Issues in Implementation of Active Structural Control Systems: A Case Study

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ABSTRACT

An active control system for a large-scale structure includes a collection of sensors, digital controllers, control logic and algorithm, power supply and active control force generation devices in an integrated system. In practical applications, the major tasks of a digital controller include not only the calculation of required control signals but also the support for structural control realization. Important issues, such as overall system configuration, sampling rates setup, analog-I/O interface, hardware offsets removal, noise rejection, signal error modification, engineering units scaling, control algorithm implementation, system status monitoring, automatic operations of power and force generators, multi-protection failsafe measures, false-alarm control command rejection, and real-time signal manipulation, are required for the implementation of control. On the other hand, active control force generation devices and sensors are commonly analog hardware. A signal interface unit equipped with conditioning, filtering, monitoring, failsafe limit detection, signal communication, and remote activation subsystems, is required to deal with the integrated system through the help of a digital computer. The required integration issues regarding the control hardware and software are addressed in this paper in a case of an active mass damper for a tall TV tower. The important hardware and software safety and compatibility features have to be identified, verified, and adjusted in order to eliminate many of the common problems that may occur in practical implementation of a complex control system. The use of a Real-Time Structural Simulator, which generates the time response signals of the tower with real time features, along with the controller hardware and software is shown herein for pre-implementation verification of the integrated control functions.

1. INTRODUCTION

The generalized hardware function of an active control system can be represented by the block diagram in Fig.1. In such a configuration, the response of a structure, the device status, the remote control status, and the failsafe status of the Active Control Force Generation System (ACFGS) are measured and then sent to the Custom-Designed Signal Interface System (CDSIS). The system information are collected together and sent to the
2. CASE STUDY

As a case study for the purposes of validation and demonstration of the generic development, we focus on the control system designed for the Nanjing Tower. The 340m high television transmission and observation tower, constructed of reinforced concrete with a steel antenna, has two observation decks, the upper one at a height of 240m. During wind storms, the expected accelerations at this level exceed the comfort limit of 15mg. An active mass damper is proposed as a means of reducing the vibrations and improving the comfort
of the occupants. An electro-hydraulic active force generation system driven by a DSP digital controller is implemented at the upper observation deck and the corresponding hardware configuration is shown in Fig.3.

**Figure 3.** Implementation layout of AMD system

### 2.1 ACFGS- Hydraulic Devices with MTS Control Console

By adapting its advantages of strong in stiffness, fast in response, and high in accuracy, a hydraulic power driven mechanism is installed on the Nanjing Tower. The hydraulic power supply equipped with 12 pumps and 9 bladder type accumulators allow for instantaneous operation at high pressure of 21 MPa (3000 psi), which is the nominal pressure required to achieve the nominal force by the actuator. The electronic portion of the hydraulic-driven system consists of the MTS MicroConsole (MTS458.10) that provides control over the hydraulic power supply for the actuator (MTS247.21), as well as a number of supporting features for an actuator command correction controller (MTS458.12) and for the third stage valve controller (MTS458.15). This analog control console provides a means of communication between the servocontrollers and control signals available from the custom-designed digital control system (DSP Controller).

### 2.2 Measuring Equipment
Apart from the LVDTs or differential pressure ($\Delta P$) cells embedded in the hydraulic control system, six FBA-11 force balance type uniaxial accelerometers are installed on the tower and the mass ring as the feedback source of active control forces. The velocities and displacements of the tower and the mass ring can be integrated in real-time through the integration module inside the microcode of the DSP controller. The displacement readouts of each actuator's LVDT transducers are also monitored and recorded in the DSP controller to provide as the reference to examine the accuracy of the integrated displacement signals and also as the reference to calculate the required actuator movement as the command of the displacement-controlled DC servocontroller.

Figure 4. Layout of custom-designed signal interface system

2.3 Custom-Designed Signal Interface System

The electrical interface circuitry for this case study shown in Fig.4 includes five major circuit boards embedded with six subsystems: (1) Accelerometer Conditioner Board (Conditioning Subsystem, Filtering Subsystem, and Monitoring Subsystem); (2) Displacement and Differential Pressure $\Delta P$ Conditioner Board (Conditioning Subsystem, Filtering Subsystem); (3) Analog Communication Input/Output (I/O) Board (Signal Communication Subsystem); (4) High Acceleration Limit Detection and Shut-Off Board
(Fail-Safe Limit Detection Subsystem); and (5) Digital Communication I/O Board (Monitoring Subsystem, Signal Communication Subsystem, and Remote Activation Subsystem). Two similar drawers are built to be implemented on the Tower and also to simulate and verify in the Structural Engineering and Earthquake Simulation Laboratory (SEESL) of SUNY at Buffalo. The detailed layout and wiring definitions of each board can be found elsewhere (Chu, et al., 2002).

2.4 Digital Control System – DSP Controller

The digital control system of this tower structure is constructed in an Intel Pentium II Windows NT environment PC, referred to as the DSP Controller. This computer is equipped with a QPC/C40B carrier board with TMS320C40 DSP processor, a 12-bit A/D converter board with 32 single-ended input channels, and a 12-bit D/A converter board with 16 output channels. The conversion cycle of the 32-channel ADC board can be adjusted and triggered through a 16-bit reloadable up-counter through software. The acceleration measurements at the upper observation deck of the tower and the mass ring are assigned to the first 12 channels. The displacement and differential pressure readouts of the actuators occupy another 12 channels. The final 8 channels are reserved to monitor the status of the analog control console. The 16-Channel Digital to Analog Conversion Board is designed to connect directly to the DSP board. The remote activation functions, the required actuator movement commands, and the software fail-safe functions are performed through this board.

3. INTEGRATION ISSUES

3.1 Issues in Hardware Performance Validation

According to the designed function of the Electrical Interface Circuits, as seen in the layout of Fig.4, the following integrated capabilities should be verified before using software to perform their real functions: (1) Accelerometer connectivity; (2) Performance test of low-pass filters; (3) Accelerometer power supply & calibration voltages; (4) Accelerometer level detect voltage settings; (5) Accelerometer level detect - output to MTS 458; (6) MTS status monitor inputs - outputs to control computer A/D; (7) Displacement connectivity; (8) ΔP connectivity; (9) DSP Controller D/A Inputs - back panel actuator command; and (10) DSP Controller D/A Inputs - remote control outputs to MTS.

3.2 Issues in Software Performance Validation

In order to demonstrate the generic modules in more detail, the digital control hardware (DSP Controller) of this tower project is used as the platform to implement and test these modules separately or integrally. The implemented modules are grouped into four major parts: (1) Interactive Configuration Group. Based on the general guideline, the System Operating State Information (SOSI) of the Nanjing Tower includes: system physical as-built layout information, signal processing information, control algorithm parameter information, and fail-safe protection information. (2) Signal Processing Group. It includes the following modules: system clock setup, analog I/O function, real-time adjustment and channel on-off identification, error detection and correction, digital filters. (3) Control Algorithm Group.
The coordinate transformation module, the real-time signal integration module, the engineering unit scaling module, the control algorithm module, and the system response monitoring and data storage and communication module are included in this group. The verification of the control algorithm prior to its real application is utmost important and is discussed elsewhere. In the meantime, the validation of real-time integration performance cannot be achieved without the help of the Real-Time Structural Simulator. The integrated displacement on the upper observation deck of the tower is compared with simulated one from the RTSS in Fig.5. (4) **Fail-Safe Protection Group.** Apart from the hardware protection built into the signal interface circuitry in Fig.4, the fail-safe multi-protection module, the smooth start-up/shut-down module and the remote control module are arranged in this group to serve as a software backup of the integrated control system.

**Figure 5.** Comparision of integrated and simulated tower displacements

**4. CONCLUDING REMARKS**

The implementational related issues related to an AMD system on a TV tower are discussed and validated in parallel in the SEESL while the same system is installed and tested on the tower. Both hardware and software integration issues can be identified and verified in the laboratory via a Real-Time Structural Simulator to assure the integrated performance of this particular system.

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**REFERENCE**