kd =0; f=39.8
Actuator 5 load PID control-- Kp=8; Ki=3; Kd =-1; f=10Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – J: 0.87; H: 1.0; (K: 0.88)
Servo valve offset (%) – J: -1.016; H: -1.016; (K: 1.016)
Servo valve spool zero (%) – J: -3.047; H: 2.001; (K: 4.062)
Hydraulic supply pressure: 3400psi

Test result
Power capacity: power output at Actuator 4 reaches 277KW. – See Figure 4.4.1.

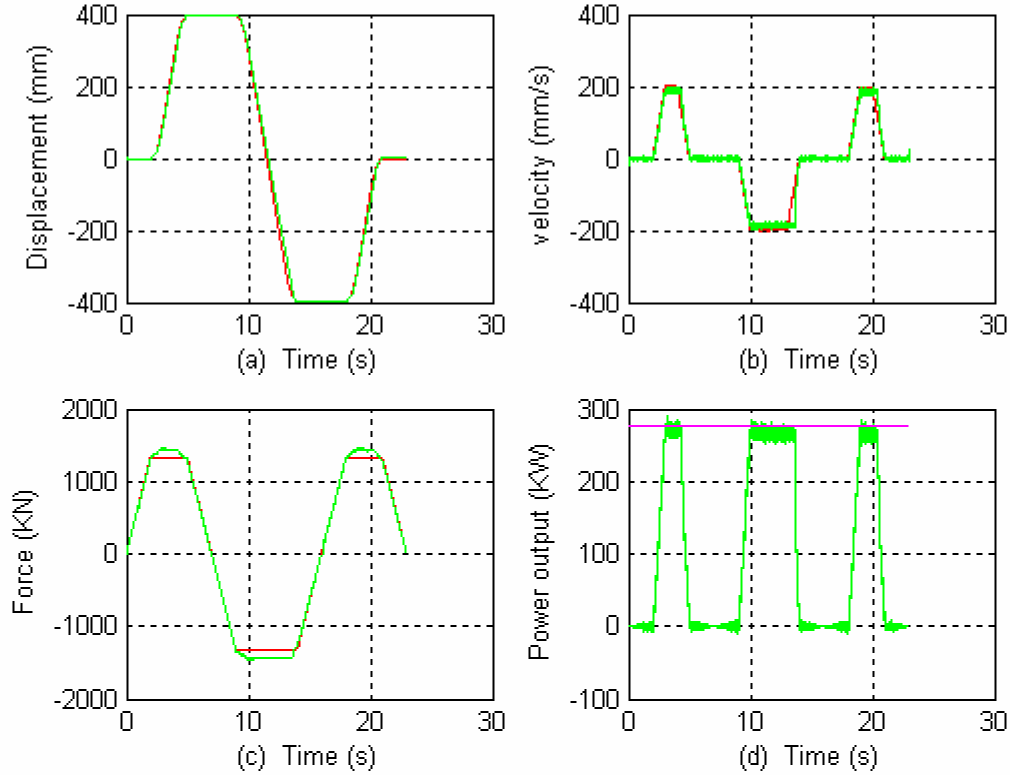


Figure 4.4.1. Power test at Actuator 4 (Test 4: 1 valve; Actuator 5 simulates load)
(Actuator 4 –displacement and Actuator 5—load)
(a) Displacement (mm) – Red: command; Green: response
(b) Velocity (mm/s) – Red: command; Green: response
(c) Force (KN) – Red: command; Green: response
(d) Power (KW) – Green: actual output; Magenta: power target value (277KW)

4.5 0.2% force accuracy test (load range: ±2300KN)

4.5.1 5% load range force accuracy test (1, 2, 3 valves)

- Test task: ±115KN force control on Actuator 4 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/30/2004

<u>Servo Control Parameter</u>
Configuration--1 valve G PID control at actuator 4
PID control-- Kp=11; Ki=2; Kd =-1.0; f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; (H: 0.0; K: 0.0)
Servo valve offset (%) – G:-2.031; (H: -1.016; K: -0.547)
Servo valve spool zero (%) – G: 5.469; (H: -0.781; K:-5.703)
Hydraulic supply pressure: 3000psi

<u>Test result</u>

Static accuracy: 0.03% with respect to force range of ±115KN (±0.04KN error)–See Figure 4.5.1.1.

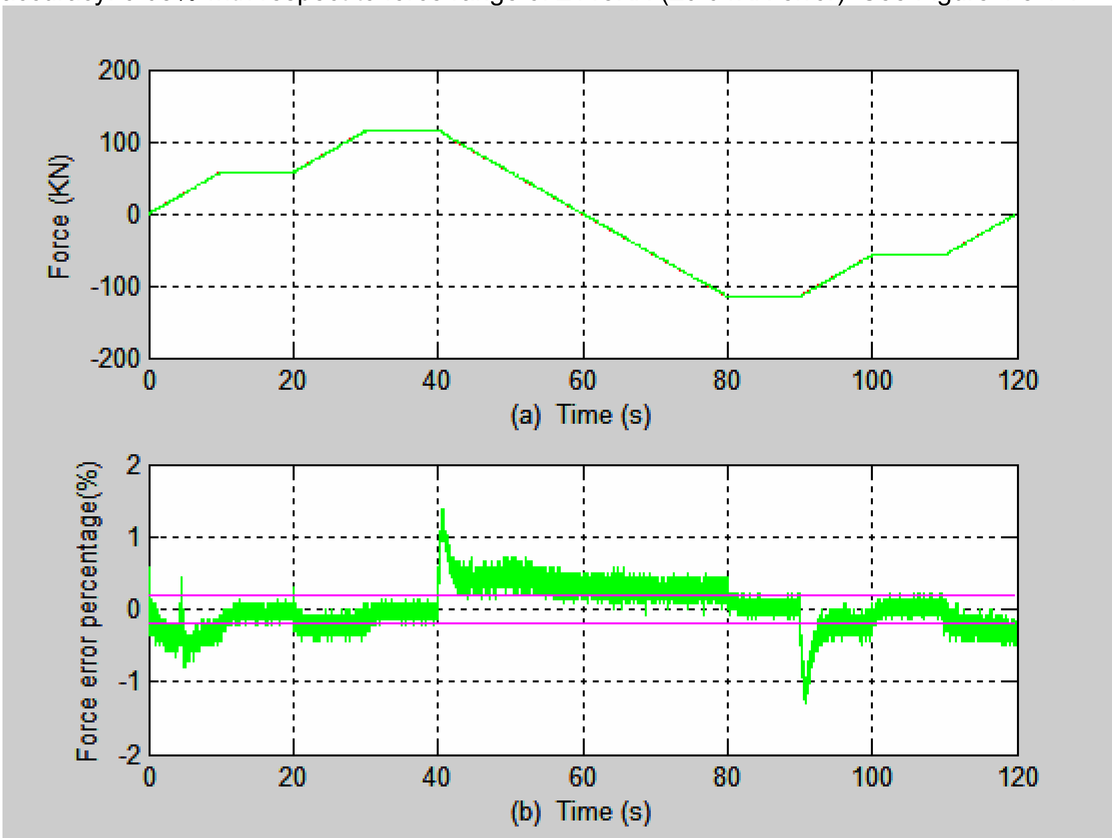


Figure 4.5.1.1. 5% maximum force accuracy test at Actuator 4 with cutoff frequency of 100Hz
(Test 5.1: 1 valve; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±115KN
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±115KN force control on Actuator 4 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/1/2004

Servo Control Parameter
Configuration--2 valve GH PID control at actuator 4
PID control-- Kp=4; Ki=1; Kd =-1, f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; (K: 0.0)
Servo valve offset (%) – G: -1.875; H: -0.938; (K: 0.391)
Servo valve spool zero (%) – G: 7.422; H: 1.562; (K: -4.688)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.03% with respect to force range of ±115KN (0.04KN error) –See Figure 4.5.1.2.

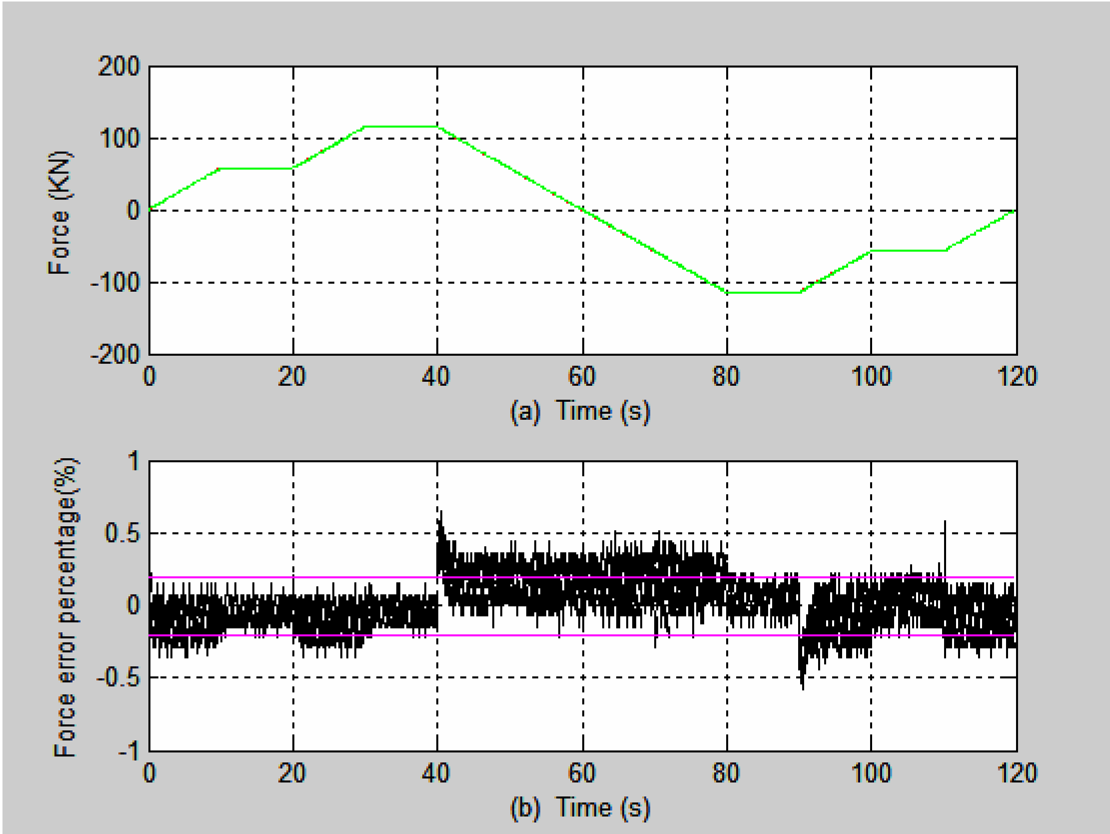


Figure 4.5.1.2. 5% maximum force accuracy test at Actuator 4
(Test 5.1: 2 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±115KN
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±115KN force control on Actuator 4 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/1/2004

Servo Control Parameter
Configuration--3 valve GHK PID control at actuator 4
PID control-- Kp=2.8; Ki=0.7; Kd =-1; f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset (%) – G: -2.032; H: -1.172; K: 0.859
Servo valve spool zero (%) – G: 0.984; H: -3.125; K: 4.922
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.03% with respect to force range of ±115KN (0.04KN error) –See Figure 4.5.1.3.

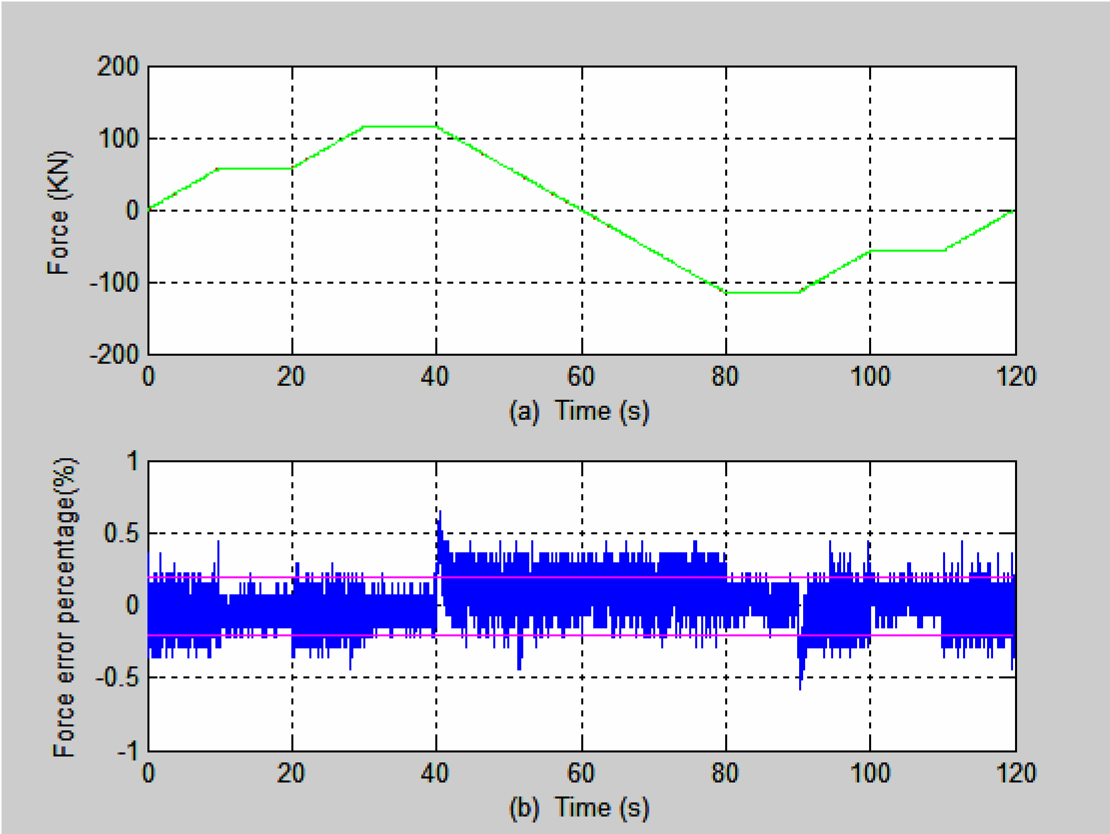


Figure 4.5.1.3. 5% maximum force accuracy test at Actuator 4
(Test 5.1: 3 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±115KN
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

4.5.2 20% load range force accuracy test (1, 2, 3 valves)

- Test task: ±460KN force control on Actuator 4 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 6/30/2004

Servo Control Parameter
Configuration--1 valve G PID control at actuator 4
PID control-- Kp=11; Ki=2; Kd =-1.0; f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; (H: 0.0; K: 0.0)
Servo valve offset (%) – G: -2.031; (H: -1.016; K: -0.547)
Servo valve spool zero (%) – G: 5.469; (H: -0.781; K: -5.703)
Hydraulic supply pressure: 3200psi

Test result
Static accuracy: 0.01% with respect to force range of ±460KN (0.03KN error) –See Figure 4.5.2.1.

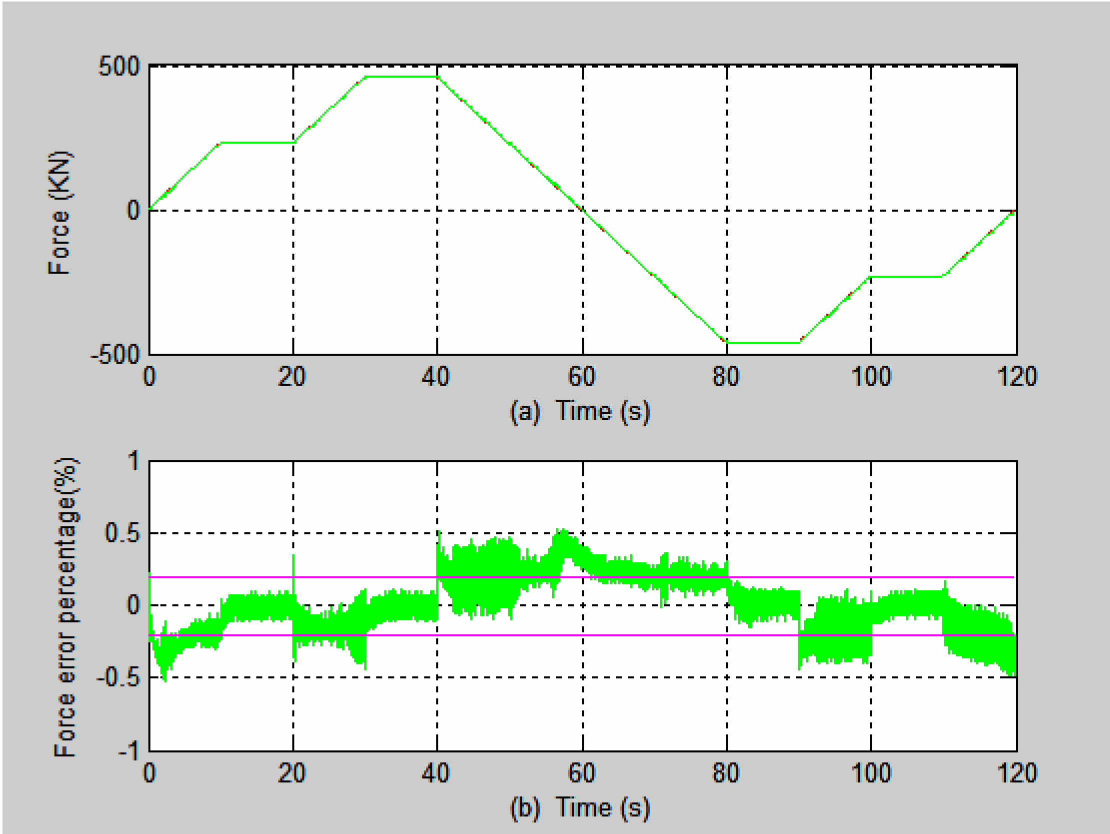


Figure 4.5.2.1. 20% maximum force accuracy test at Actuator 4
(Test 5.1: 1 valve; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±460KN
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±460KN force control on Actuator 4 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/1/2004

Servo Control Parameter
Configuration--2 valve GH PID control at actuator 4
PID control-- Kp=4.2; Ki=0.7; Kd =-1; f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; (K: 0.0)
Servo valve offset (%) – G: -1.875; H: -0.938; (K: 0.391)
Servo valve spool zero (%) – G: 7.422; H: 1.562; (K: -4.688)
Hydraulic supply pressure: 3200psi

Test result
Static accuracy: 0.01% with respect to force range of ±460KN (0.42KN error) –See Figure 4.5.2.2.

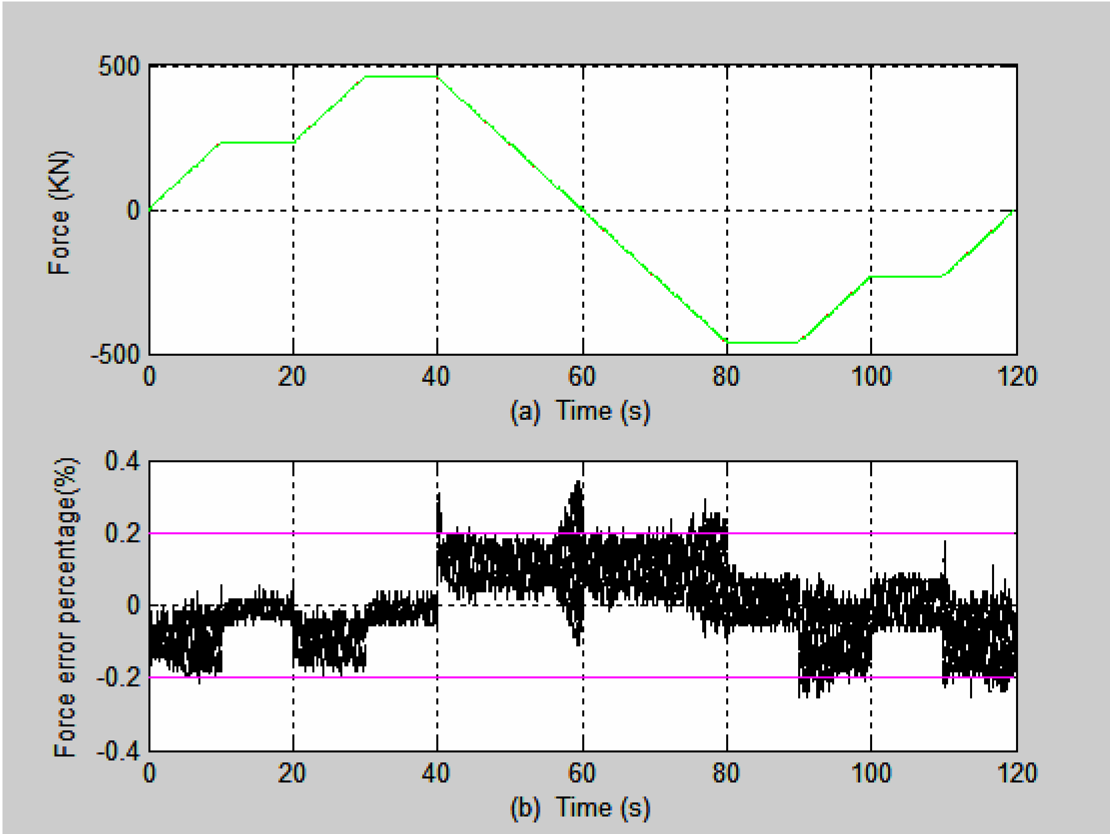


Figure 4.5.2.2. 20% maximum force accuracy test at Actuator 4
(Test 5.1: 2 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±460KN
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±460KN force control on Actuator 4 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/1/2004

Servo Control Parameter
Configuration--3 valve GHK PID control at actuator 4
PID control-- Kp=2.8; Ki=0.7; Kd =-1, f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset (%) – G:-2.032; H: -1.172; K: 0.859
Servo valve spool zero (%) – G: 0.984; H: -3.125; K: 4.922
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.01% with respect to force range of ±460KN (0.04KN error)–See Figure 4.5.2.3.

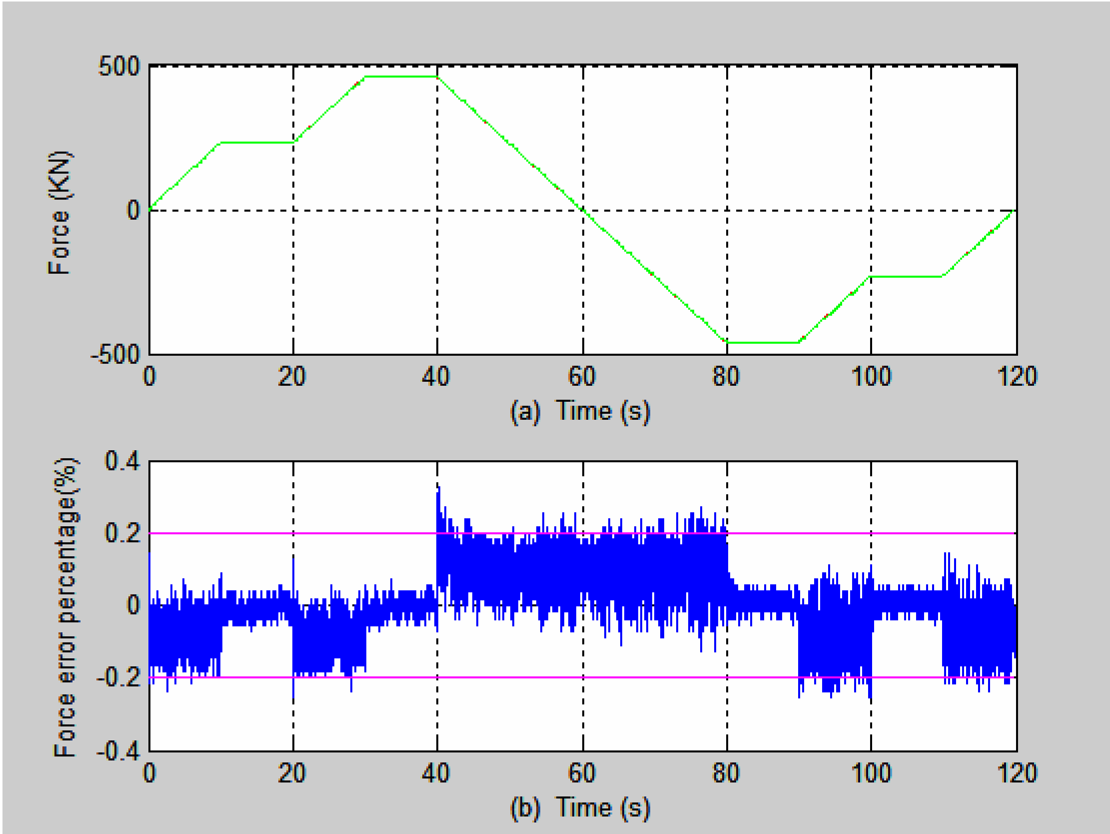


Figure 4.5.2.3. 20% maximum force accuracy test at Actuator 4
(Test 5.1: 3 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±460KN
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

4.5.3 100% load range force accuracy test (1, 2, 3 valves)

- Test task: ±2300KN force control on Actuator 4 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/6/2004

<u>Servo Control Parameter</u>
Configuration--1 valve G PID control at actuator 4
PID control-- Kp=4; Ki=1.0; Kd =-0.5, f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; (H: 0.00; K: 0.00)
Servo valve offset (%) – Compression - G:-3.125; (H: -3.984; K: -3.047)
-- Tension -- G: 2.109; (H: 2.344; K: 6.953)
Servo valve spool zero (%) – Compression - G:-3.125; (H: -3.984; K: -3.047)
-- Tension -- G: 4.141; (H: 1.719; K: 4.531)
Hydraulic supply pressure: 3200psi

<u>Test result</u>
Static accuracy:
Tension: 0.07% with respect to force range of ±2300KN (1.5 KN error) –See Figure 4.5.3.1.
Compression: 0.02% with respect to force range of ±2300KN (0.4 KN error) –See Figure 4.5.3.1.

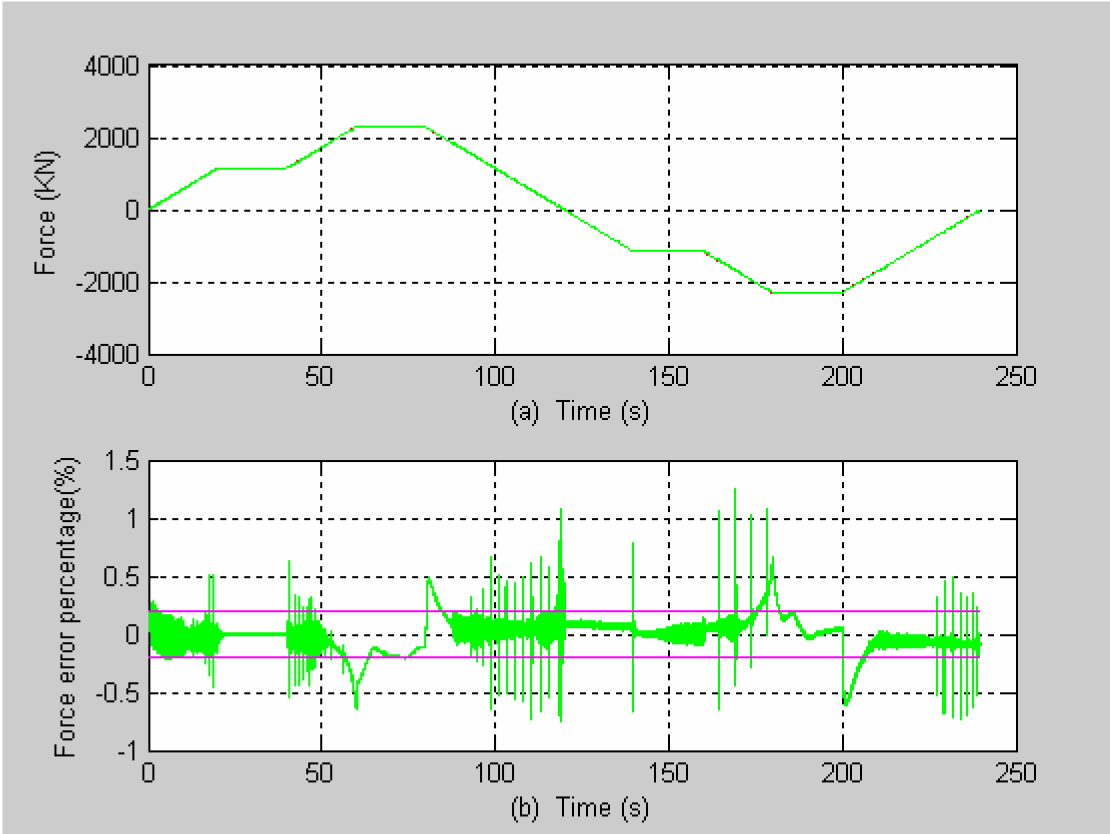


Figure 4.5.3.1. 100% maximum force accuracy test at Actuator 4
(Test 5.1: 1 valve; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±2300KN
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±2300KN force control on Actuator 4 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/6/2004

Servo Control Parameter
Configuration--2 valve GH PID control at actuator 4
PID control-- Kp=2; Ki=1.0; Kd =-0.5; f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; (K: 0.00;)
Servo valve offset (%) – G:-1.875; H: 0.938; (K: 4.6;)
Servo valve spool zero (%) – G: 7.422; H: 1.562; (K: -4.688;)
Hydraulic supply pressure: 3200psi

Test result
Static accuracy: 0.01% with respect to force range of ±2300KN (0.14 KN error)–See Figure 4.5.3.2.

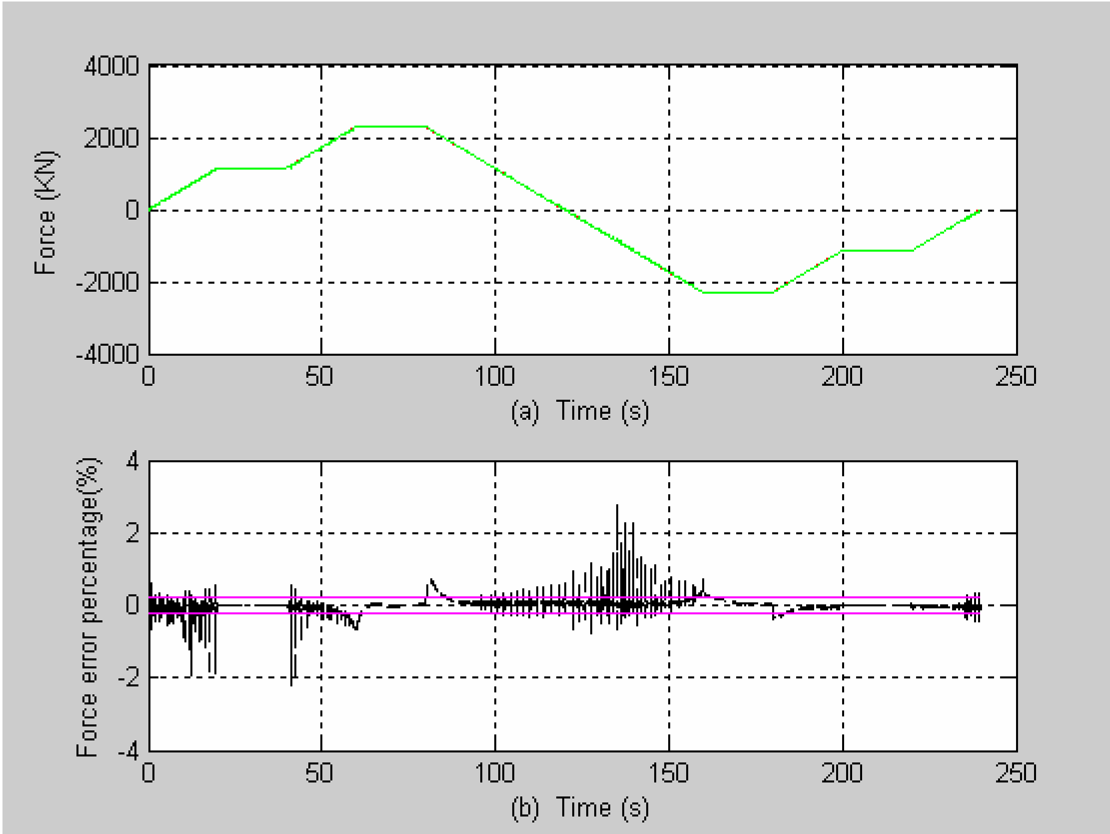


Figure 4.5.3.2. 100% maximum force accuracy test at Actuator 4
(Test 5.1: 2 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±2300KN
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±2300KN force control on Actuator 4 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/6/2004

<u>Servo Control Parameter</u>
Configuration--3 valve GHK PID control at actuator 4
PID control-- Kp=1.0; Ki=1.0; Kd =-0.9; f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset (%) – G: -2.032; H: -1.172; K: 0.859
Servo valve spool zero (%) – G: 3.984; H: -3.125; K: 4.922
Hydraulic supply pressure: 3200psi

<u>Test result</u>
Static accuracy: 0.002% with respect to force range of ± 2300KN (0.04KN error) –See Figure 4.5.3.3.

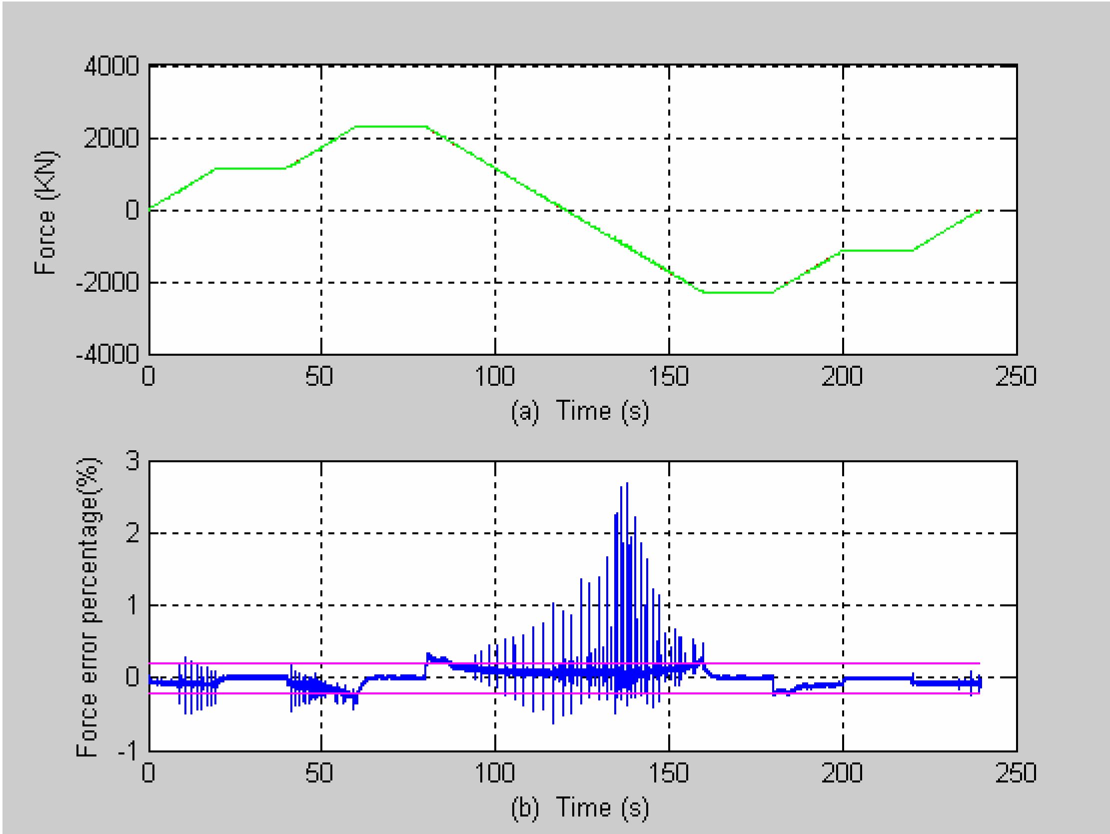


Figure 4.5.3.3. 100% maximum force accuracy test at Actuator 4
(Test 5.1: 3 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±2300KN
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

4.5.4 SCRAMNet 100% load range force accuracy test (3 valves)

- Test task: SCRAMNet ±2300KN force control on Actuator 4 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/6/2004

Servo Control Parameter
Configuration--3 valve GHK PID control at actuator 4
PID control-- Kp=1.0; Ki=1.0; Kd =-0.9; f=55Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset (%) – G: -2.032; H: -1.172; K: 0.859
Servo valve spool zero (%) – G: 3.984; H: -3.125; K: 4.922
Hydraulic supply pressure: 3200psi

Test result
Static accuracy: 0.002% with respect to force range of ± 2300KN (0.04KN error) –See Figure 4.5.4.1.

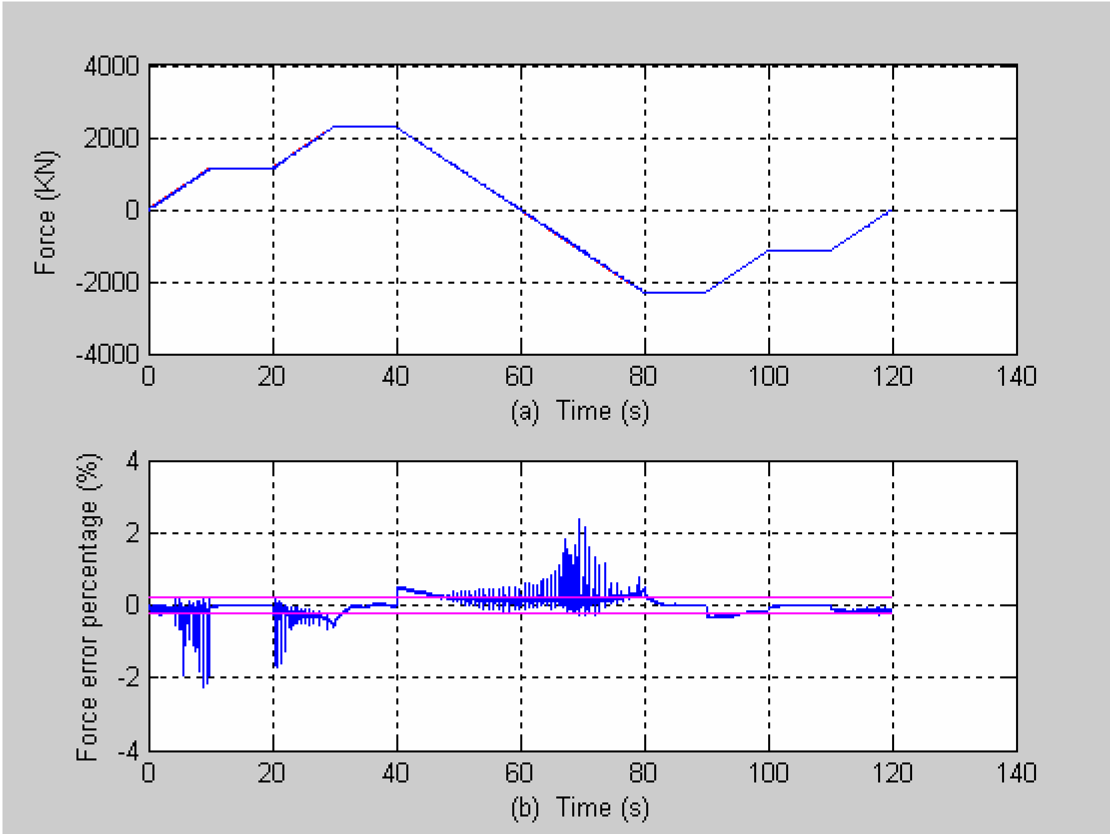


Figure 4.5.4.1. SCRAMNet 100% maximum force accuracy test at Actuator 4
(Test 5 repeats Test 5.1: 3 valves)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±2300KN; Blue: error percentage – Magenta: error acceptance boundary ±0.2%

4.6 10Hz force bandwidth test

4.6.1 ±1333KN@10Hz sinusoid with 1 valve operation

- Test task: Sinusoid force control on Actuator 4 (1valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/3/2004

Servo Control Parameter
Configuration--1 valve G PID control at actuator 4
PID control-- Kp=4.5; Ki=0.7; Kd =-1; f = 35 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; (H: 0.0; K: 0.0)
Servo valve offset – G: 1.094; (H: 1.953; K: 2.5)
Servo valve spool zero – G: 3.096; (H: 2.187; K: 2.187)
Hydraulic supply pressure: 3000psi

Test result
Dynamic bandwidth: 10Hz@980KN (26.5% attenuation, less than 3 db) –See Figure 4.6.1.1.

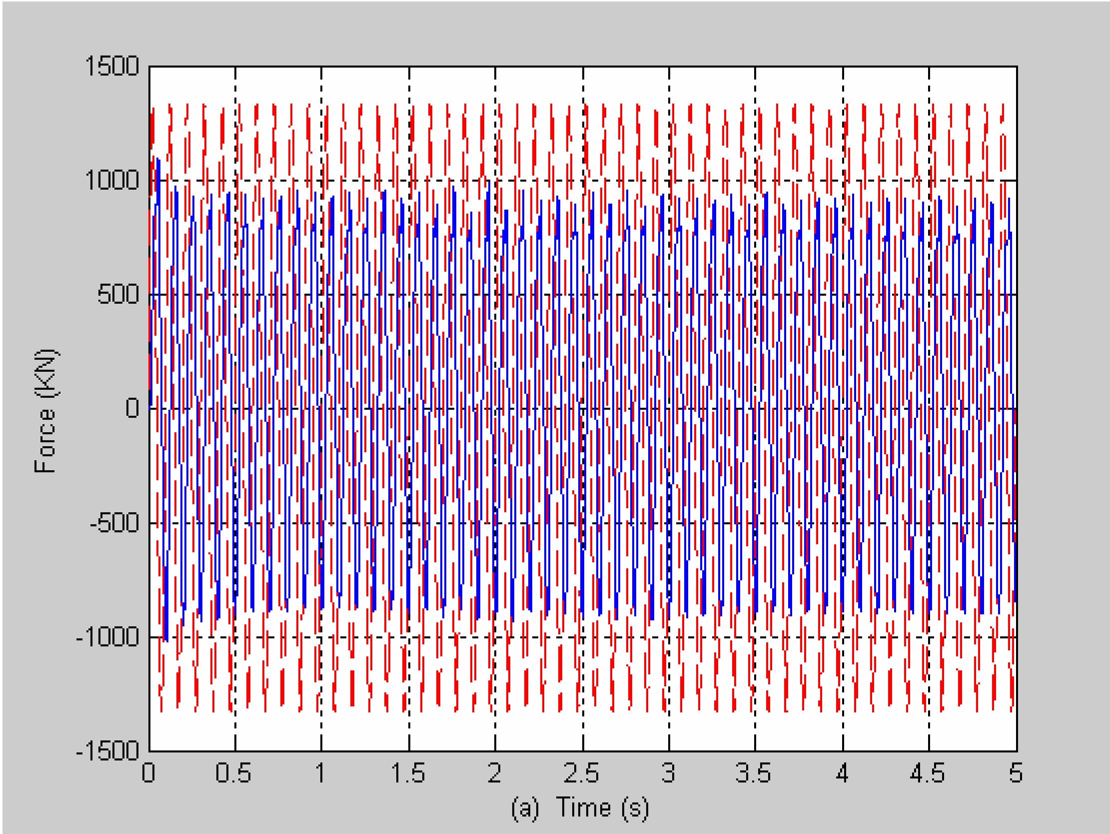


Figure 4.6.1.1. Force control dynamic bandwidth test at Actuator 4 (Test 5.2: 1 valve)
Red: command (1333KN@10Hz); Blue: response (980KN@10Hz)

4.6.2 ±1333KN@10Hz sinusoid with 2 valve operation

- Test task: Sinusoid force control on Actuator 4 (2valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/3/2004

Servo Control Parameter
Configuration--2 valve GH PID control at actuator 4
PID control-- Kp=1.8; Ki=1.0; Kd =-0.9; f = 55 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00;
Servo valve offset (%) – G: -2.031; H: -1.250;
Servo valve spool zero (%) – G: 2.891; H: 2.969;
Hydraulic supply pressure: 3000psi
Hydraulic supply flow rate: 860gpm

Test result
Dynamic bandwidth: 10Hz@1195KN (10.35% attenuation, less than 3 db) –See Figure 4.6.1.2.

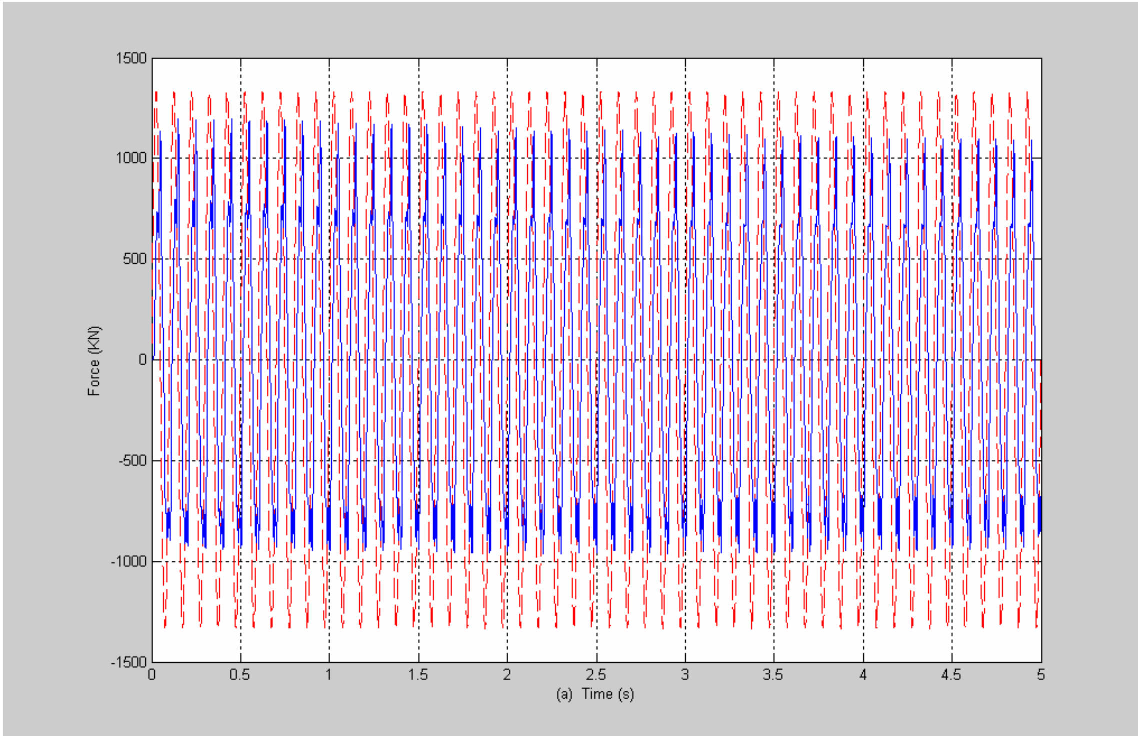


Figure 4.6.1.2. Force control dynamic bandwidth test at Actuator 4 (Test 5.2: 2 valves)
Red: command (1333KN@10Hz); Blue: response (1195KN@10Hz)

4.6.3 ±1333KN@10Hz sinusoid with 3 valve operation

- Test task: Sinusoid force control on Actuator 4 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/2/2004

Servo Control Parameter
Configuration--3 valve GHK PID control at actuator 4
PID control-- Kp=1.7; Ki=1.00; Kd =-0.9 f = 55 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset (%) – G: 0.625; H: -2.031; K: -1.172
Servo valve spool zero (%) – G: 0.703; H: 6.172; K: -1.250
Hydraulic supply pressure: 3200psi
Hydraulic supply flow rate: 860gpm

Test result
Dynamic bandwidth: 10Hz@1035KN (22.4% attenuation, less than 3 db) –See Figure 4.6.1.3.

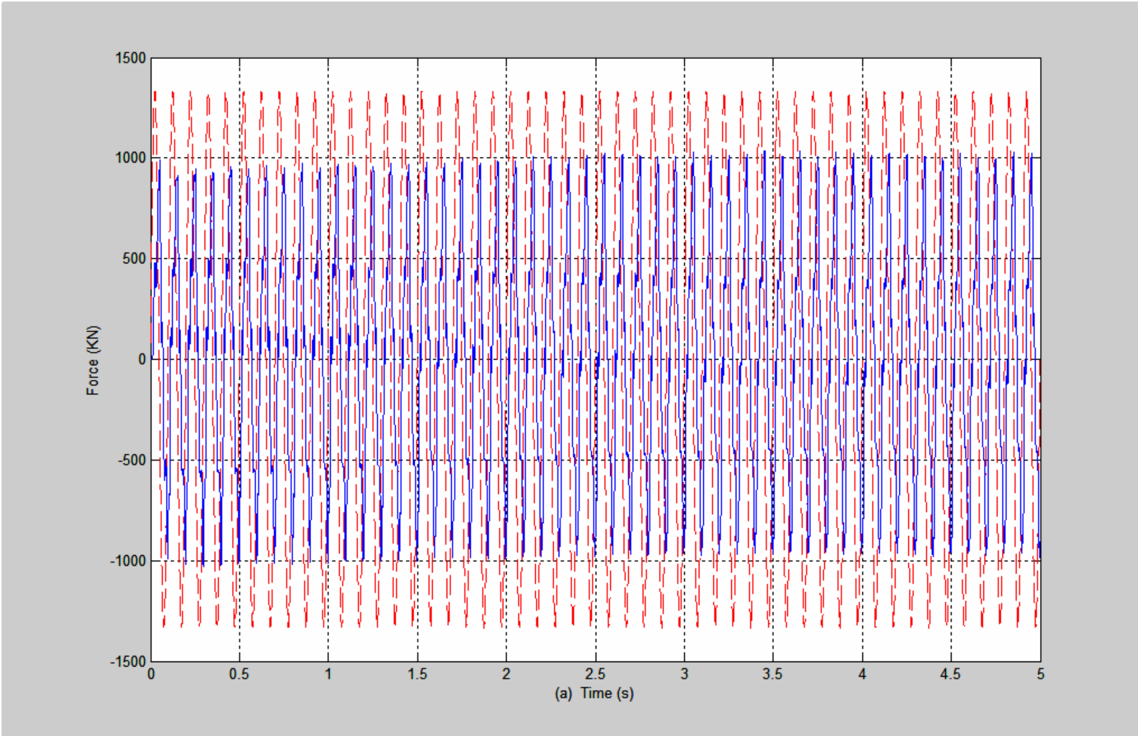


Figure 4.6.1.3. Force control dynamic bandwidth test at Actuator 4 (Test 5.2: 3 valves)
Red: command (1333KN@10Hz); Blue: response (1035KN@10Hz)

4.6.4 SCRAMNet ±1333KN@10Hz sinusoid with 3 valve operation

- Test task: SCRAMNet sinusoid force control on Actuator 4 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/2/2004

Servo Control Parameter
Configuration--3 valve GHK PID control at actuator 4
PID control-- Kp=1.8; Ki=1.00; Kd =-0.9; f = 55 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; H: 1.00; K: 0.88
Servo valve offset (%) – G: 0.625; H: -2.031; K: -1.172
Servo valve spool zero (%) – G: 0.703; H: 6.172; K: -1.250
Hydraulic supply pressure: 3200psi
Hydraulic supply flow rate: 860gpm

Test result
Dynamic bandwidth: 10Hz@1333KN (19% attenuation, less than 3 db) –See Figure 4.6.4.1.

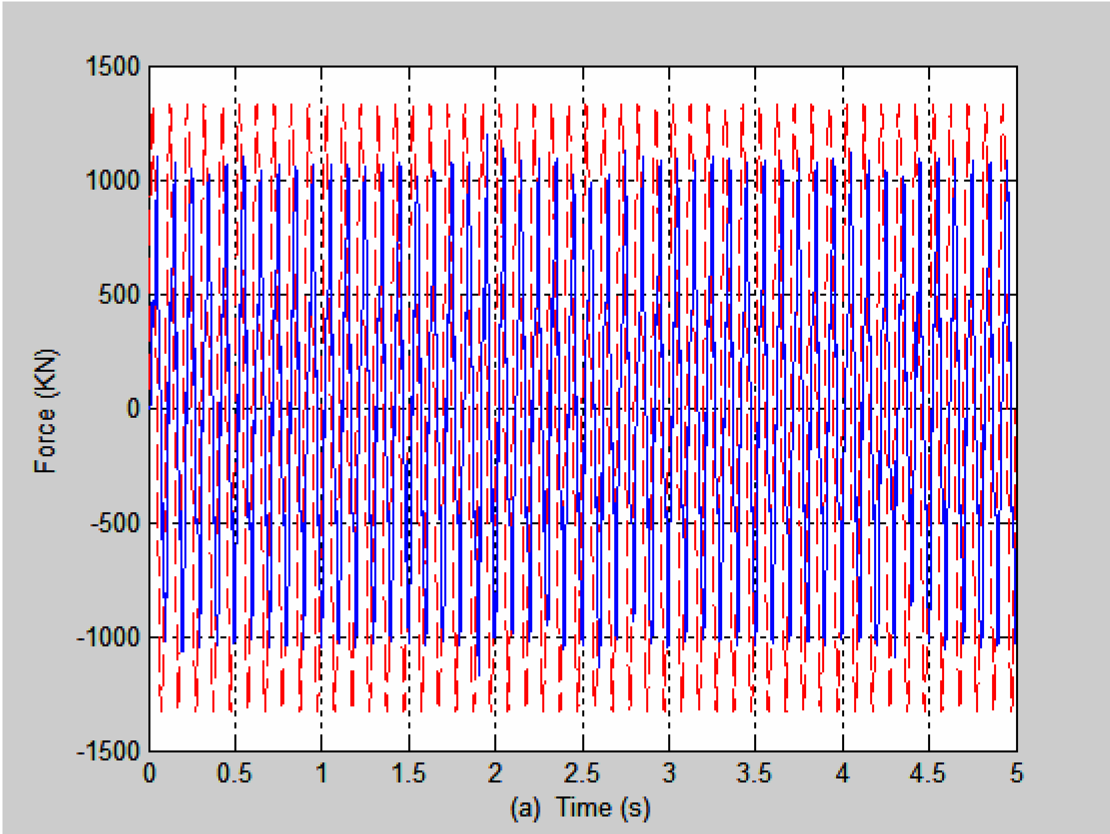


Figure 4.6.4.1. SCRAMNet force control dynamic bandwidth test at Actuator 4
(Test 5 repeats Test 5.2: 3 valves)
Red: command (1333KN@10Hz); Blue: response (943KN@10Hz)

5 ACTUATOR 5

5.1 0.2% displacement accuracy test (travel range: ±500mm)

5.1.1 10% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±50mm displacement control on Actuator 5 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter
Configuration--1 valve J PID control at actuator 5
PID control-- Kp=30; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; (K: 0.0)
Servo valve offset – (G: -7.109;) J: 0.0; (K: 1.016)
Servo valve spool zero – (G: -5.078;) J: 5.078; (K: 4.062)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error)– See Figure 5.1.1.1.

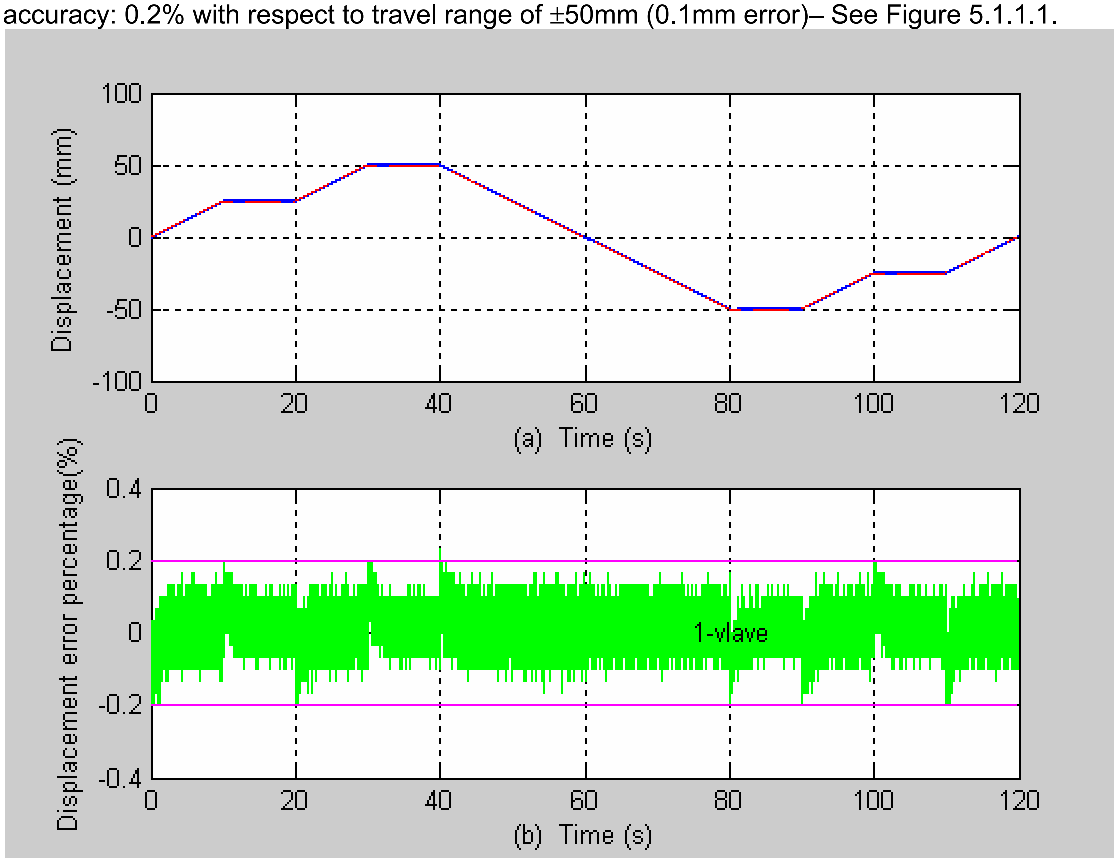


Figure 5.1.1.1. 10% stroke accuracy test at Actuator 5 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 5 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter
Configuration--2 valve JK PID control at actuator 5
PID control-- Kp=30; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; K: 0.88
Servo valve offset – (G: -7.109;) J: 0.0; K: 1.016
Servo valve spool zero – (G: -5.078;) J: 5.078; K: 4.062
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 5.1.1.2.

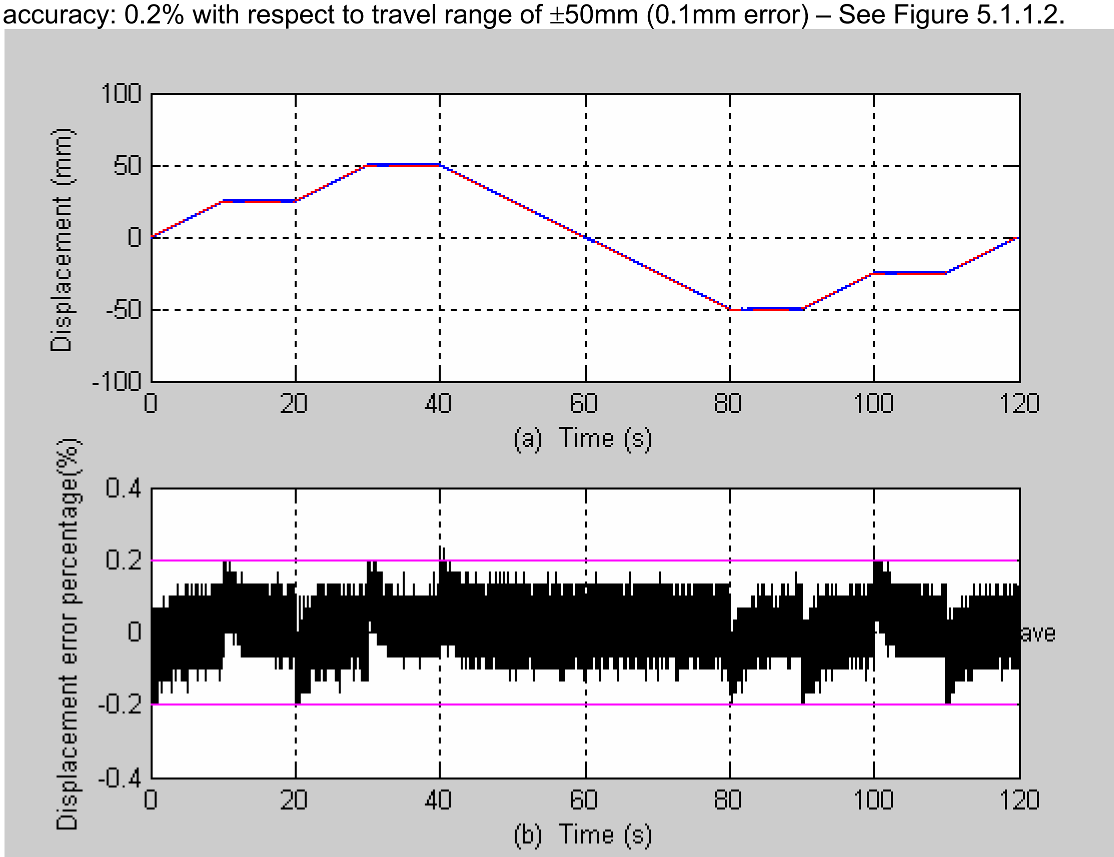


Figure 5.1.1.2. 10% stroke accuracy test at Actuator 5 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±50mm displacement control on Actuator 5 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter

Configuration--3 valve GJK PID displacement control at actuator 5
PID control-- Kp=30; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; J: 0.87; K: 0.88
Servo valve offset – G: -7.109; J: 0.0; K: 1.016
Servo valve spool zero – G: -5.078; J: 5.078; K: 4.062
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.2% with respect to travel range of ±50mm (0.1mm error) – See Figure 5.1.1.3.

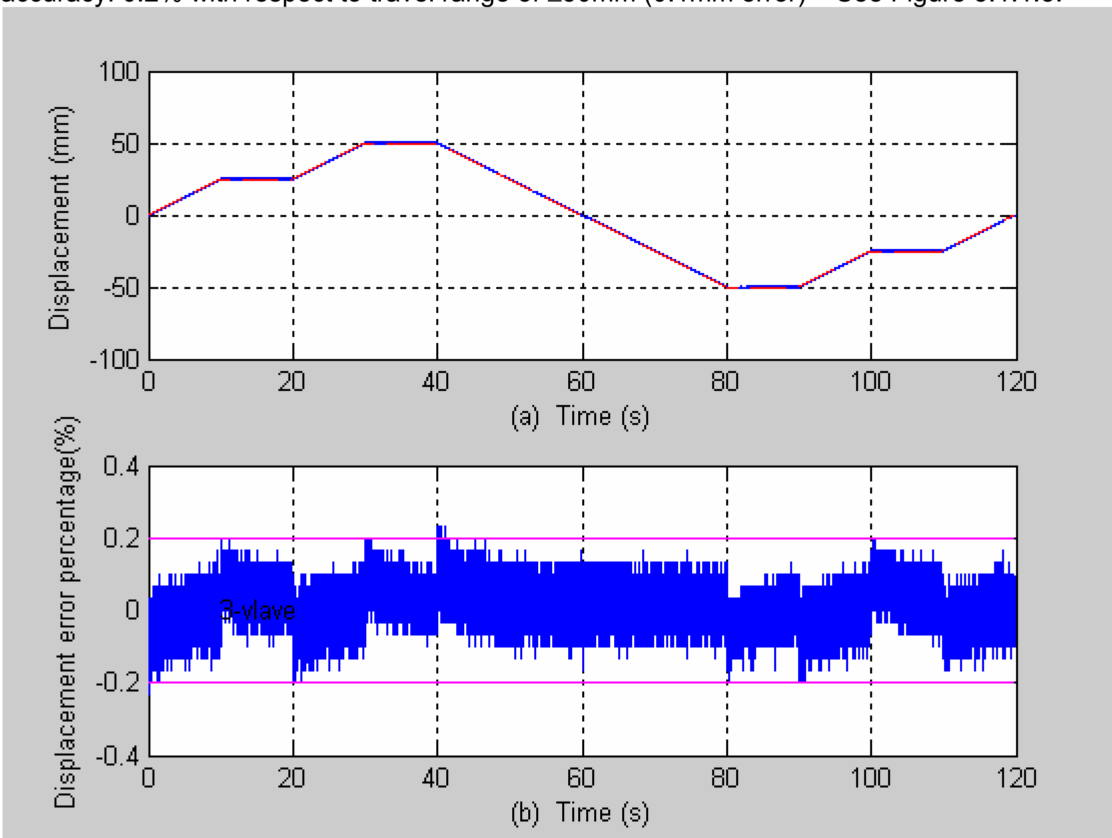


Figure 5.1.1.3.   10% stroke accuracy test at Actuator 5 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±50mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

5.1.2 20% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±100mm displacement control on Actuator 5 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter
Configuration--1 valve J PID control at actuator 5
PID control-- Kp=30; Ki=2.0; Kd =0
Servo valve loop gain -- Kv=30

Servo valve input scale – (G: 0.0;) J: 0.87; (K: 0.00)
Servo valve offset – (G: -7.109;) J: 0.0; (K: 1.016)
Servo valve spool zero – (G: -5.078;) J: 5.078; (K: 4.062)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.15% with respect to travel range of ±100mm(0.15mm error)–See Figure 5.1.2.1.

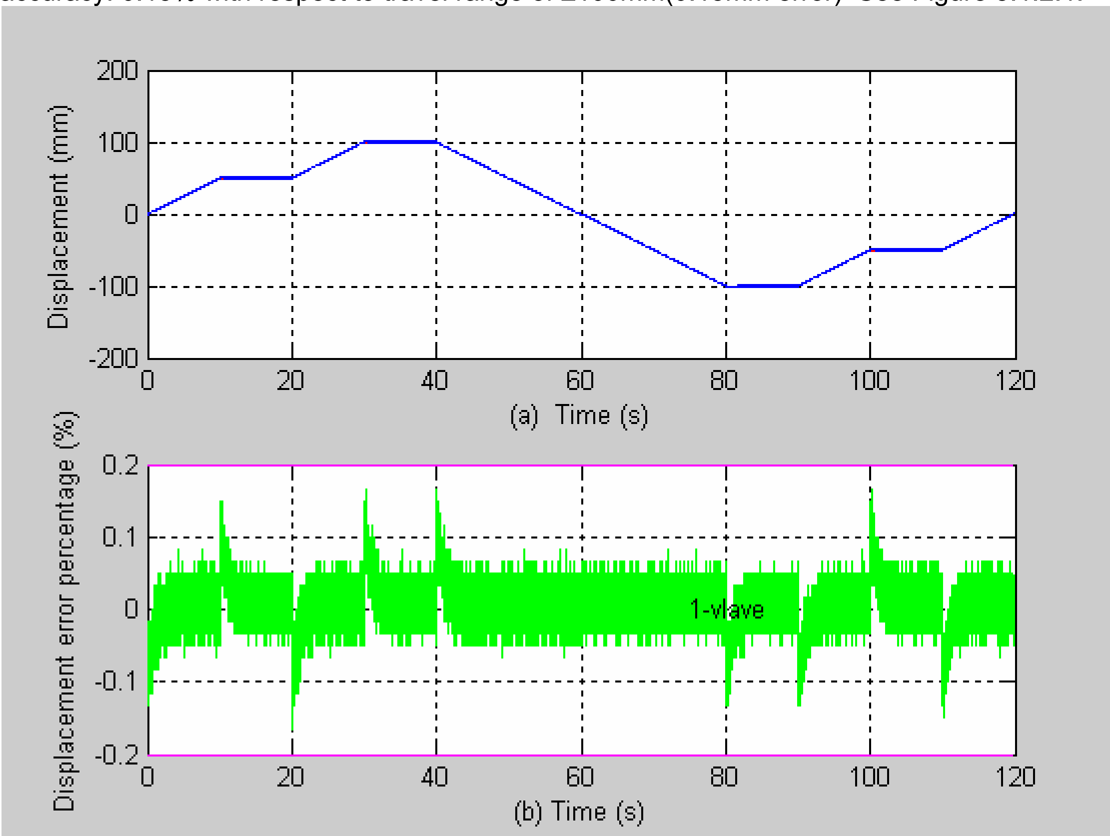


Figure 5.1.2.1. 20% stroke accuracy test at Actuator 5 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 5 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter
Configuration--2 valve JK PID control at actuator 5
PID control-- Kp=30; Ki=2.0; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; K: 0.88
Servo valve offset – (G: -7.109;) J: 0.0; K: 1.016
Servo valve spool zero – (G: -5.078;) J: 5.078; K: 4.062
Hydraulic supply pressure: 3000psi

Test result

Static accuracy: 0.2% with respect to travel range of ±100mm (0.2mm error) –See Figure 5.1.2.2.

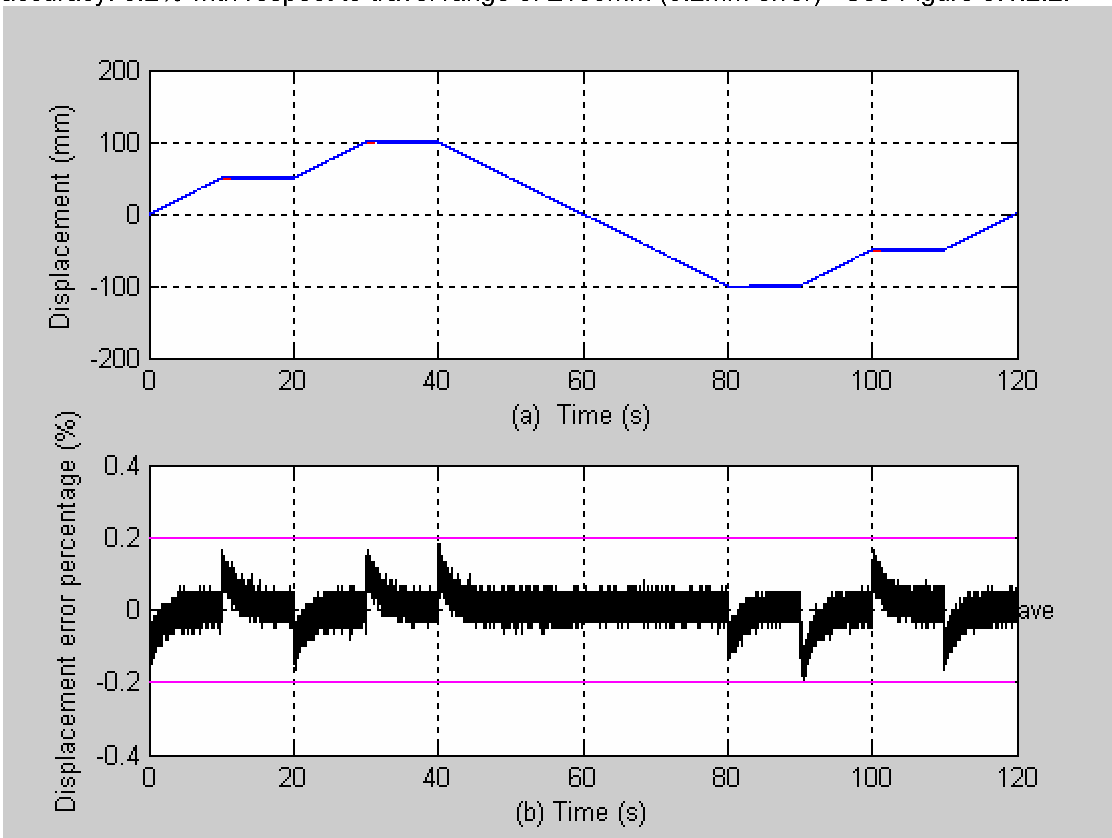


Figure 5.1.2.2. 20% stroke accuracy test at Actuator 5 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±100mm displacement control on Actuator 5 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

<u>Servo Control Parameter</u>
Configuration--3 valve GJK PID control at actuator 5
PID control-- Kp=30; Ki=2.0; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; J: 0.87; K: 0.88
Servo valve offset – G: -7.109; J: 0.0; K: 1.016
Servo valve spool zero – G: -5.078; J: 5.078; K: 4.062
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.133% with respect to travel range of ±100mm (0.133mm error)–See Figure 5.1.2.3.

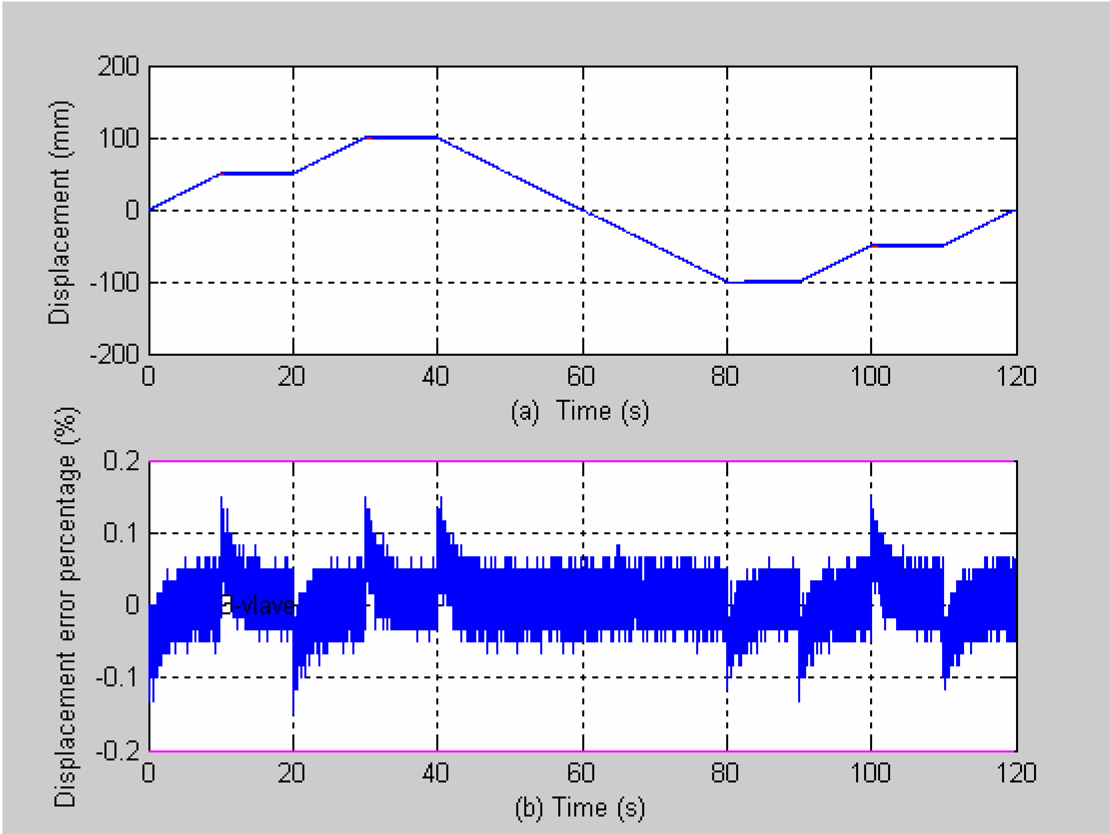


Figure 5.1.2.3. 20% stroke accuracy test at Actuator 5 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±100mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

5.1.3 100% travel range displacement accuracy test (1, 2, 3 valves)

- Test task: ±500mm displacement control on Actuator 5 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

<u>Servo Control Parameter</u>
Configuration--1 valve J PID control at actuator 5
PID control-- Kp=60; Ki=1; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; (K: 0.0)
Servo valve offset – (G: -7.109;) J: 0.0; (K: 1.016)
Servo valve spool zero – (G: -5.078;) J: 5.078; (K: 4.062)
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.114% with respect to travel range of ±500mm(0.57mm error)– See Figure 5.1.3.1.

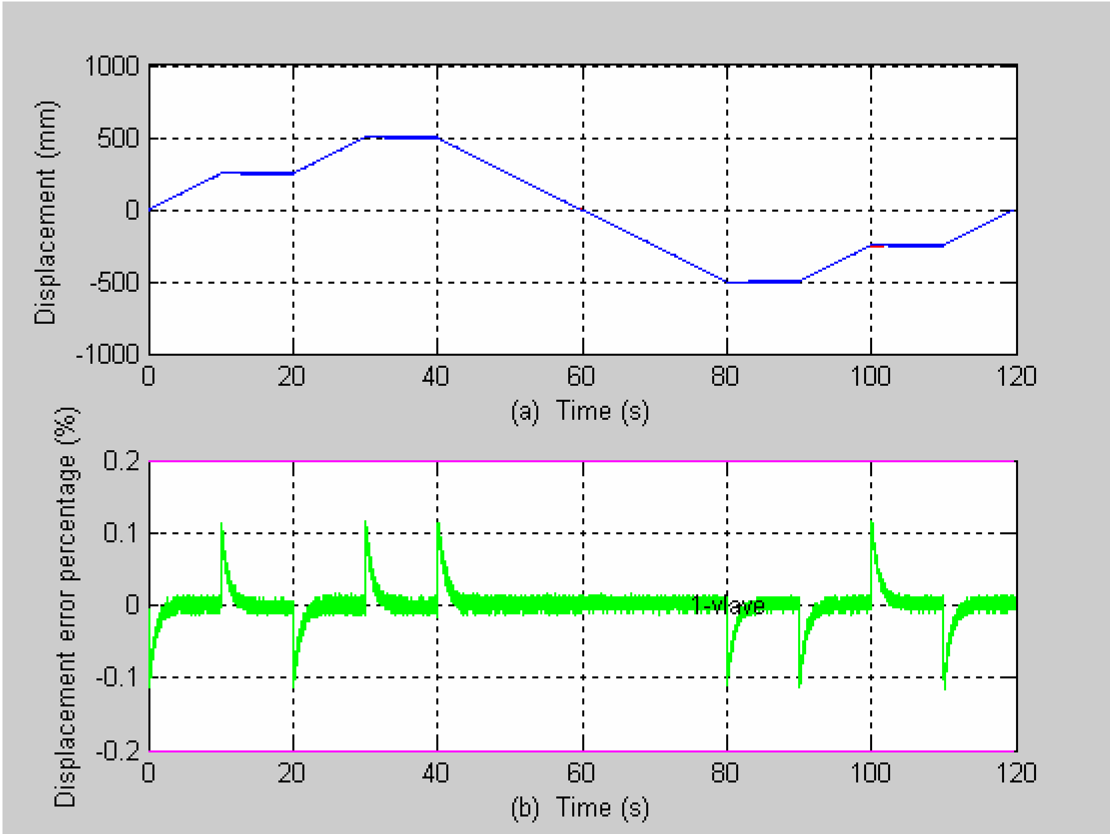


Figure 5.1.3.1. 100% stroke accuracy test at Actuator 5 (Test 1: 1 valve)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 5 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter
Configuration--2 valve JK PID control at actuator 5
PID control-- Kp=60; Ki=1; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; K: 0.88
Servo valve offset – (G: -7.109;) J: 0.0; K: 1.016
Servo valve spool zero – (G: -5.078;) J: 5.078; K: 4.062
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.03% with respect to travel range of ±500mm(0.15mm error)–See Figure 5.1.3.2.

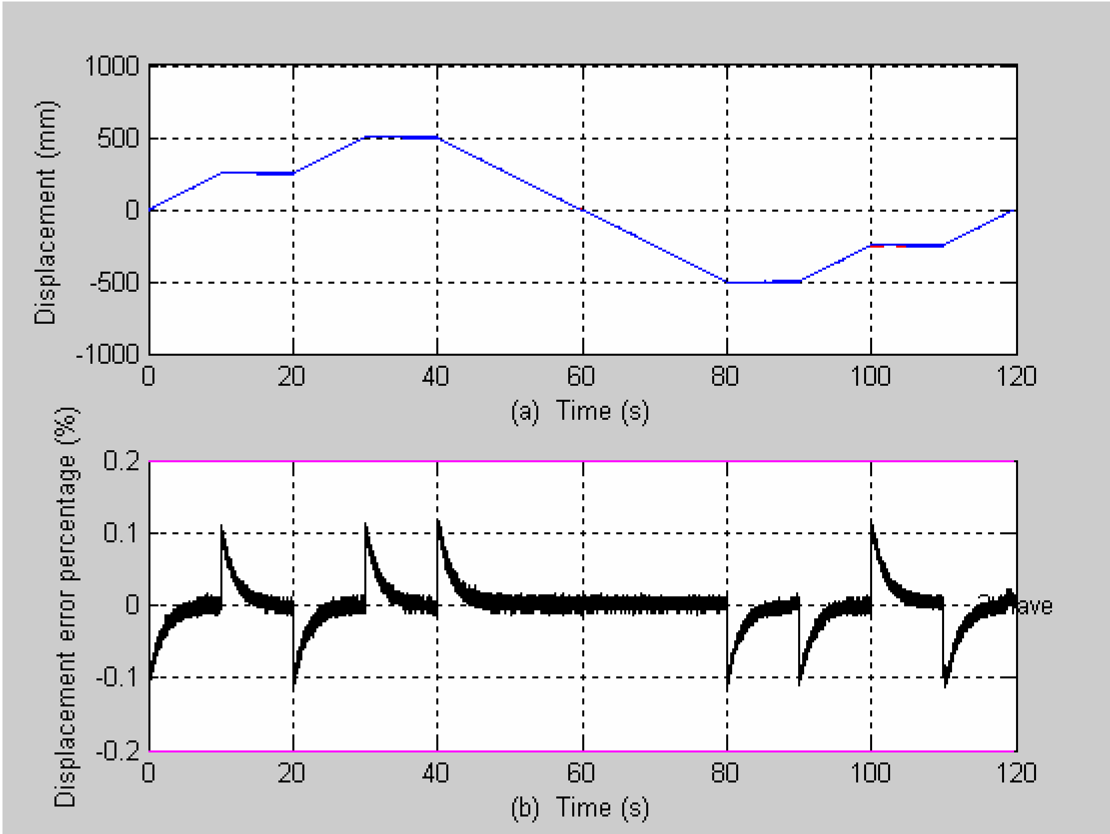


Figure 5.1.3.2. 100% stroke accuracy test at Actuator 5 (Test 1: 2 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±500mm displacement control on Actuator 5 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter
Configuration--3 valve GJK PID control at actuator 5
PID control-- Kp=60; Ki=1; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; J: 0.87; K: 0.88
Servo valve offset – G: -7.109; J: 0.0; K: 1.016
Servo valve spool zero – G: -5.078; J: 5.078; K: 4.062
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.03% with respect to travel range of ±500mm(0.133mm error)–See Figure 5.1.3.3.

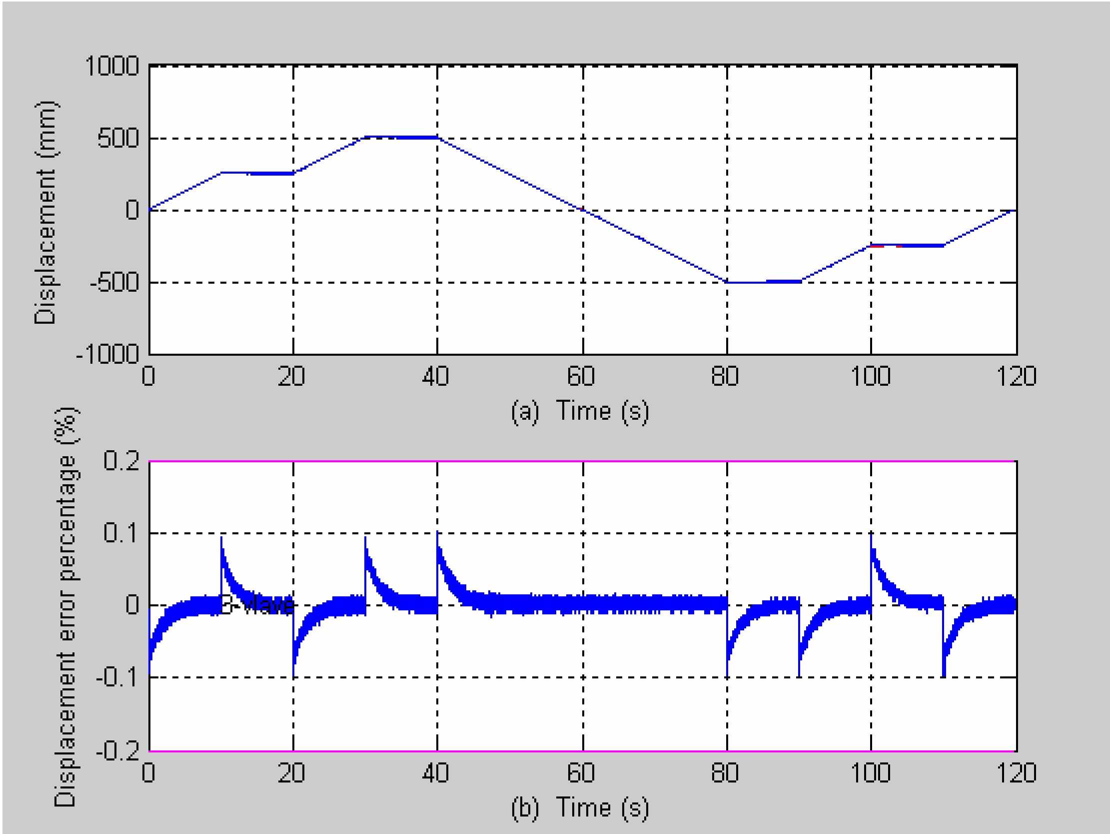


Figure 5.1.3.3. 100% stroke accuracy test at Actuator 5 (Test 1: 3 valves)
(a) Displacement (mm) – Red: command; Blue: response
(b) Displacement error with respect to travel range of ±500mm
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

5.2 10Hz displacement bandwidth test
(±3.81mm, ±7.62mm, ±11.43mm sinusoid for 1, 2, 3 valves respectively)

- Test task: Sinusoid displacement control on Actuator 5 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter
Configuration --1 valve J PID control at actuator 5
PID control -- Kp=90; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; (K: 0.0)
Servo valve offset – (G: -7.109;) J: 0.0; (K: 1.016)
Servo valve spool zero – (G: -5.078;) J: 5.078; (K: 4.062)
Hydraulic supply pressure – 3000psi
Hydraulic supply flow rate – 420gpm

Test result
Dynamic bandwidth: 10Hz@0.122inch (18.67% attenuation, less than 3 db) – See Figure 5.2.1.

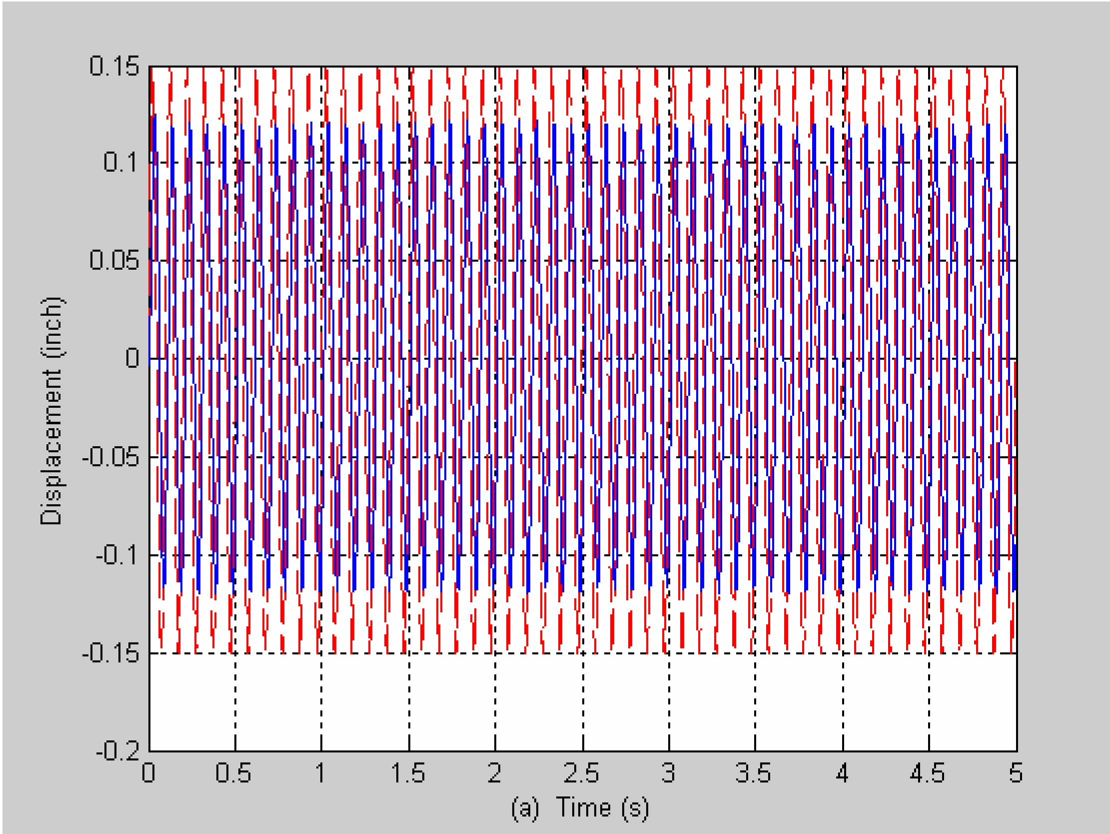


Figure 5.2.1. Dynamic bandwidth test at Actuator 5 (Test 2: 1 vale)
Red: command (0.15inch@10Hz); Blue: response (0.12inch@10Hz)

- Test task: Sinusoid displacement control on Actuator 5 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter
Configuration --2 valve JK PID control at actuator 5
PID control -- Kp=50; Ki=5; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; K: 0.88
Servo valve offset – (G: -7.109;) J: 0.0; K: 1.016
Servo valve spool zero – (G: -5.078;) J: 5.078; K: 4.062
Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 840gpm

Test result
Dynamic bandwidth: 10Hz@0.26inch (13.33% attenuation, less than 3 db) – See Figure 5.2.2.

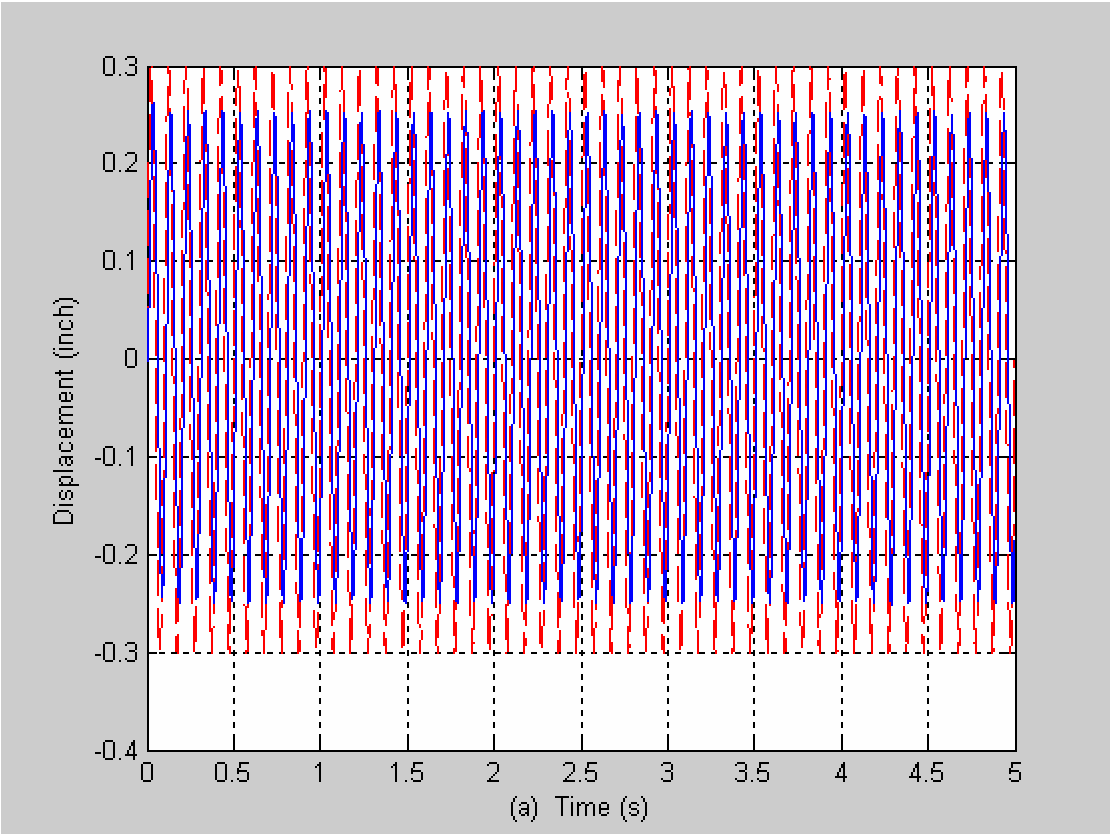


Figure 5.2.2. Dynamic bandwidth test at Actuator 5 (Test 2: 2 vales)
Red: command (0.30inch@10Hz); Blue: response (0.26inch@10Hz)

- Test task: Sinusoid displacement control on Actuator 5 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/9/2004

Servo Control Parameter
Configuration --3 valve GJK PID control at actuator 5
PID control -- Kp=35; Ki=3; Kd =0
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; J: 0.87; K: 0.88
Servo valve offset (%) – G: -7.109; J: 0; K: 1.016
Servo valve spool zero (%) – G: -5.078; J: 5.078; K: 4.062
Hydraulic supply pressure – 3200psi
Hydraulic supply flow rate – 1260gpm

Test result
Dynamic bandwidth: 10Hz@0.449inch (0.2% attenuation, less than 3 db) – See Figure 5.2.3.

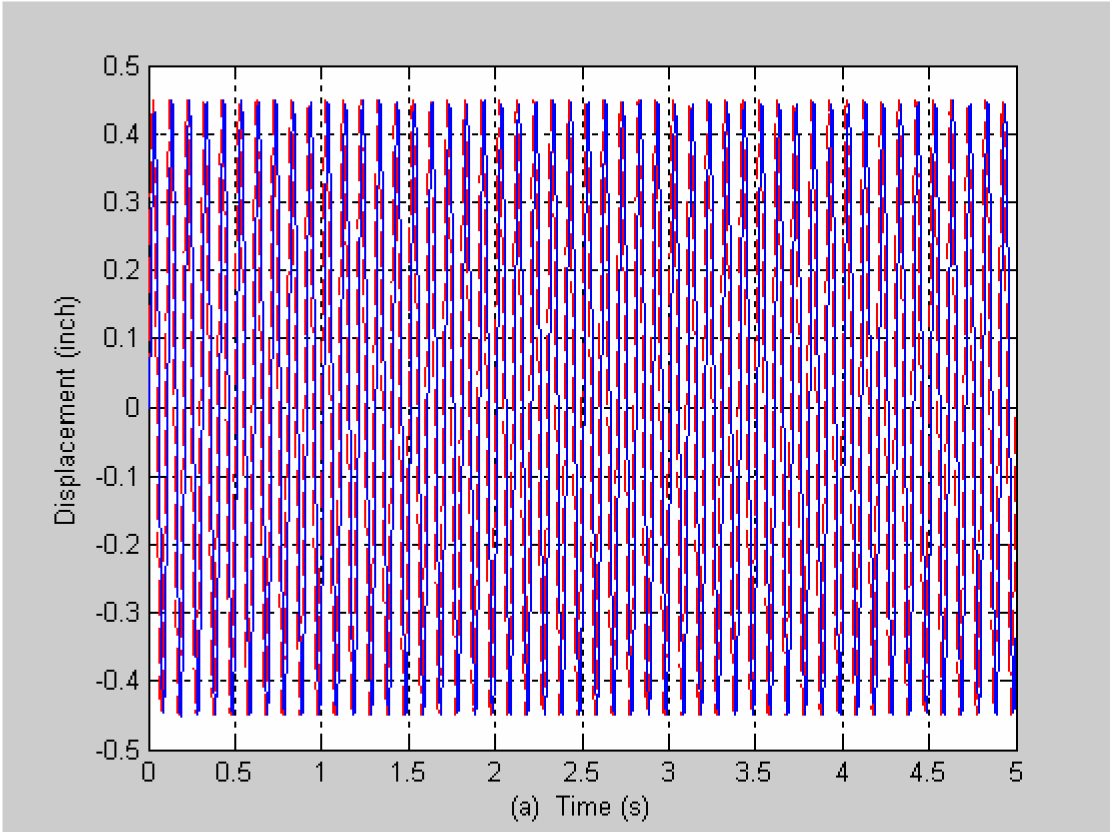


Figure 5.2.3. Dynamic bandwidth test at Actuator 5 (Test 2: 3 valves)
Red: command (0.45inch@10Hz); Blue: response (0.45inch@10Hz)

5.3 0.84m/s high velocity test

- Test task: High velocity test on Actuator 5 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/10/2004

<u>Servo Control Parameter</u>
Configuration–3 valve GHK PID control at actuator 4
PID control– Kp=35; Ki=1; Kd =0
Servo valve loop gain – Kv=30
Servo valve input scale – G: 1.0; J: 0.87; K: 0.88
Servo valve offset (%) – G: -7.109; J: 0.0; K: 1.016
Servo valve spool zero (%) – G: -5.078; J: 5.078; K: 4.062
Hydraulic supply pressure: 3200psi
Hydraulic supply flow rate: 1500gpm (with accumulator banks)

<u>Test result</u>
Speed reaches 0.84 m/s momentarily (RG accumulator used as oil supply-1500gpm) – See Figure 5.3.1.

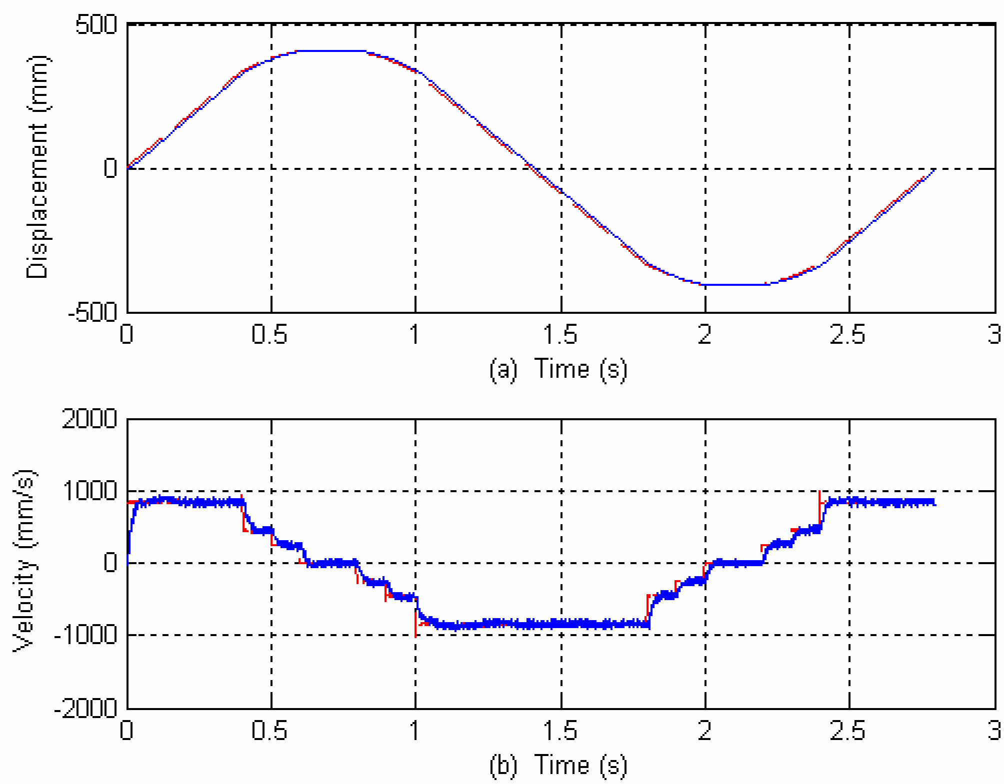


Figure 5.3.1. High velocity test at Actuator 5 (Test 3)
(a) Displacement (mm) – Red: command; Blue: response
(b) Velocity (mm/s) -- Red: command; Blue: response

5.4 277KW power test with single valve operation (0.20m/s@1333KN)

- Test task: Power test on Actuator 5 (1 valve, against Load Actuator 4)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Xiaoping Zhang
Test site: Lehigh ATLSS Center
Date: 7/14/2004 and 7/20/2004

Servo Control Parameter
1st test – 7/14/2004
Configuration:
1 valve H load PID control at Actuator 4
1 valve J displacement PID control at Actuator 5
Actuator 4 load PID control-- Kp=8; Ki=3; Kd =-1; f=10Hz
Actuator 5 displacement PID control-- Kp=45; Ki=3; Kd =0; f=39.8
Servo valve loop gain -- Kv=30
Servo valve input scale – J: 0.87; H: 1.0; (K: 0.0)
Servo valve offset (%) – J: -1.016; H: -1.016; (K: 1.016)
Servo valve spool zero (%) – J: -3.047; H: 2.001; (K: 4.062)
Hydraulic supply pressure: 3400psi

2nd and 3rd test – 7/20/2004
Configuration:
1 valve H load PID control at Actuator 4
1 valve J displacement PID control at Actuator 5
Actuator 4 load PID control-- Kp=8; Ki=3; Kd =-1; f=39.8Hz

Actuator 5 displacement PID control-- Kp=45; Ki=3; Kd =0; f=39.8
Servo valve loop gain -- Kv=30
Servo valve input scale – J: 0.87; H: 1.0
Servo valve offset (%) – J: -0.156; H: -1.094
Servo valve spool zero (%) – J: 1.719; H: 2.969
Hydraulic supply pressure: 3400psi

Test result
Power capacity: power output at Actuator 5 reaches 277KW– See Figure 5.4.1.

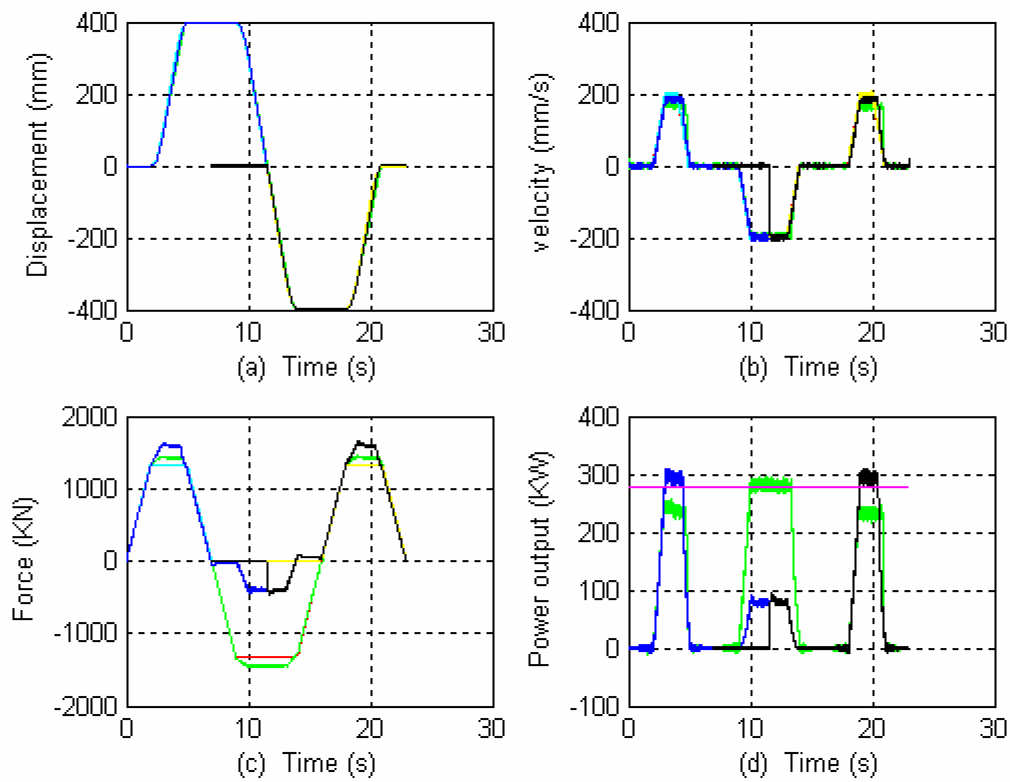


Figure 5.4.1. Power test at Actuator 5 (Test 4: 1 valve; Actuator 4 simulates load)
(Actuator 5 –displacement and Actuator 4—load)
(a) Displacement (mm); (b) Velocity (mm/s); Force (KN) ; (d) Power (KW)
– Red: command (1st test); Green: response (1st test)
– Cyan: command (2nd test); Blue: response (2nd test)
– Yellow: command (3rd test); Black: response (3rd test)
Magenta: power target value (277KW)

5.5 0.2% force accuracy test (load range: ±2300KN)

5.5.1 5% load range force accuracy test (1, 2, 3 valves)

- Test task: ±115KN force control on Actuator 5 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/7/2004

Servo Control Parameter
Configuration--1 valve J PID control at actuator 5
PID control-- Kp=3.5; Ki=0.7; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; (K: 0.0)
Servo valve offset (%) – (G: -1.563;) J: 1.172; (K: 0.234)
Servo valve spool zero (%) – (G: -2.109;) J: -4.453; (K: 0.00)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.03% with respect to force range of ±115KN (0.04KN error) –See Figure 5.5.1.1.

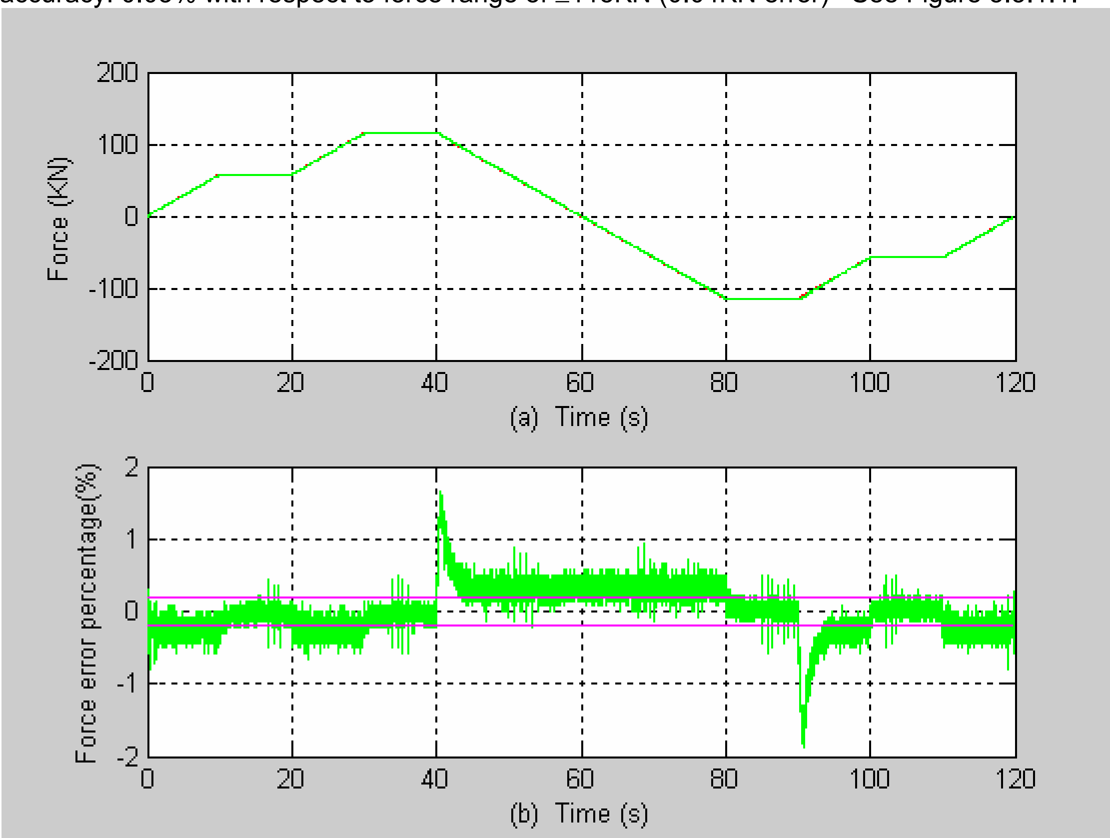


Figure 5.5.1.1. 5% maximum force accuracy test at Actuator 5 with cutoff frequency of 100Hz
(Test 5.1: 1 valve; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±115KN
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±115KN force control on Actuator 5 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/7/2004

Servo Control Parameter
Configuration--2 valve JK PID control at actuator 5
PID control-- Kp=1.5; Ki=1; Kd =-1; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; K: 0.88

Servo valve offset (%) – (G: -1.563;) J: 1.172; K: 0.234
Servo valve spool zero (%) – (G: -2.109;) J: -4.453; K: 0.000
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.03% with respect to force range of ±115KN (0.04KN error) –See Figure 5.5.1.2.

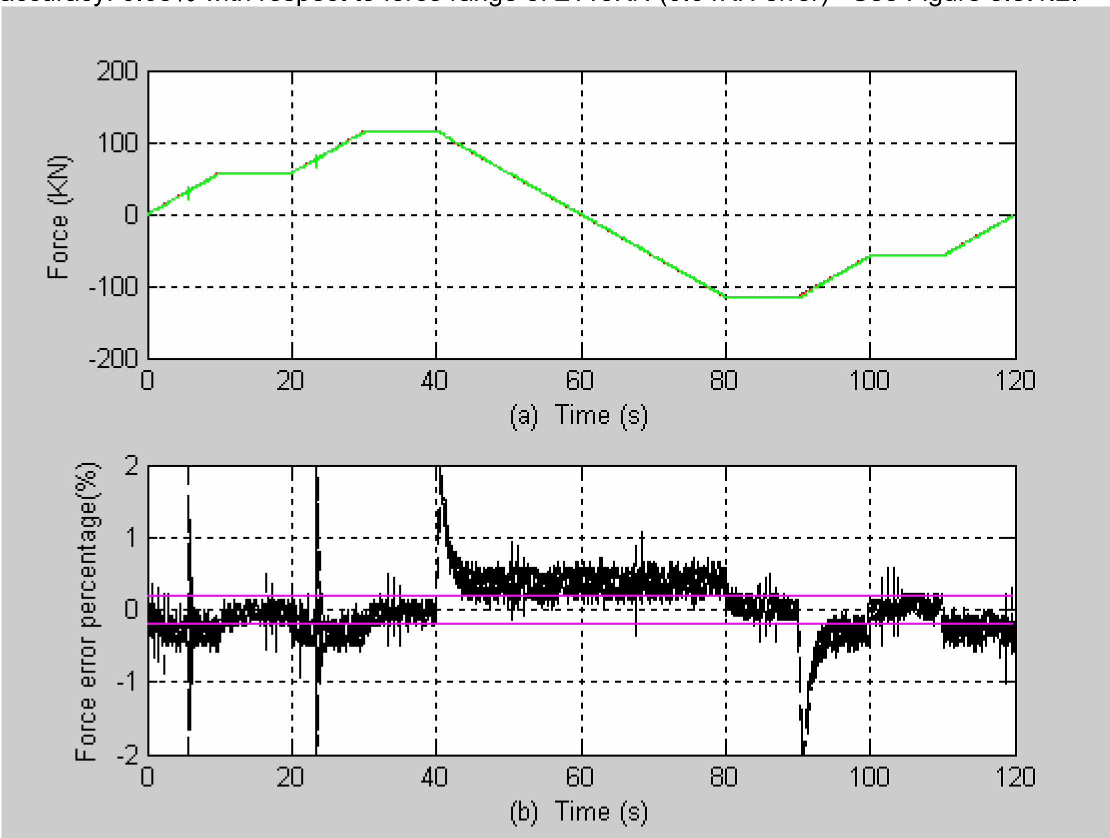


Figure 5.5.1.2. 5% maximum force accuracy test at Actuator 5
(Test 5.1: 2 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±115KN
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±115KN force control on Actuator 5 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/7/2004

<u>Servo Control Parameter</u>
Configuration--3 valve GJK PID control at actuator 5
PID control-- Kp=1.5; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; J: 0.87; K: 0.88
Servo valve offset (%) – G:-1.563; J: 1.172; K: 0.234
Servo valve spool zero (%) – G: -2.109; J: -4.453; K: 0.00
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.03% with respect to force range of ±115KN (0.04N error) –See Figure 5.5.1.3.

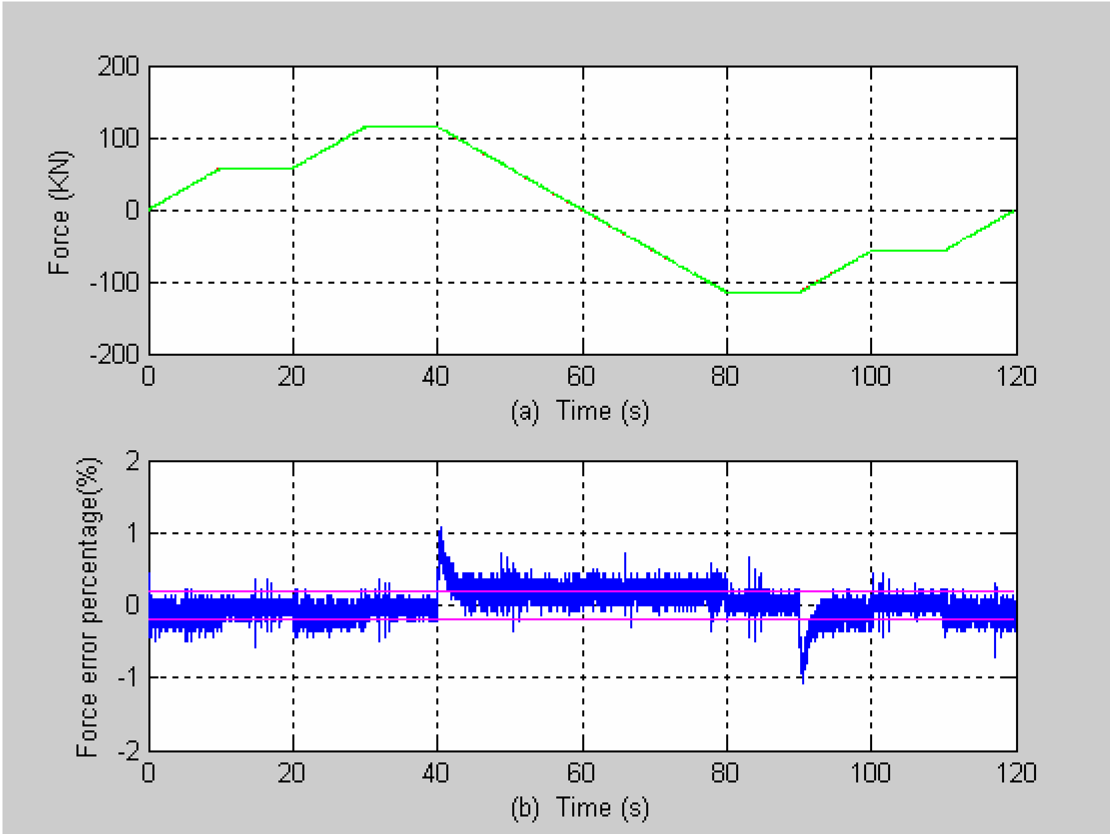


Figure 5.5.1.3. 5% maximum force accuracy test at Actuator 5
(Test 5.1: 3 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±115KN
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

5.5.2 20% load range force accuracy test (1, 2, 3 valves)

- Test task: ±460KN force control on Actuator 5 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/7/2004

Servo Control Parameter
Configuration--1 valve J PID control at actuator 5
PID control-- Kp=4.5; Ki=0.7; Kd =-1.0, f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; (K: 0.0)
Servo valve offset (%) – (G: -1.563;) J: 1.172; (K: 0.234)
Servo valve spool zero (%) – (G: -2.109;) J: -4.453; (K: 0.0)
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.01% with respect to force range of ±460KN (0.04KN error) –See Figure 5.5.2.1.

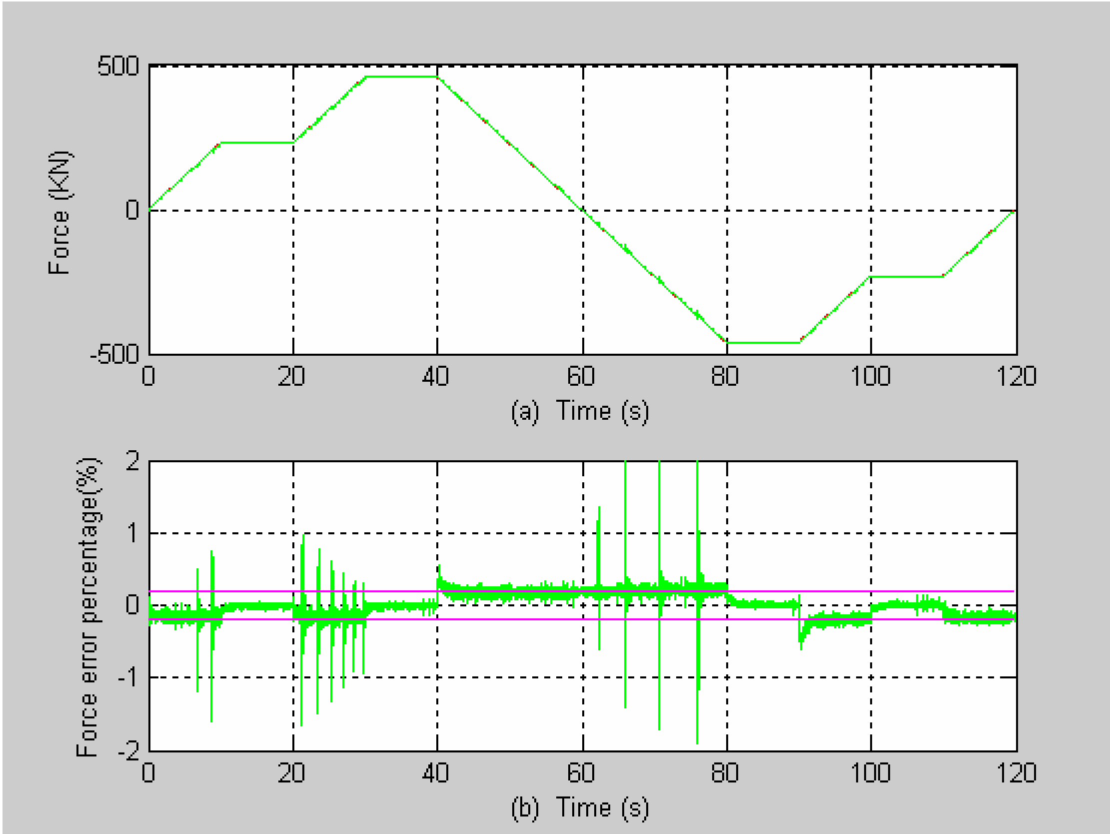


Figure 5.5.2.1. 20% maximum force accuracy test at Actuator 5
(Test 5.1: 1 valve; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±460KN
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±460KN force control on Actuator 5 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/7/2004

<u>Servo Control Parameter</u>
Configuration--2 valve JK PID control at actuator 5
PID control-- Kp=2.0; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; K: 0.88
Servo valve offset (%) – (G: -1.563;) J: 1.172; K: 0.234
Servo valve spool zero (%) – (G: -2.109;) J: -4.453; K: 0.000
Hydraulic supply pressure: 3000psi

<u>Test result</u>
Static accuracy: 0.01% with respect to force range of ±460KN (0.04KN error) –See Figure 5.5.2.2.

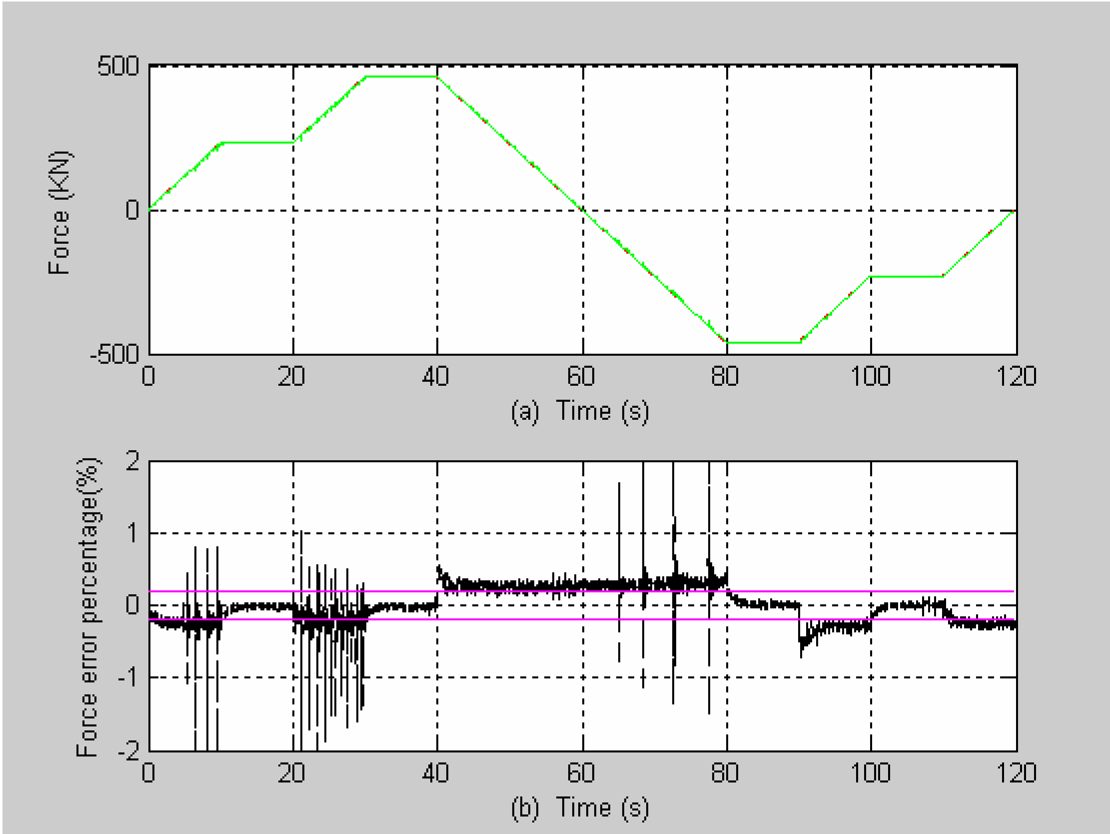


Figure 5.5.2.2. 20% maximum force accuracy test at Actuator 5
(Test 5.1: 2 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±460KN
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±460KN force control on Actuator 5 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/7/2004

Servo Control Parameter
Configuration--3 valve GJK PID control at actuator 5
PID control-- Kp=1.5; Ki=1.0; Kd =-1, f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; J: 0.87; K: 0.88
Servo valve offset (%) – G: -1.563; J: 1.172; K: 0.234
Servo valve spool zero (%) – G: -2.109; J: -4.453; K: 0.000
Hydraulic supply pressure: 3000psi

Test result
Static accuracy: 0.01% with respect to force range of ±460KN (0.04KN error) –See Figure 5.5.2.3.

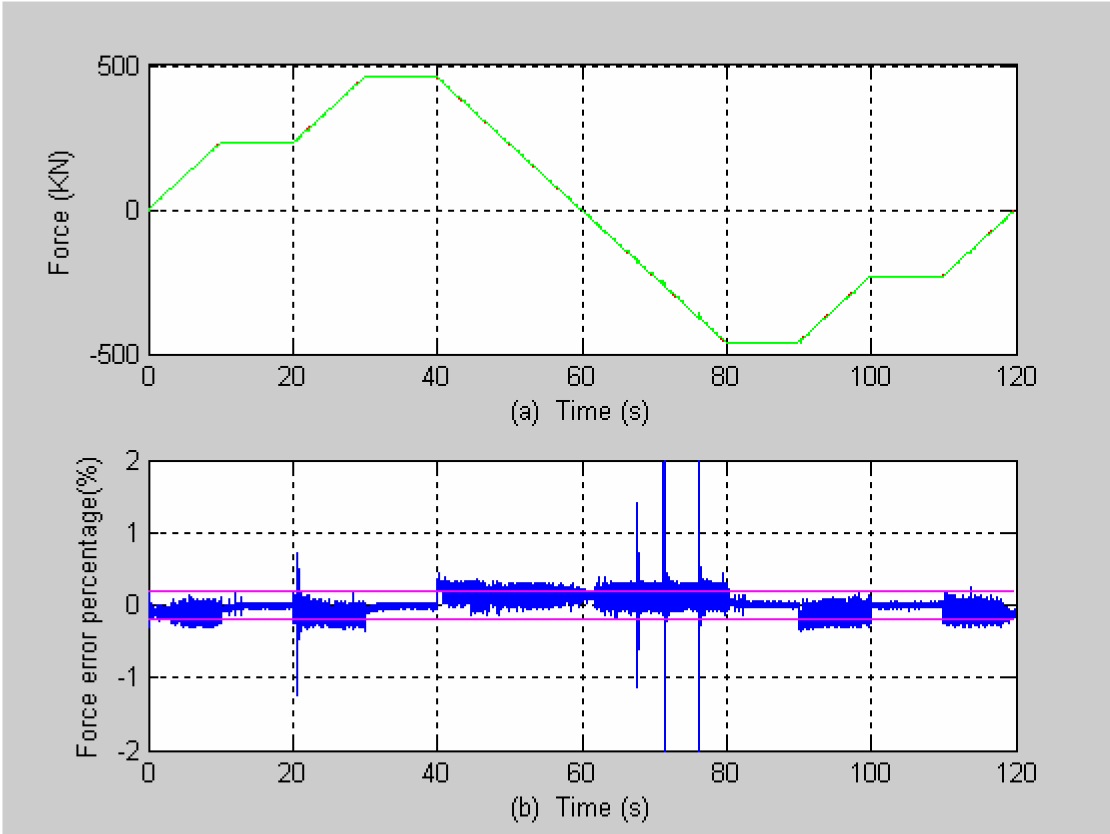


Figure 5.5.2.3. 20% maximum force accuracy test at Actuator 5
(Test 5.1: 3 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±460KN
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

5.5.3 100% load range force accuracy test (1, 2, 3 valves)

- Test task: ±2300KN force control on Actuator 5 (1 valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/8/2004

<u>Servo Control Parameter</u>
Configuration--1 valve J PID control at actuator 5
PID control-- Kp=5; Ki=0.7; Kd =-1.0, f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; (K: 0.00)
Servo valve offset (%) – Compression - J: 0.707; (K: 0.469)
-- Tension -- J: 0.707; (K: 0.469)
Note: G valve has been removed!
Servo valve spool zero (%) – Compression -J: 1.875; (K: 0)
-- Tension -- J: 1.875; (K: -1.016)
Hydraulic supply pressure: 3200psi

<u>Test result</u>
Static accuracy:
Tension: 0.04% with respect to force range of ±2300KN (0.92 KN error) –See Figure 5.5.3.1.

Compression: 0.03% with respect to force range of ±2300KN (0.75 KN error) –See Figure 5.5.3.1.

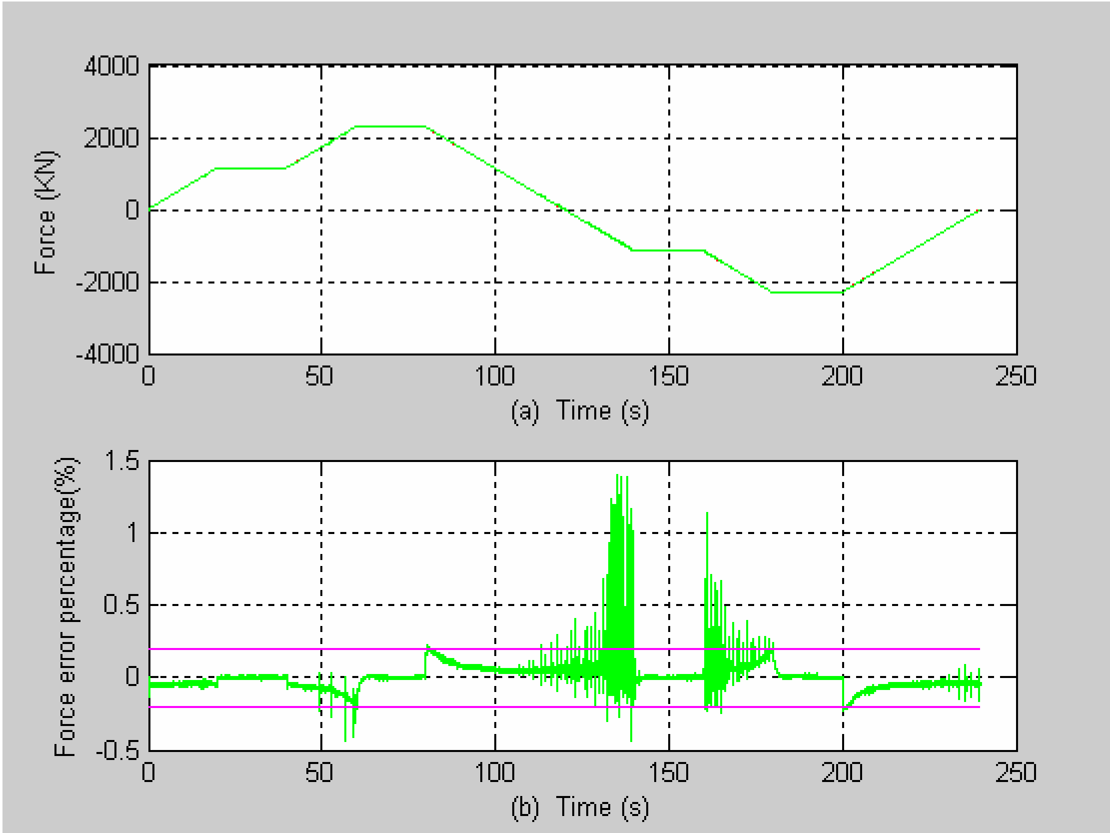


Figure 5.5.3.1.   100% maximum force accuracy test at Actuator 5
(Test 5.1: 1 valve; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±2300KN
– Green: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±2300KN force control on Actuator 5 (2 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/8/2004

<u>Servo Control Parameter</u>
Configuration--2 valve JK PID control at actuator 5
PID control-- Kp=2.5; Ki=1.0; Kd =-1.0; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; K: 0.88;
Servo valve offset (%) – (G: -1.563;) J: 1.172; K: 0.234
Servo valve spool zero (%) – (G: -2.109;) J: -4.453; K: 0.000
Hydraulic supply pressure: 3200psi

<u>Test result</u>
Static accuracy: 0.03% with respect to force range of ±2300KN (0.58 KN error) –See Figure 5.5.3.2.

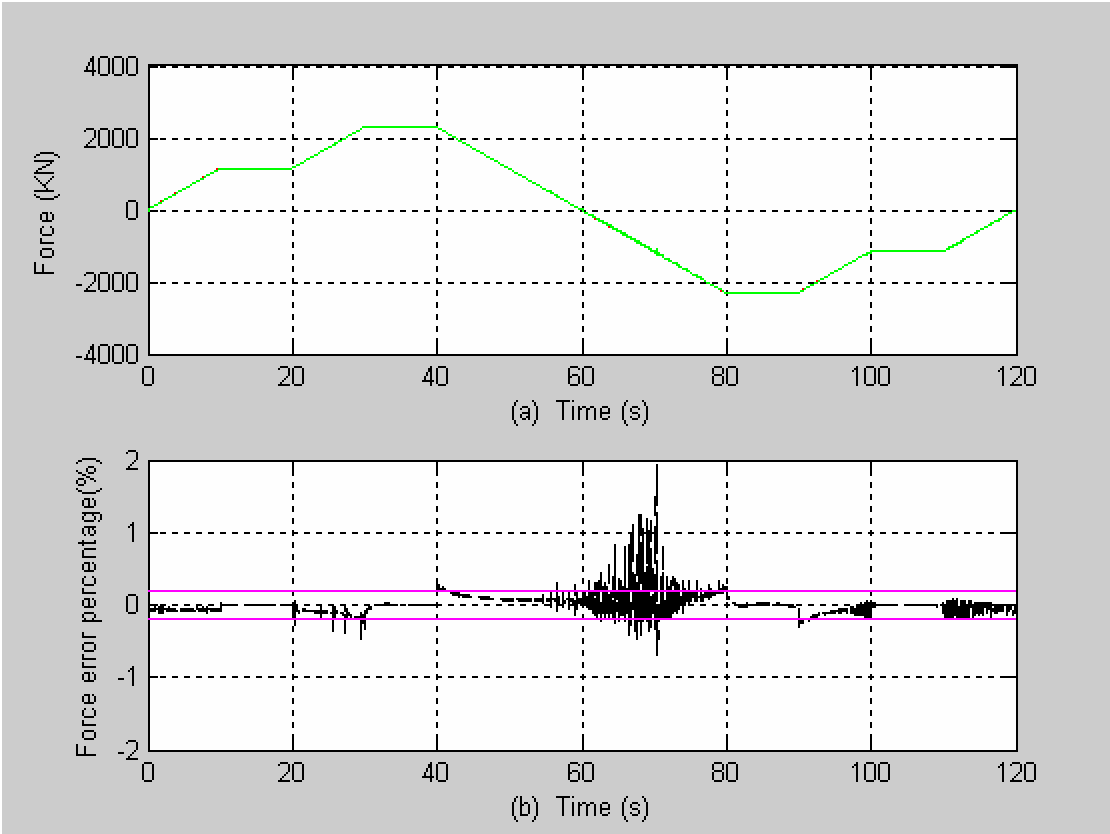


Figure 5.5.3.2. 100% maximum force accuracy test at Actuator 5
(Test 5.1: 2 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±2300KN
– Black: error percentage; Magenta: error acceptance boundary ±0.2%

- Test task: ±2300KN force control on Actuator 5 (3 valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/7/2004

<u>Servo Control Parameter</u>
Configuration--3 valve GJK PID control at actuator 5
PID control-- Kp=1.0; Ki=1.0; Kd =-0.9; f=35Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; J: 0.87; K: 0.88
Servo valve offset (%) – G: -1.563; J: 1.172; K: 0.234
Servo valve spool zero (%) – G: -2.109; J: -4.453; K: 0.000
Hydraulic supply pressure: 3200psi

<u>Test result</u>
Static accuracy: 0.002% with respect to force range of ± 2300KN (0.05KN error) –See Figure 5.5.3.3.

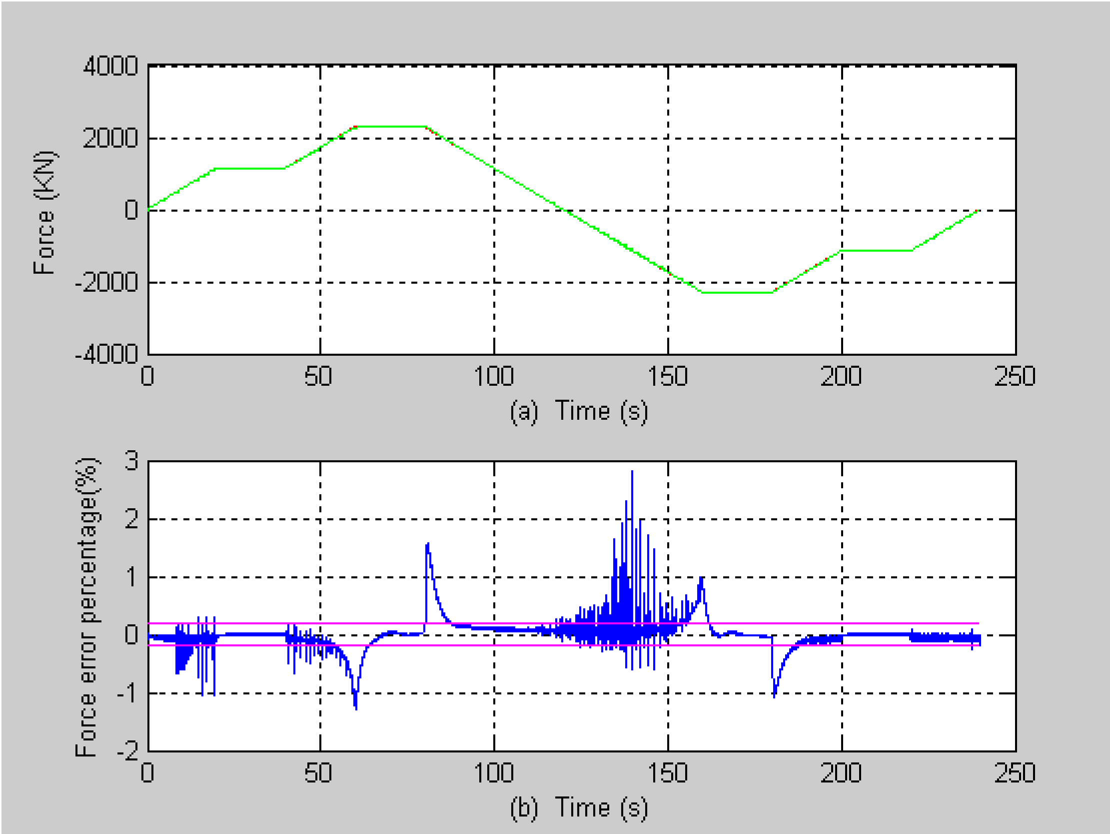


Figure 5.5.3.3. 100% maximum force accuracy test at Actuator 5
(Test 5.1: 3 valves; Data post-processed with a Butterworth filter of 100Hz)
(a) Force (KN) – Red: command; Blue: response
(b) Force error with respect to force range of ±2300KN
– Blue: error percentage; Magenta: error acceptance boundary ±0.2%

5.6 10Hz force bandwidth test (±1333KN sinusoid for 1, 2, 3 valves)

- Test task: Sinusoid force control on Actuator 5 (1valve)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/8/2004

Servo Control Parameter
Configuration--1 valve J PID control at actuator 5
PID control-- Kp=4.5; Ki=0.7; Kd =-1; f = 35 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; (K: 0.0)
Servo valve offset (%) – (G: -1.563;) J: -1.172; (K: 0.234)
Servo valve spool zero (%) – (G: -2.109;) J: -4.453; K: (0.0)
Hydraulic supply pressure: 3000psi

Test result
Dynamic bandwidth: 10Hz@1050KN (21.2% attenuation, less than 3 db) –See Figure 5.6.1.

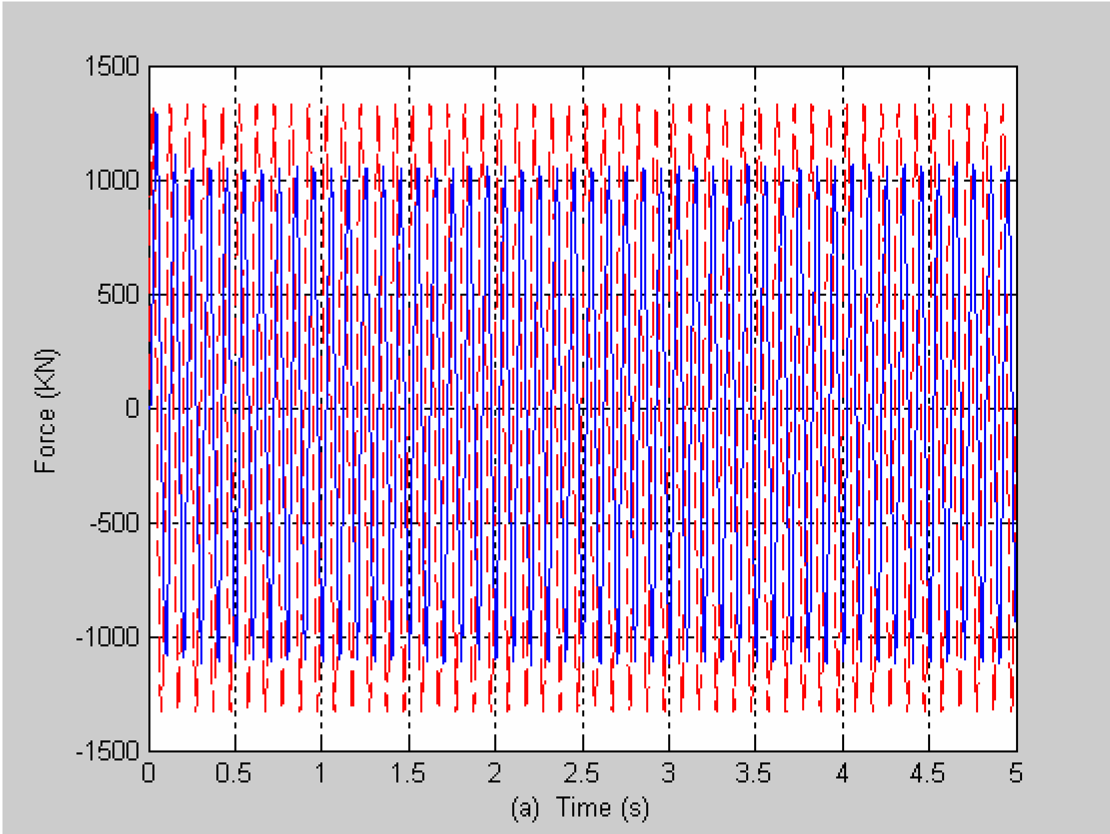


Figure 5.6.1. Force control dynamic bandwidth test at Actuator 5 (Test 5.2: 1 valve)
Red: command (1333KN@10Hz); Blue: response (1050KN@10Hz)

- Test task: Sinusoid force control on Actuator 5 (2valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/8/2004

<u>Servo Control Parameter</u>
Configuration--2 valve JK PID control at actuator 5
PID control-- Kp=2.0; Ki=1.0; Kd =-1.0; f = 35 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – (G: 0.0;) J: 0.87; K: 0.88
Servo valve offset (%) – (G: -1.563;) J: -1.172; K: 0.234
Servo valve spool zero (%) – (G: -2.109;) J: -4.453; K: 0.0
Hydraulic supply pressure: 3200psi

<u>Test result</u>
Dynamic bandwidth: 10Hz@1242KN (6.8% attenuation, less than 3 db) –See Figure 5.6.2.

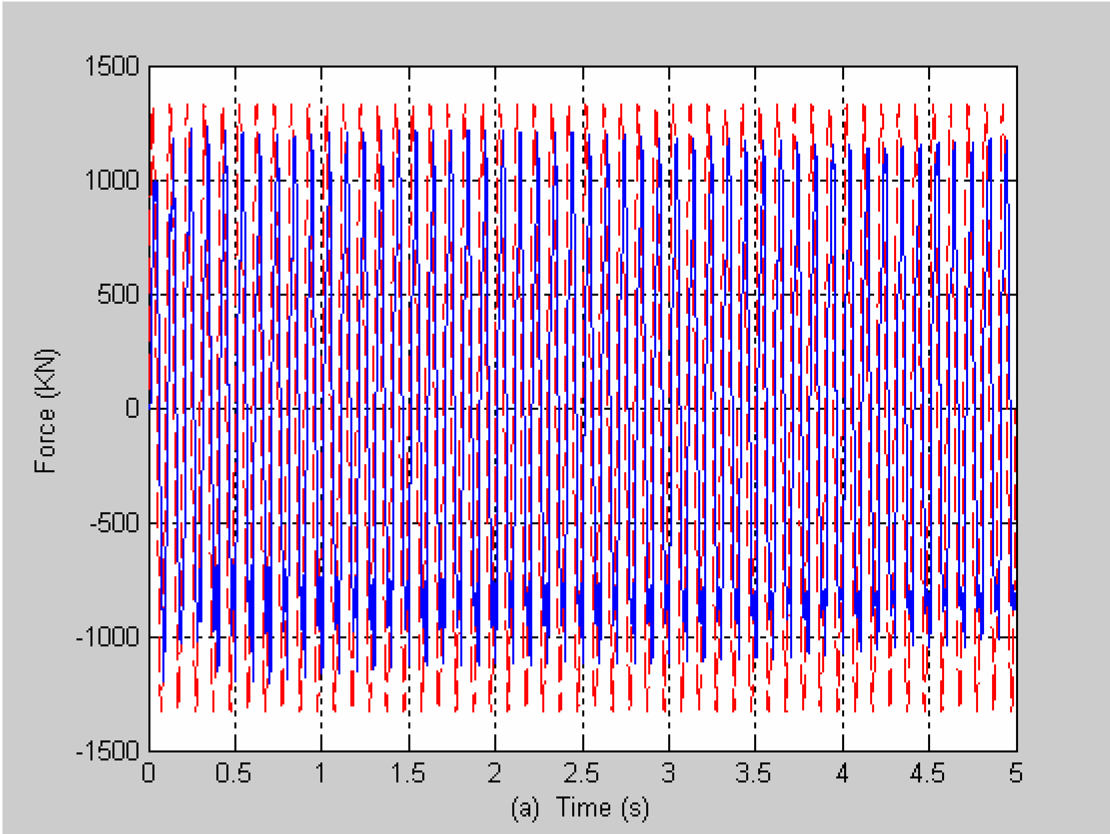


Figure 5.6.2. Force control dynamic bandwidth test at Actuator 5 (Test 5.2: 2 valves)
Red: command (1333KN@10Hz); Blue: response (1242KN@10Hz)

- Test task: Sinusoid force control on Actuator 5 (3valves)

Servotest Systems Ltd: Paul Murdoch
Lehigh University: Cheng Chen
Test site: Lehigh ATLSS Center
Date: 7/8/2004

Servo Control Parameter
Configuration--3 valve GJK PID control at actuator 5
PID control-- Kp=4.5; Ki=0.7; Kd =-1.0; f = 35 Hz
Servo valve loop gain -- Kv=30
Servo valve input scale – G: 1.0; J: 0.87; K: 0.88
Servo valve offset (%) – G: -1.563; J: -1.172; K: 0.234
Servo valve spool zero (%) – G: -2.109; J: -4.453; K: 0.000
Hydraulic supply pressure: 3000psi

Test result
Dynamic bandwidth: 10Hz@1175KN (11.8% attenuation, less than 3 db) –See Figure 5.6.3.

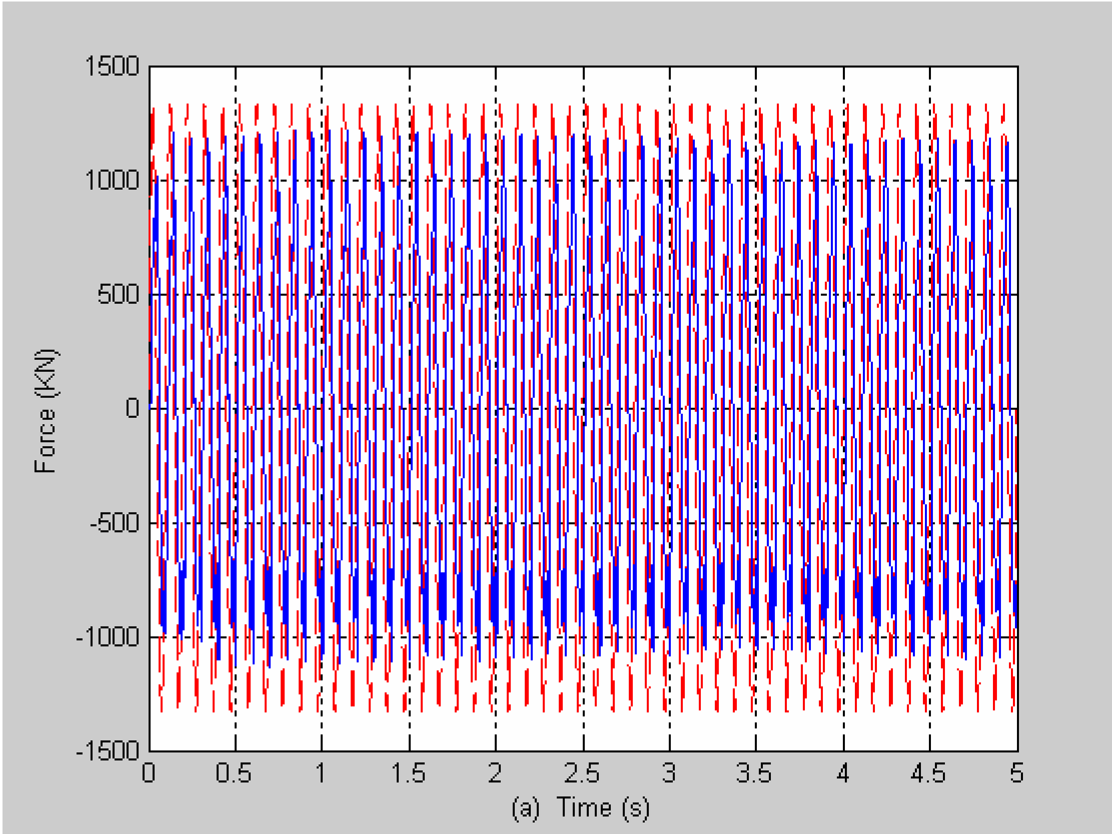


Figure 5.6.3. Force control dynamic bandwidth test at Actuator 5 (Test 5.2: 3 valves)
Red: command (1333KN@10Hz); Blue: response (1175KN@10Hz)

CONCLUSION ON ACTUATOR SYSTEMS

- All 5 actuators and controllers passed the displacement control accuracy tests. The displacement accuracy in the actuator that can be achieved is 0.2% of the defined travel range, but no higher than ±0.1mm. For example, if the actuator receives a target displacement *d* that has a travel range of ±50mm from the actuator's current position, then the actuator will achieve a displacement of *d*±0.1mm (i.e., the magnitude of error is 0.2mm) from the current actuator position.
- All 5 actuators and controllers passed the displacement control bandwidth tests. All of them hold at least 10Hz bandwidth in the PID displacement control.
- All 5 actuators and controllers passed the high velocity tests. 3 small actuators have a maximum speed of 1.14m/s and 2 large actuators of 0.84m/s.
- All 5 actuators and controllers passed the power tests. Each of their power output capacities reaches 277KW under one valve operation. Since three valves may be mounted for one actuator, the maximum power at one actuator is projected to reach 277 × 3 = 831 KW.
- All 5 actuators and controllers passed the force tests. The force control accuracy reaches 0.2% of defined force operation range, but no higher than ±0.17KN for three small ±1695KN actuators, and no higher than ±0.23KN for two large ±2300KN actuators.
- All 5 actuators and controllers passed the force control bandwidth tests. All of them hold at least 10Hz bandwidth in the PID force control.
- SCRAMNet tests passed. A standby simulation PC is able to communicate with Servotest controller in real time via the fiber optical network to complete the actuator control tasks.

PART II

ACCUMULATOR SYSTEM ACCEPTANCE TEST

ACCUMULATOR SYSTEM ACCEPTANCE TEST PLAN

ACCEPTANCE TESTS FOR RG UPGRADED HYDRAULIC SUPPLY SYSTEM

The hydraulic supply system acceptance test is conducted on site with the configuration shown in Figure 1.1. Hydraulic supply system is directly connected to HSMs and a pressure sensor is mounted at the supply pressure pipe line between Accumulator system and the HSMs. A control computer operates the 8 servo valves and 8 HSMs to conduct the hydraulic supply system test.

1. STATIC TEST -- PRESSURIZATION

Procedure:

1. Shutdown the HSMs and cutoff the pipeline by manually switching off the ball valves at the distribution headers (Ps1 and R1 in Figure 1.1).
2. Start up the power units and fill the accumulators to 3500psi.
3. Wait 15 minutes for the Nitrogen to settle at isothermal conditions.
4. Shutdown the power units and operate the solenoid valves at the accumulator manifold to open and close the accumulators.

Requirement:

1. No external leakage throughout the length of all new installed piping and connections.
2. Internal leakage should be limited to a certain level: Supply pressure is maintained at 3500psi with no more than 200psi descent during the 1 hour pressurization test. This pressurization index is equivalent to a 3 gallon/min leakage which degrades the entire power supply system efficiency 0.5% lower than its original value. Also, for a typical 30 seconds earthquake test, this leakage induced pressure descent accounts for 0.3% of the designed 500psi pressure drop capacity (from 3500psi to 3000psi).

   Pressure readings in the Static Test are based on the installed pressure gages at the accumulator manifold.

2. DYNAMIC TEST – PRESSURE HOLDING

Procedure:

1. Use the dummy servo valve manifolds to shortcut the servo valve downstream ports (Port A and B) and block the passage from these ports to the actuator chambers.
2. Manually switch on the ball valves at the distribution headers (Ps1 and R1 in Figure 1.1) so that the pressure is fed to HSMs and further to servo valve upstream ports.
3. Switch off all 8 HSMs and all 8 servo valves and charge the accumulators to 3500psi.

4. Switch on all 8 HSMs to low pressure then to high pressure state to let the flow pass through.
5. Operate the Control Computer to vary the servo valve main spool openings according to Canoga Park earthquake flow rate demand (See Figure 1.2). The relation between the flow rate demand Q (gpm) and the valve spool openings x_v (mm) is based on the standard flow rate equation $Q = n \frac{x_v}{x_{\max}} Q_{0\max} \sqrt{\frac{P_s}{P_{s0}}}$ where n = 8 is the servo valve number, x_{max} (mm) is the main spool travel range, Q_{0max} (gpm) is the maximum flow rate for a single servo valve rated at supply pressure P_{s0} (psi), P_s is the actual supply pressure measured on-line.
6. Record the supply pressure every 1.024 millisecond at the pressure sensor and store the pressure data to the Control Computer.

Note: The Control Computer, Servo valves, Servo valve manifold, Servo valve Dummy manifolds, HSMs, Pressure sensors and their conditioning system will not be provided by RG Group. Instead, RG group will provide flow rate meter to monitor the contributed flow rate at all the 5 pump stations. The total flow rate from pump stations should reach and be close to 600gpm.

<u>Requirement:</u>

The Control Computer recorded supply pressure at the HSMs (or at supply pressure header) is expected to drop as shown in Figure 1.3. The lower boundary of the recorded supply pressure is required to remain above 3000psi, which is the normal operation pressure for servo valves.

3. EMERGENCY SHUTDOWN

<u>Procedure:</u>

a. Switch off all 8 HSMs and all 8 servo valves and charge the accumulators to 3500psi. Set the Relief pressure of the safety valve at the Accumulator Manifold to 4000psi to prevent the hydraulic supply system from damage.
b. Switch on all 8 HSMs to low pressure and then to high pressure state. Operate the 8 servo valves using Control Computer and keep the servo valve main spool displacements at a constant 50% opening which is corresponding to a total flow rate of 2200gpm. (See Figure 1.4.)
c. Suddenly shutdown all the HSMs (See Figure 1.4) to simulate an emergency shutdown.

d. Record the supply pressure every 1.024 millisecond at the pressure sensor and store the pressure data to the Control Computer.

Requirement:

1. The recorded supply pressure is required to be within 2000psi~4000psi (See Figure 1.5). The safety value at the safety relief valve is set at 4000psi, so the recorded pressure data should not exceed this value.
2. No external leaks throughout the length of all new installed piping and connections.
3. Repeat Test I – Static Test to check the potential internal damages to hydraulic supply system.

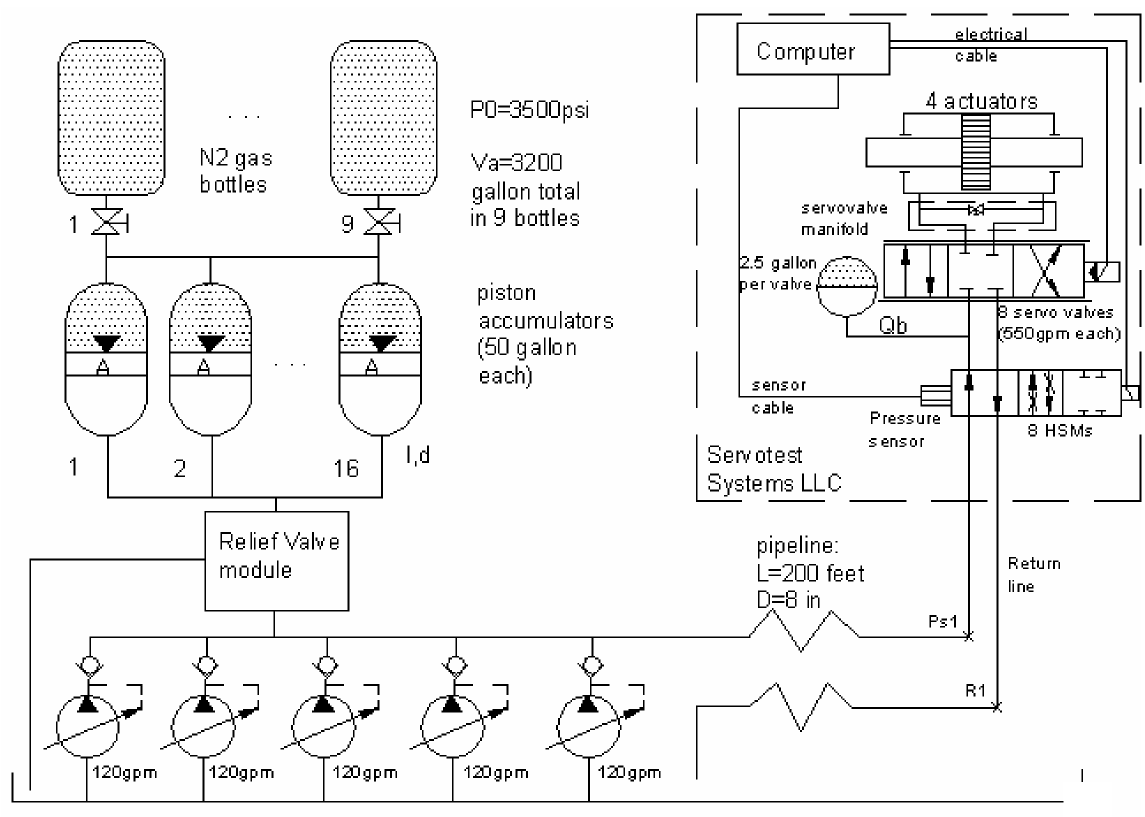


Figure 1.1 Schematic for RG upgraded hydraulic supply system acceptance test

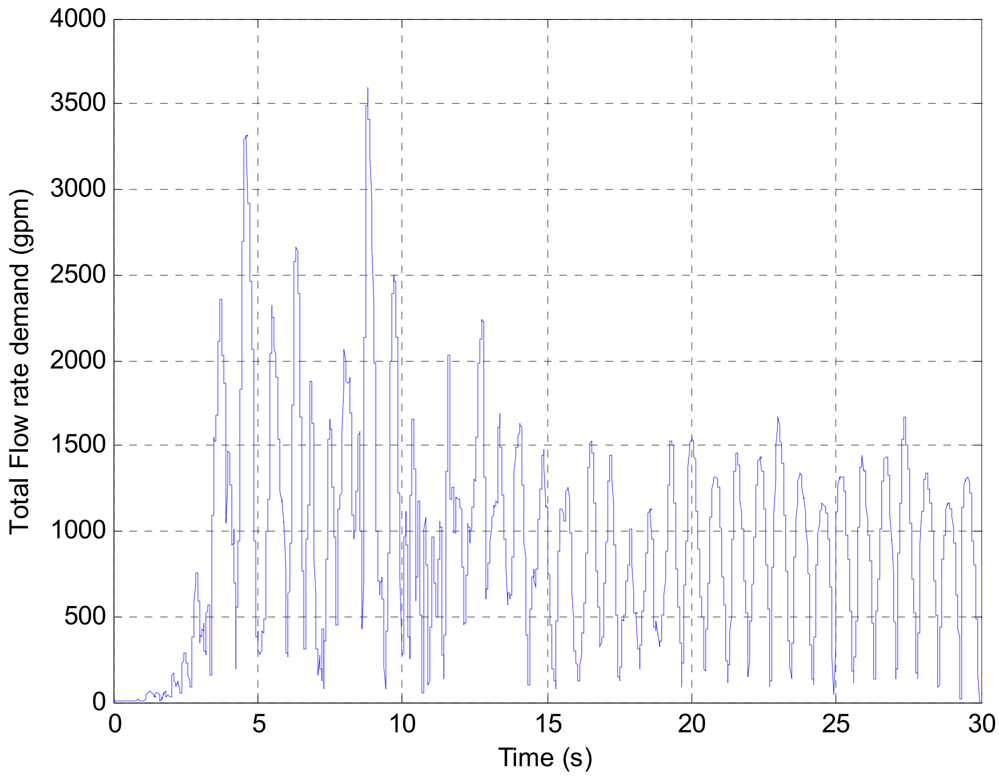


Figure 1.2 Test 2: Canoga Park earthquake flow rate demand – gpm
(Servo valve spool displacement command signals are based on this total flow rate demand.)

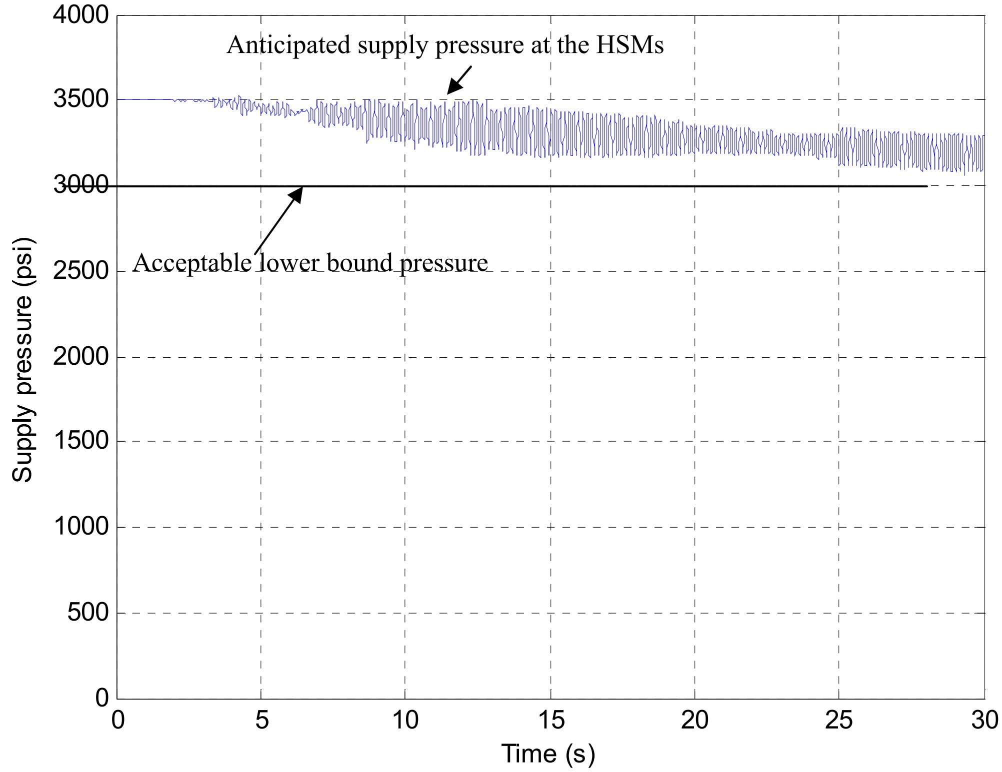


Figure 1.3 Test 2: Expected supply pressure measured at the pressure sensor (Supply pressure is required to be above 3000psi)

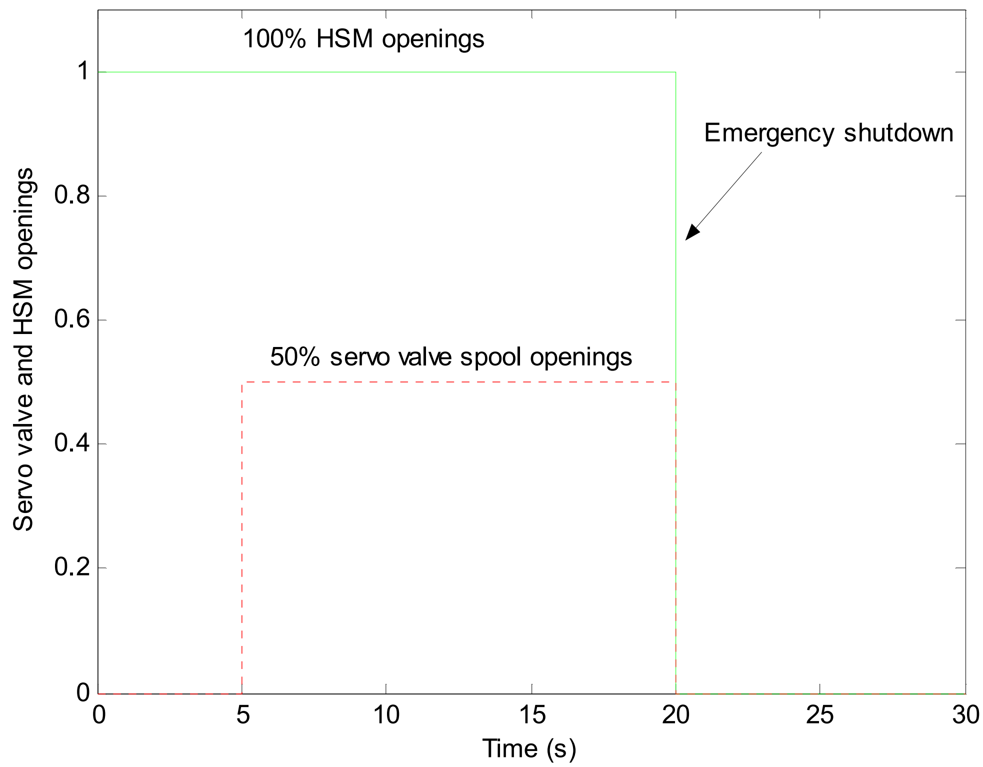


Figure 1.4 Test 3: Use HSMs to test emergency shutdown
(Red dotted line: 8 servo valve spools at 50% constant opening, a total flow rate of 2200gpm)
(Green solid line: 8 HSMs maintain high volume state with a sudden shutdown)

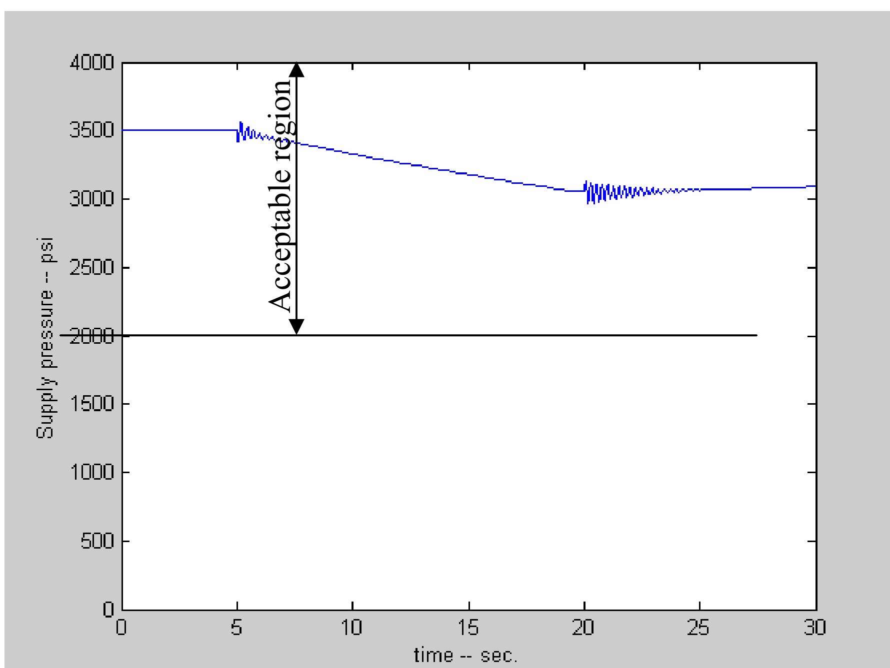


Figure 1.5 Test 3: Supply pressure measured at the pressure sensor
(Supply pressure is required to be within 2000psi ~ 4000psi)

ACCUMULATOR SYSTEM TEST PREPARATION

1. FLOW RATE CALIBRATION FOR SERVO VALVES

In the accumulator dynamic test, servo valves are used for scheduling flow rate dump. So it is necessary to calibrate servo valve input and output statically. The dynamic bandwidth of the servo valves reaches 40Hz and the scheduled flow rate has frequency component no more than 10Hz, so there is no need for dynamic calibration.

The calibration actually can be achieved using free standing actuators under velocity control. For constant velocity, there is no piston mass caused inertial effect. Also, due to the hydrostatic bearing, friction is very small. So the actuator serves as the flow meter.

The experimental is then conducted with a single actuator with two servo valves mounted. However, each time only activate one valve so that there are two calibration results to compare for these two valves respectively. The experiment result is shown in Figure 2.1.1.

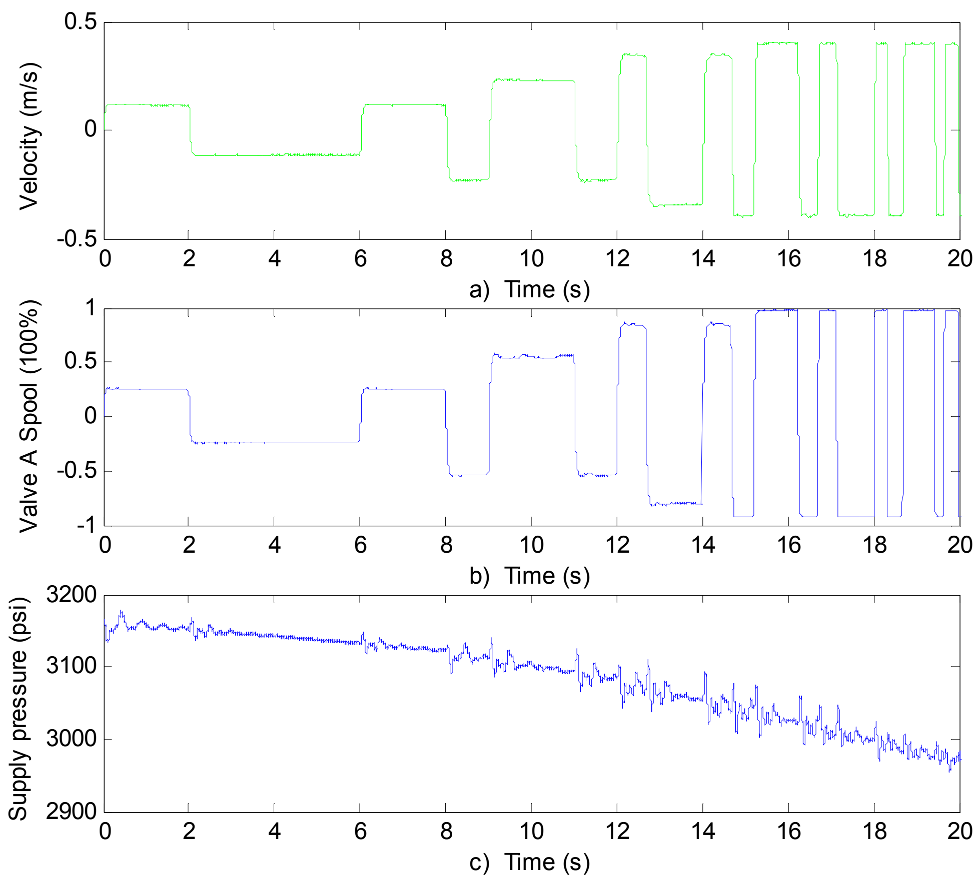


Figure 2.1.1 Using actuator for servo valve flow rate calibration
a) Actuator velocity (m/s); b) Valve opening; c) Supply pressure (psi)

The experimental result numerically establishes the relation among flow rate Q (gpm, equal to velocity multiply effective area of the hydraulic cylinder 0.0807m^2), supply pressure (psi), and servo valve spool opening (100%). Theoretically the equation is

$x_v = f\left(Q\sqrt{\frac{P_{s0}}{P_s}}\right)$ where P_{s0} = 3000 psi as the nominal supply pressure. To investigate the function *f*, the data are plotted out at Figure 2.1.2.

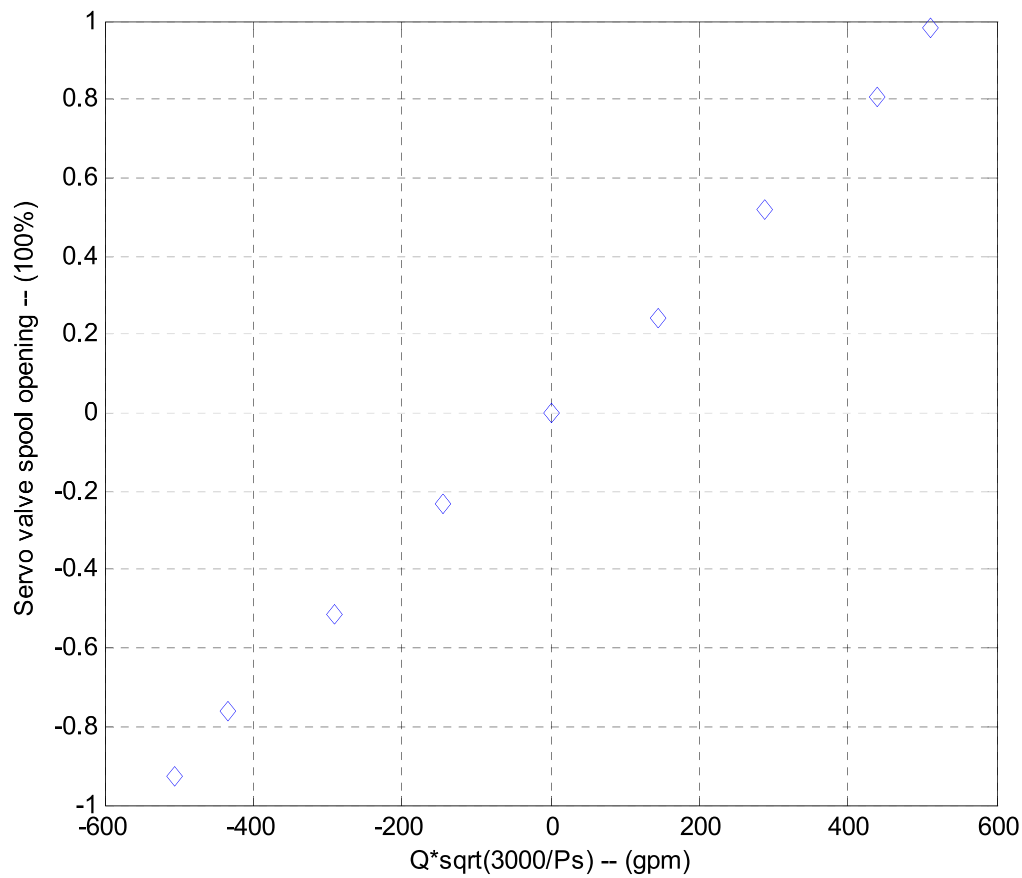


Figure 2.1.2 The linear relation between the corrected flow rate and valve opening

A least-squares curve fitting using polynomials results in a linear relationship, i.e., $x_v = k\left(Q\sqrt{3000/P_s}\right)$ where k = 0.0018 for the first valve and k = 0.0017 for the second valve. Since Servotest's valve specs indicates that the valves are 550gpm@3000psi valve which is close to $1/k$ = 555gpm, so k=0.0018 is selected as the final calibration result.

2. SOCKET BUILDING USING THE CALIBRATION DATA

The calibration result is implemented in the Servotest Controller to operate the valve spool for desired flow rate scheduling. To implement the on-line pressure feedback in $x_v = k\left(Q\sqrt{3000/P_s}\right)$, a socket needs to be built as the control algorithm to control the servo valve spool (valves are connected with dummy manifold so actuator is not moving).

The socket source is a Simulink model, as shown in Figure 2.2.1.

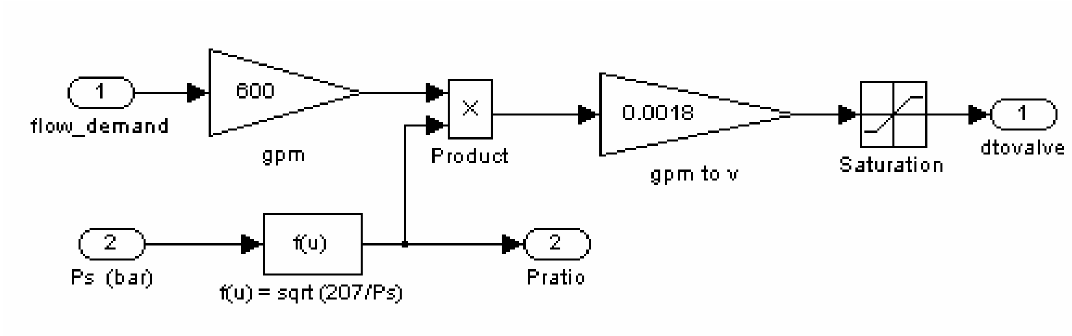


Figure 2.2.1 Simulink model for building the socket

Note:

(1) 600 is a scale factor. The single valve flow demand (gpm) is divided by 600 to form the input data file.
(2) Input port 1 connects to flow_demand, a prepared data source file with the flow rate demand in gpm for single valve, and scaled down by a factor of 600.
(3) Input port 2 connects to the filtered supply pressure measurements (bar).
(4) Output port 1, dtovalve, connects the PID displacement control input. The PID gain in Servotest controller is set as 1.0 (no integral and differential). Actuator displacement is tare to zero. Since the servo valve is mounted in dummy manifold, actuator is actually not moving. Thus the actuator is actually an all pass open loop control. Valve displacement is actually directed by the Simulink output signal, dtovalve.
(5) Output port 2, Pratio is sqrt(207/P_s), as designated by f(u) block, where supply pressure P_s is in bar, not psi. This port is only for observation. Normally, this data should be around 1.0.

The socket is then combined with fake PID displacement control to operate the valve spool for flow dumping. Since actuator is not moving, so the PID control part can be set as a pure gain block with proportional gain as 1.0. The schematic block diagram is shown in Figure 2.2.2.

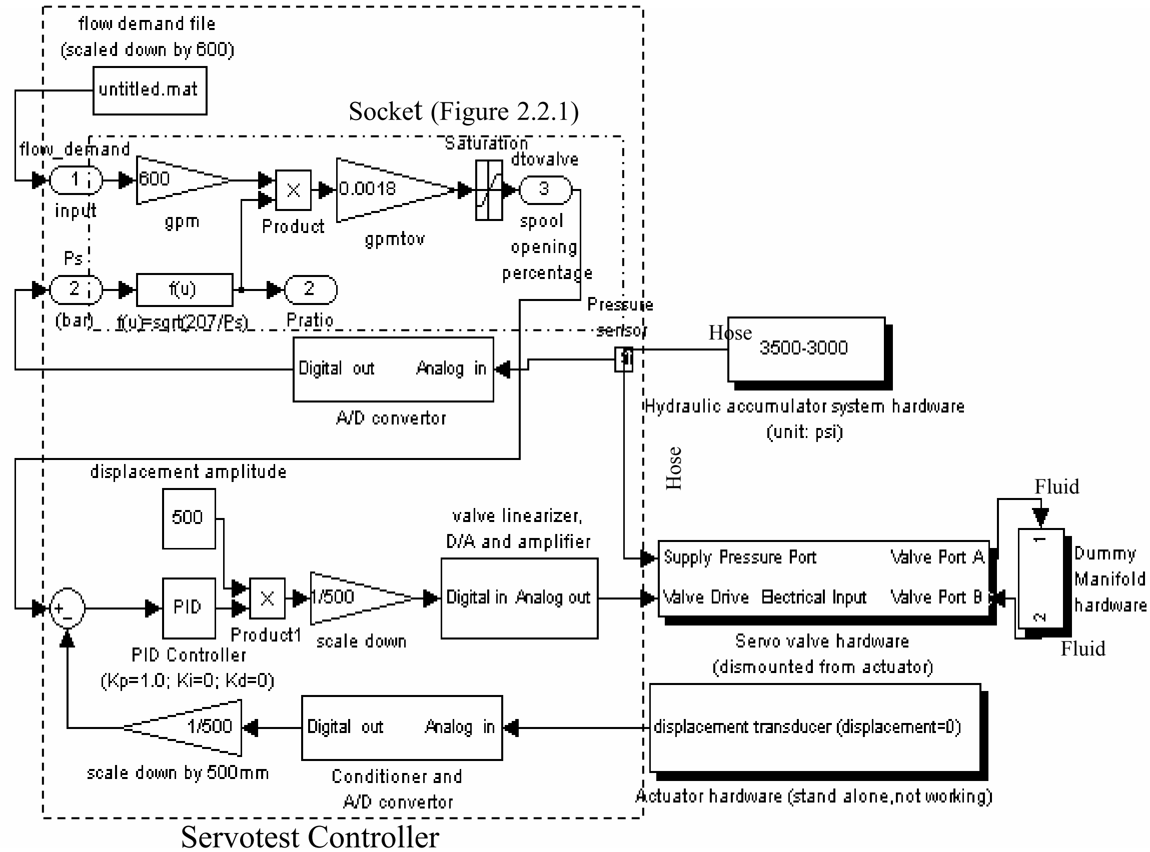


Figure 2.2.2 Schematics for accumulator system test

3. FLOW DEMAND CALCULATION

The flow demand is determined from the nonlinear time history analysis of a 4-story 0.5 scaled moment resisting frame, subjected to the most credible Canoga Park earthquake excitation. Initially, the analysis on the excited structure gives the velocity information of the floor movements. Then after a hydraulic actuator power envelope evaluation, it is decided that 1 actuator is assigned for each floor of the test structure with the actuator cross-section areas as 0.1094 m^2, 0.1094 m^2, 0.0807 m^2, 0.0807 m^2 respectively (in the order of floor 1-4). Thus the velocity times the actuator cross-section area will be the flow demand for each actuator and sum of them will be the entire flow demand.

4. EQUIPMENT DEPLOYMENT

The socket is built in Servotest Controller and the dummy manifold is then shortcut the servo valve downstream port A and B. Figure 2.3.1 show the entire test system. The actual deployment is shown in the photo in Figure 2.3.2.

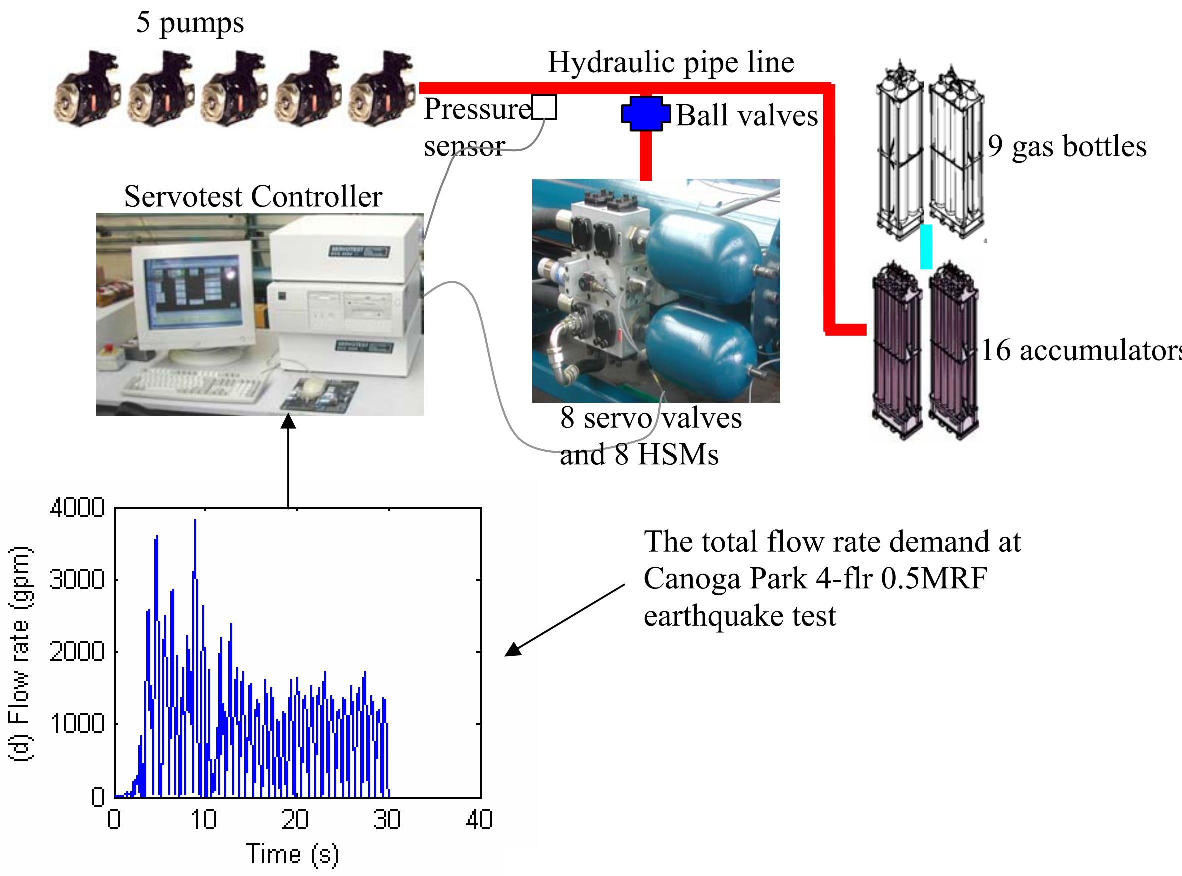


Figure 2.3.1 Accumulator system acceptance test setup

Figure 2.3.2 Deployment of the accumulator system test

ACCUMULATOR SYSTEM ACCEPTANCE TEST RESULT

Test site: ATLSS center, Lehigh University

Test participants:

Ralph Lastra (Parker Hydraulics)

Xiaoping Zhang (Lehigh University)

Test date: 8/31/2004 – 9/1/2004

1. STATIC TEST – PRESSURIZATION

The accumulator is energized to 3500psi. All the ball valves to HSMs were switched off. All pumps are shutdown. The pressurization is tested for 1 hour (3600 seconds). Computer is recording the pressure at the supply pipe line at a rate of 1.024 Hz. It was found that the pressure dropped 145 psi in one hour, as shown in Figure 3.1.1. This satisfied the less than 200psi requirement.

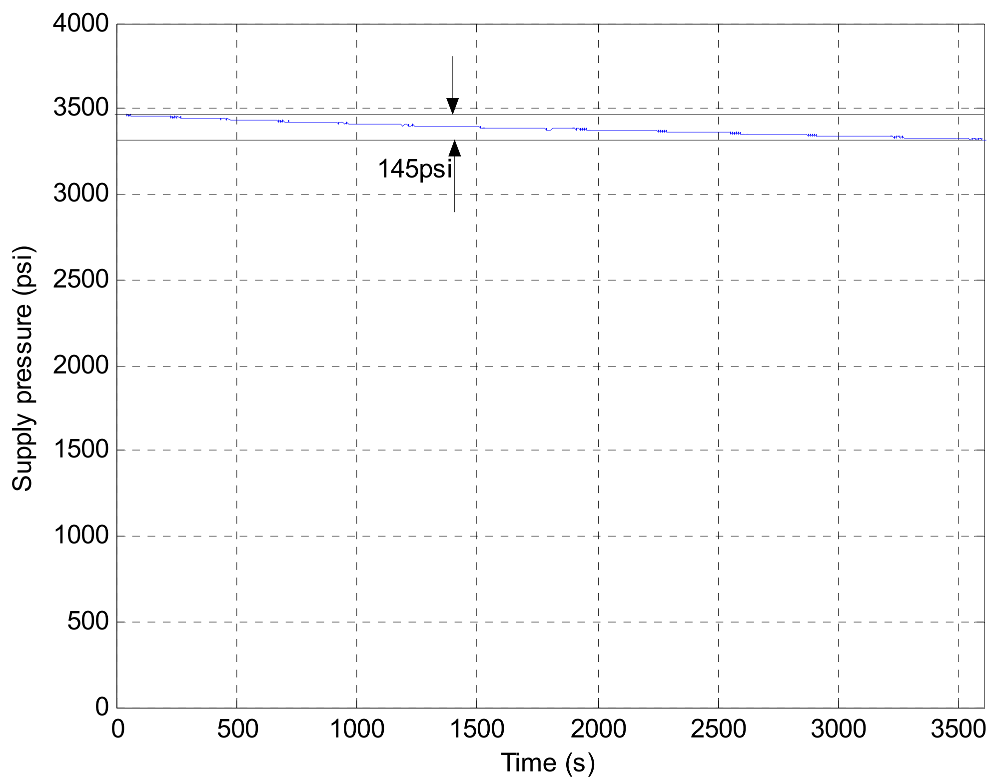


Figure 3.1.1 One hour pressurization test

2. DYNAMIC TEST – PRESSURE HOLDING

In this dynamic test, the flow rate demand at the Canoga Park 4-flr 0.5MRF earthquake test (Figure 3.2.1) is physically simulated by 8 servo valves. The computer's operation on 8 servo valves causes flow dumping from accumulator systems which leads to pressure dropping. As stated in Part I, the goal is that the supply pressure should not drop to a value below 3000psi.

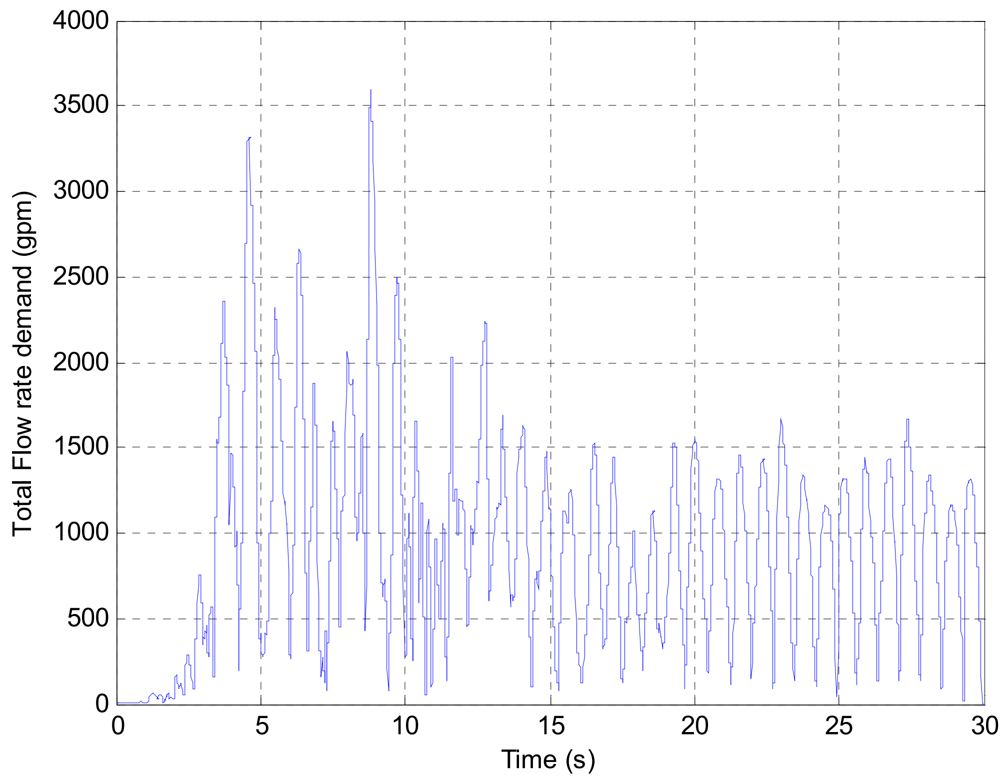


Figure 3.2.1 The flow rate demand at the 4-flr 0.5MRF Canoga Park earthquake test

The flow rate demand is then equally distributed to 8 servo valves. Since each valve is rated as 555gpm@3000psi in the calibration stage (or flow rate to valve opening ratio as 1/555=0.0018 1/gpm@3000psi). Thus it is easily to get the single valve opening command (percentage) as $x_v = \frac{Q/8}{555}\sqrt{\frac{3000}{P_s}} = 0.0018(Q/8)\sqrt{\frac{3000}{P_s}}$ where Q is the total flow demand (gpm) in Figure 3.2.1 and P_s is the supply pressure (psi). Computing of this valve opening is physically implemented by the Servotest Controller using a Socket module to accept the on-line measured supply pressure for valve opening scheduling. Using the Servotest Controller it is found that the supply pressure is able to keep its value essentially above 3000psi (at the final 5 seconds, there are points 2.4% lower than the desired 3000psi line). This essentially satisfies the requirement at dynamic test.

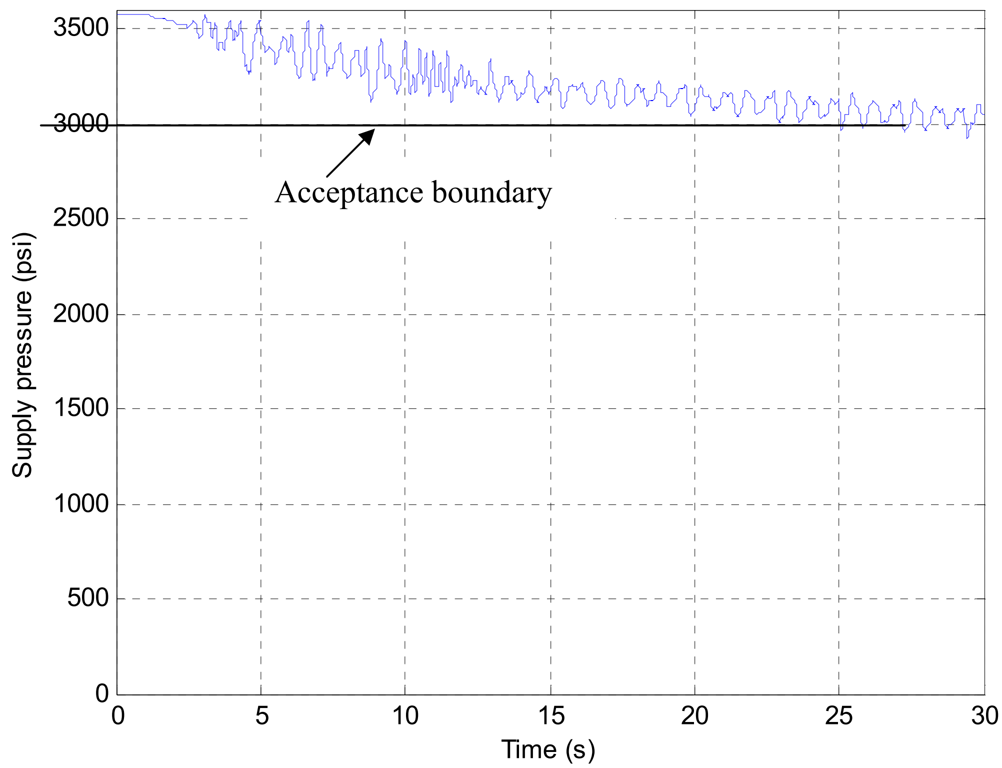


Figure 3.2.2 Supply pressure drops during the test

3. EMERGENCY SHUTDOWN

At the emergency shutdown test, 8 servo valves with 50% opening each are physically simulating the normal operation. Then an E-stop is imposed to cause all the servo valves and HSMs shut off. The accumulator output pressure is then monitored to see whether it is maintained within 2000~4000psi.

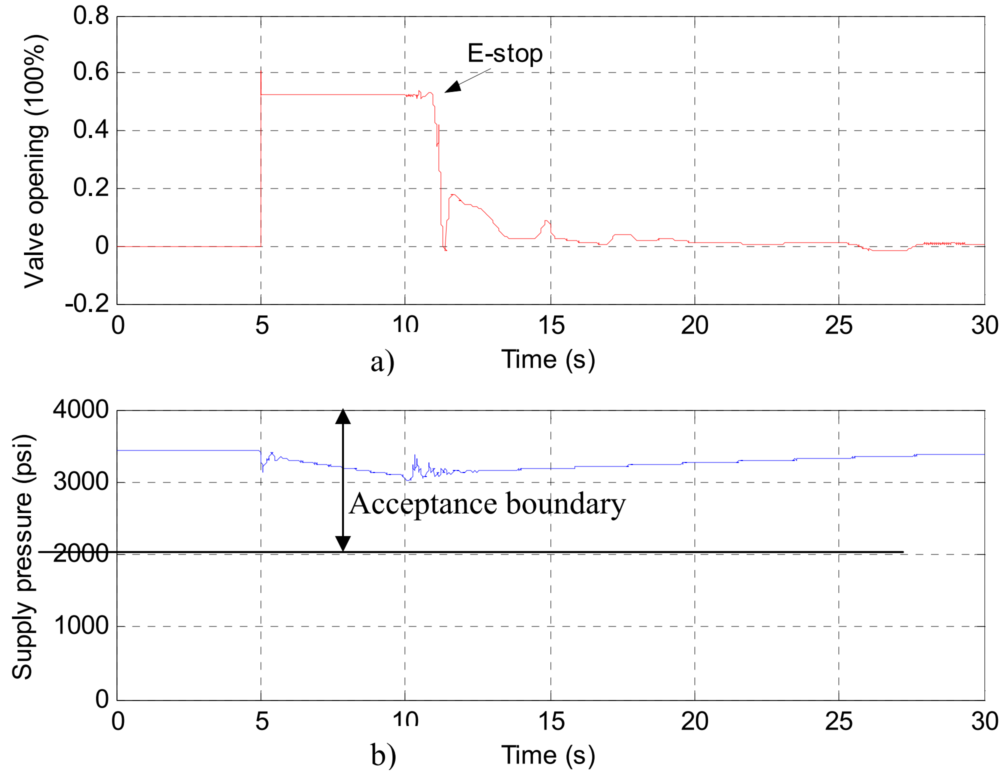


Figure 3.3.1 Emergency shutdown

As shown in Figure 3.3.1, the emergency shutdown causes 300psi oscillation. However, the supply pressure is within the acceptance boundary. This satisfies the first requirement in emergency shutdown.

After the emergency shutdown, it was found there was no external damage such as leaking. The internal damage was checked by the pressurization. That is, all the ball valves were switched off to isolate the HSMs from the Accumulator. Pumps were shut down also. And one hour pressurization was conducted. At a rate of 1.024 Hz, the computer was recording the data through the supply pressure sensor. It was found that within one hour, the pressure dropped 107psi (since this time it starts at 3200psi, a relative lower than that in static test.) as shown in Figure 3.3.2. This satisfies the 2nd requirement in the emergency shutdown.

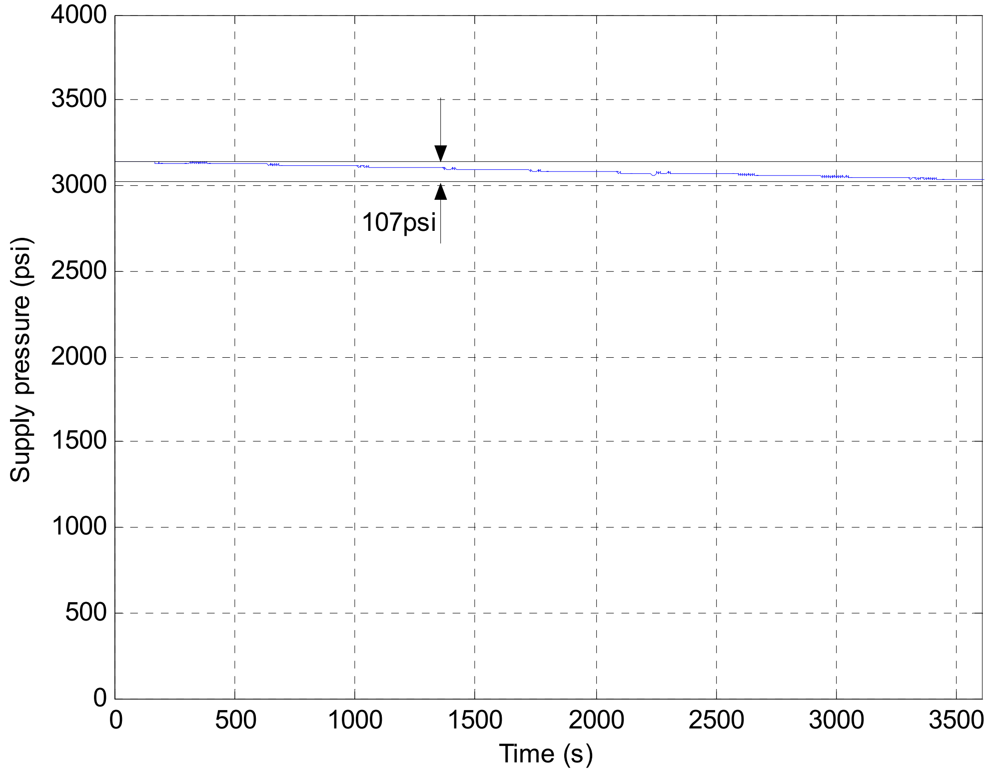


Figure 3.3.2 Pressurization test after emergency shutdown

CONCLUSION ON ACCUMULATOR SYSTEMS

- The accumulator has adequate pressurization capacity. The pressure drop in 1 hour is less than 200psi, the required limit.
- The accumulator is capable of maintain the pressure above 3000psi in the strong flow rate demanding test (Canoga Park 4-flr 0.5MRF earthquake test).
- The accumulator system is survivable in emergency shutdown. The pressure overshoot and undershoot is around 300psi. The pressure is managed within 2000~4000psi range.

In summary, the accumulator systems provided by RG Group satisfies the design requirements.